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Oak Ridge National Laboratory

REVIEW

Vol. 25, Nos. 3 and 4, 1992

DISCLAIMER

ON THE COVER

East Tennesseans celebrate the end of World War II. Fifty years ago, Oak Ridge National Laboratory was established, as part of the top-secret Manhattan Project, to develop a way to produce explosives for the atomic bomb. Using the Graphite Reactor (shown in inset on the back cover), the Laboratory succeeded in its original mission and helped hasten the end of the war. Since then, as chronicled in this history, the Laboratory (shown in its present form on the back cover) pioneered the development of nuclear reactors for peaceful purposes and achieved distinction through its contributions to the basic physical and life sciences, medical diagnosis and treatment, energy and environmental research, and technology transfer. *Photograph by J. E. Westcott*

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Editor's Note

In observation of the 50th anniversary of Oak Ridge National Laboratory, this special double issue of the *Review* contains a history of the Laboratory complete with photographs, drawings, and short accompanying articles by various contributors. Coincidentally, with the publication of this issue, the *Review* also observes an important anniversary—its 25th.

This history was researched and co-written by Leland Johnson and Daniel Schaffer. Johnson is a freelance writer and former historian for the Army Corps of Engineers. Schaffer is editor-in-chief of *Forum for Applied Research and Public Policy*, a joint publication of the University of Tennessee Energy, Environment, and Resources Center and ORNL.

We owe many thanks to ORNL's 50th Year Celebration Committee, headed by Don Trauger, for coordinating the production of this history. The committee compiled names of persons to be interviewed; recruited and hired the writers under contract; solicited help from the *Review* staff in writing, editing, procuring photographs for, and coordinating the design of the document; and coordinated the review and revision of the document to ensure its accuracy. Members of the committee heavily involved with the history were Trauger, Stanley Auerbach, Deborah Barnes, Waldo Cohn, Charles Coutant, Joanne Gailar, Ellison Taylor, Mike Wilkinson, and Alex Zucker. We also are grateful for the guidance of the other distinguished reviewers, especially former ORNL Director Alvin Weinberg.

Because of space limitations and the need to ensure the readability of the narrative, the names of many talented scientists, engineers, and support staff who made important contributions have been omitted. Thousands of people are responsible for the achievements that have made ORNL an internationally renowned institution—especially in energy technologies, studies of environmental impacts, isotope production, materials developments, and basic physical and life sciences—and all should be proud of our past accomplishments. ORNL has contributed numerous important papers to the scientific literature, and many of the ideas, recommendations, discoveries, and inventions of its award-winning staff members have been woven into the intellectual and economic fabric of society. Happy birthday, Oak Ridge National Laboratory!

—*Carolyn Krause*

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Oak Ridge National Laboratory is a multiprogram, multipurpose laboratory that conducts research in the physical, chemical, material, and life sciences; in fusion, fission, and fossil energy; and in energy conservation and other energy-related technologies.

Foreword

In 1947, when the Atomic Energy Commission inherited from the Manhattan District the two scientific children of the Chicago Metallurgical Laboratory—the facilities at Oak Ridge and Argonne—it decided to designate them "national laboratories." No one really knew what a national laboratory was. In a general way, these institutions were supposed to explore the peaceful uses of nuclear fission. But in choosing to call them "national" rather than "atomic energy" laboratories, the commission displayed extraordinary foresight, or perhaps luck. An atomic energy laboratory, in principle, goes out of business when the problems of atomic energy are solved, are taken over by commercial enterprises, or are regarded (as at present) as unimportant. A national laboratory, by contrast, is more or less ensured immortality by virtue of its name. The designation "national" implies that no problem of national importance—whether in energy, environment, defense, industrial competitiveness, or basic science—is necessarily off-limits.

In the 50 years since Oak Ridge National Laboratory was founded, it has become a full-fledged national socio-technological institute. Its capabilities span the entire range of scientific disciplines, including the social sciences. It addresses an array of problems whose only common attribute is their significance both to the nation and the world.

Who, for example, would have predicted in 1943 that ORNL in 1993 would be one of the world's most powerful environmental laboratories, equipped to address economic, climatological, ecological, and energy aspects of global climate change? Or who would have expected ORNL to emerge as one of the world's most powerful centers for the development of high-temperature materials?

How did this metamorphosis take place? After all, ORNL was conceived by its founding genius, Eugene P. Wigner, as a major center for nuclear reactor development.

In 1947, the Atomic Energy Commission, following the advice of the General Advisory Committee (GAC), decided that a laboratory in the hills of Tennessee could never achieve scientific distinction. It, therefore, designated Argonne as the country's only center for reactor development. The outlook for ORNL's survival was bleak. Robert Oppenheimer and James Conant were doubtful that the laboratory could survive; and

1941	1942	1943	1945	1946	1947	1948
Attack on Pearl Harbor by Japan	Oak Ridge selected as Manhattan Project site First fission chain reaction at Stagg Field		Atomic bombs dropped on Hiroshima and Nagasaki, ending World War II	Naval reactor program conceived at ORNL		Biology Division established, using mice to estimate radiation effects on genes
		Graphite Reactor starts up as first continuously operated reactor	Neutron scattering studies begin at ORNL	First radioisotope shipment for medical research	Atomic Energy Commission established	Union Carbide becomes operating contractor

I. I. Rabi, another prominent member of the GAC, tried to persuade the scientists of ORNL to move, en masse, to the newly formed Brookhaven National Laboratory. So, ever since it was founded, ORNL's survival has been an overriding concern.

But, in a sense, survival is the overriding concern of all organizations, profit or nonprofit. That the weapons laboratories during these 50 years have not had this worry has not saved them from confronting their survival now that peace has broken out. The question is, therefore, not, "Is survival your mission?"; the question is, "Have you accomplished 'great things' that transcend the obvious, and ever-present, issue of survival?"

To record ORNL's transition from wartime pilot plant to national sociotechnical institute and to interpret its many achievements that transcend mere survival is the task accomplished so well by historians Leland Johnson and Daniel Schaffer in *Oak Ridge National Laboratory: The First Fifty Years.*

"Gray eagles" such as myself who were present at the creation of the laboratory are falling off, one by one. With each of our deaths another bit of organizational memory disappears. Yet this memory is an important element of organizational morale. By knowing and understanding how ORNL overcame challenges to its very existence, and how it eventually achieved greatness should serve to inspire the new generation of Laboratory employees. For this accomplishment, the new generations, as well as the gray eagles, must be grateful to the authors of this splendid history of ORNL.

—*Alvin M. Weinberg*
ORNL Director (1955–1973)

86-inch cyclotron completed, with world's most intense proton beams Bulk Shielding Reactor begins operation			ORNL's experimental aircraft reactor tested	Alvin Weinberg appointed ORNL director after seven years as research director	First experimental bone-marrow transplants in mice performed at "mouse house"		Relationship between intensity of radiation doses and their genetic effects explored
1950	**1952**	**1953**	**1954**	**1955**	**1956**	**1957**	**1958**
Low Intensity Test Reactor begins operation Oak Ridge School of Reactor Technology established		ORACLE, then world's most powerful computer, installed at ORNL	ORNL ecology program started	ORNL "swimming pool" reactor showcased at UN atoms-for-peace conference	ORNL biologists find predicted messenger RNA	First ORNL fusion-energy experiment begins	Oak Ridge Research Reactor begins operation

Preface

This history of the first 50 years of Oak Ridge National Laboratory was prepared to commemorate the institution's golden anniversary in 1993. The Laboratory's 50th Year Celebration Committee provided direction and resources for the study, and we are grateful to its members for their guidance and encouragement. Don Trauger chaired the committee composed of Ed Aebischer, Bill Alexander, Darryl Armstrong, Stanley Auerbach, Deborah Barnes, Waldo Cohn, Charles Coutant, Joanne Gailar, Carolyn Krause, Charles Kuykendall, Ellison Taylor, Mike Wilkinson, and Alex Zucker—all current or retired Laboratory employees. Anne Calhoun, Kim Pepper, Barbara Baker, and Nancy Holcombe, also Laboratory staff members, coordinated the committee's work.

Our exploration of historical sources was facilitated by Martin Marietta Energy Systems librarians Mary Alexander, Gabrielle Boudreaux, Deborah Cole, Bob Conrad, Nancy Gray, Dianne Griffith, Kendra Jones, Bill Myers, Vicki Punsalan, and Deborah York; by Linda Cabage, Ray Evans, and Lynn Rodems, all of the Energy Systems Office of Public Affairs; by Becky Lawson, Lowell Langford (formerly of ORNL), Linda Crews, Shirlene Rudder, Marie Swenson, Yvonne Leffew, Shirley Adcock, Betty Clack, and Virginia Norman, all of Laboratory Records; by Carolyn Krause, Jim Pearce, and Bill Cabage, all of the Publications Division; and by photographer Frank Hoffman (retired) and his assistant Anna Conover, now of the Analysas Corporation. The authors appreciate their kind assistance.

For making available the resources of the Children's Museum of Oak Ridge, we owe special thanks to Jane Alderfer, Jim Overholt, and Selma Shapiro. Research assistants Susan Schexnayder, Cathy Shires, and Edythe Quinn provided invaluable insights into the voluminous materials, and administrative assistant Becky Robinson helped keep the information in order once it was collected. Marilyn Morgan, a graduate student in the University of Tennessee's English department and a *Review* intern, helped review the manuscript and wrote several sidebars, and Carolyn Krause, in addition to her work on Trauger's committee, helped write many of the sidebars, and, with Jim Pearce and Mike Aaron, edited the manuscript, and coordinated the work of the electronic publishers and layout artists.

For enlightenment and inspiring ideas, we are indebted to Laura Fermi, Richard Fox, Milton

1961	1962	1964	1965	1967	1968
Development begins on isotope heat sources to power space satellites	Oak Ridge Isochronous Cyclotron completed	ORNL first national lab to hire social scientists	High Flux Isotope Reactor (HFIR) and Molten Salt Reactor begin operation	Viruses separated in high-speed centrifuge	Centrifugal fast analyzer developed for medical diagnosis Zonal centrifuge makes ultrapure vaccines
	ORNL discovers ion channeling in crystalline solids	"Water for Peace," nuclear desalination concept, featured at UN conference	ORNL–Univ. of Tenn. graduate program in biomedical science established Heavy Section Steel Technology program for reactor safety started	International Biological Program launched with ORNL help	Second Molten Salt Reactor operated Oak Ridge Electron Linear Accelerator completed

Lietzke, Herbert MacPherson, Herbert Pomerance, Herman Postma, Raymond Stoughton, Chet Thornton, Elaine Trauger, Alvin Trivelpiece, Alvin Weinberg, and a host of Laboratory personnel who took time from their busy schedules for both formal interviews and informal chats that broadened our understanding of the Laboratory's past. For the many fine photographs used here, we especially thank Ed Westcott, Frank Hoffman, and Bill Norris.

Astrophysicists tell us the space-time continuum and the behavior of light prevent us from seeing a true image of the present. Like it or not, these physicists say, only the past provides a clear portrait of our lives and behavior—a conclusion that historians are more than eager to share.

Unlike physicists and other scientists, however, historians and writers live in a world of changing human perceptions and behavior, not in a world of immutable natural laws and fixed physical phenomena. For these reasons, what follows should be considered *a* history, not *the* history, of Oak Ridge National Laboratory. Except for rare instances (for example, the day that the Graphite Reactor went critical), people will disagree about the relative importance of specific Laboratory accomplishments and the relative contributions of various Laboratory staff members. Problems of assessment and attribution, moreover, are compounded by problems of space, time, and memory. For the writers, space limitations required selecting for discussion only a few of the Laboratory's many significant achievements, projects, and programs. For readers, 50 years of history dims memories and may place at odds what actually happened with what participants now think happened.

Despite these inevitable limitations, we hope this presentation of Oak Ridge National Laboratory's past will be conducive to a better understanding of its present, serving both as a guidepost for the Laboratory's strengths and a road map for its future endeavors. We also hope that readers, through these pages, are able to share some of the joy, excitement, and pride that have accompanied the Laboratory staff's journey of discovery.

—Leland Johnson and Daniel Schaffer

ORNL studies moon rocks ORNL studies environmental impacts of nuclear power plants	World's first successful freezing, thawing, and implantation of mouse embryos		Herman Postma becomes ORNL director		Research on global carbon cycle begins		President Carter visits ORNL	
1971	1972	1973	1974	1975	1976	1977	1978	1979
Research begins at ORMAK, experimental fusion tokamak	Energy conservation studies started ORNL participates in reactor cooling hearings	Alvin Weinberg becomes a White House science advisor; Floyd Culler becomes acting ORNL director		Ground-breaking for Environmental Sciences Building		Construction begins on Large Coil Test Facility for superconducting fusion magnets		ORNL's neutral-beam injectors achieve record fusion plasma temperatures

Prologue

One of the world's premier scientific research centers, Oak Ridge National Laboratory represents a marriage between science and industrial technology forged for national defense during the throes of global war. Currently managed by Martin Marietta Energy Systems, Inc., it is the oldest national laboratory on its original site, site of the world's oldest nuclear reactor, and home to the Department of Energy's largest and most diversified multiprogram laboratory.

As a government-sponsored institution managed by a private corporation to advance science and technology in partnership with universities and industrial firms, Oak Ridge, along with other national laboratories, embodied a new approach to scientific and governmental administration. Because solutions to energy and environmental problems have been found as much in engineering and applied technology as in basic science, the Laboratory, since its inception, has offered a vital link between the two and has always carried an avowedly semi-industrial appearance clothed by an academic predisposition.

Celebrating 50 years of service to the United States in 1993, Oak Ridge National Laboratory has changed the history of the nation and the world. As a remarkable and sometimes bewildering complex of sophisticated industrial, scientific, and educational activities in an isolated rural setting, the Laboratory encapsulates the ever-changing nature of the U.S. research agenda, reflecting on a small, institutional scale sweeping shifts in national and global concerns during the past 50 years.

In its early years, the Laboratory employed 1500 scientists and support staff housed in primitive wooden frame buildings. There, people worked—often unknowingly—on the construction of a nuclear reactor and the production of plutonium from uranium. Since then, the Laboratory has passed through many transitions. In the postwar years, it survived budget and staff retrenchments by focusing on nuclear science and the development of nuclear energy for peaceful uses, including production of radioisotopes for biological research. In the 1960s, it became the first national laboratory to turn to research tied only tangentially to nuclear energy. During the 1970s, it expanded its research, in accord with shifting national priorities, to encompass all forms of energy and their impacts on the environment. In the 1980s, it became a multiprogram laboratory of the Department of Energy, leading broad research

ORNL opens user facilities: accelerator lab, neutron research facilities, environmental research park	Union Carbide, operating contractor since 1948, announces withdrawal	Ecological and Physical Sciences Study Center opens	High Flux Isotope Reactor shut down temporarily	High-Temperature Materials Laboratory opens as user facility	Alex Zucker becomes acting ORNL director	Alvin Trivelpiece becomes ORNL director Science education emphasized
1980	**1982**	**1984**	**1986**	**1987**	**1988**	**1989**
	ORNL begins helping developing nations assess energy technologies and policies	Martin Marietta Energy Systems assumes ORNL operating contract Planning begins for Advanced Neutron Source, next-generation research reactor		Center for Global Environmental Studies created Human genome studies begin	Technology transfer becomes ORNL mission	High-Temperature Superconductivity Pilot Center signs several agreements with industry

initiatives responsive to national needs. By its 50th anniversary, Oak Ridge National Laboratory had emerged as a leading global research center for issues related to energy, environment, and basic science and technology.

Currently employing about 4500 people, the Laboratory's research agenda ranges from global warming to energy conservation to high-temperature superconductivity to ozone-safe substitutes for chlorofluorocarbons. It is committed to improving national science education and to speeding the transfer of its technological developments to the commercial marketplace.

Since 1943, scientists and technicians at Oak Ridge National Laboratory have confronted issues vital to human life and its environment. Established to create nuclear weapons of unprecedented destructive power, the supreme paradox of its history is its subsequent contributions to improving energy production and use, the environment, health, and the economy. Millions of people have benefited from the results of the Laboratory's isotope production and research and development activities.

Examples of applications of ORNL efforts are isotopes and instruments for medical diagnosis and treatment; ultrapure vaccines that have minimal side effects; regulations to protect human health and safety; bone marrow transplants for radiation accident victims; higher-quality meat resulting from use of the technology to freeze, thaw and implant embryos from superior animals; nuclear reactors that supply one-fifth of U.S. electricity; a more powerful U.S. Navy; energy-efficient refrigerators, hot-water heaters, and other appliances; and stronger alloys and ceramics for use at high temperatures.

During the next 50 years, the Laboratory is likely to expand its agenda to encompass the full array of scientific and technical issues facing the nation and world. In the process, it will further enhance its role as a national laboratory in service to America's—and the world's—scientific and technical needs. The Laboratory, in short, has a history worth remembering and a future worth watching.

—Alvin Trivelpiece
ORNL Director

First DOE cooperative research and development agreement signed using ORNL expertise	Zachary Taylor's remains analyzed for arsenic using neutrons at HFIR	Center for Computational Sciences established
1990	1991	1992
ORNL computer programs schedule transport of troops and equipment for Persian Gulf War		President Bush visits ORNL
Operation of High Flux Isotope Reactor resumes		

THE VICE PRESIDENT

WASHINGTON

August 19, 1993

Dr. Alvin W. Trivelpiece
Director
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831

Dear Dr. Trivelpiece:

I am pleased to have this opportunity to congratulate the Oak Ridge National Laboratory (ORNL) on its 50th Anniversary. Certainly, every American can take pride in what has been accomplished there during the past half-century.

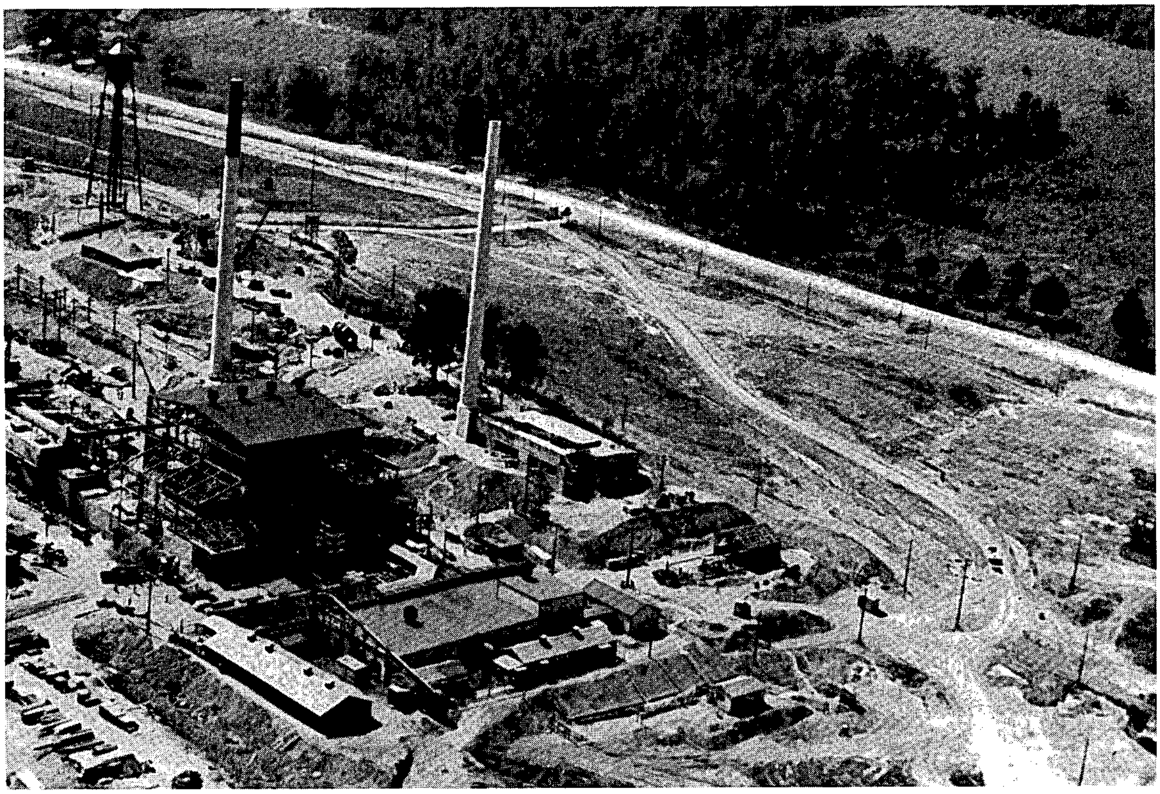
As a Tennessean, I grew up hearing the stories about the top-secret Manhattan Project and the essential role that ORNL played in bringing World War II to an end. Later, I learned how the operations at Oak Ridge evolved beyond that first, urgent mission to meet the nation's changing needs and priorities. Among the challenges tackled at ORNL have been conservation and renewable energy, cancer detection and treatment, advanced materials for the automotive and aerospace industries, techniques for cleaning up hazardous and radioactive wastes, and a greater understanding of environmental processes both microscopic and global in scale.

Such issues require the best minds, sophisticated equipment, a desire to make new discoveries, and a commitment to excellence. ORNL long has been famous for all of these qualities. For this reason, I expect the United States to continue to look to Oak Ridge for answers to the scientific and technological challenges of the next 50 years.

Sincerely,

Al Gore

AG/wem



Clinton Laboratories, X-10 site, including the Graphite Reactor, under construction in October 1943.

Chapter 1

Wartime Laboratory

Spreading out along broad valleys cut by the Clinch River and framed by the foothills of the Appalachian Mountains, Oak Ridge seems an unlikely setting for events that would change the course of history.

At the time of the Japanese attack on Pearl Harbor on December 7, 1941, century-old family farms and small crossroads communities such as Scarborough, Wheat, Robertsville, and Elza occupied what was about to become the Oak Ridge Reservation. Outsiders considered the region a quaint reminder of the 19th-century frontier that time and progress had passed by.

In truth, the area experienced enormous change during the early 20th century. On the up side, it felt the effects of Henry Ford's automobile and shared, to some extent, the comforts afforded by electricity; on the down side, it reeled from the aftershocks of the Great Depression that rocked the economy and exerted additional pressures on the region's fragile natural resources. Located just 25 miles from the Tennessee Valley Authority's (TVA's) corporate headquarters at Knoxville and just a few miles below TVA's huge Norris Dam on the Clinch River, the area was, in fact, a focal point of one of the nation's boldest experiments in social and economic engineering. The tiny Wheat community, for example, had been selected for a TVA-inspired venture in cooperative agriculture.

Residents of the Oak Ridge area in 1941 did not feel bypassed by history. But even the advent of the automobile, the introduction of electricity, the hardships of the Great Depression, and direct participation in an unprecedented government-sponsored social experiment did not prepare them for what was about to happen.

In early 1942, the Army Corps of Engineers designated a 59,000-acre (146,000-hectare) swatch of land between Black Oak Ridge to the north and the Clinch River to the south as a

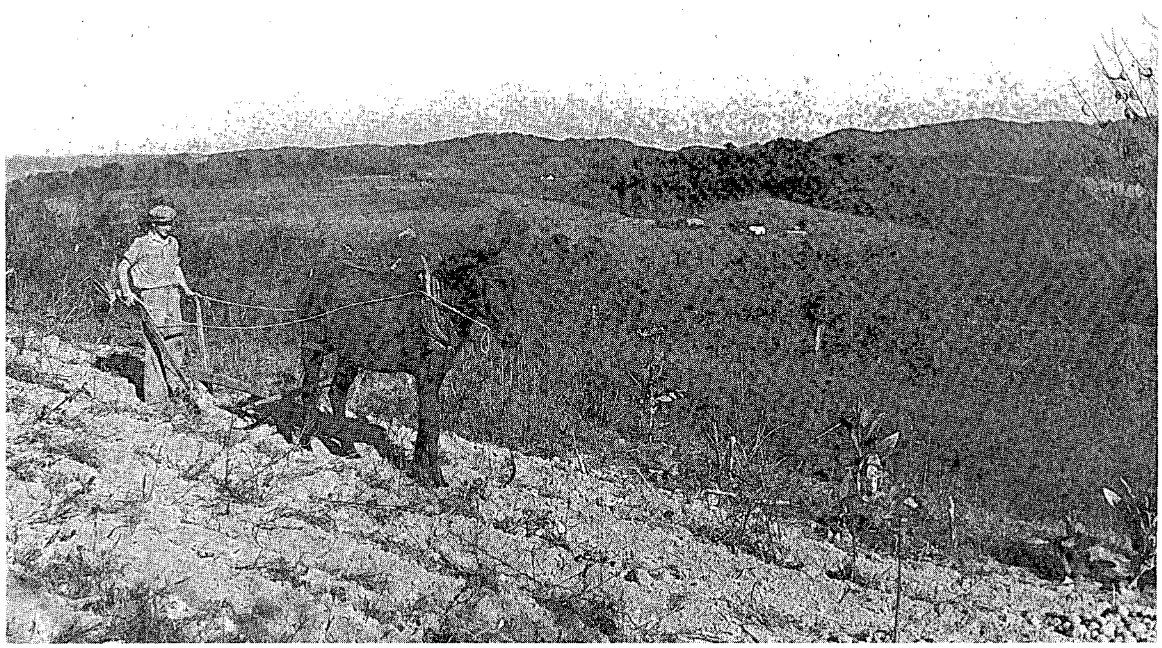
"Scientists ... swarmed into Oak Ridge to build and operate three huge facilities that would change the history of the region and the world forever."

federal reserve to serve as one of three sites nationwide for the development of the atomic bomb. About 3000 residents received court orders to vacate within weeks the homes that their families had occupied for generations. Thousands of scientists, engineers, and workers swarmed into Oak Ridge to build and operate three huge facilities that would change the history of the region and the world forever.

On the reservation's western edge rose K-25, or the gaseous diffusion plant, a warehouselike building covering more area than any structure ever built. Completed at a cost of $500 million and operated by 12,000 workers, the K-25 Plant separated uranium-235 from uranium-238. On its northern edge grew the workers' city named Oak Ridge; south of the city rose the Y-12 Plant, where an electromagnetic method was used to separate uranium-235. Built for $427 million, the Y-12 Plant employed 22,000 workers. Near the reservation's southwest corner, about 10 miles from Y-12, was the third plant, X-10.

Built between February and November 1943 for $12 million and employing only 1513 people during the war, X-10 was much smaller than K-25 and Y-12. As a pilot plant for the larger plutonium plant built at Hanford, Washington, X-10 used neutrons emitted in the fission of uranium-235 to convert uranium-238 into a new element, plutonium-239. During the war, X-10 was called Clinton Laboratories, named after the nearby county seat of rural Anderson County; in 1948, Clinton Laboratories became Oak Ridge National Laboratory.

The Laboratory, which celebrates its 50th anniversary in 1993, has evolved from a war-emergency pilot plant operated under the cloak of secrecy into one of the nation's outstanding centers for energy, environmental, and basic scientific research and technology development. It currently employs about 4500 people, including many scientists recognized internationally as experts in their fields. Laboratory endeavors range from studies of



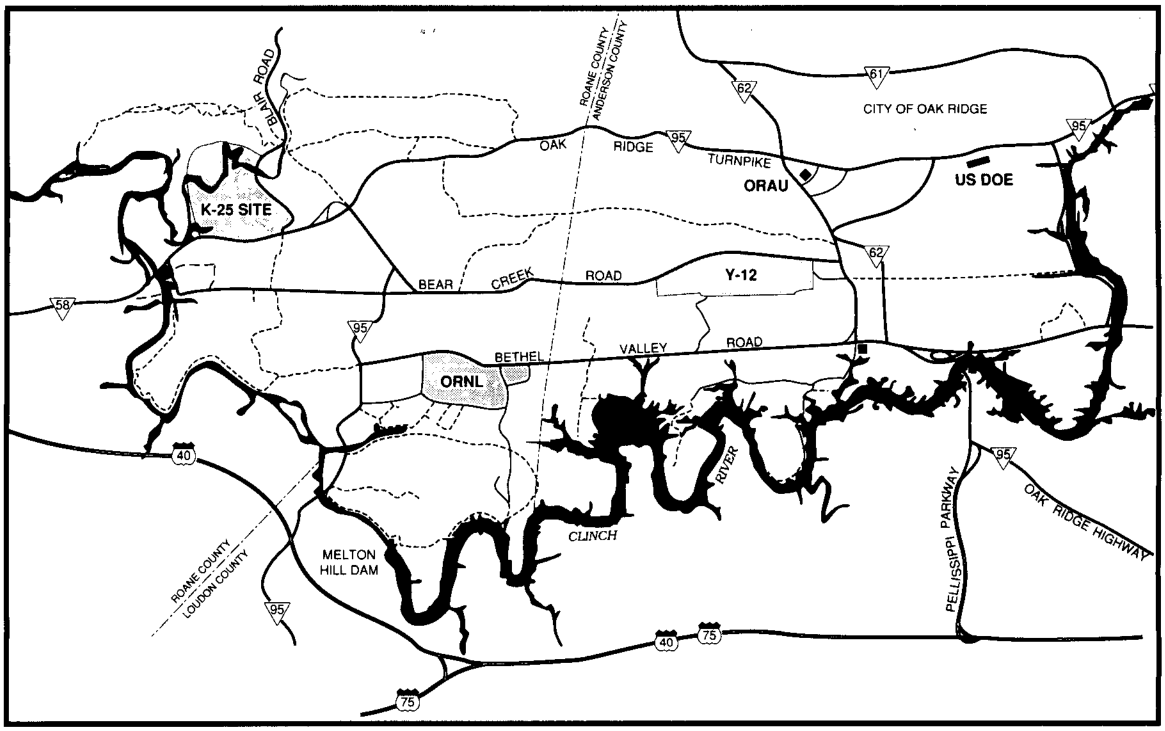
Oak Ridge area farmers on the rugged Appalachian ridges and valleys still plowed with mules before 1942.

nuclear chemistry and physics to inquiries into global warming, energy conservation, high-temperature superconductivity, and new materials. Its institutional roots, however, lie with the awesome power released by the splitting of atoms.

The Laboratory's nuclear roots run deep and nourish much of its research on improving the safety of commercial nuclear power, identifying effective methods of managing nuclear waste, and achieving practical fusion power. The roots are not only deep, they are broadly international.

Supreme irony marks the Laboratory's history. The institution was born during war and was propelled by a sense of high-stakes competition and urgency: if Hitler's scientists had developed the atomic bomb first, Nazi Germany might have placed the entire world under a fascist fist. Yet, the Laboratory's present scientific excellence could not have been achieved without the camaraderie and sense of collective purpose that propels international science. Created to build a weapon capable of unprecedented destruction, the Laboratory became an institution that nurtures the ability of people to understand and transform their universe for the better. For this reason and more, its story should be told.

The rural lifestyle of the Oak Ridge area was forever changed by the local Manhattan Project plants.



Modern map of the Oak Ridge vicinity shows the K-25, Y-12, and X-10 (ORNL) sites.

Laboratory Roots

The history of Oak Ridge National Laboratory begins in three distinctly different places: Albert Einstein's retreat on Long Island, New York; the executive offices of the White House in Washington, D.C.; and university laboratories throughout the nation and overseas, especially at the University of Chicago.

At its highest level, the scientific community is international in scope. As fascist dictators seized power in Europe during the 1930s, some of the continent's greatest scientists fled to join colleagues in Britain and America. Among them were the German, Albert Einstein; the Italian, Enrico Fermi; and Hungarians, Edward Teller, Leo Szilard, John von Neumann, and Eugene Wigner.

These brilliant minds joined cooperative international efforts to develop atomic weapons and, later, nuclear energy, significantly influencing 20th-century history in general and the history of Oak Ridge National Laboratory in particular. Eugene Wigner, in fact, has been called the "patron saint" of the Laboratory.

Eugene Wigner, a pioneering chemical engineer and physicist from Budapest, may have been the least known of the immigrant scientists. Completing a chemical engineering degree in Berlin in 1925, Wigner took a job at a Budapest tannery where his father also worked. Physics was his evening and weekend hobby. His friend John von Neumann called his attention to mathematical group theory, and Wigner soon published a series of technical papers that applied symmetry principles to problems of quantum mechanics. After two years at the tannery, he accepted an assistantship in theoretical physics in Berlin at the princely salary of $32 per month.

In Berlin, Wigner established an international reputation as a physicist, and in 1930 Princeton University hired both him and von Neumann, each on a half-time basis. For a few years, the two friends commuted every six months between Berlin and Princeton until the Nazi government terminated their employment.

Wigner then went to the University of Wisconsin to work. There he devised a fundamental formula that enabled scientists to understand a neutron's energy variations when channeled through materials having different absorption capabilities. At Wisconsin, he also discovered a university life that reached beyond academic circles to plain people who grew potatoes and milked cows, and he met scientists who repaired

Atoms In Appalachia

Before late summer of 1942, residents of four rural communities in the Clinch River valley farmed the land, growing tobacco and corn and raising cattle, chickens, and pigs. Some men made cornmeal in grist mills, and others mined coal in the nearby Cumberland Mountains. Women canned berries, beans, pickles, and peaches in their clapboard homes or log cabins. Families participated in hog killings, quilting parties, strawberry picking, ice cream making, and corn shucking. Children traded eggs and berries for candy in the country store, where villagers gossiped and exchanged news. Families worshiped and enjoyed all-day singings, square dancing, pie suppers, and homecomings at their local churches.

The land occupied by these settlers had been acquired for homesteading in 1798 by a treaty between the U.S. government and several Cherokee tribes. Some of the residents of the four communities had moved there after being displaced by government activities such as the establishment of Great Smoky Mountains National Park by the National Park Service and the construction of Norris Dam by the Tennessee Valley Authority. In September 1942, about 1000 families were displaced again by the U.S. government's acquisition of 59,000 acres for the wartime Manhattan Project.

The four displaced communities were Elza, Robertsville, Wheat, and Scarborough (now spelled Scarboro).

"Leaders of New Bethel Church were convinced that the government would tear down the church in 1942, so they voted to erect a monument to the church as their last official action."

Elza, named after a construction engineer in charge of building a railroad bridge there, was once the home of John Hendrix, the "prophet" who around 1900 predicted that Bear Creek Valley (where the Oak Ridge Y-12 Plant stands) "someday will be filled with great buildings and factories, and they will help toward winning the greatest war that ever will be."

Robertsville was settled in 1804 by Collins Roberts, who had received a 4000-acre land grant in what is now Oak Ridge. Robertsville High School was built there around 1915; its auditorium is now the gymnasium of Robertsville Junior High School.

Wheat, settled in the middle of the 19th century, was named after the first postmaster, Frank Wheat. It was the home of Roane College, a liberal arts college that was open from 1886 through 1908. The community was dispersed by acquisition of the land for the K-25 Site.

Oak Ridge National Laboratory and its surrounding land displaced Scarborough, which was founded in the 1790s and named after three early settlers—Jonathan, David, and James Scarborough, brothers from Virginia. The area had been called Pellissippi by the Cherokees.

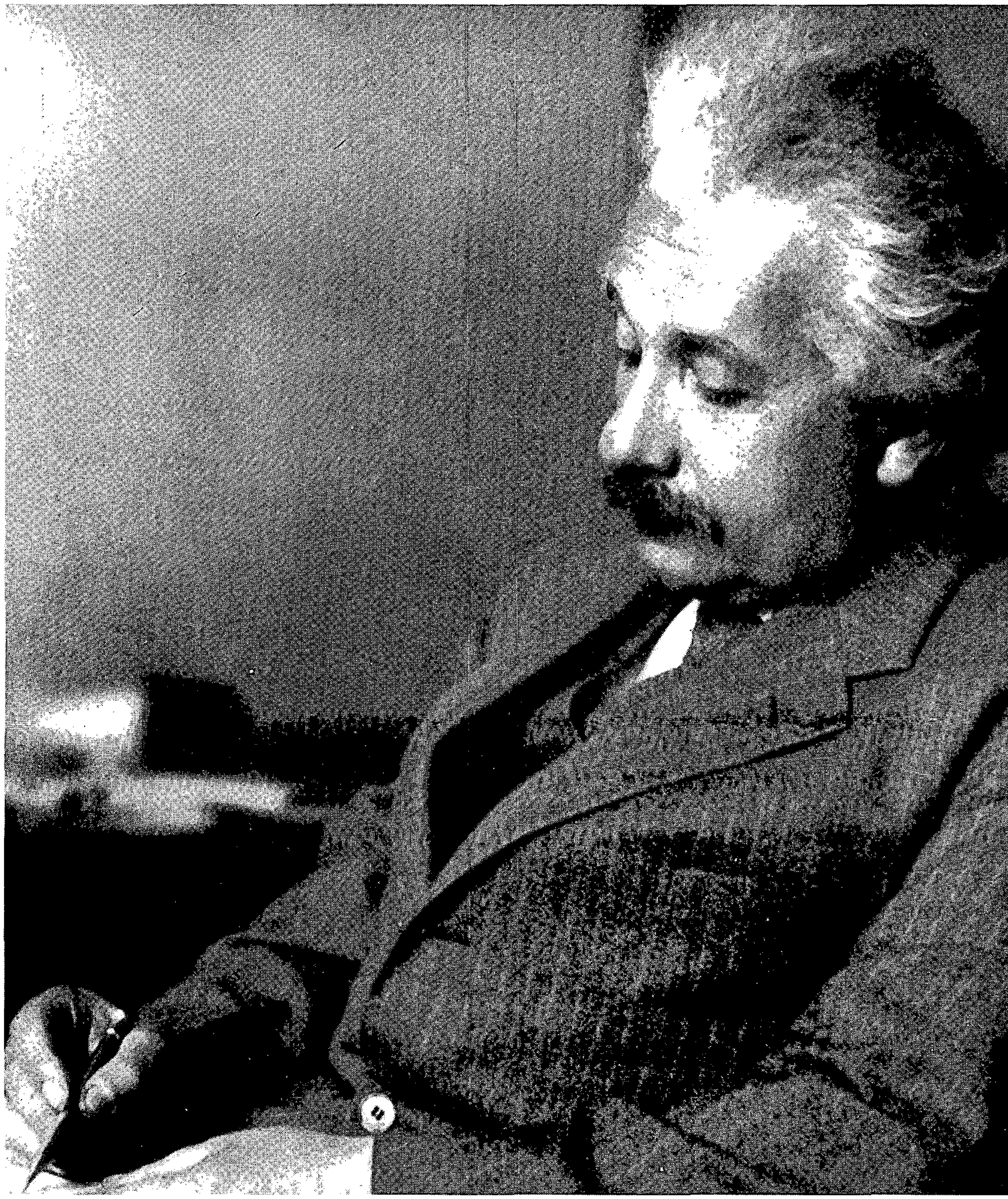
Of the four communities that predated Oak Ridge, only Scarborough retains much of its old character (although the houses and country stores along Bethel Valley Road are gone). Scarborough Elementary School burned in the late 1920s but it was rebuilt as a brick structure, part of which is still standing and used by the Oak Ridge Institute for Science and Education.

Also standing is the New Bethel Church across from ORNL. Church leaders were convinced that the government would tear down the church in 1942, so they voted to erect a monument to the church as their last official action. The memorial behind the church reads "Erected in Memory of New Bethel Baptist Church, Open 1851 Closed 1942...Church Building Stood 47 Feet in Front of this Stone."

However, the U.S. government let the building remain and used it for storage, meetings, and experiments. It serves today as a museum about the residents who had to move and leave their beloved land.

Residents of Scarborough were as unhappy as the settlers in Wheat, Robertsville, and Elza about leaving their farms and land. But, as one of them said: "What do you do? The government needed your land to win the war. Who would refuse such a request as that?"

"Thinking that Washington officials would more likely listen to the famous Albert Einstein, an old acquaintance from Berlin, Wigner and Szilard sought him out in July 1939."



Albert Einstein signed a letter to President Roosevelt in 1939 that called for the investigation of uranium fission as a potential weapon.

their cars and made home improvements. He later said that at Wisconsin he came to love his adopted country.

Returning to Princeton, he studied solid-state physics and supervised the work of graduate students. His first student, Frederick Seitz, later became president of the National Academy of Sciences and of Rockefeller University; his second, John Bardeen, developed the transistor and twice received the Nobel Prize for physics.

The increasing strength of fascist governments in Europe troubled Wigner deeply. As a youngster, he had seen Hungary's enfeebled monarchy supplanted by brutal communist and then fascist governments. From personal experience, he developed an implacable enmity toward totalitarian regimes. When he learned in early 1939 that two German chemists had discovered nuclear fission in uranium, Wigner recognized that this discovery could lead to both weapons of mass destruction and abundant energy for mass consumption. Fearing Nazi Germany would initiate a crash program to develop atomic weapons, Wigner urged the United States government to support research on nuclear fission. He found an ally in his fellow countryman Leo Szilard, who in Hungary had attended the same schools as Wigner before emigrating to the United States.

Studying nuclear fission with Enrico Fermi at Columbia University in New York City, Szilard needed additional funds to continue his experiments with uranium and graphite. Wigner gladly lent his support to Szilard's efforts. Because other scientists were lobbying authorities with their own weapon schemes, Wigner and Szilard found their campaign for nuclear fission research moved so slowly they seemed to be "swimming in syrup."

Thinking that Washington officials would be more likely to listen to the famous Albert Einstein, an old acquaintance from Berlin, Wigner and Szilard sought him out in July 1939. Learning he had left Princeton to vacation on Long Island, they drove there, found Einstein's cabin, and explained to him why the United States should initiate fission research before German scientists developed an atomic weapon. As Wigner later recalled:

> *Einstein understood it in half a minute. It was really uncanny how he dictated a letter in German with enormous readiness. It is not easy to formulate and phrase things at once in a printable manner. He did. I translated that into English. Szilard and Teller went out, and Einstein signed it. Alexander Sachs took it to Washington. This helped greatly in initiating the uranium project.*

In October 1939, President Franklin Roosevelt appointed a committee of prominent scientists and government administrators to manage federally funded scientific research. Wigner, Szilard, and Edward Teller met with the committee and requested $6000 to purchase graphite for fission experiments. They listened to an Army officer on the committee expound at length upon his theory that civilian and troop morale, not experimental weapons, won wars.

Four nuclear physicists who advanced our understanding of nuclear power: left to right, Walter Zinn, Leo Szilard, Eugene Wigner, and Alvin Weinberg.

"This first $6000 of federal funding for nuclear energy research launched a vast, multibillion-dollar program that has continued unabated ...."

Szilard later recalled that "suddenly Wigner, the most polite of us, interrupted him. He said in his high-pitched voice that it was very interesting for him to hear this, and if this is correct, perhaps one should take a second look at the budget of the Army, and maybe the budget should be cut." The officer glared in silence at Wigner, and the committee agreed to provide funds for the experiment.

This first $6000 of federal funding for nuclear energy research launched a vast, multibillion-dollar program that has continued unabated under the successive management of the U.S. Army, Atomic Energy Commission, Energy Research and Development Administration, and Department of Energy. The program has had direct and lasting ties to atomic research, development, and production sites across the United States, including Oak Ridge.

The initial funds for the uranium and graphite experiments, however, were not released until late 1940. Wigner became increasingly exasperated as the irreplaceable months passed. After the war, he contended that the delay, largely the result of bureaucratic footdragging, cost many lives and billions of dollars.

American scientists, nevertheless, made vital advances in the interim. At Columbia University, in March 1940, John Dunning and his colleagues demonstrated that fission occurred more readily in the isotope uranium-235 than in uranium-238, but only one of 140 uranium atoms was the 235 isotope. Using cyclotrons at the University of California, in 1940 Edwin McMillan and Philip Abelson discovered element 93, the first element heavier than uranium, atomic number 92. They named this transuranium element neptunium. A year later, Glenn Seaborg and colleagues discovered element 94 (the decay product of the newly synthesized number 93), named it plutonium (in the planetary sequence Uranus, Neptune, Pluto), and demonstrated its fissionability. Two doors to atomic weapons and energy thus were opened for future exploration: uranium-235 could be separated from uranium-238 for weapons use, and uranium-238 could be bombarded with neutrons—in a nuclear pile or reactor—to produce plutonium that could then be chemically extracted for weapons production.

Metallurgical Laboratory

The day after the Japanese attacked Pearl Harbor, Arthur Compton, a Nobel laureate at the University of Chicago, contacted Eugéne Wigner to discuss the possibility of consolidating nationwide plutonium research efforts in Chicago. At meetings in January 1942, Compton brought together scientists experimenting with nuclear chain reactions at Princeton and Columbia universities with those investigating plutonium chemistry at the University of California to outline the plutonium project's objectives. Compton's schedule called for determining the feasibility of a nuclear chain reaction by July 1942, achieving the first self-sustaining chain reaction by January 1943, extracting the first plutonium from irradiated uranium-238 by January 1944, and producing the first atomic bomb by January 1945. In the end, all these deadlines were met except the last, which occurred six months later than planned.

To accomplish these objectives, Compton formed a "Metallurgical Laboratory" as cover at the University of Chicago and brought scientists from the east and west coasts to this central location to develop chain-reacting "piles" for plutonium production, devise methods for extracting plutonium from the irradiated uranium, and design a weapon. Remaining in charge of the overall project, Compton selected Richard Doan as director of the Metallurgical Laboratory. An Indiana native, Doan had earned a physics degree from the University of Chicago in 1926 and had been a researcher for Western Electric and Phillips Petroleum before the war.

Compton also placed Glenn Seaborg in charge of the research on plutonium chemistry and assigned him the task of devising methods to separate plutonium from irradiated uranium in quantities sufficient for bomb production. To coordinate the theoretical and experimental phases of research associated with a chain reaction, Compton chose Eugene Wigner, Enrico Fermi, and Samuel Allison. Fermi continued his experiments with ever-larger piles of uranium and graphite, while Samuel Allison directed a cyclotron group, including Canadian Arthur Snell, who assessed nuclear activities in uranium and graphite piles. Wigner and Snell later joined the X-10 staff.

Eugene Wigner headed the theoretical physics group crowded into Eckart Hall on the University of Chicago campus. His "brain trust" of 20 scientists studied the arrangement, or lattice, of uranium and control materials for achieving a chain reaction and planned the design of nuclear reactors. Among Wigner's group were Gale Young, Kay Way, and Alvin Weinberg, all of whom later moved to Oak Ridge.

Having a chemical engineering background, Wigner also offered advice to Glenn Seaborg and his staff of University of California chemists, who were seeking to separate traces of plutonium from uranium irradiated in cyclotrons. This task was particularly challenging because to that point no one had isolated even a visible speck of plutonium. By September 1942, the team had obtained a few micrograms of plutonium for experimentation, but they needed much more for additional analysis.

In 1942, Compton brought Martin Whitaker, a North Carolinian who chaired New York University's physics department, to Chicago to help Enrico Fermi and Walter Zinn build subcritical uranium and graphite piles. He later put Whitaker in charge of a laboratory under construction in the Argonne forest preserve on Chicago's southwest side. It was here that Compton initially planned to bring the first nuclear pile to critical mass. A strike by construction workers, however, prevented the laboratory's timely completion. As a result, Compton and Fermi decided to build a graphite pile housed in a squash court under the stands of the University of Chicago's stadium.

Leo Szilard and later Norman Hilberry were placed in charge of supplying materials for the pile experiments. They obtained impurity-free graphite from the National Carbon Company in Cleveland, Ohio, and the purest uranium metal available from Frank Spedding's research team at Ames, Iowa.

Under this University of Chicago football stadium, scientists achieved the world's first nuclear chain reaction.

Revolving Door of Success

Who can enter a revolving door behind you and exit it before you? A Hungarian!

This complimentary joke referred to the band of scientifically gifted Hungarians who came to America during the Great Depression of the 1930s looking for freedom and opportunity. Among them, Edward Teller is best known as the "father of the hydrogen bomb" and an advocate of the "Star Wars" defense strategy. Leo Szilard, remembered for his whimsical ingenuity, envisioned the nuclear chain reaction and conceived a cyclotron; he also held a joint patent with Albert Einstein for a refrigerator cooled by liquid metal. John von Neumann's mathematical wizardry aided the development of mathematical theory and early computers. Least known of the group was Eugene Wigner, a chemical engineer and physicist who was an instrumental figure in the Manhattan Project and in the Laboratory's formative years.

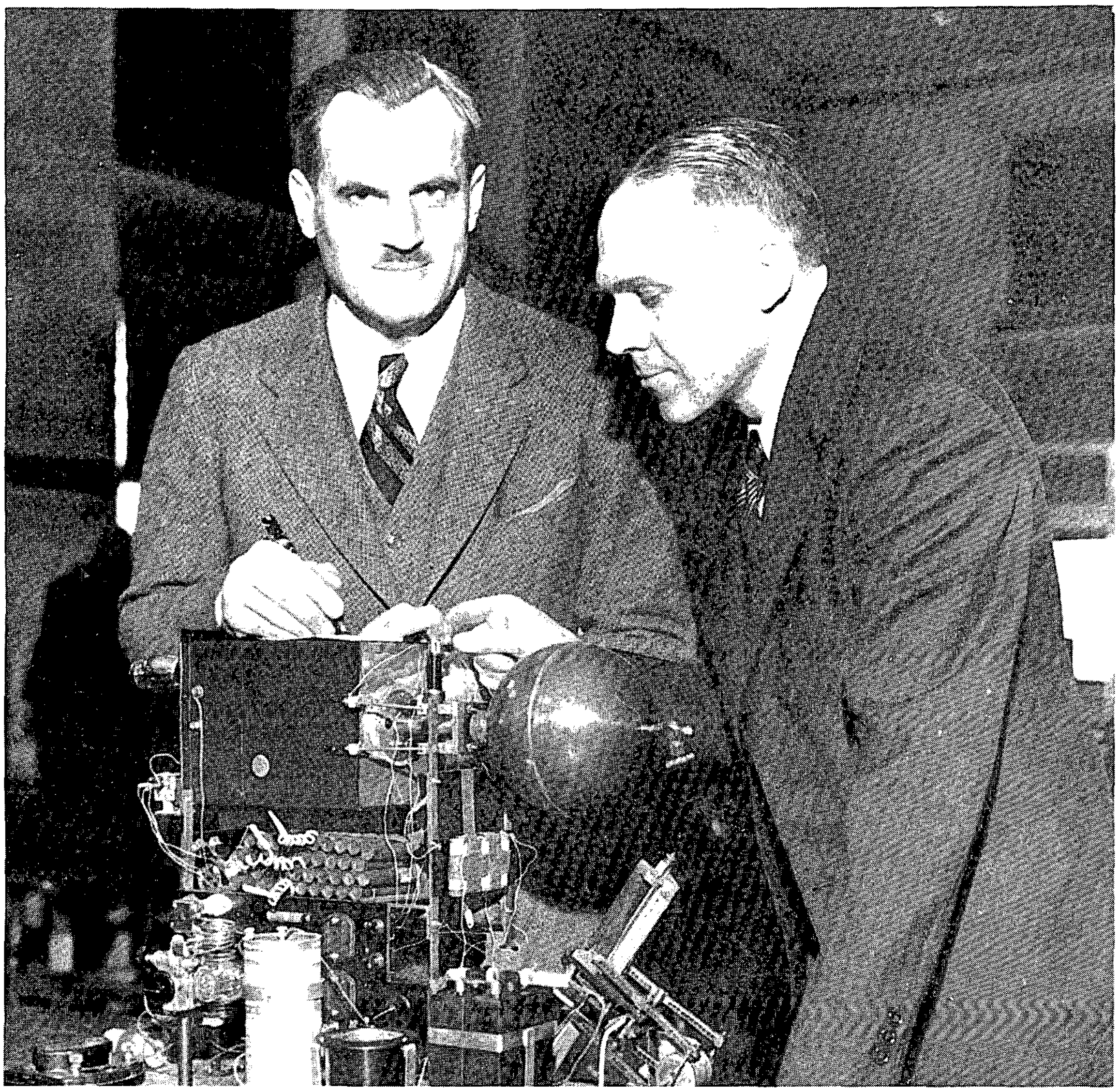
> *"He played a pivotal role in the development of the atomic bomb and in the design of nuclear reactors that produced weapon materials and electrical power."*

All four scientists were from Budapest. In fact, von Neumann and Wigner attended the same high school and were inspired by the same teacher, Laszlo Ratz, who opened the doors to science and mathematics for them. For the brilliant von Neumann, Ratz created a special class of one, possibly explaining why von Neumann, as an adult, seemed aloof. Wigner remained with the other students, but when Ratz asked the class questions, he often told Wigner to be quiet to give the others a chance to respond. Wigner was quiet by nature—shy and so slight that his classmates dubbed him "Little Gene." Impeccably dressed, usually in gray, he blended unnoticed into crowds.

Wigner came to America with his friend von Neumann in 1930. He played a pivotal role in the development of the atomic bomb and in the design of nuclear reactors that produced weapon materials and electrical power. After World War II, he became the Laboratory's research director. His career took him back and forth from what he described as "monastic" university life at Princeton University to the turmoil of industrial-strength science, including many visits and three lengthy stays at the Laboratory. He was in Oak Ridge in 1963 when news came that he had been awarded the Nobel Prize for physics.

Like Wigner's Hungarian schoolmates, his friends at Oak Ridge learned to admire his steadfast passion for perfection in both science and his personal life. Although unassuming, Wigner's Hungarian accent, singular style, and unmatched scientific ability made him a rare personality. To Wigner, a piece of work was "amusing" if right and symmetrical but "interesting" if disorderly and wrong. People at Oak Ridge, as elsewhere, found it impossible to enter a doorway after him, because he always opened doors for them, holding the portal ajar for others to emerge triumphant. Widely admired and loved, Wigner was a scientific genius of rare human kindness.

> *"To Wigner, a piece of work was 'amusing' if right and symmetrical but 'interesting' if disorderly and wrong. People at Oak Ridge, as elsewhere, found it impossible to enter a doorway after him, because he always opened doors for them, holding the portal ajar for others to emerge triumphant, both literally and figuratively."*



Arthur Compton and his assistant Richard Doan headed the Metallurgical Laboratory at the University of Chicago. Compton made Doan research director at Clinton Laboratories in 1943. *Argonne National Laboratory photograph*

George Boyd and chemists at Chicago analyzed the materials to ensure the absence of impurities that might interfere with a nuclear reaction, and Fermi and his colleagues put the materials into a series of subcritical uranium and graphite piles built in what was to become the world's most famous squash court. Fermi called them piles because, as the name implies, they were stacks or piles of graphite blocks with lumps of uranium interspersed between them in specific lattice arrangements. Uranium formed the "core," or source of neutrons, and graphite served as a "moderator," slowing the neutrons to facilitate nuclear fission. In truth, the piles were small, subcritical nuclear reactors cooled by air, but the name reactor did not replace pile until 1952. Fermi gradually built larger subcritical piles, carefully measuring and recording neutron activity within them, edging toward the point at which the pile would reach "critical mass" and the reaction would be self-sustaining.

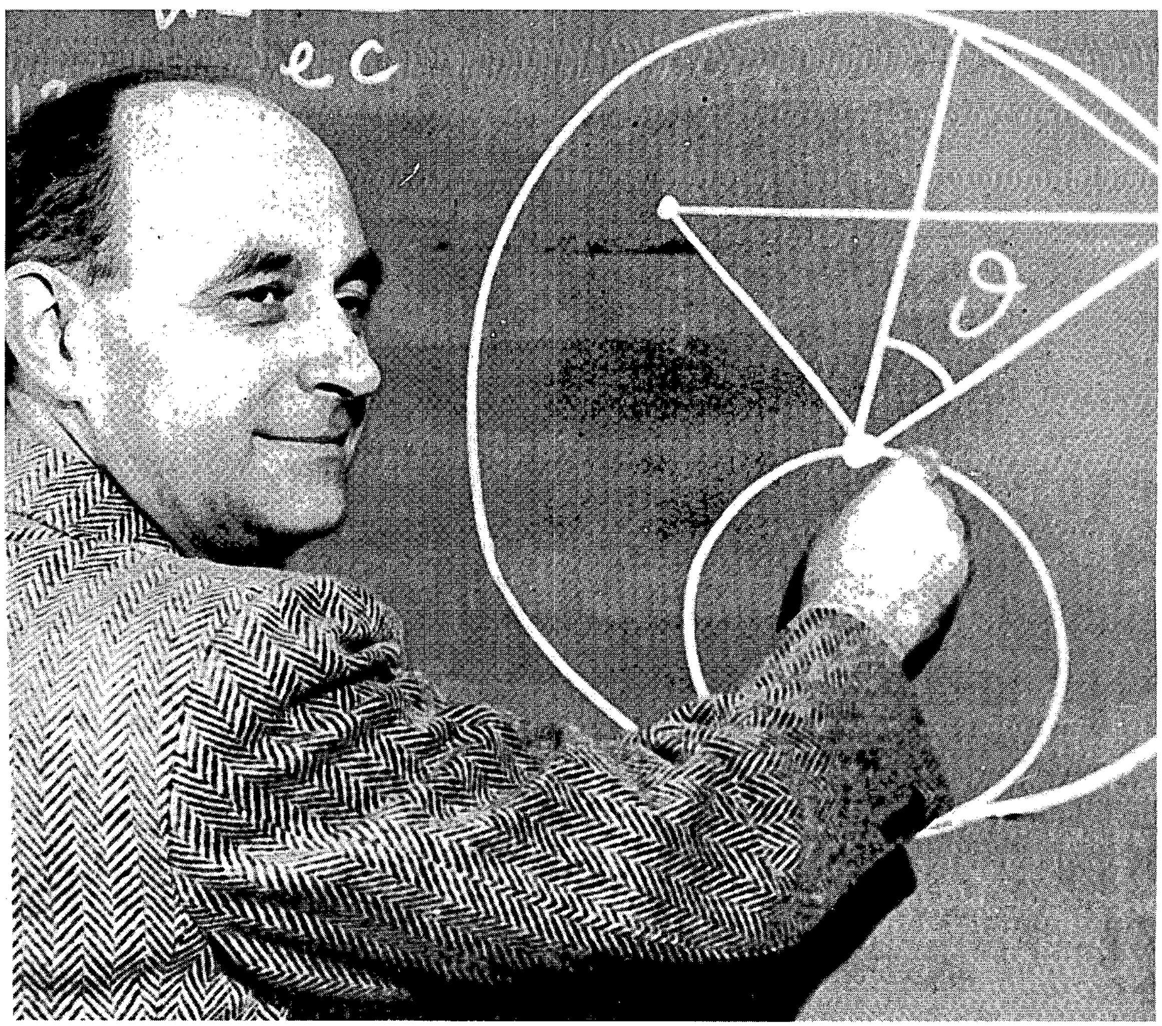
On December 2, 1942, Fermi, Whitaker, and Zinn piled tons of graphite and uranium on the

"The pile went 'critical,' achieving self-sustaining status at 3:20 p.m., an event later hailed as the dawn of the Atomic Age."

"On December 2, 1942, Fermi, Whitaker, and Zinn piled tons of graphite and uranium on the squash court to demonstrate a controlled nuclear reaction for visiting dignitaries standing on a balcony."

squash court to demonstrate a controlled nuclear reaction for visiting dignitaries standing on a balcony. Controlling the reaction with a rod coated with cadmium, a neutron-absorbing material, Fermi directed the phased withdrawal of the rod, carefully monitoring the increased neutron flux within the pile. The pile went "critical," achieving self-sustaining status at 3:20 p.m., an event later hailed as the dawn of the Atomic Age. Having no shield to prevent a release of radiation, Fermi briefly operated this Chicago Pile 1, disassembled it, and in 1943 rebuilt it with concrete radiation-protecting shielding as Chicago Pile 2 at the Argonne laboratory.

Richard Fox, who rigged the control-rod mechanism for Fermi's pile, stood behind Fermi worrying throughout the first critical experiment. "The manual speed control was nothing more elaborate than a variable resistor," Fox recalled, "with a piece of cotton clothesline over a pulley and two lead weights to make it 'fail-safe' and return to its zero position when released." Once the experiment succeeded and his concern that the clothesline would slip off the pulley proved unfounded, Fox recalled his elation: "It was as though we had discovered fire!"



Physicist Enrico Fermi directed design of the Chicago Pile 1 and Graphite Reactor at Oak Ridge.

After the dignitaries departed, Wigner brought out a bottle of Italian Chianti in honor of Fermi's achievement and shared toasts with the workers. He had carried the bottle from Princeton and later claimed it had taken more foresight to anticipate that the war would make Chianti a rare wine than to predict that Fermi's chain reaction would succeed. Among the celebrants were Richard Fox and Ernest Wollan, who had monitored and recorded the radiation emitted by the reaction. Both left Chicago for Oak Ridge in 1943. Wollan conducted neutron diffraction experiments, and Fox applied his talents in the Instrumentation and Controls Division, where he worked for half a century.

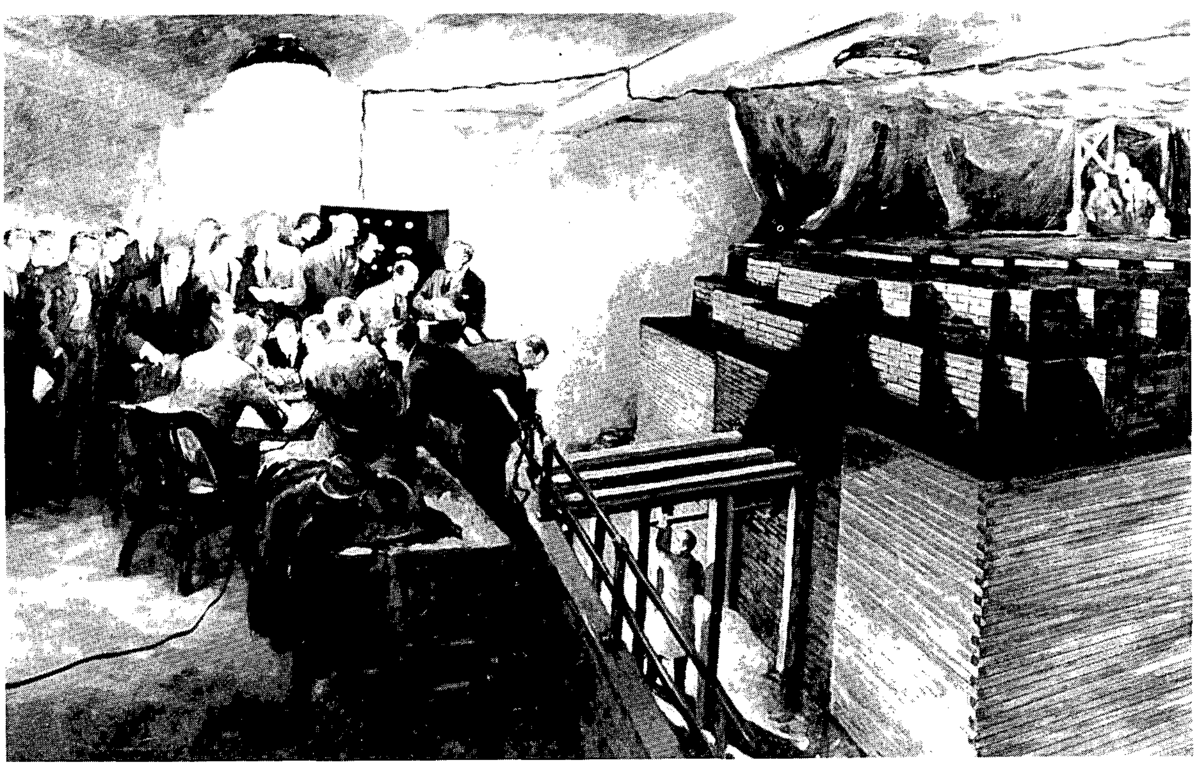
Producing sufficient plutonium for weapons required the construction of large reactors operating at high power levels and releasing large amounts of heat and radiation. Metallurgical Laboratory engineers Thomas Moore and Miles Leverett, both recruited from the Humble Oil Company, began an intensive investigation of potentially larger reactor designs. Scaling up Fermi's pile would not do, because extracting plutonium from the uranium would require tearing the pile apart each time and then reassembling it—a risky, time-consuming exercise. Moore and Leverett developed a new design that used helium gas under pressure as the coolant to remove heat from the pile during a nuclear reaction. To extract the uranium without disassembling the graphite moderator, they designed holes or channels that extended through the graphite to allow the insertion of uranium rods. The rods could then be removed after they had been irradiated.

Scientists agreed that thick shells of concrete could contain the radiation from reactors, but they disagreed about methods for removing the heat. Fermi wanted an air-cooled reactor, with fans forcing air through channels alongside the uranium rods. Moore and Leverett preferred using helium gas

"It was as though we had discovered fire."

—Richard Fox

Witness to first self-sustaining nuclear reaction at the University of Chicago, December 2, 1942.



Sketch of the 1942 scene when the nuclear pile under the University of Chicago stadium went critical.

"Wigner's water-cooling plan eventually was adopted for use in large reactors ...."

under pressure. Szilard favored a liquid bismuth metal coolant, similar to the system he and Einstein had patented for refrigerators. And Wigner preferred plain river water, with uranium rods encased in aluminum to protect them against water corrosion. Wigner's water-cooling plan eventually was adopted for use in large reactors, but not before the decision to build Fermi's air-cooled graphite and uranium pilot reactor at Oak Ridge had been made.

The proposed pilot reactor would test control and operations procedures and provide the larger quantities of plutonium required by the project's chemists. In mid-1942, Glenn Seaborg's group had used a lanthanum fluoride carrier process to separate micrograms of plutonium from uranium irradiated in cyclotrons; they now sought a means to achieve the separation on an industrial scale. In addition, Isadore Perlman, Charles Coryell, Milton Burton, George Boyd, and James Franck headed teams investigating the chemical and radiation novelties of plutonium, radiation, and fission products created during nuclear reactions.

Among the various methods investigated for separating plutonium were the ion-exchange and solvent-extraction processes. Although not adopted in 1943, these studies provided foundations for the postwar separation of radioisotopes and the widely used solvent-extraction methods for recovering uranium and plutonium from spent nuclear fuel. In 1943, Seaborg and Du Pont chemist Charles Cooper settled on a small pilot plant using the lanthanum fluoride carrier built on the Chicago campus and another pilot plant using a bismuth phosphate carrier planned for Oak Ridge. In both cases, the separation would have to be conducted by remote control in "hot cells" encased in thick concrete to protect the chemists from radiation.

To the Hills

As the Metallurgical Laboratory's research continued, studies began of potential sites for the planned industrial-scale uranium separation plants and pilot plutonium production and separation facilities. An isolated inland site with plenty of water and abundant electric power was desired.

At the recommendation of the War Production Board, Compton's chief of engineering, Thomas Moore, and two consulting engineers visited East Tennessee in April 1942. They found a desirable site bordering the Clinch River between the small towns of Clinton and Kingston that was served by two railroads and Tennessee Valley Authority electric power. Arthur Compton then inspected the site, approved it, and visited David Lilienthal, chairman of the TVA, to describe the unfolding plans to purchase the land.

Lilienthal was dismayed by news that land near Clinton would be taken. He objected that the site included land selected for an agricultural improvement program and proposed instead that Compton choose a site in western Kentucky near Paducah.

Compton refused to consider Lilienthal's proposal and advised him that the land in East Tennessee would be taken through court action for immediate use. He urged Lilienthal not to question his judgment or inquire into the reasons for the purchase. "It was a bad precedent," Lilienthal later complained. "That particular site was not essential; another involving far less disruption in people's lives would have served as well, but arbitrary bureaucracy, made doubly powerful by military secrecy, had its way."

In June 1942, President Roosevelt assigned to the Army the management of uranium and plutonium plant construction and nuclear weapons production. High-ranking Army officials, in turn, delegated this duty to Colonel James Marshall, commander of the Manhattan Engineer District headquartered initially in New York City and later relocated to Oak Ridge. Because Fermi had not yet achieved a self-sustaining chain reaction, Marshall and Army authorities postponed their efforts to acquire the land. The delay disturbed some scientists anxious not to lose ground to the Germans. It also perturbed the hard-driving deputy chief of the U.S. Army Corps of Engineers, Brigadier General Leslie Groves.

Given command of the Manhattan Project in September 1942, Groves ordered the immediate purchase of the reservation, first given the code name Kingston Demolition Range after the town south of the reservation and later renamed Clinton Engineering Works after the town to the north. The Army sent an affable Kentuckian, Fred

Fifty years after the momentous events at Chicago's Stagg Field, a piece of history was found at ORNL. Kermit Campbell holds a plastic bag containing uranium-238, shipped from Stagg Field, in the can in his arm.

Morgan, to open a real estate office near the site and purchase the land through court condemnation, thereby securing clear title for its immediate use. About 1000 families on the reservation were paid for their land and forced to relocate. Existing structures were demolished or converted to other, war-related uses. New Bethel Baptist Church at the X-10 site, for example, was used for storage, meetings, and experiments.

To speed production of weapons materials, Groves selected experienced industrial contractors to build and operate the plants. In January 1943, he persuaded Du Pont to initiate construction of both the pilot facilities at X-10 in Oak Ridge and the full-scale reactors to be built later in Hanford, Washington. Involved in too many military projects and reluctant to undertake the work at X-10, Du Pont executives were persuaded to accept Groves' request partly through appeals to their patriotism. The contract stipulated that Du Pont would withdraw from the job at war's end, accept no work-related patents, and receive no payment other than their costs plus a $1 profit. After the war, Groves reported with amusement that government auditors allowed Du Pont a profit of only 66¢ because the company had finished its job ahead of schedule.

Groves called on the University of Chicago to operate the pilot plutonium plant planned at X-10. Scientists at the Metallurgical Laboratory in Chicago expressed initial dissatisfaction with this proposal. Wigner and others had wanted to design and construct the plants, and they were not interested in operating them after Du Pont had been given the jobs they had sought. Also, university scientists and administrators preferred building the

"... Groves selected experienced industrial contractors to build and operate the plants."

ORNL and TVA

Partnership for East Tennessee

Ten years and 40 miles separate the two institutions. One was born during the Great Depression as a government-sponsored social experiment that uplifted the nation's most economically depressed region; the other was created in secrecy to produce the atomic bomb before the Nazi war machine could beat the United States to it.

At first glance, the Tennessee Valley Authority (TVA) and Oak Ridge National Laboratory (ORNL) seem to have little in common. But they share a common geography (East Tennessee) and a common political heritage (both are products of the Franklin Roosevelt administration). Most importantly, TVA and the Laboratory have provided the scientific infrastructure responsible for the region's international reputation in two related fields: water and energy.

When TVA arrived in May 1933, the Tennessee Valley was plagued by an unruly river that drained the region's economic vitality by flooding its farms and cities. East Tennessee farmers, for example, earned less than $100 a year, and 90% of them had no electricity. TVA not only harnessed the river and electrified the valley, it also boosted the region's wage rate in 1933 by offering laborers $1 a day.

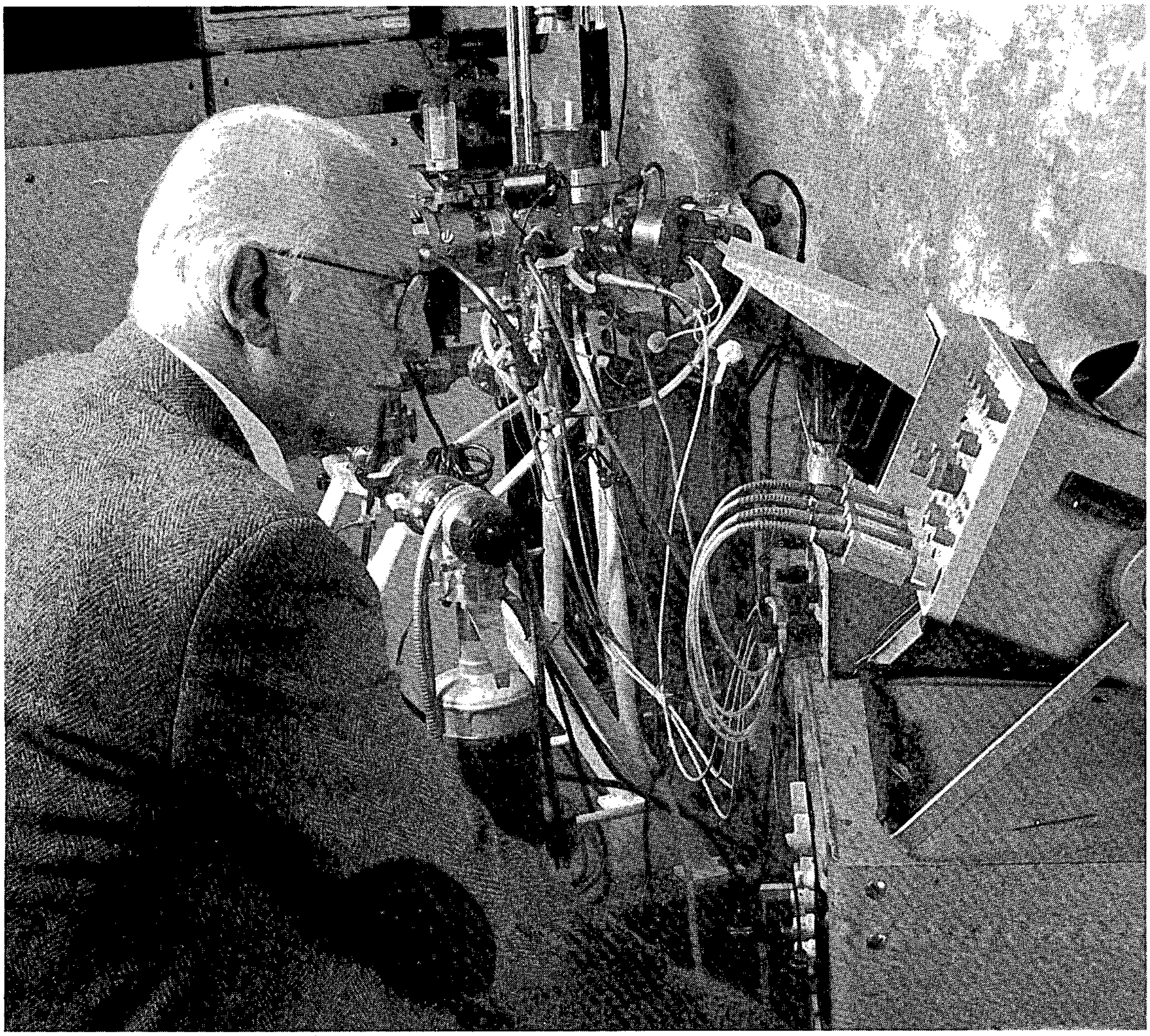
When the nuclear project entered the valley under a cloak of secrecy in the fall of 1942, perhaps no other region of the nation had fewer scientists or less sophisticated laboratory equipment. In fact, government investigators seeking a location for top-secret, war-related research found East Tennessee's isolation one of its prime attractions (another was cheap and abundant TVA electricity). The Laboratory's presence drew top scientists to the region and provided well-paying jobs for machinists, plumbers, and other craftspeople. For many East Tennessee women, the Laboratory offered their first opportunity to work outside the home.

> *"At first glance, the Tennessee Valley Authority and Oak Ridge National Laboratory seem to have little in common. But they share a common geography and a common political heritage. Most importantly, TVA and the Laboratory have provided the scientific infrastructure responsible for the region's international reputation in two related fields: water and energy."*

The impacts of TVA and the Laboratory extended far beyond the construction of dams, office buildings, and scientific facilities. Spurred by soup lines at home and by Nazi armies conquering most of Europe, the two institutions launched a socioeconomic revolution in a remote region of the country that 20th-century technology had left behind.

TVA and the Laboratory, as centers of scientific research and technical application, have continued to join forces in projects of common concern. In the 1960s, the Laboratory's abiding interest in commercial nuclear power aided TVA's efforts to become one of the nation's largest nuclear utilities. In the 1970s, the two institutions joined hands in the failed effort to build the Clinch River Breeder Reactor. In the 1980s, together with the University of Tennessee, they formed a consortium of research institutions, which was designed to bring the region's scientific and technical experts closer together in an effort to better address regional and global issues related to energy and the environment. In the 1990s the three institutions continue to collaborate under the newly formed Joint Institute for Energy and the Environment.

TVA and the Laboratory's positive impact on East Tennessee cannot be overlooked. Their scientific and technological activities have touched every hill and valley of the region. The two institutions helped transform East Tennessee from an isolated, depressed region into an international center for energy and environmental research.



Richard Fox participated in the achievement of the first nuclear chain reaction at the University of Chicago in December 1942 and then transferred to Oak Ridge, where he has stayed for half a century.

pilot plant in the Argonne forest convenient to Chicago; the prospect of operating industrial facilities 500 miles from their campus in the remote hills of Tennessee did not elicit much enthusiasm.

Groves and the Army again used appeals to patriotism to help persuade the university to accept the challenge. The compromise called for Chicago to supply the managers and scientists needed for the operations and for Du Pont to mobilize construction and support personnel.

X-10 Construction

On February 1, 1943, Du Pont started clearing the X-10 site, installing utility systems, and building the first temporary buildings, mostly wooden barracks. In March, construction of six hot cells for plutonium and fission product separation began. The cells had thick concrete walls with removable slab tops for equipment replacement. The cell nearest the nuclear reactor

"On February 1, 1943, Du Pont started clearing the X-10 site, installing utility systems, and building the first temporary buildings . . . ."

"Du Pont officials considered development of chemical separations processes the most challenging mission at X-10."

housed a tank for dissolving uranium brought from the reactor through an underground canal; four other cells housed equipment for successive chemical treatment of the uranium—precipitation, oxidation, reduction; a sixth cell stored contaminated equipment removed from the other cells. An adjoining frame structure housed the remote operating gallery and offices.

Other structures rising at X-10 housed chemistry, physics, and health physics laboratories; machine and instrument shops; warehouses; and administration buildings. Because construction of the Y-12 and K-25 plants on the reservation also began in 1943, Du Pont had difficulty finding enough workers. It remedied the shortage by dispatching recruiters throughout the region.

Including the smallest structures, about 150 buildings were completed that summer by 3000 construction workers, at an initial cost of $12 million. Construction materials included 30,000 cubic yards of concrete, 4 million board feet of lumber, 4500 gallons of paint, and 1716 kegs of nails. Buildings went up rapidly, but needs so outran accommodations that a workers' cafeteria operated in a striped circus tent and an old schoolhouse served as office space and a dormitory.

Foundation excavations for the Graphite Reactor began in late April 1943; the reactor's 2-meter–(7-foot)–thick concrete front face was in place by June, and the side and rear walls were constructed in July. The National Carbon Company delivered graphite of the required purity to X-10, where Du Pont built a fabrication shop to machine graphite blocks to the desired dimensions. In September, a crew stacked the first of 73 layers of graphite blocks within the concrete shield to form a cube 7.3 meters (24 feet) on a side and at month's end installed steel trusses to support the concrete lid capping the reactor. Under government contract, the Aluminum Company of America began encasing 60,000 uranium slugs in aluminum for the reactor. Mounted in a building near the reactor, two of the world's largest fans sucked outside air through the reactor and then up a stack. The stack and the black building that housed the reactor (called the "black barn") were prominent features everyone noticed when arriving at X-10 during the war.

Charles Coryell of MIT, one of many brilliant chemists who served at Clinton Laboratories during the war.

Because Wigner had changed the cooling system design for the larger reactors built at Hanford, Washington, from helium to water, the air-cooled X-10 reactor was not truly a pilot plant for Hanford's water-cooled reactors. Instead, Du Pont officials viewed the hot cells of the separations building adjacent to the X-10 reactor as a pilot plant for similar facilities to be built at Hanford, and they considered development of chemical separations processes the most daunting mission at X-10.

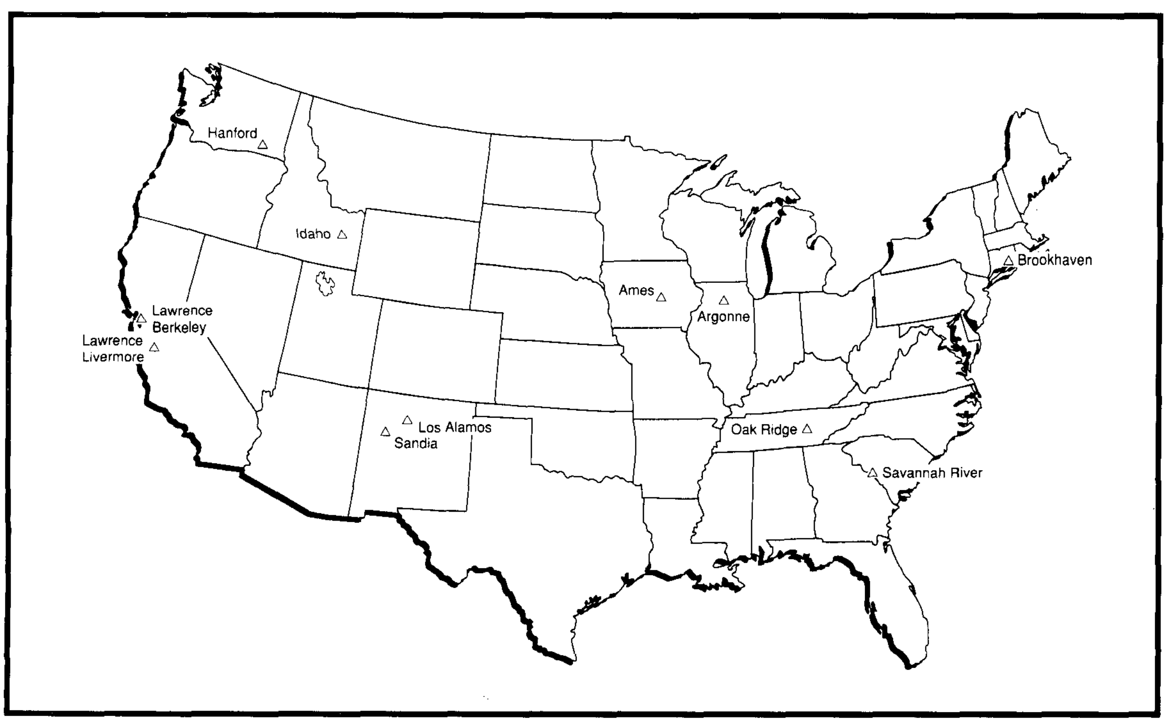
The need for safe plutonium separation challenged chemical engineers to design, fabricate, and test equipment for remotely transferring and evaporating liquids, dissolving and separating solids, and handling toxic gases. Instrumentation was needed for remote measurements of volumes, densities, and temperatures in a hazardous environment. Techniques to separate microscopic amounts of radioactive elements from volumes of liquid thousands of times larger had to be invented. The unknown effects of intense radiation on the solvents had to be identified and handled. Disposal of contaminated equipment and unprecedented volumes of radioactive wastes had to be addressed. These were a few of the difficulties facing Clinton Laboratories personnel as work progressed at X-10 during the autumn of 1943.

The organization of Clinton Laboratories was in constant flux during the war. Scientists and technicians moved from Chicago to Oak Ridge to Hanford and Los Alamos as if they were in a revolving door. Many members of the original Oak Ridge research staff came from Chicago. The Du Pont Company brought its construction and operations personnel to Oak Ridge for training, then moved them to Hanford. Most Du Pont personnel came to X-10 from ordnance plants the company had constructed before 1943. Wartime employment at Clinton Laboratories leveled off in 1944 at 1513 scientists, technicians, and operating personnel, including 113 soldiers from the Army's Special Engineering Detachment assigned to the Manhattan Project.

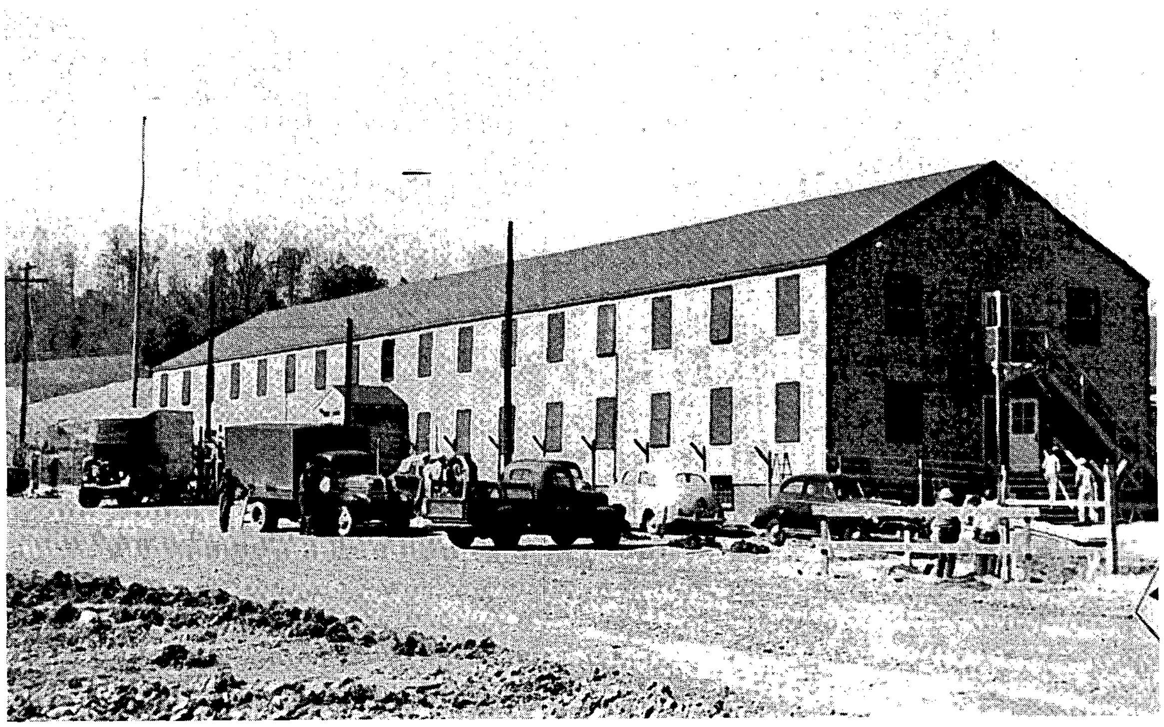
Organization of the Laboratory proceeded in 1943, with Martin Whitaker as its director and Richard Doan as its associate director for research. Reporting directly to Whitaker were research manager Doan, Simeon Cantril (and later John Wirth) of the Health Division, and plant manager S. W. Pratt, who brought many Du Pont personnel to Oak Ridge. When its initial organization took shape, Clinton Laboratories had units for chemistry, health, engineering, and accounting, together with sections devoted to physics and radiation biology.

Reactor Goes Critical

By Halloween in 1943, when Du Pont had completed the final engineering of the Graphite Reactor, Whitaker brought Compton and Fermi from Chicago to witness its first operation. Three



Efforts to build an atomic weapon and develop nuclear energy for peaceful uses led to a network of laboratories by the mid-1950s.



Main office building at Clinton Laboratories under construction in May 1943.

"... when Du Pont had completed the final engineering of the Graphite Reactor, Whitaker brought Compton and Fermi from Chicago to witness its first operation."

days later, workers began to insert thousands of uranium slugs into the reactor. The sequence involved loading a ton or two, withdrawing control rods to measure the increase in neutron flux, reinserting the rods into the pile, loading another batch of uranium, then stopping again to assess activity, each time attempting to estimate when the reactor would achieve a self-sustaining chain reaction. A second shift continued this tedious procedure into the night, with Henry Newsom and George Weil plotting the flux curve. Weil had manipulated the control rod when Fermi brought Chicago Pile 1 to criticality the previous December, and he had come from Chicago to help achieve the same result in Oak Ridge.

The day shift loaded nearly 10 tons of slugs, and the night shift set out to beat this record, working at both ends of the scaffold elevator at the reactor's face under the supervision of Kent Wyatt. In the middle of the night, Newsom and Weil, in the plotting room, recognized that one more batch of slugs would bring the reactor to the critical point, and they stopped the loading. Before dawn on November 4, Louis Slotin drove to the Guest House to awaken the two Nobel laureates, Compton and Fermi, known by the aliases Holley and Farmer in Oak Ridge. In the dark, they raced down Bethel Valley Road to witness the reactor going critical at 5:00 a.m. Scientists aware that the world's first powerful nuclear reactor had gone critical that morning were thrilled. John Gillette, a Du Pont engineer on the graveyard shift that had loaded the last 20 tons of uranium slugs, was "too pooped to care."

Arthur Rupp of the Engineering Division had been dubious of Wigner's theoretical calculations of the amount of heat that uranium would emit during fission. To test the computations, he and his colleagues calibrated the air flow through the reactor and installed temperature, humidity, and barometric instruments. They then compared the uranium fission rate with the amount of heat released. When the experimental value proved nearly the same as the theoretical prediction,

Leslie R. Groves:

Manhattan Project's Main Man

In September 1942, Brigadier General Leslie R. Groves took charge of the Manhattan Project. His influence was to be felt far and wide by people swept into service for this top secret project. In Oak Ridge, in the red mud and yellow dust, he was the driving force behind the construction and operation of the large wartime plants that would come to define the "Atomic City."

Groves is remembered for his management style and personality traits. Those who liked him recall that he was hard-driving, courageous, tough, responsible, and efficient. They say he demanded respect and got the job done. Those less fond of his style remember him as blunt, impatient, ruthless, tyrannical, severe, and inconsiderate. For them, he was a strict taskmaster.

The day before he came to Oak Ridge, Groves was in a meeting with Secretary of War Henry Stimson. By age and rank, Groves was the junior person. Stimson proposed a committee of seven to nine persons to run the Manhattan Project; Groves countered that such a committee would be inefficient and proposed a committee of three. After some discussion, the group accepted Groves' suggestion. Then, in the presence of his superiors, Groves abruptly excused himself from the meeting, saying he had to take the train to Oak Ridge to select a site for the first atomic plant.

On September 19, 1942, Groves met with Colonel James Marshall and inspected the site in Oak Ridge. Groves was pleased with the site because it offered abundant electrical power and water, good access by road and train, a sparse population, a nearby source of labor, and a mild climate that made outdoor work possible year round.

Although scientific research leading to industrial production of fissionable material was not yet complete, Groves decided to take a chance on constructing uranium-235 production plants in Oak Ridge. To accomplish this task, some 59,000 acres were purchased at a cost of $60 to $70 per acre.

During the war, Groves frequently visited Oak Ridge, staying at a special suite permanently reserved for him in the Guest House, now the Alexander Motor Inn. When the hotel was booked up, guests were allowed to stay in the general's suite provided that they agreed to leave if he should show up (he sometimes arrived in the middle of the night).

Besides production of enriched uranium through electromagnetic separation and gaseous diffusion, which was done at Oak Ridge, another goal of the Manhattan Project was to produce plutonium through transmutation of uranium. Although the Graphite Reactor was a pilot plant for creating plutonium, Groves ruled out Oak Ridge as a major site for large-scale plutonium production. He was concerned about the proximity of the site to Knoxville and the possibility, however remote, of a reactor explosion that might endanger Knoxville.

Groves, a native of Albany, New York, who graduated fourth in his class from the U.S. Military Academy, headed the Manhattan Engineer District for three years. He retired from the Army in 1948 with the rank of lieutenant general and wrote several books, including *Now It Can Be Told: The Story of the Manhattan Project*. He served as a vice president of the Sperry Rand Corporation until 1961 and died in 1970 in Washington, D.C.

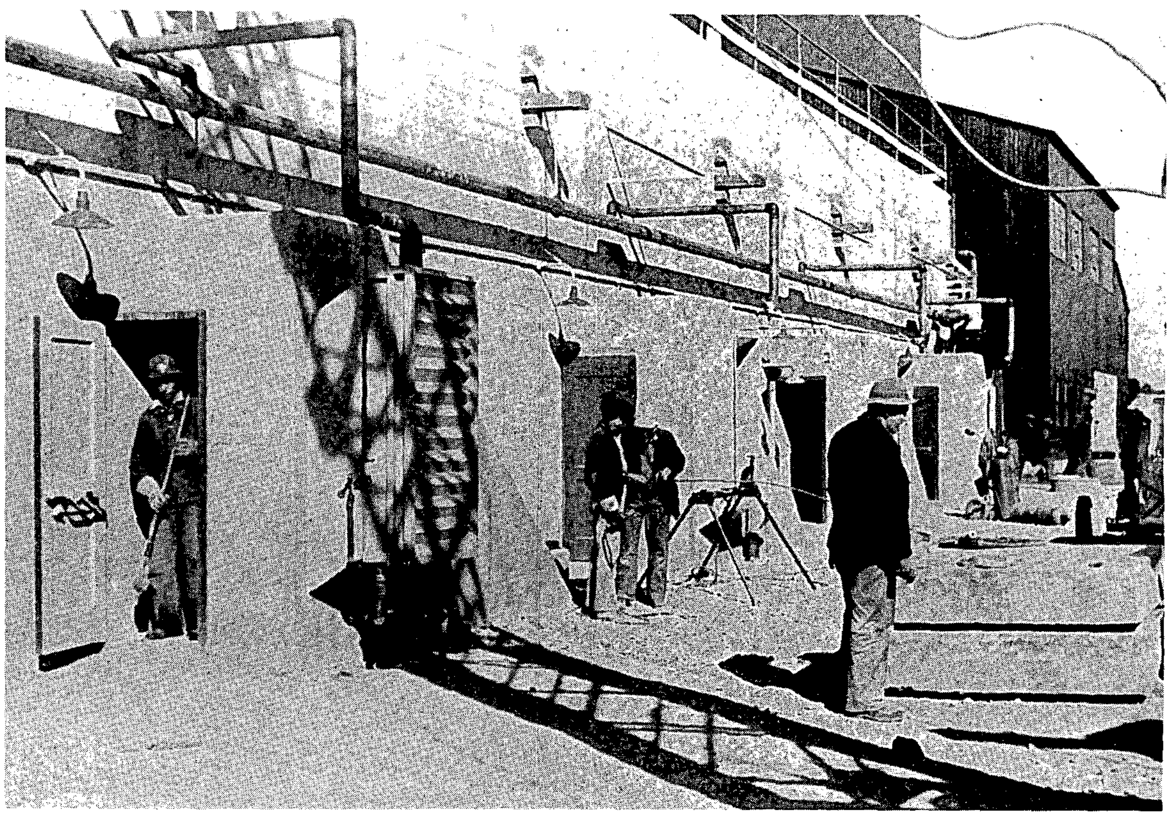
"Scientists aware that the world's first powerful nuclear reactor had gone critical that morning were thrilled."

Rupp's skepticism ended. "I knew then," he said, "the atomic bomb was going to work!"

As Wigner and Alvin Weinberg at Chicago had predicted during the design phase, the reactor had gone critical when about half its 1248 channels were loaded. Initially called the X-10 or Clinton Pile, it became known as the Graphite Reactor. Noted for its reliability, it worked with few operational difficulties throughout 20 years of service. Near the end of November 1943, it discharged the first uranium slugs for chemical separation. By year's end, the chemists had successfully extracted 1.54 milligrams of plutonium from the slugs and dispatched them to Chicago, by secret courier, in a container resembling a penlight. Blocking empty channels in the graphite (to concentrate the cooling air) allowed an increase in the reactor's thermal power to 1800 kilowatts in early 1944. Subsequent air-flow modification, plus the installation of larger fans for cooling, permitted its operation at more than 4000 kilowatts, nearly four times the original design capacity, with corresponding increases in plutonium production.

Plutonium Production

In February 1944, the first plutonium shipment went from Oak Ridge to Los Alamos. By spring, the

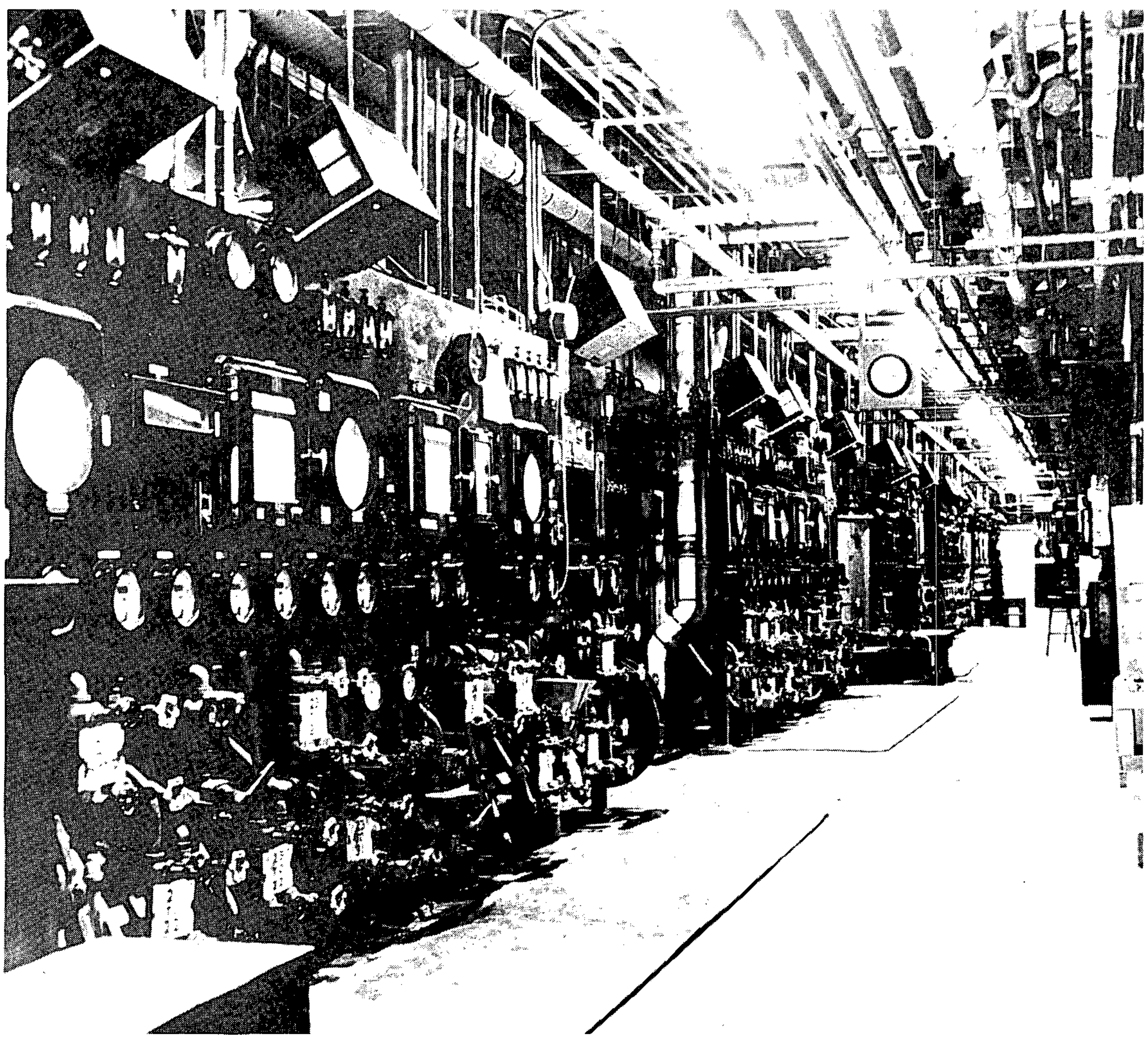


Constructing the concrete hot cells of the chemical separations building in November 1943. In 1992, this Radiochemical Development Facility (Building 3019) was designated a Nuclear Historic Landmark by the American Nuclear Society.

chemists had improved the bismuth phosphate separation process to the point that 90% of the plutonium in the slugs was recovered. In early 1945, when plutonium separation ceased at X-10, the Graphite Reactor and separations plant had produced a total of 326.4 grams of plutonium, a substantial contribution to nuclear research and ultimately to weapons development.

In early 1945, Robert Oppenheimer urgently asked Clinton Laboratories to supply Los Alamos with large quantities of pure radioactive lanthanum, called "RaLa," the decay product of radioactive barium-140. Clinton's chemists separated the first quantity of this isotope from the reactor's fission products in glass equipment in the chemistry laboratory. To obtain larger amounts safely, Martin Whitaker assigned Miles Leverett the job of designing, constructing, and operating a barium-140 production facility. With support from the Chemistry Division, Leverett, Charles Coryell, and Henri Levy met the schedule and Oppenheimer's requirements. "I believe," Leverett later speculated,

"In February 1944, the first plutonium shipment went from Oak Ridge to Los Alamos."



Remote controls for the plutonium separations process in the adjacent hot cells in 1944.

Safety Margins

A major concern of Clinton Laboratories during the war was the potential effect of radiation on health. The Oak Ridge facility hired health physicists who monitored radiation throughout the X-10 area, introduced measures for personnel safety, and conducted research on radiation and its effects. Caged rodents were placed near the reactor to detect the effects of any escaping radiation. Despite these precautions, the rush to meet deadlines and aid the war effort sometimes led to radiation overexposures.

Martin Whitaker (right), director of Clinton Laboratories, discusses wartime administration problems with, from left, Colonel J. S. Hodgson, Robert Thumser, and Colonel K. D. Nichols.

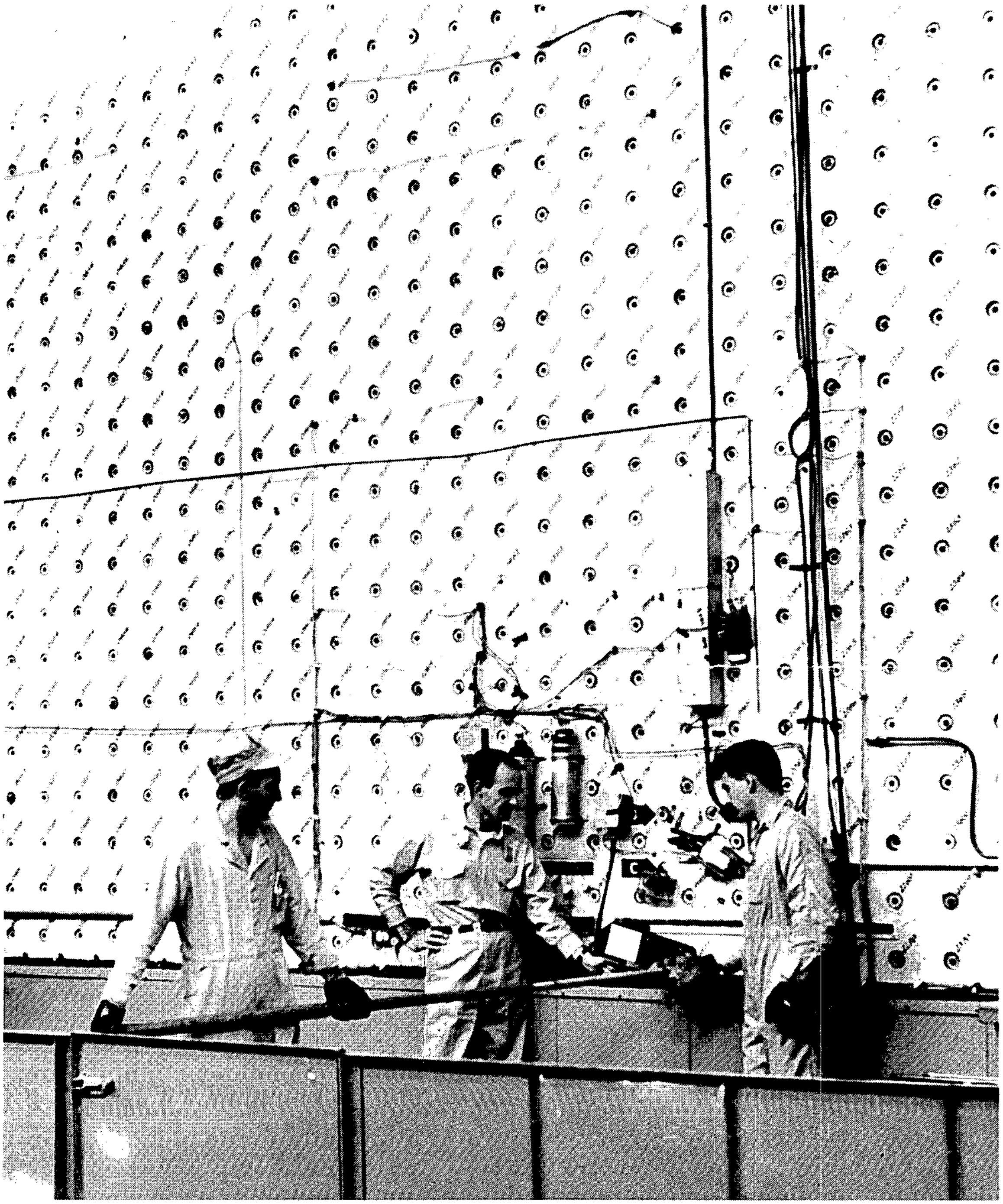
A victim of one of the largest radiation exposures during the war was Martin Whitaker, director of Clinton Laboratories. On the west side of the Graphite Reactor was a large opening through the concrete shield to the graphite-uranium pile. Materials such as shielding samples were placed in the opening to test their ability to stop radiation. When testing was not under way, water was pumped into a tank in the opening to block the radiation.

While escorting dignitaries from Washington, D.C., on an inspection of the Graphite Reactor in 1944, Martin Whitaker ignored "No Admittance" signs and took the visitors past the front of the tank, thinking it full of water. Unfortunately, it had been drained. The exposure to radiation could be only estimated, not measured, because no one in the group wore a dosimeter. The chief health physicist later called this debacle a blessing in disguise, because health physics regulations thereafter became mandatory at Clinton Laboratories.

"that this was the first production of a radioisotope on a large scale."

To assist with the design of Hanford's plutonium production reactors, many experiments were performed at the Graphite Reactor during 1944. One test involved laminated steel and masonite radiation shields designed for Hanford. The shield samples were set in an opening in the Graphite Reactor to study the interactions between the samples and radiation. Brass, neoprene, bakelite, rubber, and ordinary construction materials to be used at Hanford also were exposed to radiation in the Graphite Reactor to analyze their performance. Because the Hanford reactors were to be water cooled, tubes were installed in the Graphite Reactor to circulate water and observe its cooling and corrosive effects.

The conventional relationship between pilot plant and production plant existed between the Clinton Laboratories' hot cells and similar concrete structures built at Hanford. George Boyd, John Swartout, and other chemists from Chicago moved to Oak Ridge in October 1943, where they continued their investigations of plutonium separation processes and the properties of plutonium. The Clinton experience



Workers use a long rod to push uranium slugs into the concrete face of the Graphite Reactor.

indicated the bismuth phosphate carrier process was not entirely suitable for the plutonium separation process, but Seaborg's other process, using lanthanum fluoride, worked well. This process was incorporated into Hanford's separation facilities. So was the experience of hundreds of personnel trained at Clinton Laboratories.

Physicist John Wheeler worried that unwanted isotopes capable of stopping chain reactions would be found in the irradiated uranium. Like the boron and cadmium used in reactor control rods, the isotopes would have a large neutron-capture cross section—that is, they might absorb enough neutrons to kill a nuclear chain reaction. This problem occurred at the first Hanford reactor during its trial run, a nasty surprise to Fermi and all concerned. After the chain reaction became self-sustaining, the reactor stalled. A few hours later, the reactor, for unexplained reasons, started again. Fermi and Wheeler suspected that the isotope xenon-135 was the culprit because the time required for this short-lived isotope to decay was roughly equal to the duration of the reactor's shutdown.

Urgent, around-the-clock efforts to measure the neutron-absorption cross section of xenon-135 began at the Argonne and Clinton laboratories. Scientists worked 40 hours at a stretch to separate xenon-135 from its parent iodine, place samples in the Graphite Reactor, and obtain rough estimates of its ability to capture neutrons, an ability measured in "barns" (from the folk idiom "big as the broad side of a barn").

They measured xenon-135 at four million barns; that is, tiny amounts of xenon could shut down large reactors, which would start again after the xenon decayed.

Clinton Laboratories was criticized for not detecting xenon's effects during earlier Graphite Reactor operations. A decline of reactivity resulting from xenon poisoning had occurred in the Graphite Reactor, but the reactor's conservative design had overcome the poisoning effects. The reactor did not shut down, and the staff did not notice its decline in reactivity.

Fortunately, at Hanford the DuPont engineers had designed reactors larger than necessary. This overdesign allowed the insertion of sufficient uranium fuel to overcome xenon's poisoning effects and to continue production of the plutonium later used in the "Trinity" test in July 1945 and in the bomb that devastated Nagasaki, Japan, on August 9.

The first atomic bomb, dropped on August 6 on Hiroshima, used fissionable uranium-235 electromagnetically separated from nonfissionable uranium-238 in 1100 calutrons at the Oak Ridge Y-12 Plant; the Laboratory later used some of these calutrons for the separation of stable isotopes needed for industrial and medical purposes.

"We had helped to do a bold and difficult job and had stopped a war in its tracks. That was enough for the moment. Second thoughts came later."

—Oak Ridge physicist, August 1945

Uranium slugs encased in aluminum fell from the back of the Graphite Reactor into a canal. Shielded from radiation by the water, workers pulled buckets full of uranium slugs into the nearby separations building for the extraction of plutonium.

The end of World War II brought great public relief and considerable concern about the future at Oak Ridge.

The Silver Lining of the Calutrons

The 1100 calutrons at the Oak Ridge Y-12 Plant that provided the explosive power for the first atomic bomb eventually achieved incredible economic value. In 1943 the AEC borrowed 14,700 tons of precious silver from the U.S. Treasury to use as electrical conductors in bus bars and windings for the calutrons' magnets. The silver was borrowed because of the wartime shortage of copper.

In a series of shipments from the late 1940s through the early 1950s, almost 12,500 tons of silver were returned to the U.S. Treasury. In 1968 most of the remaining silver was returned, leaving only 70 tons for four calutrons being used by the Laboratory to produce samples highly enriched in stable isotopes. The 1968 market value of the returned 2145 tons of silver was $124 million!

Battle of the Laboratories

Announcing the bombing of Hiroshima, President Harry Truman mentioned the weapons facilities built at Oak Ridge, Hanford, and Los Alamos, commenting: "The battle of the laboratories held fateful risks for us as well as the battles of the air, land, and sea, and we have now won the battle of the laboratories as we have won the other battles."

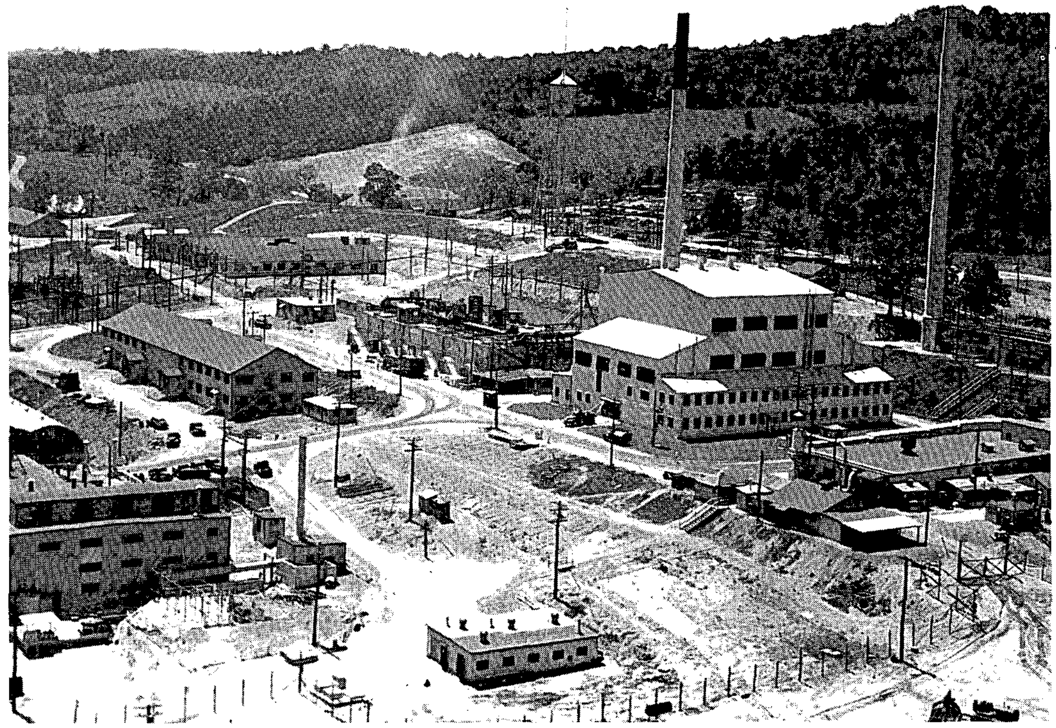
This news came as a surprise even to some employees at Clinton Laboratories. Before he heard the president's announcement, reactor operator Willie Schuiten did not believe co-workers who told him the reactor's work was tied to a new weapon. He later commented, "The people in charge really did a good job of keeping the project a secret."

Many Oak Ridge scientists, however, knew or surmised the purposes of the project. News of the bomb's success elated them, especially if they had relatives serving in the armed forces in the Pacific. One physicist commented that "we had helped to do a bold and difficult job, and had stopped a war in its tracks." He added, "That was enough for the moment. Second thoughts came later."

A few days later came Japan's surrender and the end of World War II. Staff members drifted about Clinton Laboratories, gathering and talking, seemingly bereft of energy. "Everyone," admitted one scientist, "felt a sense of disorientation, of slackness, of loss of direction."

The war's end had come while Clinton Laboratories was in the throes of a management change. In July 1945, one month before the first atomic bomb was dropped, the University of Chicago withdrew as the contract operator, and the

News of the end of World War II was a historic event for Oak Ridgers. The war's end directly touched their personal and work lives.



Aerial view of Clinton Laboratories after the war. Just right of the center is the Graphite Reactor, and immediately to its right is the long, concrete separations building.

Army selected Monsanto Chemical Company as the new operator. This major change, combined with the fact that many scientists planned to return to the universities and their prewar research, raised a fundamental question: "What would become of the Lab?"

Living with Peace

Winning the war left the staff of Clinton Laboratories with both a pride in their accomplishment and a sense of anxiety. Their prime task of guiding the Hanford facility in producing and separating plutonium for use in an atomic bomb had been accomplished on schedule. But with this task successfully completed, the future looked uncertain. Could the research facility be as useful and productive in peace as it had been in war? Would its scientists be content to remain in the hills of East Tennessee, or would they opt to return to more cosmopolitan settings in Chicago, New York, and California? Would the federal government be willing to invest as much money in the peaceful uses of nuclear energy as it had in weapons production?

Although the Oak Ridge facility had shed its wartime cloak of secrecy to emerge as a heroic place, its future was still uncertain. Impressed by the bucolic atmosphere and substantial record of accomplishment, Wigner thought Clinton Laboratories did indeed have a future. In late 1944, he drew up a plan for an expanded postwar laboratory for nuclear research with perhaps 3500 personnel and an associated school of reactor technology. Furthermore, he hoped he and his theoretical group in Chicago would be transferred as a unit to Oak Ridge. When that was not done, he persuaded some of his staff in Chicago to move south, starting in May 1945 with Alvin Weinberg. Wigner followed in 1946, marking the opening of a volatile era in the Laboratory's history. Like the rest of America and the world, the Laboratory, whose energies and resources had been focused exclusively on war, would have to learn to live with peace.

General Leslie Groves and David Lilienthal discuss the transfer of responsibility for atomic energy research and development and weapons production from the Army to the civilian Atomic Energy Commission.

Chapter 2

High-Flux Years

High-flux conditions prevailed at Clinton Laboratories after the war, when surprising decisions affecting the facility's future were made in St. Louis, Chicago, and Washington, D.C. At the federal level, management of the national laboratories shifted from General Leslie Groves and the Army Corps of Engineers to David Lilienthal and the newly created civilian Atomic Energy Commission (AEC). In Oak Ridge, the contract with Monsanto Chemical Company, the industrial operator for Clinton Laboratories, was not renewed. The University of Chicago, the proposed academic operator, failed to assemble a management team, resulting in the selection of a new industrial contractor, Union Carbide Corporation. Clinton Laboratories became Clinton National Laboratory in 1947 and Oak Ridge National Laboratory in 1948. Change was the watchword in the tumultuous postwar period, as one unexpected event followed another.

Despite management uncertainties and fluctuations, solid accomplishments in science and

"Under the leadership of Eugene Wigner, Clinton Laboratories designed a high-flux Materials Testing Reactor, the precursor of all modern light-water reactors."

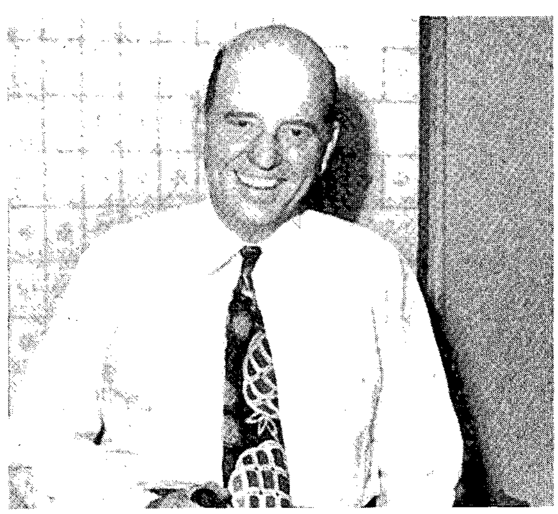
technology were achieved. Under the leadership of Eugene Wigner, Clinton Laboratories designed a high-flux Materials Testing Reactor, the precursor of all modern light-water reactors, and experimented with the Daniels Pile, a forerunner of high-temperature gas-cooled reactors. The first of thousands of radioisotope shipments left the Graphite Reactor in 1946, initiating a program of immense value to medical, biological, and industrial science. New organizational units were formed to study biology, metallurgy, and health physics, and several solid scientific accomplishments were recorded in these fields before the departures of Wigner and Monsanto.

Management fluctuations proved a source of anxiety and despair among Laboratory staff during the 1947 Christmas season. By the start of the new year in 1948, however, crucial management decisions ensured the survival of Clinton Laboratories, which was given a much broader mandate for fundamental science than it had during the war.

James Lum became executive director of Clinton Laboratories in 1945.

Monsanto's Management

During the war, security concerns required officials to refer to Clinton Laboratories by its code name, X-10. The personnel of Monsanto Chemical Company, the new operating contractor, continued this practice in the postwar years. The remote Appalachian location of Clinton Laboratories, along with unpaved streets and spartan living conditions, presented an easy target for ridicule. Metallurgical Laboratory personnel in Chicago called X-10 "Down Under," while Du Pont personnel labeled it the "Gopher Training School." In official telegrams, Monsanto's staff referred to Oak Ridge as "Dogpatch," taking their cue from *Li'l Abner*, a popular comic strip lampooning "hillbilly" Appalachian life. Such ill-concealed scorn did not bode well either for postwar Monsanto administration or Laboratory research.



Charles Thomas served as Clinton Laboratories project director from 1945 to 1947. He later became president of the American Chemical Society and the Monsanto Corporation.

The choice of Monsanto as contract operator of Clinton Laboratories seemed logical because of the Laboratories' focus on chemistry and chemical technology. Monsanto was also interested in becoming a key player in nuclear reactor development. Charles Thomas, Monsanto vice president, was the driving force behind the company's entry into nuclear science. A famous chemist, Thomas had established a laboratory at Dayton, Ohio, that Monsanto purchased in 1936, making it the company's central research laboratory.

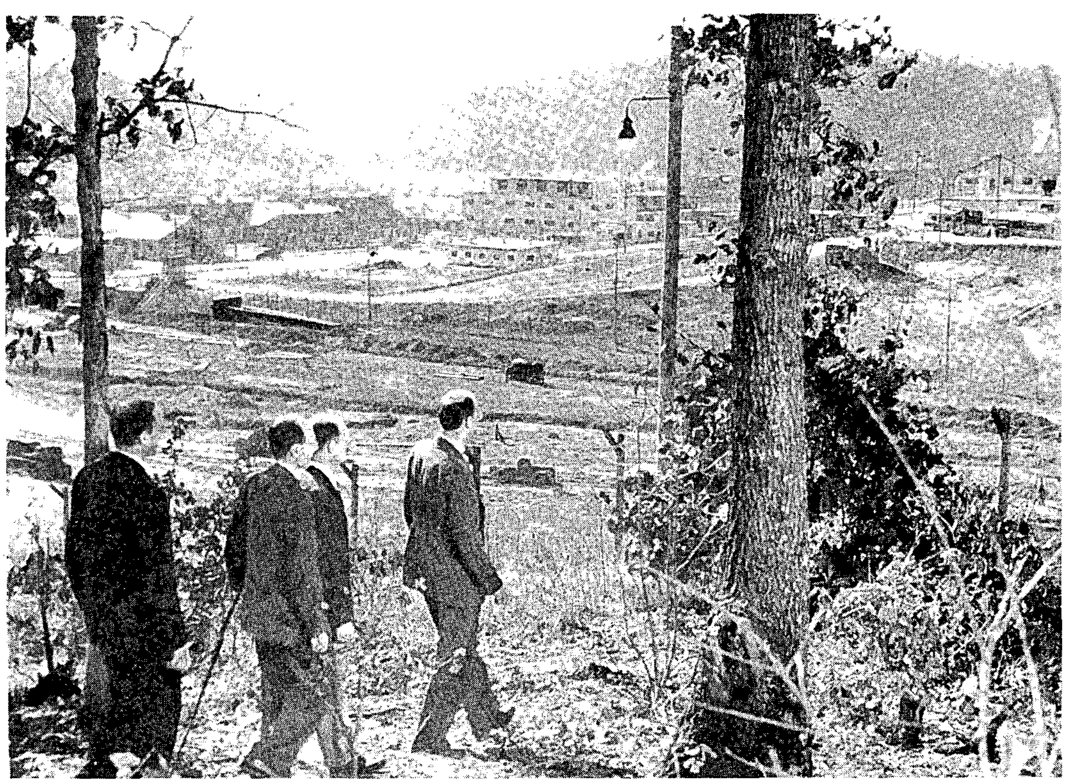
In 1943, General Groves gave Thomas and Monsanto responsibility for fabricating nuclear triggers at the Dayton laboratory. When Thomas also agreed to supervise the operation of Clinton Laboratories in 1945, he merged both facilities into a single project and appointed himself project director, although he kept his main office at Monsanto's corporate headquarters in St. Louis.

When Whitaker and Doan left Oak Ridge, Thomas decided to establish a dual directorship at Clinton Laboratories with both directors reporting to him. For executive director in charge of general administration and operations, he selected James Lum, who had assisted him in managing the Dayton laboratory. As Lum's assistant, he brought in Prescott Sandidge, who had managed Monsanto phosphate and munitions plants.

Transferring 60 staff members to Oak Ridge from other Monsanto plants, Thomas reorganized the administration of Clinton Laboratories. Among the new administrators were plant manager Robert Thumser, shop and instrument superintendent Hart Fisher, chief accountant Clarence Koenig, and superintendent of support services Harold Bishop. Because many scientists returned to universities at the end of the war, Thomas and the Clinton staff also had to recruit replacements. Among the new staff members were Walter Jordan, P. R. Bell, and Jack Buck, who came from the radar laboratory at the Massachusetts Institute of Technology, and Ellison Taylor, Henry Zeldes, Harold Secoy, and Frank Miles, who came from the closed wartime laboratory at Columbia University.

In 1947, under Monsanto's management, Clinton Laboratories employed 2141 workers, making building expansion imperative. A moratorium on new construction during 1946 and

"The first of thousands of radioisotope shipments left the Graphite Reactor in 1946."



Members of the 1946 management team—Frederick Seitz, James Lum, Eugene Wigner, and Alexander Hollaender—hike a ridge overlooking the Laboratory.

Samuel Lind

Tennessee's Own

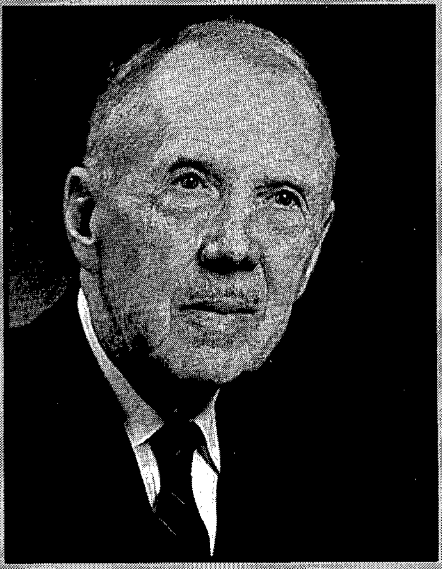
Samuel Colville Lind, called the father of radiation chemistry in America, came to the Laboratory in 1948 as a consultant after a long and distinguished career that was far from over. Author of 160 scientific articles, the first published in 1903 and the last in 1964, Lind's career began in Tennessee, took him to Europe at the turn of the century, and ended at the Laboratory in 1965.

A son of a Swedish immigrant, Lind received his early education in McMinnville, Tennessee. In 1895, he enrolled in the humanities program at Washington and Lee College, where he avoided science until senior requirements forced him to take chemistry. Lind's chemistry professor inspired him to return to the college after receiving his humanities degree to spend a fifth year studying chemistry. He then pursued the study of chemistry at the Massachusetts Institute of Technology and the University of Leipzig. Lind received his doctorate in 1905.

During Lind's 10 years as a college student, the study of radioactivity was beginning in Europe. In 1895, Wilhelm Roentgen discovered X rays; in 1896, Henri Becquerel discovered the radioactivity of uranium; in 1897, J. J. Thomson discovered the electron; and in 1898, Marie and Pierre Curie discovered the radioactive elements radium and polonium.

Earning a university sabbatical, Lind went to France in 1910 to study the new phenomenon of radioactivity at the laboratory of Madame Curie, who received the Nobel Prize for chemistry in 1911. The Curie laboratory, he wrote:

> *consisted of about a dozen research rooms scattered over the ground floor, including a small shop and library. Only workers already having the Ph.D. degree were accepted. Madame Curie interviewed me in the little library and advised me to take a course of laboratory training in radioactivity from her first assistant, Dr. Debierne. This I did and at the same time attended Madame Curie's lectures on radioactivity at the Sorbonne. Her lectures were most interesting in*



> *tracing the history of the discovery of radium and polonium by herself and her late husband, Pierre Curie, and their subsequent studies of them. As was the custom for lectures by one of great distinction, her first few lectures were attended in her honor by many other scientists of high, established rank.*

At the Curie laboratory, Lind collected radon from solutions of radium salts and used it to study alpha particles. In 1911, he departed for a radium institute in Vienna as a visiting scientist and worked there with Victor Hess, who later received the Nobel Prize for physics for his discovery of cosmic rays.

Returning to the United States in 1912, Lind could find no radium with which to continue his experiments with alpha particles. At the time, radium was so rare that it cost $120,000 per gram. Learning that the U.S. Bureau of Mines in Denver was recovering radium from Colorado ore for use in cancer therapy, Lind took a job there as a chemist in 1913, adopting Curie's fractional crystallization method to extract about 8.9 grams of radium worth nearly $1 million.

The Bureau of Mines placed a half gram of radium in Lind's custody for research, and he carried it with him throughout his career, using it for many radiation studies with graduate students and other collaborators. He also carried some radium in his body as a result of an accident in Denver; his presence in a laboratory would sometimes set off radiation alarms.

After finishing his work for the Bureau of Mines in 1923, Lind went to Washington, D.C. as chief chemist of the Bureau of Mines and then as associate director of the Fixed Nitrogen Laboratory of the Department of Agriculture. In 1926 he moved to the University of Minnesota as director of the School of Chemistry and later as dean of the Institute of Technology. He retired in 1948 and came to Oak Ridge as a consultant to Clark Center, head of Carbide operations in Oak Ridge.

Most of his work naturally was concerned with research operations in Oak Ridge, and he spent most of his time at ORNL, particularly in the Chemistry Division. He even served as acting director of the division from 1951 to 1954. He continued his research and scientific publications, and at the age of 82 published, with Clarence Hochanadel and John Ghormley, a revision of his classic monograph, *The Radiation Chemistry of Gases*. Having been elected to the National Academy of Sciences in 1930, he was the sole Laboratory staff member with that honor until the 1957 election of biologist Alexander Hollaender.

An active outdoorsman, Lind avidly fished for trout in streams near Oak Ridge. In 1965 at age 86, Lind drowned when caught by the rapidly rising water of the Clinch River below Norris Dam while fishing for trout. A colleague at the Laboratory remarked that, although his death was a great loss to his friends and associates: "We do, however, have the consolation that, both literally and figuratively, Samuel Colville Lind died with his boots on."

1947, while the facility's future was debated in Washington, caused personnel and equipment to be moved into empty buildings at the Y-12 Plant, which was shifting its focus from the electromagnetic separation of uranium-235 to precision machining of weapons components.

Expecting Clinton Laboratories to build the nation's first peacetime research reactor and the first electric power–generating reactor, Thomas courted Eugene Wigner, bringing him from Princeton to Oak Ridge several times during late 1945 to conduct seminars and consult on reactor designs. In early 1946, he lured Wigner into a year's leave from Princeton University to become Clinton Laboratories' research and development director by promising to relieve him of administrative duties, which Thomas assigned to James Lum. Wigner also acquired an assistant for the administration of research and development, Edgar Murphy, a scientist who had served as Army major in the Manhattan Engineer District office during the war.

When his Princeton colleagues asked Wigner why he was going to Dogpatch, he told them that, as one of the three major nuclear research laboratories in the United States, Clinton Laboratories would become important "in the life of the whole nation."

As its research director, he intended to focus on science education by (1) developing research reactors suitable for use at universities, (2) establishing nuclear science training under his former graduate student Frederick Seitz, and (3) coordinating scientific research with universities throughout the South. "Only too much have both Chicago and Oak Ridge lived in the past on fundamental knowledge that has been acquired either before the war or at one of the other government research centers," Wigner observed. "As these wells begin to run dry, this situation becomes increasingly unhealthy."

Early in his tenure, Wigner outlined his weekly routine. On Mondays, he would remain in his office with an open door to hear staff advice and grievances. On "Holy" Tuesdays, he would vanish, pursuing his own research to "keep my knowledge alive." Although he avoided committee meetings to the extent possible, the remainder of the week he would attend to duties, circulating through the Laboratories to discuss scientific and administrative problems. "We'll have long arguments just as you are having them now with each other," he warned the staff, "and I fully expect to be wrong in most of them—that is, from Wednesday to Friday."

High-Flux Designs

When Wigner arrived as research director, staff at Clinton Laboratories had begun designing new types of reactors. Researchers investigated the possibilities of developing a high-neutron-flux reactor for testing materials and a gas-cooled Daniels Pile for demonstrating the use of nuclear energy for electricity production. The Laboratories' chemists also initiated research aimed at a high-flux homogeneous reactor.

Wigner devoted most of his attention to the high-flux reactor, subsequently renamed the Materials

Miles Leverett helped lead the Oak Ridge team that designed the Materials Testing Reactor.

"Squeezing heavy water out of the reactor design, they selected ordinary water as both moderator and coolant."

"Wigner's best-known contribution was the curved design of the aluminum fuel plates in the reactor core."

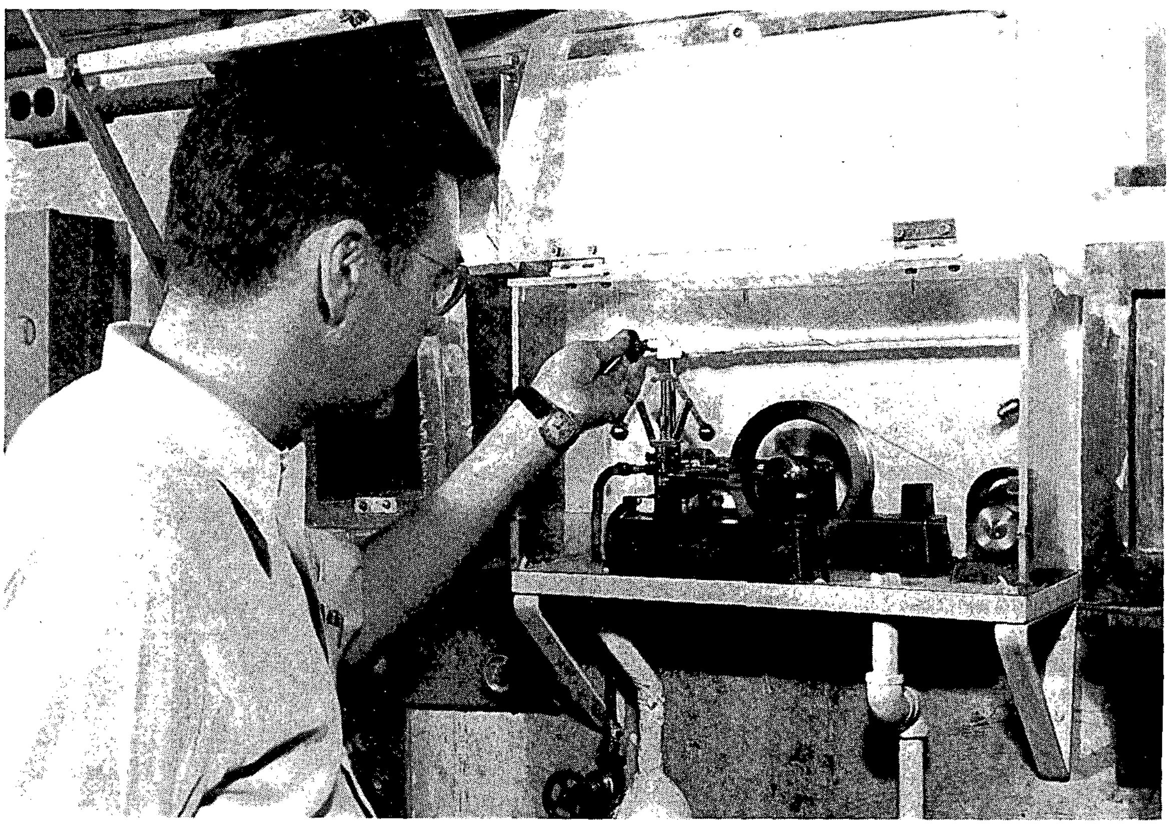
Testing Reactor. Its chief function was to bombard test materials with neutrons to determine which materials would be best for future reactors. A reactor designer's reactor, it provided the most intense neutron source at the time.

Initial designs called for use of enriched uranium fuel, heavy water in the interior lattice to moderate the neutrons, and ordinary (light) water to cool the exterior. Wigner and Alvin Weinberg, appointed by Wigner to be Lothar Nordheim's successor as chief of physics, concluded that use of heavy water could severely reduce the flux of very fast neutrons.

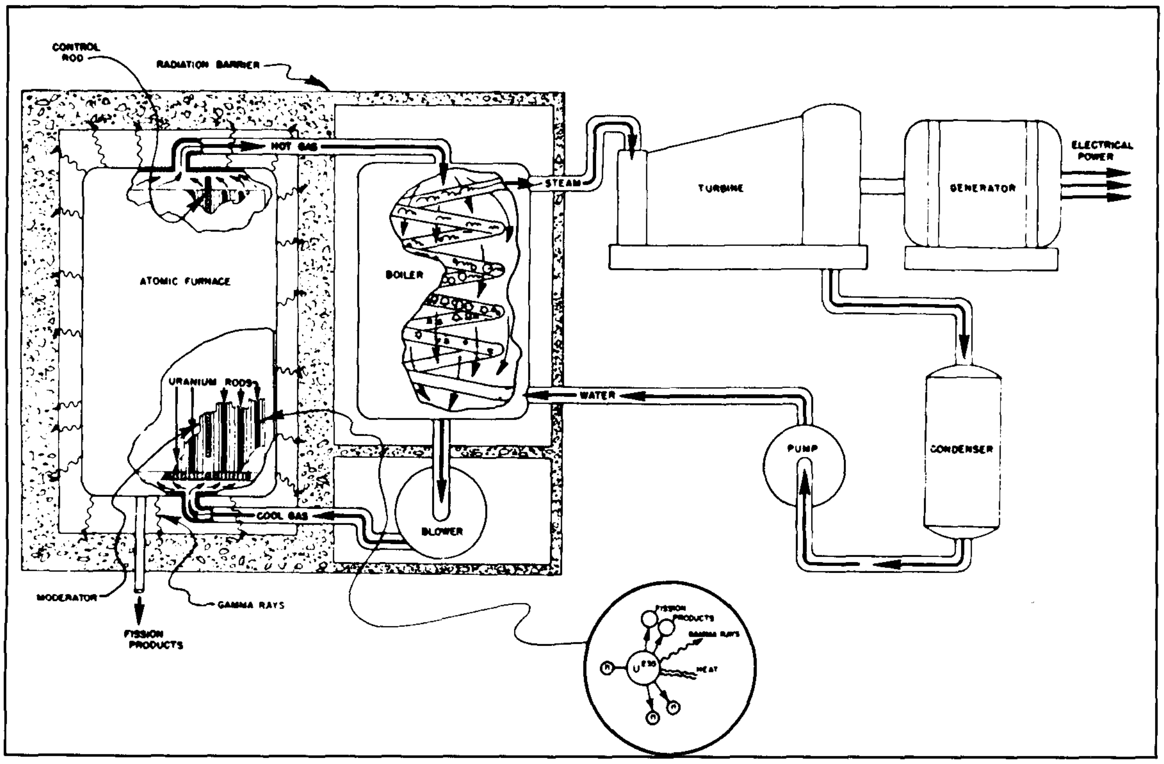
Squeezing heavy water out of the reactor design, they selected ordinary water as both moderator and coolant. Instead of uranium rods canned in aluminum as in the Graphite Reactor, the fuel element or core would be uranium sandwiched between aluminum cladding or plates. To ensure a high thermal neutron flux for research, the plates were surrounded by a neutron reflector made of beryllium. In time, this design served as the prototype for many university research reactors and, in a sense, for all light-water reactors that later propelled naval craft and generated commercial power.

Miles Leverett and Marvin Mann headed a team of scientists and engineers who designed the Materials Testing Reactor at Oak Ridge. About 60 staff members became involved in the design over nearly six years.

Wigner's best-known contribution was the curved design of the aluminum fuel plates in the reactor core. These plates were placed parallel to one another with narrow spaces between for the cooling water; the reactor's power was largely set by how much water



Logan Emlet of the Laboratory Operations Division inspects the toy engine that used heat from the Graphite Reactor to demonstrate that nuclear power could generate electricity.



This 1946 sketch was the first released by the Laboratory to explain to the public the proposed use of a nuclear reactor to generate electricity.

flowed past the fuel plates. Concern arose that intense heat might warp the plates, bringing them in contact and restricting coolant flow. After pondering this potential problem, Wigner directed that the plates be warped, or curved, to improve their structural resistance to stress. Because warped plates could only bow in one direction, they would not constrict water flow.

Adjacent to the Materials Testing Reactor, Leverett's team planned to construct a plant to reprocess spent nuclear fuel, using the precipitation process developed during the war. In reprocessing, nuclear fuel is extracted from the spent fuel and separated from the accumulated fission products for reuse in reactors. Chemists John Swartout and Frank Steahly recommended that the "25 solvent-extraction process" replace the more expensive precipitation process. Their recommendation was accepted. Solvent extraction—separating one material from others dissolved in one liquid by transferring it into another liquid that cannot mix with the first—eventually became the standard method worldwide for reprocessing spent nuclear fuel.

Monsanto's principal concern was the Daniels Pile, named for Farrington Daniels who, at the Chicago Metallurgical Laboratory in 1944, had designed a reactor with a bed of enriched uranium pebbles moderated by beryllium oxide and cooled by helium gas. Some called it the pebble-bed reactor. In May 1946, the Manhattan Engineer District directed Monsanto to proceed with the design, leading to the construction of an experimental Daniels Pile to demonstrate electric power generation.

To accomplish this task, Monsanto brought Daniels from the University of Wisconsin as a consultant. The company also recruited engineers from industry and brought them to Clinton Laboratories, where they formed a Power Pile Division headed by Rogers McCullough. This division identified materials suitable for high-temperature reactors and developed pressure vessels and pumps, piping, and seals for high-pressure coolants; it also studied heat exchanger designs.

Because its staff was recruited largely from outside Clinton Laboratories, the Power Pile Division was never fully integrated into the organization. The project, moreover, encountered numerous design problems. Critics of the Daniels Pile contended that it would never become a practical power-generating reactor and that building a demonstration project wasted time and resources. After all, Logan Emlet and operators of the Graphite Reactor had demonstrated power production with a toy steam engine and generator that used heat from the air-cooled reactor. Why, critics said, should we pursue a more complicated and expensive power-production strategy?

"Solvent extraction eventually became the standard method worldwide for reprocessing spent nuclear fuel."

Radioisotopes and Health

Trace of Hope

In August 1946, the Laboratory's research director, Eugene Wigner, handed the first shipment of a reactor-produced radioisotope, a container of carbon-14, to the director of the Barnard Free Skin and Cancer Hospital of St. Louis, Missouri.

The peacetime production of radioisotopes at the Graphite Reactor for industrial, agricultural, and research applications began in 1946 under the management of Waldo Cohn of Clinton Laboratories and Paul Aebersold of the AEC. In August 1946, the Laboratory's research director, Eugene Wigner, handed the first shipment of reactor-produced radioisotopes, a container of carbon-14, to the director of the Barnard Free Skin and Cancer Hospital of St. Louis, Missouri.

During its first year of production, the Laboratory made more than 1000 shipments of 60 different radioisotopes, chiefly iodine-131, phosphorus-32, and carbon-14. These were used for cancer treatment in the developing field of nuclear medicine and as tracers for academic, industrial, and agricultural research. Many thousands of shipments of radioisotopes produced at the Graphite Reactor were made before production was shut down permanently in 1963.

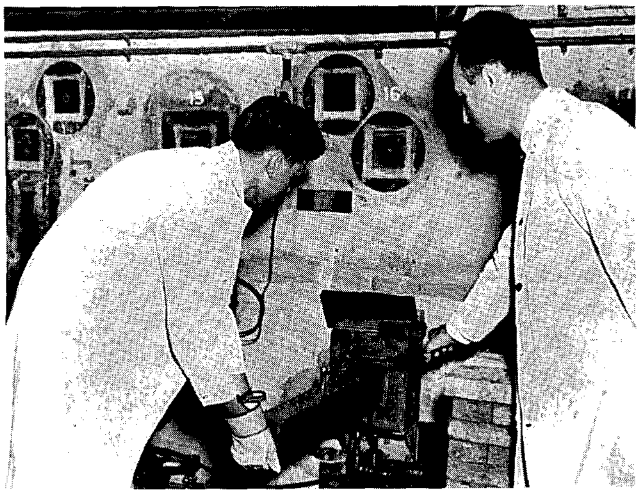
Following the closing of the Graphite Reactor, the Oak Ridge Research Reactor produced most of the Laboratory's radioisotopes. The Laboratory also used calutrons at the Y-12 Plant to produce stable isotopes and cyclotrons to produce isotopes such as gallium-67, widely used for tumor imaging. The Oak Ridge Research Reactor closed in 1987, but ORNL's High Flux Isotope Reactor remains an important source of radioisotopes for medical and industrial uses.

The Laboratory's nuclear medicine program now centers on the development of new radiopharmaceuticals and radionuclide generators for diagnosis and treatment of human diseases, including cancer and heart ailments.

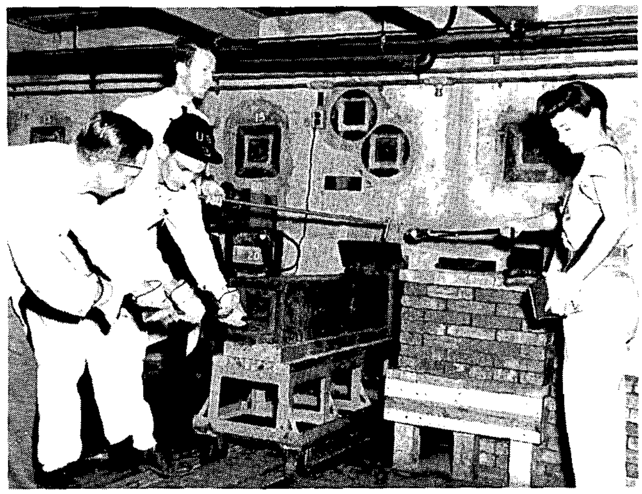
Today radioisotopes are used for diagnosing 100 million patients each year. This number gives credence to former ORNL Director Alvin Weinberg's noted statement:

"If at some time a heavenly angel should ask what the laboratory in the hills of East Tennessee did to enlarge man's life and make it better, I daresay the production of radioisotopes for scientific research and medical treatment will surely rate as a candidate for the very first place."

Radioisotopes: Step by step



1. Waldo Cohn inserts a sample in a graphite stringer that is then pushed into the Graphite Reactor for irradiation.



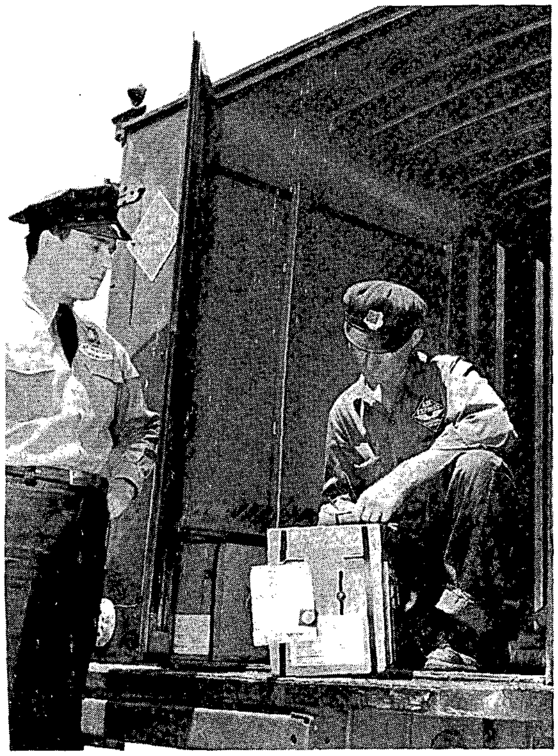
2. Irradiated materials are drawn from the Graphite Reactor.

Such criticism caused high-level support for the Daniels Pile to wane by 1948. It was never constructed, and Daniels, as a professor at the University of Wisconsin, would gain renown as a national expert on solar energy.

Atoms for Health

Distribution of the radioisotopes produced at the Graphite Reactor for biological and industrial research rapidly became the most publicized activity at Clinton Laboratories in the postwar years. Orders began arriving soon after the Laboratory published a radioisotope catalogue in the June 1946 issue of *Science*, which listed isotopes Laboratory staff could prepare and ship. On August 2, 1946, Wigner stood in front of the Graphite Reactor to hand the first peacetime product of atomic energy, a small quantity of carbon-14, to an official of a cancer research hospital in St. Louis, home of Monsanto Chemical Company. Soon, nearly 50 different radioisotopes were regularly available for distribution. In 1947, to handle their production and distribution, Logan Emlet of Operations established an Isotopes Section headed by Arthur Rupp; as the program expanded, it later became the Isotopes Division, which was headed by Rupp and John Gillette, among others.

3. Useful radioisotopes are extracted by chemical processes and packed for shipment.



The Railway Express Agency trucks the 1000th shipment of radioisotopes from the Laboratory.

One of the earliest cases of technology transfer from Clinton Laboratories came as a spin-off of the radioisotopes program. Abbott Laboratories located its original radiopharmaceutical production plant in Oak Ridge near the source of the radioisotopes. The plant moved to Chicago in the 1960s when the Laboratory ceased commercial production of most radioisotopes.

"The shops even included an old-fashioned Tennessee blacksmith who fabricated lead bricks for radiation shielding."

High-Flux Organization

Like most new managers, Wigner sought to sharpen the organization's mission and improve its performance. He made both minor changes, such as the appointment of Edward Shapiro as chief of the Laboratories' technical libraries, and major changes, such as forming and staffing new divisions. Thinking solid-state physics was a key to reactor design, Wigner established a small group for solid-state studies in the Physics Division under Sidney Siegel and Douglas Billington; he formed a new division to investigate the effects of radiation on metals; and he persuaded Monsanto executives to consolidate and augment staffing of the machine shops that supported the research projects.

During the war, small machine shops scattered among several divisions provided the tooling, finishing, and precision machine work required for scientific experimentation. In 1946, Wigner urged that these shops be merged into groups comprising at least 200 craftsmen. After some resistance to the suggestion, Executive Director James Lum established the central research shops in 1947 and imported Paul Kofmehl, a Swiss craftsman, as superintendent, with Earl Longendorfer as his assistant.

Skilled crafts people, who machined the hardware for the reactors and other projects, were put to work in the research shops. They acquired apprentices in the ancient tradition of the crafts and supplied scientists and engineers with the unique equipment and tools they required. As the work load increased, the research shops evolved into central machine shops and eventually became the Fabrication Department in the Plant and Equipment Division under the supervision of Robert Farnham. The shops even included an old-fashioned Tennessee blacksmith, Miller Lamb, who fabricated lead bricks for radiation shielding and produced customized nuts, bolts, and metal parts. Nearly a quarter century after Lamb retired in 1969, Laboratory personnel still pass his handiwork every day: he forged the ladder rungs on the smokestacks at the Laboratory.

In 1945, Miles Leverett purchased a secondhand mill to roll, cast, and forge reactor fuel elements and metal parts. He also recruited metallurgists for materials research. Declaring that "an integrated program on the properties and possibilities of materials from the structural and nuclear point of view is greatly to be desired," in 1946 Wigner hired William Johnson from Westinghouse as a consultant on the formation of a Metallurgy Division. Johnson recruited a half-dozen metallurgists to form the division under the leadership of John Frye, Jr.

Metallurgists faced the challenge of fabricating reactor components of uranium and aluminum

Alexander Hollaender

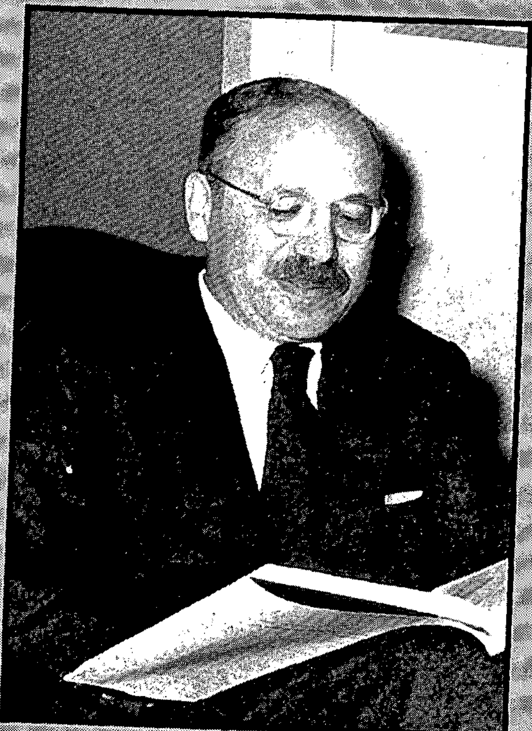
A Radiant Biologist

Alexander Hollaender was director of ORNL's Biology Division from 1946 through 1966. Under his leadership, it became the Laboratory's largest division and gained international recognition for its contributions to radiation genetics, biochemistry, radiation carcinogenesis, and molecular biology.

Hollaender, a native of Germany, became renowned both locally and nationally. He was elected a member of the National Academy of Sciences; in 1968, he was awarded a Finsen Medal at the Fifth International Congress of Photobiology; in 1983 he received the Fermi Award, the Department of Energy's highest honor; and in 1984, he received the National Medal of Science. "He has made superior contributions in three different fields of endeavor—scientific discovery, scientific education, and scientific administration," wrote Richard B. Setlow, formerly of ORNL's Biology Division and now an associate director at Brookhaven National Laboratory.

"Alexander Hollaender, director of ORNL's Biology Division for 20 years, made his mark in scientific research, education, and administration."

Hollaender earned his Ph.D. degree in physical chemistry at the University of Wisconsin. Before coming to Clinton Laboratories in 1946, he directed a radiobiology laboratory at the National Institutes of Health (NIH), where he examined the effects of ultraviolet radiation on fungi. From his studies, he correctly suggested in 1939 that nucleic acids, not the cell's proteins, carried the genetic information in reproduction.



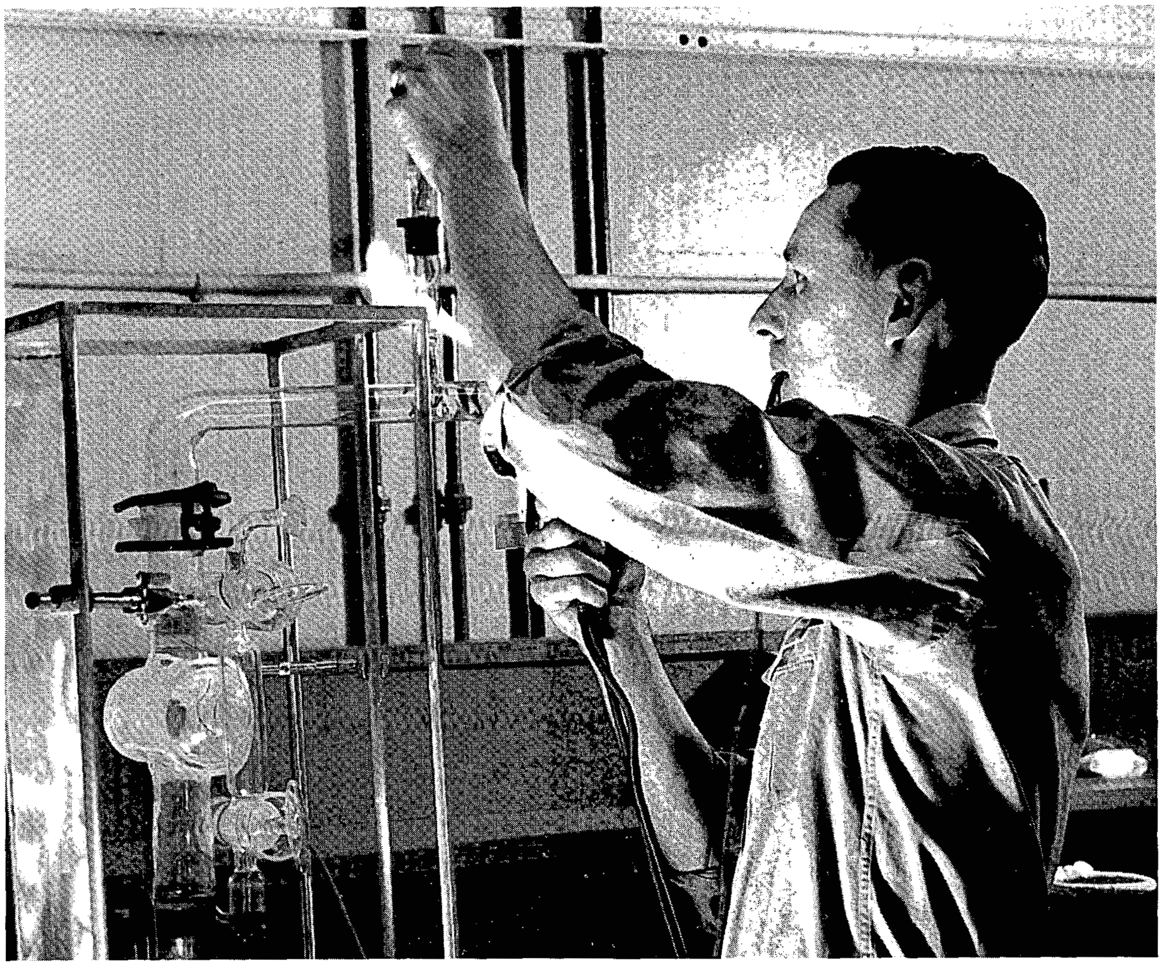
Hollaender was attracted to Clinton Laboratories because of its variety of radiation sources. He intended to acquire staff and equipment and form a National Institutes of Health Institute of Radiation Health at Oak Ridge. Instead, he formulated a plan for a new Biology Division, which was given space in buildings initially constructed for chemical reprocessing at the Y-12 Plant.

Hollaender was opportunistic and open to new ideas. He originally thought the effects of radiation on the genes of all species could be determined by studies of simple cells in microorganisms and fruit flies. But when he heard of the pioneering work on the genetic effects of radiation on mice by Bill and Liane Russell at Bar Harbor, Maine, he realized that the results of mouse studies might be more applicable to humans than the results of fruit fly studies. He conceived of starting a large mouse genetics project, however risky in terms of the cost and the long time needed for useful results. So when Russell was thinking of leaving Bar Harbor, Hollaender hired him and his wife Liane to set up a genetics laboratory at ORNL, dubbed the Mouse House.

In addition to his scientific expertise and leadership, Hollaender was an educator. With Mary Bunting and Glenn Seaborg of the AEC, and Andy Holt of the University of Tennessee, in 1968 he founded the University of Tennessee–Oak Ridge Graduate School of Biomedical Sciences.

He is remembered for organizing many symposia on biological topics held in Gatlinburg, Tennessee, for designing student trainee programs in the Biology Division, and for leading group hikes in the Cumberland Mountains. At Hollaender's retirement from the Laboratory in 1966, Alvin Weinberg assessed Hollaender's career, which extended beyond his specific accomplishments to a new way of thinking that transformed and enriched both the Laboratory and the biological sciences:

> *Alex Hollaender invented a new style of biological investigation: the melding of enormous, expensive mammalian experiments with basic investigations on a much smaller scale in which the principles underlying the mammalian experiments could be demonstrated and tested in the most delicate and far-reaching way. It is this unique combination of the big and the small, the mission-oriented and the discipline-oriented, that is Alex Hollaender's great contribution to biomedical science. It is a contribution that has forever changed biology.*



Ernest Sneed in the Laboratory's glass shop fabricates glassware for use in an experiment.

alloys, beryllium, zirconium, and other exotic metals and conducted intensive research into the functioning of metallic elements under high temperatures and radiation stress in reactors. Starting with fewer than a dozen staff members, the Metallurgy Division increased to as many as 300 people. In 1952, Frye also organized a group under John Warde as a ceramics laboratory. In addition to conducting ceramics research, it fabricated crucibles, insulators, and fuel elements, and customized parts for reactors. The group also employed a practical potter or two to make molds. From these modest beginnings, the Laboratory would become a world center for metallic alloy and ceramics research.

High-Flux Biology

Just as the atom's nucleus captivated physical scientists, the living cell was the center of attention for life scientists. The Graphite Reactor supplied a variety of radioisotopes that helped bring about a revolution in the life and medical sciences by leading to a new understanding of metabolic processes and genetic activities. Developments in biological sciences and the need to better understand the effects of radiation on human health and the environment led Wigner to expand the biology and health physics organizations.

When John Wirth, head of the Health Division, returned to the National Cancer Institute in September 1946, Wigner and Lum split the Health Division into two new research sections, plus a medical department, which was headed by physician Jean Felton and later by Thomas Lincoln and then Seaton Garrett. In October, Wigner recruited Alexander Hollaender to form and head a Biology Division. Hollaender had received degrees in physical chemistry from the University of Wisconsin. At the National Institutes of Health, he had studied the effects of radiation on cells and the use of ultraviolet light to control airborne diseases.

Hollaender's initial research plan at Clinton Laboratories called for studying radiation's effects on living cells, including such cell constituents as proteins and nucleic acids.

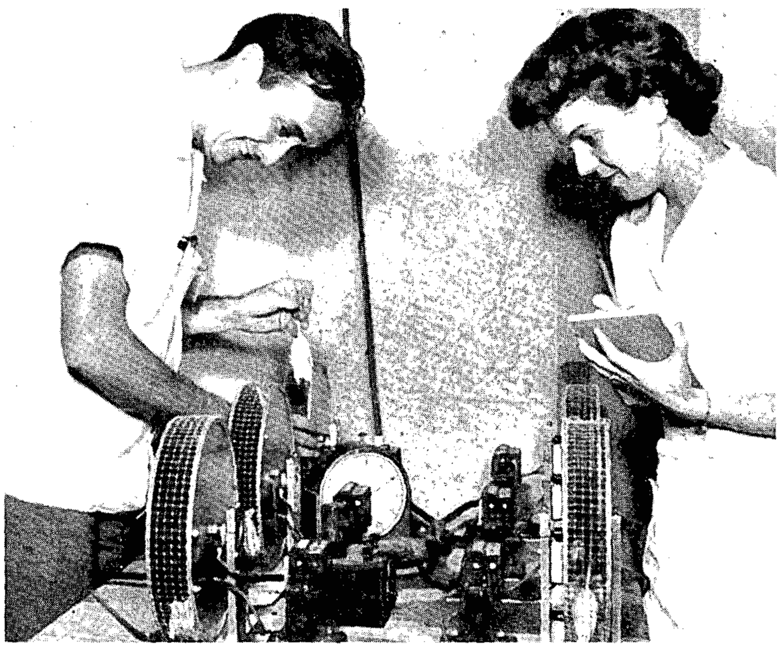
Beginning with a few radiobiologists studying microorganisms and fruit flies in crowded rooms behind the dispensary, Hollaender initiated a broad program that would make his division the largest biological laboratory in the world. Hollaender would successfully unite fundamental research in the biological sciences with physics, chemistry, and mathematics and would recruit widely to staff the initial research units in biochemistry, cytogenetics, physiology, and radiology. William Arnold, Waldo Cohn, Richard Kimball, Elliot Volkin, and William and Liane Russell were among the Biology Division's most respected staff members, a group that included 70 scientists and technicians by 1947. Lacking space at the X-10 site, the new division moved into vacated buildings at the Y-12 Plant.

The biological research that attracted the most public interest was the genetic experiments conducted under the supervision of William and Liane Russell, who used mice to identify the long-term genetic implications of radiation exposure for humans. Among the division's early scientific accomplishments, however, Hollaender took special pride in William Arnold's discoveries of the electronic nature of energy transfer in photosynthesis, Waldo Cohn and Elliott (Ken) Volkin's discovery of the nucleotide linkage in ribonucleic acid (RNA), and Volkin and Larry Astrachan's discovery of messenger RNA.

The Biology Division's greatest long-term influence on science, however, may have come from its cooperation with the University of Tennessee–Oak Ridge Graduate School of Biomedical Sciences and with universities and research centers throughout the nation and the world.

The second division separated from the old Health Division in 1946 was Health Physics, directed by K. Z. Morgan. The Health Physics Division eventually included 70 staff members who monitored radiation levels in research and production areas and furnished improved radiation

"Hollaender initiated a broad program that would make his division the largest biological laboratory in the world."

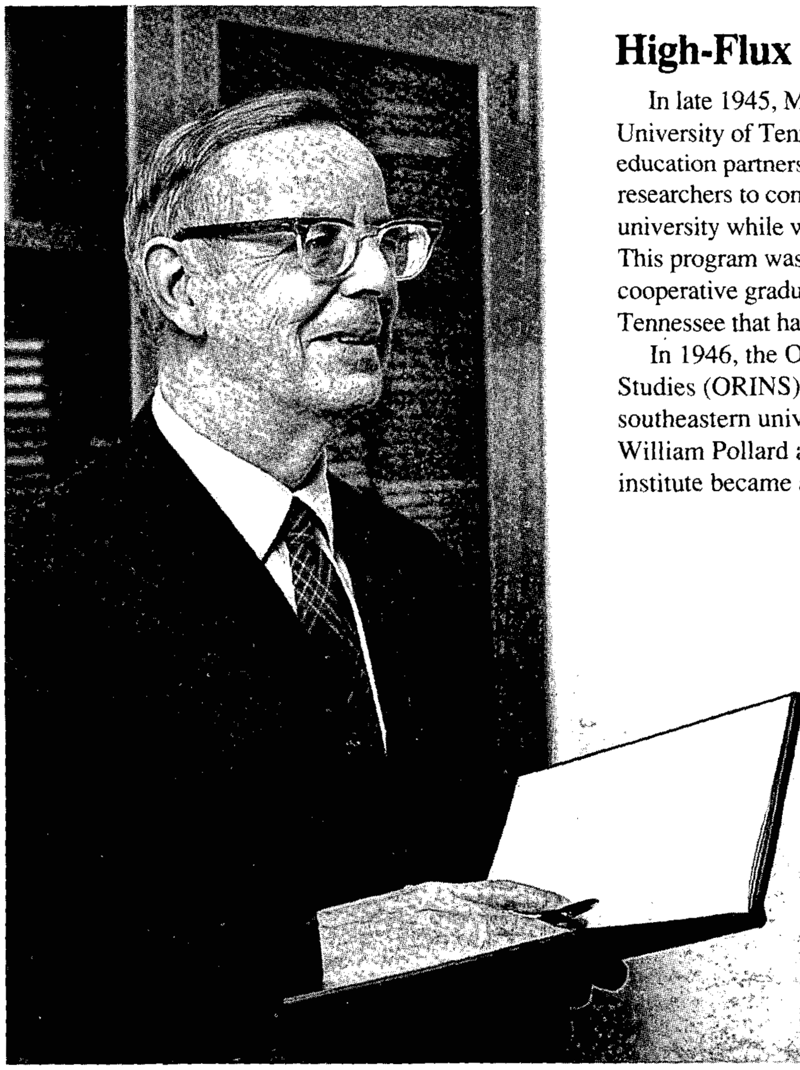


Researchers at Clinton Laboratories studied the responses of mice to varying amounts of radiation.

"Among the Biology Division's early scientific accomplishments was the discovery of messenger RNA."

detection devices. Early research included studies of radioisotopes discharged into river systems, estimates of thermal neutron tolerances, and development of new methods to detect radiation.

In 1944, Oak Ridge health physicists trained personnel responsible for radiation protection at Hanford. They continued this schooling at Oak Ridge until 1950 when the AEC established fellowships for graduate study at Vanderbilt and Rochester universities. The Army, Navy, and Air Force also sent personnel to receive health physics training at Oak Ridge. In addition to its land-based monitoring efforts, the Health Physics Division used boats to measure radioactivity entering the Clinch River from White Oak Creek and airplanes to monitor radioactivity in the air above Oak Ridge. As a result, the division was said to have its own "army, air force, and navy."



William Russell, who conducted pioneering studies of the mutagenic effects of environmental radiation and chemicals on mice.

High-Flux Education

In late 1945, Martin Whitaker met with University of Tennessee officials to discuss a science education partnership that would allow young researchers to complete graduate studies at the university while working at Clinton Laboratories. This program was the precursor of an extensive cooperative graduate program with the University of Tennessee that has continued to this day.

In 1946, the Oak Ridge Institute of Nuclear Studies (ORINS), a nonprofit corporation of 14 southeastern universities, was chartered with William Pollard as its director. In 1947, the institute became an AEC government-owned, contractor-operated facility. Under its authority, Clinton Laboratories' Biology Division trained scientists ir the use of radioisotopes. Later ORINS opened a clinical facility where radioisotopes were used for cancer treatment.

In 1949, the institute obtained support from the AEC to open the American Museum of Atomic Energy in a wartime cafeteria building. In 1974, the museum, renamed the American Museum of Science and Energy, move into a new building adjace to the corporate headquarters of the Oak

William Pollard (center) and Gould Andrews, both of the Oak Ridge Institute of Nuclear Studies, welcome Eleanor Roosevelt to Oak Ridge.

Ridge Institute of Nuclear Studies, which itself had been renamed Oak Ridge Associated Universities and had nearly 50 sponsoring members.

Universities that joined the institute were invited to use the Laboratory's scientific facilities. Under the management of Russell Poor, the institute began a program for faculty research at the Laboratory in the summer of 1947 with two participants. That number increased to 70 by 1950, a level maintained for many years. Supplementing this research program were traveling lectures and seminars conducted by Laboratory scientists at the participating universities. The resulting interaction between Laboratory scientists and university faculty, along with faculty and student use of research equipment available at the Laboratory, contributed significantly to the spectacular growth in graduate science education throughout the Southeast during the postwar years.

High-Flux Training

In August 1946, Eugene Wigner opened the Laboratories' Clinton Training School with Frederick Seitz as its director. Although Wigner envisioned it as a small postdoctoral seminar in nuclear technology, more than 50 people from the military, industry, and academia enrolled. Among the first participants were Herbert MacPherson, Sidney Siegel, John Simpson, Everitt Blizard, Douglas Billington, and Donald Stevens, all of whom subsequently became renowned for their activities in science. The most famous graduate, however, was Captain Hyman Rickover of the U.S. Navy.

The Navy had first provided Wigner and Szilard funding for nuclear experiments in 1939. During the war, Navy scientists developed a thermal diffusion process for separating uranium isotopes; the S-50 plant in Oak Ridge was built during World War II for this purpose. Navy interest in using nuclear energy for ship propulsion continued, and in early 1946 Philip Abelson of the Navy research team spent several months at the Laboratory studying Wigner's approach to reactor design. In May 1946, Admiral Chester Nimitz assigned five Navy officers and three civilians to Oak Ridge. The officers were Hyman Rickover, Louis Roddis, James Dunford, Raymond Dick, and

Karl Z. Morgan

Man on a Mission

Protecting people from exposure to unsafe levels of radiation has been the mission of Karl Z. Morgan, sometimes known as the father of health physics.

Affectionately called "K. Z.," Morgan first made his mark in radiation protection as director of the Health Physics Division of Clinton Laboratories. With Elda Anderson, Myron Fair, and Doc Emerson, he spearheaded the formation of the national Health Physics Society and, with Jim Hart and Harold Abee, formed the International Radiation Protection Association. He was the first president of both of these organizations. Morgan also established one of the first programs to train health physicists and, with the help of Jim Turner and other Health Physics Division scientists, wrote the first textbook on health physics.

Health physics was launched unofficially as a profession in December 1942 when the staff took precautions to protect themselves from radiation during the first controlled chain reaction at the University of Chicago's uranium-graphite pile. Health divisions were subsequently set up at the University of Chicago and Oak Ridge under Robert Stone to deal with health and safety issues at the Chicago pile and Graphite Reactor, respectively. The physicists who staffed these divisions were called health physicists. They instituted remote handling of radioactive material, controlled access to "hot" areas, use of protective clothing, and decontamination procedures for those inadvertently exposed.

"Protecting people from exposure to unsafe levels of radiation was the mission of Karl Z. Morgan, sometimes known as the father of health physics."

Although trained and experienced as a cosmic-ray physicist, Morgan became one of the nation's earliest health physicists, along with the Laboratory's Herbert Parker and Ernest Wollan. These men brought to this new field a thorough knowledge of basic physics and radiation instrumentation. They redesigned and adapted the early ionization chambers, film meters, electrometers, and Geiger-Müller counters to meet requirements for personnel monitoring and radiation surveys of buildings and the environment.

Morgan came from Chicago to Clinton Laboratories in 1943 as a member of the Health Physics Section, which Herbert Parker managed until he left for Hanford, Washington, in 1944. In 1946, the section became a division and Morgan its director. In this capacity, he established a vigorous program to upgrade existing instrumentation using improved techniques that emerged in wartime research to develop radar and the atomic bomb. He remained an enthusiastic supporter of basic physical research to aid the development of health physics instruments and dosimeters.

As chairman of subcommittees of both the National Council on Radiation Protection and the International Commission on Radiological Protection, which were concerned with safe limits for radionuclides in the human body, Morgan identified internal dosimetry as an important area of research for his division and, in 1960, formed the Internal Dosimetry Section. Under Morgan, division scientists determined radiation doses to the Japanese from the atomic bombs dropped on Hiroshima and Nagasaki and predicted radiation doses from nuclear explosives proposed for use by Project Plowshare to excavate canals and liberate trapped natural gas.

Acting as first editor-in-chief of the *Health Physics Journal* and playing a major role in establishing a system for the certification of health physicists were among his chief contributions to the health physics profession.

In 1972 Morgan retired from the Laboratory and later became a professor at Georgia Institute of Technology. He has continued to speak vigorously on his lifetime mission—reducing low-level radiation emissions from radon, medical procedures, and nuclear power.

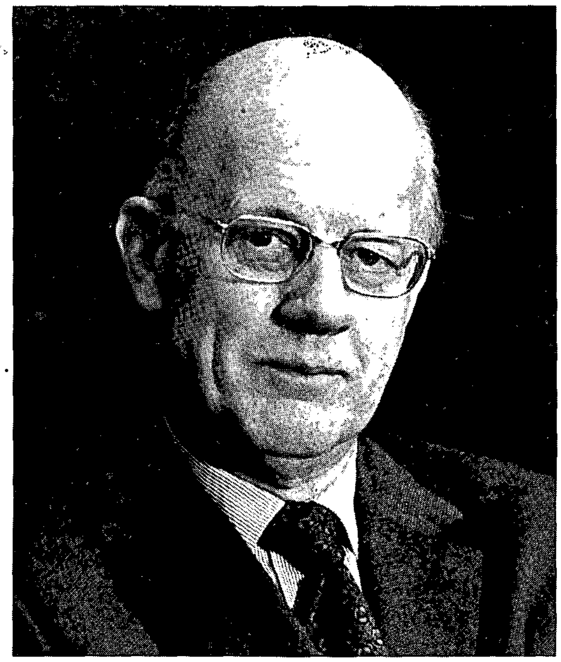
"He has continued to speak vigorously on reducing low-level radiation emissions from radon, medical procedures, and nuclear power."

Miles Libbey. Rickover later recalled his Oak Ridge experience:

> *When I started at Oak Ridge in 1946, there were 4 other naval officers along with me and 3 civilians. Each was sent to Oak Ridge individually, and each started working on his own. . .As soon as I got to Oak Ridge, I realized that if we ever were going to have atomic power plants in the Navy, I would have to assemble these people and train them as a group. And I used a very simple expedient; I arranged to write their fitness reports, so once they knew I was writing their fitness reports, they started paying attention to me. So once I did that, then I was able to weld them into a team and teach them specialized duties in order to get ready for building a submarine plant. Well, the first attempt at building a power plant at Oak Ridge was a civilian one, and it failed. Then unofficially I persuaded the people, the engineers, and the scientists, who were engaged in that enterprise, without any formal permission, to start working on a submarine plant, and they did this for a while. Meanwhile, I advised the Chief of the Bureau of Ships to retain this group of trained people together, and as soon as we came back to Washington, to have us start working on a submarine plant.*

Under Rickover's exuberant direction, navy officers enrolled in the Training School attended every seminar, interviewed every scientist willing to talk, and wrote numerous reports that became the paper foundation of the nuclear navy. Rickover later chose the pressurized-water reactor proposed by Alvin Weinberg to propel the nuclear ships built by the Navy. Legends about Rickover's activities at Clinton Laboratories still abound. For example, he sometimes elicited information from scientists by introducing himself: "I'm Captain Rickover; I'm stupid."

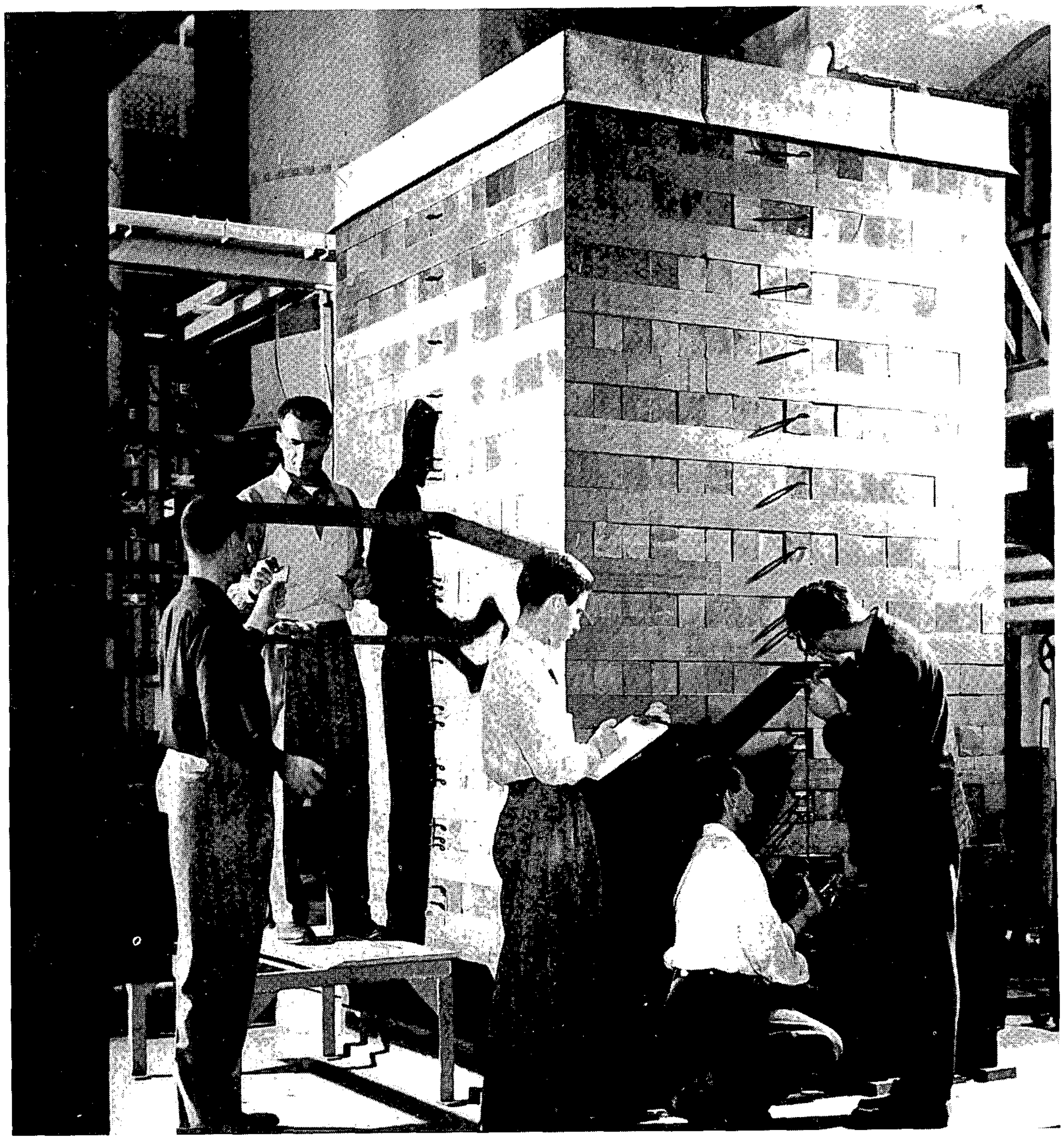
With the end of Monsanto management and the return of Wigner and Seitz to their universities in 1947, the Clinton Training School ceased to exist. Despite its brief tenure, the school was responsible for launching a long and fruitful relationship between the Navy and the Laboratory. Rickover



Frederick Seitz, who directed the Clinton Training School in 1946, became president of the National Academy of Sciences and Rockefeller University.

Everitt Blizard, an expert on radiation shielding.

"Rickover later chose the pressurized-water reactor proposed by Alvin Weinberg to propel the nuclear ships built by the Navy."



Group of students conducts an experiment at the Oak Ridge School of Reactor Technology.

entered into several nuclear design contracts with the Laboratory, and he often employed Laboratory scientists, such as Theodore Rockwell, Frank Kerze, and Jack Kyger, on Navy projects. Everitt Blizard, a civilian who had accompanied Rickover to Oak Ridge, remained at the Laboratory, where he supervised investigations of reactor shielding. Rickover sometimes advised Alvin Weinberg on Laboratory management. He also strongly supported the formation and subsequent educational work of the Oak Ridge School of Reactor Technology (locally dubbed the Klinch Kollege of Knuclear Knowledge) housed at the Laboratory between 1950 and 1965.

Research and Regulations

By his own account, Wigner's most troublesome problems as research director emanated from the Army bureaucracy. In the postwar years, the Army continued its wartime security policies. This meddlesome oversight made the exchange of scientific data with Hanford and Los Alamos difficult for Wigner and his research staff. This and similar problems caused Wigner to have several confrontations with Army authorities, notably Colonel Walter Leber.

Colonel Leber had replaced Captain James Grafton as the Army representative for Clinton

Laboratories in May 1946, and he hired a large number of people to monitor its activities. His office staff included 22 people to inspect construction and administration, 3 to investigate security breaches, and 29 to examine research and development. This large group audited even minor details, down to the book titles ordered by the library. Their actions soon alienated both scientists and Monsanto executives, and James Lum strenuously objected to Leber's efforts to "interfere and assume responsibilities which are reserved only for Monsanto under the present contract." To reduce confusion and improve communications, Lum and Wigner asked Edgar Murphy, formerly an Army major, to serve as a liaison with Leber's staff.

Tensions continued, however, notably in the case of experiments Wigner wished to conduct to test the use of beryllium as a neutron trap or reflector. He encountered a "Catch 22" situation created by Leber's interpretation of a regulation the Army had imposed after Louis Slotin lost his life during a critical experiment at Los Alamos. Wigner insisted the tests were completely safe, but Leber required that the debilitating regulations, which brought the tests to a virtual standstill, be meticulously observed. Only after review at the highest level were the experiments allowed to continue. Such delays discouraged Wigner and in time caused him to return to university life.

High-Flux Science

"Speaking as individuals who have been interested in radiation effects on solids since the conception of the first large reactors," Wigner and Frederick Seitz wrote, "we find it gratifying that a phenomenon which originated as a pure nuisance promises to provide us with useful information about the solid state in general and about many of the materials we use every day."

By "nuisance," they meant the swelling and distortion of graphite under the bombardment of neutrons from nuclear fission, an effect predicted by Wigner and thus called the Wigner disease. Concern about the effects of this "disease" on the Graphite Reactor at Oak Ridge and similar reactors at Hanford stimulated intense interest in solid-state physics at Clinton Laboratories and elsewhere in the postwar years. This fascination played a role in Wigner's formation of the Metallurgy Division and in his personal attention to neutron scattering experiments and zirconium investigations.

Although aluminum had served as cladding for uranium in the Graphite Reactor and other early reactors, it was not suitable for use in the high-temperature reactors designed in the late 1940s. Metallurgists considered substituting zirconium, a metal that resists corrosion in water at high temperatures. Zirconium, however, seemed to have a strong tendency to absorb neutrons, ultimately "poisoning" or slowing nuclear reactions.

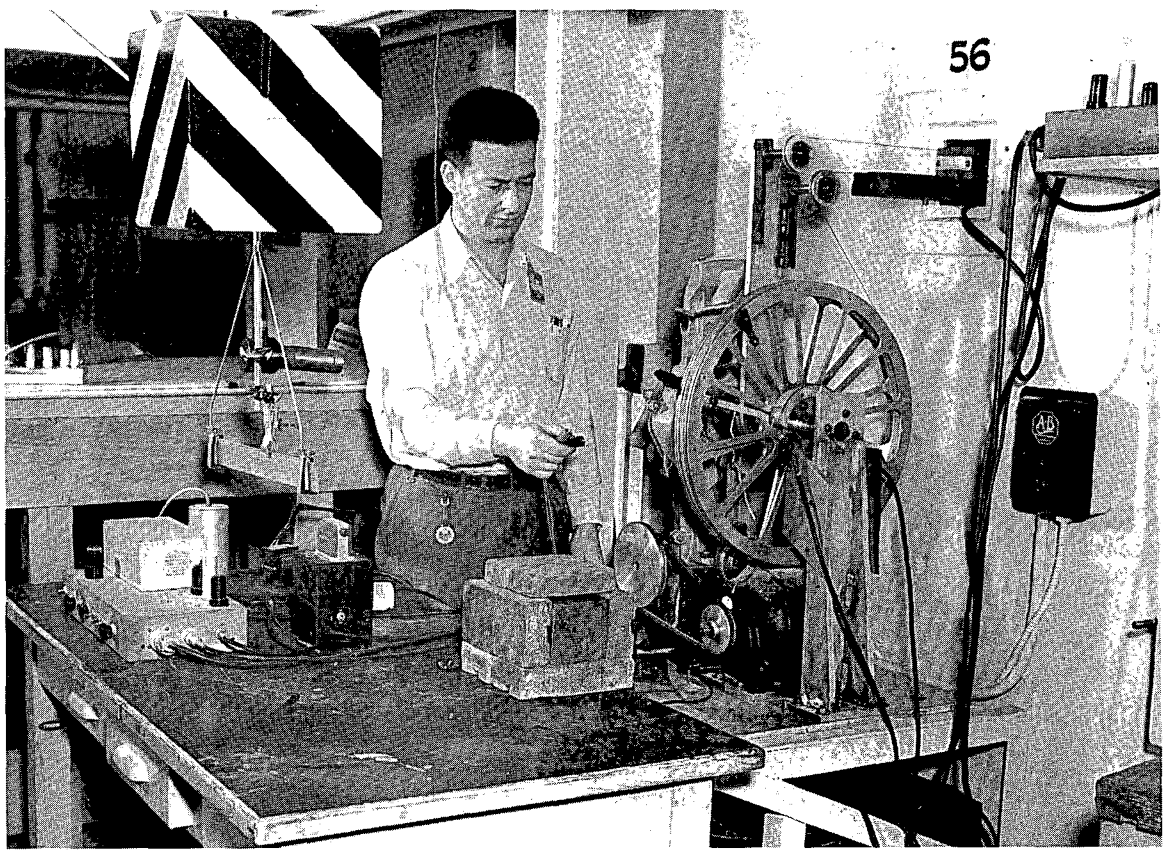
In 1947, Wigner authorized a group of Laboratory researchers to study this problem. Wigner devised a "pile oscillator" to move materials regularly in and out of a reactor. Using a washing machine gearbox to power the oscillator, Herbert Pomerance later that year discovered that zirconium's capability for neutron absorption had been vastly overstated because of its contamination by the element hafnium, which had a much greater poisoning effect.

Zirconium minerals have traces of hafnium, whose chemical characteristics are nearly identical to zirconium's, making economical separation of the two difficult. With funding from Captain Rickover and the Navy, laboratory researchers across the country investigated ways to separate the two elements. In 1949, chemical technologists at the Y-12 Plant, under the direction of Warren Grimes, developed a successful separation technique and scaled it to production level under the direction of Clarence Larson, then superintendent of the Y-12 Plant.

Zirconium alloys became essential first to the Navy's reactors and later to commercial power reactors. Zirconium rods filled with uranium pellets made up the fuel cores of nearly all light-water reactors, and hafnium was used in the control rods to regulate nuclear reactions.

As authorities on solid-state physics, Wigner and Seitz were intrigued by the interaction of radiation with materials, and especially by the neutron scattering experiments of the Laboratory's Ernest Wollan and Clifford Shull.

"Herbert Pomerance discovered that zirconium's capability for neutron absorption had been vastly overstated."



Herbert Pomerance uses a washing-machine mechanism (called the pile oscillator) to oscillate materials in and out of the Graphite Reactor for neutron irradiation.

With a modified X-ray diffractometer that Wollan installed at a beam hole of the Graphite Reactor in late 1945, Wollan and Shull systematically studied the fundamentals of thermal neutron scattering. Having difficulty making sense of the diffuse scattering from various forms of carbon—diamond dust, graphite powder, and charcoal—they called on Wigner for advice. Shull later recalled:

> *I well remember a discussion that Ernie and I had with Eugene Wigner, then the research director of the laboratory and a physicist of infinite wisdom and physical intuition, about this puzzling feature. After listening to our tale of woe and reflecting on the problem, he surprised us very much by calmly suggesting "maybe there is something new here, and maybe we have to relax our notions about conservation of particles." I can only say that I came away from that meeting with the feeling that Wigner had more faith in our experiments than perhaps Ernie and I had!*

After a few months of additional experimentation, Wollan and Shull recognized that the consistency of their data had been distorted by spurious multiple scatterings in the specimens being investigated, an effect unfamiliar to them. This finding allowed them to pursue their studies, which established neutron diffraction as a quantitative research tool fostering scientific knowledge of crystallography and magnetism.

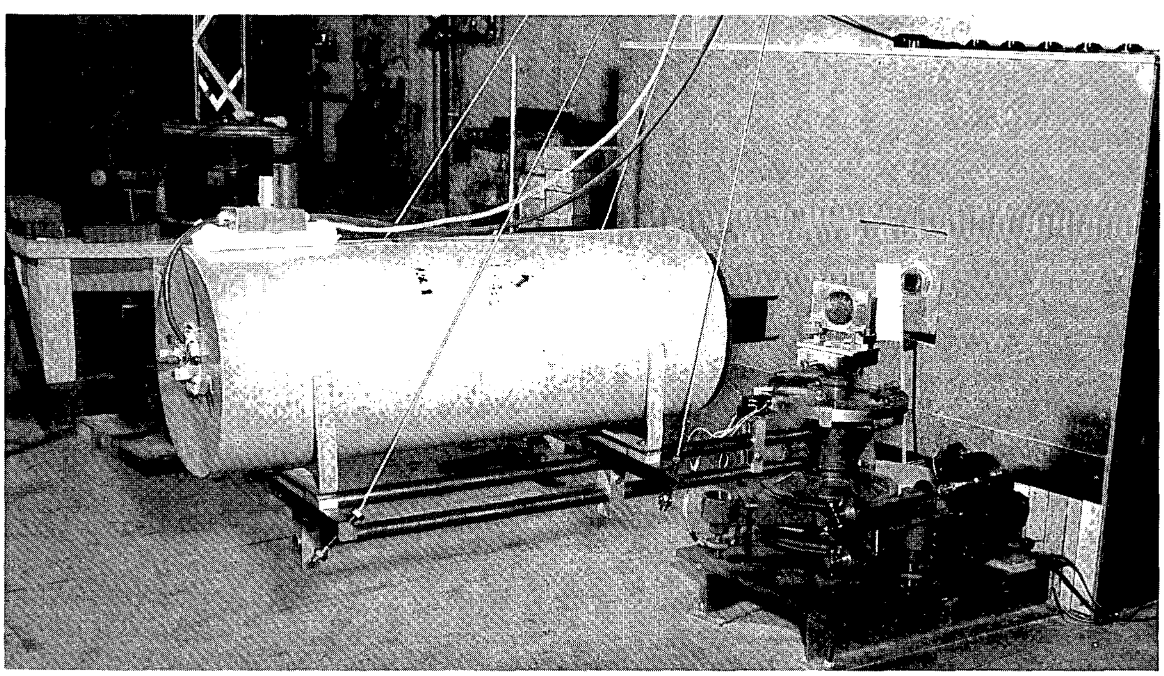
Their work built the foundation on which neutron scattering research developed throughout the world, including a neutron crystallography program under Henri Levy in the Chemistry Division at the Laboratory. Although a half-century has passed since the initial experiments, neutron scattering remains a fertile field of research.

High-Flux Management

In late 1945, the War Department drafted a bill to continue military control of atomic research and energy. Atomic scientists at Chicago and Oak Ridge vigorously opposed the measure and formed associations to lobby for civilian control. After a protracted political battle, the Atomic Energy Act of 1946 established civilian control under a five-member commission. With David Lilienthal, formerly chairman of the Tennessee Valley Authority, as its first chairman, the AEC assumed control from the Manhattan District in January 1947. While this high-level political struggle was in progress, the disposition of the facilities built by the Manhattan District, including Clinton Laboratories, was at issue as well.

In early 1946, General Groves had appointed a committee of prominent scientists to plan the Manhattan District's nuclear activities and budget for 1947. Overall, the committee urged expansion of research and development for both production of fissionable materials and advancement of nuclear power. On the one hand, it suggested awarding contracts to university and private laboratories for unclassified basic research. On the other hand, it urged that national laboratories conduct classified research requiring equipment too expensive or products too hazardous for universities to handle.

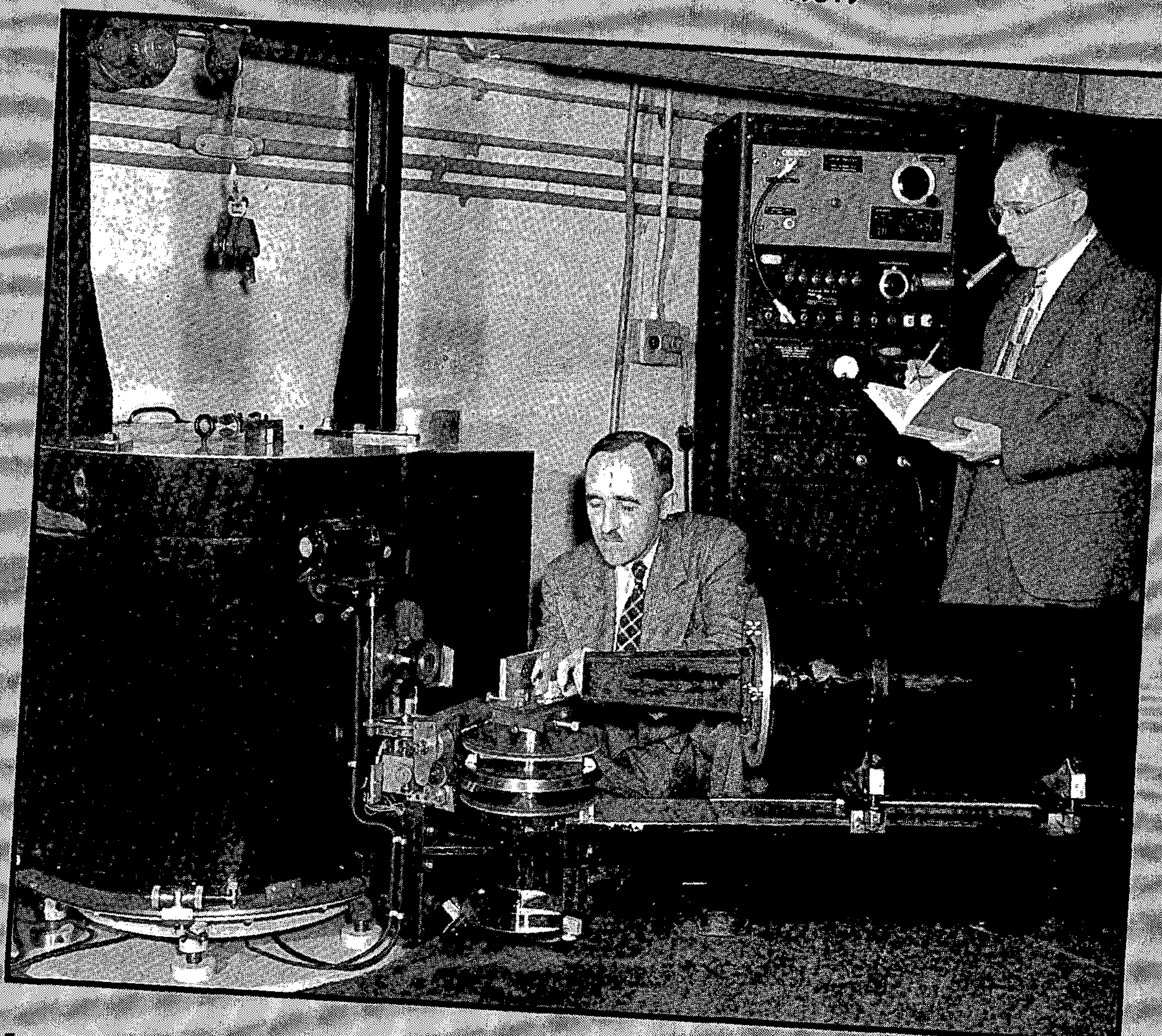
As the committee viewed it, each national laboratory should have a board of directors from universities in its region that would form



The first two-axis diffractometer for neutron scattering research included an X-ray instrument that Ernest Wollan had used at the University of Chicago before bringing it to the Laboratory. Part of this instrument is displayed at the Smithsonian Institution.

Ernest Wollan

Badge of Solid Distinction



Ernest Wollan and Clifford Shull conducted some of the world's first neutron scattering experiments using this diffractometer built at ORNL and installed at the Graphite Reactor in 1950.

Ernest Wollan, who had studied crystal structures using X-ray diffraction under Arthur Compton at the University of Chicago, came to Oak Ridge in 1943. Known for developing the film badge to monitor personal exposure to radiation, Wollan was present at the University of Chicago's Stagg Field on December 2, 1942, when Enrico Fermi's team achieved the first self-sustaining nuclear chain reaction. He recorded the event on an instrument that measured the intensity of the gamma radiation emitted in the reaction.

Wollan came to Oak Ridge as a health physicist, and the Laboratory hoped to use his expertise on film-badge dosimeters. His interest in and experience with X-ray diffraction, however, prompted him to conduct similar experiments using neutrons.

Installing a modified X-ray diffractrometer at a beam hole of the Graphite Reactor in late 1945, he examined the scattering of neutrons from various materials bombarded by a neutron beam from the reactor. Thermal, or slow, neutrons have ideal wavelengths for studying atomic structure and atomic vibrations, and because they have no more energy than a molecule of room-temperature air, they hardly disturb the materials. These and other properties make neutron scattering a valuable scientific tool.

Joined by Clifford Shull in 1946 and later by Wallace Koehler and Mike Wilkinson, Wollan and his associates devised machines and diffraction techniques for determining the atomic structure and magnetic properties of crystal lattices. This work laid the foundation for a number of programs in solid-state physics and materials science at the Laboratory and, later, throughout the world.

associations to sponsor research and perhaps become the contracting operators. The committee initially recommended only two national laboratories, one at Argonne near Chicago and another serving the northeastern states. It expected the eventual formation of a national laboratory in California, but it ignored the Southeast and other regions.

Led by George Peagram and Isidor Rabi of Columbia University, universities in the northeast campaigned to acquire a national laboratory. The Radiation Laboratory at the Massachusetts Institute of Technology had closed at the war's end, and the Substitute Alloy Materials Laboratory at Columbia University had been moved to the K-25 Plant in Oak Ridge. Columbia and other northeastern universities urged the relocation of Clinton Laboratories to the Northeast, and some scientists at Clinton Laboratories liked the idea. More importantly, General Groves was amenable to it, and he selected an old Army post on Long Island as the future site of Brookhaven National Laboratory.

In April 1946, the University of Chicago agreed to operate Argonne National Laboratory, with an association of midwestern universities offering to sponsor the research. Argonne thereby became the first "national" laboratory. It did not, however, remain at its original location in the Argonne forest. In 1947, it moved farther west from the "Windy City" to a new site on Illinois farmland. When Alvin Weinberg visited Argonne's director, Walter Zinn, in 1947, he asked him what kind of reactor was to be built at the new site. When Zinn described a heavy-water reactor operating at one-tenth the power of the Materials Testing Reactor under design at Oak Ridge, Weinberg joked it would be simpler if Zinn took the Oak Ridge design and operated the Materials Testing Reactor at one-tenth capacity. The joke proved unintentionally prophetic.

Clinton Laboratories' rural ambiance did not please Robert Oppenheimer, Isidor Rabi, and

The first Atomic Energy Commissioners. From left: William Waymack, Lewis Strauss, David Lilienthal, Robert Bacher, and Sumner Pike.

Promethium Unbound

A New Element

Jacob Marinsky and Larry E. Glendenin were the first to identify element 61.

During World War II, chemists focused on the actinide series, a group name for elements with atomic numbers between 89 and 104 in the periodic table. Glenn Seaborg, Edwin McMillan, and colleagues at the University of California at Berkeley had discovered the elements 93, neptunium; 94, plutonium; 95, americium; and 96, curium. At Clinton Laboratories in Oak Ridge, chemists investigated these elements and the lanthanide series (elements with atomic numbers between 57 and 71), long known as the rare earth elements.

The existence of one rare earth, element 61, was predicted by the 1930s, but it had never been produced and identified before Charles Coryell's chemistry group at Clinton Laboratories did so in 1944. Larry Glendenin and Jacob Marinsky, using ion-exchange chromatography applied by Waldo Cohn for separating fission products, separated element 61 from other rare earth elements produced by uranium fission in the Graphite Reactor.

Too busy with defense-related chemistry during the war, Glendenin and Marinsky did not claim their discovery until 1946 after Coryell had moved to the Massachusetts Institute of Technology. Having established their claim as the discoverers of element 61, they were accorded the privilege of naming it. After considering "clintonium" in tribute to the Laboratories, they instead chose the name "promethium," suggested by Coryell's wife, in recognition of Prometheus of Greek mythology, who stole fire from heaven for human benefit.

James Conant, all influential members of the AEC's scientific advisory committee. Early in 1947, Oppenheimer declared that "Clinton will not live even if it is built up." Perturbed by this attitude, Charles Thomas of Monsanto demanded changes in Monsanto's operating contract at the Laboratories, in part as a sign that East Tennessee would be included in the federal government's postwar plans. On a no-profit, no-loss basis, the contract's chief attractions for Monsanto were the inside knowledge it provided of nuclear reactor advances and the public relations benefits it accrued for the company as a result of its patriotic efforts to protect the nation's security and advance the nation's technological capabilities.

Such virtues had their limits, especially when the war's outcome was no longer at stake. During negotiations to renew the contract in 1947, Thomas requested that Monsanto be allowed to increase its maximum fee for services from $65,000 a month to $100,000 a month. This request was not warmly received at the AEC; moreover, Thomas's request to build the Materials Testing Reactor near Monsanto's Dayton laboratory or near its corporate headquarters in St. Louis rather than Oak Ridge was also unacceptable. In May 1947, Thomas and Monsanto decided not to seek to renew the contract for operating Clinton Laboratories when it expired in June. The company, however, agreed to serve on a month-to-month basis until the AEC secured another contract operator.

Loss of the contract at Clinton Laboratories did not mar Charles Thomas's career. In early 1948, he signed a contract to operate the new AEC plant at Miamisburg near Dayton, later named Mound Laboratory. That same year, he was elected president of the American Chemical Society, and in 1951 he became president of Monsanto. His director at Clinton Laboratories, James Lum, left for Australia in August 1947 to build an aspirin factory. Thomas made Lum's assistant, Prescott Sandidge, the Laboratories' executive director, pending final contract closure. Colonel Walter Leber, temporary director for the Army, left in the summer of 1947 as well, later becoming Ohio River Division commander for the Corps of Engineers and governor of the Panama Canal Zone.

Warren Johnson, wartime director of the Laboratory's Chemistry Division and later chairman of the University of Chicago's Chemistry Department.

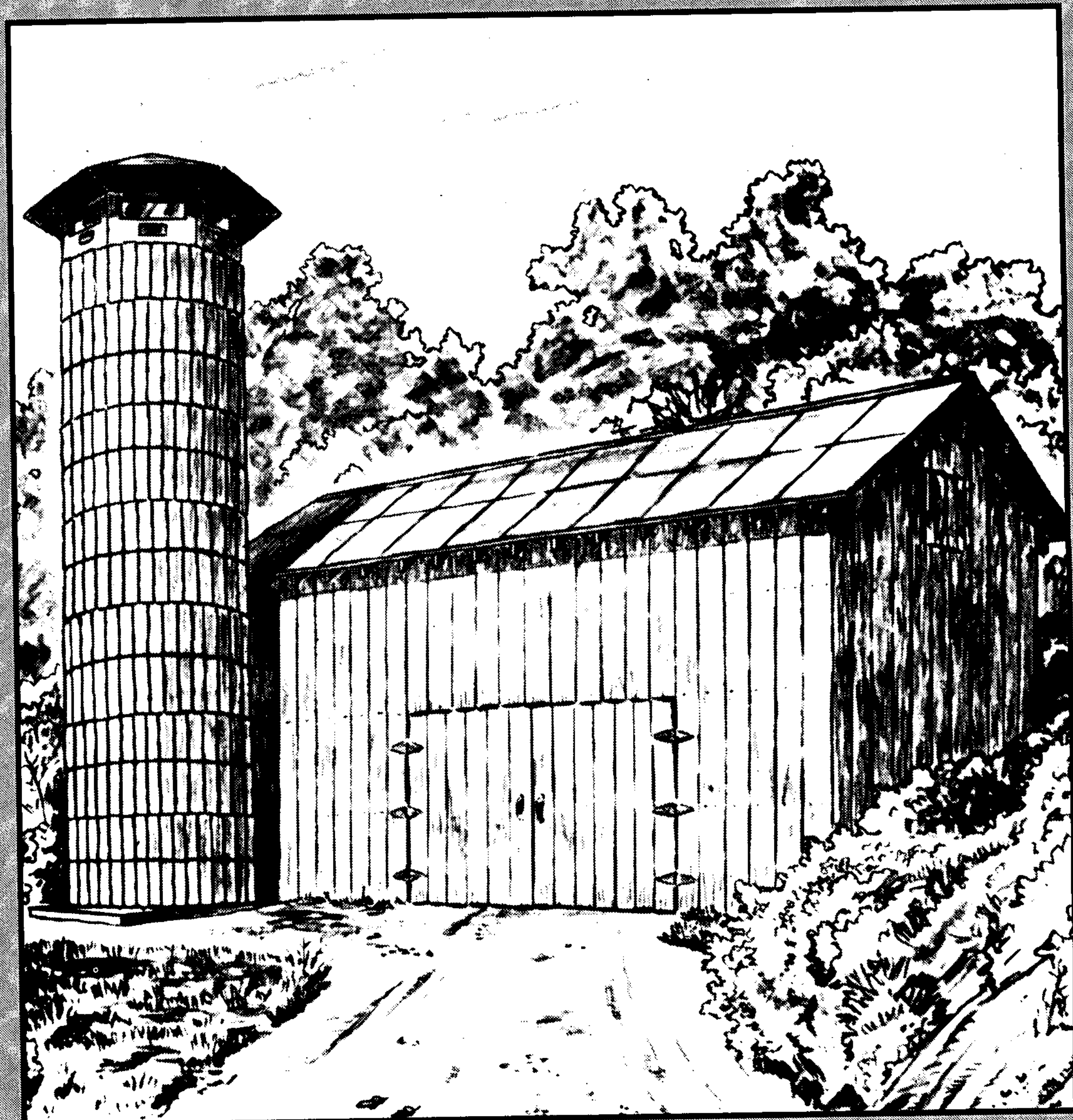
When Wigner returned to "monastic" life at Princeton University, also in the summer of 1947, Clinton Laboratories was left without a research director. Thomas decided to leave selection of Wigner's successor to the new contract operator. He asked Edgar Murphy, Wigner's assistant, to coordinate research pending selection of a new contractor and director.

Of his work at the Laboratory in 1946 and 1947, Wigner later lamented: "Oak Ridge at that time was so terribly bureaucratized that I am sorry to say I could not stand it. The person who took over was Alvin Weinberg, and he slowly, slowly improved things. I would not have had the patience."

"The person who took over was Alvin Weinberg, and he slowly, slowly improved things. I would not have had the patience."

—Eugene Wigner

From Installation Dog to Katy's Kitchen



An artist's sketch of the barnlike structure originally built in 1948 to temporarily store enriched uranium processed at the Y-12 Plant. The facility was later called Katy's Kitchen.

In the fall of 1947, Luther Agee, a draftsman at the new Oak Ridge office of the Atomic Energy Commission, was asked to work on a special project. He was told to design a secret facility according to specifications but was not told the purpose of the facility. He was instructed to say nothing about the project. After its completion, Agee and the other personnel involved in the facility's design, construction, or maintenance had to undergo periodic polygraph tests to determine how much they knew and if they had discussed this project with anyone.

Agee's design included a concrete building that was partially underground, a barn-type structure, and a farm silo. The idea was to camouflage the facility so that it could not be distinguished from other old farm buildings in the area.

The barn covered the outside entrance to the building, which was actually built into the side of a hill. A plain wooden structure with large swinging doors, the barn was designed to fit on the hill and was draped over the building's entrance. From the ground it looked unusual, but from the air it resembled an ordinary barn with a silo.

The building's outer walls were made of thick reinforced concrete, and it contained a long room designed so a truck could be driven into it, a pump room, and a "room within a room." This inner room was of standard bank-vault construction. A barbed wire fence and an elaborate alarm system surrounded the structure. Alarm panels and controls were located in the Y-12 area, and responses were sent out from there. Even intruding animals like foxes could set off the alarms.

For a year, Installation Dog, as this facility located near ORNL was called, served as a temporary storage facility for enriched uranium after it was produced at the Y-12 Plant. The uranium was taken to and from the

"For a year, Installation Dog served as a temporary storage facility for enriched uranium after it was produced at the Y-12 Plant."

facility by truck. No one was allowed into the area unless authorized, and no one actually worked in the building, except to unload and load the trucks. Two security guards patrolled the facility at all times.

Although Installation Dog was used only from May 1948 to May 1949, it was kept under guard for several years in case the need for it arose again. After 1949, enriched uranium was never stored there again; instead, it was shipped to a weapons assembly site in the West.

In 1957, ORNL's Analytical Chemistry Division acquired the facility from the AEC to use as a low-level counting laboratory. Its isolated location and shielded walls made it ideal for such work.

"The facility came to be known as Katy's Kitchen when Katherine Odom, the secretary for Myron Kelley of the Analytical Chemistry Division, visited the facility several times. She often had lunch there, so Katy's Kitchen seemed an appropriate name."

The facility came to be known as Katy's Kitchen when Katherine Odom, the secretary for Myron Kelley of the Analytical Chemistry Division, visited the facility several times. She often had lunch there, so Katy's Kitchen seemed an appropriate name.

In the 1970s, Katy's Kitchen was used as a laboratory for the Walker Branch Watershed studies by the Environmental Sciences Division. And more recently a steel structure has been built in front of the vault to be used by the Department of Energy's Atmospheric Radiation Monitoring Program to study changes in cosmic rays and solar radiation that may occur as a result of increased greenhouse gas concentrations.

The vault is used to store animal skins, plant tissues, and aquatic insects for use by researchers at ORNL's National Environmental Research Park. Ironically, the vault that once stored bomb-grade uranium now stores samples of dead organisms, some of which have been contaminated by low levels of uranium fission products. What goes around comes around.

"Oak Ridge clearly qualified for national laboratory rank, becoming one of three original national laboratories."

Black Christmas

Because the Argonne and Brookhaven laboratories would be operated by associations of universities, William Pollard and the Oak Ridge Institute of Nuclear Studies considered assuming Monsanto's contract. The AEC, however, preferred that the University of Chicago resume its operation of Clinton Laboratories, and it announced in September 1947 that a contract would be negotiated with Chicago. The university thereby would become contract operator of both the Argonne National Laboratory and Clinton Laboratories, which was renamed Clinton National Laboratory in late 1947 while negotiations with Chicago were under way.

The AEC was willing to enter a four-year contract with the university. Negotiations floundered, however, over the division of responsibilities between the university and the AEC for personnel policies, salaries, auditing, and oversight. Moreover, the university decided to recruit a new director and management team for the Laboratory, despite pleas for the return of Wigner. William Harrell, the university business manager, paraded prominent scientists to the Laboratory for orientation; but when offered the director's position, all demurred. Near the end of 1947, Warren Johnson, wartime chief of the Laboratory's Chemistry Division, agreed to serve as the interim director.

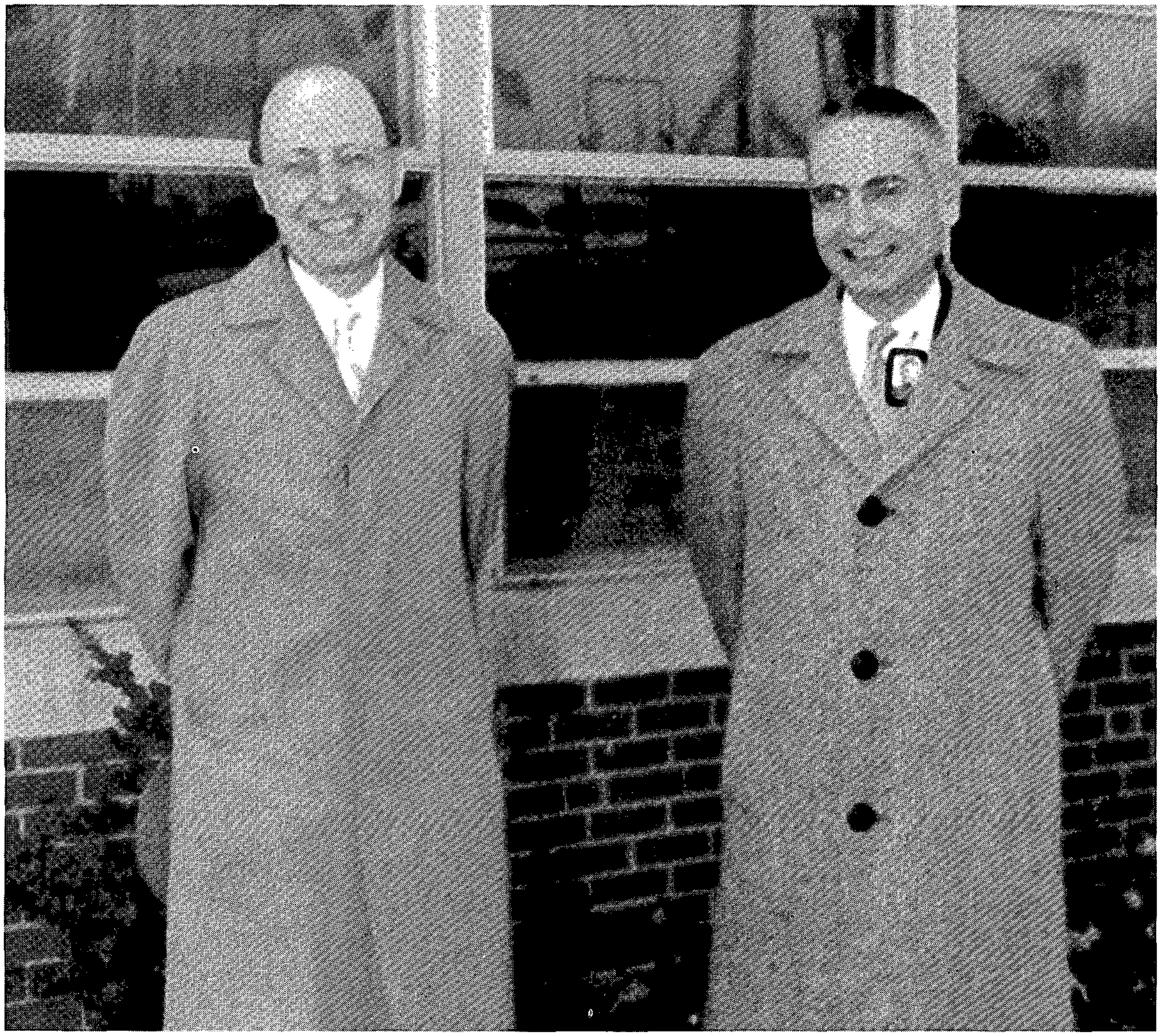
Concerned that the AEC's research program might become too academic, Lilienthal established a committee of industrial advisers, and during a November visit to Oak Ridge, he discussed with Clark Center, manager of Carbide & Carbon, a subsidiary of Union Carbide Corporation at Oak Ridge, the possibility of the company assuming management of the Laboratory. Union Carbide managed the nearby Y-12 and K-25 plants, and it already had a staff and offices in Oak Ridge that could easily add the Laboratory to their responsibilities. In addition, Union Carbide wanted to simplify its labor union relations. Workers at K-25 had joined the Congress of Industrial Organizations union, and craftsmen at the Laboratory had joined the American Federation of Labor union. A December 1947 strike over wages and benefits at K-25, which were lower there than at the Laboratory, threatened the company's tranquility and productivity. By assuming the Laboratory's management, Union Carbide possibly could abate labor tension.

With Lilienthal ill and bedridden and other AEC commissioners on holiday excursions, Carroll Wilson, the AEC's general manager, made the decision on Christmas Eve in 1947 to replace the University of Chicago with Union Carbide. At the same time, he decided to centralize all reactor development at Chicago's Argonne National Laboratory, transferring responsibility for Oak Ridge's high-flux Materials Testing Reactor there.

The day after Christmas, the AEC concurred with these decisions. Wilson went to St. Louis to persuade Monsanto to hang on at Oak Ridge an additional two months until Union Carbide could become sufficiently organized for the task. The job of carrying the message to Oak Ridge fell to James Fisk, director of research, and he received the welcome one would expect for a bearer of ill tidings.

Remembered in the Laboratory long afterward as "Black Christmas," the shock came during the round of holiday parties. Reaction to the surprise was caustic. "Deck the Pile with Garlands Dreary," followed by several bawdy verses, reverberated through the halls. "It was rapid-fire and rough," admitted Lilienthal. He went on to say, "The people at Clinton Lab engaged in fundamental research felt they had been double-crossed, for we proposed to have Carbide & Carbon operate the lab (what was left of it, that is, minus the high-flux reactor), and this caused great anguish, not only among the chronic complainers but quite generally."

Laboratory staff declared the decisions represented a demotion from national laboratory status to a radioisotopes and chemical-processing factory. Leaders of the Oak Ridge Institute for Nuclear Studies fired messages to President Truman and the AEC protesting the decisions as a blow to Southern scientific aspirations. This thinking ignored the AEC's promise to continue fundamental research at Clinton Laboratories, specifically in physics, chemistry, biology, health physics, and metallurgy. Rather than reducing the facility's status, in January 1948 the AEC changed its official name to Oak Ridge National Laboratory,



Eugene Wigner and Alvin Weinberg served successively as Laboratory research directors. Over the years, they became close friends and coauthored several publications.

ending the use of Clinton, which had been the nearest town during project construction.

The first impact of the decisions on the Laboratory was the transfer of the Power Pile Division, formed to study the Daniels pebble-bed reactor, to Argonne National Laboratory. Before leaving Oak Ridge, the division had begun studying Rickover's naval reactor. Harold Etherington, Samuel Untermyer, and others in the group subsequently gained recognition for their designs of reactor prototypes for the atomic-powered *Nautilus* submarine and an early breeder reactor.

The AEC never released a precise definition of "national laboratory." It granted the title, however, only to laboratories that engaged in broad programs of fundamental scientific research, had facilities open to scientists outside the laboratories, and cooperated with regional universities in extensive science education efforts.

Oak Ridge clearly qualified for national laboratory rank, becoming one of three original national laboratories. Argonne and Brookhaven laboratories were built in 1948 on new sites, making Oak Ridge the oldest national laboratory on its original site.

As these postwar manueverings suggest, Oak Ridge, located in the Appalachian Mountains far from the bright lights of any metropolis, has had to prove from its earliest days that its location was appropriate for its purpose. Surviving in an environment of political and administrative intrigue has required institutional perseverance and ingenuity—qualities that would serve the Laboratory's science and management well in the years ahead.

Chapter 3

Accelerating Projects

"Discovering how radiation does what it does to inorganic, organic, and living matter will benefit the entire world," declared biochemist Waldo Cohn as he speculated about the Laboratory's postwar research agenda.

The dilemma facing the Laboratory in the years following World War II was how to obtain the means to pursue such research. After all, the Laboratory's brief history had been devoted largely to supporting development of the atomic bomb. Although scientists had touted peaceful applications of the atom, there were no assurances that the government would be willing—or able—to shift its administrative gears and resources to support such research.

One answer to the Laboratory's postwar research dilemma came from an unexpected source: investigations into nuclear-powered aircraft sponsored by the AEC and partially funded by the U.S. Air Force. The plane never got off the ground, but the research directed toward this effort lifted to new heights scientific knowledge in biology, chemistry, and physics and, at the same time, led to new advances in technologies related to reactors, computers, and accelerators.

In the long run, spin-offs from research into atomic travel—in funding for biology, medicine, genetics, and computer science—would prove more useful than the primary research goal itself.

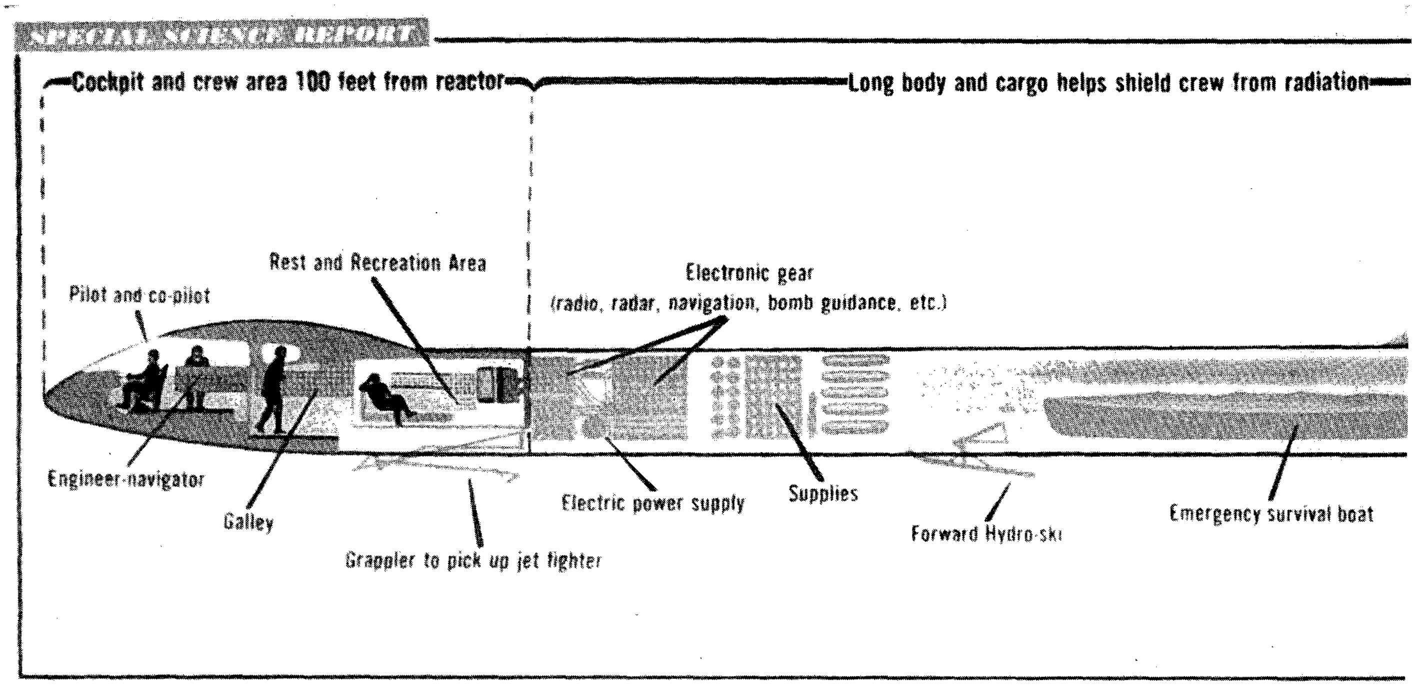


Diagram of a proposed nuclear aircraft, published in *Newsweek* in the 1950s.

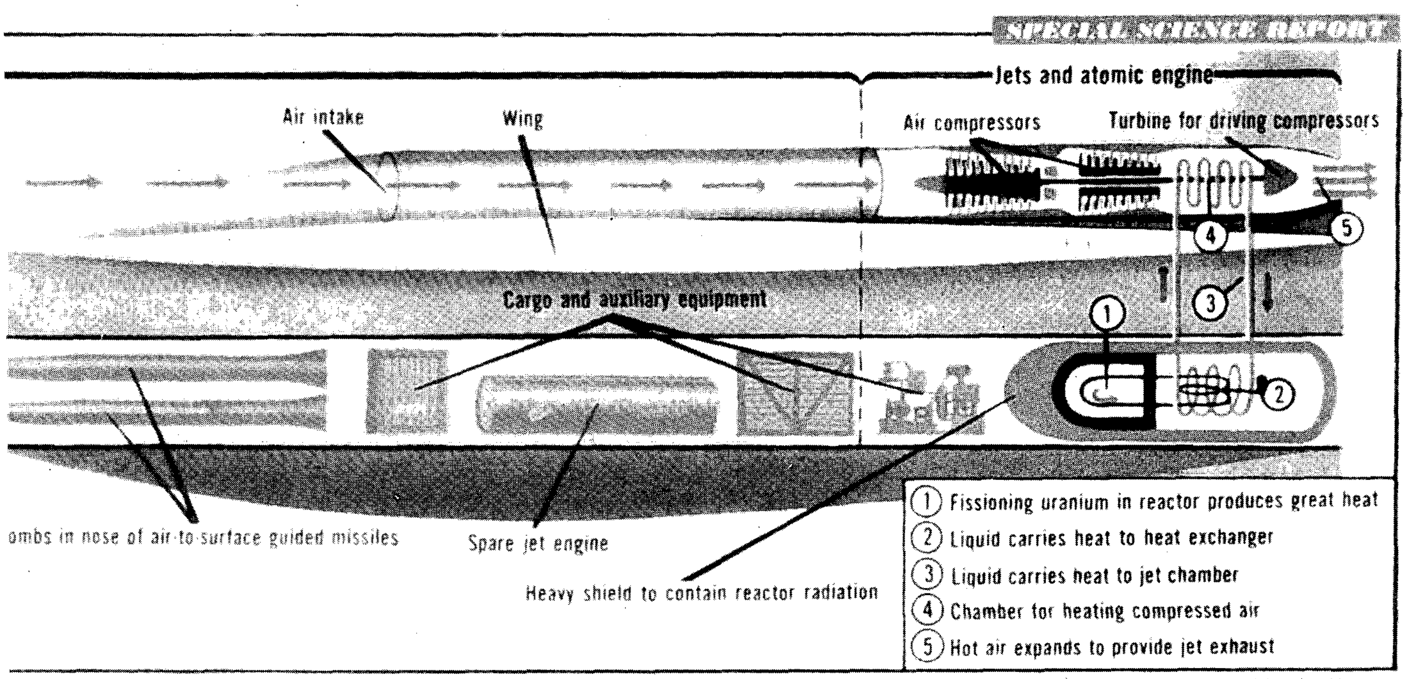
Flights of Fancy

Fantasies about future applications of atomic power abounded just after World War II. Popular writing and art, which depicted atomic-powered ships, submarines, aircraft, trains, automobiles, and even farm tractors, stimulated public interest. These popular images came into sharp focus at Oak Ridge, where the Laboratory participated in development of nuclear-powered submarines, aircraft, and ships during the late 1940s and 1950s.

The application of atomic power to motion and travel became a centerpiece of the Laboratory's research program in the postwar era, and efforts to devise nuclear-powered transport, especially aircraft and submarines, involved many Laboratory researchers. This research, in turn, contributed to the design of three nuclear reactors, the adoption of high-speed digital computers, and the acquisition of particle accelerators for nuclear physics. Moreover, the efforts fueled the Laboratory's budget and staffing, both of which increased during the late 1940s and early 1950s under the management of its new contract operator, Union Carbide Corporation.

In February 1950, the Laboratory merged with the research divisions at the Y-12 Plant—a move that strengthened and diversified the Laboratory's research efforts. One direct result of this merger was a set of projects designed to build reactor-driven machines that could travel over land, work underwater, and perhaps even fly. In the process, the Laboratory hoped to turn the public's postwar atomic dreams into concrete demonstrations of atomic energy's potential contributions to society.

Acquiring the Y-12 Plant's research divisions increased Laboratory staff by 50% and, by 1953, more than 3600 people were employed at the newly merged facilities. Moreover, the merger enabled the Laboratory to acquire divisions with strong



"Union Carbide soon proved its mettle both to the AEC and Laboratory personnel."

capabilities in applied science and heavy industrial technology. The Laboratory also benefited from the transfer of state-of-the-art hardware, such as cyclotrons that could accelerate subatomic particles to unprecedented speeds.

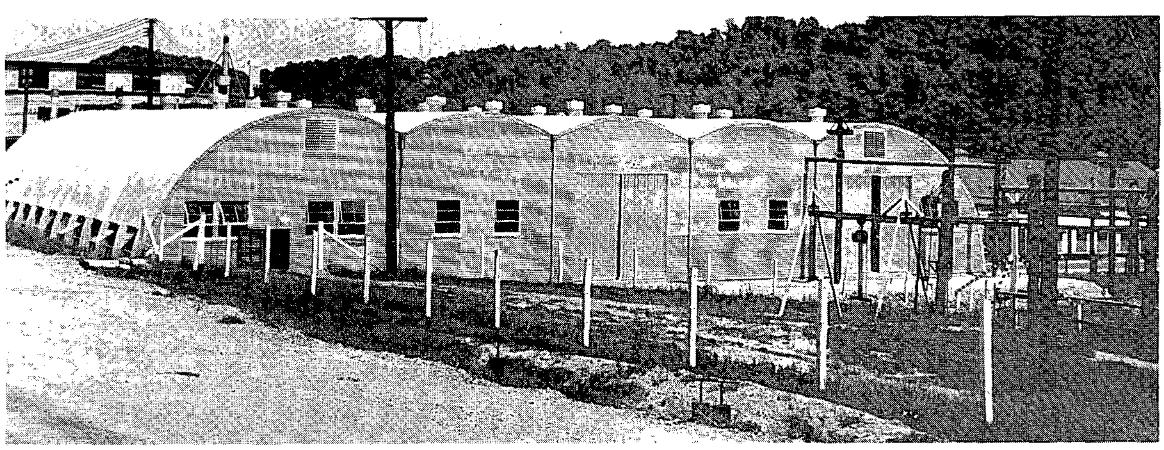
Accelerated Administration

Added responsibilities, personnel, and equipment created new challenges in Laboratory management and administration. In late 1947, Union Carbide Corporation's Carbide & Carbon Chemical Company, later renamed the Union Carbide Corporation Nuclear Division, became the Laboratory's operations contractor. It enjoyed two advantages that would serve both the company and the Laboratory well.

First, the company's expertise in chemical engineering fit the tasks it would be asked to accomplish. Second, Union Carbide was no stranger to Oak Ridge. Since 1943, it had managed a large staff that operated the K-25 Plant. In 1947, the government extended Union Carbide's responsibilities to the Y-12 Plant's production facilities. Thus, when the AEC called on Union Carbide to oversee Laboratory research activities in December 1947, it placed all Oak Ridge operations under unified management.

Union Carbide soon proved its mettle both to the AEC and Laboratory personnel. Under the arrangement, Carbide executives—both at the corporation's international headquarters in New York City and at its regional headquarters in Oak Ridge—set Laboratory work rules and pay scales. Virtually the entire Laboratory staff went on Union Carbide's payroll. For its services, Union Carbide received a fixed fee from the AEC that amounted to less than 2% of the Laboratory's annual budget.

Nelson Rucker (right), executive director of the Laboratory from 1948 to 1950, accepts a safety award.



In the late 1940s the Laboratory built only temporary structures, such as these quonset huts.

Director Alvin Weinberg

Mr. ORNL

Alvin Weinberg's special gift is his ability to communicate, even to inspire. The son of Russian emigrants who was trained in mathematical biophysics at the University of Chicago, Weinberg, as much or more than any other scientist of his generation, communicated the meaning and intent of "Big Science," a phrase that became commonplace among both scientists and policymakers.

A member of the wartime team of theoretical physicists at Chicago headed by Eugene Wigner, Weinberg moved to Oak Ridge in 1945 and served as director of the Physics Division before becoming Laboratory research director in 1948 and Laboratory director in 1955. As a scientist, he coauthored the standard text on nuclear chain reaction theory with Wigner. Weinberg also proposed the development of pressurized-water reactors, which became the standard for naval propulsion and for most commercial power generation. A vigorous proponent of nuclear energy, he first proposed the formation of the American Nuclear Society.

In 1961 he chaired President John F. Kennedy's Panel of Science Information, which produced a landmark report issued by the White House. The report was entitled *Science, Government, and Information*, but it has often been referred to as "The Weinberg Report." Through this effort Weinberg fostered the communication of science to technical and lay audiences.

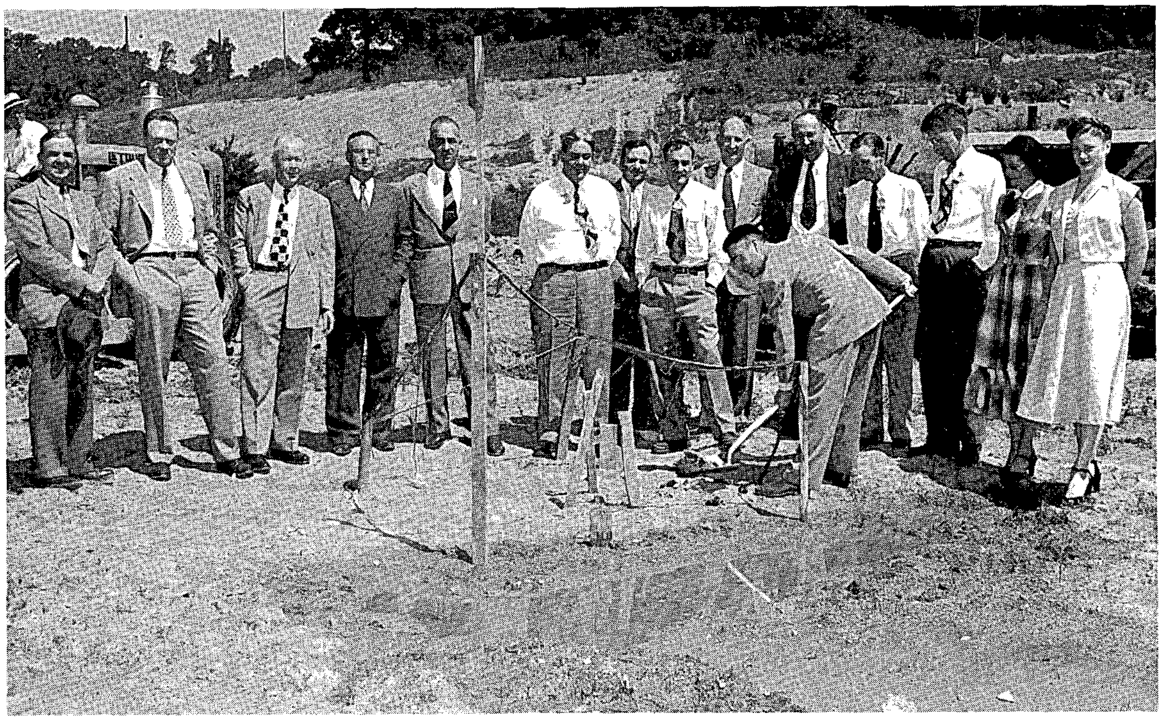
His many publications, including the book *Reflections on Big Science*, vividly articulated the issues associated with nuclear energy and more broadly the relationships between technology and society. Speaking eloquently on behalf of the national laboratories and science, he coined phrases, such as "big science," "technological fix," "nuclear priesthood," and "Faustian bargain," which became embedded in the English language.

After leaving the Laboratory, Weinberg continued to influence public scientific policy as director of the Office of Energy Research and Development in President Richard Nixon's White House and as director of the Institute for Energy Analysis. His interests included "the second era" of nuclear energy, national defense, and the greenhouse effect. In retirement, he has applied his communication skills to editing the papers of Eugene Wigner and to preparing his own memoirs. When asked where he obtained his great skill and enormous drive to communicate, he attributed it not to formal English classes but to working as editor of his high school newspaper.

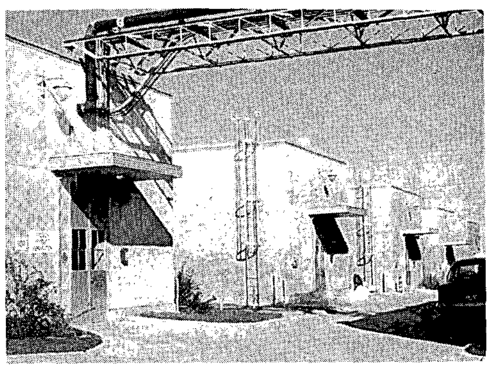
Although literally thousands of people have contributed significantly to the success and prominence of the Laboratory, Weinberg above all others guided the institution in directions later to be recognized as vital to society. He was one of the first to see and communicate the importance of exploring other research areas besides nuclear science and technology at national laboratories. Early biological studies at ORNL to quantify the effects of radiation on human genetics contributed to the acceptability of nuclear power. The introduction of environmental studies using radioactive tracers to understand the impacts of various energy systems on their surroundings became a major feature of ORNL research in the 1960s. Energy conservation studies begun at ORNL in the early 1970s were roundly criticized by industry. Through all of this, Weinberg instilled in Laboratory staff a desire to achieve high excellence as he asked friendly, but penetrating, questions in all areas of research and development.

"Alvin Weinberg has been a highly effective communicator as well as scientist and administrator."

As indicated by his publications and speeches, Weinberg maintained broad interests in issues of national and global importance. In decade after decade, Weinberg's hand can be seen shaping the programs of ORNL. Throughout his tenure as director, it can be properly said that Alvin Weinberg and Oak Ridge National Laboratory were one.



Alvin Weinberg and staff break ground in 1950 for Building 4500-North.



The Laboratory's Isotopes Alley.

Union Carbide appointed Nelson Rucker as the Laboratory's director until a permanent director could be found. A graduate of Virginia Military Institute, Rucker joined Union Carbide in 1933 to manage a Carbide plant in West Virginia. He moved to Oak Ridge with Carbide in the early 1940s and remained there throughout the war. At the time of his appointment to the position of Laboratory executive director, he was serving as the Y-12 Plant's manager.

Rucker was responsible for overseeing the Laboratory's daily activities. Playing a role comparable to that of a city manager, he saw that the institution functioned efficiently on a day-to-day basis, but he did not set its technical agenda. Union Carbide had as much difficulty filling the position of director in the late 1940s as the University of Chicago had had a few years earlier. Several prominent scientists, including John Dunning, rejected the position. In December 1948, Carbide asked Alvin Weinberg to become director. He also declined, citing his youth and lack of experience, but agreed to become the associate director for research and development.

A biophysicist, Alvin Weinberg had studied the fission of living cells at the University of Chicago during the late 1930s. In 1941, he joined the Metallurgical Project to investigate nuclear fission. As an assistant to Eugene Wigner, he participated in wartime reactor designs. In May 1945, on Wigner's advice, he moved to Oak Ridge to join the Laboratory's Physics Division, where he succeeded Lothar Nordheim as division chief in 1947. Weinberg, whose ability to communicate his thoughts in writing was exceeded only by his rare scientific talent, captured both the spirit of excitement and that of confusion that existed at the Laboratory during the late 1940s when he wrote Wigner about his responsibilities as head of the Physics Division. "I feel in my new job a little bit like a trick horseback rider at a circus," Weinberg told Wigner. "The idea seems to be to ride standing on three or four spirited horses, all of which are interested in going in different directions."

Limited work space constituted a major challenge facing Rucker, Weinberg, and other Laboratory managers in the late 1940s. During the postwar turmoil, the AEC suspended new construction and often deferred maintenance on existing structures, pending the government's decision on the Laboratory's future. This wait-and-see attitude, which made sense given the uncertainties in Washington, continued while wartime frame structures swiftly deteriorated. The only new facilities erected at the Laboratory between 1946 and 1948 were surplus Army quonset huts to relieve overcrowding, plus an electric substation and steam power plant constructed in futile anticipation that the proposed Materials Testing Reactor would be built in Oak Ridge.

Overcrowding became serious in 1948 as the Laboratory added new divisions, hired more personnel, and installed new equipment. These events led physicist Gale Young to complain, "In accumulating technical people which it cannot use for lack of accommodations, I believe that the Laboratory has embarked on a course which is suicidal to itself and detrimental to the national interest. Until considerably more buildings have been erected, staff reductions, rather than increases, are in order."

In 1949, with the Laboratory's future on a firmer, more stable footing, the AEC budgeted $20 million for new construction, and Union Carbide initiated its "Program H" to replace wooden wartime structures with more permanent brick and mortar. In addition to paving of streets, landscaping of grounds, and renovation of older structures, about 250,000 ft^2 of new office and laboratory space opened in the early 1950s. Among the new facilities, three were of particular importance: Building 4500, the Laboratory's principal research building and administrative headquarters; a radioisotope complex consisting of 10 buildings designed to process, package, and ship the Laboratory's most valuable material exports; and a pilot plant for use in chemical processing. With this new construction, the AEC and Union Carbide gradually hoisted the Laboratory out of the East Tennessee mud.

Accelerated Development

The AEC's 1947 decision to centralize reactor development at Argonne National Laboratory proved ill-considered. Argonne's mandate from the AEC to support Navy reactor development and new programs for civilian power and breeder reactors strained its resources and capabilities. As a result, it supported Oak Ridge's efforts to continue design and fabrication work in East Tennessee to free its staff to concentrate on its own full plate of responsibilities in Chicago.

Taking advantage of this unexpected turn of events, in 1948 Oak Ridge urged the AEC to build the Materials Testing Reactor on the Cumberland Plateau, 20 miles from Oak Ridge. The AEC,

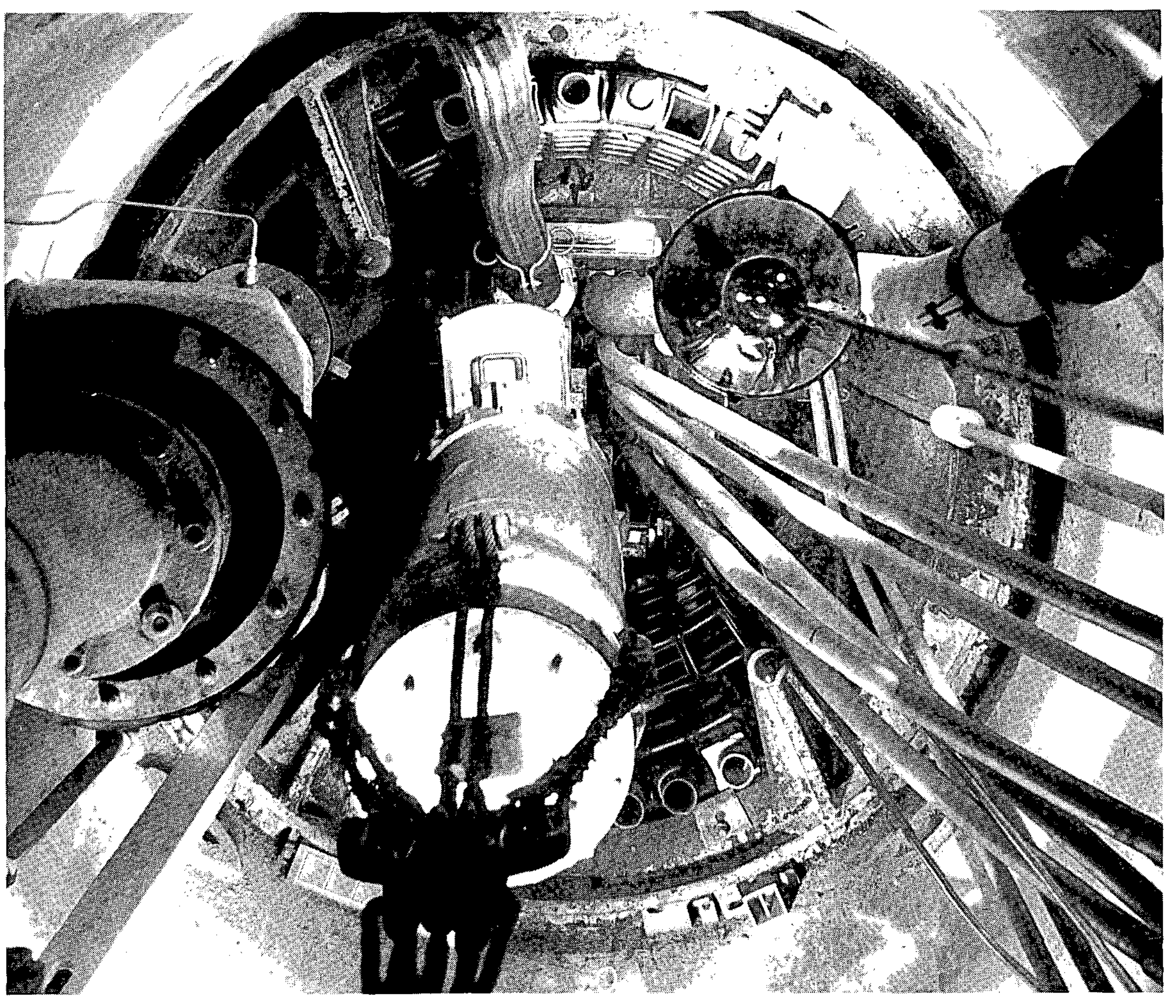
Control panel for the Low Intensity Test Reactor, built initially as a mock-up of the Materials Testing Reactor, which was designed in Oak Ridge and built in Idaho.

"Overcrowding became serious in 1948 as the Laboratory added new divisions, hired more personnel, and installed new equipment."

"The Laboratory had the world's first solid-fuel and light-water reactor operating in Oak Ridge."

however, acquired a site in Idaho and, four years later, the newly built Materials Testing Reactor at the Idaho National Engineering Laboratory began successful operation under the supervision of Richard Doan, formerly the research director at Oak Ridge. Two years before the reactor in Idaho began operation, however, the Laboratory had the world's first solid-fuel and light-water reactor operating in Oak Ridge. Despite the government's intentions to end reactor work at the Laboratory, the facility's deeply rooted efforts in development of this technology refused to wither.

While designing the Materials Testing Reactor in 1948, the Laboratory built a small mock-up of the reactor to investigate the design of its controls and hydraulic systems. In 1949, Weinberg proposed installing uranium fuel plates inside the mock-up to test the reactor design under critical conditions. The AEC staff feared that Weinberg's initiative might become an opening wedge for a revived reactor program at Oak Ridge. "We have no plans," Weinberg reassured them, "to convert the critical experiment into a reactor." In February 1950, the mock-up experiment at Oak Ridge produced the first visible blue Cerenkov glow of a



The core of the Low Intensity Test Reactor.

Democratic Responsibility

"Just as the problem of individual responsibility looms as the central problem in the carrying on of our way of life, so does the same problem exist in the successful working of such an institution as the Oak Ridge National Laboratory. When one considers that the Laboratory is a bewildering and remarkable combination of private industry, government, labor, and education institutions. . .ORNL is in a small way a surprisingly apt replica of our country. . .things which seem important in the operation of the Laboratory ought to be important in the operation of our country.

"And finally the ultimate responsibility—the responsibility to get the job done well, and cheaply, and relevantly—this rests squarely with the individual scientist and technician and craftsman."

"An institution such as ORNL, with its technical staff of 1200, is already much too large to allow the central management to follow in close detail the individual scientist's or engineer's daily doings. Thus there is established necessarily a hierarchy of responsibility in which management on each level depends on the integrity and sense of responsibility of the next level to do the job sensibly and well.

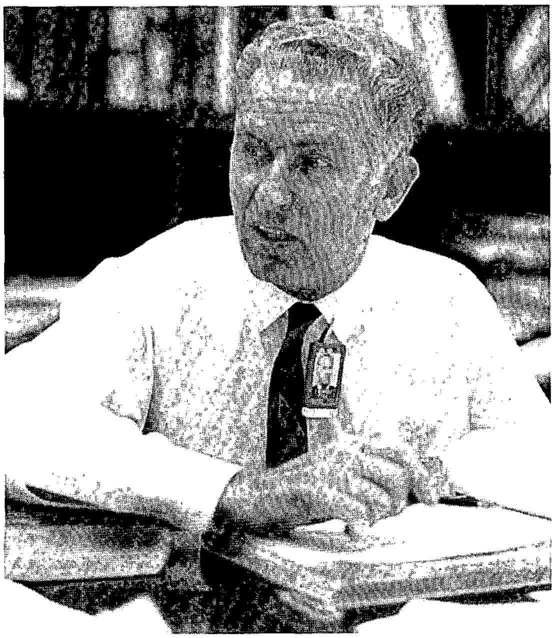
"At the top is the Atomic Energy Commission which, although ultimately responsible for the operation of its laboratory, must rely on the integrity and sense of responsibility of the Laboratory management to spend its money wisely and not to ask for more money than it needs. The central laboratory management must depend on the division directors to carry out their jobs responsibly, to do what ought to be done, to keep within their budgets, to insist on excellence in work. The division directors must depend on section chiefs, they on group leaders. And finally the ultimate responsibility—the responsibility to get the job done well, and cheaply, and relevantly—this rests squarely with the individual scientist and technician and craftsman.

"In an organization as large as ours, there are always conflicts of interest between groups, between divisions, between division and laboratory, or on an even larger scale, between one AEC laboratory and another. Sometimes Laboratory management must persuade division directors that the interest of the individual must be subjected to the interest of the group. In all cases it is an appeal to the sense of responsibility which tempers loyalty to one's group, or division, or laboratory, with concern about the well-being of the higher organizational entity. . .this concern for more than oneself, we have seen at the Oak Ridge National Laboratory, pays off over and over again not only in terms of more rapid advancement, higher pay, etc., but also in increased respect with which the most mature segments of the scientific community hold the individuals who have such a sense most keenly developed.

"Nor is the struggle one which will, in final analysis, be determined by nuclear weapons. In the long run it will be won by the side which provides a way of life that offers the most to its people."

"The lesson in social responsibility which we learn in the operation of our Laboratory, I think, has the greatest sort of relevance for our country as a whole and for our way of life. These are times when the essential strength of democratic capitalism as opposed to authoritarian communism is being put to test. Nor is the struggle one which will, in final analysis, be determined by nuclear weapons. In the long run it will be won by the side which provides a way of life that offers the most to its people."

Alvin Weinberg
1960



Francois Kertesz, an electrochemist from the Sorbonne, became the Laboratory's linguist and translator.

nuclear reaction underwater, and it provided superb training for those who were to serve subsequently as operators for the full-scale reactor in Idaho.

As its reactor program burgeoned, the AEC relaxed its previous plans to centralize reactor development and construction at Argonne National Laboratory and Idaho National Engineering Laboratory. In fact, the AEC allowed the Laboratory to upgrade the mock-up's shielding and cooling systems. These improvements raised the system's capacity to 3000 thermal kilowatts, only one-tenth of the Materials Testing Reactor's maximum power but still useful for experiments.

Labeled the "poor man's pile" by Wigner, the mock-up formally became the Low Intensity Test Reactor (LITR). Experiments conducted at the LITR established the feasibility of the boiling-water reactor, which later became one of the design prototypes for commercial nuclear power plants. Operated remotely from the Graphite Reactor control room, the "poor man's pile" served the Laboratory until 1968 when the AEC shut it down after a long, useful life.

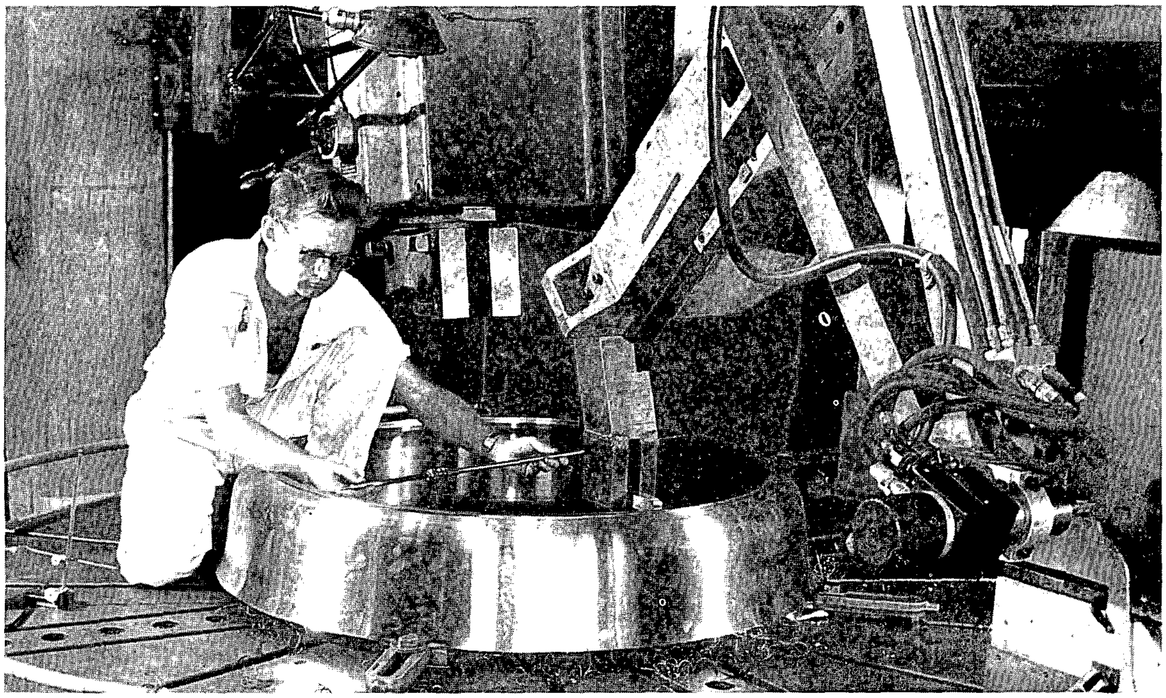
"Experiments conducted at the LITR established the feasibility of the boiling-water reactor."

Flying Reactors

With funds drawn largely from the U.S. Air Force, the Laboratory's major entrance into reactor development during the 1950s came through efforts to design a nuclear airplane. British and German development of jet engines at the end of World War II had given quick, defensive fighters an advantage over slower long-range offensive bombers. To address the imbalance, General Curtis LeMay and Colonel Donald Keirn, both of the Air Force, urged development of nuclear-powered bombers. In 1946, they persuaded General Groves to approve Air Force use of the vacated S-50 plant near the K-25 Plant in Oak Ridge to investigate whether nuclear energy could propel aircraft.

The initial concept called for a nuclear-propelled bomber that could fly at least 12,000 miles at 450 miles per hour without refueling. Such range and speed would enable nuclear weapons to be delivered via airborne bombers anywhere in the world. The aircraft, however, would require a compact reactor small enough to fit inside a bomber and powerful enough to lift the airplane into the air, complete with lightweight shielding to protect the crew from radiation.

Under Air Force contract, the Fairchild Engine and Airplane Corporation then established a task force at the S-50 plant to examine the feasibility of nuclear aircraft and arranged with Wigner to receive scientific support from the Laboratory. Initial studies conducted by the Fairchild Corporation at the S-50 plant showed promise and, in 1948, the AEC asked the Massachusetts Institute of Technology (MIT) to evaluate the feasibility of nuclear-powered flight. MIT sent scientists to Lexington, Massachusetts, for a summer's appraisal, and they reported that such flight could be achieved within 15 years if sufficient resources were applied to the effort. In September 1949, the AEC approved Laboratory participation in an aircraft nuclear propulsion project. Weinberg was made project director and Cecil Ellis coordinator. Raymond Briant, Sylvan Cromer, and Walter Jordan later served as directors of the Laboratory's Aircraft Nuclear Propulsion (ANP) project.



"The Laboratory's initial aircraft work focused on the development of light-weight shielding."

Machinist works on the Aircraft Reactor Experiment.

Soon after the Laboratory acquired its nuclear propulsion project, General Electric took over the work of Fairchild and relocated it from Oak Ridge to its plant in Ohio. Although some Fairchild personnel transferred to Ohio, about 180 remained in Oak Ridge to join the Laboratory's aircraft project in May 1951. Among those who decided to stay in East Tennessee were Francois Kertesz, a multilingual scientist; Edward Bettis, a computer wizard before the age of computers; William Ergen, a reactor physicist; Fred Maienschein, later the director of the Laboratory's Engineering Physics and Mathematics Division; and Don Cowen of the Laboratory's Information and Reports Division.

Much of the Laboratory's initial aircraft work focused on development of lightweight shielding to protect airplane crews and aircraft rubber, plastic, and petroleum components from radiation. Knowing a nuclear aircraft would never become airborne carrying the thick walls typical of reactor shields, Everitt Blizard and his team worked two shifts daily, testing potential lightweight shielding materials in the lid tank atop the Graphite Reactor. As research progressed, however, the Graphite Reactor proved inadequate to meet the level of research activity. To continue its shielding investigations, the Laboratory added two unique nuclear reactors to its fleet.

Col. Clyde Gasser, USAF, at the controls of the Aircraft Reactor Experiment. Sylvan Cromer, Ed Bettis, and Larry Meem look on.

Small Science in a Big Laboratory

"Where are they? Where's George? Where's Mary Jane? That's a nice picture of Charles, but where's Milton?" Do you have questions like these? Don't feel bad, you're not alone. There's too little space and too many memories. This brief history has to cover a lot of years, a lot of people, a lot of accomplishments. And many of the readers won't have your background.

The story has to have continuity to give them a chance to understand what the Laboratory—what we—were all about. It must concentrate on the big projects, the big science, the big bucks that built the reactors, the pilot plants, Building 4500-North. You'll find some smaller things in here. A neat physics experiment by a couple of people. A new chemical element. Stuff like that. For someone from outside—not you, Jim—for someone who thinks that the Laboratory was mainly involved with bombs and reactors and airplanes and a million mice—maybe there ought to be some explanation about how the little stuff fits into the big picture. And about how much of it there was.

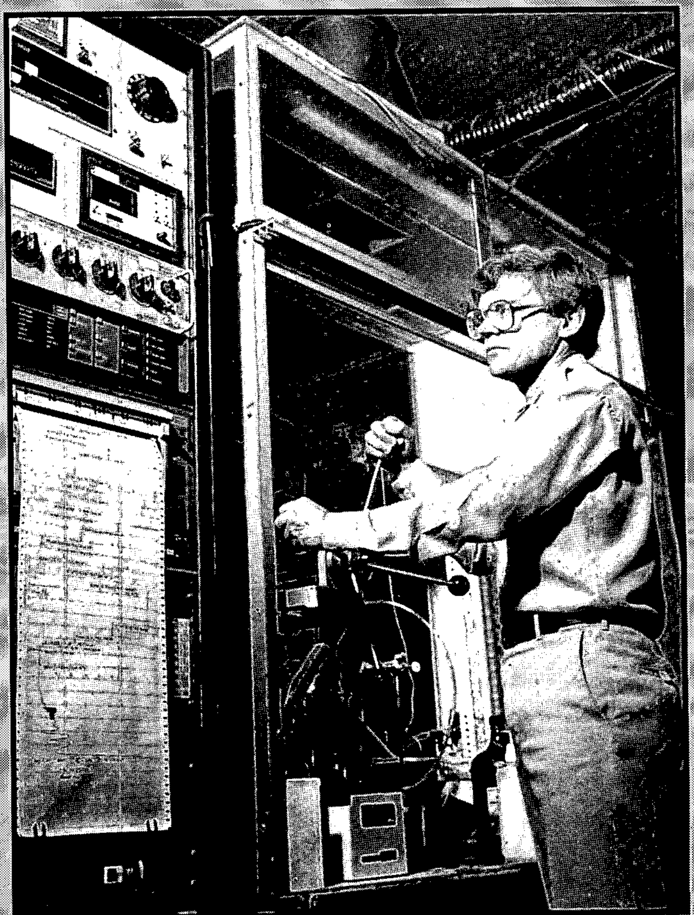
It was all Big Science in the beginning. The Project. Get the pile up, get out some plutonium. No time for anything that wasn't needed for Hanford or Los Alamos. But, so much of what came up was new and interesting. New radioisotopes. New problems in chemical separation. Neutrons in unheard of numbers. Almost every practical problem, solved or unsolved, revealed new physics or chemistry or biology that ought to be studied as science, but had to be left waiting until Hanford and Los Alamos and everybody else had what they needed.

All these opportunities didn't go unnoticed. People talked about them at lunch, stored them away in their minds, wrote little paragraphs about them in research notebooks, even got out memos-to-file or secret reports on this or that item that ought to be looked at after the War. If they were still here to do it. Or for someone else if they weren't.

Well, the War did end. And the Laboratory was still here, along with many of the people and many of the memos-to-file. And some big new things started up, and there were left over big Project things still to do, and new people were brought in to fill in for the ones that went away. These new people saw all the new things and they, too, had ideas about what could be done with them. So, here were all these people with new ideas set down in the midst of new science and new technology in a laboratory that didn't any more have a single big mission nor a clear idea about what it was supposed to do. So, they all set about doing what they thought they should do and making up reasons for doing it (beyond the fact that it was fun and good science).

As long as the Manhattan Engineer District was in charge, money was no problem. They were used to buying whatever the scientists said they needed. After the AEC came along, there was at first still no problem about funding, at least for the things that didn't require a big chunk of capital money. The program monitors in Washington were largely old Project people, and they understood the new science and the new ideas. The first budget, at least the first one to come down to the divisional level, was put together in a few hours by setting down what each group was currently spending, adding proportional amounts for the new things they wanted to do, and putting in a little more for contingencies. It really took only one afternoon in the Chemistry Division.

Now, where does all this fit into the background of overall Laboratory development, into the reactors and the mice and the politics that are the foreground of this history? The new ideas of some of the people were part of the Laboratory's big technology, such as reactors and fuel reprocessing. They



Don Palmer injects a solution into an electrochemical cell in an experiment to determine the nature of a sample of chromium.

"Almost every practical problem, solved or unsolved, revealed new physics or chemistry or biology that ought to be studied as science, but had to be left waiting until Hanford and Los Alamos and everybody else had what they needed."

joined right in with the large groups devoted to such items and became part of the big picture and got noticed in the history. They were still physicists or chemists or biologists or whatever, but their goals were those of their particular project.

Another large set of people had seen their future in some of the science that underlay the technology: nuclear physics, separations chemistry, radiation biology. Work in these fields found ready acceptance from the Laboratory management and from the AEC, since it was clearly important to any technology that might be developed. So, these people set happily to work studying the radioactivity of new isotopes, neutron cross sections of elements and isotopes, solubility of uranium compounds at high temperatures, the mechanism of the radiation decomposition of water, the effects of radiation on *Paramecium*.

Many of these people moved back and forth between their small-science research and the big projects, driven by their changing interests and by the changing needs of the Laboratory. One of the Laboratory's chief strengths was the existence of this cadre of experienced, imaginative basic scientists who could be called on to solve practical problems and who would respond enthusiastically. They had been loyal to the Project and now they were loyal to the Laboratory.

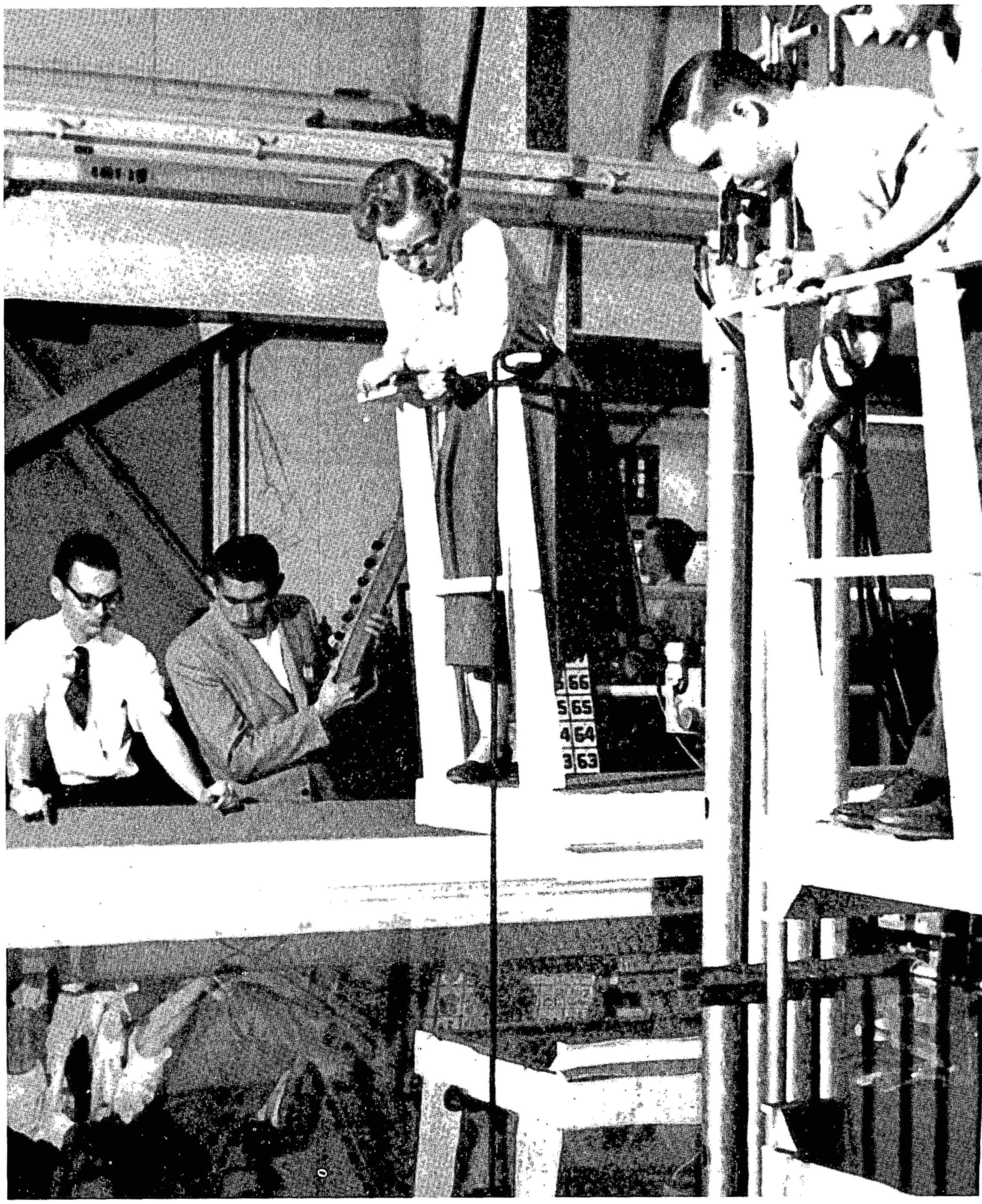
Another set of people had another kind of idea, one that could be carried out only at the Laboratory but didn't really underlie any of its technological interests. Probably foremost among these was the distribution of radioisotopes. The Laboratory was a unique source, in terms of production in the Graphite Reactor and the ability to separate them into forms suitable for shipment and use. Because its value transcended the Laboratory's interests, it became a major effort, and this history naturally treats it as such in the appropriate place. Other examples of work that could only be done near the reactor included use of short-lived radioisotopes for various kinds of research in chemistry and the study and use of neutrons and other radiations from the reactor. Research being what it is, many of these efforts and many of the kind underlying the technology turned up related questions of scientific interest or developed capabilities that were not necessarily related to the original goals. They might no longer be supportive of the particular interests of the Laboratory or might no longer require the particular materials or facilities that had justified their undertaking. Nevertheless, when they appeared to be good science, the Laboratory supported them, and the AEC generally concurred.

These kinds of small science, carried out in groups of from one to a dozen or so people, were characteristic of the Physics and Chemistry Divisions and later of the Solid State Division. There were also groups of similar size and origin in Biology, Metallurgy and other divisions, but those divisions tended to be more programmatic or thematic, and their accomplishments generally fit more understandably into the main thread of the history.

"One of the Laboratory's chief strengths was the existence of this cadre of experienced, imaginative basic scientists who could be called on to solve practical problems and who would respond enthusiastically. They had been loyal to the Project and now they were loyal to the Laboratory."

All of this small science added up to a significant part of the Laboratory. In a typical year between 1955 and 1968, about 35% of the Laboratory's budget supported small science. That's where Henry and John and Tony were. Perhaps incognito by necessity in this history, but important to the Laboratory and remembered by those who were there.

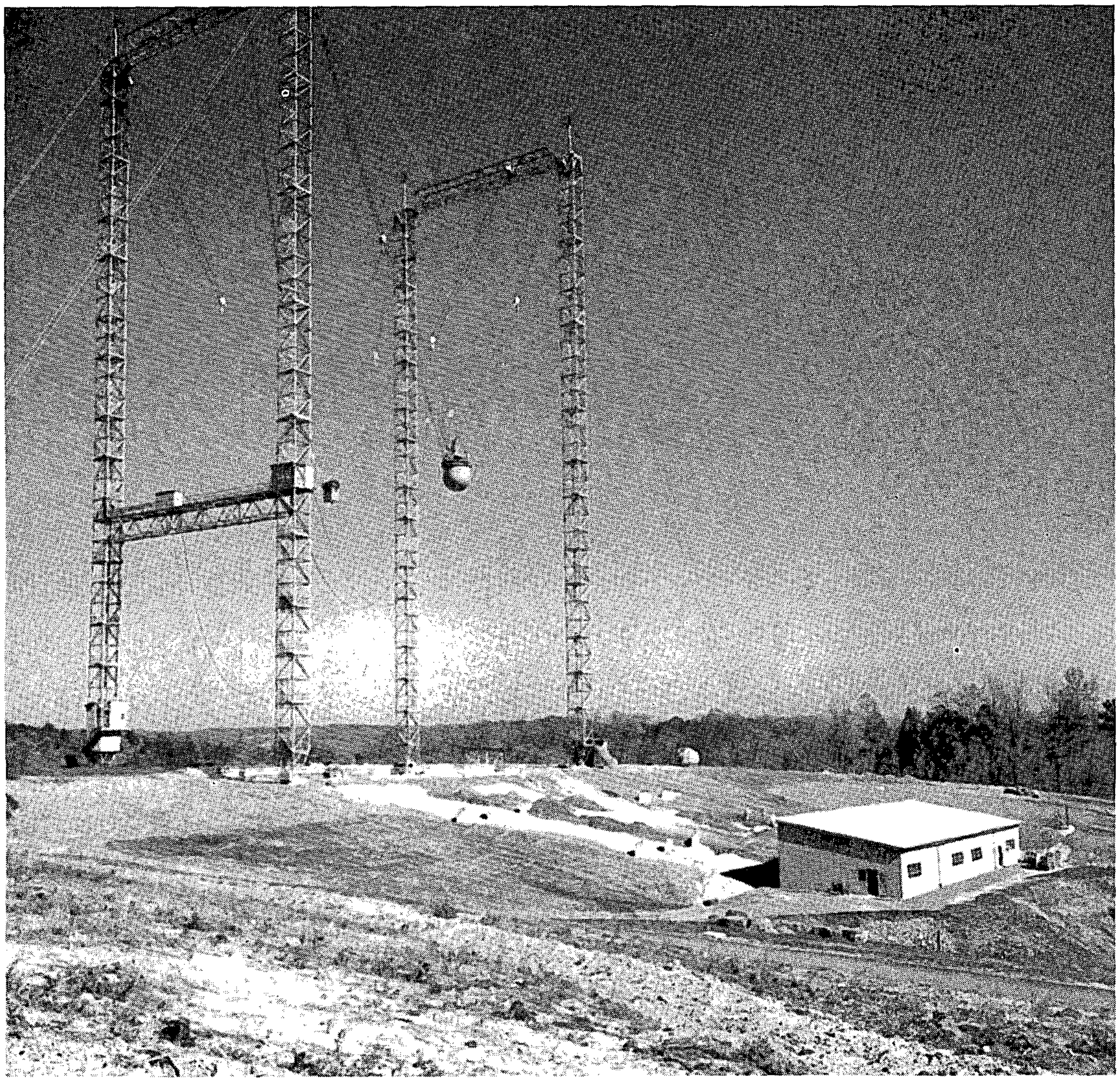
"The Laboratory standardized this inexpensive, safe, and stable design, which became a prototype for many research reactors built at universities and private laboratories around the world."



Researchers watch an experiment in progress at the Bulk Shielding "swimming pool" reactor.

First, in December 1950, the Laboratory completed its 2-MW Bulk Shielding Reactor at a cost of only $250,000. To build this reactor, the Laboratory modified its earlier Materials Testing Reactor design to create what became popularly known as the "swimming pool" reactor. This reactor's enriched uranium core was submerged in water for both core cooling and neutron moderation. From an overhead crane, the reactor could be moved about a concrete tank, the size of a swimming pool, to test bulk shielding in various configurations. A 10-kW nuclear assembly (named the Pool Critical Assembly) was subsequently placed in a corner of the pool to permit small-scale experiments without tying up the larger reactor.

The Laboratory standardized this inexpensive, safe, and stable design, which became a prototype



The Tower Shielding Facility's four towers suspended a reactor core in air for studies of shielding materials.

"The Tower Shielding Reactor helped scientists answer questions about radiation from a reactor flying overhead."

for many research reactors built at universities and private laboratories around the world. Upgraded with a forced cooling system in 1963, it supplanted the Graphite Reactor (retired that year) and proved extremely useful for irradiation and study of materials at low temperatures.

A second Laboratory reactor resulting from the nuclear aircraft project was the Tower Shielding Facility, completed in 1953. Cables from steel towers could hoist a 1-MW reactor in a spherical container nearly 200 feet (60 meters) into the air. Because no shielding surrounded the reactor when suspended, it operated under television surveillance from an underground control room. Containing uranium and aluminum fuel plates moderated and cooled by water, this reactor helped scientists answer questions about radiation from a reactor flying overhead; it also helped researchers better understand the type and amount of shielding that would be needed aboard a nuclear aircraft.

Experiments indicated that a divided shield, consisting of one section around the aircraft's reactor and another around its crew, would comprise a combined weight less than that of a single thick shield blanketing the aircraft's reactor. Researchers, however, could never devise a reactor and shielding light enough to ensure safe flight. They even considered a "tug-tow" arrangement in which the crew and controls would be in a towed glider, separated from, yet tied to, the reactor by a long umbilical cable. The Tower Shielding Facility reactor later was upgraded, and shielding experiments recently took place there in support of breeder reactor development, long after visions of a nuclear aircraft faded from memory.

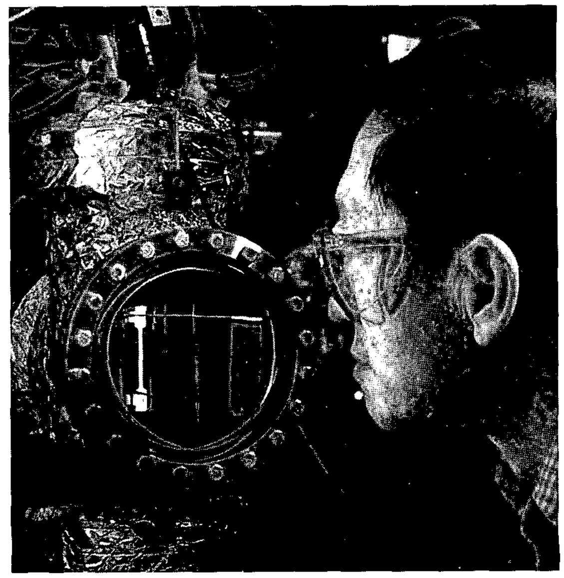
"The first test run of the Aircraft Reactor Experiment took place in October 1954. The reactor ran at 1 MW for 100 hours."

Fireball Reactor

The Bulk Shielding Reactor and Tower Shielding Facility were designed to test materials that might be used on a nuclear-powered aircraft. For the U.S. Air Force, improved materials represented a means toward an end: a nuclear-powered engine that could drive long-range bombers to takeoff speeds and propel them around the world. To achieve this goal, the Laboratory designed an experimental 100-kW aircraft reactor as a demonstration. This small reactor, operating at high temperatures, used molten uranium salts as its fuel, which flowed in serpentine tubes through an 18-inch (46-centimeter) reactor core. A heat exchanger dissipated the reactor's heat into the atmosphere. In 1953, the Laboratory constructed a building to house this experimental reactor.

To contain molten salts at high temperatures within a reactor, the Laboratory used a nickel-molybdenum alloy, INOR-8, designed by Oak Ridge researchers and fabricated at the International Nickel Company. Able to resist corrosion at high temperatures while retaining acceptable welding properties, the alloy was commercialized as

Mock-up of ORNL's "Fireball" reactor designed for sophisticated experiments.



Henry Inouye, who helped develop INOR-8, devoted his Laboratory career to making alloys more suitable for nuclear and space applications.

Hastelloy-N by private industry (an early example of technology transfer) to supply tubing, sheet, and bar stock for industrial applications. The aircraft reactor also compelled Laboratory personnel to learn how to perform welding with remote manipulators and how to remotely disassemble molten-salt pumps. In addition, Laboratory researchers also devised two salt reprocessing schemes to recover uranium and lithium-7 from spent reactor fuel.

The first test run of the Aircraft Reactor Experiment took place in October 1954. The reactor ran at 1 MW for 100 hours. Don Trauger and other observers of the reactor's operations recall that the reactor core, pumps, valves, and components literally became red hot. Completing the design, fabrication, and operation of such an exotic nuclear reactor in five years was considered a noteworthy event, and dignitaries such as General James Doolittle, Admiral Lewis Strauss, and Captain Hyman Rickover visited Oak Ridge to see the red-hot reactor in action.

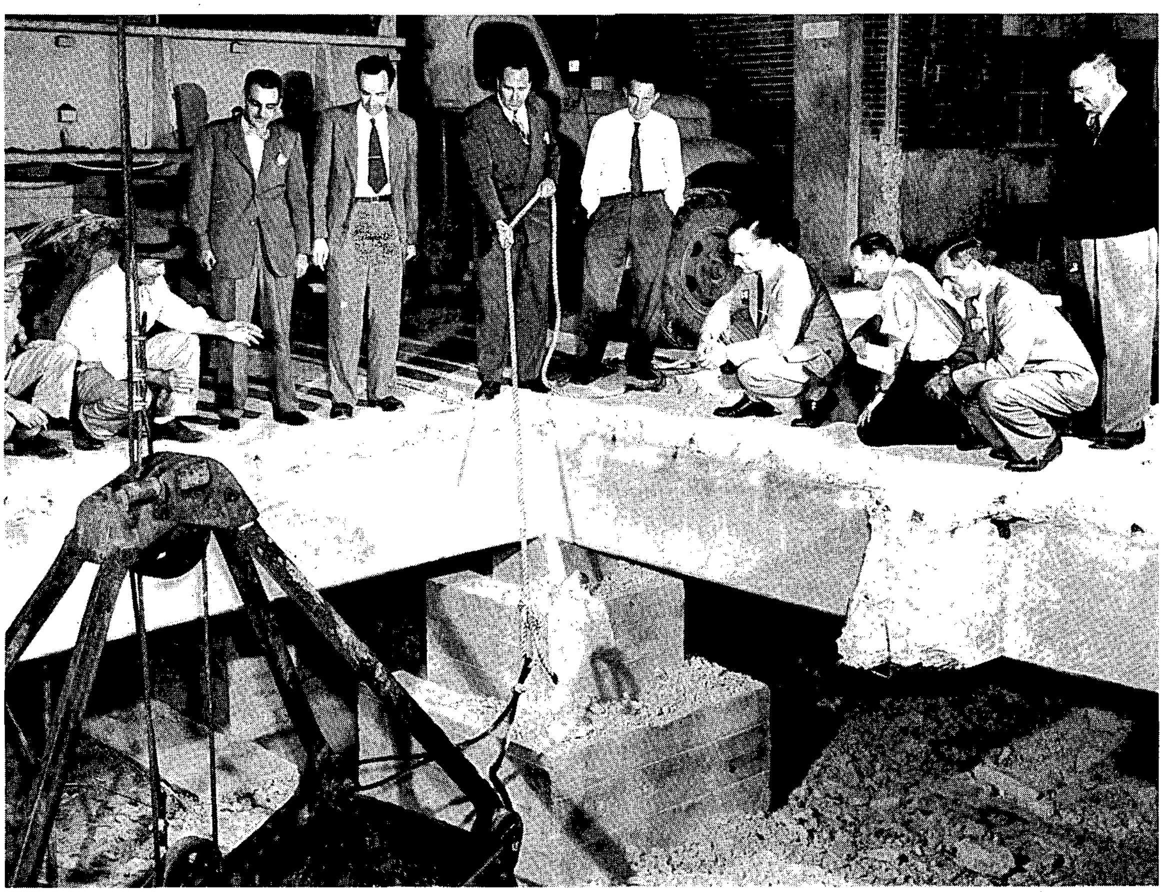
Its success led the Laboratory to propose additional study of this reactor concept and the design of a larger 60-MW, spherical prototype, known as the "fireball reactor," to conduct more sophisticated experiments. Laboratory researchers, for example, asked what would happen if an airplane turned upside down while irradiated molten liquid pulsated through the engine. More significantly, they wondered what would happen if the plane failed in midair or during takeoff or landing.

Three unique reactors were not the only hardware the Laboratory acquired as a result of its nuclear aircraft project. The project helped justify construction of a critical experiments facility to test reactor fuels and a physics laboratory to study the effects of radiation on solid materials. It also advanced Laboratory efforts to acquire its first nuclear particle accelerators and digital computers.

Because the success of nuclear flight depended on expensive and complex hardware on the ground, the Laboratory benefited from being on the receiving end of a well-funded government project. However, the Laboratory's ability to take advantage of this situation also depended on the skill of its research and support staff and the managerial expertise of its leaders. Internal administrative adjustments, including the merger of the Y-12 Plant's research division with the Laboratory, also helped.

ORNL's Y-12 Laboratories

By 1950, all parties—the government, the Laboratory, and the company—largely viewed Carbide's management of the Laboratory as a success. Recognizing that staff loyalties resided with the Laboratory, Carbide did not attempt to convert them to "company personnel." It eagerly



Director Clarence Larson initiates construction of the 86-inch cyclotron.

Clarence Larson

The Right Chemistry

Clarence Edward Larson, a former ORNL director, distinguished himself both as a chemical engineer and leader of scientific activities of vital interest to the United States.

A native of Minnesota who completed undergraduate work in chemistry and chemical engineering at the University of Minnesota, he received his Ph.D. degree in biochemistry in 1937 from the University of California at Berkeley. While a graduate student, he experimented with cyclotron-produced isotopes obtained from cyclotron inventor Ernest O. Lawrence.

"Clarence Edward Larson, a former ORNL director, distinguished himself both as a chemical engineer and leader of scientific activities of vital interest to the United States."

In 1937, Larson joined the Chemistry Department of the College of the Pacific, later becoming department chairman. He continued experiments using cyclotron-produced isotopes and, as a result of this work, joined Lawrence in the Manhattan Project in 1942. His responsibility was to solve the chemical problems associated with electromagnetic separation of fissionable uranium-235 from the more abundant nonfissionable uranium isotope. The calutrons used for this process were designed and built under Lawrence's leadership.

One chemical problem was that the calutrons directed the uranium beam against the walls of the steel-and-graphite receivers with such energy that the uranium atoms buried themselves in the stainless steel, greatly reducing the amount of enriched uranium that could be recovered. Larson suggested that the embedded uranium could be easily recovered from the receiver walls if they were plated with copper. Lawrence liked the idea and demanded that Larson assemble a team to copperplate the receivers and put the process into operation in one day. "Fortunately," Larson said recently, "the equipment was available and, on the next day, the operations started successfully."

Another problem was to recover the uranium scattered all over the calutron interiors. Because of the extremely corrosive conditions, large amounts of impurities entered the solutions, making recovery of the uranium difficult. It was known that uranium could be precipitated selectively by hydrogen peroxide, but this recovery system, says Larson, "was almost explosively unstable because of the catalytic effects of the impurities." Recalling that many unstable biological compounds can be prevented from decomposing if subjected to frigid conditions, Larson devised double-walled vessels containing a cooling system for the uranium precipitation system. "This system," Larson says, "worked successfully throughout the project. By fortunate coincidence both of these process problems were solved by applying electrochemical and separations techniques used in my graduate research."

In 1948, Larson became director of the Y-12 Plant, and in 1950 he became director of Oak Ridge National Laboratory. Larson presided over the Laboratory's $20-million expansion program involving completion of nine new buildings, large-scale modification of four buildings, and acquisition of space for ORNL activities at the Y-12 Plant. Under his administration, the Bulk Shielding Reactor, the Homogeneous Reactor Experiment, and the Aircraft Reactor Experiment began operation and

the Tower Shielding Facility was completed for the Aircraft Nuclear Propulsion Program. The Laboratory's first large computer was installed, and an ORNL reactor exhibit received rave reviews at the first "Atoms for Peace" conference in Geneva, Switzerland.

In 1955, Larson left Oak Ridge to become vice president of the National Carbon Division of Union Carbide Corporation. Later he became deputy manager of corporate research there. In 1961, he returned to Oak Ridge, where he served as president of Union Carbide Nuclear Division until 1969. In this capacity, he oversaw management of ORNL, the Y-12 Plant, and the Oak Ridge and Paducah gaseous diffusion plants for the Atomic Energy Commission (AEC). From 1969 through 1974 he was an AEC commissioner, the only person from Oak Ridge to attain this position. In 1973, Larson was elected to the National Academy of Engineering for "the development of processes for recovery and purification of uranium and leadership in nuclear plant design."

identified and rewarded ambitious Laboratory staff (elevating some to managerial positions), undertook sorely needed facility reconstruction and expansion, and fostered basic and applied sciences. "Carbide management has demonstrated," asserted one manager, "that first-rate basic research can be done in an industrial framework."

When Nelson Rucker, Carbide's executive director of Laboratory operations, transferred to a plant in West Virginia in 1950, a major reorganization ensued. Alvin Weinberg, formerly associate director, became the Laboratory's research director, and Clarence Larson, formerly the Y-12 Plant manager, became the Laboratory's new director.

A chemist from Minnesota, Larson had worked at the University of California's radiation laboratory before moving to Oak Ridge to become the Y-12 Plant research director in 1943 and superintendent in 1948. An able manager and accomplished scientist, Larson strengthened and broadened the Laboratory's research activities.

Before Larson's appointment, Union Carbide considered moving the Laboratory to the Y-12 Plant, where the Biology Division already occupied a building. By 1950, however, the chilling tensions of the Cold War and the heated battles of the Korean War sparked rapid expansion of nuclear weapons production, which increased the workload at the Y-12 and K-25 plants and led to construction of new gaseous diffusion plants at Paducah, Kentucky, and Portsmouth, Ohio. As a result, space became precious at the Y-12 Plant, and plans to move the Laboratory there were aborted. Thus, the Laboratory's acquisition of the Y-12 Plant's three research divisions—Isotope Research and Production, Electromagnetic Research, and Chemical Research—left everyone and everything in the same place. However, as a result of the administrative realignment, Y-12 Plant researchers in these divisions began reporting to Laboratory management.

Isotopes

By 1950, the Laboratory was distributing more than 50 different radioisotopes to qualified research centers. Cobalt-60, used for cancer research and therapy, was a prime isotope on the Laboratory's distribution list. When the Laboratory began to ship isotopes overseas, the AEC approved a cooperative arrangement between the Laboratory and the Oak Ridge Institute of Nuclear Studies to train foreign scientists in radioisotope research. The Laboratory's isotope research efforts were further advanced through the merger of the Y-12 Plant's Isotope Research and Production Division with the Laboratory's Isotopes Division. This union added stable, nonradioactive isotopes to the Laboratory's catalog.

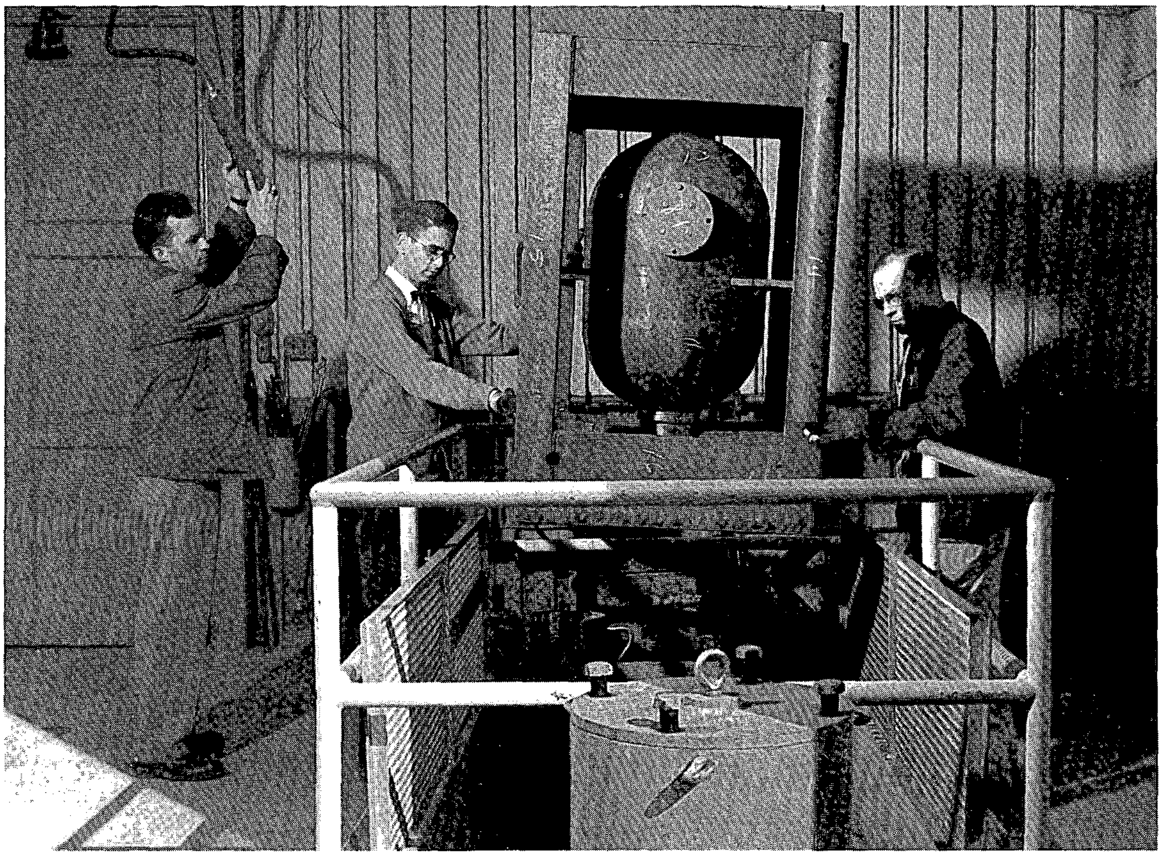
The Y-12 Plant's stable-isotopes program had emerged at the end of the war when Y-12 staff ceased separating uranium isotopes for atomic weapons. Eugene Wigner then urged continued use of some calutrons to separate the stable isotopes of all elements. "We should have as the very basis of future work in nuclear physics and chemistry knowledge of the various cross sections of pure stable isotopes," he urged. The AEC approved Wigner's proposal, and a group led by Clarence Larson, Christopher Keim, and Leon Love began to separate various isotopes of stable elements.

Researchers at first used four calutrons salvaged from electromagnetic equipment. Stable-isotope research and development required modifications to the calutrons, better

Eugene Wigner urged continued use of some calutrons to separate the stable isotopes of all elements.

Christopher Keim displays containers of stable isotopes to Laboratory managers.

"The Laboratory's isotopes program continued to expand through the 1970s, sometimes generating more than $1 million annually in sales revenue."

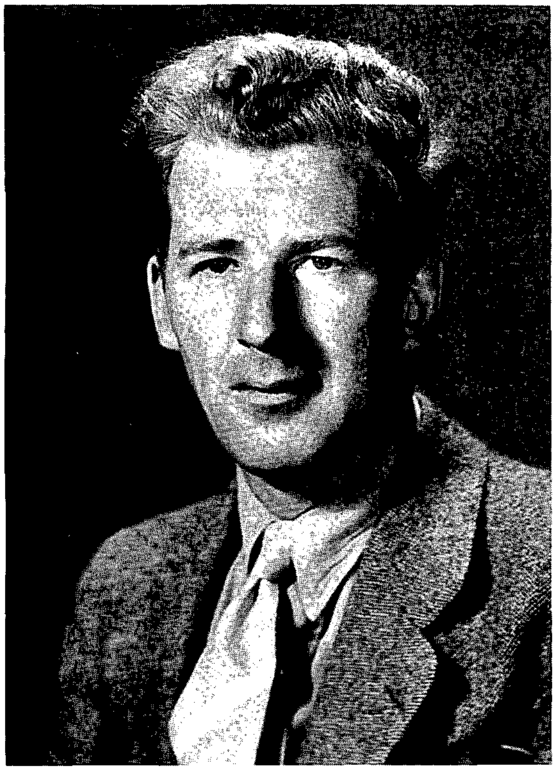


Henry Grimoc, W. R. Casto, and G. L. Neely prepare a container for shipping radioactive cobalt-60 from the Laboratory to Los Angeles for use in treating cancer patients.

understanding of the obscure chemistry of less common elements, spectroscopic analysis of nuclear properties, and advances in the use of isotopes as tracers.

Christopher Keim, a group leader, later recalled that copper isotopes were the first to be collected. Using enriched copper-65 as the source material for neutron irradiation, George Boyd, John Swartout, and colleagues positively identified nickel-65 as a nickel isotope with a half-life of 2.6 hours. This discovery represented the first use of calutron-separated stable isotopes in research. "All that had to be done," Keim modestly explained, "was to put copper chloride into the charge bottle, heat it with uranium tetrachloride, lower the magnetic field, and space the collector slots to receive the copper-63 and copper-65 ion beams."

Stable isotopes of iron, platinum, lithium, and mercury, for example, were separated and shipped to university, government, and industrial laboratories worldwide to aid basic research in physics, chemistry, earth sciences, biology, and biomedicine. They became especially valuable to medical science, for which they were converted into radionuclides used as tracers to diagnose cancer, heart disorders, and other diseases affecting human internal organs and bones. Contributing to basic scientific knowledge and enhancing the quality of human life, the Laboratory's stable isotopes program continued to expand through the 1970s. At its height, the



Arthur Snell, director of the Physics Division and later an ORNL associate director, came to the Laboratory from the Metallurgical Laboratory at Chicago.

program generated more than $1 million annually in sales revenue.

Particle Accelerators

In 1950, the Y-12 Plant's Electromagnetic Research Division, under Robert Livingston, became the Laboratory's Electronuclear Division, switching from studies of calutrons to fundamental research on the formation and motion of ions in electric fields. The Electronuclear Division was also in charge of the cyclotrons used for particle acceleration. At the same time, Arthur Snell and colleagues in the Physics Division entered the particle acceleration field as well, using electrostatic accelerators.

Thus the Laboratory, during the early 1950s, pursued two independent lines of particle acceleration—cyclotrons in the Electronuclear Division and electrostatic accelerators in the Physics Division. This hot pursuit of fast-moving subatomic particles was propelled by rapid postwar advances in the basic science of nuclear physics.

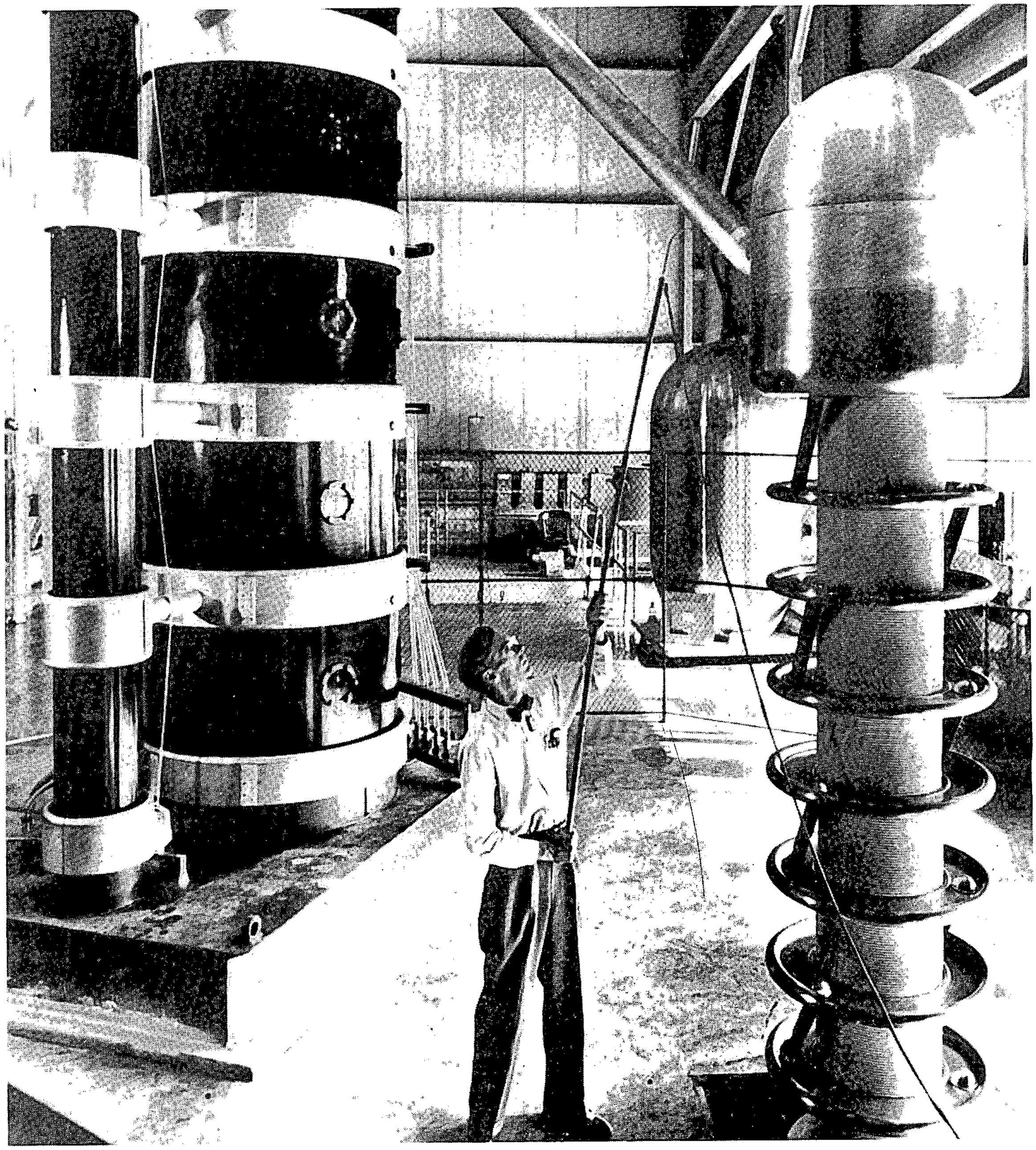
During the postwar years, exploration of the unknown particles and forces of atomic nuclei led to the discovery of subatomic particles smaller than neutrons, electrons, and protons. The study of these elementary particles emerged from nuclear science as a subfield labeled high-energy physics. Oak Ridge, as a national laboratory dedicated to fundamental research, was anxious to participate in subatomic explorations.

Its research efforts had an abortive start in 1946, however, when the Laboratory proposed to purchase a large betatron accelerator to join the hunt for elusive subatomic particles. This purchase required approval by the Army, and the resulting bureaucratic delays made the 160-ton betatron obsolete when it finally arrived. Saddled with an outdated piece of equipment, the Laboratory sold it as surplus to another government agency. By 1948, however, the Laboratory's nuclear aircraft program, with support from the U.S. Air Force, was inching down the runway. This project added impetus to accelerator research because of the need to understand the effects of radiation on shields and other materials that would be part of the aircraft.

In 1948, Arthur Snell, director of the Physics Division, asked Wilfred Good and Charles Moak to start an accelerator program using materials readily and inexpensively available at the Laboratory and the Y-12 Plant. "The objective was clear," recalled Good. "Neutrons were the key to the new frontier of applied nuclear energy; to fully exploit neutrons, their behavior had to be thoroughly understood; and the Van de Graaff accelerator was the only known source of neutrons of precisely determined energies." The Chemistry Division had acquired a 2.5-MV Van de Graaff electron accelerator from the Navy. Richard Lamphere of the Instrumentation and Controls Division converted it into a 3-MV proton accelerator that could bombard lithium targets with protons to produce a stream of neutrons. This little Van de Graaff accelerator supported research for 30 years, its most important service to science coming when John Gibbons, Richard Macklin, and

"The nuclear aircraft program added impetus for accelerator research because of the need to understand the effects of radiation on shields."

"The 5-MV Van de Graaff accelerator produced its first beam in 1951, making it the world's highest energy machine."



One of the most famous of the "atom smashers" is the Van de Graaff accelerator, which accelerates charged particles or atoms and propels them into a target.

colleagues used it to confirm a theory that atomic elements originated through nucleosynthesis in the centers of stars.

To test radiation effects at energies lower than those generated by the Van de Graaff accelerator, the Laboratory also acquired a Cockcroft-Walton accelerator, an early particle accelerator named for its inventors. The Laboratory installed these first accelerators in an abandoned powerhouse.

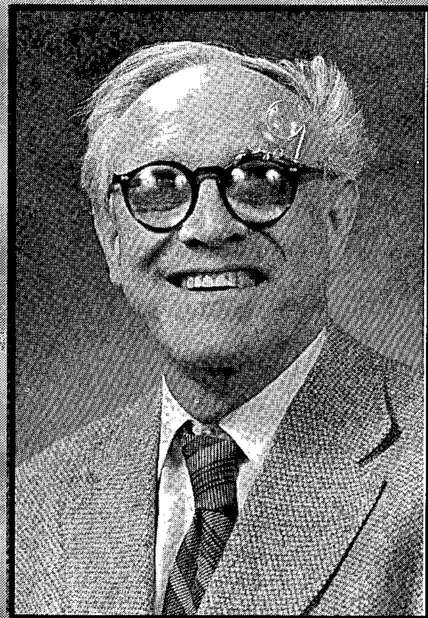
In March 1949, Alvin Weinberg and Herman Roth of the AEC met Air Force commanders and contractors to discuss priorities in the nuclear aircraft research program. After concluding that a 5-MV Van de Graaff accelerator was needed, the Air Force agreed to purchase it if the Laboratory would construct a building to house it. First installed at the Y-12 Plant, the 5-MV Van de Graaff accelerator produced its first beam in 1951, making it the world's highest-energy machine of its kind. In 1952, the Laboratory completed the building for the High Voltage Laboratory and moved the three electrostatic particle accelerators into it. A decade later, it added a 6-MV tandem Van de Graaff

P. R. Bell

Scanning the Future

Physicist P. R. Bell came to the Laboratory from the University of Chicago in 1946. During the war, he had worked at the U.S. government's radiation laboratory at the Massachusetts Institute of Technology, which sought to improve the effectiveness of radar in detecting aircraft and ships.

At the Laboratory, he led a scientific team that focused on developing new instruments. The team sought to improve the scintillation spectrometer,



"Today, scanners based on Bell's improved device are an essential tool of medical diagnosis used by doctors throughout the world to locate cancerous tumors and examine the results of other internal diseases."

an electronic device for detecting and recording small pulses of light, or scintillations, emitted by phosphors when bombarded by radiation.

In the early 20th century, the United Kingdom's renowned scientist Lord Rutherford visually counted scintillations in alpha particle experiments. Visual methods were later replaced by the Geiger counter. After World War II, scintillations were detected by photomultiplier tubes, which were highly sensitive to light. In this technique, phosphors were placed in the direct path of radiation and the emitted light was converted into electric signals. The signals were then amplified and registered as electrical pulses with a circuit similar to that used in Geiger counters.

Recognizing the potential value of this device for detecting and measuring beta and gamma rays, Bell and his colleagues improved the scintillation spectrometer, achieving notable success

"Bell's pioneering studies on the scintillation spectrometer, and the improvements and adaptations that followed, have prevented untold human suffering and extended millions of lives."

in developing instruments that measured radiation levels and energies.

These improvements had practical applications not only for radiation dosimetry but also for medical diagnosis. Bell and his colleagues C. C. Harris and J. E. Francis, for example, modified this radiation detector for use in locating brain tumors. The detector highlighted trouble spots, making intrusive surgery unnecessary for cancer detection.

Today, scanners based on Bell's improved device are an essential tool of medical diagnosis used by doctors throughout the world to locate cancerous tumors and examine the results of other internal diseases. Bell's pioneering studies on the scintillation spectrometer, and the improvements and adaptations that followed, have prevented untold human suffering and extended millions of lives.

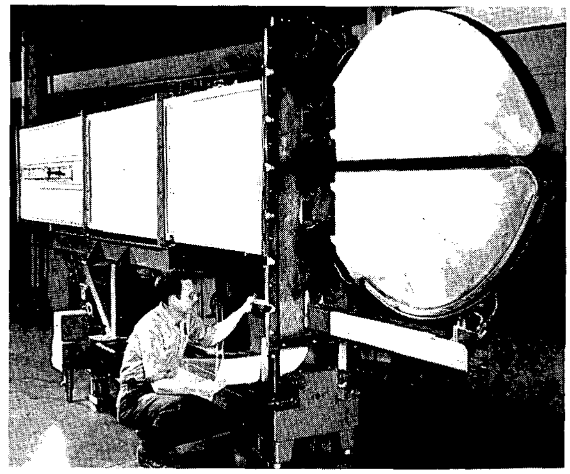
accelerator to extend the energy capability of the existing machines and to accelerate ions heavier than helium. Thirty years later, Laboratory physicists still view this accelerator as a valuable research tool.

Cyclotron Acceleration

While Arthur Snell and members of the Laboratory's Physics Division concentrated on particle acceleration through direct-current high-voltage machines, Robert Livingston and the Y-12 Plant's electromagnetic team pursued an independent course of achieving acceleration with cyclotrons. Invented in 1930 by Ernest Lawrence at Berkeley, cyclotrons had two D-shaped electrodes (dees) in a large and nearly uniform magnetic field. The dees operated at high electric potential and were alternately positive or negative. They accelerated the charged particles (ions), and the magnetic field confined them to a circular orbit.

Cyclotrons were the forerunners of the giant synchrotrons of the 1990s, and during their 60 years of development they increased the energy of protons (nuclei of hydrogen atoms) from one million electron volts to 20 trillion electron volts. The cost of the machines also multiplied from $100,000 each to $10 billion each.

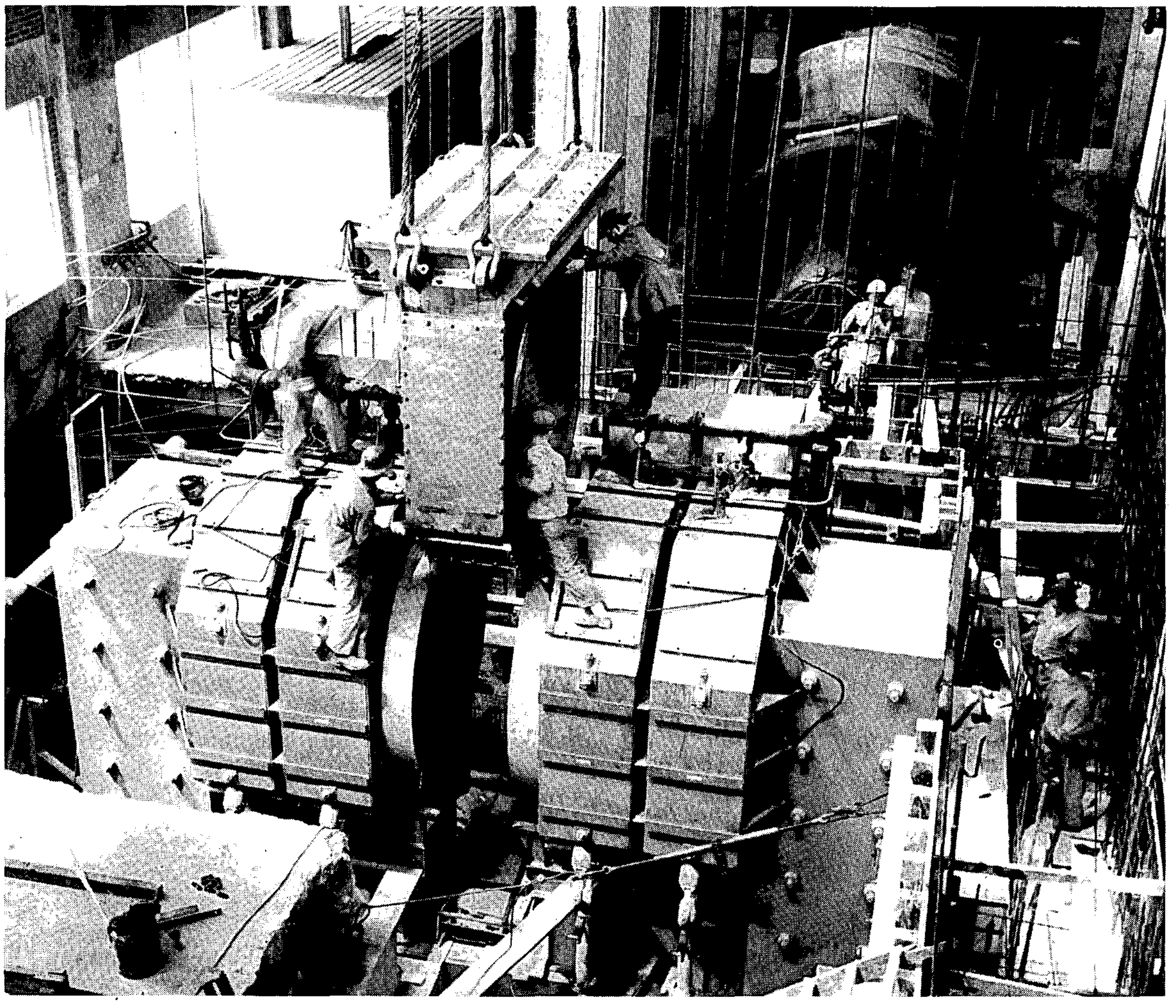
Having built calutrons during the war for electromagnetic separation of uranium isotopes, Livingston and his associates at the Y-12 Plant had abundant experience and took advantage of the unused electromagnets left over from the war effort. During the late 1940s and early 1950s, they built three cyclotrons to study the properties of compound nuclei and heavy particle reactions. The cyclotrons were identified by their diameters measured across the dees as 22-inch, 63-inch, and 86-inch machines.



Inspection in 1952 of the 63-inch cyclotron dees.

Livingston's team built the 22-inch cyclotron in the late 1940s to test how electromagnets in calutrons could be used and how high-current calutron ion-source techniques could be applied to cyclotron functioning. The cyclotron served its

Robert Livingston and Alex Zucker confer at a bank of cyclotron controls during the early 1950s.



Workers complete the 86-inch cyclotron.

purpose, and its size was later doubled to 44 inches for testing new ion sources, new beam-focusing methods, and new ways to increase the intensities of accelerated beams.

The 86-inch cyclotron began operation in November 1950 and was used to perform radiation damage studies for the nuclear aircraft project. As the world's largest fixed-frequency proton cyclotron, it produced a proton beam four times more intense than any other cyclotron; its blue beam projected through the air as much as 16 feet (5 meters), visibly impressing visitors. Bernard Cohen, chief physicist for this machine, used it to study proton-induced nuclear reactions and to supply the isotope polonium-208 until a commercial source became available.

This was the era of hydrogen bomb development, and the question arose whether a powerful hydrogen bomb might ignite nitrogen in the atmosphere, causing a worldwide holocaust. To find the answer, the AEC asked the Laboratory to build a cyclotron that would accelerate nitrogen ions to determine the probability that they would react with each other at hydrogen-bomb temperatures to produce carbon, oxygen, and enormous amounts of energy. The Laboratory asked Alex Zucker, a newly minted Ph.D.

"Zucker and his collaborators demonstrated that a hydrogen bomb would not ignite a giant chain reaction that would immolate the earth."

from Yale University, to develop a source of multiply charged nitrogen ions. After successfully completing this task, he was directed to build a cyclotron to measure the cross section of the nitrogen-nitrogen reaction and thereby determine whether the atmosphere would burn.

Built in 18 months at a cost of $300,000, the cyclotron became operational in 1952. Zucker and his collaborators, Harry Reynolds and Dan Scott, soon demonstrated that a hydrogen bomb would not ignite a giant chain reaction that would immolate the earth. They then turned the cyclotron into a basic research instrument, the world's first source of energetic heavy ions, making the interactions of complex nuclei a new field of scientific investigation.

The Laboratory's first cyclotrons were the most economical ones ever built because the Electronuclear Division used surplus electromagnetic equipment that required little modification. Because the Y-12 Plant's calutron tracks had been placed side by side in vertical formation, the Laboratory's cyclotrons were marked by their unique vertical mounting instead of the horizontal position of the dees found at other laboratories. These pioneering cyclotrons helped advance the technology of high-beam currents, and they have since been the force behind the Laboratory's versatile Oak Ridge Isochronous Cyclotron completed in 1962 and still later the Holifield Heavy Ion Research Facility completed in 1980.

Alston Householder, a University of Chicago biophysicist, directed the Laboratory's Mathematics Panel.

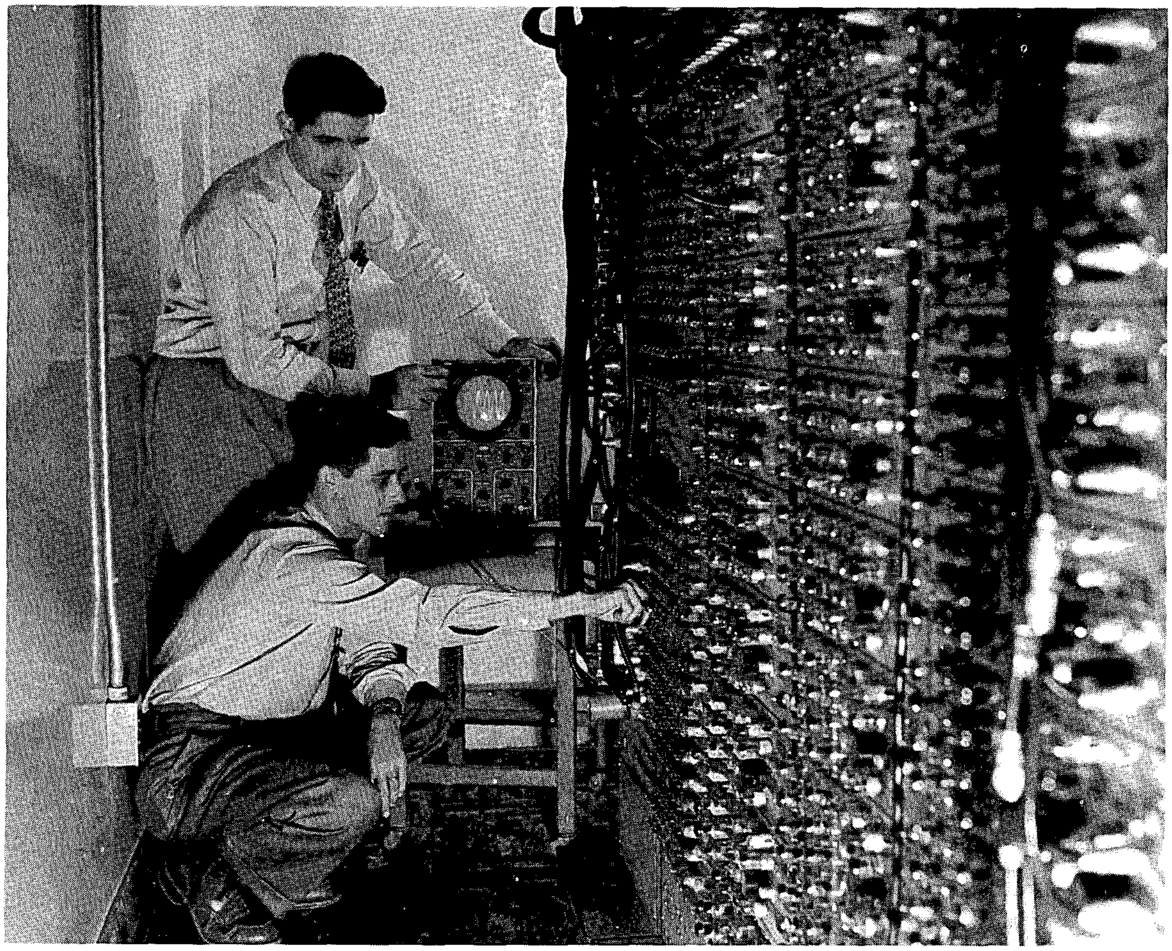
Information Acceleration

The aircraft nuclear propulsion project, together with the reactors and particle accelerators developed to support it, generated immense quantities of scientific data that required rapid analysis. This need stimulated Laboratory interest in electronic computers, which became available during the 1940s.

In 1947, Weinberg created a Mathematics and Computing Section within the Physics Division under the direction of Alston Householder, a mathematical biophysicist from the University of Chicago, who in 1948 converted the section into an independent Mathematics Panel to manage the Laboratory's acquisition of computers.

Before 1948, complex, multifaceted computations at the Y-12 and K-25 plants were done on electric

H. B. Goertzel and L. R. Gitgood key data into a computer acquired in 1950 for the nuclear aircraft project.



"The aircraft nuclear propulsion project generated immense quantities of scientific data that required rapid analysis."

For the nuclear aircraft program, the Laboratory acquired this early computer in 1950. Les Oakes, standing, and James Stone check its circuitry.

calculators and card programming machines. Because of its participation in the nuclear aircraft project, the Laboratory obtained a matrix multiplier to solve linear equations. At the Laboratory's urging, the AEC also leased Harvard University's early Mark I computer. Householder and Weinberg insisted that the Laboratory should also acquire its own "automatic sequencing computer" to be used by staff scientists doing difficult computations for the nuclear aircraft project. The computer, they contended, could also serve to educate university faculty and researchers visiting the Laboratory. When purchased, it became the first electronic digital computer in the South.

Householder and the Laboratory's leadership were familiar with the pioneering work of Wigner's friend, John von Neumann, who had pursued experimental computer development near the end of the war for the Navy. Admiral Lewis Strauss thought the Navy needed computers to aid in weather forecasting, vital to ships at sea. With his urging, the Navy in 1946 sponsored fabrication of the first von Neumann digital computer at Princeton University. After considering Raytheon and other commercial computers, the Laboratory and Argonne National Laboratory decided to build their own von Neumann–type computers, tailored specifically to solve nuclear physics problems. Laboratory engineers assisted

Radiation Effects in Materials

Cultivated in Oak Ridge

The high state of development of the science and engineering of irradiated materials is due in large part to the contributions of the Laboratory. Three overlapping areas are covered by this research: radiation effects, the development and radiation characterization of materials for nuclear reactors, and the production of new materials with properties that are applicable in a variety of technologies.

In 1946 while at the University of Chicago, Eugene Wigner, first suggested that neutron irradiation could displace atoms, causing changes in materials properties. In short order, colleagues at the Clinton Engineering Laboratories' Metallurgy Division carried out experiments in the Graphite Reactor to confirm this hypothesis, but it was not until the 1950s and 1960s that studies by the Solid State Division staff at the Graphite Reactor, the Bulk Shielding Reactor, and the Oak Ridge Research Reactor revealed the magnitude and pervasiveness of radiation-induced changes.

"In 1946, while at the University of Chicago, Eugene Wigner first suggested that neutron irradiation could displace atoms, causing changes in materials properties."

In 1953, the Metallurgy Division began work on the aircraft propulsion nuclear reactor. After irradiation of the high-temperature structural alloy Inconel 600, ORNL scientists measured extreme reductions in its ability to resist rupturing under stress. It was later shown that helium produced by neutron interactions with the alloy accumulated between the metal crystals, leading to the poor performance. The problem was solved by alloying Inconel 600 with titanium. This element effectively neutralized boron, which was responsible for the helium-producing reactions.

Irradiation experiments on light-water-reactor pressure vessel steels began at ORNL in the mid-1950s. At that time, it was unknown if such steels could exhibit levels of fracture resistance high enough to ensure the integrity of reactor pressure vessels after they had been exposed to neutrons from the fuel core. Later experiments involved the largest specimens ever irradiated (about 50 kg each), and demonstrated that high levels of post-irradiation fracture resistance could be maintained. Extensive experiments have also been carried out to investigate the effects of radiation on embrittled materials.

In the 1970s the Metals and Ceramics Division (formally the Metallurgy Division) received large infusions of funding for research on the physical mechanisms underlying radiation effects and the liquid-metal-cooled fast breeder reactor and the fusion reactor. Burgeoning work in this field was a worldwide phenomenon, and U.S. efforts were paralleled, by similar work in the Great Britain, France, Germany, the Soviet Union, and Japan.

During this period in the Solid State Division, the emphasis was on the fundamentals of calculating damage to materials caused by the displacement of atoms by particle irradiation. Two theoretical contributions to the field of damage production were developed at ORNL. These are the damage production computer code MARLOWE and the Norgett-Torrens-Robinson (NRT) standard method of calculating damage production. MARLOWE is widely used today to obtain detailed information about displacement production for a variety of projectiles and materials. The NRT method is now the standard through the world for obtaining the number of displacements per atom for a given material and type of particle irradiation.

Today, the main efforts in radiation effects on materials are centered in the Metals and Ceramics Division in groups led by Tim Burchell, Lou Mansur, Randy Nanstad, and Arthur Rowcliffe. The emphases in these groups are: radiation effects in carbon materials, physical mechanisms of radiation effects, materials for present-day light-water reactors, gas-cooled reactor pressure vessels, and materials development for fusion reactors, respectively. The Advanced Neutron Source will also benefit from work in these groups.

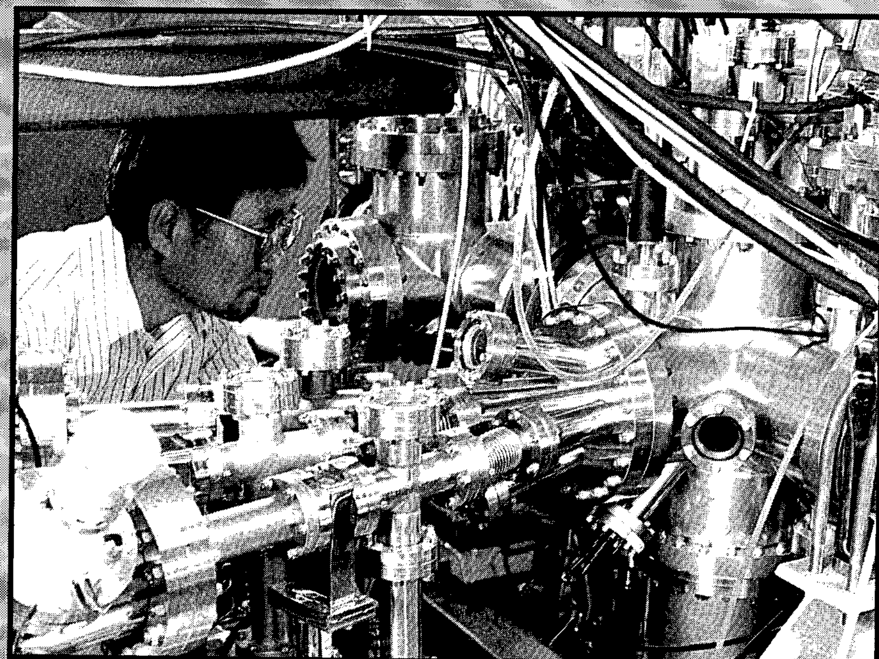
The effects of neutron irradiation on carbon materials are being investigated on two fronts. Shape changes, creep behavior, and changes in mechanical, fracture, and thermal-physical properties induced by neutron irradiation are being determined for several nuclear graphites. Also carbon-carbon composites, a newer and distinctly different class of carbon material, are of interest as a potential structural material for high-temperature control rods, and other reactor components.

Research into the physical mechanisms of radiation effects has yielded principles for design of radiation-resistant materials as well as prediction of their behavior in fission and fusion reactors. Ion irradiation has also been used to develop new materials and properties that are applicable to a variety of advanced technologies unrelated to fission and fusion. In fact, research into improving the surface, mechanical, and physical properties of polymers received an R&D 100 award from *R&D Magazine* recognizing it as one of the top 100 technological developments in the nation in 1992.

The division's work on the development of materials for fusion reactor systems has made it a key participant in the design of the proposed International Thermonuclear Experimental Reactor.

The largest single concern of the group dealing with radiation effects centers on the relationship between the effects of irradiation on embrittlement of commercial gas-cooled reactors and the fracture toughness of reactor vessel materials. Researchers are also evaluating the effects of radiation on components being designed for the Advanced Neutron Source.

The main facilities at ORNL for experiments in radiation effects are the High Flux Isotope Reactor (HFIR) for neutron irradiations and the Multiple Ion Facility for charged particle irradiations. The HFIR began operation in 1965 and continues today as a workhorse for the basic, fusion, and pressure vessel programs. The Multiple Ion Facility was built up for materials science research over the past 20 years. It is unique in that it can be used to irradiate materials with up to three ion beams simultaneously. Today it is used heavily for experiments on the basic mechanisms of radiation effects and for related work on ion beam treatment of materials.



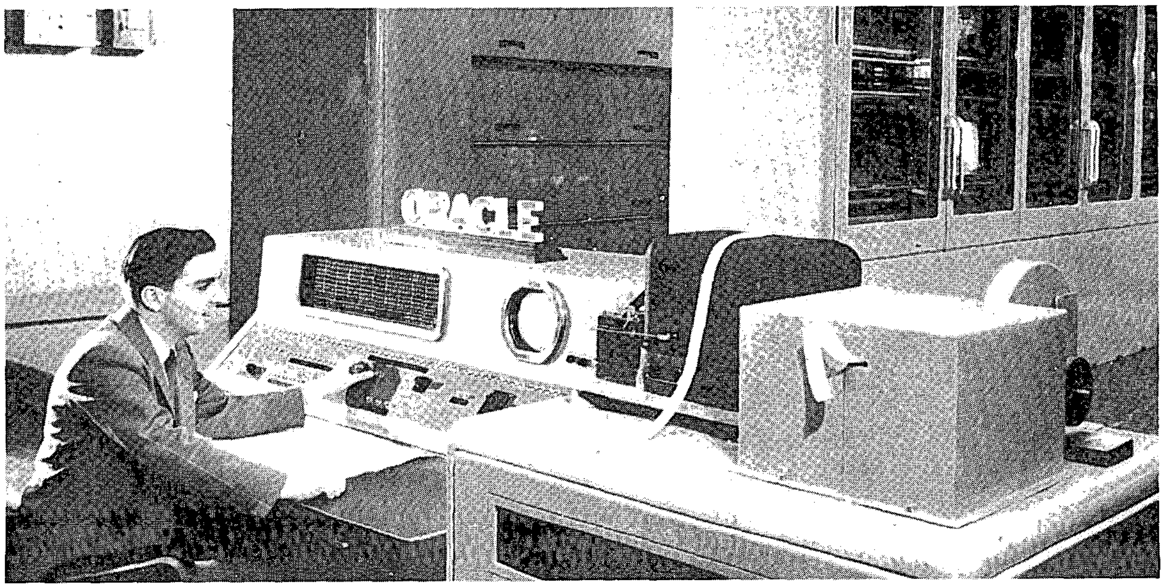
Eal Lee peers into the Triple Ion Irradiation Facility's target chamber where as many as three ion beams are simultaneously focused on a target to create a new type of polymer material.

"ORNL's extensive capabilities for radiation effects research will serve well in the design, construction, and operation of the Advanced Neutron Source."

Activity in radiation effects has always been broader than the direct needs of nuclear technology. While nuclear materials is a subfield of materials science and engineering, the capability to irradiate materials can be viewed as a new dimension, like temperature. Virtually all processes and properties can be affected by irradiation. Even materials and properties can be created. With this powerful tool, new insights into the fundamental behavior of materials have also been gathered.

Irradiation of materials is at once a source of engineering problems and a basis for unique capabilities for producing and understanding new materials and properties. ORNL's extensive capabilities for radiation effects research will serve well in the design, construction, and operation of the Advanced Neutron Source. This reactor will make ambitious demands on our understanding of the irradiation behavior of materials. It will also serve as an irradiation test bed for materials that will benefit basic research and the technologies of fission and fusion reactors of the next century.

"Operational in 1954, for a time the ORACLE had the fastest speed and largest data storage capacity of any computer in the world."



The Laboratory's first large computer was the ORACLE, or Oak Ridge Automatic Computer and Logical Engine. The ORACLE could do 100 person-years of computing in 8 hours.

Argonne during the early 1950s in design and fabrication of the Oak Ridge Automatic Computer and Logical Engine. Its name was selected with reference to a lyrical acronym from Greek mythology—ORACLE, defined as "a shrine in which a deity reveals hidden knowledge."

Assembled before the development of transistors and microchips, the ORACLE was a large scientific digital computer that used vacuum tubes. It had an original storage capacity of 1024 words of 40 bits each (later doubled to 2048 words). The computer also contained a magnetic-tape auxiliary memory and an on-line cathode-tube plotter, a recorder, and a typewriter. Operational in 1954, for a time the ORACLE had the fastest speed and largest data storage capacity of any computer in the world. Problems that would have required two mathematicians with electric calculators three years to solve could be done on the ORACLE in 20 minutes.

Householder and the Mathematics Panel used the ORACLE to analyze radiation and shielding problems. In 1957, Hezz Stringfield and Ward Foster, both of the Budget Office, also adopted the ORACLE for more mundane but equally important tasks—annual budgeting and monthly financial accounting. As one of the last "homemade computers," the ORACLE became obsolete by the 1960s. The Laboratory then purchased or leased its mainframe computers from commercial suppliers. From the initial applications of the ORACLE to nuclear aircraft problems, computer enthusiasm spread like lightning throughout the Laboratory, and in time, use of the machines became common in all the Laboratory's divisions.

Particle Counting

Scintillation spectrometers and multichannel analyzers were other machines that benefited from—and contributed to—the Laboratory's involvement with the nuclear aircraft project and its related studies of atomic particle behavior and radiation damage.

In 1947, German scientists observed that some crystals emitted flashes of light when struck by radiation beams and that the intensity of the flash was proportional to the radiation's energy. By 1950, a scientific team at the Laboratory led by P. R. Bell devised an improved scintillation spectrometer to measure the number and intensity of light flashes emanating from crystals exposed to radiation.

Douglas Billington established the Physics of Solids Institute in 1950 to pursue solid-state studies of radiation damage.

Electronic recording of these measured flashes by multichannel analyzers permitted complete and rapid analysis of particle and gamma-ray energies.

Bell's group later converted the scintillation spectrometer into a medical pulse analyzer and developed a "scintiscanner" and an electronic probe to assist physicians using radioisotopes to locate tumors without surgery. In 1956, Bell's team received funding from the AEC to continue this work, and they formed a Medical Instruments Group in the Laboratory's Thermonuclear Division at the Y-12 Plant, where they primarily investigated fusion energy. Later, they incorporated electronic computers in medical scanners to improve diagnostic techniques. Commercial versions of the machines they invented became common at major medical centers throughout the world.

Radiation Damage

Prolonged exposure to radiation often alters the properties of solid materials and compromises their structural integrity. Thus, the success of the Laboratory's nuclear airplane project depended in part on understanding the potential impact of radiation on solid materials. This understanding was essential in determining how to protect materials from radiation and in developing new materials that were radiation-resistant. Such concerns lifted the importance of solid-state research throughout the Laboratory in the early 1950s.

The first step towards a Solid State Division was taken in 1950 when a Physics of Solids Institute was established under the direction of Douglas Billington. Formed by joining the Solid State Section of the Physics Division with the Radiation and Physical Metallurgy Section of the Metallurgy Division, institute researchers occupied a new laboratory built south of the Graphite Reactor. In 1952, the institute became the Solid State Division, and its primary mission was to obtain basic scientific knowledge about radiation damage processes in materials.

"Inasmuch as a thorough understanding of the normal behavior of solids is necessary for a complete understanding of effects induced by nuclear radiation in metals and other solids," Billington declared, "studies in related solid-state fields are being carried out in conjunction with the radiation effects experiments." One notable discovery, made by Mark Robinson and Ordean Oen, was the theoretical prediction of the "ion channeling" phenomenon, in which charged particles move undisturbed for long distances between the layers of atoms in a solid. This prediction was quickly followed by experimental programs at laboratories throughout the world, including ORNL, to study the channeling effect and to use it in research involving ion scattering and ion implantation.

Because research showed that some radiation-induced defects in metals move at room temperatures and below, it was necessary to produce these defects in samples at very low temperatures and to study them while they were "frozen-in" at the low temperatures. Such experiments, which were a tour de force for the Laboratory, were performed first at the Graphite Reactor and later at the Bulk Shielding Reactor by Tom Blewitt, Ralph Coltman, Tom Noggle, Charles Klabunde, and Jean Redman. The samples were placed in or very close to the reactor core. To keep the samples at low temperatures as the reactor operated, refrigerators with extreme cooling

"The success of the Laboratory's nuclear airplane project depended in part on understanding the potential impact of radiation on solid materials."

The Russells

A Family Affair

The Russells have made significant discoveries about mammalian genetics through experiments on mice using radiation and chemicals.

William Lawson (Bill) Russell and Liane Brauch (Lee) Russell, the eminent husband-and-wife team who have studied mammalian genetics for 45 years at ORNL's Biology Division, have much in common. Both received the International Roentgen Medal, both earned Ph.D. degrees in zoology and genetics from the University of Chicago, and both worked at the Jackson Memorial Laboratory in Bar Harbor, Maine, before coming to the Laboratory, where they have headed genetics research in the Biology Division. Also, both were elected to the National Academy of Sciences, one of only 11 couples so honored.

Bill Russell, the former scientific director of the Mammalian Genetics Section in the Biology Division and now an ORNL consultant, is a native of Newhaven, England, with a B.A. degree in zoology from Oxford University. Lee, head of the Mammalian and Genetics Development Section of the Biology Division since 1975, is a native of Vienna, Austria, with a B.A. degree in chemistry from Hunter College in New York City.

In 1947, Bill wanted to leave Jackson Memorial Laboratory but would only accept a new position if Lee were offered one, too. Alexander Hollaender, director of the new Biology Division at Clinton Laboratories, came through with such an offer, and Bill and Lee came to Oak Ridge in November 1947 shortly after Jackson Memorial Laboratory burned to the ground.

Bill's first achievement in Oak Ridge was to develop efficient and reliable genetic methods to determine the rate at which mouse genes are mutated by different types and levels of radiation. But, to do this, he had to set up the Mouse House, a national resource that contains more than a quarter million mice, for which he designed cages, food containers, racks, and machines for washing bottles and cages. Soon after experiments got under way, he found that the mutation rate in the mouse was 15 times that in the fruit fly. As a result, the National Council on Radiation Protection and Measurements reduced the permissible levels for occupational exposure to radiation.

In 1952, as a result of Lee's studies of the vulnerability of early embryos of irradiated mice, the Russells recommended that physicians use diagnostic X rays on the pelvic regions of childbearing women only during that part of the menstrual cycle when pregnancy cannot occur.

In 1958, the Russells and Elizabeth Kelly discovered that the mutation rate in mice exposed to chronic radiation

"Bill's first achievement in Oak Ridge was to develop efficient and reliable genetic methods to determine the rate at which mouse genes are mutated by different types and levels of radiation."

(spread over time) was between one-third and one-fourth the mutation rate in mice exposed to acute radiation (delivered in a matter of minutes). It was a significant finding because no dose-rate effect had been found in fruit-fly studies and because it suggested that a genetic repair mechanism corrects minor damage caused by low doses of radiation. By the mid-1960s the Russells had proved that sensitivity to radiation differs not only between mice and fruit flies but also between male and female mice.

"As a result of Lee's studies of the vulnerability of early embryos of irradiated mice, the Russells recommended that physicians use diagnostic X rays on the pelvic regions of childbearing women only during that part of the menstrual cycle when pregnancy cannot occur."

They then started a new area of investigation: determining the genetic effects on mice of chemicals from drugs, fuels, and wastes. In 1971, Bill and his associates published a paper recommending that, based on mouse studies, the drug hycanthone should continue to be used as a therapeutic drug for schistosomiasis, a debilitating parasitic disease common in the Third World. In 1975, Lee developed a fur-spot test for identifying chemicals likely to be mutagenic in reproductive cells. In 1979, Bill found that the laboratory chemical ethylnitrosourea (ENU) is the most potent mutagen ever tested

"They then started a new area of investigation: determining the genetic effects on mice of chemicals from drugs, fuels, and wastes."

in mice, making it a prime tool for studying mechanisms of mutagenesis.

In the 1980s, while continuing her research on the effects of chemicals on mice, Lee enlarged her genetic studies on the nature of mutational lesions caused by different treatments. Under her leadership, her section has increased in scientific staff and moved into areas of modern molecular genetics, including insertional mutagenesis and targeted mutagenesis—techniques that alter random or selected mouse genes. The research may unlock the secrets of human DNA by locating specific genes responsible for specific functions or malfunctions, such as diseased kidneys. DOE has recently recognized the section's unique capability for adding to the genome research effort.

In 1991, the international journal *Mutation Research* dedicated a special issue to Bill on his 80th birthday. In their introduction, the journal's editors stated, "No single person has contributed more to the field of mammalian mutagenesis, and thus to genetic risk assessment in man, than Dr. W. L. Russell." They might have added that his accomplishments likely would have been half as impressive without the scientific research conducted by his wife. Together, the Russells have formed one of the most fruitful collaborations in the annals of American science.

The Laboratory's Biology Division used thousands of mice in its radiation and genetics studies.

"From this work came the discovery that RNA has the same general structure as DNA."

capabilities were required; fortunately large refrigerators that had been built for early work on the hydrogen bomb had become surplus and were available for this work. Sample temperatures down to 3°K were ultimately obtained, and experiments in which the samples' dimensional changed, electrical resistivity, and stored energy were measured provided very important information on defect production by radiation and on defect removal as the sample temperatures were raised.

Important early radiation damage investigations on semiconductor materials were performed by Jim Crawford, John Cleland, and J. C. Pigg. The electrical properties of semiconductors are very sensitive to small numbers of defects, and these experiments were an important tool in establishing models of radiation damage and in understanding the changes in electrical properties caused by defects. Other important early radiation damage investigations included experiments by Fred Young, Jr., and Leslie Jenkins to study the chemical properties of metal surfaces. These experiments determined the effects of radiation on various chemical processes, such as oxidation. Results from the various radiation-damage experiments were important to the nuclear airplane project and to other types of reactor programs throughout the world, and members of the Solid State Division quickly gained international recognition for their research.

Researchers in the Biology Division shared a concern for radiation effects. Their focus was not inert solid materials but living cells. The nuclear plane project boosted this research as well, because calculating the sensitivity of cells to radiation would help determine the amount of shielding that would be necessary to protect passengers from potential radiation. This knowledge, in turn would have a direct effect on the design of the airplane.

Like so many other aspects of the nuclear plane project, this research had ramifications beyond its immediate goals. For example, Laboratory biologists learned that nucleoproteins, present in living cell nuclei and essential to normal cell functioning, are sensitive to ionizing radiation. Paper chromatography and ion-exchange methods used to separate compounds, Laboratory researchers reasoned, could help scientists and medical researchers measure and gauge this sensitivity.

After applying ion-exchange chromatography to separation of fission products and starting the Laboratory's radioisotopes program, Waldo Cohn used the same technique to separate and identify the constituents of nucleic acids. From this work came the discovery with Elliott Volkin that ribonucleic acid (RNA) has the same general structure as deoxyribonucleic acid (DNA), a concept that had a fundamental impact on molecular biology, virology, and genetics.

Of Mice and Mammals

By 1949, 10,000 mice were housed in ORNL's renovated facilities at the Y-12 Plant. Research on mice, led by the Biology Division's William and Liane Russell, was designed to advance understanding of radiation effects on mammals. According to William Russell, mice are used for genetic studies because they have few diseases, can be fed and maintained economically, reproduce rapidly, and have the same essential organs as humans. Liane Russell's 1950 survey of the gestation period of mice to examine their sensitivity to radiation yielded valuable information about critical periods during embryo development. She showed that radiation-induced changes of cells were more likely to occur during gestation. Largely because of her discovery of the greater radiation sensitivity of embryos, women have been cautioned about X-ray examinations during pregnancies.

The Russells, a cosmopolitan husband and wife team from England and Austria, came to Oak Ridge in 1948 from Bar Harbor, Maine. They expected Oak Ridge to be a backward community with minimal social and cultural opportunities. The Biology Division had an international clientele, however, and Liane Russell was surprised by the extent to which the world beat a path to Oak Ridge and the Laboratory. The Russells became renowned for taking their international guests on mountain hiking trails. They later played key roles in the creation of the Big South Fork National River Recreation Area, a wilderness preserve just north of Oak Ridge.

Technology School

Just as the Biology Division had an international reputation, the Oak Ridge School of Reactor Technology (ORSORT) established in 1950 enjoyed national prestige. ORSORT was the reestablished version of the original reactor training school of 1946–47. Because reactor technology was security-sensitive and could not be taught in universities, the AEC, with considerable support from Captain Rickover and the Navy, sponsored this school for outstanding engineers and scientists. Frederick VonderLage, the school's first director, was a former Navy officer who had taught physics at the Naval Academy. The faculty included Laboratory staff, and the school's text consultant was Samuel Glasstone, who published several overviews of nuclear reactor technology.

John Swartout was an ORNL deputy director.

"Just as the Biology Division had an international reputation, the Oak Ridge School of Reactor Technology enjoyed national prestige."

Rickover

Setting the Nuclear Navy's Course

He was blunt, had a knack for quick comebacks and, as an officer in the U.S. Navy, subjected his prospective staff to grueling interviews to determine their reactions under stress. He earned a place in the history of nuclear technology, but never achieved his goal of becoming a submarine skipper. He was the legendary Hyman G. Rickover, who received a Congressional Gold Medal in 1959 "in recognition of his achievements in successfully directing the development and construction of the world's first nuclear-powered ships and the first large-scale nuclear power reactor devoted exclusively to production of electricity." His success, in part, was rooted in his nuclear training at Oak Ridge.

In May 1946, Rickover received word that the Navy had selected him to go to Oak Ridge to study nuclear engineering. His response was to collect and study books on atomic physics, chemistry, and mathematics. He also reviewed all Navy reports and memos on atomic energy and learned that Navy physicist Ross Gunn had proposed using nuclear energy to power submarines.

When he arrived at the Clinton Laboratories Training School, he found four other Navy officers there. He gathered them together and told them he had been assigned the task of preparing their fitness reports, which are similar to performance appraisals. This bold tactic, uncertified by his superiors, gave Rickover substantial influence over the assignments and promotions of his peers. Using this power, he then asked the officers to take detailed notes and write definitive reports on specific topics. By getting the officers to work for him, Rickover took the first step toward developing a nuclear navy.

Theodore Rockwell, a former ORNL engineer, was a classmate of Rickover in Oak Ridge and tells this story about the captain in his recent book *The Rickover Effect: How One Man Made A Difference:*

The lecturer was Dr. Frederick Seitz, an eminent physics professor who later became head of the National Academy of Sciences and president of Rockefeller University. . . [Rickover] kept asking simple, basic questions, making himself look pretty stupid and getting a lot of knowing chuckles from the wiseacres. "I'm not getting this. Would you please go over it again?" Rickover, the silver-haired captain, would say. The prof asked condescendingly, "Would you perhaps like to have us provide you with some tutoring in the evenings?"

Not taking this as a putdown, the captain said merely, "I would appreciate that very much, sir." So the tutoring class was in fact set up, despite the chuckles, and I decided I could probably get some good out of it myself. When I got to the tutoring class a little late, I was surprised to see not only the captain but a dozen or more of his classmates, including some of the chucklers, all busily taking notes. Noting my startled look, the captain said, "I guess I'm not the only dummy in the class. Just the only one with the guts to admit it."

Admiral Hyman G. Rickover, father of the nuclear navy, converses with Edward Teller, father of the hydrogen bomb.

Rickover later worked with Alvin Weinberg, then ORNL's director of research, both to establish the Oak Ridge School of Reactor Technology (ORSORT), known locally as the Klinch Kollege of Knuclear Knowledge, and to begin the design of the pressurized-water reactor for submarine propulsion.

Graduates of the one-year program in nuclear science and technology were awarded the degree of Doctor of Pile Engineering, allowing them to write D.O.P.E. after their names. ORSORT turned out 100 graduates a year, many of whom became leaders in the nuclear industry.

In 1958, the first commercial nuclear power plant in the United States, the Shippingport plant in Pennsylvania, began operating, and the first nuclear submarine, the *Nautilus*, sailed submerged from Hawaii to England by way of the North Pole. Rickover's leadership and his nuclear knowledge from Oak Ridge played a major role in these historic achievements, earning him the sobriquet father of the nuclear navy.

Aerial view of the Laboratory in the early 1950s. Notice the 4500-N building in the foreground and the Graphite Reactor and quonset huts in the upper right corner.

The 50 members of the school's first class in 1950 came from the AEC, government contractors, and the armed services; the second class came largely from industries needing personnel trained in reactor engineering and operations; later, college graduates planning to work in the nuclear industry were accepted. Students took courses in reactor technology that covered reactor neutron physics, radiation damage, reactor materials, chemical separations processes, and experimental reactor engineering. They spent a year in Oak Ridge and supplemented their classroom training with part-time research assignments at the Laboratory. After two semesters, students would load fuel into the movable assembly in the Bulk Shielding Reactor, plotting the power output curve as fuel was added and the flux increased. They then compared the onset of critical mass with their predictions. Later, they spent a summer investigating specific problems, often analyzing a reactor design under consideration by the AEC and then submitting a thesis on its feasibility.

The school expanded during the 1950s, occupying a new building completed by the Laboratory in 1952 and specializing in advanced subjects not taught at universities. Under director Lewis Nelson, the school in 1957 joined six universities in offering a standard two-year curriculum. At the end of the decade, the first international students enrolled. Five years later, the school closed when university science and engineering programs became equal to the task of providing this type of specialized instruction. Of its 986 enrollees during the school's 15 years of instruction, only 10 did not complete the course. Some of its graduates became leaders in the nuclear industry.

Flying High

When Union Carbide assumed management of the Laboratory, the Graphite Reactor was the only nuclear reactor on the Oak Ridge Reservation.

"The scientific data gleaned from the aircraft project, however, soon proved useful when the Laboratory undertook the design of a molten-salt reactor for electric power production."

By 1953, the Laboratory had three reactors operating, two nearing completion, and several others in various stages of planning and development. In addition, it had high-speed computers, high-energy cyclotrons, and Van de Graaff particle accelerators. Equally important, the Laboratory had succeeded in assembling an aggressive research staff that worked with a sense of urgency rivaling that of the war years.

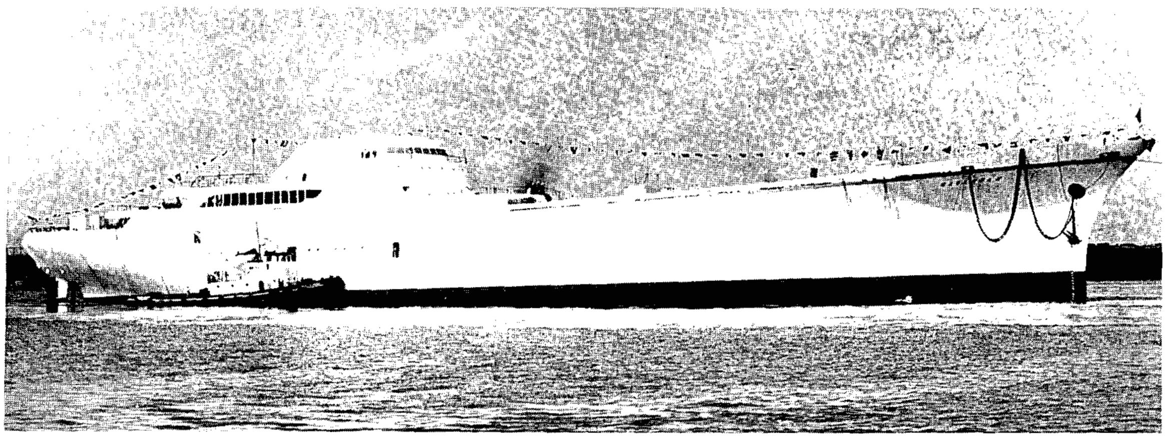
As the Laboratory expanded its reactor and shielding programs in response to the nuclear aircraft project and acquired the Y-12 Plant's research organization in the early 1950s, administrative realignment became necessary. Electronics experts from the Physics Division, for example, moved into an Instrumentation and Controls Division, and the Shielding group became a separate Neutron Physics Division (renamed the Engineering Physics Division, and later the Engineering Physics and Mathematics Division). The Mathematics Section also became an independent division. Similar organizational changes took place in chemistry, reactor technology, and other Laboratory research pursuits.

By 1953, Laboratory personnel numbered 3600, more than double the wartime peak; the staff was divided into 15 research and operating divisions. "I am sometimes appalled by the size and scope of our operation here," Weinberg admitted privately to Wigner. "It seems that we have become willy-nilly victims, in a particularly devastating way, of the big operator malady."

In response, Wigner advised Weinberg to appoint deputy and assistant directors to assist central management. Weinberg accepted the advice. John Swartout, director of the Chemistry Division, became Weinberg's assistant director in 1950 and deputy director in 1955. For administrative functions, Swartout became "Mr. Inside," while Weinberg was "Mr. Outside." Other assistant directors of the early 1950s included Elwood Shipley, Charles Winters, Robert Charpie, Walter Jordan, Mansell Ramsey, Ellison Taylor, and George Boyd.

"There is," observed Weinberg, "a hierarchy of responsibility in which management on each level depends on the integrity and sense of responsibility of the next level to do the job sensibly and well." This line of responsibility from individual to group leader to section chief to division director to assistant or associate director to Laboratory director remained the prevailing administrative framework within the Laboratory during the ensuing decades.

Leaders of the Laboratory's nuclear aircraft project during a May 1957 visit to Wright-Patterson Air Force Base.



In the late 1950s, the Laboratory participated in the power plant design for the nuclear ship *Savannah*.

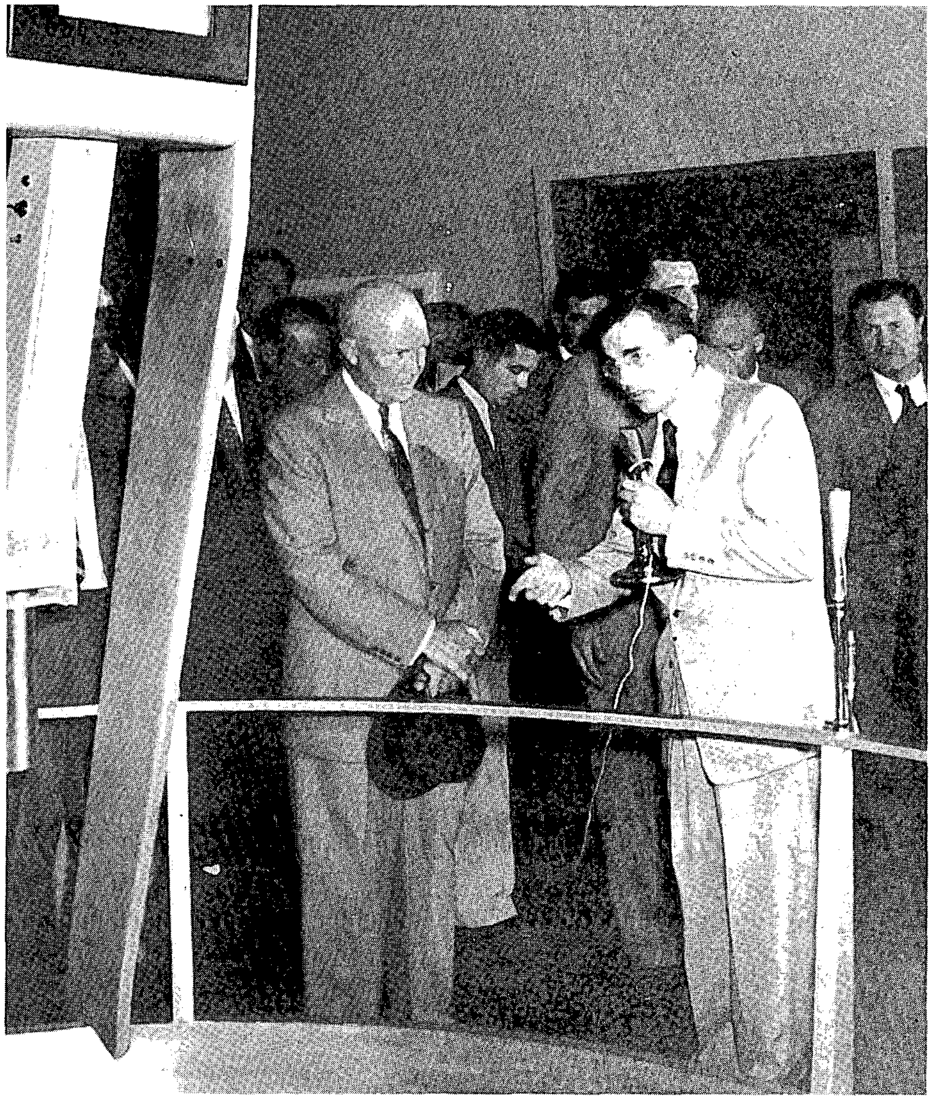
The prime force behind Laboratory expansion during the early 1950s ended in 1957, when Congress objected to continuing the costly nuclear aircraft project in the face of supersonic aircraft and ballistic missile development that made the nuclear aircraft concept obsolete. In response to this congressional decision, the Laboratory shelved its aircraft shielding and reactor prototype investigations. In 1961, President John Kennedy canceled the remainder of the nuclear aircraft project.

The scientific data gleaned from the aircraft project, however, soon proved useful when the Laboratory undertook the design of a molten-salt reactor for electric power production. William Manly, a veteran of the nuclear aircraft program, later pointed out that the knowledge gained in handling liquid metals and fused salts also proved useful in design of nuclear generators and reactors for use in space. As Laboratory metallurgist George Adamson summarized it, "The program quite literally didn't get off the ground, but out of it grew the base for the high-temperature materials technology needed by NASA and in several industrial fields."

Although the nuclear aircraft project stalled, the Laboratory's participation in efforts to apply nuclear energy to vehicle propulsion continued briefly in consultation with the Maritime Commission, which in 1957 built a nuclear-powered merchant ship. The 21,000-ton ship, propelled by a pressurized-water reactor, was a floating laboratory, demonstrating the feasibility of commercial ships propelled by nuclear energy. At the Laboratory, a Maritime Reactors group headed by Alfred Boch provided technical review of the ship reactor design, while other Laboratory units assisted with on-board health monitoring, environmental studies, and waste disposal.

Completed in July 1959, the *N.S. Savannah* could remain at sea for 300,000 miles without refueling, proving the scientific and engineering feasibility of such ships. Nuclear-powered ships, however, could not compete economically with oil-fired vessels; thus, the *N.S. Savannah* became the first and last U.S. ship of its kind.

In the 1960s, the Laboratory became involved in nuclear power studies for the national space program, and in the 1980s it studied space reactors for the Strategic Defense Initiative. Despite these efforts, it is fair to say that the Laboratory's work on the *N.S. Savannah* marked the end of its nuclear transportation programs. Postwar dreams of nuclear-powered trains, automobiles, aircraft, and tractors ended, but the scientific findings that evolved from these endeavors would find applications in other areas in the years ahead.



Leo Holland, an ORNL reactor expert, describes the 1955 Geneva Conference reactor to President Dwight Eisenhower. The reactor was built at ORNL.

Chapter 4

Olympian Feats

A symbol of peaceful competition first in the ancient world and then in the 20th century, the Olympics were revived after World War I, not only in quadrennial athletic performances but also in scientific competitions. Sparked in 1953 by President Dwight Eisenhower's call for international cooperation in the peaceful uses of atomic energy, in 1955 and 1958 scientists worldwide showcased their achievements at international conferences that resembled the athletic Olympics. In these competitions, the world-class research at Oak Ridge National Laboratory often took the laurels.

Science during the 1950s became a full-blown instrument of foreign policy, both in Cold War weapons competition and in peaceful applications of nuclear science, especially nuclear fission reactors and fusion energy devices. As an international center for nuclear fission research by the mid-1950s, the Laboratory had as many as six

"All the News That's Fit to Print"

The New York Times.

LATE CITY EDITION

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STRIKE ENDS ON 6 PAPERS ON 11TH DAY

FACT BOARD SET UP

Engravers Accept Plan of Mediators—20,000 Return to Work

NOTICE

KNOWLAND ASSERTS REDS WILL BE ISSUE IN '54, '56 ELECTIONS

G.O.P. Chief Predicts Pressure to Toughen Policy on Allied Trade With Communists

EISENHOWER BIDS SOVIET JOIN U. S. IN ATOMIC STOCKPILE FOR PEACE; WEST ASKS 4-POWER PARLEY JAN. 4

REPLY SENT SOVIET

Allies Assure Russians of Peace Aims—Will Weigh 5-Power Talk

ENERGY POOL GOAL

President Offers New Idea in U. N. Talk to End Long Impasse

2 TRUCKERS KNIFED IN GARBAGE STRIKE

Several Others Beaten on East Side as Violence Spreads in Day-Old Walkout

PROPOSES NEW ATOMIC CONTROLS: President Eisenhower as he addressed the United Nations General Assembly yesterday. On platform in rear are Dag Hammarskjold, Secretary General of the U. N., and Mme. Vijaya Lakshmi Pandit, President of the General Assembly.

Dean Calls Soviet 'Warlike' As Reds Bar U.N. Korea Plan

PRESIDENT BARES HUGE ATOMIC GAINS

New York Times announces President Eisenhower's "Atoms for Peace" program.

reactors under design or construction. The Laboratory's chemical technology expertise also made it a leader in reactor fuel reprocessing and recovery. Both these programs earned the Laboratory much prestige at the 1955 scientific olympics. Also, in 1958, the Laboratory's tiny fusion energy research effort vaulted above larger programs elsewhere to win the gold at the second United Nations Conference on Peaceful Uses of Atomic Energy.

The Laboratory and other AEC facilities also embarked on a program of experimental reactor development in 1953. That year, the Laboratory's experimental homogeneous reactor, under Samuel Beall's direction, first generated electric power. Elsewhere, other nuclear mileposts were passed: a demonstration atomic reactor to propel submarines and an experimental breeder reactor began operating in Idaho, and the first university research reactor was unveiled at North Carolina State University.

In a dramatic speech on the future of the atom to the United Nations in 1953, President Eisenhower pledged the United States "to find the way by which the miraculous inventiveness of man shall not be dedicated to his death, but consecrated to his life." The president's "Atoms for Peace" speech, hailed throughout the world as a prologue to a new chapter in the history of nuclear energy, was to guide the research efforts of the AEC and the Laboratory for years to come. The initiative, Alvin Weinberg declared, would make nuclear science the "touchstone of peace."

Soon after this address, President Eisenhower signed the 1954 Atomic Energy Act, which fostered the cooperative development of nuclear energy by the AEC and private industry. In response, the AEC began a massive declassification of nuclear science data for the benefit of private users, and the Laboratory assumed a key role in the AEC's five-year plan to develop five new demonstration nuclear reactors.

Launched in 1954, the AEC plan called for construction of a small pressurized-water reactor by Westinghouse Corporation; an experimental boiling-water reactor by Argonne National Laboratory; a fast breeder reactor, also by Argonne; a sodium-graphite reactor by North American Aviation; and an aqueous homogeneous-fuel reactor by Oak Ridge National Laboratory.

Beyond its work on the homogeneous reactor, the Laboratory in the 1950s—as a national center for chemistry and chemical technology—focused on developing fluid fuels for nuclear reactors. The

"A homogeneous reactor held the promise of simplifying nuclear reactor designs."

"Despite his enthusiasm, Weinberg found AEC's staff decidedly bearish on homogeneous reactors."

Laboratory concentrated on three possible options: fuels in solution, fuels suspended in liquid (or slurries), and molten salt fuels. Each one posed fundamental challenges in chemistry and chemical technology. Moving confidently from solids to liquids to gases in support of the AEC efforts on behalf of the atom, the Laboratory also conducted research for heterogeneous, solid-fuel reactors. It also provided conceptual designs for a transportable Army package reactor, a maritime reactor, and a gas-cooled reactor.

The Cold War and President Eisenhower's "Atoms for Peace" speech reenergized and refocused the Laboratory's research efforts. In effect, it gave the Laboratory a multifaceted research agenda, many aspects of which were tied to the development and application of nuclear power. Summarizing the impact of the nation's postwar aims on the work of the Laboratory, Director Clarence Larson commented, "1954 has witnessed the transition that many of us have hoped for since the war. The increasing emphasis on peacetime applications of atomic energy," he went on to say, "has been a particular source of gratification."

Homogeneous Reactor

In addition to the Aircraft Reactor Experiment, the Bulk Shielding Reactor, and the Tower Shielding Facility built as part of its Aircraft Nuclear Project for the Air Force, the Laboratory had three other major reactor designs in progress during the mid-1950s: its own new research reactor with a high neutron flux; a portable package reactor for the Army; and the Aqueous Homogeneous Reactor, which was unique because it combined fuel, moderator, and coolant in a single solution (designed as one of five demonstration reactors under AEC auspices).

Initial studies of homogeneous reactors took place toward the close of World War II. It pained chemists to see precisely fabricated solid-fuel elements of heterogeneous reactors eventually dissolved in acids to remove fission products—the "ashes" of a nuclear reaction. Chemical engineers hoped to design liquid-fuel reactors that would dispense with the costly destruction and processing of solid fuel elements. The formation of gas bubbles in liquid fuels and the corrosive attack on materials, however, presented daunting design and materials challenges.

With the help of experienced chemical engineers brought to the Laboratory after its acquisition of the Y-12 laboratories, the Laboratory proposed to address these design challenges. George Felbeck, Union Carbide manager, encouraged their efforts. Rather than await theoretical solutions, Laboratory staff attacked the problems empirically by building a small, cheap experimental homogeneous reactor model. Engineering and design studies began in the Reactor Experimental Engineering Division under Charles Winters, and in 1951 the effort formally became a project under John Swartout and Samuel Beall.

This was the Laboratory's first cross-divisional program. Swartout provided program direction to groups assigned in the Chemistry, Chemical Technology, Metallurgy, and Engineering divisions, while Samuel Beall led construction and operations. Beecher Briggs headed reactor design; Ted Welton, Milton Edlund, and William Breazeale were in charge of reactor physics; Edward Bohlmann directed corrosion testing; and Richard Lyon and Irving Spiewak performed fluid flow studies and component development.

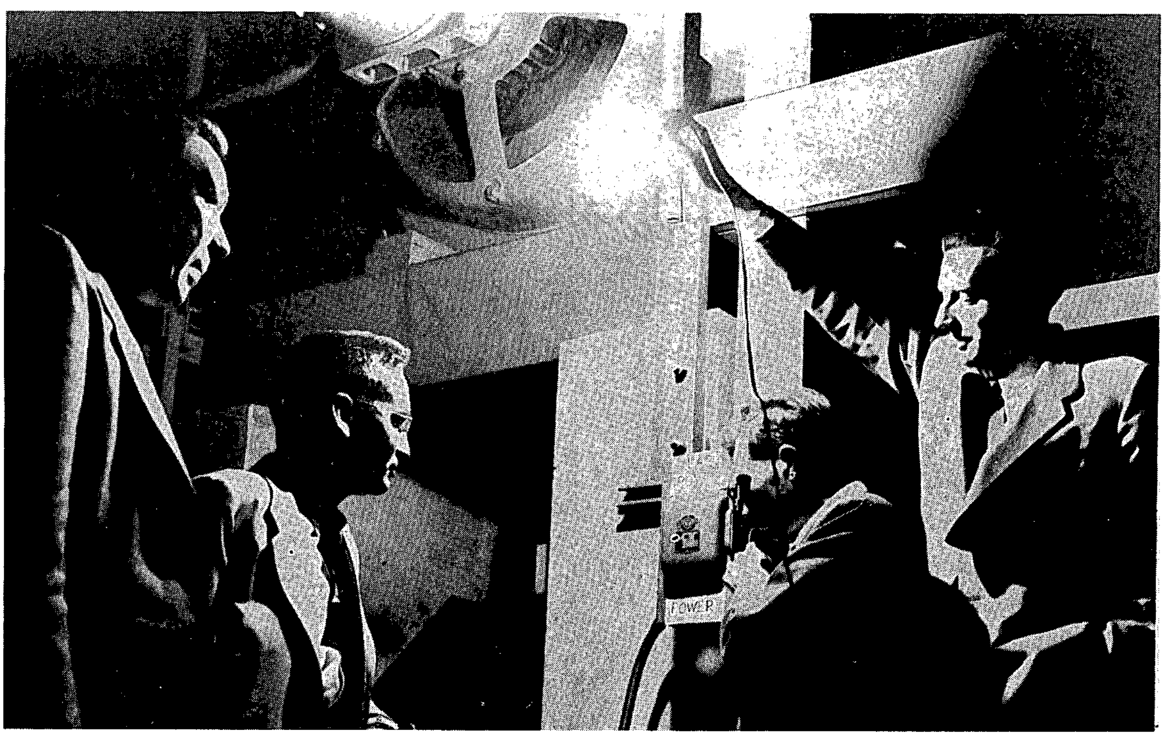
A homogeneous (liquid-fuel) reactor had two major advantages over heterogeneous (solid-fuel and liquid-coolant) reactors. Its fuel solution would circulate continuously between the reactor core and a processing plant that would remove unwanted fissionable products. Thus, unlike a solid-fuel reactor, a homogeneous reactor would not have to be taken off-line periodically to discard spent fuel. Equally important, a homogeneous reactor's fuel and the solution in which it was dissolved served as the source of power generation. For this reason, a homogeneous reactor held the promise of simplifying nuclear reactor designs.

A building to house the Homogeneous Reactor Experiment was completed in March 1951. The first model to test the feasibility of this reactor used uranyl sulfate fuel. After leaks were plugged in the high-temperature piping system, the power test run began in October 1952, and the design power level of one megawatt (MW) was attained in February 1953. The reactor's high-pressure steam twirled a small turbine that generated 150 kilowatts (kW) of electricity, an accomplishment that earned its operators the honorary title "Oak Ridge Power Company."

Marveling at the homogeneous reactor's smooth responsiveness to power demands, Weinberg found its initial operation thrilling. "Charley Winters at the steam throttle did everything, and during the course of the evening, we electroplated several medallions and blew a steam whistle with atomic steam," he exulted in a report to Wigner, asking him to bring von Neumann to see it. Despite his enthusiasm, Weinberg found AEC's staff decidedly bearish on homogeneous reactors and, in a letter to Wigner, he speculated that the "boiler bandwagon has developed so much pressure that everyone has climbed on it, pell mell." Weinberg surmised that the AEC was committed to development of solid-fuel reactors cooled with water and Laboratory demonstrations of other reactor types—regardless of their success—were not likely to alter its course.

Despite AEC preferences, the Laboratory dismantled its Homogeneous Reactor Experiment in 1954 and obtained authority to build a large pilot plant with "a two-region" core tank. The aim was not only to produce economical electric power but also to irradiate a thorium slurry blanket surrounding the reactor, thereby producing fissionable uranium-233. If this pilot plant proved successful, the Laboratory hoped to accomplish two major goals: to build a full-scale homogeneous reactor as a thorium "breeder" and to supply cheap electric power to the K-25 plant to enrich uranium.

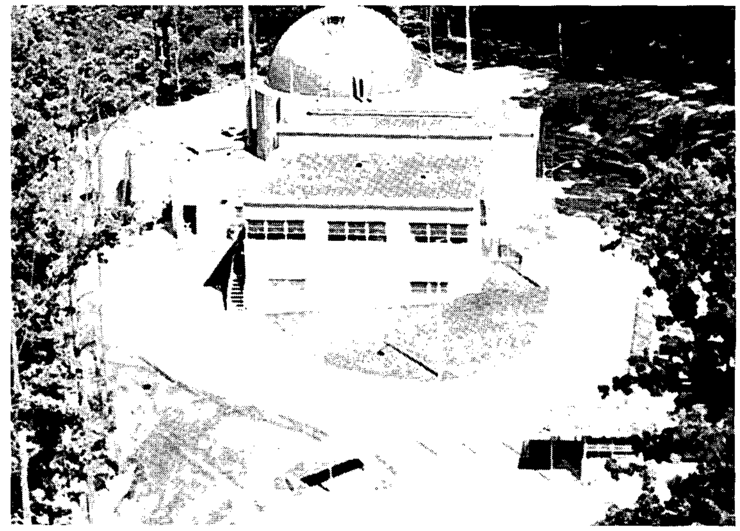
Initial success stimulated international and private industrial interest in homogeneous reactors, and in 1955 Westinghouse Corporation asked the Laboratory to study the feasibility of building a



ORNL Director Alvin Weinberg and colleagues start the Homogeneous Reactor Experiment–1. The reactor produced enough power to light 50 homes.

"Initial success stimulated international and private industrial interest in homogeneous reactors."

full-scale homogeneous power breeder. British and Dutch scientists studied similar reactors, and the Los Alamos Scientific Laboratory built a high-temperature homogeneous reactor using uranyl phosphate fluid fuel. If the Laboratory's pilot plant operated successfully, staff at Oak Ridge thought that homogeneous reactors could become the most sought-after prototype in the intense worldwide competition to develop an efficient commercial reactor. Proponents of solid-fuel reactors, the option of choice for many in the AEC, would find themselves in the unenviable position of playing catch-up. But this was not to be.



Aerial view in 1957 of the Army Package Reactor building at Fort Belvoir, Virginia.

Army Package Reactor

Similar initial success flowed from studies at the Oak Ridge School of Reactor Technology, where a study group in 1952 proposed a compact, transportable package reactor to generate steam and electric power at military bases so remote that supplying them with bulky fossil fuels was too difficult and costly.

The AEC and Army Corps of Engineers expressed a great deal of interest in this concept, and in early 1953 Laboratory management met with Colonel James Lampert and Army Corps of Engineers staff to initiate planning for such a mobile reactor. Alfred Boch and a team including Harold McCurdy and Frank Neill in the Electronuclear Division were given responsibility to design this small reactor. They selected a heterogeneous, pressurized-water, stainless steel system design that could use standard components wherever possible for easy replacement at remote bases. Walter Jordan led a Laboratory team that drew up specifications for a package reactor capable of generating 10 MW of heat and 2 MW of electricity. General Samuel Sturgis, chief of the Army Engineers, decided to build the reactor at Fort Belvoir, Virginia, where his officers could be trained to operate it.

"With a core easily transportable in a C-47 airplane, the Army Package Reactor could generate power for two years without refueling."

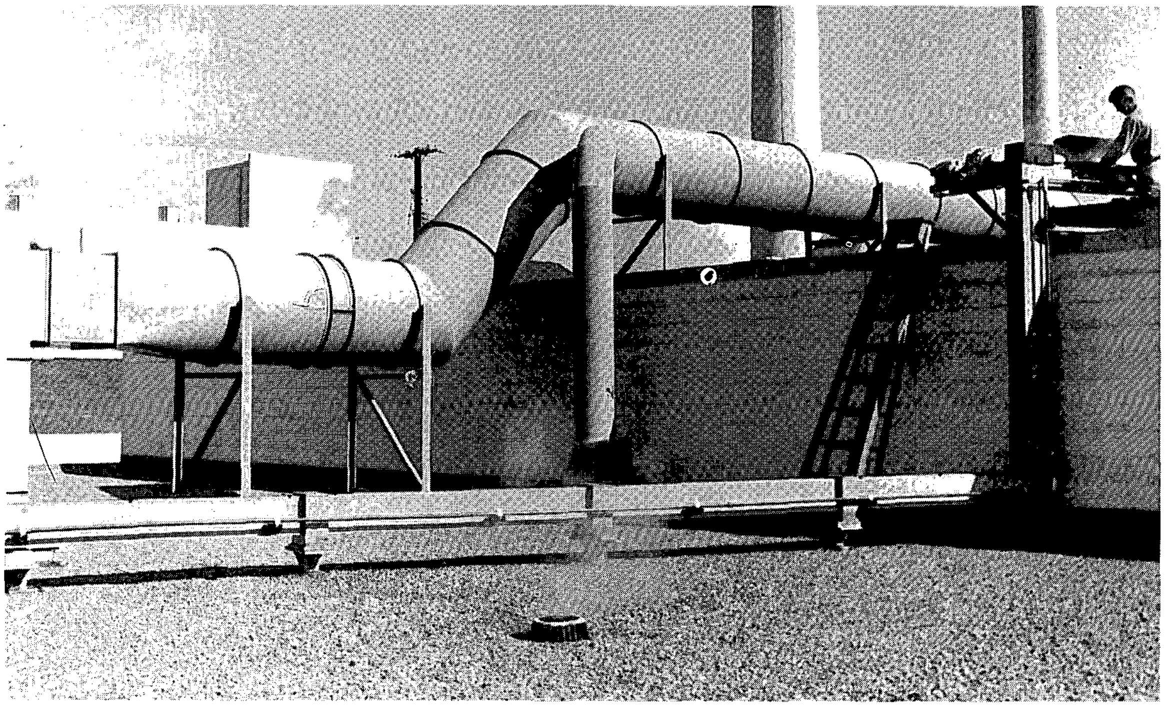
The Army Package Reactor was the first reactor built under bid by private contractors. The Army Corps of Engineers, in fact, received 18 bids that ranged from \$2.25 million to \$7 million. The Corps awarded the contract to Alco Products (American Locomotive Company) in December 1954, and Alco completed the reactor in 1957.

With a core easily transportable in a C-47 airplane, the Army Package Reactor could generate power for two years without refueling; a small oil-fired plant would consume 54,000 barrels of diesel fuel over the same period. The Army later built similar package reactors for power and heat generation in the Arctic and other remote bases.

Purification

Ancient athletes considered the Olympics a purifying experience. Purification was also a preoccupation of scientists who participated in the nuclear olympics of the 1950s—not personal purification, but fuel purification to enable nuclear reactors to operate more efficiently.

Although designers of the homogeneous reactor hoped to achieve simultaneous reactor operation and fuel purification, other Laboratory technologists led successively by M. D. Peterson, Frank Steahly, and



Sample conveyor on Building 3019 for the THOREX pilot plant's tests of nuclear fuel reprocessing methods.

Floyd Culler sought to improve fuel purification by recovering valuable plutonium and uranium from spent fuel elements and separating them from fission products. Laboratory interest in these efforts was reflected by the subdivision of its Technical Division into the Reactor Technology and the Chemical Technology divisions in February 1950. The Reactor Technology Division carried out Laboratory responsibilities for reactor development, whereas the Chemical Technology Division, following the lead of the Laboratory's "separations and recovery" experience during and after World War II, sought to improve chemical separations processes.

The Laboratory's most important achievement during World War II had been the recovery of plutonium from Graphite Reactor fuel. Drawing on its wartime experience, the Laboratory attained notable success during the postwar years recovering uranium stored in waste tanks near the Graphite Reactor. Hanford's management called on Laboratory staff to address similar recovery problems at its plutonium production facilities in the state of Washington. The Laboratory also built a pilot plant to improve Argonne National Laboratory's REDOX process for recovering plutonium and uranium by solvent extraction. The pilot plant served as a prototype for an immense REDOX process plant completed at Hanford in 1952. To recover uranium from fuel plates at the AEC's Idaho reactor site, Frank Bruce, Don Ferguson, and associates improved the so-called "25 process," and Floyd Culler completed design of a large plant that used this process, also in 1952.

Recovery, separation, and extraction—the primary components of fuel purification—were big business at the Laboratory during the 1950s. Such efforts played a major role in developing the Plutonium and Uranium Extraction (PUREX) process selected in 1950 for use at the Savannah River Plant reactors. Two huge PUREX plants were built at Savannah River in 1954 and a third at Hanford in 1956. Later, large plants using the PUREX process were built in other nations, and some Laboratory executives believe the PUREX process may constitute the Laboratory's greatest contribution to nuclear energy.

"The PUREX process may constitute the Laboratory's greatest contribution to nuclear energy."

By 1954, the Laboratory's chemical technologists had completed a pilot plant demonstrating the ability of the THOREX process to separate thorium, protactinium, and uranium-233 from fission products and from each other. This process could isolate uranium-233 for weapons development and also for use as fuel in the proposed thorium breeder reactors.

During the 1950s, the Laboratory's Chemical Technology Division served as the AEC's center for

VIPs at the ORR

ORNL Director Alvin Weinberg (second from right) shows the Oak Ridge Research Reactor control room to then Senator John F. Kennedy, Senator Albert Gore, Sr., and Jacqueline Kennedy.

In the late 1950s and early 1960s, the Oak Ridge Research Reactor (ORR) attracted a host of famous people, including a queen, two kings, and three future U.S. presidents—Gerald Ford, Lyndon Johnson, and John F. Kennedy.

Senator Kennedy's visit to Oak Ridge on February 24, 1959, was described in great detail by *The Oak Ridger*, but no details were included on his visit to the ORR. From the available photos and newspaper stories, we know that he visited the reactor in the afternoon with his wife Jacqueline, Tennessee Senator Albert Gore Sr., and ORNL Director Alvin Weinberg.

Weinberg says the following about Kennedy's visit: "John Swartout, the deputy director of ORNL, and I accompanied our visitors. Since I was director, I chose to accompany Jackie. John was left to show Jack and Senator Gore around."

Before visiting ORNL, Senator Kennedy had told 300 people at the Oak Terrace Restaurant in Grove Center that he was planning to run for president in 1960. He expressed support for peaceful uses of atomic energy and praised Senator Gore for being a leading exponent in the Senate for this cause.

Kennedy, who was described as "youthful and personable" by *The Oak Ridger*, said in his talk, "Here in Oak Ridge this nation has demonstrated the vast power which results from the combination of many talents and resources—abundant power, scientific personnel, industrial capabilities, fuel supplies, and zealous government administration."

Senator Lyndon Johnson visited the ORR in 1958, and U.S. Representative Gerald Ford toured it in 1965. Vice President Hubert Humphrey was a guest at the ORR on February 4, 1965, and Senator John Pastore visited the reactor in January 1963.

"The ORR's engineering-scale experiments, although not the first of their type, were the most advanced for their time."

ORNL Director Alvin Weinberg shows a model of Building 4500-North to Queen Frederika of Greece.

King Hussein of Jordan operates manipulators at the Oak Ridge Research Reactor.

"Why was the Oak Ridge Research Reactor such an attraction for royalty and famous politicians? At the time, according to Weinberg, research reactors were a novelty, and peaceful uses of nuclear energy were considered an unquestionable boon to humankind. The ORR was especially appealing because the beautiful blue glow from Cerenkov radiation that suffused its core was unlike anything the visitors had ever seen."

At the Oak Ridge Research Reactor, Weinberg hosted several members of royalty. King Leopold, former ruler of Belgium, visited the ORR in September 1957, and King Bhumibol Adulyadej of Thailand came in 1960.

Queen Frederika of Greece toured the reactor on November 7, 1958, prompting a flurry of photographs. She was the first queen ever to visit ORNL. *The ORNL News* reported that the queen "revealed a keen sense of knowledge of the nuclear energy field in her conversations with ORNL scientists."

The March 30, 1959, visit of King Hussein of Jordan, only 23 years old at the time, prompted an article in *The ORNL News* detailing the young monarch's life story to date.

Other distinguished visitors to the ORR included Sardor Mohammed Davd, prime minister of Afghanistan (June 28, 1958); Sir Ahmadu Bello, premier of Northern Nigeria (1960); and Ambassador Indira Nehru of India (October 26, 1963), who later became the country's prime minister. The heads of a Soviet Union laboratory and the Soviet Academy of Science were guests at the ORR in 1959, and Nobel Laureate Glenn Seaborg visited the reactor in 1963.

Why was the Oak Ridge Research Reactor such an attraction for royalty and famous politicians? At the time, according to Weinberg, research reactors were a novelty, and peaceful uses of nuclear energy were considered an unquestionable boon to humankind. The ORR was especially appealing because it was the most powerful research reactor in the world and because the beautiful blue glow from Cerenkov radiation that suffused its core was unlike anything the visitors had ever seen. For all these reasons, the ORR was a standard stop on all VIP tours of the Laboratory.

"The new Oak Ridge Research Reactor was completed and reached its design power in March 1958."

pilot plant development, echoing the Laboratory's wartime role in plutonium recovery and extraction. The succession of challenges it had to meet—uranium-235 recovery, PUREX development, and construction and operation of the REDOX and THOREX pilot plants—swelled the ranks of the Chemical Technology Division from fewer than 100 people in 1950 to almost 200 in 1955. A similar expansion took place in the Analytical Chemistry Division. Its staff increased from 110 people to 214 people during the same period.

The fuel purification program brought Eugene Wigner back to the Laboratory in 1954. Wigner had been working for Du Pont on the design of the Savannah River reactors when he agreed to return to Oak Ridge to apply his chemical engineering expertise to design a solvent extraction plant. Labeled Project Hope because it promised to extend the supply of fissionable materials for energy production, Wigner's 1954 study resulted in the design of a processing plant able to recover uranium-235 from spent fuel for reuse in reactors at a cost of $1 per gram, much lower than the prevailing cost of $7.50 per gram of uranium from ore.

His study helped turn the attention of the Laboratory's chemical technologists from improving individual processes for recovery of uranium, plutonium, and thorium to developing an integrated plant capable of separating all nuclear materials at a single site. The proposed power reactor fuel reprocessing facility would have competed with private industry, however, and eventually the AEC decided not to construct it.

Oak Ridge Research Reactor

In 1953, the Laboratory received AEC approval to build a new research reactor. The reactor design, blueprinted by Tom Cole's team, combined features of the Materials Testing Reactor and the Bulk Shielding Reactor. With a thermal power rating of 20 MW, its neutron flux—the neutron beam intensity so critical for research—was 100 times greater than that of the Graphite Reactor and was exceeded only by that of the Materials Testing Reactor in Idaho.

After several construction delays, the new Oak Ridge Research Reactor (ORR) was completed and reached its design power in 1958. A flexible, high-performance reactor with an easy-to-access core, it facilitated research during 30 years of operations under Jim Cox and successors, supporting many scientific advances.

Physicists Cleland Johnson, Frances Pleasonton, and Arthur Snell performed the first scientific experiments at the Oak Ridge Research Reactor. Examining the relative directions of neutron and electron (beta particle) emissions in the decay of helium-6 nuclei, they confirmed the electron-neutrino theory of nuclear beta decay. The results guided the improvement of the recoil spectrometry techniques pioneered by Snell and his colleagues. Information on the masses, energies, and nuclear particles of fission fragments was obtained at the ORR by John Dabbs, Louis Roberts, George Parker, John Walter, and Hal Schmitt. Jack Harvey, Bob Block, and Grimes Slaughter used time-of flight spectrometry to obtain data for the design of fission power reactors.

Neutron scattering research at the ORR by Wallace Koehler, Mike Wilkinson, Ralph Moon, Joe Cable, and Ray Child examined the magnetic properties of rare earths and other materials. Using a triple-axis spectrometer at an ORR beam port, Harold Smith, Wilkinson, Bob Nicklow, and Herb Mook gained new insights on the dynamic properties of solids and the interatomic forces in various crystals. Henri Levy, Selmer Peterson, Smith, Bill Busing, and George Brown pioneered automated single-crystal neutron diffraction studies, producing information on the structure of such materials as sugar crystals.

A Physics Division team composed of Philip Miller, James Baird, and William Dress worked at the ORR in collaboration with Norman Ramsey of Harvard for a decade, conducting a series of experiments on an electrical charge characteristic of neutrons. They designed and operated a novel neutron spectrometer based on Ramsey's separated oscillatory-field method for magnetic resonance. For this work and other investigations of the fundamental characteristics of the proton and neutron, Ramsey was awarded the Nobel Prize in physics in 1989.

Another example of pioneering research at the ORR was completed from 1974 to 1978 by Kirk

Dickens, Bob Peelle, Temple Love, and Jim McConnell of the Neutron Physics Division together with Juel Emory and Joe Northcutt of the Analytical Chemistry Division. They measured the rate of heat generation from the decay of fission products in reactor fuel, an effect crucial to determining what might happen during loss-of coolant accidents at reactors and how much emergency cooling would be required for reactor cores.

Using sets of capsules moved mechanically into and out of the ORR's neutron stream, nuclear fuels for reactors were tested. These capsules often had colorful names, such as the "eight-ball capsule" used to test spherical fuel for a German gas-cooled reactor. For gas-cooled reactor experiments led by John Conlin, John Coobs, and Edward Storto, two fuel irradiation test loops using circulating helium were installed at the ORR.

The Oak Ridge Research Reactor was built at the Laboratory during the 1950s.

To qualify a second reactor core for the nuclear ship *Savannah*, I. T. Dudley installed a pressurized-water loop at the ORR. Donald Trauger, who had charge of the tests using capsules and loops, notes that the testing facilities were later copied for similar testing of reactors in the Netherlands and elsewhere.

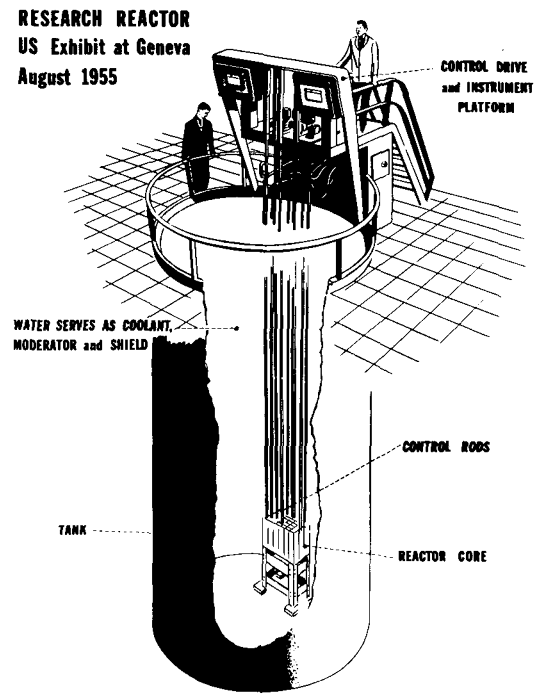
Clifford Savage built and operated an engineering-scale test loop at the ORR to study fuel behavior and corrosion rates for the Laboratory's Homogeneous Reactor Experiment. Although not the first of their type, these engineering-scale experiments were the most advanced of their time.

During the last experiments at the ORR before its operation ceased in 1987, its highly-enriched uranium fuel was replaced with low-enriched fuel containing only 20 percent uranium-235. The last experiments revealed that low-enrichment fuel could be substituted for highly enriched fuel in most research reactors. Such a switch could allay fears that highly enriched fuel might be diverted into nuclear weapons production.

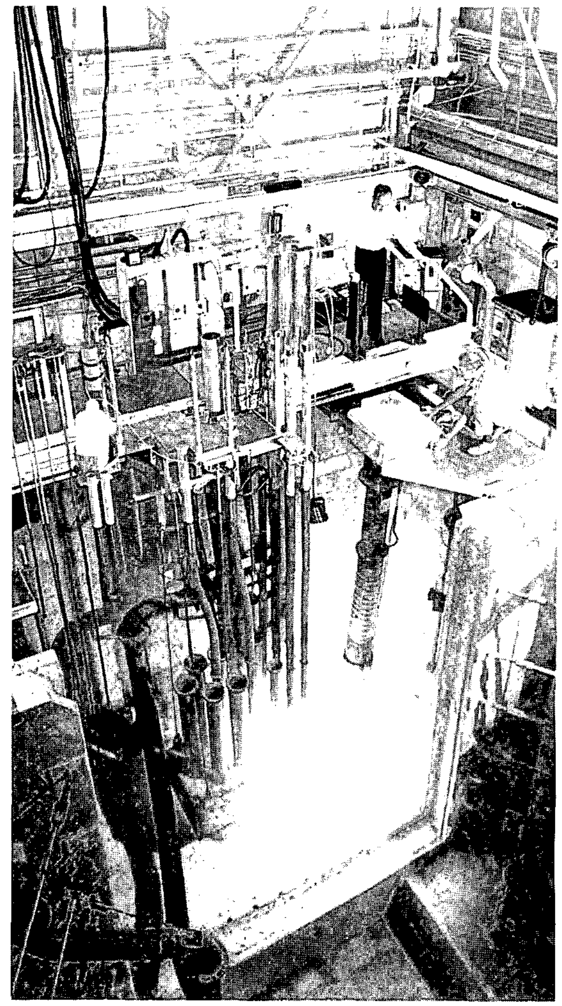
The research reactor's presence caused scientists and engineers from throughout the world to seek assignments at the Laboratory. For the less scientifically inclined, the reactor became a tourist attraction. An impressive structure, silhouetted by the blue glow of Cerenkov radiation emanating from the core within its protective pool, the Oak Ridge Research Reactor was admired in person by Senator John Kennedy, U.S. Representative Gerald Ford, and other noted and aspiring political figures. Thanks to relaxed security requirements in the wake of President Eisenhower's call for international cooperation, the reactor also lured many foreign scientists and dignitaries, such as the queen of Greece and the king of Jordan, who came to the Laboratory on other business but could not pass up an opportunity to see one of the facility's most notable pieces of equipment.

1955 Geneva Conference

The Laboratory's new research reactor was being designed at the same time that plans were being made for the first United Nations Conference on Peaceful Uses of Atomic Energy. That conference was scheduled for Geneva, Switzerland, in August 1955. A staid, professional



Drawing of "swimming pool" reactor designed and built for display at the 1955 Geneva Conference.



Cerenkov glow of nuclear fission in water was visible at the Bulk Shielding Reactor.

scientific meeting, organized in response to Eisenhower's "Atoms for Peace" initiative, it also became an extravagant science fair with exhibits from many nations emphasizing their scientific achievements.

Never before had the accomplishments of nuclear power been placed on such a public stage. And never before had scientists so openly presented their findings as symbols of national prestige. Just as the athletic Olympics in the post–World War II era emerged as peaceful arenas for venting Cold War animosities, the 1955 Geneva conference on the atom became a platform for comparing the relative strengths of science in capitalist and communist societies.

Because critical assessments of the exhibits, especially those brought by the Soviets and Americans, were expected, the AEC asked its laboratories for spectacular exhibit concepts. At Oak Ridge, Tom Cole's suggestion that the AEC build and display a small nuclear reactor was welcomed.

In early 1955, a Laboratory team led by Charles Winters and William Morgan designed and fabricated a scaled-down version of the Materials Testing Reactor, operating at 100 kW instead of 30 MW. The Laboratory designed it as the first reactor to use low-enriched uranium dioxide fuel. When the fuel plates were fabricated, however, a reaction between the uranium dioxide and aluminum caused the plates to distort. Jack Cunningham's team finished resetting the plates just before shipment.

After testing, the reactor was disassembled and sent by air from Knoxville to Geneva, where the

1955 Geneva Conference

ORNL leaders inspecting the 1955 Geneva Conference reactor were (from left) Alvin Weinberg, Charles Winters, Robert Charpie, and E. P. Epler.

As a result of President Eisenhower's "Atoms for Peace" program, the United Nations in August 1955 conducted the first International Conference on Peaceful Uses of Atomic Energy in Geneva, Switzerland.

For display at this conference, the Laboratory designed and built a small nuclear reactor in just three months and transported it by air to Geneva. Called Project Aquarium because it was a "swimming pool" type reactor, it served as a prototype for research reactors overseas that could be fueled with the low-enrichment fissionable material contributed by the United States to the international stockpile.

In Geneva, President Eisenhower took personal interest in the reactor, received a full briefing, and pressed the control button that activated it. Afterward, the Laboratory staff designated him an "honorary reactor operator."

More than 62,000 people, including kings, queens, presidents, and other dignitaries, queued up to see the reactor's blue glow during the two-week-long conference. It became the most popular exhibit at the conference. Enrico Fermi's wife subsequently labeled it the world's "most beautiful little reactor."

"After testing, the reactor was disassembled and shipped by air from Knoxville to Geneva, where the Laboratory team reassembled it."

Laboratory team reassembled it in a building constructed on the grounds of the Palais des Nations. Designed, built, tested, transported to Geneva, and reassembled in only five months, it became the most spectacular display at the conference, admired by political dignitaries such as President Eisenhower as well as by the public and media. The reactor and the 28 scientific papers presented to the conference by staff members gave the Laboratory a claim to the laurels of the international competition.

Heralding the multifaceted applications of peaceful atomic power, the Geneva conference captured the public's imagination. After the conference, the U.S. exhibit returned home for a triumphant national tour, minus its most eye-catching element. The Swiss government had purchased Oak Ridge's model Materials Testing Reactor to use at a research facility.

At the same time, the Laboratory acquired its own version of the Geneva reactor. To ensure against loss of the reactor during shipment to Switzerland, Charles Winters had made duplicates of all its components. These were assembled in the pool of the Laboratory's Bulk Shielding Reactor and became known as the Pool Critical Assembly. John Swartout later recalled the chiding he received from AEC management for allowing the Pool Critical Assembly to be built without advance AEC approval. Swartout pointed out that if the reactor were safe enough to be operated within the city of Geneva, it certainly was safe within the confines of the Laboratory.

"Our Laboratory stands today as an institution of international reputation," exulted Alvin Weinberg, who became Laboratory director shortly after the conference. "This we sense from our many distinguished foreign visitors, from the numerous invitations which our staff receives to foreign meetings, and in the substantial part which we played at Geneva. But with international reputation comes international competition." And, as any Olympic champion will tell you, as difficult as it is to win the first gold medal, it is even more difficult to sustain a level of performance unequalled by others.

Gas-Cooled Reactor

International exchange on nuclear matters brought the Laboratory a new assignment from the AEC:

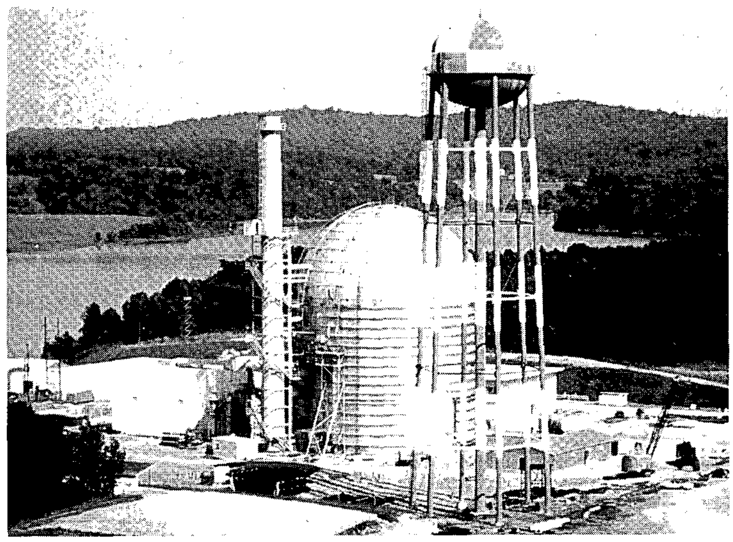
Tom Cole proposed building a small nuclear reactor for the 1955 Geneva Conference. He led reactor development at the Laboratory for years.

to explore gas-cooled nuclear reactor technology. Although U.S. studies of gas-cooled reactors waned after investigations into the Daniels Power Pile were halted in 1948, British scientists successfully designed and built several large gas-cooled reactors in the early 1950s.

In 1956, Congress reacted to the British advances by directing the AEC to gain first-hand experience with gas-cooled, graphite-moderated reactors. In response, AEC turned to the Laboratory, which formed a study team headed by Robert Charpie. The team's key task was to compare the feasibility and costs of gas-cooled and water-cooled reactors.

Encouraged by the initial findings, in 1957, the AEC asked the Laboratory to design fuel elements for the Experimental Gas-Cooled Reactor (EGCR), which the AEC planned to build in Oak Ridge. By early 1958, the Laboratory had completed a conceptual design for a helium-cooled, graphite-moderated reactor. Its core was to consist of uranium oxide clad in stainless steel. A team led by Murray Rosenthal also studied fuel elements coated with graphite as an alternative. John Conlin, Frank McQuilkin, and Don Trauger led a team that assessed these competing concepts.

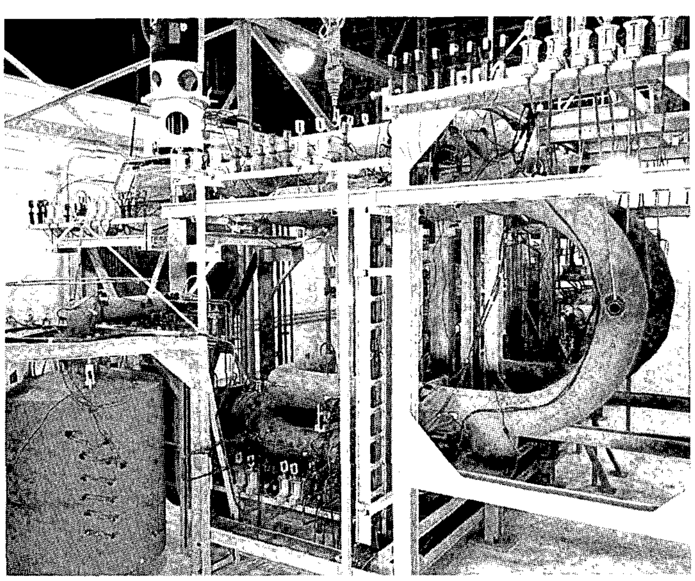
In 1959, after the Tennessee Valley Authority agreed to become the reactor operator, the AEC arranged for the EGCR to be constructed on the banks of the Clinch River near the Laboratory. The reactor was to serve as a prototype for electric power generation and TVA—the nation's largest public utility—hoped to participate in a demonstration that held great promise for helping the agency meet its customers' future power needs. In line with its previous research, ORNL was given responsibility for developing and fabricating the EGCR's fuel elements and moderator.



The AEC's Experimental Gas-Cooled Reactor in Oak Ridge. Today the Robotics and Process Systems Division is located there.

"ORNL developed and fabricated the fuel elements and secured the moderator for the EGCR."

Eight test loops inside the reactor would have allowed Laboratory scientists to test the various fuel elements. Construction delays and increasing project costs, however, soon caused the test loops to be eliminated from the design. Then, in 1966, the AEC ordered the project stopped even though all construction on the reactor had been completed and its fuel elements had been manufactured and fully tested. The light-water reactor industry had advanced so rapidly that the Oak Ridge gas-cooled reactor prototype had become obsolete before it had become operational.

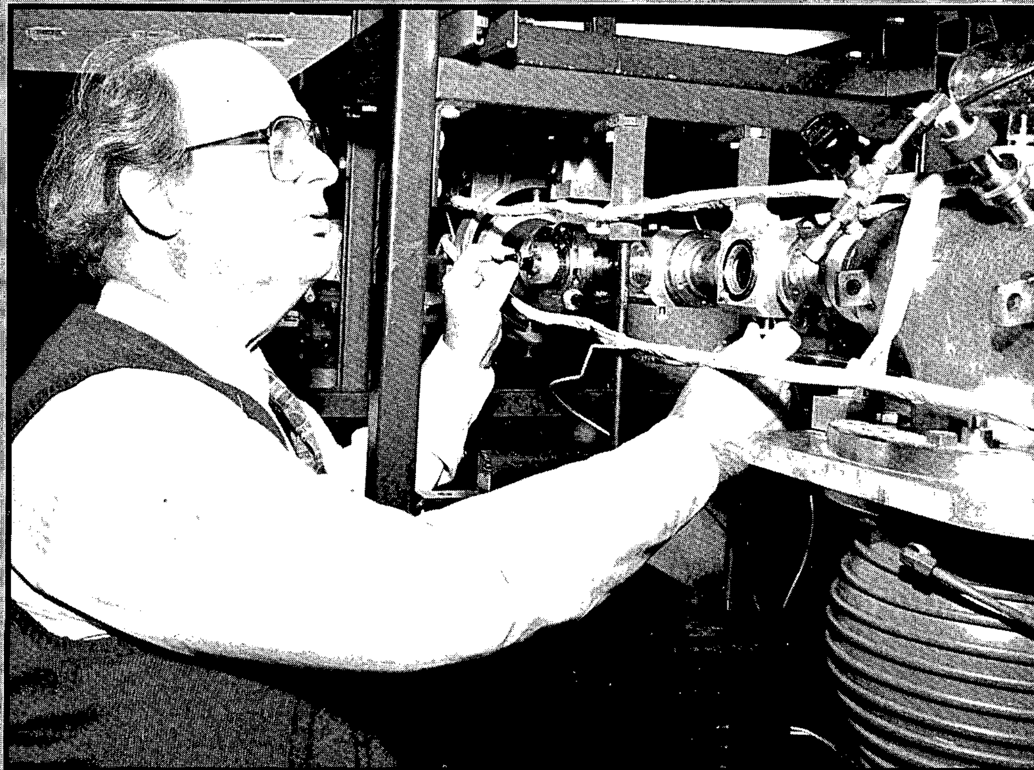


Equipment for the Molten Salt Reactor Experiment.

Molten Salt Technology

Another innovative nuclear reactor design was developed at the Laboratory in 1956 when a team headed by Herbert MacPherson investigated the application of molten salt technology. The Laboratory's aircraft reactor experiments during the early 1950s used molten (fused) uranium fluorides (salts) as reactor fuel. Molten-salt fuel could

Crossing the Swords



The first step in understanding the details of chemical processes was taken at the Laboratory in 1954 when Sheldon Datz and Ellison Taylor invented a technique for studying chemical reactions by crossing a beam of one kind of molecule with that of another. Before Datz and Taylor's pioneering work, scientists had to be content with examining molecules before or after their reactions, not during the transitional phase.

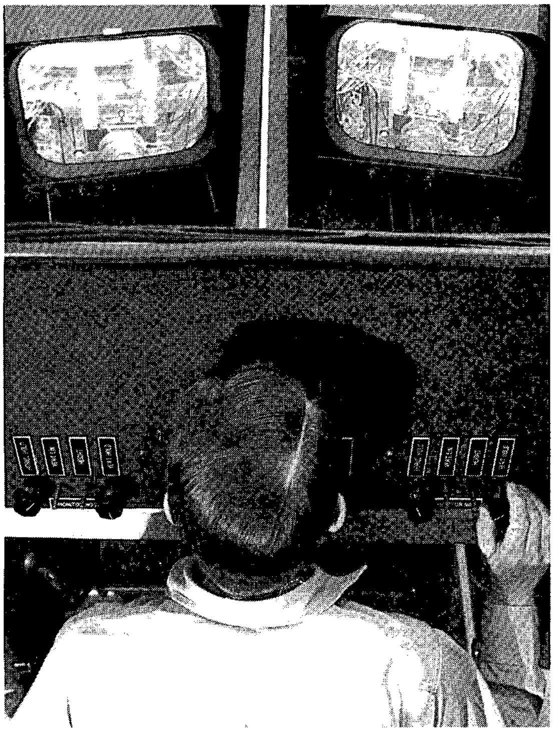
Understanding the dynamics of elementary physical and chemical processes at the molecular level requires fundamental investigations of the movement of molecules and the results of their encounters—in brief, what happens during a chemical reaction. The reactions occur so incredibly fast, however, that observing and understanding a reaction's transition phase seemed impossible before Datz and Taylor invented their technique.

Datz and Taylor believed that much could be learned about chemical reactions if two reactants could be brought together as crossed beams, creating a shower of new molecules. Because each new molecule would result from a single collision, this process avoided the complications of accounting for chain reactions and collisions with container walls common to simpler experiments.

"Sheldon Datz collaborated with Ellison Taylor on crossing molecular beams, resulting in a powerful new method of studying reaction mechanisms."

In 1954, they "crossed the swords" of two accelerated, collimated (focused) beams, one composed of potassium atoms and the other of hydrogen bromide molecules. They found that they could measure the products' angular distribution. As a result, they could draw conclusions about the relative effectiveness of the various orientations of the colliding reactants.

Datz and Taylor's crossed-beam scattering technique energized the science of chemical dynamics when their results were published in 1955. The technique was recognized by the 1986 Nobel Prize in chemistry, which went to three men who refined the Oak Ridge technique. Applying infrared-emission spectroscopy, laser probes, and other modern tools to the crossed-beam scattering technique, modern scientists have begun to understand the dynamic interchange of atoms during chemical reactions.

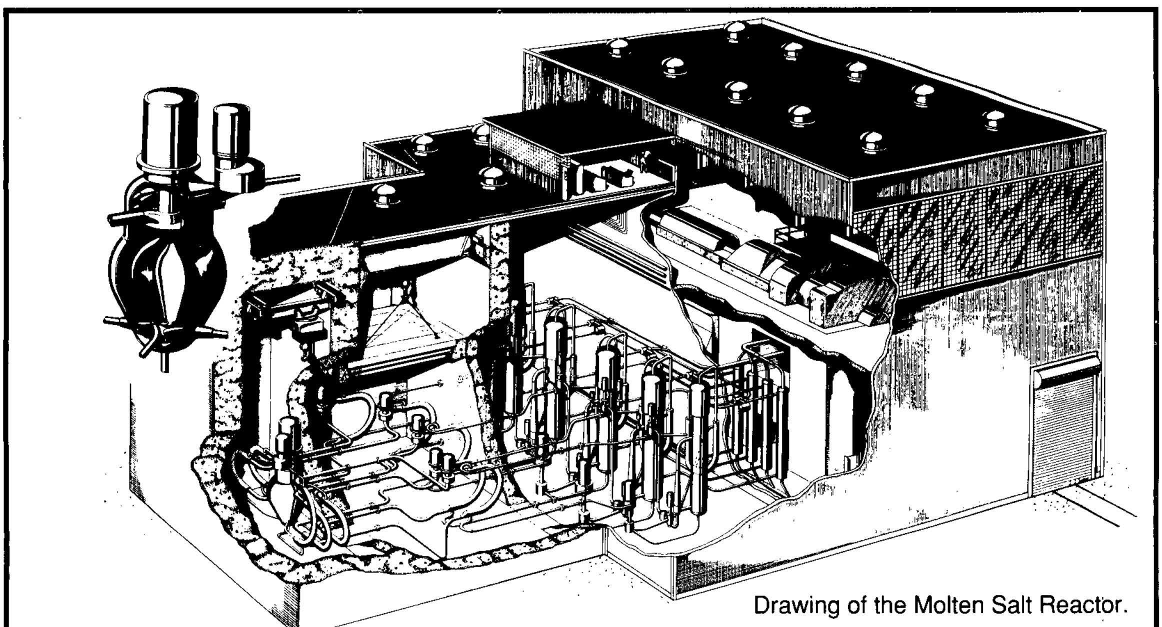


Controls for remote operation and maintenance of the Molten Salt Reactor.

function at high temperatures and low pressures in a liquid system that could be cleansed of fission products without stopping the reactor. Like other liquid nuclear fuels, however, molten salts were highly corrosive and posed significant materials challenges.

To meet these challenges, MacPherson organized a group that studied molten materials in the test loops built for the aircraft reactor project and assigned to Alfred Perry the cost studies for various molten-salt reactors. Teams headed by Beecher Briggs, Paul Kasten, L. E. McNeese, and William Manly developed improved designs and focused on identifying corrosion-resistant materials for use in molten-salt reactors.

When an AEC task force in 1959 identified molten salt as the most promising of the liquid-fuel reactor systems, the AEC approved construction of the Molten Salt Reactor Experiment. By 1960, the Laboratory was designing an experimental molten-salt reactor using graphite blocks as the moderator. A uranium-bearing fuel of molten fluorides was pumped through the core and through a heat exchanger made of a nickel-molybdenum alloy, called Hastelloy N, developed earlier at the Laboratory for the aircraft reactor. Ed Bettis headed a design team that continually refined the reactor



Drawing of the Molten Salt Reactor.

configuration. Warren Grimes provided chemical insights that determined many features of the system.

Molten-salt reactor experiments continued at the Laboratory through the 1960s and into the early 1970s. In 1969, Keith Brown, David Crouse, Carlos Bamberger, and colleagues adapted molten-salt technology to the problem of breeding uranium-233 from thorium, which could be extracted from the virtually inexhaustible supply of granite rocks found throughout the earth's crust. When bombarded by neutrons in the molten-salt reactor, thorium was converted to fissionable uranium-233, another nuclear fuel.

Project Sherwood

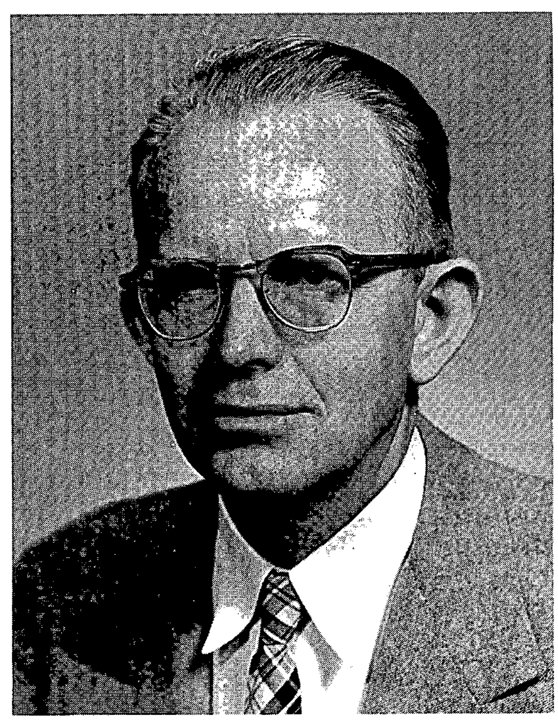
Alvin Weinberg described the Laboratory's use of the uranium-233 reactor fuel bred from neutron irradiation of thorium as "burning the rocks"; conversely, he called its secret investigations of producing fusion energy from heavy water (deuterium oxide), which could be obtained from sea water, "burning the sea." Thus, by the late 1950s Laboratory researchers were searching for an inexhaustible energy supply extracted either from the earth's crust or seas. Using elements found in abundance in granite or seawater would potentially provide limitless energy.

The Laboratory's fusion research efforts were no less Promethean than its fission research. Such research began in Oak Ridge in 1953 as a small part of the AEC's classified Project Sherwood. By the time of the second scientific olympics at Geneva in 1958, however, the Laboratory had become a world leader in fusion research.

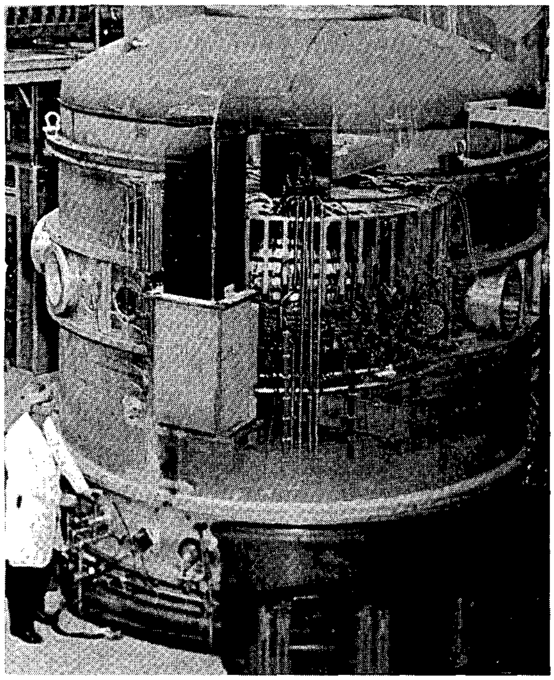
Hydrogen nuclei release enormous energy when they fuse together, as in the thermonuclear reaction associated with detonation of a hydrogen bomb. Fusion temperatures of the hydrogen isotopes deuterium and tritium are about one million degrees.

Major research aimed at fusing these isotopes in a controlled thermonuclear reaction began in 1951,

Ed Bettis headed a team that improved the design of the Molten Salt Reactor.



Herbert MacPherson succeeded John Swartout as deputy director of the Laboratory.

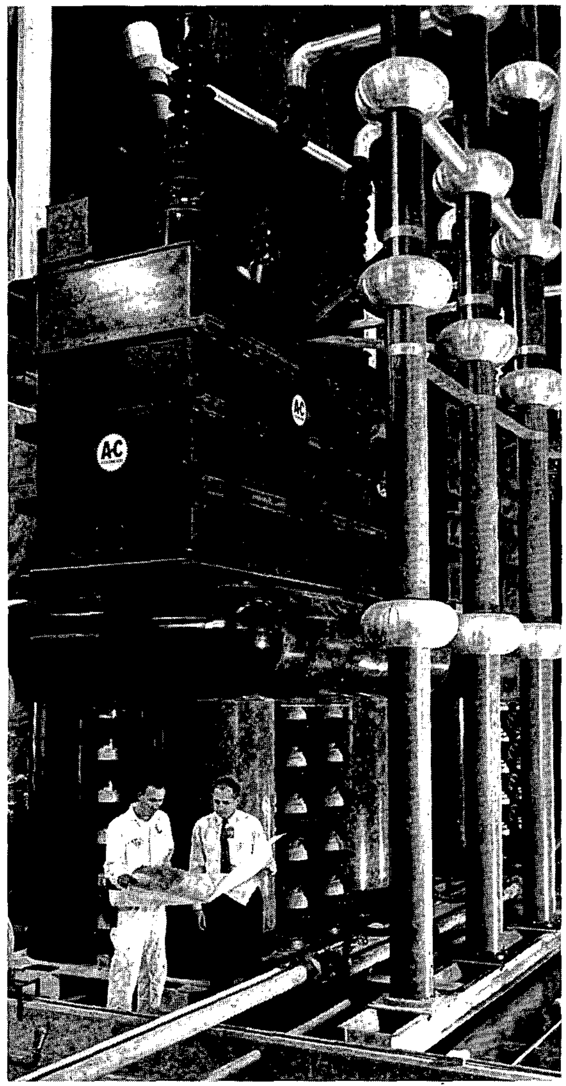


The Oak Ridge experimental tokamak, called ORMAK, used for fusion energy experiments.

when Argentine President Juan Peron announced that scientists in his country had liberated energy through thermonuclear fusion without using uranium and under controlled conditions that could be replicated without causing a holocaust.

Peron's claim proved false, but it stimulated a host of international fusion research initiatives, including the AEC's classified Project Sherwood. Legend has it that the name Sherwood came from the answer to the question, "Would you like to have cheap, nonpolluting, and everlasting energy?" The answer was "Sure would." In reality, the name was derived from a complicated pun on the story of Robin Hood of Sherwood Forest, which involved robbing Hood Laboratory at the Massachusetts Institute of Technology to fund James Tuck's fusion research at Los Alamos.

To achieve fusion, scientists sought to contain a cloud, or plasma, of hydrogen ions at high temperature in a magnetic field. Because the plasma cooled if it touched the sides of its container, electromagnetic forces (pushing from different



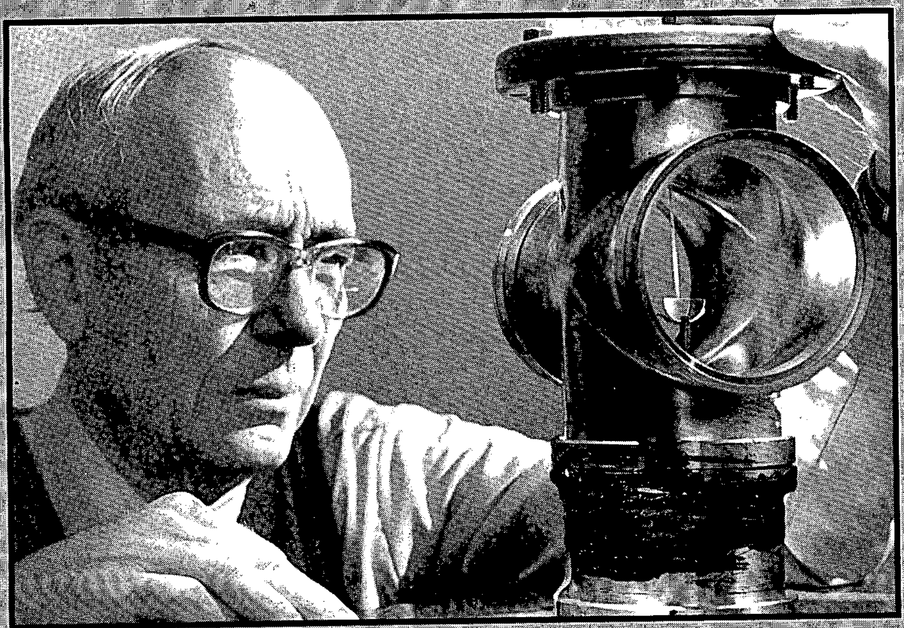
Model of the Laboratory's Direct Current Experiment (DCX) for fusion energy research.

directions) were necessary to hold the plasma in the center away from the container's sides. If the plasma were suspended in the same place long enough and at a high enough density and temperature, scientists believed a fusion reaction would begin and become self-sustaining.

In its early years, Project Sherwood focused on three fusion devices. Princeton University had a stellarator, a hollow twisted doughnut-shaped metal container, with electric wires coiled around it to

Ellison Taylor

Player-Coach of Chemistry



Just as player-coaches are rare in sports, so are laboratory division directors who continue their scientific research. Ellison H. Taylor, director of ORNL's Chemistry Division for 20 years, found time to pursue his own research interests during his directorship. Fortunately, he was division director from 1954 to 1974 when the demands of the federal bureaucracy were not as great on managers as they are today.

Taylor joined the Chemistry Division in the fall of 1945, after conducting research on gaseous diffusion for uranium isotope separation for the Manhattan Project at Columbia University. He served in interim positions as acting director of the Chemistry Division and associate director of the Laboratory. When he took over the position of Chemistry Division director, he succeeded his friend and associate Samuel C. Lind, who had served as acting director.

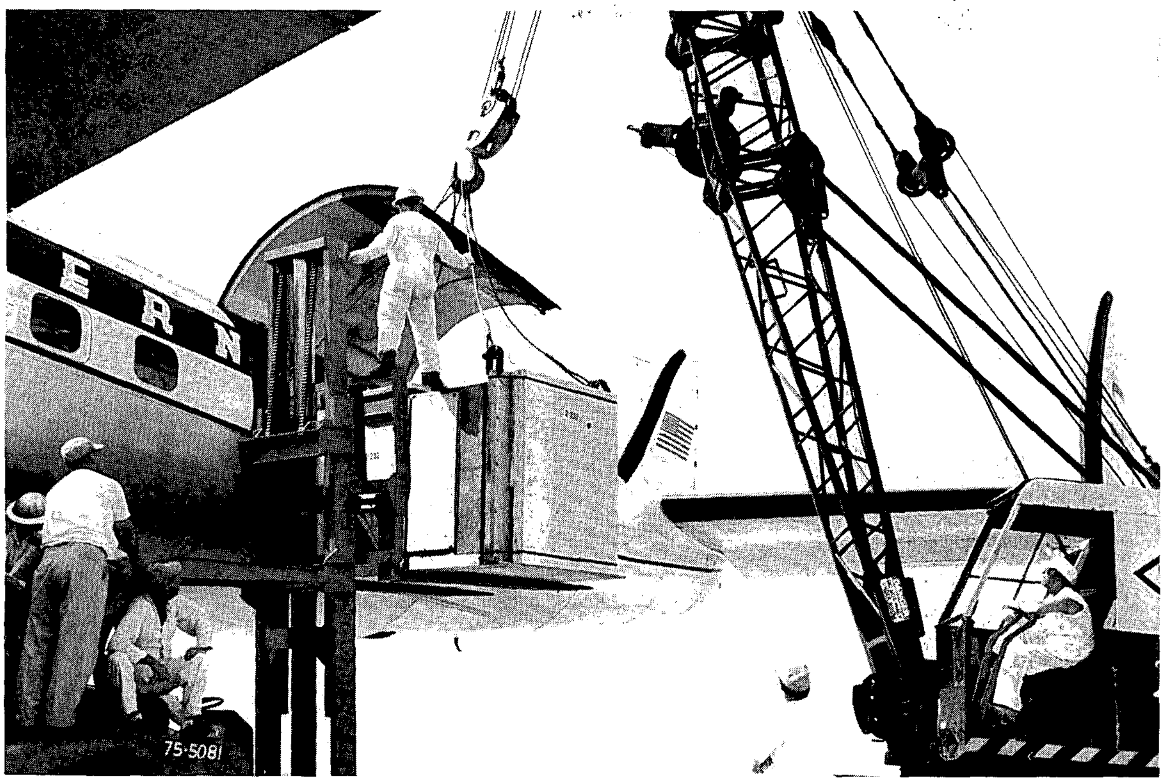
Besides molding the physical science programs of the Chemistry Division, Taylor participated in them. He had a general interest in the chemical applications of molecular beams and began to investigate and refine various approaches. In 1951 he began collaborating with new staff scientist Sheldon Datz, who brought a familiarity with beam techniques from Columbia University. This collaboration grew into a major research activity. In 1955 their landmark publication on crossing molecular beams introduced a powerful new method of studying reaction mechanisms.

> *"As both a division director and researcher for many years, Ellison Taylor molded and participated in the research programs of the Chemistry Division."*

Taylor collaborated with Ralph Livingston and Henry Zeldes in the first unambiguous identification by electron-spin resonance spectroscopy of a radiation-produced free radical, the hydrogen atom, in certain frozen acids. Working with J. A. Wethington, Taylor was the first to successfully study the effect of ionizing radiation on solid catalysts, stimulating a new area of research.

In the late 1960s, a flurry of scientific activity suggested the existence of a new form of water, called polywater or anomalous water. Taylor was intrigued by these reports and carried out his own investigations in the 1970s. The original reports of anomalous water were discredited in the literature, and Taylor terminated his studies with a paper arguing against polywater's existence.

Taylor and W. C. Waggener studied a novel approach to measurement of the adsorptive forces of gases on solids and published a report on the subject. His research activities continued until his retirement from the Laboratory in 1978, and subsequently he became a consultant to the Chemistry Division. His long-term service as a player-coach—dedicated to both the management and practice of research—makes Ellison Taylor the most influential figure in the division's history.



Components of the DCX exhibit for the 1958 Geneva Conference are loaded onto an airplane.

supply a magnetic field to confine the charged hydrogen ions. Lawrence Livermore Laboratory in California had a "mirror" device with a magnetic field stronger at its ends than in the middle to reflect hydrogen ions back to the middle of the field. And James Tuck's "Perhapsatron" at Los Alamos sought to contain the hot plasma through a "magnetic pinch"—that is, magnetic forces were designed to hold, or pinch, the plasma toward the middle of the container.

In Oak Ridge, the Laboratory focused not on a particular device but on two problems basic to fusion devices: how to inject particles into the devices and how to heat the plasma to temperatures high enough to ignite the reaction.

With large surplus electromagnets on hand at the Y-12 Plant from the calutrons once used to separate uranium-235 from uranium-238, an ion source group in the Electronuclear Division, which included Ed Shipley, P. R. Bell, Al Simon, and John Luce, became responsible for fusion research. Their background in electromagnetic separation and high-current cyclotrons led them to studies of energetic ion injection to create a hot plasma. Theoretical work showed promise and, in 1957, the Laboratory formed a Thermonuclear Experimental Division with a staff of 70 people to pursue the fusion challenge. Personnel came from the Physics and Electronuclear divisions and from the discontinued aircraft reactor project.

In 1957, published stories and unsubstantiated rumors hinted that British scientists might have achieved a successful fusion reaction. Although overstated, the stories and rumors nevertheless encouraged greater emphasis on fusion research by both the AEC and the Laboratory. Moving a particle accelerator into the Y-12 Plant to provide a beam of high-energy deuterium molecular ions, Luce, Shipley, and their associates built the Direct Current Experiment (DCX), a magnetic mirror fusion device.

"AEC Chairman Lewis Strauss threw the AEC's full support behind fusion research."

"The most popular attractions were models of the Laboratory's DCX fusion machine."

In August 1957, they "crossed the swords," injecting a deuterium molecular beam into a carbon arc that dissociated the beam into a visible ring of circulating deuterium ions (shaped like a bicycle tire). This advance transformed Project Sherwood from a remote, abstract theory to a real possibility.

Planning for a second United Nations Conference on Peaceful Uses of Atomic Energy coincided with the Laboratory's advance in fusion research. AEC Chairman Lewis Strauss, determined that the United States should achieve a triumph equal to that of 1955 at the 1958 scientific olympics, threw the AEC's full support behind fusion research. He hoped that American scientists could display an operating fusion energy device at the 1958 Geneva conference, just as they had displayed a successful nuclear reactor three years earlier.

"I have received a letter from Chairman Strauss exhorting the Laboratory to do everything it possibly can to have incontrovertible proof of a thermonuclear plasma by the time of Geneva," Weinberg informed Laboratory staff. He went on to say:

> *We are now engaged in this enterprise; we have mobilized people from every part of the Laboratory for this purpose and, with complete assurance of unlimited support from the Commission, we have put the work into the very highest gear. I can think of few things that would give any of us as much satisfaction as to have Oak Ridge the scene of the first successful demonstration of substantial amounts of controlled thermonuclear energy.*

1958 Geneva Conference

By the time of the second United Nations Conference on Peaceful Uses of Atomic Energy in September 1958, intense media attention on the miracles of nuclear energy had jaded the public. Saturated for years with news about the potential miracles of nuclear energy, Americans turned their attention to other matters. Moreover, Soviet scientists, so prominent at the 1955 conference, were no longer subjects of great public curiosity.

As a result of this diminishing public interest, the second Geneva conference turned out to be less a media circus and more a conventional scientific conference. In 1958, only schemes and devices for achieving controlled thermonuclear reaction through fusion enjoyed the glamour linked to the first conference.

The second conference, however, was the largest international scientific conference ever held. Exhibits filled a huge hall built on the grounds of the Palais des Nations. Sixty-one nations participated, and 21 exhibited fusion devices, fission reactors, atom smashers, or models of nuclear power plants.

The United States, Great Britain, and the Soviet Union declassified their fusion research at the time of the conference, and Chairman Lewis Strauss resigned from the AEC to lead the American delegation to Geneva. It took nearly 10 hours to view the United States exhibit alone. The most popular attractions were models of the Laboratory's DCX fusion machine.

The Laboratory provided two full-scale working models of its DCX machine to display its operating principles. Through viewing windows, visitors could see the beam, and the ring of ions wound around it like a ball of yarn. Using a bit of showmanship, the Laboratory made the trapped ring visible by dusting it with tungsten particles from above.

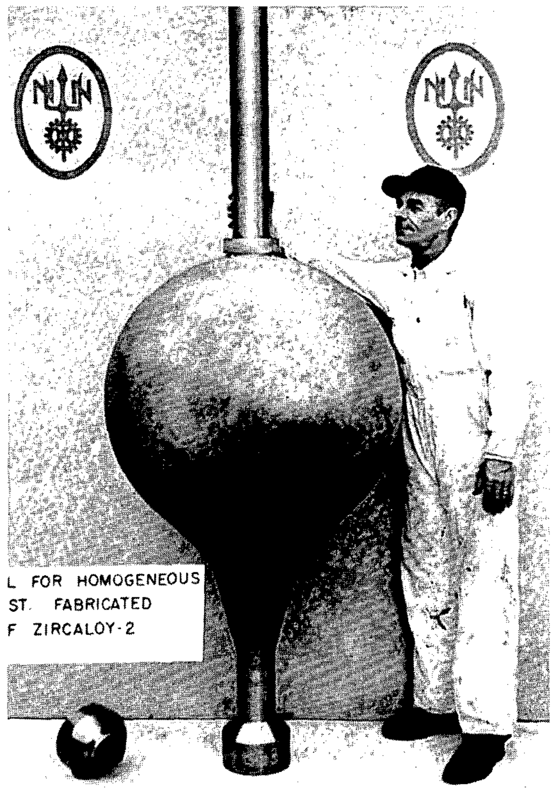
Soviet fusion specialists took intense interest in the DCX display because they were also pursuing a molecular-ion-injection approach to fusion. After the conference, other nations, drawing on the Laboratory's experience, built DCX-type machines, making them fundamental tools for plasma research.

Optimism over the future success of fusion energy, however, soon faded. The supposed British achievement of fusion with a pinch-type device proved premature, and the ability of pinch machines to provide a stable plasma was questioned. Unstable plasma escaping the magnetic field also plagued the Princeton stellarator, and by the end of 1958, Laboratory scientists learned that their carbon arc lost trapped ions, forcing the DCX staff to study different types of arcs and to plan an improved device, called DCX-2.

In 1959 Alvin Weinberg, a proponent of nuclear fission and thorium breeding reactors, compared Project Sherwood to "walking on planks over quicksand." Plasma physics was so novel then that solid spots remained unknown, nor was it fully apparent that any existed. "Working in this field requires a rugged constitution," Weinberg concluded, "but I'm told that those who can stand it find it stimulating."

Eugene Wigner reported that Soviet scientists were more cooperative at the 1958 Geneva conference than they had been in 1955, perhaps because of the successful launch of the Sputnik satellite into orbit in 1957. Wigner found them open about their nuclear fission and fusion energy research but unwilling to share information about their space missions or their particle acceleration program. "Pure science in the Soviet Union still seems to be far from an open book," he observed.

Early Soviet achievements in space exploration sent shock waves throughout American political and scientific circles. Following the Soviet Union's successful launch of Sputnik, international scientific competition shifted from fission and fusion energy research to the race for space. As international scientific interests shifted, so did the focus of the federal government from the AEC to the new National Aeronautics and Space Administration (NASA). Nuclear research remained an important aspect of America's scientific agenda, but it now had to share the policy spotlight with space issues. Geneva conferences on the atom were held occasionally after 1958, but none ever gripped the public imagination as had the first and second stellar events.



Bulb-shaped core vessel built for ORNL's experimental Homogeneous Reactor Test.

After the Gold

Nuclear reactor development at the Laboratory reached a pinnacle in 1956 and began a slow descent in 1957 with the cancellation of its aircraft reactor program and troubles with its second experimental homogeneous reactor. In 1956, when the Laboratory budget was $60 million and its staff reached 4369, Weinberg boasted: "We are the largest nuclear energy laboratory in the United States, and we are among the half-dozen largest technical institutions in the world."

With cancellation of the aircraft reactor in September 1957, the Laboratory budget was slashed 20% and its staffing cut to 3943. The 1957 reduction would have been even steeper if the Laboratory had not absorbed some people into the molten-salt reactor, gas-cooled reactor, and Sherwood programs. Moreover, the Eisenhower administration froze the Laboratory's budget in 1957, forcing postponement of a major building expansion program that included an east wing of the general research building, an instruments building, and a metallurgy and ceramics building, which together would have added a half million square feet of work space. Weinberg called these actions "cataclysmic setbacks" that ranked with the loss of the Materials Testing Reactor in 1947.

Homogeneous Reactor

After successful operation of the first aqueous homogeneous reactor in 1954, the Laboratory proceeded with design of a larger homogeneous reactor on a pilot-plant scale. Whereas the first reactor had been a one-time experiment to prove

"We are the largest nuclear energy laboratory in the United States."

"The reactor operated continuously for 105 days—at the time, a record for uninterrupted operation of reactors."

yet unproven theoretical principles, the second reactor, sometimes identified as the Homogeneous Reactor Test, was designed to operate routinely for lengthy periods.

The second homogeneous reactor was fueled by a uranyl sulfate solution containing 10 grams of enriched uranium per kilogram of heavy water, which circulated through its core at the rate of 400 gallons (1450 liters) per minute. Its fuel loop included the central core, a pressurizer, separator, steam generator, circulating pump, and inter-connected piping. Its core vessel was approximately a meter in diameter and centered inside a 60-inch (152-centimeter) spherical pressure vessel made of stainless steel. A reflector blanket of heavy water filled the space between the two vessels.

Underground tanks stored radioactive wastes from the Graphite Reactor.

Perhaps the most exotic nuclear reactor ever built, it gave Laboratory staffers trouble from the start. During its shakedown run with pressurized water, chloride ions contaminated the leak-detector lines, forcing replacement of that system and delaying the power test six months.

In January 1958, the Laboratory brought this reactor to critical mass and operated it for many hours into February 1958, when it became apparent that its outside stainless steel tank was corroding too rapidly. In April the reactor reached its design power of 5 MW. Then, in September, a hole suddenly formed in the interior zircaloy tank. Viewing the hole through a jury-rigged periscope and mirrors, operators determined that it had been melted into the tank—that is, the uranium had settled out of the fuel solution and lodged on the tank's side.

By the end of 1958, the AEC considered abandoning the Homogeneous Reactor Test, and Eugene Wigner came to the Laboratory to inspect it personally. "The trouble seems to be that the rich phase adsorbs to the walls and forms a solid layer there," Wigner reported to the AEC staff, relaying the findings of the Laboratory staff. He thought altering the flow of fluid through the core would provide the velocity needed to prevent the uranium from settling on the tank walls. "It is my opinion that abandoning the program would be a monumental mistake," he warned, pointing out that the reactor could convert thorium into uranium-233 to supplement a dwindling supply of uranium-235.

The AEC allowed the Laboratory to alter the reactor flow and continue its testing in 1959. These activities were accomplished by interchanging the inlet and outlet to reverse the fluid flow through the reactor. Several lengthy test runs followed in 1959, and the reactor operated continuously for 105 days—at the time, a record for uninterrupted operation of reactors. The lengthy test run demonstrated the advantages of a homogeneous system in which new fuel could be added and fission products removed during reactor operation.

Near the end of the year, a second hole burned in the core tank. Laboratory staff again patched the hole using some difficult remote repairs and started another test run. Because of these difficulties, Pennsylvania Power and Light Company and Westinghouse Corporation abandoned their proposal to build a homogeneous reactor as a central power station.

During the shutdown and repairs, Congress viewed the aqueous homogeneous reactor troubles unfavorably, and in December 1960, the AEC directed the Laboratory to end testing and turn its attention to developing a molten-salt reactor and thorium breeder. The last aqueous homogeneous reactor test run continued until early 1961. For months, the reactor operated at full power until a plug installed earlier to patch one of the uranium holes disintegrated. Although the homogeneous reactor never found direct commercial applications, the Laboratory's efforts to test its long-term usefulness ultimately strengthened its capabilities for maintaining and repairing highly radioactive systems.

Material Challenges

The rapid pace of reactor development at the Laboratory prompted research in detecting flaws in reactor materials that could be signs of impending failure. In short, Laboratory staff investigated not only how reactors would run, but whether materials in reactor components could withstand the stresses of radiation over the long term.

In 1955, for example, R.B. Oliver was given responsibility for developing and applying new techniques to detect welding flaws. Nuclear reactors, on a commercial scale, would contain miles and miles of piping and machinery seamed together by an endless series of welds, which would prove critical to a reactor's operation and safety. Moreover, the materials used for the pumps, piping, and containment of a nuclear reactor all would be subject to long-term, sometimes intense, radiation.

"Material" concerns had been a major focus of the nuclear airplane program and it remained a key research initiative throughout the Laboratory's reactor development era between the 1950s and 1970s. In fact, by developing and demonstrating non-obstrusive techniques to test the integrity of materials (for example, ultrasonic waves and penetrating-radiation), the Laboratory became a world leader in "nondestructive" materials testing. Robert McClung headed this Laboratory program from the 1960s to the 1980s.

Health physicists continued to seek a better understanding of how radiation from reactors and other sources interacts with solids and liquids. In the early 1950s ORNL scientists measured energy losses of swift electrons after penetrating thin metal foils. Rufus Ritchie launched the quantitative understanding of electron energy losses in irradiated solids and liquids by discovering the surface plasmon, a motion of electrons in matter. In this motion, electrons move collectively in response to the electric field of a penetrating charged particle. This surface motion remains a major topic of research because it helps explain surface phenomena. Only now are the potential applications of this knowledge being realized in computing, communications, laser technology, environmental monitoring, and medical diagnosis and treatment.

Ecological Challenges

Even as the Laboratory moved forward with its nuclear energy program, unmet challenges relating to nuclear fission and the Laboratory's missions arose—most notably, the threat of radioactive fallout from atmospheric testing of nuclear bombs and the need to deal more effectively with radioactive wastes called for research by the Laboratory's scientists. The need to broaden the Laboratory's base and avoid competition with private industry also challenged its management.

Until 1963, fission and fusion bomb tests were conducted in the atmosphere, causing much public concern about radioactive fallout. A principal concern during the early 1950s was the fallout of strontium-90, a calcium-mimicking, bone-seeking fission product that fell from windblown clouds to the soil below, where it could be taken up by grass and eaten by cows to wind up in milk consumed by humans.

To study this and other issues of radiation ecology, the Laboratory, responding to the recommendation of Edward Struxness, hired Orlando Park, an ecologist from Northwestern University, as a consultant in 1953. The Laboratory subsequently asked Park's student, Stanley Auerbach, to join its Health Physics Division. Both Park and Auerbach were expert investigators of the effects of radioactivity on ecological systems, particularly how radioactive nuclides migrate from water and soil to plants, animals, and humans. A major issue in the early 1950s was how quickly strontium-90 in the soil was taken up by plants. In fact, this and other questions about radioactive

"A major issue in the early 1950s was how quickly strontium-90 in the soil was taken up by plants."

"The Laboratory built a waste treatment plant during the 1950s to remove strontium and other fission products from its drainage."

fallout became issues in the 1956 presidential election. During the same year, the Laboratory expanded its scientific studies of radioactive fallout into a Radiation Ecology Section in the Health Physics Division, and Auerbach was named section leader.

Auerbach and his colleagues found a ready field laboratory for their work in the bed of White Oak Lake, a drained reservoir where the Laboratory once had flushed low-level wastes. Examining the native plants and even planting corn in the radioactive lake bed, the ecologists studied the manner in which vegetation absorbed radionuclides from the environment. Investigations of insects, fish, mammals, and other creatures followed, enabling Laboratory ecologists to establish international reputations in aquatic and terrestrial radioecology.

Taking advantage of the Laboratory's isotopes, the ecologists used radioactive tracers to follow the movements of animals, the route of chemicals through the food chain, and the rates of decomposition in forest detritus. Sponsoring national symposia on ecosystems and related subjects, their work added much to the study of radioecology, an emerging scientific field that counts Auerbach and his colleagues among its founders. When atmospheric bomb testing ended in 1963 and interest in fallout waned, the ecologists refocused their studies, forming the nucleus of the Ecological Sciences Division, established at the Laboratory in 1970 and later renamed the Environmental Sciences Division.

During World War II, the Laboratory stored its radioactive wastes in underground tanks for later recovery of the uranium and released its low-level wastes untreated into White Oak Lake. To reduce the level of radioactivity entering White Oak Creek and eventually the Clinch River, the Laboratory built a waste treatment plant during the 1950s to remove strontium and other fission products from its drainage. Uranium and other materials were recovered from underground tanks, and the remaining wastes were pumped into disposal pits.

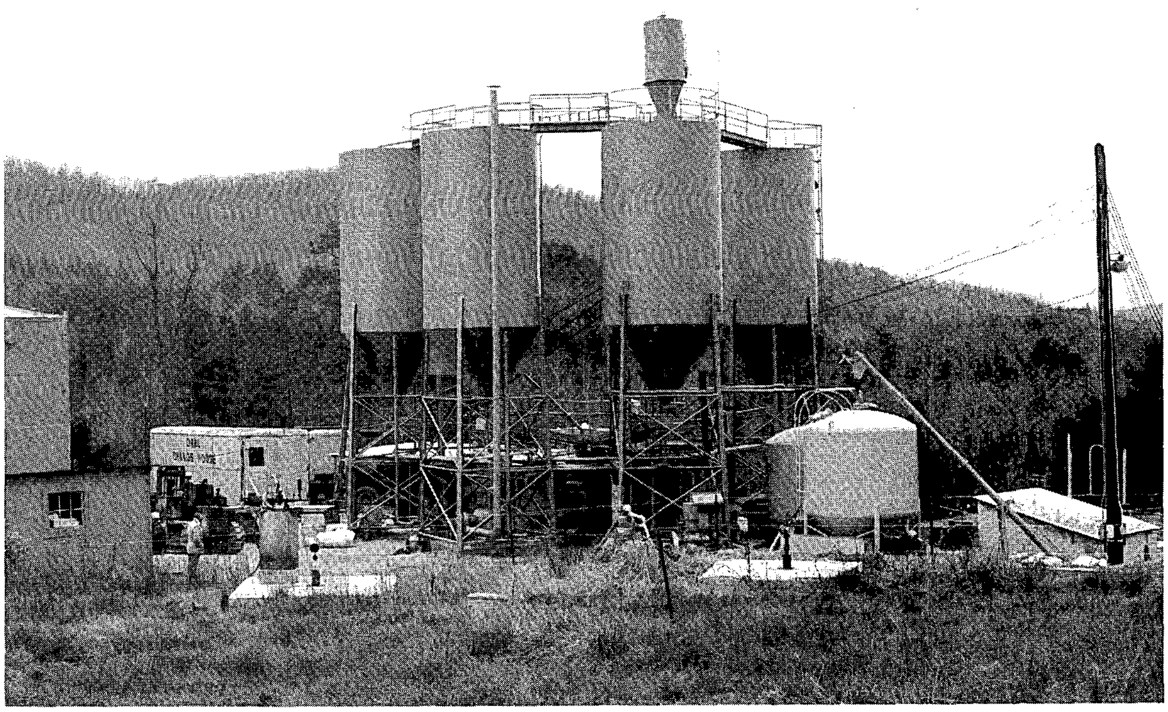
In 1953, the Laboratory initiated a multipronged remediation program designed to address its higher-level waste disposal problems. The

Stanley Auerbach, later the director of ORNL's Environmental Sciences Division, conducts field study.

Chemical Technology Division devised a pot calcination strategy that heated high-level liquid wastes in steel pots, converting the wastes into ceramic material for easier handling and storage. The Health Physics Division, under the direction of Edward Struxness and Wallace de Laguna, explored the hydrofracture disposal method used by the petroleum industry. The strategy consisted of drilling deep wells, applying pressure to fracture the rock substrata, and pumping cement grout mixed with radioactive wastes down the wells into the rock cracks, where the mixture spread out and hardened. Struxness and Frank Parker of the Health Physics Division initiated studies of waste disposal in salt mines, which were believed to be isolated from water. In 1959 the Laboratory tested this method by storing electrically heated, nonradioactive wastes in a Kansas salt mine. Under pressure from the state of Kansas, the AEC asked the Laboratory to stop the Kansas studies after wells were found near the salt mines. This and other methods that seemed promising during the 1950s presented difficulties, and none permanently resolved the disposal challenges.

As the Laboratory's operating nuclear reactors increased in number and its fuel processing program burgeoned, the safety of equipment and the health of its personnel became a growing concern. Such concerns came to the forefront after a serious nuclear mishap in England during the late 1950s.

At Windscale, England, a British graphite-moderated reactor caught fire in 1957 when its operators attempted to anneal it to release the energy stored in the graphite as a result of the "Wigner disease." (Annealing is a process of heating and slow cooling to increase a material's



One of the Laboratory's hydrofracture facilities that injected wastes into subsurface strata.

In the early years, the Laboratory placed low-level wastes, such as protective clothing, in trenches.

toughness and reduce its brittleness.) Herbert MacPherson and a Laboratory team visited Windscale to review the accident and consider its implications for operation of the Laboratory's Graphite Reactor. MacPherson reported that the Laboratory's reactor operated at lower power and higher temperature than the Windscale reactor and that a similar accident could not occur in Oak Ridge. In the early 1960s, the Graphite Reactor was annealed three times without difficulties by reversing and reducing its air flow and slowly raising power.

Although ORNL had experienced no reactor accidents, in 1959 it encountered three threatening situations involving radioactive materials. First, fission products accidentally entered the liquid waste disposal system from the THOREX pilot plant, and they were trapped in a settling basin. Second, ruthenium oxide trapped on the brick smokestack's rusty ductwork shook loose during maintenance at the pilot plant, forcing installation of more filters and scrubbers in the stack. And, third, a chemical explosion in the THOREX pilot plant during decontamination released about six-tenths of a gram of plutonium from a hot cell, spreading it onto a street and into the Graphite Reactor building next to the plant.

Largely by chance no personnel suffered overexposure from these accidents, and the Laboratory immediately stopped its radiochemical operations for safety review. Improved containment measures followed, and Frank Bruce took charge of the Laboratory's radiation safety and control office to implement stricter safety precautions. P. R. Bell and Casimir Borkowski also devised ingenious compact radiation monitors, including the "pocket screamer," which was worn in the pocket and chirped and flashed at a speed proportional to gamma dosage rate. These devices were supplied as needed to Laboratory personnel who worked with reactors and hot cells.

In addition to these challenges, the Laboratory found it increasingly difficult to keep background radiation at acceptable levels because the amount of radioactivity handled by the Laboratory increased during the 1950s, while government regulators steadily reduced the permissible levels to which workers could be exposed. Karl Morgan and other Laboratory health physicists maintained that the maximum permissible levels should be so low that hazards resulting from radiation were no greater than other occupational hazards. Laboratory biologists, however, had obtained differing results in studies of the effects of background radiation. Arthur Upton, for example, found that mice subjected to chronic low-level radiation seemed to have an improved survival rate from infections or other biological crises.

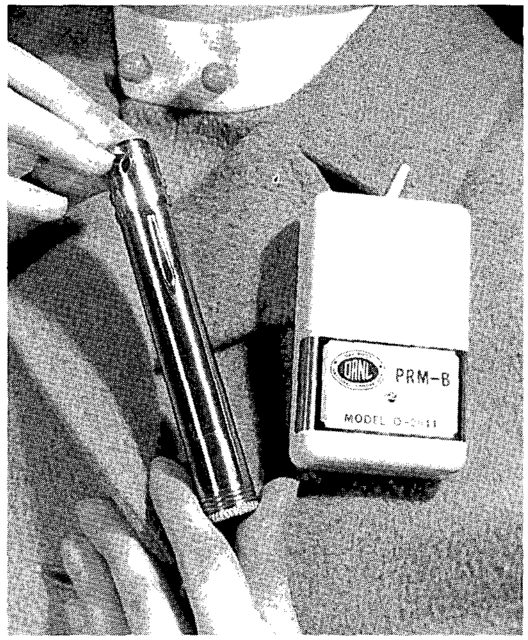
In 1955 ORNL's Health Physics Division became involved in helping to determine the health effects of various levels and types of radiation from the atomic bomb. With researchers from Los Alamos Scientific Laboratory, ORNL health physicists conducted the first major field experiment to measure levels of neutron and gamma radiation at various distances from the hypocenter of bomb blasts at the Nevada Test Site.

In 1956 health physicists Sam Hurst and Rufus Ritchie made the first of a series of Laboratory visits to Japan to correlate the Laboratory's information from the Nevada tests with data developed by Japan's Atomic Bomb Casualty Commission. Laboratory researchers evaluated the shielding capabilities of Japanese houses and other structures and recommended a dosimetry program to determine whether the survivors were properly shielded from radioactive materials in the environment.

Competitive Challenges

The Laboratory faced not only international competition during the late 1950s but also increasing competition at home from private nuclear companies. By 1959, the rapidly growing nuclear industry questioned the role of national laboratories, urging that some of their work be contracted to private industry or even that the laboratories be closed. Partly as a result of these pressures, the AEC circumscribed Laboratory programs in the late 1950s. For example, the AEC canceled the power reactor fuel reprocessing facility that the Chemical Technology Division hoped to build in Oak Ridge. In 1959, the Laboratory also recognized that it could soon lose its homogeneous and gas-cooled reactor programs.

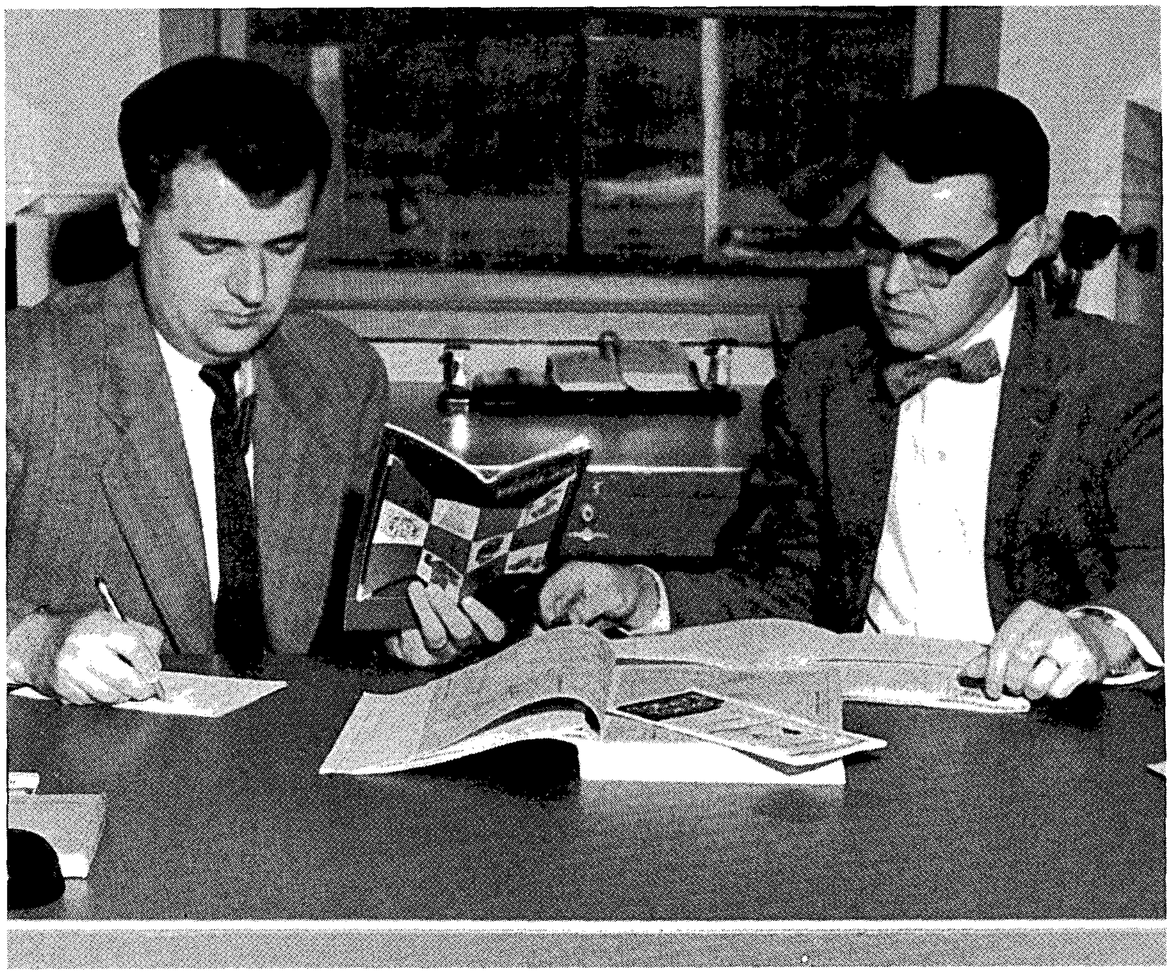
In response to the expected decline in its nuclear reactor and chemical reprocessing programs, the



Personnel radiation dosimeters of the 1950s and 1960s included the pocket screamer, or "chirper."

Arthur Upton directed studies of radiation and cancer at the Laboratory before becoming director of the National Cancer Institute.

"The Laboratory faced not only international competition during the late 1950s but also increasing competition at home from private nuclear companies."



ORNL's Samuel Hurst (left) and Rufus Ritchie in 1955 worked with the Atomic Bomb Casualty Commission to determine the health effects of radiation from the atomic bombs dropped on Japan.

Laboratory conducted an advanced technologies seminar in 1959 to identify possible missions beyond nuclear energy. The seminar recommended additional study of nationally valuable research programs that had not been commercially exploited. Desalination of sea water, meterology, oceanography, space technology, chemical contamination, and large-scale biology were mentioned as potential broad avenues of inquiry.

Although convinced that federal investment in national laboratories was too great to permit their abandonment, Weinberg recognized that a realignment of their missions was in order. Asked to forecast the role of science and national laboratories during the 1960s, Weinberg expressed his hope that they "will be able to move more strongly toward those issues, primarily in the biological sciences, which bear directly upon the welfare of mankind."

The Olympics of antiquity had begun as a single event: a long distance race between the best runners of competing Greek city-states. The modern Olympics, particularly in the post-World War II era, have been transformed into a sports carnival where athletes display their diverse skills as runners, swimmers, equestrians, weight lifters, skeet shooters, and volleyball and basketball players.

In the same way, the scientific olympics in which the Laboratory competed began as a contest comparing the scientific prowess of the Soviet Union and the United States. The Laboratory, as one of America's primary institutions for scientific research, had a simple goal: display the nation's scientific talent and accomplishments in the most dramatic way possible.

As the 1950s unfolded, however, the contest became more diverse and complicated. Space issues eclipsed the importance of nuclear research as the most important symbol of a nation's scientific capabilities; other goals began to compete for the Laboratory's resources and energies; and the initial successes of fission and fusion research proved difficult to replicate. In short, like Olympic runners who followed in the path of their earliest brethren, Laboratory scientists by the end of the 1950s found they would have to share the arena with other figures and other events. As the Laboratory entered the 1960s, its work would be less dramatic but no less important, and its focus more diverse but no less compelling. ornl

Gerald Goldstein tests the ability of the GeMSAEC analyzer to detect and measure trace pollutants in air and water—one symbol of the Laboratory's scientific diversity.

Chapter 5

Balancing Act

In 1961, Director Alvin Weinberg predicted that historians would view atom-smashing accelerators, fission reactors, and fusion energy machines as prime symbols of modern history, just as the Egyptian pyramids and Roman Colosseum have come to symbolize those ancient cultures. The same year Weinberg made that prediction, however, Laboratory activities began to shift slowly from a reliance on the traditional sciences and engineering hardware to sciences related to social engineering and environmental restoration.

In the 1960s, when congressional committees called on the Atomic Energy Commission (AEC) to expand and diversify national laboratory programs to create more "balanced laboratories," the call struck a responsive chord in Oak Ridge. Program disruptions that followed the ORNL terminations of the Materials Testing Reactor in 1947, the Aircraft Reactor Experiment in 1957, and the Homogeneous Reactor Test in 1961 taught Laboratory management the dangers of relying on a few large hardware programs. In addition, nationwide scientific involvement in the space race intensified competition for federal research dollars.

Responding to the "balanced laboratory" challenge, Director Weinberg organized an advanced technologies seminar to consider the Laboratory's future. "What we should try to do is to identify long-range, valid missions which in scope and importance are suitable for prosecution by ORNL," he said. "Most missions of this sort will probably not fall in the field of nuclear energy. This need not bother us since, in the very long run, ORNL very possibly will not be in nuclear energy exclusively."

As a member of science panels advising presidents Dwight Eisenhower and John Kennedy, Weinberg aggressively sought to use Laboratory expertise to help solve national and international environmental and social problems. Under Weinberg's leadership, and the leadership of Alexander Hollaender in biology, the Laboratory broadened its programs during the 1960s. Although basic nuclear science continued as a mainstay, the Laboratory increasingly focused on applications and safety of nuclear energy: how commercial nuclear power could help curb air pollution and chemical contamination resulting from burning fossil fuels and produce fresh water from the seas for agricultural and industrial applications.

The Laboratory had been a nuclear science center from its inception; in 1961, it took the first steps toward becoming a national laboratory in a broader sense. Before 1961, all Laboratory funding came from the AEC. A decade later, about 14% of its $100 million annual budget came from agencies outside the AEC, mostly for programs connected with civil defense, desalination, space travel, and cancer research.

Information Please

An immediate local result of Weinberg's service on presidential science panels was the development of programs to manage the scientific "information revolution." A historian in 1961 pointed out that the first science journal was published in 1665; the number climbed to 100 in 1800, 10,000 in 1900, and 40,000 by 1961. Science was being buried under a blizzard of new publications. This information explosion, along with increasing specialization and a threatened shortage of scientists, the historian predicted, could cause the collapse of science by 1970. Placed in charge of a presidential task force investigating this ominous trend, Weinberg echoed the historian's sentiments when he said scientists were "being snowed under by a mound of undigested reports, papers, meetings, and books."

To help solve this crisis, Weinberg proposed the creation of information centers. Rather than traditional libraries with stacks of books and shelves of journals available to researchers, these centers would consist of scientists who would read virtually everything published in their specialty, review the data, and provide their colleagues with abstracts, critical reviews, and bibliographic tools. In addition, these scientific "middle people" would contribute to science directly by uncovering new intellectual ties and applications during their in-depth reviews of the literature in their fields.

The recommendation of the Weinberg panel, outlined in the *Science, Government, and Information* report (dubbed the Weinberg report), received broad acceptance. Nationally, more than 300 science information centers were formed, including a dozen at the Laboratory. Among the early Laboratory information centers was the nuclear data group, begun at the Laboratory in the mid-1940s by Kay Way as a continuation of her nuclear data work at the University of Chicago. In 1949 Way moved the nuclear data project to Washington, D.C., under sponsorship of the National Bureau of Standards and later the National Academy of Sciences. In 1964 Weinberg brought Way and her team of seven physicists back to the Laboratory, where they continued the systematic collection and evaluation of nuclear data, publishing it in tabulated form for use by researchers.

Other Laboratory information centers specialized in the fields of accelerators, atomic-collision cross sections, charged particles, engineering, isotopes,

"Laboratory activities began to shift slowly from... traditional sciences and engineering hardware to... social engineering and environmental restoration."

"The Laboratory employed some of the world's foremost solution chemists."

nuclear safety, materials research, radiation shielding, toxic substances, and the environmental and life sciences. Coordinated by Walter Jordan and François Kertesz, these centers disseminated the information they collected largely by publishing review journals such as *Nuclear Safety*, annotated bibliographies, charts, and digital computerized information. Widely acclaimed, many of these publications and services have continued to be useful sources of information for researchers.

Desalting the Waters

Although less successful in the long run than the information centers, research into removing salt from seawater to produce fresh water for drinking and agriculture attracted the most public and political attention of all the Laboratory endeavors to achieve "balance."

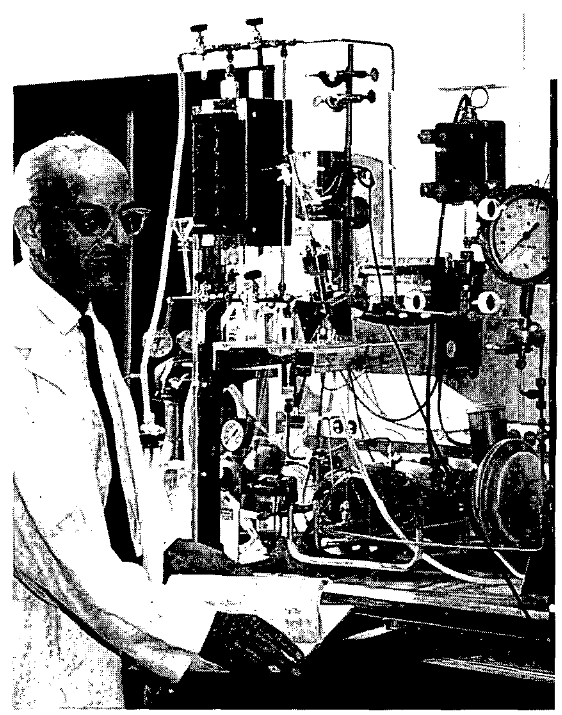
As a result of its research into fluid-fuel reactors and the chemical processing of nuclear fuels, the Laboratory in 1961 employed some of the world's foremost solution chemists. Some of these chemists had become intrigued by the chemistry involved in desalinating seawater. They voiced support for desalination as a new Laboratory mission in Weinberg's advanced technology seminars, and a committee headed by Richard Lyon explored its potential with the Office of Saline Water, a research arm of the Department of the Interior.

In Washington, D.C., Weinberg discussed desalination with other presidential science advisers. He also met with Secretary of the Interior Stuart Udall. Managers at the Department of the Interior's Office of Saline Water were not thrilled about funding desalting research at the Laboratory, but Udall and Glenn Seaborg, chairman of the AEC, orchestrated a "shotgun marriage" between the two federal agencies.

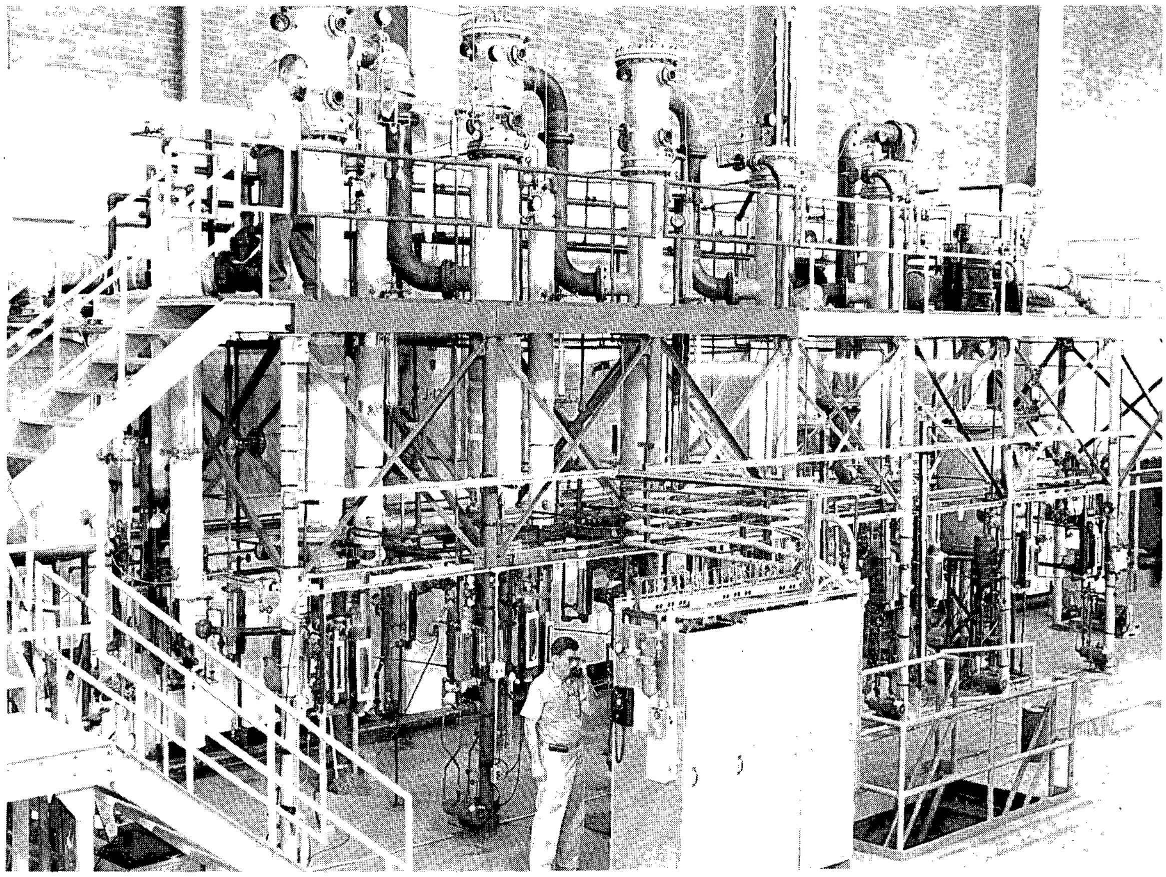
Funded initially at $600,000 a year by the Office of Saline Water and the AEC, a team of Laboratory chemists and engineers led by Kurt Kraus investigated the physical chemistry of seawater, focusing on hyperfiltration (reverse osmosis) to remove salts and contaminants from water. Development of dynamic membranes for rapid production of fresh water from seawater earned the team wide recognition.

A second phase of the desalting work originated with Philip Hammond, who contended that large nuclear reactors could produce power and heat cheaply enough to desalt seawater, providing electricity for industry and fresh water for agriculture.

Presidents John Kennedy and Lyndon Johnson judged desalination to be in the national interest. Johnson, in fact, sought to make it an instrument of foreign policy, hoping to build nuclear desalination centers in arid regions such as the Middle East to reduce international competition for natural resources. Echoing the president, Weinberg said, "I can think of few major technical achievements, including manned exploration of space, that would have as much beneficial political impact as would making the deserts bloom with nuclear energy."



Chemist Kurt Kraus directed the Laboratory's water research program during the 1960s.



"I can think of few major technical achievements... that would have as much beneficial political impact as would making the deserts bloom with nuclear energy."

ORNL's desalination pilot plant used highly efficient heat transfer tubes to desalt large amounts of seawater.

At the 1964 United Nations Conference on Peaceful Uses of Atomic Energy in Geneva, President Lyndon Johnson and Soviet Premier Nikita Khrushchev viewed the Laboratory's proposed nuclear agro-industrial complexes favorably. Dubbed "nuplexes" by the media, these blueprints called for huge nuclear reactors to produce fresh water from the ocean to irrigate crops and generate electric power. With international support, Laboratory staff in 1964 began to travel to Israel, India, Puerto Rico, Pakistan, Mexico, and the Soviet Union to assist with plans for desalination plants.

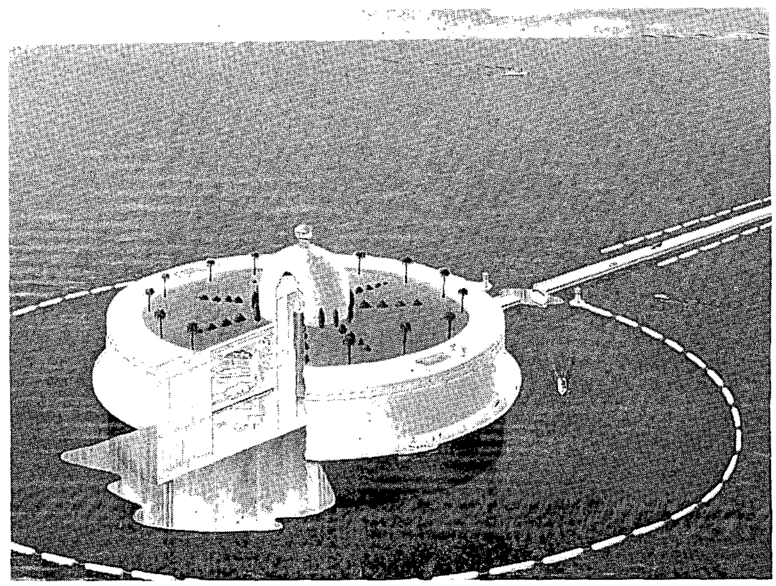
In private, however, Weinberg warned AEC Chairman Seaborg that desalination publicity had outrun the program's technical capabilities and that the Laboratory needed increased research funding "so that the technical basis for the politicians' speeches always remains as firm as possible."

By 1965, when President Johnson announced his "Water for Peace" program, 100 ORNL researchers were studying desalination. One important development was a set of vertical evaporator tubes four times more efficient at producing fresh water from seawater than earlier models. In addition, the Rockefeller Foundation, which funded research into disease- and drought-resistant seedlings to nurture the Green Revolution, became interested in nuplexes as potential food factories in poverty-stricken nations. Former President Eisenhower and former AEC Chairman Strauss endorsed a desalination plant in the Middle

" 'Solving today's social and economic problems with tomorrow's technology is risky,' Weinberg lamented."

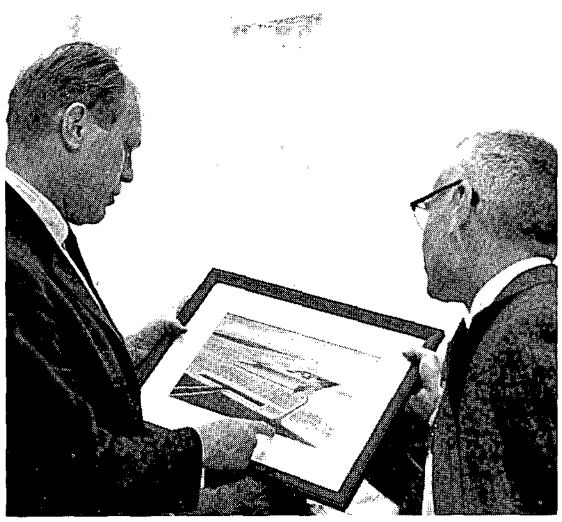
East sponsored by private funds funneled through the International Atomic Energy Agency.

The desalination bubble burst as quickly as it had formed. By 1968, the costs of nuclear plants had escalated so rapidly that desalination plants no longer seemed economically feasible. As nuclear power costs skyrocketed and the country's social and environmental concerns moved to the forefront, the media and political leaders lost interest in nuplexes. None was ever built, and funds for desalination research dried up as new grain varieties that could be grown with little water staved off famine.



Artist's sketch of a proposed island "nuplex" using nuclear energy to generate electricity and desalt seawater for irrigating crops.

"Solving today's social and economic problems with tomorrow's technology is risky," Weinberg lamented near the close of this Laboratory effort to become more "balanced." Yet, the information obtained from desalination research later proved valuable for Laboratory technologies developed to treat contaminated water and sewage. Furthermore, a desalination pilot plant planned for a power station near Los Angeles draws extensively on ORNL evaporator tube technology.



Congressman Gerald Ford and Alvin Weinberg examine a sketch of a coastal "nuplex."

Big Biology

Alexander Hollaender's Biology Division prospered enormously during Laboratory efforts to "balance" its research programs. Staffed by experts who studied the genetic and physical effects of radiation on living organisms, the division also hoped to shed light on radiation's impact on the environment.

When Rachel Carson's *Silent Spring* was published in 1962, it stimulated intense public concern about the role chemical agents might play in biological and environmental degradation. This widespread worry prompted increased research funding for the National Institutes of Health (NIH), whose managers soon received visits from Hollaender, Weinberg, and other Laboratory staff. The discussions—and subsequent funding—bore fruit during the 1960s in the form of increased

Alexander Hollaender managed the Laboratory's Biology Division from 1946 to 1966.

biological understanding and improved tools for science and medicine.

With support from the National Cancer Institute, the Biology Division opened a Biophysical Separations Laboratory, taking advantage of centrifuge designs by Paul Vanstrum and fellow researchers at the Oak Ridge Gaseous Diffusion Plant. The team there had devised improved centrifuges to produce enriched uranium for nuclear reactor fuel, and in 1961 a biology team headed by Norman Anderson, with advice from Jonas Salk of polio vaccine fame, adapted centrifuge technology to separating viruses from human leukemic plasma, hoping to identify a cure for leukemia. This striking use of nuclear separations technology to advance science and medical research led in several directions.

A hollow cylinder subdivided into sectors, which creates a zonal centrifuge whirling at high speeds, can separate substances at the molecular level into their constituents according to size and density. Anderson and his team experimented with centrifuges whirling up to 141,000 revolutions per minute and learned the machines could separate impurities from the viruses causing polio and Hong Kong flu. By cleansing vaccines of foreign proteins, the zonal centrifuge could produce a vaccine pure enough to minimize the fever reactions that often accompanied immunizations. By the late 1960s, commercial zonal centrifuges based on the ORNL invention produced vaccine for millions of people and purified rabies vaccines for their pets.

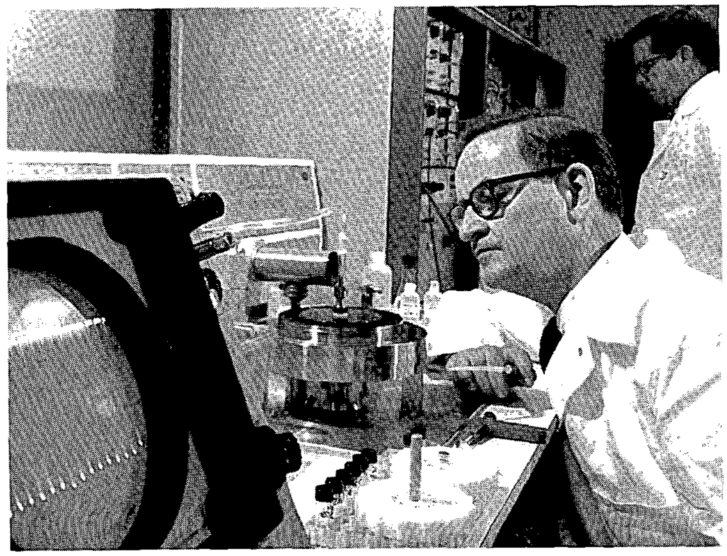
Peter Mazur and Stanley Leibo, both of the Biology Division, pioneered the freezing and transplanting of embryos, successfully implanting the thawed embryos of black mice in white female mice in 1972. With other cryobiologists, they developed methods to preserve embryos from superior cattle and implant them into the uteruses of inferior animals, helping to spur a revolution in animal husbandry that increased the quality and abundance of meat.

"Zonal centrifuges based on the ORNL invention produced vaccine for millions of people and purified rabies vaccines for their pets."

Peter Mazur pioneered ways to freeze and store mouse embryos for implantation into other mice.

"The Molecular Anatomy (MAN) Program sought to identify the metabolic profiles and chemical characteristics of all cell constituents."

In a project jointly sponsored by the AEC and NIH, the Molecular Anatomy (MAN) Program managed by Norman Anderson sought to identify the metabolic profiles and chemical characteristics of all cell constituents. Charles Scott and associates in the MAN Program devised portable centrifugal analyzers commonly used later in medical clinics across the nation. Spinning at high speeds, these analyzers could assay components of blood, urine, and other body fluids in minutes, recording the data on computers for medical diagnosis. The best known of these machines was the Laboratory's GeMSAEC, so named because its development was funded jointly by the NIH's General Medical Sciences Division and the AEC. Using a rotor that spun 15 transparent tubes past a light beam, GeMSAEC displayed the results on an oscilloscope and fed the data into a computer, completing 15 medical analyses in the time it previously took to perform 1 analysis.



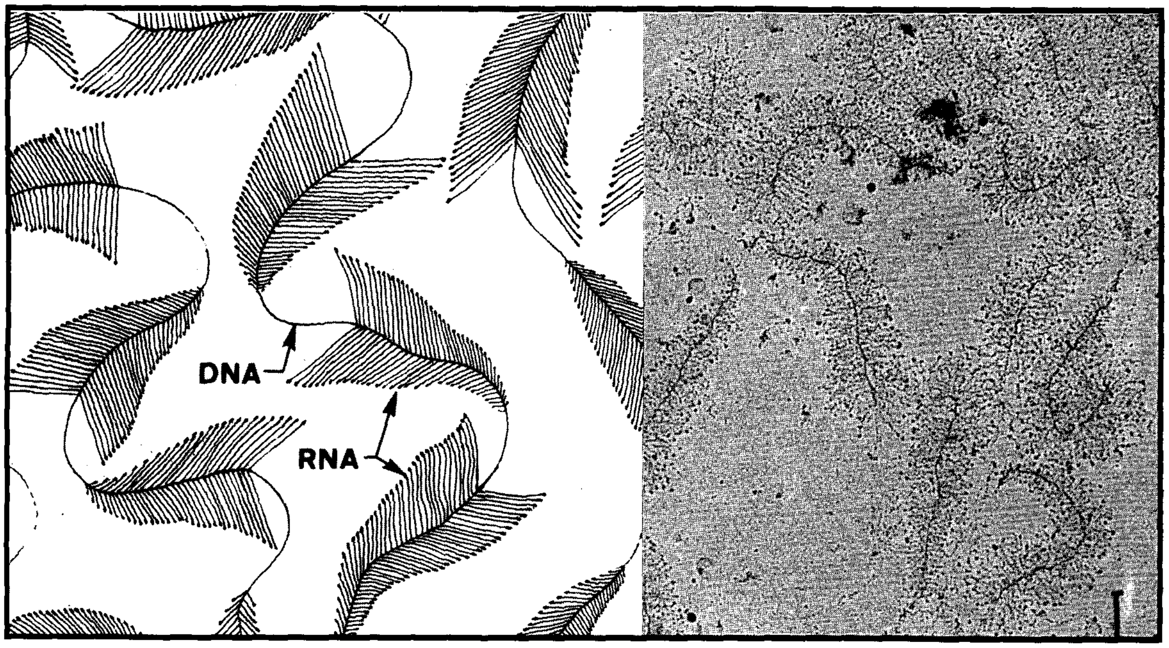
Norman Anderson and Warren Harris observe the GeMSAEC fast analyzer, a 1968 diagnostic instrument later commercialized.

Another eye-catching development in the Biology Division emanated from the Laboratory's search for powerful microscopes able to view and photograph objects the size of a few atoms.

After the Biology Division built an experimental microscope with high resolution in 1967, Oscar Miller and Barbara Beatty placed frog eggs under it and photographed genes in the act of making RNA. "I never expected to see the thread of life, the mysterious stuff that poets conjured long ago to explain the passage of the heartbeat from generation to generation across the eons," mused John Lear of *Saturday Review of Literature*, who came from New York to peer into the microscope. "Yet today the thread lies clearly visible before me, under the lens of an electron microscope, here in the Tennessee hills."

In addition to funding from the NIH for centrifuge and microscope research, the Biology Division received support in 1965 from the National Cancer Institute for a Co-Carcinogenesis Research Laboratory to investigate the

Oscar Miller and Barbara Beatty produce DNA images vital to biological sciences.



DNA strands: diagram (left); under microscope (right).

"By the late 1960s, the Biology Division, which employed 450 people, had become the Laboratory's largest division."

complex biochemical events leading to cancer growth. This work took advantage of the nearly quarter-million mice on hand in the Biology Division. Biologists Richard and Jane Setlow discovered that thymine dimers in experimental animals blocked repair of cellular damage caused by ultraviolet radiation. Arthur Upton and his associates used the mice to study the physical effects of radiation and chemical agents on the environment and on human health. The experiments largely concerned airborne carcinogenesis, or the induction of lung cancer by exposure to pesticides, sulfur dioxide, city smog, or cigarette smoke, both singly and together. Mice exposed to these irritants in an inhalation chamber were then placed in a clean environment while scientists observed the formation of tumors. Upton later left the Laboratory to become director of the National Cancer Institute.

At the time, the components of cigarette smoke were largely unknown. To overcome this handicap, a Lung Cancer Task Force from the Analytical Chemistry Division became involved in carcinogenesis studies when they devised the "ORNL Smoking Machine, Model Number 1." It smoked six cigarettes at a time, even mimicking human inhalation. "This isn't an easy task by any means," commented Herman Holsopple, who built the machine. "Every component in cigarette smoke must first be identified and then studied for its biological effect on humans, and right now we're just trying to identify some of the components." The same approach later was used to determine the biological effects of synthetic fuels made from coal and shale.

To assess how environmental hazards threaten human health required big protocols, large epidemiologic studies, and expensive machines supported by the latest advances in statistics—just the requirements that Big Biology at the Laboratory could provide. By the late 1960s, the Biology Division, which employed 450 people, had become the Laboratory's largest division.

Medical knowledge and clinical machines developed at the Laboratory with NIH funding stimulated the formation of a University of Tennessee–Oak Ridge National Laboratory Graduate School of Biomedical Science. Thanks to grants from the Ford Foundation, the Laboratory had entered a cooperative program with the University

"In 1967, the UT-ORNL Graduate School of Biomedical Science opened, with Clinton Fuller as its first director."

of Tennessee during the early 1960s. As many as 50 Laboratory scientists worked several days each week as Laboratory researchers and spent the remainder of the week as members of the university science faculty.

This cooperation laid the groundwork for a challenge presented in 1965 by James Shannon, director of NIH. Shannon planned a graduate school in biomedical science near NIH headquarters at Bethesda, Maryland, and as a condition for expanding NIH programs at the Laboratory, he urged creation of a similar graduate school in Oak Ridge.

After Weinberg, Clarence Larson, Alexander Hollaender, and James Liverman obtained approval for such a school from the AEC commissioners and Donald Hornig, President Johnson's science advisor, Weinberg asked Andrew Holt, president of the University of Tennessee, if he would be interested in developing the school cooperatively. "Our location in Appalachia and the strong contribution which a major new biomedical program would make to President Johnson's Great Society," Weinberg told Holt, "should enlist the aid of our U.S. senators and congressmen as well as the president."

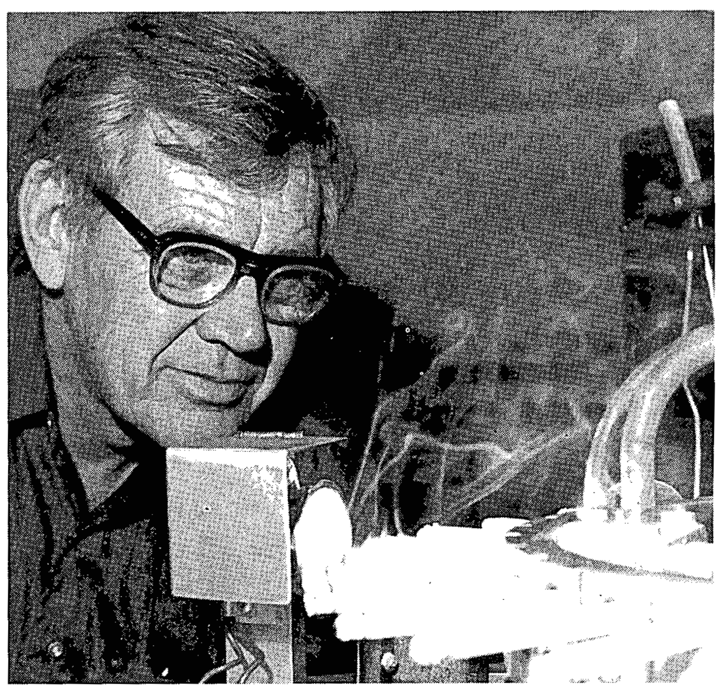
President Holt and university trustees approved the school in late 1965. Governor Frank Clement contributed $100,000 of state funds, and Clarence Larson arranged a $100,000 contribution from Union Carbide. In 1967, the UT-ORNL Graduate School of Biomedical Science opened, with Clinton Fuller as its first director. It was staffed chiefly by Biology Division personnel holding joint appointments with the University of Tennessee and the Laboratory.

Civil Defense

At the same time the Graduate School of Biomedical Science was being organized, Weinberg explored formation of a Civil Defense Institute at Oak Ridge. The origins of this concept may be traced to the closing ceremony for the Laboratory's historic Graphite Reactor in November 1963.

AEC Chairman Seaborg, Eugene Wigner, Richard Doan, and other alumni of the Laboratory's wartime campaign returned to Oak Ridge for a nostalgic ceremony formally deactivating the Graphite Reactor on November 4, 1963, after 20 years of service. The next morning, Wigner learned that he would receive the Nobel Prize for physics, an award adding to his public visibility and prominence. At the time, he was campaigning for improved national civil defense. "According to the preamble to the Constitution, one of the purposes of the Union was to provide for the common defense," said Wigner. "It seems difficult to think of defense without making every effort toward protecting what is most important: the lives of the people."

Confrontations with the Soviet Union over Berlin and Cuba had spurred major funding for civil defense in the United States. Schoolchildren practiced air-raid drills, and homeowners built fallout shelters in their backyards. Although it seems a



Bob Holmberg operates a 30-cigarette smoker used for inhalation testing at the Laboratory.

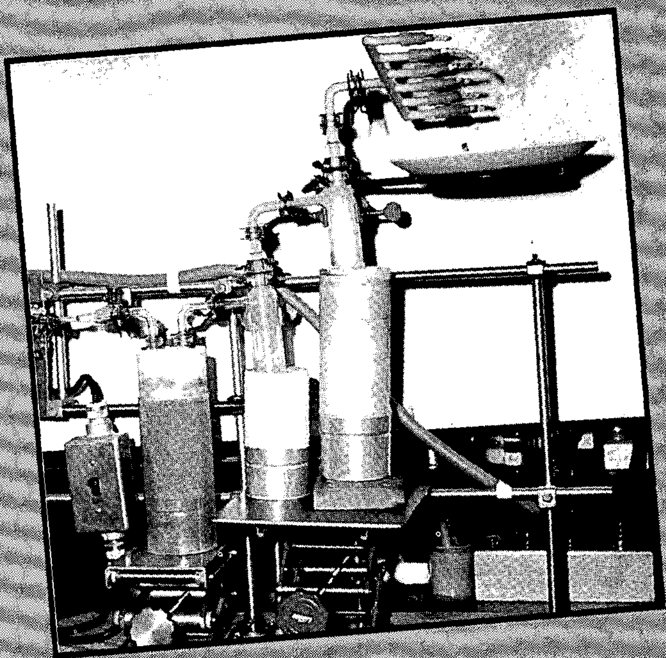
Smoking Out The Facts

The Laboratory entered the field of smoking research in 1968 to support the National Cancer Institute's (NCI) goal of producing a "less hazardous cigarette." The NCI asked Laboratory researchers to participate in a new program coordinated by the Tobacco Working Group, which included government and tobacco industry scientists and administrators. W. T. Rainey, Jr., headed the first team in the Analytical Chemistry Division at the Laboratory.

Commercial cigarettes could not be used in the studies because their exact compositions were trade secrets, so the tobacco industry produced more than 100 kinds of cigarettes specifically for experimental purposes. Later, the University of Kentucky produced a standardized cigarette, called the Kentucky Reference Cigarette, to be used in the tests. These standardized cigarettes were burned on large smoking machines that smoked 360 cigarettes at a time and produced tar by the kilogram. While other contractors used the tar for animal studies, Laboratory researchers performed chemical analyses on the tar and smoke.

In the early 1970s, the NCI wanted inhalation studies done, but at that time no devices were available to replicate the way a smoker actually inhales. The Analytical Chemistry Division set to work on this problem. Its researchers developed one inhalation apparatus that the NCI used extensively and also contributed to development of several others for the tobacco industry.

One of the biggest problems with inhalation studies is that the rodents typically used in these studies naturally breathe through their noses. Because the substances of interest in the tobacco smoke were trapped in the test rats' nasal passages, they did not reach the lungs as the researchers intended. To solve this problem, the Laboratory's Biology Division devised an intratracheal cannula — a tube that could be inserted into the rodent's mouth to put the smoke directly into the lung.



This Rube Goldberg–like device, built in 1968, was ORNL's first smoking machine. Researchers analyzed the cigarette smoke.

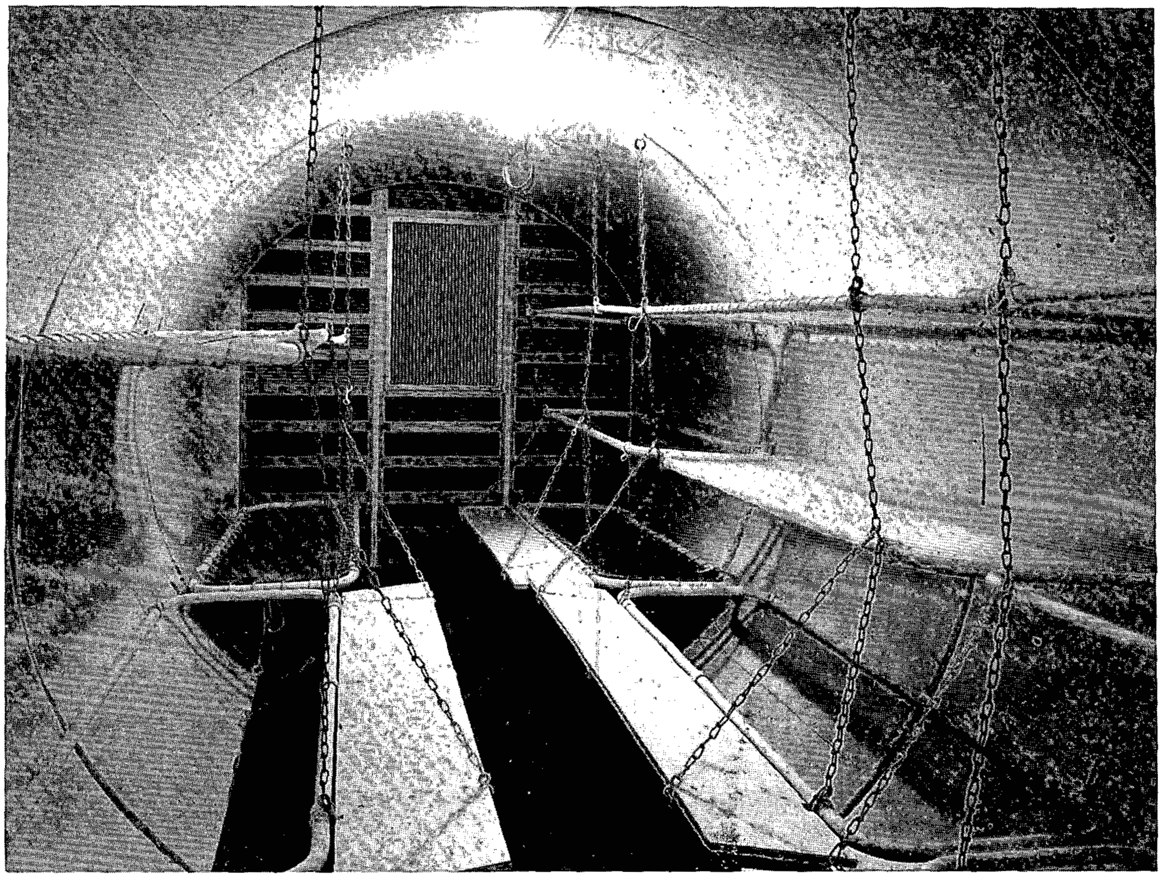
In the late 1970s, biological "smoke" studies became a smaller part of Laboratory research. The focus shifted to chemistry—isolating and identifying the constituents of smoke that cause cancer and mutations. Laboratory researchers provided support for other NCI contractors all over the country. Roger Jenkins, Bob Gill, and Brad Quincy, all of the Analytical Chemistry Division, traveled frequently during the late 1970s, taking their expertise in tobacco smoke chemistry, inhalation toxicology, and inhalation exposure monitoring on the road from laboratory to laboratory.

In December 1978, the U.S. government committed itself to analyzing all commercial brands of cigarettes for carbon monoxide in addition to tar and nicotine. The Federal Trade Commission laboratory had unforeseen instrument problems, though. The automated infrared system government scientists used for the carbon monoxide analysis failed, and it began to look as though the project would not be completed on time. The Analytical Chemistry Division was asked to help out by analyzing as many of the cigarette brands as possible before the deadline. The Laboratory successfully analyzed some 75 different brands of cigarettes.

Some support for the Laboratory's smoking research has been provided by the tobacco industry through its research consortium, the Council for Tobacco Research. The American Cancer Society has also sponsored research at the Laboratory, including a study done by Jim Stokely in which he measured the concentration of radioactive polonium-210 in cigarettes.

Today the emphasis in smoking research is on so-called passive smoke, or environmental tobacco smoke (ETS), and the Laboratory continues in its supporting role. At the University of California at Davis, Laboratory expertise in designing smoke inhalation systems is being put to use in a study of the health effects of ETS on fetal and newborn rats. Results from scientific studies of ETS may help policymakers clarify a still-cloudy issue.

Beyond the research, the Laboratory in 1991 became a smoke-free environment after an extensive informational and educational program designed to help staff members break the habit.



Interior of a fallout shelter used at the Laboratory during the 1960s for civil defense experiments.

"Wigner would receive the Nobel Prize, adding to his public visibility and prominence. At the time, he was campaigning for improved national civil defense."

national obsession in retrospect, the threat then was clearly defined by U.S. and Soviet nuclear capabilities.

Wigner returned to the Laboratory in 1964 to organize a small, yet vigorous, civil defense research project to assess national vulnerabilities in the event of a nuclear attack and to explore ways to reduce the impact of an atomic assault on America. After organizing this effort, Wigner returned to Princeton, leaving James Bresee as project director, although Wigner made monthly visits to the Laboratory to provide broad programmatic direction.

The Laboratory's civil defense research initially focused on underground tunnels to protect urban populations and on related issues such as how to rid the tunnels of body heat; protect them against firestorms and blasts; and provide them with power, air, and other utilities.

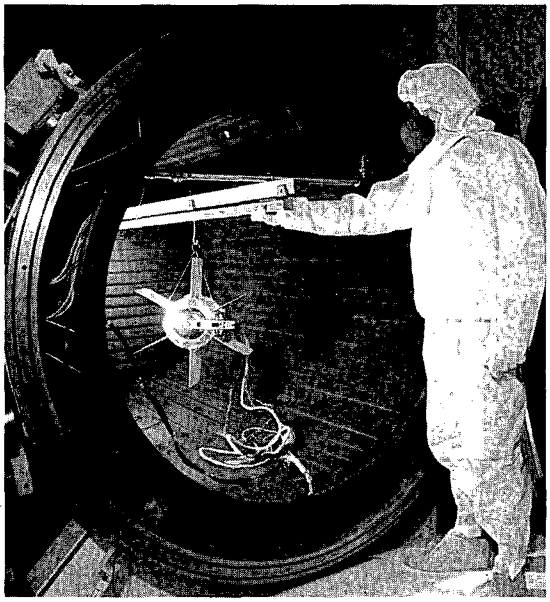
Designing civil defense systems required demographic knowledge, such as the number and probable age distribution of the people to be protected. To uncover this information, the Laboratory hired demographers Everett Lee and William Pendleton and joined Oak Ridge Associated Universities in sponsoring formation of the Southern Regional Demographic group in 1970.

The research also required understanding the reactions of people under the stresses that would accompany emergency use of underground shelters. To explore this problem, the Laboratory hired its first social scientists.

The potential effects of nuclear fallout on the natural environment became a major concern of Stan Auerbach and his fellow radioecology scientists. Auerbach had attended early civil defense conferences with Wigner because of public concerns about the ecological consequences of a nuclear war. As one result, in 1967 small plots of land at the Laboratory were treated with cesium-137–coated particles to observe the environmental effects of simulated radioactive fallout. This experiment proved to be the last large-scale, fresh field application of radionuclides at the Laboratory, although radiotracer studies continued in previously contaminated sites.

James Bresee (right), who directed the Laboratory's civil defense program, converses with physicist Edward Teller.

During the late 1960s, Weinberg explored with the University of Tennessee and state officials the formation of a Civil Defense Institute in Oak Ridge, similar to the Space Science Institute established at Tullahoma, Tennessee. This effort proved unfruitful, but the Laboratory's studies of emergency technology continued under Conrad Chester in the Energy Division, concentrating on evacuation and sheltering from chemical hazards. The group also evaluated the theory that nuclear war could cause major fires, resulting in "nuclear winter" that could plunge much of the world into cold and darkness as the smoke and dust block out sunlight. At the outbreak of the 1991 Persian Gulf War, military authorities thought it worthwhile to reexamine the Laboratory's old civil defense reports on chemical and biological weapons.



During the 1960s, the Laboratory aided development of nuclear power sources for space exploration.

Lab in Space

In the early 1960s, Alvin Weinberg expressed his concerns about prospects of a "scientific olympics" with the Soviets that focused on launching manned spacecraft. He thought the space race had little connection with the well-being of people, and he worried about shielding spacecraft crews against solar radiation. Despite Weinberg's reservations, the National Aeronautics and Space Administration (NASA) supported Laboratory studies of radiation shielding and the biological effects of solar radiation. NASA also partially funded the AEC Systems for

"The research also required understanding the reactions of people under the stresses that would accompany emergency use of underground shelters."

In the Nation's Defense

In the early 1960s, the shadow of the Cuban Missile Crisis hung over the land. Many Americans feared that the country was on the brink of nuclear war.

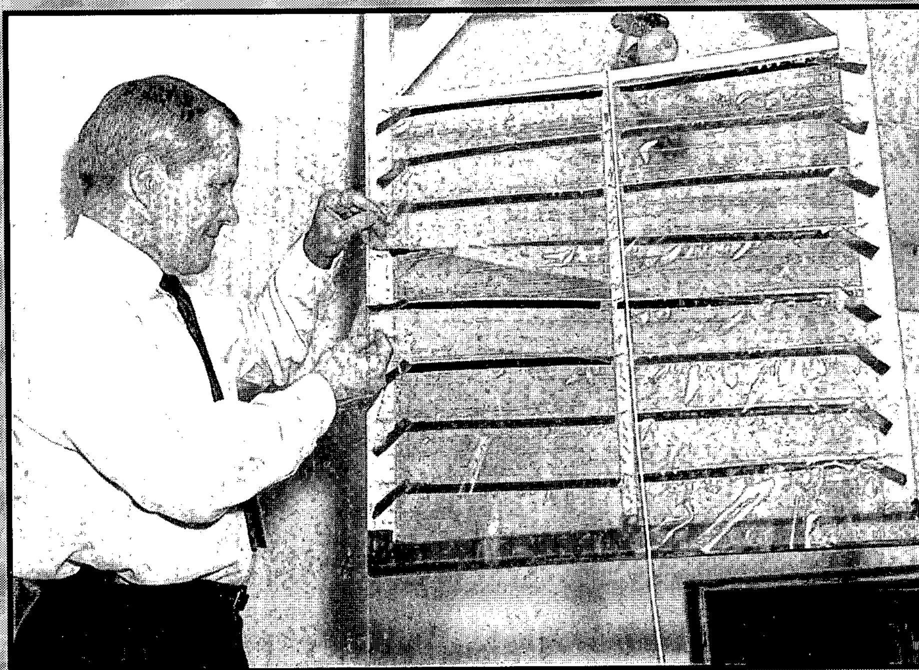
Schoolchildren practiced air raid drills—knees bent, heads bowed; store owners dusted off their air raid shelter signs—faded yellow backgrounds, black lettering, arrows usually pointing downward; suburbanites turned portions of their backyards into air raid shelters—holes dug deep, stocked with canned goods and bottled water. Civil defense, in short, was a national obsession.

In retrospect, the public reaction seems eerie and irrational, but at the time the fears were real and the threat was clearly defined by the nuclear capabilities of the Soviet Union.

The Laboratory joined this effort in 1964 by organizing a small but vigorous Civil Defense Research Project led by one of the Laboratory's founding fathers, Eugene Wigner. Wigner believed that a strong civil defense could reduce the possibility of a nuclear confrontation by blunting the force of imprudent adventures. Other physicists were surprised by Wigner's commitment to the civil defense initiative. A Hungarian by birth and an American citizen by choice, Wigner viewed communism not only as a political challenge but a personal affront.

The Civil Defense Research Project assessed the nation's vulnerabilities in the event of a nuclear attack and explored ways to lessen the impact of the unthinkable—an atomic assault on American soil.

Wigner provided broad directional support for the 20-member interdisciplinary staff during his once-a-month visits to the Laboratory. James Bresee was appointed project director with responsibility for the daily research efforts. Lawrence Dresner built baffles that could weaken the shock waves expected to ripple across the land after nuclear blasts. Cresson Kearny designed and constructed a fallout shelter equipped with a fan to ventilate it and drew blueprints for homemade dosimeters that could measure radiation.



Cresson Kearny designed and built fallout shelters for ORNL's civil defense project.

David Nelson studied the effects of nuclear explosions and fallout on transistors and other electronic components. Conrad Chester studied the threat of chemical and biological warfare agents. Davis Bobrow examined why political officials failed to place civil defense on the top of the policy agenda. And Claire Nader, sister of political activist Ralph Nader, studied the problems that cities would face in the event of nuclear attack. The program also tracked the progress of Soviet civil defense efforts. Joanne Gailar headed this effort, which included translation and publication of a 240-page handbook, *Soviet Civil Defense*.

Other areas of study included the feasibility and effectiveness of blast and fallout shelters, methods of shielding livestock from radiation (and decontaminating meat from irradiated cattle), and human reactions to stress in the wake of a nuclear attack.

By the early 1970s, the nation's —and Laboratory's — fears of an imminent nuclear war were eclipsed by concerns about energy shortages and skyrocketing energy prices. In 1974, the Laboratory discontinued its Civil Defense Research Program and its staff either left the Laboratory or found work in other areas. The program's findings, thankfully, never found direct application; however, many of the research results have been used by civic defense organizations today in times of floods, earthquakes, hurricanes, and other natural disasters.

The program's multidisciplinary approach foreshadowed the efforts of the Energy Division and created an opening for the fields of economics, political science, demography, and policy analysis—all of which have gained increasing acceptance at the Laboratory during the past two decades. This project was the first at any AEC laboratory to include social scientists as members of the team.

Nuclear Auxiliary Power for long-distance space exploration. In fact, the space race brought $3 million into the Laboratory budget in 1962, and by 1966, the Laboratory had 160 personnel in 10 different divisions participating in the space olympics.

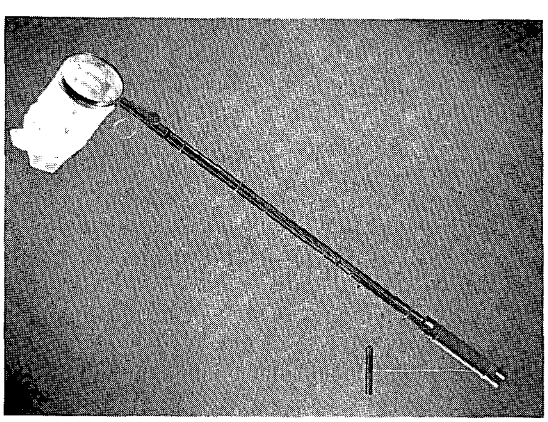
The Biology, Health Physics, and Neutron Physics divisions received assignments to assay the biological effects of radiation from the Van Allen Belt and solar flares and to devise lightweight shields to protect crews of the *Apollo* spacecraft. In addition to ground research, the Biology Division sent boxes containing bacteria and radioactive phosphorus aboard *Gemini 3* and *11* and also placed blood samples aboard satellites to assess radiobiological effects in space. The Health Physics Division exposed small animals and plastic phantoms resembling humans to fast-burst radiation in the Health Physics Research Reactor, thereby estimating the radiation doses to internal organs that might await the *Apollo* crews. Fred Maienschein, Charles Clifford, and others in the Neutron Physics Division used data from the Tower Shielding Facility and linear accelerators to design lightweight shielding for the *Apollo* spacecraft.

J. S. Eldridge and K. J. Northcutt admire a moon rock used at the Laboratory to assay lunar samples for uranium and thorium.

The AEC Systems for Nuclear Auxiliary Power program, begun in 1956, aimed to design compact, maintenance-free power generators for use in remote locations at sea, on land, and in space. Under AEC assignment, the Laboratory undertook studies of two types of generators: miniature nuclear reactors and radioisotope generators.

Arthur Fraas led a team studying a small reactor that used molten potassium to spin a turbine, generating electricity for use in airless, weightless environments. Although not adopted by the AEC for space missions, its boiling-potassium technology found applications in other scientific endeavors.

The Isotopes Division received a major assignment from the AEC to produce massive blocks and pellets of radioactive curium isotopes, which became incandescently hot as they decayed and provided power for the thermoelectric generators. Most of these isotopes went into portable power generators built by Martin Marietta Corporation to supply power to weather stations



The Laboratory helped develop scoops used by Apollo astronauts to retrieve lunar rocks and soil samples.

"Richard Fox designed the vacuum-sealed boxes that housed lunar rock samples after their return to Earth."

in the Arctic and to Navy navigation buoys and beacons at sea. Because deep space exploration required too many panels for the use of solar energy in the spacecraft, some tiny space probes launched toward the outer planets of the solar system during the 1970s used radioisotopic heat sources capable of producing electricity for as long as 30 years without refueling. These survey craft returned spectacular pictures of the outer planets back to Earth a decade or more later.

As planning for NASA missions to the moon began, the Laboratory lost personnel to NASA, including P. R. Bell, who, as director of NASA's Lunar Receiving Laboratory in Houston, requested assistance from his friends in Oak Ridge. Neil Armstrong in July 1969 and other astronauts who later landed on the moon carried telescoping scoops for collecting moon rocks; these scoops were designed by Union Carbide's General Engineering Division and fabricated by the Plant and Equipment Division in Oak Ridge. Richard Fox of the Laboratory's Instrumentation and Controls Division—one of the veterans of the 1942 Fermi experiments in Chicago—designed the vacuum-sealed boxes that housed lunar rock samples after their return to Earth; some of those samples came to the Laboratory for intensive study.

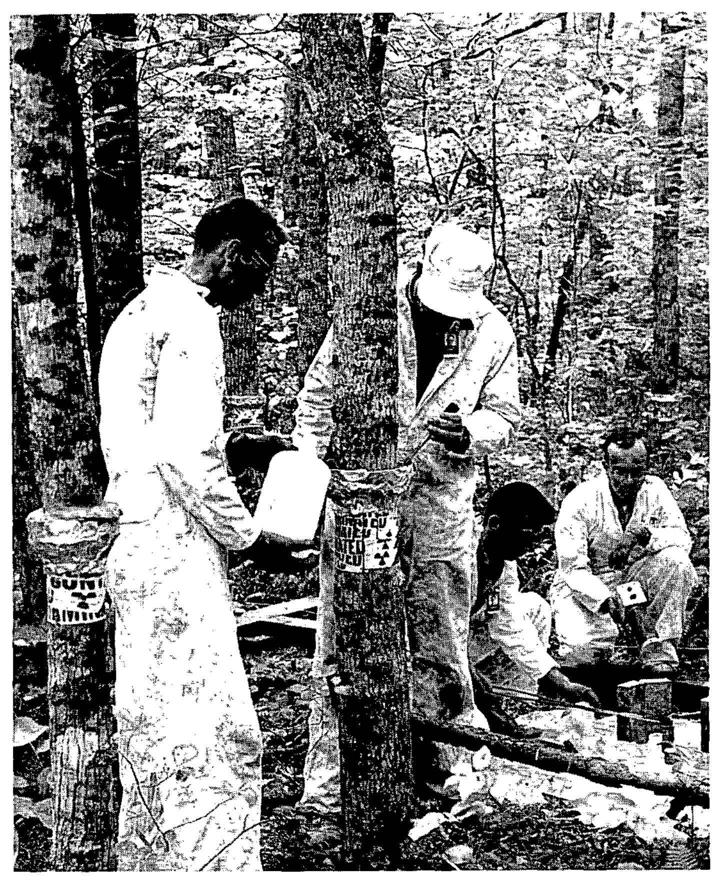
Although less than 4% of the Laboratory's budget came from NASA programs, the personnel involved took pride in helping win the space race. In reflecting on the Laboratory's work for NASA at the end of the 1960s, Weinberg observed that its scientific aspects had been challenging and its management even more so. NASA and other non-AEC projects were subject to micromanagement by the agencies providing the funding, and the Laboratory often missed the budgetary flexibility that AEC-funded programs allowed.

"By 1969, 14% of the Laboratory's programs consisted of non-nuclear work for agencies other than the AEC."

Environment

Because the AEC had no firm policy on performing work for other agencies, the Laboratory during the 1960s approached external efforts one at a time, gaining approval from AEC headquarters for each venture. By 1969, 14% of the Laboratory's programs consisted of non-nuclear work for agencies other than the AEC. Argonne, Brookhaven, and other laboratories then had less than 1% of their work funded outside the AEC.

In 1967, Congress amended the Atomic Energy Act to further encourage work for other agencies by AEC laboratories. The AEC, along with Congressman Chet Holifield of the Joint Committee on Atomic Energy, urged the laboratories to initiate studies of environmental pollution, then



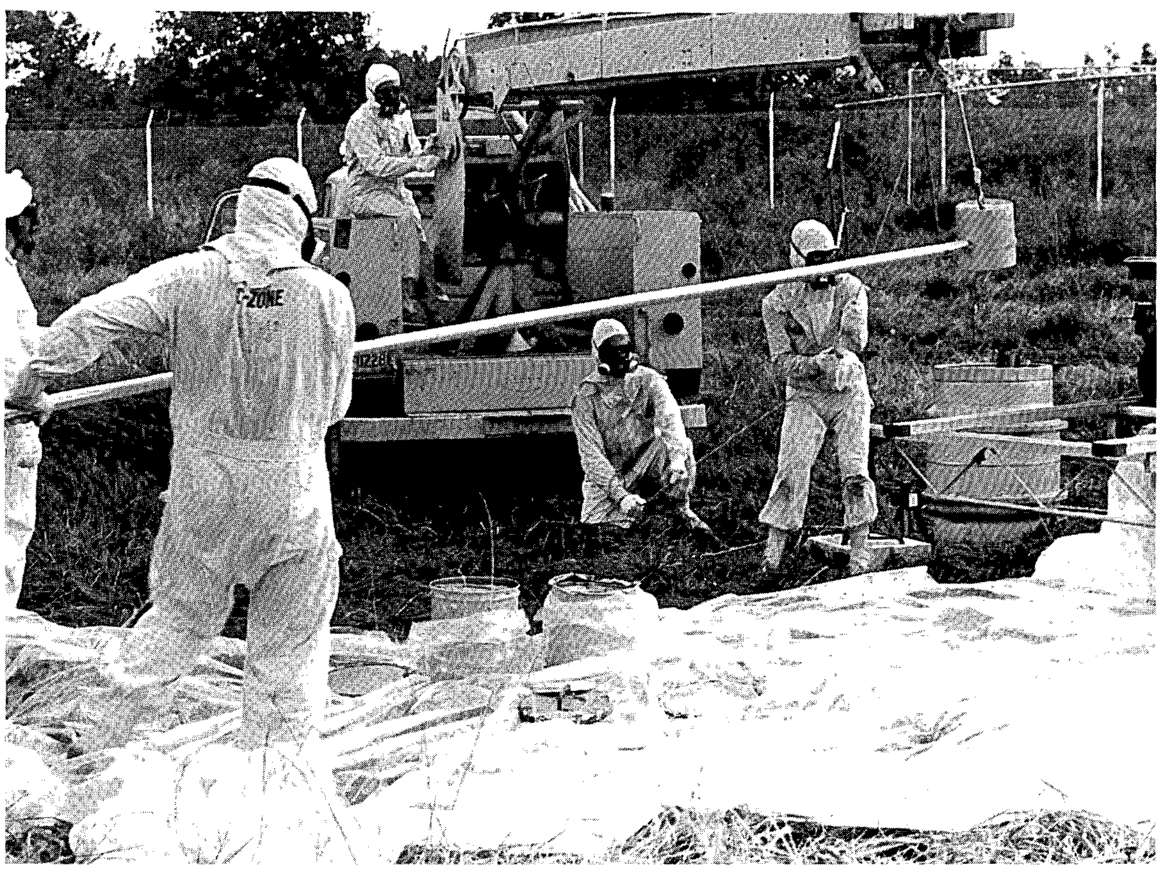
ORNL scientists tag poplar trees with cesium-137. Left to right: William Cate, Jerry Olson, Hubert Waller, and Stan Auerbach.

an increasingly popular and well-funded program under the Federal Water Pollution Control Agency. Weinberg advised the AEC's general manager that Auerbach's ecological studies and Kraus's water research placed the Laboratory in a strategic position to attack water pollution by identifying water pollutants and assessing their effects on aquatic and terrestrial life. Technology developed during the desalination studies, moreover, could be adapted to improve sewage wastewater treatment. Also, Laboratory capabilities in analytical chemistry could be applied to investigations of atmospheric pollution, and biologists could expand their analysis of the effects of chemical agents on living organisms.

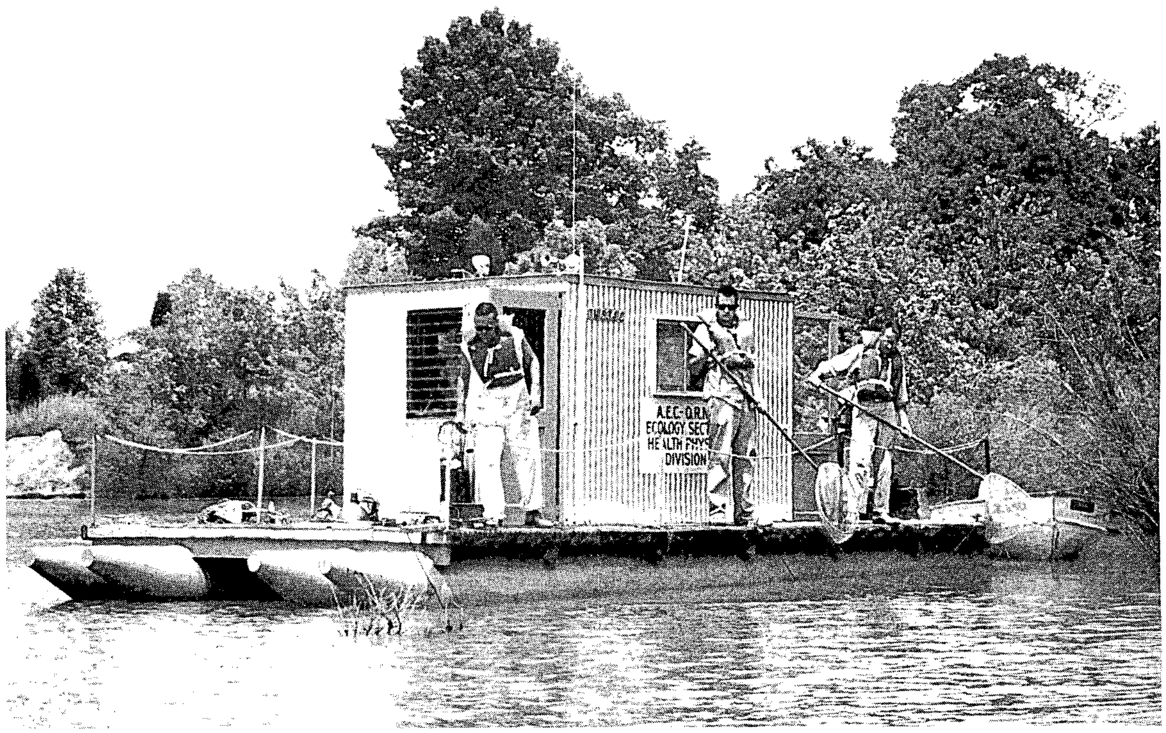
The Federal Water Pollution Control Agency did not accept the Laboratory's first proposal in 1967 to investigate stream eutrophication. Auerbach and his ecologists then proposed to the AEC that it approve Laboratory study of the impacts of heated water released from power plant cooling facilities into aquatic systems. When the AEC approved this initiative, Auerbach recruited Chuck Coutant, an expert on aquatic thermal effects, to lead this research effort.

For environmental research at the Laboratory, 1967 was literally and figuratively a watershed year. The AEC approved Daniel Nelson and James Curlin's proposed development of the Walker Branch Watershed research facility, a small stream basin near the main Laboratory complex, as an experimental center for studies of the relationships between terrestrial and aquatic ecosystems. With

"For environmental research at the Laboratory, 1967 was literally and figuratively a watershed year."



Stanley Auerbach operates a hoist handling a cask of cesium-137-tagged sand during a radioecology study. Left to right: Roger Dahlman, Paul Dunaway, Jay Story, and an unidentified scientist behind the pushpole.



The Laboratory's ecology workboat built in 1959 for a survey of the Clinch River. Collecting specimens are (from left) Bill Martin, Neal Griffin, and Daniel Nelson.

instruments located both above and below ground for precise measurement of stream flows, the Walker Branch facility, Auerbach later recalled, marked the beginning of educating Laboratory personnel about the requirements of large-scale environmental research. Also in 1967, the National Science Foundation appointed Auerbach director of the ecosystems component of an International Biological Program for the eastern United States. Funded at about $1 million annually for eight years, this was the first major program supported by the National Science Foundation at an AEC laboratory.

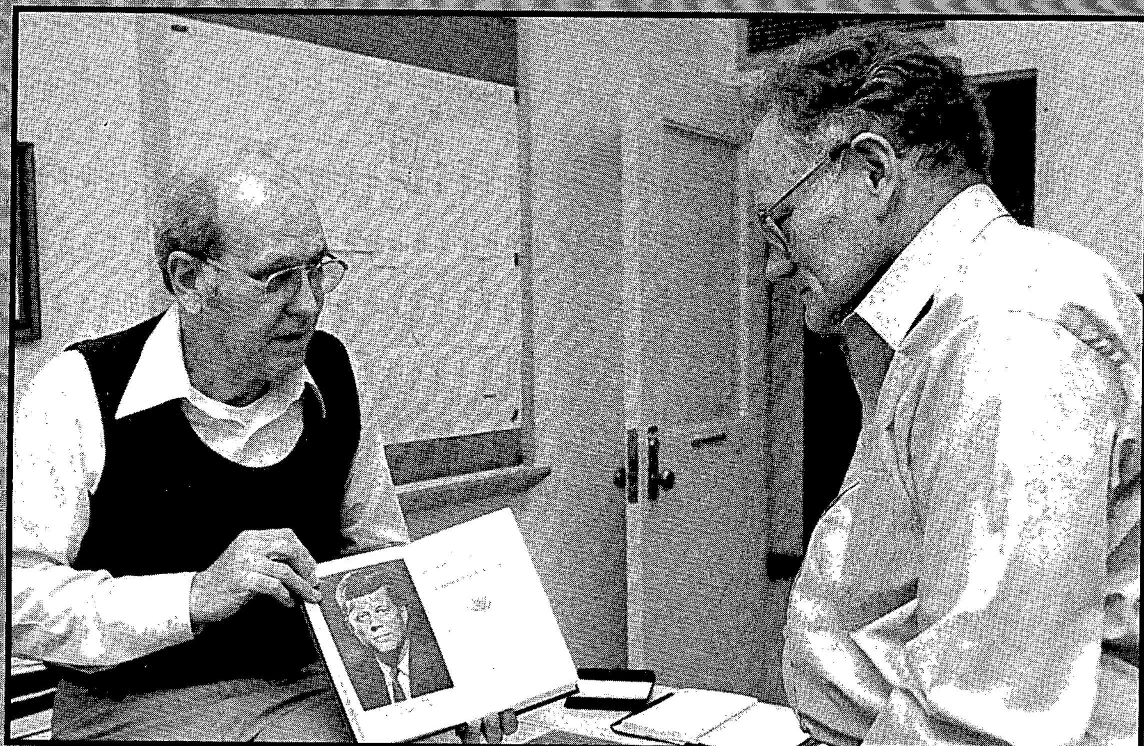
"By the end of the 1960s, 20% of the Laboratory's reactor budget was devoted to nuclear safety."

As the 1960s waned, national awareness of ecological damage and the threat of pollution increased. As the environmental movement fermented, the Laboratory's potential as a center for environmental research received more and more recognition. Auerbach, William Russell, and other Laboratory ecological and life scientists went on the road to public hearings where they found people concerned about the environmental and health impacts of nuclear energy. Although spearheading investigations of environmental pollution, the Laboratory, along with the AEC and the nuclear industry, found itself on the defensive against charges leveled by environmental activists. Questions about the safety of nuclear reactors became increasingly pertinent to Laboratory research programs.

Nuclear Safety

By the end of the 1960s, 20% of the Laboratory's reactor budget was devoted to nuclear safety. The Laboratory operated a nuclear safety pilot plant to test fission-product release and fuel transport. It developed a mock-up facility to test fast breeder reactor fuel bundles and a heat-transfer facility to test fuel element behavior in the event of loss-of-coolant accidents. It also devised filters to contain

Neutrons and JFK



Juel Emery and Frank Dyer, ORNL radiochemists, reminisce about their studies of the Kennedy assassination. Their results were published in the *President's Commission Report on the Assassination of President Kennedy*.

Most Laboratory personnel learned of the assassination of President John Kennedy over the Laboratory's public address system on the afternoon of November 22, 1963. A week later, the Federal Bureau of Investigation (FBI) asked the Laboratory to study fragments of the bullets that struck the president and the paraffin casts taken of the hands and face of Lee Harvey Oswald, the accused assassin.

This request was made because the Laboratory had facilities and scientists available for performing neutron activation analysis. When neutrons from a reactor activate the atomic elements in a material, each element emits characteristic gamma rays, revealing its presence and concentration in the material.

About five years after John Kennedy had admired the Oak Ridge Research Reactor as a U.S. senator, evidence relating to his assassination came to the Laboratory, where William Lyon, Frank Dyer, and Joel Emery, all of the Analytical Chemistry Division, tested it in the High Flux Isotope Reactor's neutron flux. The FBI hoped Laboratory researchers could match gunpowder particles on the paraffin casts with gunpowder from a rifle found at the crime scene. The fact that Oswald had fired a pistol, killing a Dallas policeman, the day of the assassination, and earlier tests made on the paraffin casts complicated the research and made the Laboratory's results inconclusive.

"The FBI hoped Laboratory researchers could match gunpowder particles on the paraffin casts with gunpowder from a rifle found at the crime scene."

The FBI hoped that ORNL's neutron activation analysis of the bullet fragments taken from the president's limousine could determine whether the bullets were fired from a single weapon. Lead bullets have traces of silver and antimony, and the Laboratory's analysis of these traces indicated that the bullets did indeed come from the same rifle. Later independent study by a University of California neutron activation specialist confirmed the Laboratory's conclusion. ORNL's Nuclear and Radiochemistry Analysis group complied with many requests for neutron activation analysis in connection with crimes until the 1970s when commercial laboratories entered the field.

"The national requirement that environmental impact statements be prepared for new federal projects brought considerable work"

radioactive iodine that might be released during accidents and participated in the design of auxiliary cooling systems for reactors to prevent meltdowns.

The Laboratory's Heavy-Section Steel Technology Program, under Joel Witt and Graydon Whitman, closely examined reactor pressure vessels to ascertain their performance under stress. Early steel pressure vessels in reactors had ranged from 8 to 25 centimeters (3 to 10 inches) thick, but the larger vessels designed by 1968 were as much as 35 centimeters (14 inches) thick. The Heavy-Section Steel Technology Program's task was to investigate this armorlike steel and devise safety codes and standards for its use in reactor vessels.

Private nuclear industry shared the costs of heavy-section steel investigations and other nuclear safety programs with the AEC, but these studies were not considered work for other agencies. Instead they were viewed as key Laboratory initiatives, rooted to the institution's historic concerns and mandated by the broad nuclear policy responsibilities granted to the AEC.

Lab of Tomorrow

To address possible future roles, the Laboratory obtained National Science Foundation funding for summer seminars in environmental sciences during the late 1960s. These seminars began in 1967 with a multidisciplinary study of a nuclear agro-industrial complex and expanded in 1968 to include investigations by Laboratory, Tennessee Valley Authority, and university scientists and engineers of the Middle East, its resources, and the health and education of its people. Milton Edlund and James Lane headed the Middle East studies and visited this distant region to explore potential developments there.

In the summers of 1969 and 1970, seminars organized by David Rose, who came to the Laboratory from the Massachusetts Institute of Technology, and by Laboratory staff members John Gibbons, Claire Nader, and James Liverman, addressed environmental issues and the general role of science in the formation of public policy. In retrospect, these far-ranging seminars were pivotal events in the formation of the Laboratory's Environmental Sciences Division and Energy Division, which employ most of the Laboratory's social scientists. Out of these seminars grew a proposal to create national environmental laboratories, or at least one in Oak Ridge.

Declaring that "ecologists have displaced the physicists and the economists as high priests in this new era of environmental concern," Weinberg formed a National Environmental Concept Committee under David Rose. This committee of ORNL thinkers conceived of the need for "national environmental laboratories" to examine environmental problems holistically. Rose wrote a controversial paper calling for such institutions and suggesting that ORNL might be one of them. The committee delivered a copy of *The Case for National Environmental Laboratories* to Senator Howard Baker of Tennessee, who had it printed as a congressional document. Weinberg and Rose then met with senators Baker and Edmund Muskie to discuss it. In early 1970, a House committee added $4 million to the National Science Foundation budget earmarked for studies at the Laboratory of sewage hyperfiltration, air pollution, waste management, and chemical toxicity, and senators Baker and Muskie sponsored a resolution establishing a National Environmental Laboratory at Oak Ridge. Momentarily, it appeared that the Laboratory might jump into the forefront of environmental science.

Congressman Chet Holifield of the Joint Committee on Atomic Energy surprised the Laboratory's staff when he blasted the Baker-Muskie resolution. Rumor had it that he said, "Let Muskie get his own laboratories!" Holifield added a rider to the 1970 AEC authorization that read:

> *The Joint Committee sees signs that ambition to acquire new knowledge and expertise in fields outside the present competence and mission of an AEC National Laboratory, in order to attain and provide wisdom which this country needs in connection with non-nuclear environmental and ecological problems, is spurring at least one laboratory to solicit activities unrelated to its atomic energy programs and for which it does not now have special competence or talents.*

Laboratory's Collective Strength

"There is a general view, nurtured by members of the academic community, that the really worthwhile basic research is research done at universities. But those who hold this view are thinking of research in a parochial and narrow fashion. They are thinking mainly of the brilliant individual flashes of theoretical and experimental insight which characterize the best university research as performed by a gifted professor and his coterie of students. They seem to overlook the other style of research, perhaps originally exemplified by the German institute, where a massive attack on a given set of problems is made by teams representing different disciplines. No one member of the team may be as brilliant as the best professor in a university. But the members of the team bring a professionalism to their jobs that goes much beyond what graduate students can do; moreover, cooperation is much easier in such an institute than it is in a university. In the institute the whole is greater than the sum of its parts since the members of an institute interact so strongly with each other.

"Now the research style of the institute, rather than of the university, characterizes basic research in the best of the large government laboratories. The people in these laboratories are usually not geniuses (although Eugene Wigner is spending a year here at Oak Ridge), but they are competent and they are professional. At Oak Ridge, and the other AEC laboratories, they are given great freedom provided only that the area in which they work is relevant to the mission of our supporting agency.

"My main point is to persuade you to state in unmistakable words that the professionalism and interdisciplinary competence found in the AEC laboratories is an extraordinarily valuable national scientific asset."

—Alvin Weinberg to E. R. Piore of the President's Science Advisory Committee and Naval Research Advisory Committee, February 2, 1965

Thus chastised, Oak Ridge saw its chances of becoming the National Environmental Laboratory fade. Nevertheless, with enactment of the National Environmental Policy Act of 1970 and formation of the Environmental Protection Agency, the Laboratory moved into environmental research on a broader scale. In March 1970, shortly before the first Earth Day celebrations, Weinberg expanded Auerbach's Ecology Section into an Ecological Sciences Division.

Then, in 1972, with the addition of radiological assessment and geosciences groups, the Ecological Sciences Division became the Environmental Sciences Division. The national requirement that environmental impact statements be prepared for new federal projects brought the new division considerable work, and the division formed an Environmental Sciences Information Center to support preparation of impact statements. It also participated in a multidisciplinary study, led by Bill Fulkerson, Wilbur "Dub" Shults, and Bob Van Hook, that examined environmental impacts associated with fossil-fuel power plants.

In new buildings constructed at the west end of the Laboratory grounds, the expansion of the Environmental Sciences Division at the Laboratory continued into the 1990s. If not in name, the Laboratory became in fact a national environmental assessment laboratory.

"If not in name, the Laboratory became in fact a national environmental assessment laboratory."

Constraints

As early as 1967, Weinberg recognized that the costly Vietnam War was constraining the national budget for science. "Because of Vietnam, we shall

"Because the AEC was determined to proceed with the liquid-metal fast breeder reactor, it slashed funding from the Laboratory's molten-salt thermal breeder program."

be lucky to get as much money as we had this year," he told the staff. "We can only hope that Vietnam will be resolved quickly; and that, as peace is restored, we can devote ourselves and our expanding technologies to the creation of a better world."

The war did not end quickly, and in 1968 budgetary constraints forced retrenchments. Weinberg adamantly denied that the Laboratory's non-nuclear efforts were intended to counter reductions in nuclear science budgets; in fact, he reminded critics that those efforts had begun long before the budgetary shortfalls of the late 1960s. Although Laboratory funding remained constant from 1965 to 1970, inflation eroded the funding's value by as much as 25%.

Other factors, in addition to the costs of the war, had a role in the declining budget. Because the AEC was determined to proceed with the liquid-metal fast breeder reactor, it slashed funding from the Laboratory's molten-salt thermal breeder program. As part of the social upheaval of the 1960s, strong antiscientific sentiment, marked by confrontations even at professional scientific conventions, also affected congressional support for research.

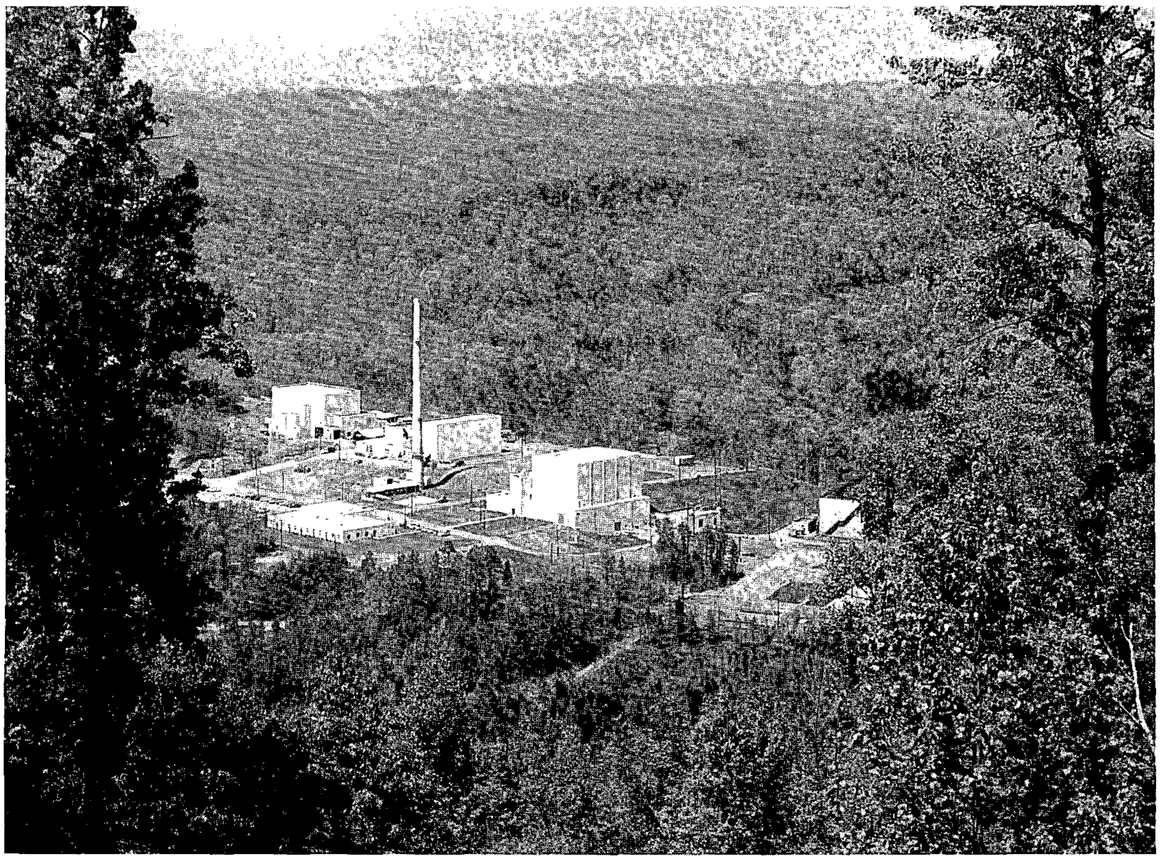
Weinberg and Laboratory staff saw several demonstrations against science by disillusioned youth. After witnessing one in Boston in 1969, Weinberg wrote:

> *We in Oak Ridge, living as we do in a sheltered and pleasant scientific lotus-land, just don't know what our colleagues in the beleaguered universities are up against. What a shock it is to go to the hub of the intellectual universe for what one expects to be a rather routine scientific meeting, and to run smack into a full-scale confrontation between the scientific establishment and the Angry Young People. I haven't had such an exciting time in years, certainly never at a scientific meeting.*

At Christmas 1969, the Bureau of the Budget ordered across-the-board cuts at the Laboratory, reducing staff from 5300 to less than 5000. Its thermal breeder program was cut by two-thirds, and its proposed new particle accelerator, known as APACHE, was scrapped entirely. Departing friends made the 1969 holiday season in Oak Ridge as gloomy as that of 1947. In the close-knit Oak Ridge community, when friends lost their jobs, they usually had to leave to find work elsewhere.

"Our vast scientific apparatus is deployed against scientific problems—yet what bedevils us are strongly social problems," Weinberg noted. "Can we somehow deploy our scientific instrumentalities, or invent new instrumentalities, that can make contributions to resolving these social questions?"

"We lost our innocence in 1969," Bill Fulkerson, the Laboratory's associate director for Energy and Environmental Technologies recalled years later. Realizing that scientific problems had social contexts as well as technical components, the chastened Laboratory entered the 1970s less innocent but more ready to meet the challenges of this tumultuous decade—one in which the nation would experience two energy crises and federally sponsored environmental programs that would forever alter the way the Laboratory conducted its business.



The High Flux Isotope Reactor and facilities for processing transuranium elements in Melton Valley.

Chapter 6

Responding to Social Needs

By the 1970s, after 30 years of steady progress in nuclear reactor design and technology, growing public concern over problems with nuclear waste disposal, the environmental and health effects of radiation, and the possibility of accidents at nuclear power plants had undermined public confidence in both the AEC in particular and nuclear energy in general. These concerns, which shook the nuclear energy industry, led to dramatic changes in leadership within the AEC.

From the early 1960s until the early 1970s, the AEC was led by Chairman Glenn Seaborg, a Nobel laureate chemist associated with the Metallurgical Laboratory in Chicago during World War II. The AEC was led subsequently by an economist and then a marine biologist, before being split into the Energy Research and Development Administration (ERDA) and the Nuclear Regulatory Commission (NRC) in 1974. In addition, the Joint Committee on Atomic Energy, which had directed AEC activities for decades, disbanded. This transition confirmed that the institutional framework, which had served nuclear power well in the years following World War II, would no longer be sufficient to meet the challenges of the future.

The Laboratory reacted to the dramatic transitions within the AEC with its own critical changes. Although not sundered like the AEC, it expanded its traditional focus on uranium fission to undertake broader missions that encompassed all forms of energy. At the same time, Laboratory leadership passed from the hands of a fission expert to a nuclear fuel reprocessing specialist and, finally, to an expert in fusion energy.

"The Laboratory became a premier international center for producing and separating transuranic elements."

As more powerful research reactors and accelerators were added during the 1960s, the Laboratory became a premier international center for producing and separating transuranic elements. Researchers studied the structures and properties of transuranic elements and nuclei using accelerated particles that range in mass from protons to curium ions. In support of the AEC reactor program, the Laboratory pursued development of a molten salt reactor and also investigated liquid-metal and gas-cooled reactor technologies. By 1970, in response to the new political realities that the nuclear industry faced, the Laboratory also became a center for exploring the safety, environmental, and waste disposal challenges presented by nuclear energy.

The Laboratory's advance into new research frontiers was both a response to necessity and a deliberate effort to assume new challenges. Budget shortfalls between 1969 and 1973 shelved plans for new reactors and reduced staff from nearly 5500 in 1968 to fewer than 3800 by 1973. Moreover, wartime veterans, now in their 50s and 60s, began to retire as the Laboratory's 30th anniversary neared in 1973. The departure of Oak Ridge's Manhattan Project engineers and scientists left a void in the institutional culture that was progressively filled by a new generation who brought their own interests and experiences to the research agenda. Having come of age in the 1960s, this new generation carried somewhat different priorities and sensibilities to the workplace than had the original scientists, for whom World War II had served as the defining period in their careers.

To meet these challenges, Laboratory management reorganized and launched a series of retraining programs designed to transcend the traditional uranium fission focus. These new efforts led to investigations into all forms of energy—a broadening of research that made the Laboratory more responsive to the political and social changes sweeping the nation.

In the aftermath of Earth Day in April 1970 and passage of a series of environmental laws and regulations intended to bring environmental concerns to the forefront of the nation's policy agenda, the public clamored for more "socially relevant" science that would address everyday concerns. In 1973, as Americans lined up to purchase gasoline and turned down their thermostats because of shortages of imported oil, the desire for relevant science was never more urgent.

Laboratory efforts to explore new, non-nuclear energy issues proved both timely and critical. Born at the dawn of the nuclear age and nurtured to maturity during nuclear power's great leap forward in the 1950s, the Laboratory was not about to abandon its ties to nuclear research. Nevertheless, as it experienced and then responded to the dramatic changes of the 1970s, it emerged from this tumultuous decade a multipurpose science research facility, ready to tackle the increasingly complex issues of energy and the environment.

Super-Duper Cooker

The high-flux reactor designed under Eugene Wigner's supervision in 1947 and built in Idaho provided the highest neutron flux then available. By the late 1950s, however, the Soviets had designed a reactor that surpassed it.

"We do not believe the United States can long endure the situation of not having the very best irradiation facilities in the world at its disposal," commented Clark Center, Union Carbide chief at Oak Ridge. "Therefore, we would like to suggest that the Atomic Energy Commission undertake actively a design and development program aimed at the early construction of a very high-flux research reactor." Glenn Seaborg, an expert in transuranic chemistry, concurred with Center and urged the AEC to build a higher-flux reactor.

With these statements of support echoing in Washington, ORNL embarked on the design of what Weinberg labeled a "super-duper cooker." Trapping a reactor neutron flux inside a cylinder encasing water-cooled targets, the proposed High Flux Isotope Reactor would make possible "purely scientific studies of the transuranic elements" and augment the "production of . . . radioisotopes." Weinberg also insisted that the reactor be built with beam ports to provide access for experiments.

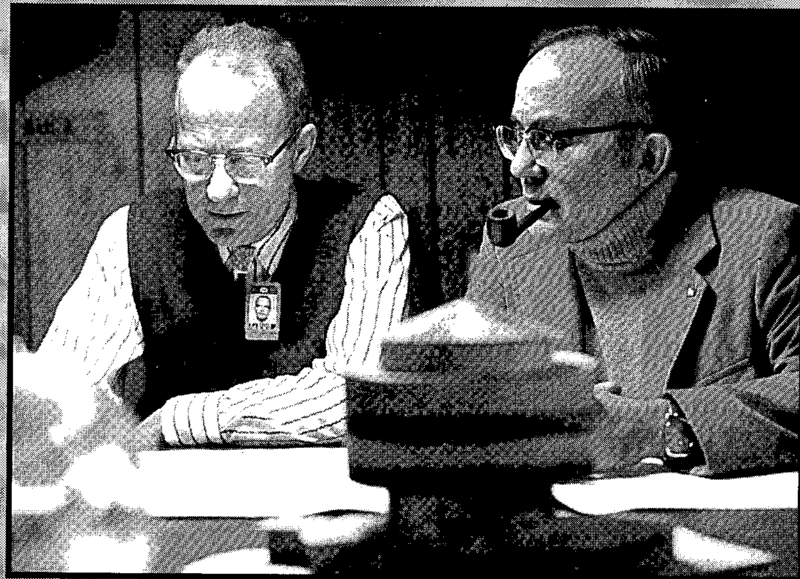
Charles Winters, Alfred Boch, Tom Cole, Richard Cheverton, and George Adamson led the

Earth Day 1970

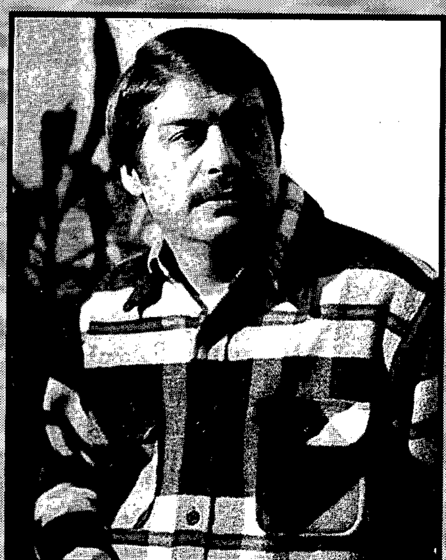
"This has been the year of the environment," Laboratory Director Alvin M. Weinberg said in his 1969 State of the Laboratory address. "On every hand we are being told the fruits of technology are endangering our living space...The ecologists have displaced the physicists as high priests in this new era of environmental concern."

Weinberg, in his usual fashion, not only captured a new national trend but also pinpointed a new target for public concern and research. Public interest in the environment manifested itself dramatically in 1970, culminating in Earth Day on April 22.

Laboratory researchers participated in Earth Day's national and local celebrations. On the national scene, three staff members delivered speeches at various universities. Stanley Auerbach, director of the Ecological Sciences Division, gave a talk at the University of Illinois; Dan Nelson, assistant director of the same division, spoke at the Massachusetts Institute of Technology; and David Reichle, Laboratory ecologist and member of the Oak Ridge Regional Planning Commission, made a presentation at the University of Tennessee in Knoxville.



Dan Nelson and Stanley Auerbach discuss plans for the new Environmental Sciences Division building.



David Reichle is now ORNL associate director for Environmental, Life, and Social Sciences.

At the Earth Day Fair at Oak Ridge High School, the Laboratory's Ecological Sciences Division set up an exhibit describing its ecological research. Examples were the effect of fertilizer on the Walker Branch Watershed, retention of radioactive fallout by agricultural crops, the study of bedded geologic deposits as disposal sites for radioactive wastes, and Laboratory management of the Eastern Deciduous Forest Biome Research Program for the International Biological Program. On hand to explain the exhibit to the 500 people who attended the fair were John Gilbert, L. C. Landry, Ronald Rahn, and Robin Wallace.

ORNL researchers contributed to Earth Day observances in Oak Ridge in other ways. Gilbert's article on Oak Ridge's environmental problems was published on the front page of *The Oak Ridger*. He noted that the city had problems with water, air, and visual pollution; litter; and pesticides, including mercury compounds and mercury-coated seeds.

Two Laboratory staff members participated in a panel discussion held at Oak Ridge High School on "Appalachian Coal and Nuclear Energy—Their Effects on Our Environment and Their Future Use." Bill Russell, the noted geneticist and a founder of Tennessee Citizens for Wilderness Planning, spoke of the harmful environmental impacts of increasing energy production.

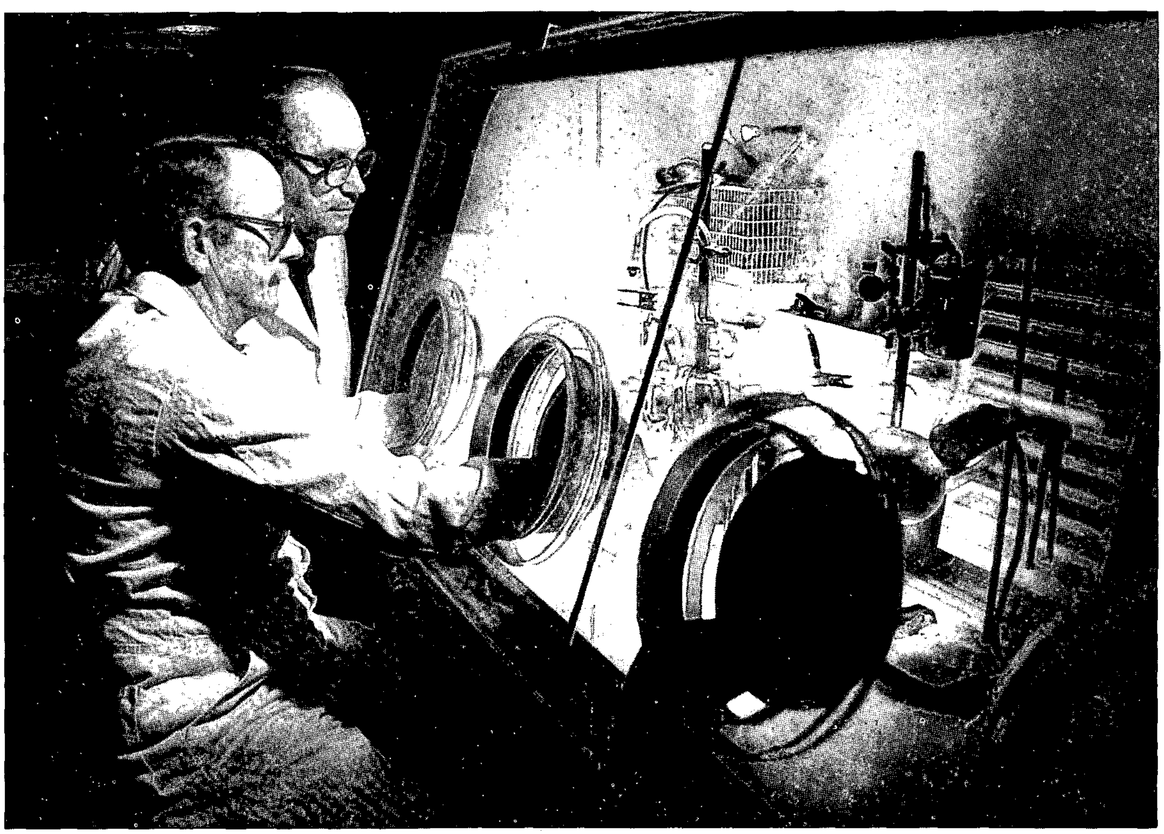
James Liverman, ORNL's associate director for Biomedical and Environmental Sciences, summed up Oak Ridge's observance of Earth Day by saying, "Ultimately, improving the quality of life will depend on you and me in our daily lives, on our making a commitment to the environment."

"The Laboratory distributed the heavy elements to scientists throughout the world and to its own scientists housed in the new Transuranium Research Laboratory."

design, engineering, and metallurgical teams for this 100-megawatt (MW) reactor, completed in 1965 as the centerpiece of the Laboratory's new transuranium facilities. Seaborg, having been appointed AEC chairman by President Kennedy, returned to the Laboratory in November 1966 for the dedication. He declared that the exotic experiments made possible by the new High Flux Isotope Reactor would "deepen our comprehension of nature by increasing our understanding of atomic and nuclear structure."

Built in Melton Valley across a ridge from the main X-10 site in Bethel Valley, the High Flux Isotope Reactor irradiated targets to produce elements heavier than uranium at the upper and open end of the periodic table. At the heavily shielded Transuranium Processing Plant adjacent to the reactor, A.L. (Pete) Lotts of the Metals and Ceramics Division led the teams that fabricated targets. Placed in the high neutron flux of the reactor, atoms of the target materials absorbed several neutrons in succession, making their way up the periodic table as they increased in mass and charge. Then, under a program managed by William Burch, the irradiated targets were returned to the processing plant for chemical extraction of the heavy elements berkelium, californium, einsteinium, and fermium.

The Laboratory distributed the heavy elements to scientists throughout the world and to its own scientists housed in the new Transuranium Research Laboratory. Previously available only in microscopic quantities, the milligrams of heavy elements produced at the High Flux Isotope Reactor proved valuable for research. "Our main effort at ORNL," said Lewin Keller, head of transuranium



Lew Keller watches as Chick Wiggins uses a protective glove box at the Transuranic Processing Plant to achieve final purification of the transplutonium elements produced in the High Flux Isotope Reactor.

research, "is directed toward ferreting out their nuclear and chemical properties in order to lay a base for a general understanding of the field."

Of the transuranic elements, an isotope of element 98 garnered greatest attention. Named for the state where it was discovered, californium-252 fissions spontaneously and is an intense source of neutrons, able to penetrate thick containers and induce fission in uranium-235 and plutonium-239. It could provide short-lived, on-site isotopes in hospitals for immediate use in patients. Cancerous tumors could be treated by implanting californium needles instead of the less effective radium needles used previously. Other transuranic elements afforded practical applications such as tracers for oil-well exploration and mineral prospecting.

Thanks to Weinberg's foresight in demanding beam ports, Wallace Koehler, Mike Wilkinson, Henri Levy, and their associates in the Solid State and Chemistry divisions could use the high-flux reactor's intense neutron beams for materials studies. Of particular significance were materials investigations that focused on the magnetic interactions of neutrons with materials, which helped to explain unusual magnetic properties of rare earth metals, alloys, and compounds.

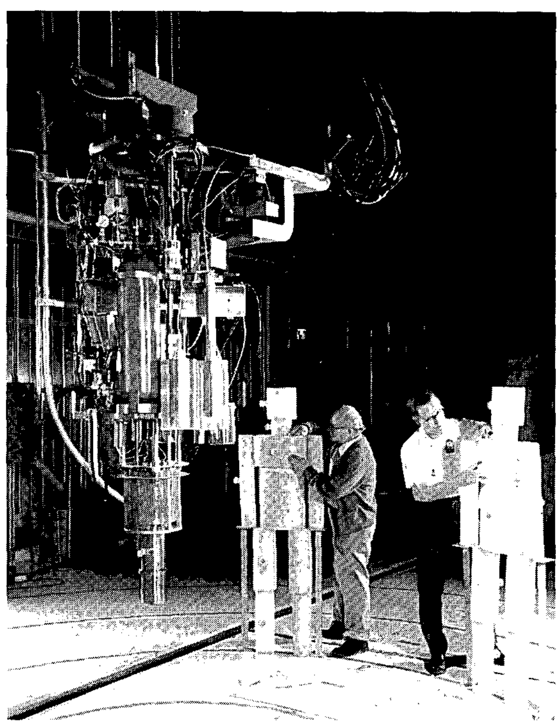
The High Flux Isotope Reactor served science, industry, and medicine for more than a quarter century. Although shut down because of vessel embrittlement in November 1986 and subsequently restarted at 85% of its original power, by 1991 it had gone through 300 fuel cycles that provided benefits ranging from advancing knowledge of materials to enhancing understanding of U.S. history. In 1991, neutron activation analysis of hair and nail samples from the grave of President Zachary Taylor indicated he had not been poisoned by arsenic while in office, as one historian suspected. Americans can rest assured knowing that President Taylor died of natural causes—thanks to the Laboratory's High Flux Isotope Reactor and to the analysis made there by Larry Robinson and Frank Dyer, both of the Analytical Chemistry Division.

The Last Reactors

Between the 1940s and 1960s, new reactor construction was part of the Laboratory's ever-changing landscape. Those built in the 1960s, however, would mark the end of the Laboratory's "bricks and mortar" reactor era. No new reactors would be built during the 1970s and 1980s, a remarkable dry spell given the rapidly changing nature of nuclear research.

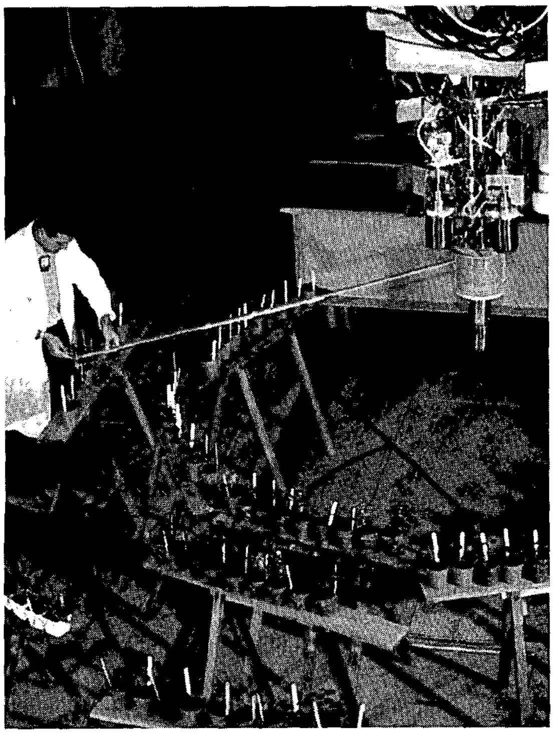
Before being forced to close its doors on new reactor construction, the Laboratory (in addition to its work on the High Flux Isotope Reactor) completed the Health Physics Research Reactor, experimented with a molten-salt reactor, and conducted research for AEC's liquid-metal fast breeder reactor and for high-temperature gas-cooled reactors that stirred the interest of the private sector. Next to the High Flux Isotope Reactor, the longest-lived Laboratory reactor built during this decade was the Health Physics Research Reactor.

Known originally as the "fast burst reactor," the Health Physics Research Reactor was installed

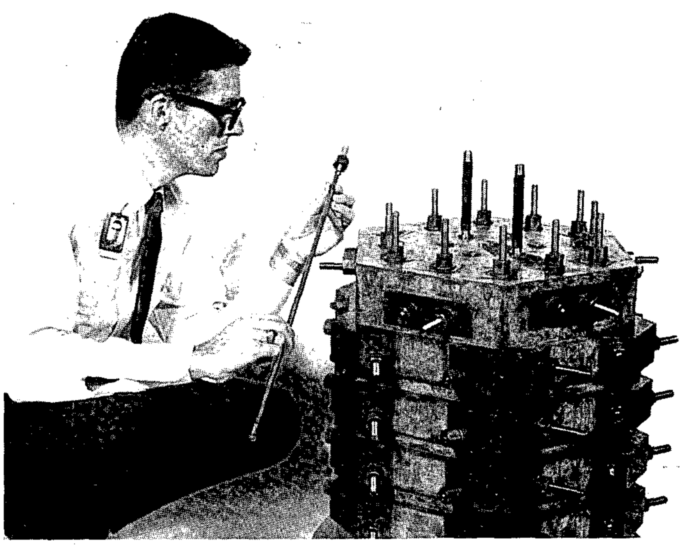


Phantoms for estimating radiation doses in the human body are checked at the Health Physics Research Reactor.

"Cancerous tumors could be treated by implanting californium needles instead of the less effective radium needles used previously."



Potted plants irradiated at the Health Physics Research Reactor.



Jim Corum examines a prestressed concrete test vessel for an experimental gas-cooled reactor.

in the new Dosimetry Applications Research facility in 1962. John Auxier, later director of the Health Physics Division, managed the design and operation of this small, unmoderated, and unshielded reactor.

Composed of a uranium-molybdenum alloy and placed in a cylinder 20 centimeters (8 inches) high and 20 centimeters in diameter, its operation required insertion of a rod into the cylinder to release a neutron pulse used for health physics and biochemical research. In particular, the reactor, which remained operational until 1987, provided data that guided radiation-instrument development and dosage assessment. During the 1960s, for example, it helped scientists estimate the solar radiation doses to which *Apollo* astronauts would be subjected.

By the mid-1960s, light-water reactors had become the option of choice for the commercial nuclear industry. As a result, the AEC suspended work on the Experimental Gas Cooled Reactor in 1966 in Oak Ridge. When Gulf General Atomic Corporation obtained orders for four high-temperature gas-cooled reactors in 1972, however, the AEC renewed its interest in this reactor technology and boosted Laboratory funds for additional research. The program, which has been managed successively by Robert Charpie, Herbert MacPherson, William Manly, Don Trauger, Paul Kasten, and Frank Homan, has focused most recently on passively safe modular designs.

Laboratory research into the liquid-metal fast breeder reactor, which had been developed at Argonne National Laboratory, expanded during the late 1960s. William Harms coordinated the Laboratory breeder technology program. His staff simulated the fast breeder's fuel assemblies, using electric heaters, and tested reactor coolant flows and temperatures. A metallurgical team headed by Peter Patriarca evaluated the materials to be used in the fast breeder's heat exchangers and steam generator. Several Laboratory teams lent support to the effort. For example, William Greenstreet and associates devised a structural design assessment technology to ensure the operational integrity of fast breeder components.

Work on the breeder accelerated in 1972, when the AEC made Oak Ridge the site of the AEC's demonstration Clinch River Breeder Reactor Project. Laboratory efforts continued until Congress canceled the project in the mid-1980s, following more than a decade of political controversy and debate fueled by concerns about plutonium weapons proliferation and the gradual realization that the United States would not need a breeder reactor for at least 20 years because of the low cost and availability of uranium.

Alvin Weinberg at the control panel of the Molten Salt Reactor Experiment in October 1967 after it had operated 6000 hours at full power.

"Dark Horse" Breeder

"A dark horse in the reactor sweepstakes." That's how Alvin Weinberg once described the Laboratory's Molten Salt Reactor Experiment to Glenn Seaborg. Weinberg explained that if Argonne's fast breeder encountered unexpected scientific difficulties, Oak Ridge's molten-salt thermal breeder could serve as a backup that would help keep the AEC's research efforts on track.

Based on technology developed for the Aircraft Nuclear Propulsion project, an experimental molten-salt reactor was designed and constructed in the same building that had housed the aircraft reactor. Its purpose was to demonstrate key elements needed for a civilian power reactor. Operation of the Molten Salt Reactor Experiment (MSRE) using uranium-235 fuel began in June 1965 under the supervision of Paul Haubenreich. Program directors Herbert MacPherson, Beecher Briggs, and Murray Rosenthal successively supervised efforts to develop a molten-salt breeder reactor. In an uninterrupted six-month run, the MSRE demonstrated the practicality of this exotic breeder concept. Fuel salt was processed at the reactor, and all the uranium-235 was removed.

When the fuel was changed to uranium-233 in October 1968, AEC Chairman Seaborg joined Raymond Stoughton, the Laboratory chemist who co-discovered uranium-233, to raise the reactor to full power. "From here," said Rosenthal, "we hope to go on to the construction of a breeder reactor experiment that we believe can be a stepping stone to an almost inexhaustible source of low-cost energy."

Weinberg and the Laboratory's staff pressed the AEC for approval of a molten-salt breeder pilot plant. They hoped to set up the pilot plant in the same building that had housed the AEC's Experimental Gas Cooled Reactor until that project was suspended in 1966.

Argonne's fast breeder had the momentum, however, and Congress proved unreceptive to Laboratory requests to fund large-scale development of a molten-salt breeder. Appealing personally to Seaborg, a chemist, Weinberg complained: "Our problem is not that our idea is a poor one—rather it is different from the main line, and has too chemical a flavor to be fully appreciated by non-chemists."

Meanwhile, the Molten Salt Reactor Experiment operated successfully on uranium-233 fuel from October 1968 until December 1969, when the

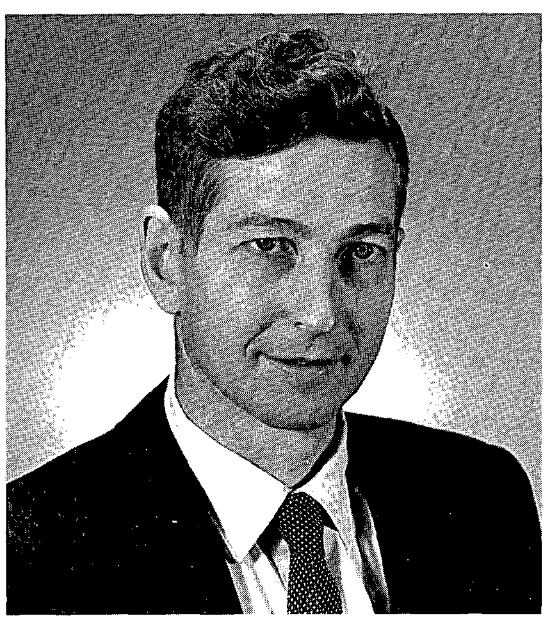
"The Molten Salt Reactor Experiment operated successfully on uranium-233 fuel from October 1968 until December 1969."

"The molten-salt reactor, in Weinberg's opinion, was ORNL's greatest technical achievement."

Laboratory exhausted project funds and placed the reactor on standby. The Laboratory continued molten-salt reactor development, as limited funding allowed, until January 1973, when the AEC Reactor Division abruptly ordered work to end within three weeks.

In the wake of the energy crisis in late 1973, however, new funding for molten-salt reactor research was found and continued until 1976. A unique Laboratory project, the molten-salt reactor, in Weinberg's opinion, was ORNL's greatest technical achievement. He maintained that the molten-salt reactor was safer than most other reactor types. As late as 1977, an electric utility executive advised President Carter of his company's interest in a commercial demonstration of the molten-salt breeder reactor. The government's preoccupation with the liquid-metal fast-breeder reactor, however, drove Oak Ridge's thermal breeder into obscurity. To Weinberg's chagrin, the "dark horse" reactor never emerged from the pack to lead the nuclear research effort.

AEC Chairman Glenn Seaborg operates the controls of the Molten Salt Reactor on October 8, 1968.



Raymond Stoughton, a Laboratory chemist, who co-discovered uranium-233.

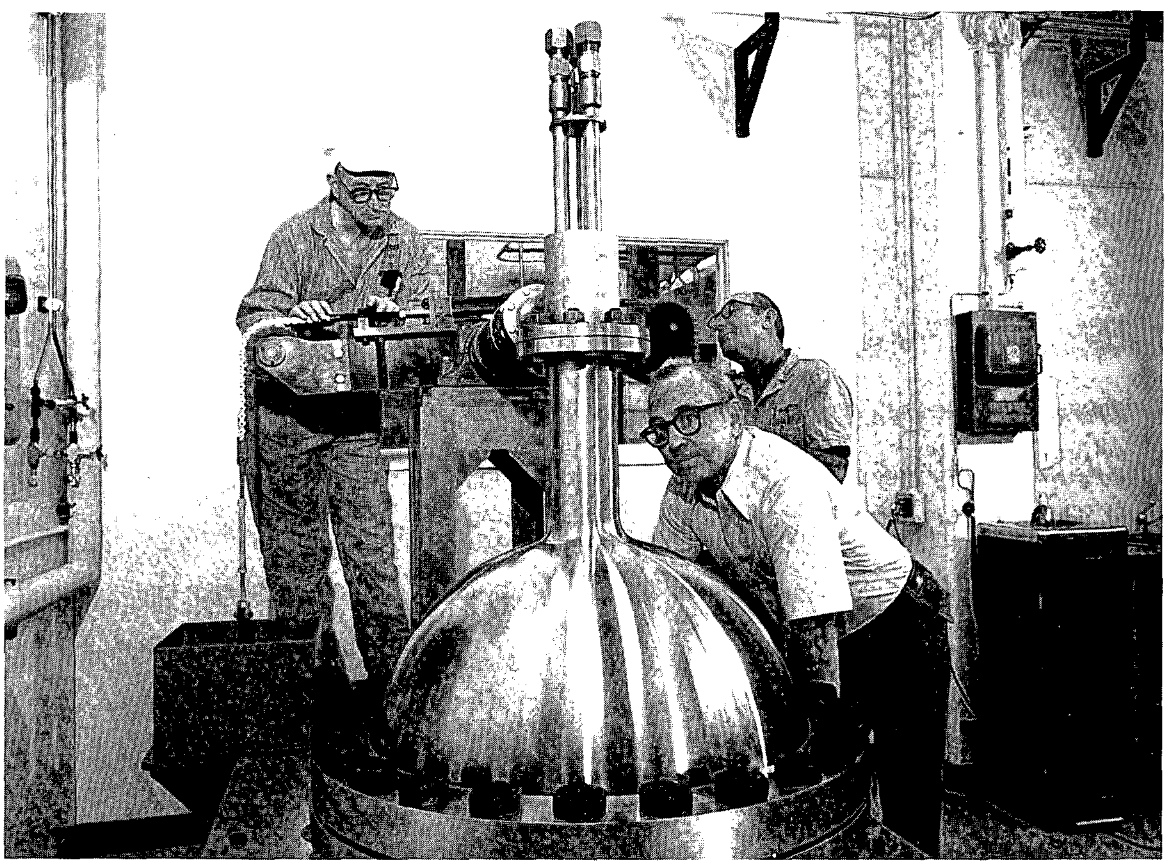
Accelerators

An evolution similar to the molten-salt breeder program marked the Laboratory's accelerator program of the 1960s. The Laboratory's advanced particle accelerators, an isochronous cyclotron and an electron linear accelerator, moved it to the forefront of the nation's research efforts in accelerator physics. However, competition from other accelerator projects, as well as funding constraints, would stall the program in the early 1970s.

The Oak Ridge Isochronous Cyclotron (ORIC) began operating in 1963, firing protons, alpha particles, and other light projectiles into various targets to produce heavy ions. Instead of the uniform magnetic fields used in the Laboratory's first cyclotrons, ORIC employed tailored sectors with a varying magnetic field. This design compensated for increases in the mass of ions as they accelerated, both focusing their paths and keeping them in resonance at high energies. In its day, ORIC's design was considered a major technological breakthrough.

ORIC provided ion beams of nitrogen, oxygen, neon, and argon, making them available for research in physics and chemistry. Built on the east side of the X-10 site in Bethel Valley, the new cyclotron brought Robert Livingston's Electronuclear Division to the Laboratory from the Y-12 Plant. In 1972, the Electronuclear Division consolidated with the Physics Division under the direction first of Joseph Fowler and later of Paul Stelson and James Ball, all of whom reported to Alex Zucker, the associate director for physical sciences.

A year after ORIC obtained its first heavy-ion beam, the Laboratory completed the Oak Ridge Electron Linear Accelerator (ORELA). Except for an office and laboratory building, this accelerator was underground, covered by 6 meters (20 feet) of earth shielding. Electron bursts traveled 23 meters (75 feet) along the accelerator tube to bombard a water-cooled tantalum target, producing more than 10 times as many neutrons for short pulse operation than any other linear accelerator in the world. From the target room, the neutrons passed through 11 radial flight tubes to underground stations for experiments.



Craftsmen B. E. Burdette and W. A. Wilburn and engineer Malcolm Richardson, in foreground, adjust a nozzle-to-sphere test machine for the Liquid Metal Fast Breeder Reactor Program in 1975.

Nuclear Physics Research

Little Things Mean a Lot

Little things mean a lot, but in nuclear physics, big things are needed to discover them and find out what they mean. At the Laboratory, the chief goal of nuclear physics research has been to determine the structure of the nucleus of the atom and to understand the course of reactions between nuclei. Detailed information on the properties of tiny atomic nuclei can be obtained only by the use of huge accelerators. A beam of particles from an accelerator is propelled against a target; the effect of the bombardment on the projectile beam and the resulting emission of particles from the collision shed light on the structure and behavior of the target nuclei and on the reaction mechanisms.

The likely shape of a deformed uranium-234 nucleus as determined by the results of 1971 accelerator studies.

Early nuclear physics research at the Laboratory made use of reactors. Later, the original Physics Division relied on a series of electrostatic, or Van de Graaff, accelerators and the Oak Ridge Electron Linear Accelerator (which was operated by the Neutron Physics Division mainly to determine the neutron-absorbing abilities of nuclei of candidate breeder-reactor shielding materials). The Electronuclear Division depended on an increasingly sophisticated series of cyclotrons, which accelerated charged particles in circular orbits.

In the late 1940s a landmark experiment by Arthur Snell and Frances Pleasanton provided the first accurate measurement of the lifetime of the neutron. They also measured the gravitational force on the neutron.

Using newly built cyclotrons in the 1950s, Laboratory physicists studied the reactions between heavy projectile ions and target nuclei that collided at high energies. Alex Zucker and Harry Reynolds pioneered in research on heavy-ion reactions using the 63-inch cyclotron, which produced the world's first multicharged heavy-ion beams.

At the Van de Graaff Laboratory, Paul Stelson and Francis McGowan carefully measured the Coulomb excitation–the energized state in a nucleus resulting from its interaction with the projectile particle's electric field–in a wide range of nuclei. This seminal work showed clearly that the classical interpretation of low-energy nuclear collisions was inadequate, setting the stage for the development of a quantum-mechanical model.

Using 22-MeV protons from the 86-inch cyclotron to generate particles of higher energies, Bernard Cohen and his associates showed that transfer reactions (in which a nucleon–neutron or proton–is transferred from the target to the projectile nucleus) at these energies did not result as expected from the decay of a compound nucleus formed during the collision between the incident and target nuclei. Instead, the transfer resulted from a direct nuclear reaction in which the projectile particle passing through the target nucleus interacts with only part of the nucleus. This "direct" process also was not well described in terms of a classical model.

Work by Cohen also resulted in the discovery of a new low-lying collective mode in nuclei. This collective mode is a low-energy state of the nucleus that causes it to vibrate as a single system, just as the tone from a ringing bell results from the vibration of the entire bell structure. Originally dubbed "anomalous inelastic scattering," these low-energy states appeared even stronger than the well-known low-lying "quadrupole vibrational states" in which the vibrating nuclei alternate between shapes resembling an egg and Earth. These newly discovered states proved to arise from "nuclear octupole vibration" in which the vibrating nuclei are alternately spherical and pear-shaped. This observation helped affirm the picture that the nucleus, as a system, could support many modes of collective resonant behavior.

In the early 1950s, the shell model was developed to explain many features of nuclei. In this model the nucleons are considered to occupy shells and subshells (like electrons in the atom) and act independently according to a preassigned set of shell energy levels. A model to explain direct nuclear reactions was also formulated. Neither of these models could be fully used until the advent of large, fast digital computers a decade later. The Laboratory was a pioneer in developing mathematical methods and using computing facilities to refine these models to interpret experimental measurements at ORNL and elsewhere.

In the 1960s ORNL theorists led by Ray Satchler pioneered the application of the distorted-wave Born approximation with which he and Bob Bassel and Dick Drisko made great advances in understanding nuclear reactions. They developed methods for extracting quantitative information from single-nucleon transfer reactions and inelastic scattering–scattering resulting from a collision in which the total kinetic energy of the colliding particles is not the same after the collision as before it. Results of their work include two computer codes to extract information from nuclear reactions in experiments–SALLY and JULIE. The latter became the world standard for extraction of nuclear structure data from direct nuclear reactions.

At the same time, Francis Perey and Brian Buck developed a computer program that was applied extensively to the understanding of neutron-scattering measurements. Perey developed the global optical model search code GENOA, which became the standard for use in calculations of the distorted-wave Born approximation, which was set down by Satchler (who is also known for his widely used college textbook on angular momentum). A long series of detailed measurements of scattering and transfer reactions done at the EN-tandem accelerator by Perey, Kirk Dickens, and Bob Silva served as critical benchmarks in the early development of these computer programs, validating their usefulness to a worldwide community.

In the late 1960s the interpretation of the shell model's low-lying nuclear levels (low-energy shells) was given a big boost with the development of the Oak Ridge-Rochester Multi-Shell Program. Completed under the direction of Edith Halbert, this was the most sophisticated program of its type for years and was used extensively for computing detailed nuclear properties and for understanding the general applicability of the nuclear shell model.

Also in the late 1960s at ORNL, measurements of the neutron-absorption cross section in the energy region from 5,000 to 200,000 electron volts for nuclei from fluorine (mass 19) to uranium (mass 238) were made. These measurements by Jack Gibbons, Dick Macklin, and their colleagues proved useful not only to nuclear theorists and nuclear engineers but also to astrophysicists seeking to understand the process of nucleosynthesis in stars, which builds heavy elements from light ones and governs the relative amounts of elements in the universe.

"The Laboratory was a pioneer in developing mathematical methods and using computing facilities to refine these models to interpret experimental measurements at ORNL and elsewhere."

By the early 1970s, the Laboratory nuclear physicists had available to them the higher-energy ions produced by the Oak Ridge Isochronous Cyclotron (ORIC) accelerator. One of the most fundamental discoveries to emerge from this program was the work of Fred Bertrand, Monte Lewis, and their collaborators, who made the first observation of the nuclear giant quadrupole resonances–types of a giant resonance in which an appreciable fraction of the nucleons move together in a collective mode when selectively excited by the appropriate nuclear reactions. This work opened up the new field of using charged particles and heavy ions to excite the multipole resonant modes of the nucleus, making it deform as it alternately expands and compresses in different directions.

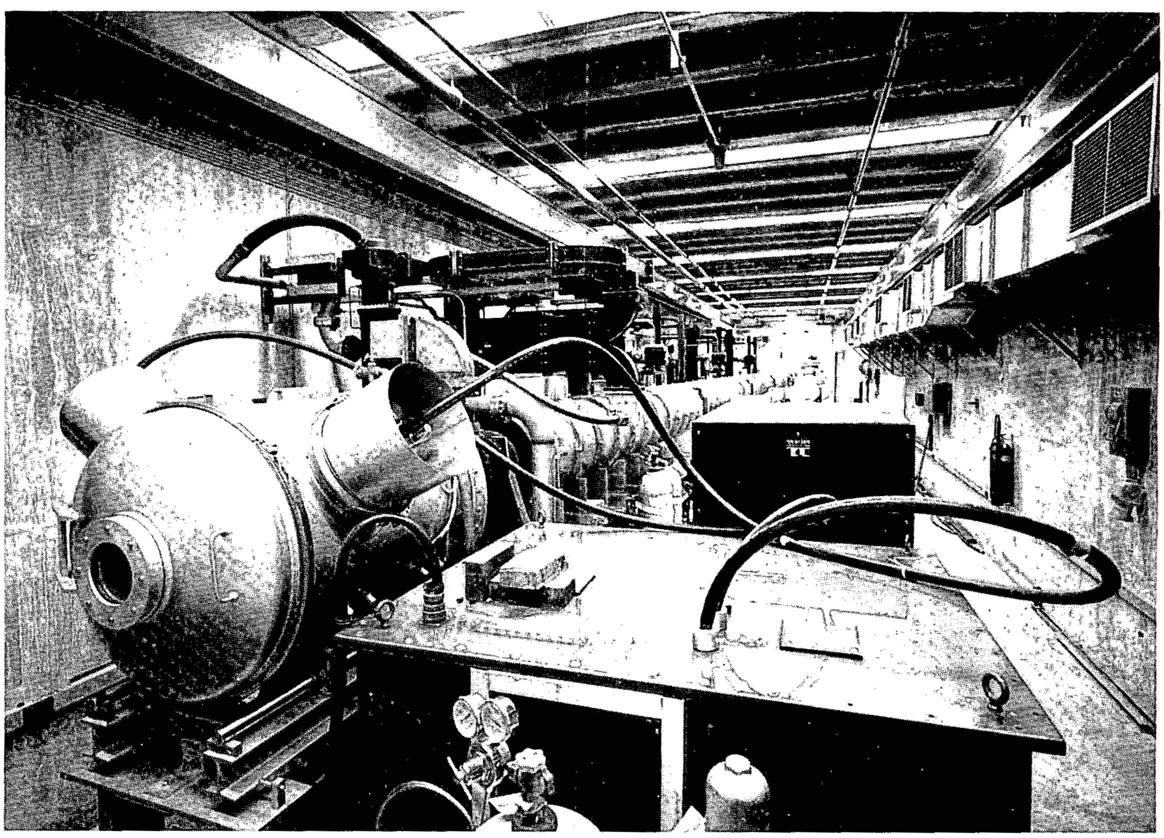
As heavy ions became available from the ORIC, transfermium elements could be produced using its beams on transuranium targets prepared at the High Flux Isotope Reactor. Particularly notable was a series of complex experiments by Curt Bemis, Pete Dittner, Dick Hahn, and Bob Silva using coincident alpha and X-ray detection to provide the first unequivocal identification of elements 102, 103, 104 and 105.

The history of major contributions by ORNL researchers to the field of nuclear physics has been marked by the development of sophisticated instruments and by the use of large-scale computers and the development of long, complex computer codes to interpret and analyze experimental phenomena. This tradition of using big things to better understand little things continues to this day.

A joint project of the Physics and Neutron Physics divisions, with Jack Harvey and Fred Maienschien as co-directors, ORELA's main purpose was to obtain fast-neutron cross sections for the fast-breeder reactor program–that is, to determine the probability that a given fuel, shielding, or structural material would absorb fast neutrons. It served this purpose admirably, and it still contributes a great deal to fundamental physical science. In 1990, for example, ORELA's intense neutron beams bombarded a lead-208 target, allowing researchears to measure the size of the force holding together the three quarks composing a neutron. This research effort, led by Jack Harvey, Nat Hill, and researchers from the University of Vienna, advanced scientific understanding of the strong force that glues a neutron together.

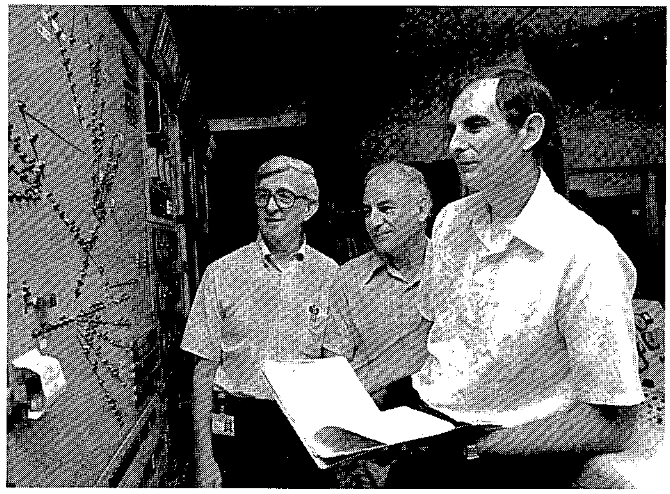
By the time ORIC and ORELA were fully operational in 1969, the Laboratory had planned to build another machine capable of accelerating heavy ions into an energy range where superheavy transuranic elements could be investigated. With the support of universities throughout the region, this accelerator began as a southern regional project. In fact, the Laboratory considered naming it CHEROKEE (after one of the Southeast's most noted Native American tribes), but top scientists could not find the words to form an appropriate acronym; so it was named APACHE, the Accelerator for Physics And Chemistry of Heavy Elements.

Balking at its $25-million cost, President Richard Nixon's budget office rejected the Laboratory's regional APACHE concept in 1969. Discussing the administration's unfavorable



Original electron injector and linear accelerator of the Oak Ridge Electron Linear Accelerator.

decision at AEC headquarters, Alex Zucker learned the budget office and the AEC would consider only national, not regionally sponsored, accelerators. To secure approval for an advanced accelerator, it would be necessary for the Laboratory to explain the unmet challenges of heavy-ion research, show that it served "truly important national needs," and demonstrate that it would protect the United States from being surpassed in scientific research by other nations, particularly the Soviet Union.



Noah Johnson, Dan Horen, and Fred Bertrand viewing an illuminated map of Oak Ridge Isochronous Cyclotron beam lines.

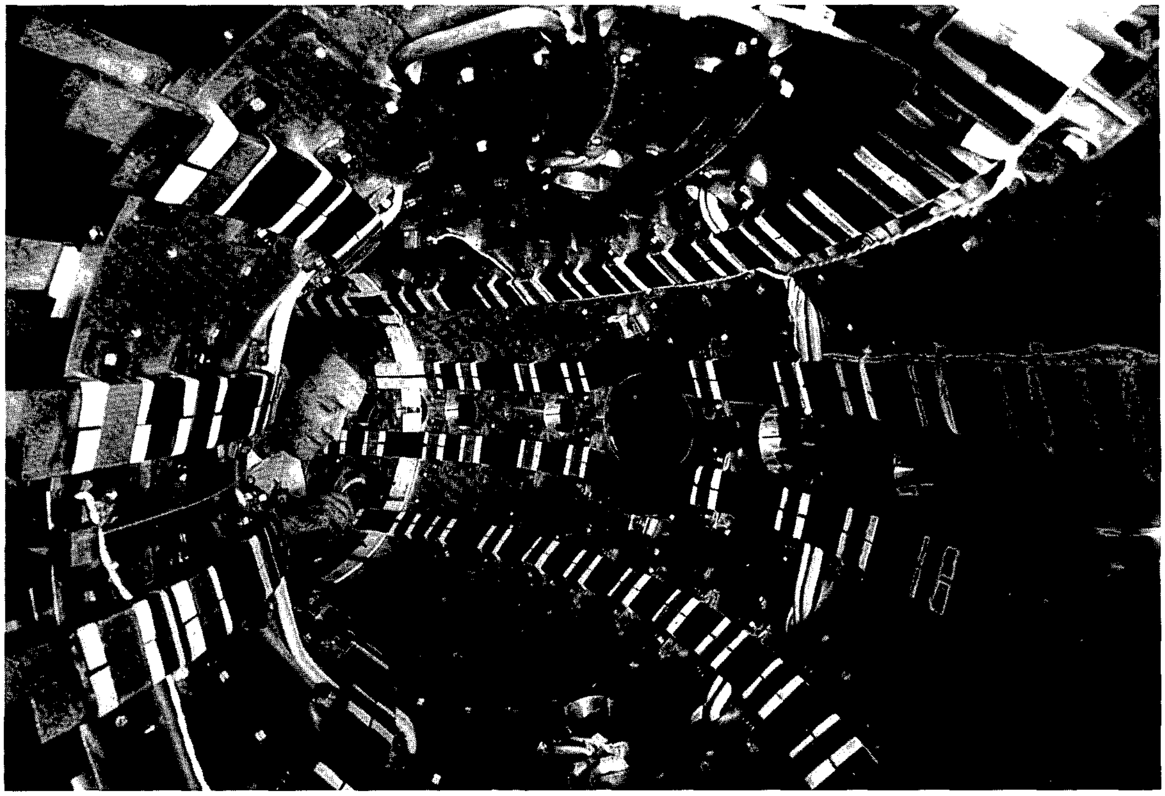
Asserting that the proposed accelerator would advance understanding of "the behavior of nuclei in close collision and the properties of highly excited, very heavy nuclear aggregates," Zucker recommended that the Laboratory recast its new accelerator project in broader terms, naming it the National Heavy Ion Laboratory. Accepting this counsel, Weinberg established a steering committee headed by Paul Stelson to reformulate the proposal. The committee's efforts were fostered by university physicists who saw value in having the accelerator located in Oak Ridge.

Jim Ball (left) and John Pinajian (right) meet Joseph Hamilton of Vanderbilt University at the entrance to the Oak Ridge Isochronous Cyclotron beam room.

Led by physicists Joseph Hamilton of Vanderbilt University and William Bugg of the University of Tennessee, a consortium formed in 1968 to unite physicists from 18 universities interested in heavy-ion research at ORIC and the Laboratory's proposed national accelerator. Working with Robert Livingston and Zucker, the consortium obtained combined funding from their universities, state government, and the AEC to finance construction of an addition to the ORIC building. The addition housed the University Isotope Separator of Oak Ridge (UNISOR) that interfaced with beam lines from ORIC.

Only the Soviet Union had another on-line separator connected to a heavy-ion accelerator. Equally important, this effort represented the first combined funding project for nuclear research hardware in the United States. When the separator facility was completed in 1972, UNISOR's consortium scientists initiated research into new radioisotopes for medical and industrial applications and heavy-nuclei generation in the stars.

UNISOR and ORIC's ongoing research and widespread academic participation gave the Laboratory proof that its proposed National Heavy



Inside ORMAK, the Laboratory's first tokamak, which achieved a plasma temperature of 20 million degrees.

Ion Laboratory would serve national needs. Budgetary constraints, however, delayed approval of this new facility until 1974. Named the Holifield Heavy Ion Research Facility after Congressman Chet Holifield, chairman of the Joint Committee on Atomic Energy for many years, this project, under the direction of Jim Ball, became operational in 1980. The new 25-million-volt tandem accelerator, with its tower dominating the landscape, served as the centerpiece of the Laboratory user facilities during the 1980s, attracting scientists from all over the world.

Gold-Plated Fusion

Although the Laboratory's proposals for a molten-salt breeder and APACHE accelerator hit fiscal walls in 1969, its fusion energy research continued to receive funding under the stimulus of international competition. In 1969, the AEC authorized the Laboratory to construct a gold-plated fusion machine called ORMAK.

After a wildly optimistic, but essentially unsuccessful, entry into fusion energy research in the 1950s, the world's scientists recognized that better understanding of hydrogen plasma behavior was necessary before any real progress could be made. As a result, fusion scientists settled into the computer trenches during the 1960s hoping to improve the theoretical underpinnings of fusion energy. When it came to fusion, scientists faced a fundamental shortcoming: although confident of their theoretical calculations, they were unsure of how to make it work in practical terms.

At the Laboratory, attention focused on the electric-field microinstabilities found within the plasma of fusion devices. Empirical experiments continued both with a second Direct Current

Y Not Swans?

In the spring of 1964, three years after a pond was created near the Engineering Physics and Mathematics Division buildings, physicist Frances (Tony) Pleasonton of the Physics Division organized a campaign to buy a pair of mute swans for the pond. She was assured that the Laboratory would take care of the swans if her fund-raising effort proved successful. Within two weeks, 200 people contributed an average of 65 cents each to buy and ship the swans from Holland to Oak Ridge.

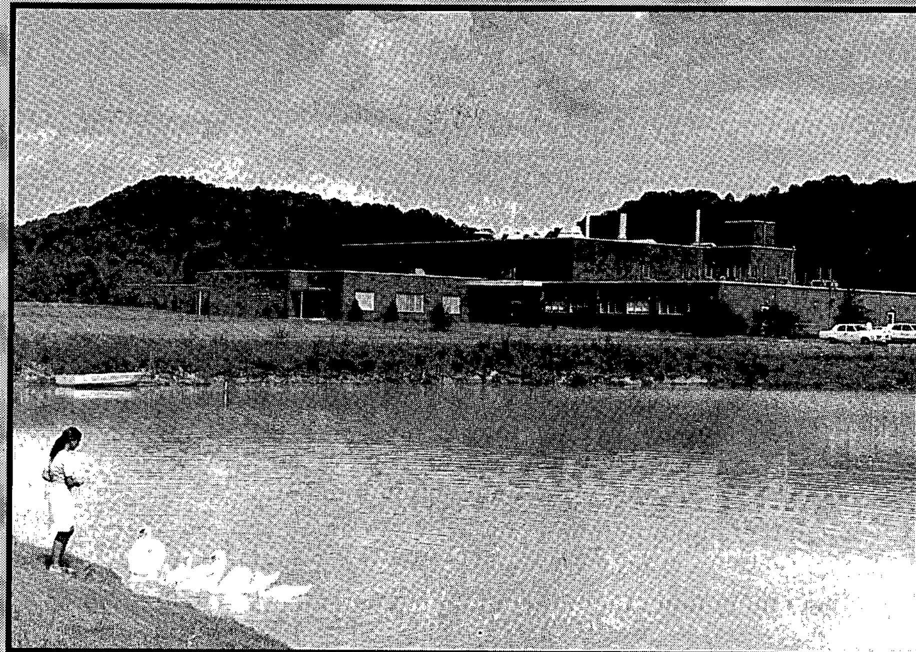
The idea for the names of the swans came from the engineer who drew up plans for the pond's island. When asked why he was designing an island, he would answer, "*Why not*? Tony says the swans will need it." The same response was also a frequent reaction to Pleasonton's requests for donations.

As a result, when the swans finally arrived, they were named "Y" and "Not." They became permanently identified with Pleasonton, the "Swan Lady." In fact, some people thought Y and Not were named after her (Tony spelled backward).

The swans' first winter at Oak Ridge was cold. A groundsperson, called in for special duty on a Saturday, unsuccessfully tried to pick up the swans as the temperature sank below zero. The swans survived, however, and even walked happily on the ice.

Pleasonton was pleased by the number of young swans (cygnets) produced at the pond. "We have been extremely fortunate to have had cygnets," Pleasonton wrote in 1976, "since it is claimed that mute swans seldom breed successfully in captivity."

By 1976, Y and Not were almost 13 years old and had bred for at least nine years, producing 18 to 20 cygnets. Because it was thought that the pond could support only two adult swans, some cygnets were given to the Knoxville Zoo, the Fermi National Accelerator Laboratory, and the Huntsville Garden Club. Proceeds from the sale were deposited in a credit union savings account for "Laboratory swans."



A view of the Laboratory's swan pond near the Physics Division buildings before construction of the Holifield Heavy Ion Research Facility tower.

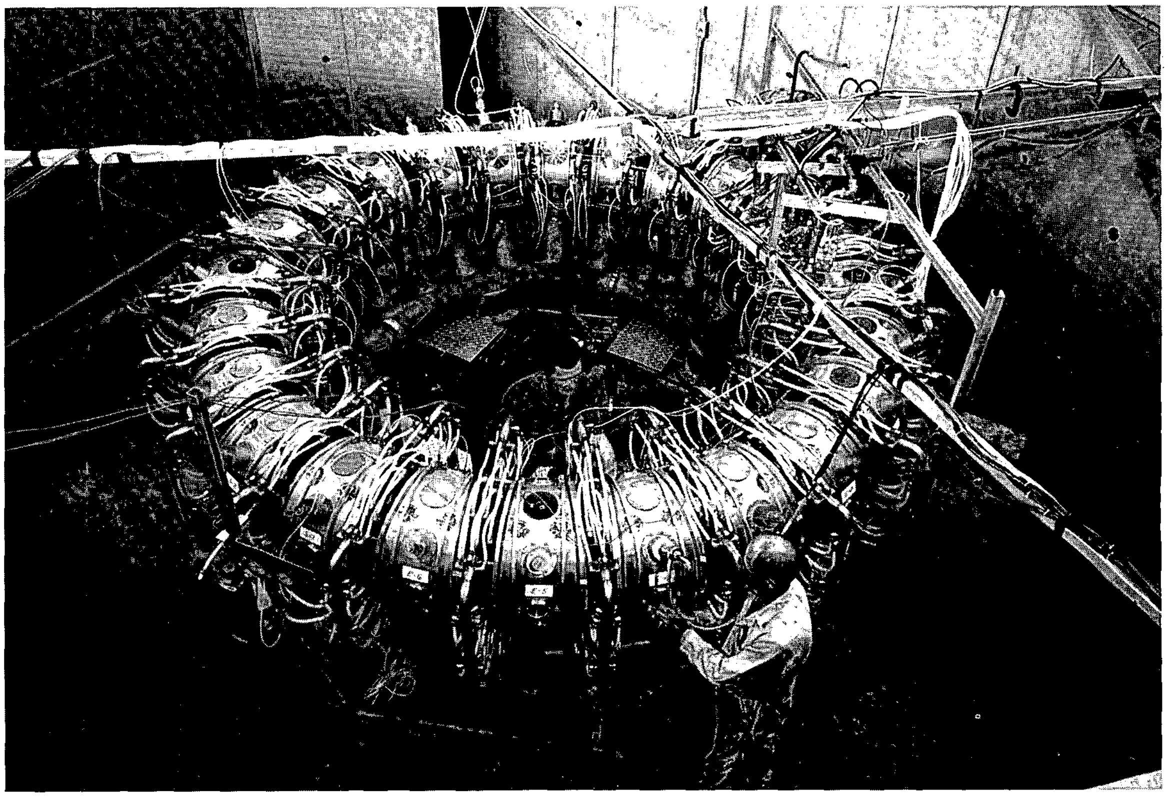
"Altogether, this venture has turned out to be a most successful and satisfying example of good employee-management relations and cooperation," Pleasonton wrote.

Retiring at the end of 1976, Pleasonton announced that Vivian Jacobs of the Information Division would be the new "mentor of swans." "Before I could say anything," Jacobs once wrote, "Tony noted that she had already cleared this transfer of responsibility with Herman Postma, then Laboratory director. . .I was committed to being the new mentor of the swans, which quickly changed to several other titles. I called myself Swan Mama, and I was once referred to on an index card as SOB, which I assumed meant Supervisor of Birds."

In 1980, a month after being treated for a deep gash on his left side, Not came out of the pond on his own, a rarity for him, and died while being transported to the UT Veterinary Hospital. The autopsy, corroborated by the Centers for Disease Control and by the National Fish and Wildlife Health Laboratory, indicated that he died from a rare amoebic disease caused by a parasite that attacked the cells of the brain. A veterinarian said the death was not preventable, but suggested stocking the pond with mallards, which feed on the snails that are the intermediate host for this parasite. So mallards joined the swans in the pond.

Three months after Not died, Y became tangled in the nylon line leading to a turtle trap on Swan Lake. She was removed from the water and taken to UT, where nothing terribly wrong was found other than a few scrapes and bruises. Unfortunately, the inhalation of water, the trauma, and perhaps the loss of Not were too much for her, and Y died the next day.

In 1990, the remaining swans hatched by Y and Not were 10 years old. Each spring, they would build nests and lay eggs that didn't hatch. Today, only three white mute swans remain. Nevertheless, the Swan Pond, its white mutes, and their more than 50 cygnets have become symbolic of Oak Ridge's tranquility and the natural beauty that surrounds the Laboratory.



ELMO Bumpy Torus, built at ORNL for fusion energy experiments, set a record for plasma heating.

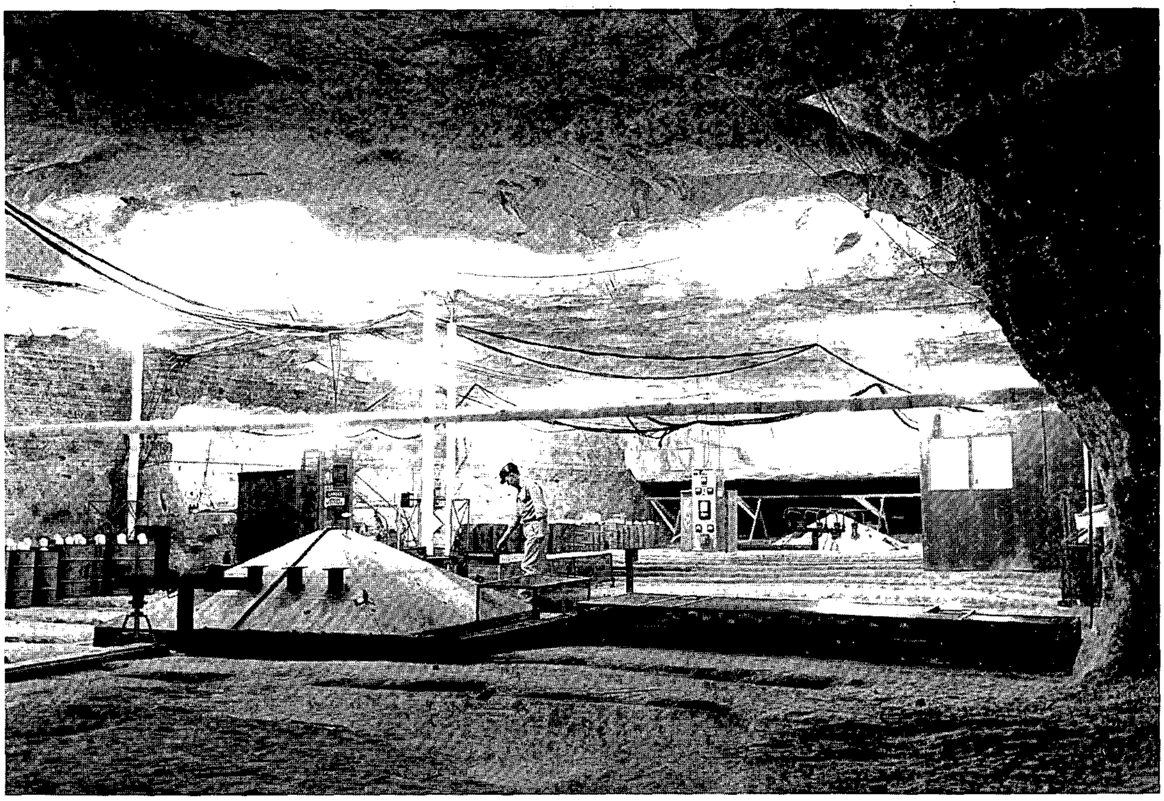
Experiment and a steady-state fusion device conceived by Raymond Dandl and given the odd name ELMO Bumpy Torus. ELMO's electron cyclotron heating set a record for steady, stable hot-electron plasma.

Optimism about fusion resurfaced in 1968, when Soviet scientist L.A. Artsimovich of Moscow's Kurchatov Institute announced his doughnut-shaped tokamak had confined a hot plasma. When Artsimovich visited the United States in 1969, Herman Postma, Laboratory chief of fusion research, dispatched a Laboratory team to discuss tokamaks with him.

Enthusiastic about what they heard, Postma's team proposed to the AEC construction of a tokamak at the Laboratory. They received quick approval, together with a mandate to have it operational by 1971. While the Oak Ridge tokamak, called ORMAK, brought the Laboratory back into a race with the Soviets, Artsimovich and other Soviets, in the unique cooperative spirit that characterized fusion research even during the Cold War, provided helpful information for ORMAK's design.

Sometimes working three shifts daily, the Laboratory's thermonuclear staff, with assistance from skilled craftsmen at the Y-12 Plant, rushed ORMAK's construction. The plasma was created inside a doughnut-shaped vacuum chamber (torus) of aluminum with a gold-plated liner. Coils of electrical conductors cooled by liquid nitrogen provided the magnetic field. Michael Roberts, ORMAK's project leader, described the assembly of this complicated machine as an unusual exercise like "putting an orange inside an orange inside an orange, all from the outside."

In the summer of 1971, ORMAK generated its first plasma and experiments began, with



Interior of a salt mine near Lyons, Kansas, a Laboratory test site for storing nuclear wastes.

encouraging results achieved by 1973. Herman Postma worried, however, whether the high-speed neutrons generated in the plasma would destroy the fusion reactors. Materials had to be found to make fusion reactor walls that would withstand the particle damage and stresses before the ORMAK or other fusion devices could generate even a glimmer of interest among commercial power producers.

More optimistic, Weinberg noted that the ORMAK design permitted installation of a larger vacuum chamber ring (torus) that would become ORMAK II. "With great good luck," he forecast, "ORMAK II might tell us that it would be a good gamble to go to a big ORMAK III, which might be the fusion equivalent of the 1942 experiment at Stagg Field in Chicago." Elusive plasma slipped from ORMAK's golden grip, however, and neither ORMAK nor subsequent fusion machines has yet achieved a self-sustaining fusion reaction.

Nuclear Energy and the Environment

While basic science and experimental reactor and accelerator hardware dominated activities within the Laboratory, political, legal, and popular protests far from the Oak Ridge Reservation contributed mightily toward reorienting its missions after 1969. Although dozens of reactors for commercial power production were then in the planning and construction phases, the nuclear industry remained troubled by three concerns: reactor safety, power-plant environmental impacts, and safe disposal of radioactive wastes. These concerns also challenged the Laboratory.

After 13 years of study, the Laboratory proposed entombing high-level radioactive wastes in deep salt mines near Lyons, Kansas. In 1970, the AEC provided $25 million to proceed with the salt mine repository.

ORNL and Nuclear Criticality Safety

From Standards to Software

Nuclear criticality safety—ensuring the safe storage, handling, and transportation of fissionable materials—is one of several areas of science and technology upon which ORNL has had a major international impact.

In any activity involving sizeable quantities of fissionable materials, a nuclear criticality safety program must seek to prevent an unintentional, uncontrolled fission chain reaction that results from an excess of fissionable materials (e.g., uranium-235 and plutonium-239) in close proximity during processing, storage, or transport. The aim is to protect against the consequences of an inadvertent nuclear chain reaction. The need for industrial controls at sites where fissionable materials were prepared, produced, or processed was recognized in the earliest days of the nuclear program. Early sites needing these controls included the K-25 and Y-12 plants and the facilities at Hanford and Los Alamos.

The K-25 gaseous diffusion plant was the focus for the earliest criticality studies. In the mid-1940s, Edward Teller and his colleagues reviewed the plans for this plant for potential unsafe accumulations. In late 1945, Art Snell of the Laboratory investigated the safety of "product drums" for transferring uranium hexafluoride enriched in low amounts of uranium-235. It was determined that criticality might be achieved in a drum if the enrichment were greater than 10%.

In the late 1940s, experimental results were obtained at Oak Ridge and later at Los Alamos, Hanford, and Rocky Flats to guide safe use of fissionable materials in storage and transport, chemical processes being designed and operated, and metallurgical operations including machining and disposal of scrap. Of even greater importance has been the experimental data used as benchmark information to verify and validate calculation methods that are only now reaching maturity.

Dixon Callihan, chaired committee that produced first criticality safety standards.

In 1949 the demand for this information by the rapidly growing nuclear community resulted in expansion of the Critical Experiments Laboratory. The team that operated this Y-12 Plant facility was transferred into the ORNL organization because its chief mission was to guide new reactor designs using data from critical experiments. However, it had an opportunity to assess the effects of a criticality safety accident in its own backyard.

In June 1958 the first critical accumulation of a fissionable material in an industrial process occurred within the Y-12 Plant. The cause was a leaky valve that allowed a solution containing uranium-235 to flow into a large vessel, resulting in exposure of eight men to radiation. A study at ORNL's Critical Experiments Laboratory of the energy released by the chain reaction confirmed early medical observations that the exposures were not as severe as first feared. Prompt evacuation by the personnel from the area where the reaction persisted minimized their exposures. None suffered any ill effects.

In 1950 Dixon Callihan and Sidney Visner established the ORNL Criticality Review Committee to review and approve Laboratory operations that involve potentially critical quantities of fissionable materials. The committee was headed by Joe Thomas recently.

The Laboratory supported the effort to develop national standards within the nuclear community through the American Nuclear Society program. A committee, first chaired by Callihan in the early 1960s and subsequently by Jack McLendon and Thomas, produced the first nuclear standard that gave quantitative guidance in 1964. It is one of a family of more than 20 national standards on criticality safety prepared by this international group still administered out of ORNL.

For more than 20 years, staff members at ORNL have been developing criticality safety software. The most internationally recognized software of this type is KENO, which was developed by Elliott Whitesides and Nancy Landers. The results of ORNL's critical experiments provided the benchmark data against which the results of the computer code calculations could be checked.

John Mihalczo recently has developed a technique for determining the margin by which a quantity of fissionable material is subcritical. DOE's Nuclear Criticality Technology and Safety Project, which has been managed at ORNL, created an "apprentice program" to train future experts in criticality safety.

Noting that the wastes would be hazardous for thousands of years, Weinberg warned, "We must be as certain as one can possibly be of anything that the wastes, once sequestered in the salt, can under no conceivable circumstances come in contact with the biosphere." Laboratory scientists concluded that the salt mines, located in a geologically stable region, would not be affected by earthquakes, migrating groundwater, or continental ice sheets that might reappear during the wastes' long-lived radioactivity.

People living near Lyons supported the Laboratory's salt vault plan, but environmental activists and Kansas state officials opposed use of the salt mines on several grounds. Their concerns extended beyond questions of technical capability to deep-seated worries about sound and effective administration over the long haul. Activists claimed that underground disposal for millennia would require creation of a secular "priesthood" charged with warning people never to drill or disturb the burial grounds. "It is our belief that disposal in salt is essentially foolproof," replied Weinberg, although conceding that a "kind of minimal priesthood will be necessary."

During intense design studies in 1971, the Laboratory and its consultants found that the many well holes already drilled into the Lyons salt formation in some circumstances might allow groundwater to enter the salt mines, thus raising technical questions about the site's long-term suitability. The salt mine disposal plan also became a heated political issue in Kansas. In 1972, the AEC authorized the Kansas geological commission to search for alternative salt mines in Kansas and directed the Laboratory to study salt formations in other states. For the moment, the AEC announced, radioactive wastes would be solidified and stored in aboveground concrete vaults at the site of their origin. That moment has turned into decades, as scientific and political debates concerning radioactive waste disposal issues continue to this day. They are not likely to be resolved soon.

In the 1970s, the public became concerned about the health effects of exposure to wastes at the other end of the nuclear fuel cycle—the uranium mine. In 1973 ORNL health physicists Fred Haywood, George Kerr, Phil Perdue, and Bill Fox traveled to Grand Junction, Colorado, to determine the radiation hazards in buildings constructed with or on materials containing uranium mine tailings, which are a source of cancer-causing radon daughter products. In the 1980s, a new office called ORNL West was established in Grand Junction. Managed by Craig Little, this office worked with the Instrumentation and Controls Division to develop a field survey technique using triangulated ultrasound signals and a computer for mapping concentrations of radioactivity to determine where remediation is needed or if it has been effective.

Because of the Laboratory's research on the health effects of radiation from nuclear energy,

Willie Lijinsky and Wayne Taylor examine a tumor induced in a rat by feeding it an amine and a nitrite.

"Laboratory researchers were well positioned to attack the cancer problem."

including cancer, ORNL played a role in President Nixon's "war on cancer." With additional support, researchers in the Laboratory's Biology Division focused on radiation and chemicals and later viruses and genes, including genes that promote tumors and those that suppress them. Consumer advocates who worried about the safety of hot dogs were especially interested in the findings of ORNL's Willie Lijinsky, who demonstrated that the nitrites widely used as food preservatives react with amines in food and drugs to form cancer-causing nitrosamines during digestion in the stomach.

Laboratory researchers were well positioned to attack the cancer problem because they had long sought to understand how organisms prevent or recover from the damaging effects of radiation and how to stimulate these self-protective mechanisms. They had discovered that cells can repair radiation-induced damage after radiation exposure ceases and that deficiencies in cellular repair mechanisms can predispose the organism to cancer.

Public and legal concerns about the environmental effects of nuclear power brought the Laboratory's studies of terrestrial and aquatic habitats to the forefront of its research agenda during the early 1970s. Using the "systems ecology" paradigm pioneered by Jerry Olson, Laboratory ecologists investigated radionuclide transport through the environment. Olson examined the migration of cesium-137 through forest ecosystems by inoculating tulip poplar trees behind the Health Physics Research Reactor with cesium-137, thereby establishing the first such experimental research center for forest ecosystem studies.

In 1968, the National Science Foundation placed Stan Auerbach in charge of a deciduous forest biome program in which the Laboratory contracted with universities for studies of photosynthesis, transpiration, soil decomposition, and nutrient cycling in forest systems in the eastern United States. That same year, David Reichle led a Laboratory forest research team that initiated large-scale forest ecosystem research. This work was a forerunner of subsequent Laboratory programs that investigated acidic deposition, biomass energy production, and global climatic change.

Environmental studies at the Laboratory received an unexpected boost in 1971 when a federal court, in a decision on a planned nuclear plant at Calvert Cliffs, Maryland, ordered major revisions of AEC environmental impact statements as an essential part of reactor licensing procedures. Required to complete 92 environmental impact statements by 1972, the AEC asked for help from its Battelle Northwest, Argonne, and Oak Ridge national laboratories. Giving this effort the highest priority, Weinberg declared, "Nuclear energy, in fact any energy, in the United States simply must come to some terms with the environment."

The Laboratory's skeleton staff for environmental impact statements, headed by Edward Struxness and Thomas Row, expanded in 1972 to include about 75 scientists and technicians. Staff working on these reports formed the nucleus of the Energy Division, established in 1974 under Samuel Beall's leadership.

The Calvert Cliffs decision required the AEC to consider the effects of nuclear plant discharges of heated water on the aquatic environment. Chuck Coutant led a Laboratory team assigned the task of developing federal water temperature criteria to protect aquatic life. For these and related studies, the Laboratory initiated construction of an Aquatic Ecology Laboratory, completed in 1973. Only the Pacific Northwest Laboratory had a similar laboratory. Its initial equipment consisted of 20 water tanks, each containing various fish species, and a computer-controlled heated-water system to supply water of proper temperature to the tanks; outside were six ponds for breeding fish and conducting field experiments. Early experiments at the aquatics laboratory investigated the survival rate of fish and fish eggs at elevated temperatures.

To determine the water temperature preferences of fish in streams, Coutant and Jim Rochelle of the Instrumentation and Controls Division developed a temperature-sensitive ultrasonic fish tag. The "electronic thermometer," which can be surgically implanted into a fish, transmits temperature information as high-pitched sound waves of varying frequencies to a hydrophone in a boat or on shore. It has been used by private utilities and government agencies for fish studies.

An indirect result of the aquatic studies came during licensing hearings for Consolidated Edison's Indian Point–2 nuclear plant on the

Hudson River, just north of New York City. Because the Environmental Sciences Division (following recommendations by environmental groups) identified Indian Point as a spawning ground for striped bass, the impact statement for Indian Point–2 called for closed-cycle cooling towers to protect aquatic life from the adverse effects of thermal degradation. Thus, cooling towers, which now serve as the towering symbol of nuclear power plants, were built at Indian Point.

Gordon Blaylock and Neal Griffin collect fish in 1968 from White Oak Lake to study the effects of low-level radiation on fish reproduction.

The legal battle that led to the Indian Point decision took 10 years to complete. During this litigation, Laboratory staff provided technical information to all participants—environmental groups, utility company officials, the Environmental Protection Agency, and other state and federal agencies.

The high cost of environmental mitigation, reflected both in lengthy courtroom dramas and construction of elaborate cooling systems, concerned many nuclear power advocates. They were troubled as well by stringent reactor safety standards that the Laboratory staff proposed in 1970. Under the direction of Meyer Bender of General Engineering Division, the Laboratory had recommended nearly 100 interim safety standards. Many of these standards were based on investigations by the Heavy Section Steel Technology Program conducted in the Reactor and Metals and Ceramics divisions. Other standards relating to reactor controls were developed by the Instrumentation and Controls Division.

William Unger and his associates, for example, designed and tested shipping containers for radioactive materials to determine the design that could best withstand collisions during transport. Richard Lyon and Graydon Whitman assessed the ability of reactors to withstand earthquakes, joining with soil engineers who simulated mini-earthquakes by detonating dynamite near the abandoned Experimental Gas Cooled Reactor. George Parker's team studied fission product releases from molten fuels, and Philip Rittenhouse's team investigated the failure of engineered safeguards, particularly the effects of interruptions in water flow to reactors.

Emergency Core Cooling Hearings

"We find ourselves increasingly at those critical intersections of technology and society which underlie some of our country's primary social concerns," Weinberg declared in 1972. He also noted that Laboratory veterans longed for the days when "what we did at ORNL was separate plutonium, measure cross sections, and develop instruments for detecting radiation." Those days were part of the Laboratory's history and were overshadowed in the heated climate of political discourse and public opinion that emerged during the Emergency Core Cooling Systems (ECCS) hearings in 1972.

The AEC Hearings on Acceptance Criteria for Emergency Core Cooling Systems for Light-Water-Cooled Nuclear Power Reactors, or the ECCS

"The hearings forced the Laboratory to face the harsh realities of the new nuclear era of controversy, conflict, and compromise."

Structure and Soundness

A reactor pressure vessel in a nuclear power plant springs a leak. Water used to cool the nuclear fuel escapes. The fuel overheats, causing localized melting of the thick vessel wall and a discharge of radioactivity into the containment building.

Although such a scenario has never occurred in the United States, preventing it has been a prime concern of the Laboratory's Heavy Section Steel Technology (HSST) Program for 25 years.

The HSST program was established in response to a November 1965 letter by William Manly of the Advisory Committee on Reactor Safeguards to the Atomic Energy Commission, which recommended a more sophisticated approach to evaluation of the structural soundness of pressure vessels. In March 1967 the HSST program, sponsored by the AEC's Division of Reactor Development and Technology, came into being under Laboratory management. Its first director was F. J. Witt; successors have been Grady Whitman, Claud Pugh, Bill Corwin, and Bill Pennell. Today the HSST program, which continues as a major effort in the Engineering Technology and Metals and Ceramics divisions, is sponsored by the U.S. Nuclear Regulatory Commission (NRC).

In 1990, John Merkle (left) briefs Admiral Kenneth Carr, chaiman of the Nuclear Regulatory Commission, the Laboratory's Heavy-Section Steel Technology program.

Using large-scale testing procedures, the HSST program demonstrated that the thick steel walls of new reactor pressure vessels possess enough ductility—the ability to accommodate stresses caused by pressurization, heating, and cooling—to prevent vessel failure. In the late 1960s, the program also initiated a fracture toughness data base for reactor vessel materials. This information, detailing the ability of materials to resist cracking, is essential to all fracture-margin assessments for reactor pressure vessels.

During manufacture of steel plates for vessel walls, flaws may develop and spread into cracks as the walls become brittle. "Thermal shock" may occur when the heated walls of a vessel are suddenly subjected to cold water as a result of loss of pressure and the operation of safety injection systems to cool the nuclear fuel. In the late 1970s, ORNL researchers led by Dick Cheverton discovered that thermal shock, combined with repressurization (during emergency cooling, for example), could drive a crack through the vessel wall under postulated conditions.

More recently, Laboratory researchers have turned their attention to the problem of vessel aging. Over many years, as the vessel interior is bombarded by neutrons from nuclear reactions in the fuel, the walls tend to lose their ductility. Such radiation-induced embrittlement can occur in older pressurized-water reactors and, to a lesser extent, in boiling-water plants.

For older nuclear power plants, radiation-induced embrittlement is an issue that must be addressed if plant operating licenses are to be renewed. The HSST program provides the NRC with guidance on this issue by estimating the probability that a reactor vessel will fail over a specific operating time. The embrittlement rate in each reactor vessel is monitored, and operating limits are imposed by NRC regulations and regulatory guides that the Laboratory has helped to establish.

Today, the HSST program continues to investigate the properties of materials for pressure vessels to develop and evaluate ways to predict fracture, fatigue and creep. It also conducts vessel and material tests to assess the validity of the predictions, which help to set and update national codes, standards, and regulations. HSST researchers intend to carry on the tradition of the past 25 years by providing the NRC with information that will help the agency respond to the new challenges of reactor safety.

In 1977 Carolyn Young studied effects of warm effluents from Bull Run Steam Plant on Melton Hill Lake milfoil.

hearings for short, proved a critical event, one that forced the Laboratory to face the harsh realities of the new nuclear era of controversy, conflict; and compromise.

In 1971, President Nixon appointed James Schlesinger, an economist from his budget office, to succeed Glenn Seaborg as AEC chairman. Schlesinger aimed to convert the AEC from an agency that unabashedly promoted nuclear power to one that served as an unbiased "referee." When protest greeted the AEC's interim criteria for emergency core-cooling systems, he convened a quasi-legal hearing for comments from reactor manufacturers, electric utility officials, nuclear scientists, environmentalists, and the public. The hearing began in Bethesda, Maryland, in January 1972 and would continue the entire year.

To present their views, environmental groups hired attorneys and scientific consultants, who joined attorneys for reactor manufacturers, utilities, and the government to pack the ECCS hearings. Witnesses were subjected to dramatic cross-examinations—a new experience for most scientists, who were accustomed to establishing scientific truth through publications subject to sedate peer review, not through raucous adversarial legal proceedings.

For reactors with less than 400 MW of capacity, containment vessels can confine radioactive fuel melting even in the event of a serious accident, rendering impossible what is popularly known as the China Syndrome. For reactors with more than 400 MW of capacity, containment vessels are important, but no longer sufficient. An elaborate cooling system must also be built to ensure safety. Weinberg thought it unfortunate that some AEC staff members had not been impressed by the seriousness of this requirement until forced to confront it by antinuclear activists.

"Laboratory experts generally considered that existing criteria for reactor safety were based on inadequate research."

Now that the AEC and nuclear industry had been called into account on this issue, Weinberg urged Laboratory staff to offer their expertise fully and without reservation, regardless of whether they agreed with the existing criteria. Schlesinger agreed. Weinberg complained, however, that his staff should have been involved as fully in preparing the criteria as they would be in testifying at the hearings.

Among Laboratory staff participating in these lengthy, sometimes contentious, sometimes tedious hearings were William Cottrell, Philip Rittenhouse, David Hobson, and George Lawson. They and other witnesses were grilled by attorneys for days. More than 20,000 pages of testimony were taken from scientists and engineers, who often expressed sharp dissent on technical matters concerning the adequacy of the safety program. Laboratory experts generally considered that existing criteria for reactor safety were based on inadequate research.

As a result of these showdown hearings, in 1973 the AEC tightened its reactor safety requirements to reduce the chances that reactor cores would overheat as a result of a loss of emergency cooling water. This measure, however, failed to placate critics who preferred a moratorium on nuclear reactor construction.

The Laboratory's emphasis on reactor safety and environmental protection made it and Director Weinberg unpopular among some nuclear power advocates and members of the AEC staff—a strange turn of events for Laboratory scientists who had devoted their careers to inventing and advancing practical applications of nuclear energy. Opponents of nuclear power, on the other hand, enjoyed quoting Weinberg's chilling declaration:

> *Nuclear people have made a Faustian contract with society; we offer an almost unique possibility for a technologically abundant world for the oncoming billions, through our miraculous, inexhaustible energy source; but this energy source at the same time is tainted with potential side effects that, if uncontrolled, could spell disaster.*

Although other events and considerations also played a part, the ECCS hearings of 1972 no doubt influenced major management shifts in 1973 at the Laboratory and AEC. More fundamentally, they influenced the federal government's subsequent decision to dissolve the AEC and to place its regulatory responsibilities and research- and development-related activities into two separate entities. These changes would mark the most profound transition in energy research and development since 1946.

Energy Transition

Another crisis—not in public confidence but in energy supplies—threatened the nation during the early 1970s. To meet this challenge, Weinberg sought to reorient and broaden the Laboratory's mission. He was encouraged both by the National Science Foundation (NSF) and the AEC, which in 1971 received congressional approval to investigate energy sources other than nuclear fission. At AEC headquarters, James Bresee, who had headed the Laboratory's civil defense studies, became head of a general energy department, which managed funding for Oak Ridge's innovative energy studies.

When Congress authorized the AEC in 1971 to investigate all energy sources, Weinberg appointed Sheldon Datz and Mike Wilkinson as heads of a committee to review opportunities for non-nuclear energy research. In addition, he made Robert Livingston the head of an energy council assigned the task of considering new Laboratory missions.

At the AEC, James Bresee reviewed Laboratory proposals for broad energy research. Among these were studies of improved turbine efficiency, alternative heat disposal methods at power plants, coal gasification, high-temperature batteries, and synthetic fuels made from coal and shale to supplement petroleum and natural gas.

As these innovative energy studies began, Weinberg also moved the Laboratory into broader environmental programs. He brought David Rose from the Massachusetts Institute of Technology to the Laboratory to manage multidisciplinary research on broad societal problems. The study teams for these innovative research efforts, which Rose hoped would tackle national issues, included such "young turks" as Herman Postma, Bill Fulkerson, and Jack Gibbons.

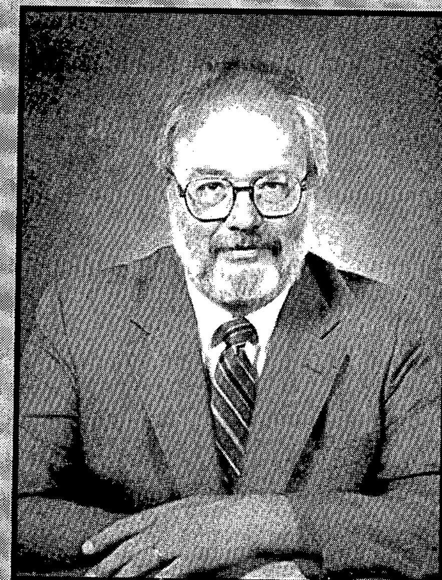
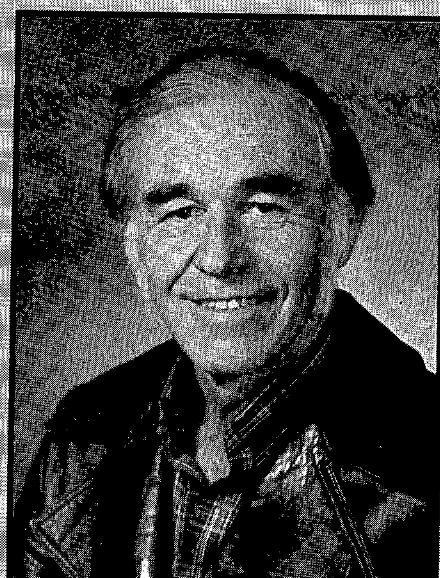
The ECCS Hearings

Throughout 1972, the Emergency Core Cooling System (ECCS) hearings on the safety of light-water nuclear reactors attracted the media's attention and raised concerns among personnel in the nuclear energy establishment, including Oak Ridge National Laboratory. Many questioned the adequacy of interim safety standards for nuclear reactors that the AEC issued in 1971, and the chairman of the AEC in 1972 convened quasi-legal hearings on those standards at Bethesda, Maryland. The hearings pitted the nuclear power industry against the opponents of nuclear power and seriously divided researchers at the AEC and its laboratories. Placed on the witness stand during heated adversarial legal proceedings, some scientists expressed confidence in the interim safety standards, and others did not.

In a letter to Hans Bethe, Nobel laureate professor at Cornell University, and former director of Los Alamos Scientific Laboratory's Theoretical Division, ORNL Director Alvin Weinberg pointed out that emergency cooling systems provided a final defense against melting of fuel in the case of a loss-of-coolant accident in the largest light-water nuclear reactors. "And it makes me all the more unhappy," Weinberg concluded, "that certain quarters in the AEC have refused to take it seriously until forced by intervenors who are often intent on destroying nuclear energy!"

Weinberg and the Laboratory staff sometimes found themselves at odds with the members of the AEC staff during the trying ECCS hearings of 1972. When the Laboratory safety specialists expressed serious reservations about the degree of emergency core cooling safety, they soon heard their reservations quoted by the opposition, declaring, "Nobody will call these scientists loony; they are ranking members of the atomic energy establishment, whose words we have been taught to accept without question."

When the hearings concluded, the AEC issued revised nuclear safety standards that its opponents decribed as a "continuation of the AEC coverup of critical safety problems." The hearings contributed in no small way to the political decision of 1973 to form from the AEC a new agency for research and development and the Nuclear Regulatory Commission for safety review functions. The hearings contributed to major mission and management changes at the Laboratory as well.


Several ORNL researchers participated in the Emergency Core Cooling Hearings held by the AEC in 1972 at Bethesda, Maryland. Shown above, from top left, are William B. Cottrell, David Hobson, Philip Rittenhouse (bottom left), and George Lawson.

James Liverman and Pete Craven drew up a proposal to the National Science Foundation to fund environmental studies at the Laboratory. With support from Congressman Joe Evins, Weinberg and Rose took this proposal to the NSF and received funding from the NSF Research Applied to National Needs (RANN) program for a 1970 summer study. Using regional modeling, social indicators, and system analysis, Rose and his team examined national environmental challenges, such as renewable energy resources.

This first attempt at the Laboratory to look at national problems holistically evolved during late 1970 into the NSF Environmental Program managed by Jack Gibbons. Out of this program a few years later came the Laboratory's Conservation and Renewable Energy program, which by 1993 had become the Laboratory's largest energy activity.

When the NSF first announced its RANN program, Weinberg advised NSF director William McElroy that the Laboratory had "rather miraculously" identified many national needs for research that it could conduct. A poll of Laboratory staff produced 150 new energy and environmental research proposals, a few of which were approved by the NSF.

Bill Fulkerson is now ORNL associate director for Energy and Environmental Technologies.

Noting that many environmental problems arose as a result of increasing energy use, Roger Carlsmith, Eric Hirst, and their associates initiated studies that examined ways to reduce energy demand by promoting energy conservation. In 1970, they emphasized the importance of better home insulation in substantially cutting energy use for home heating. Moreover, they concluded that increasing the efficiency of transportation and home appliances could significantly lower levels of energy consumption. For design of more efficient central power stations, the Laboratory investigated improved turbine cycles, cryogenic power transmission lines, and "power parks" to cluster power stations outside of urban areas.

Interest in solar energy flared in 1971, when solar energy advocate Aden Meinel visited the Laboratory and proposed using solar energy to heat liquid sodium and molten salts for large-scale generation of electricity. Murray Rosenthal, who managed the Laboratory's Molten Salt Reactor Program, led a group that assessed the economics of using energy from the sun to produce electricity.

Although the group concluded that solar power generation would cost more than nuclear or fossil fuel power, Rosenthal recommended additional studies because solar energy could ultimately prove economically attractive if two possible scenarios became a reality: "One is that environmental concerns or other factors could increase coal and nuclear energy costs more than we can foresee; the other is that the collection and conversion of solar energy could become much less costly than we assume."

With NSF backing, the Laboratory examined solar energy as a potential long-term backup for other energy sources. In addition, David Novelli and Kurt Kraus studied the use of solar heat to enhance biological production of hydrogen and methane fuels as petroleum substitutes. The Laboratory's knowledge of surface physics and semiconductors eventually led to investigations of ways to improve the efficiency of photovoltaic cells

Environmental Impact Assessments

In his State of the Laboratory address for 1971, Director Alvin Weinberg suggested that "the most important event of the year in nuclear energy was legal, not scientific or technical."

Weinberg was referring to a July 1971 decision by the U.S. Court of Appeals for the District of Columbia requiring the Atomic Energy Commission (AEC) to fully examine the environmental impacts of nuclear power plants. The judge invoked the National Environmental Policy Act as the basis for his decision.

Weinberg summarized the intent of the decision, which would have far-reaching implications for the Laboratory.

The Commission is now required to examine thermal as well as radiological effects of reactors; it must consider alternatives to the use of nuclear power plants; it must evaluate all of these things independently and not depend on local regulations and standards; and it must summarize its findings in a cost-benefit analysis that weighs such imponderable costs as the destruction of a stand of timber against the economic benefit of lower-cost energy. What makes the whole matter so critical is that such environmental impact statements have now become so essential a part of the reactor licensing procedure. There is at stake about 100 million kilowatts of nuclear electricity, almost 25 percent of the total U.S. central station load.

Weinberg reported that the AEC sought help from three of its laboratories—Battelle Northwest, Argonne, and Oak Ridge. "The job," he said, "is formidable: 91 environmental impact statements to be completed by July of 1972 or as quickly thereafter as possible. Of these, the Laboratory already is working with the AEC Washington staff on 13, with another dozen or so expected. This task has been given the highest priority in the Commission and, in consequence, at the Laboratory."

Elizabeth Peelle (foreground) studied socioeconomic impacts of nuclear power plants.

A full-time team of 75 people led by Ed Struxness was assembled from 14 Laboratory divisions. Tom Row was selected as the deputy leader. Bill Fulkerson took over leadership of this effort in 1974. The team was helped by many part-time reviewers and consultants from almost every part of the Laboratory. Altogether about 130 members of the scientific staff and 50 support personnel were involved in preparation of environmental impact statements in the early 1970s.

The impact statements, predicted Weinberg, "undoubtedly will create demands for more knowledge in several areas besides ecology—cooling tower technology, micrometeorology, possibly regional modeling, and the like. I would venture to suggest, therefore, that what may seem at the moment to be an awkward diversion from our main interests will, in fact, create new and more valid interests for many of the divisions at ORNL."

Weinberg's prediction proved correct. The Laboratory became a national leader in environmental impact assessments. Since the late 1970s, the Laboratory has examined socioeconomic as well as environmental impacts of nuclear power plants (fission and magnetic fusion) and of non-nuclear energy projects such as geothermal, solar, fossil, synthetic-fuel, biomass conversion, and hydropower projects. Other assessment projects included disposal of chemical weapons at U.S. Army sites, disposal of low-level radioactive waste, renewal of nuclear power plant licenses, remediation of contaminated sites, Air Force low-level flying operations, and research activities in the pristine environment of Antarctica.

Today, as many as 100 persons at the Laboratory work on environmental impact statements and assessments, including risk assessments. For more than 20 years, the Laboratory has been a leader not only in developing energy technologies but also in assessing their benefits and risks to society.

"The highlight of Culler's year was the Laboratory's participation in the national energy strategy."

by Richard Wood and associates in the Solid State Division as part of the Laboratory's modest solar program.

Management Transition

The Laboratory's 1971 venture into non-nuclear energy research did little to ease its fiscal woes. Successive annual budget reductions in its nuclear energy programs forced corresponding reductions in staff and continuous efforts to lower overhead. As one cost-cutting measure, the Laboratory closed its food service canteens scattered about the complex for employee convenience and replaced them with vending machines.

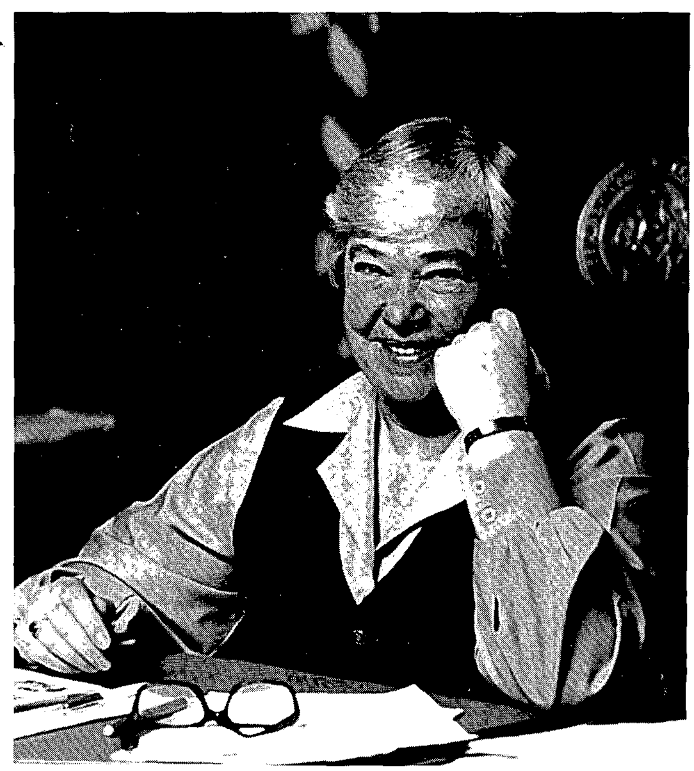
Typical of his management style, Weinberg appointed long-range planners to identify supplemental Laboratory missions. Commenting that he felt at times "like a man with a canoe paddle trying to change the course of an ocean liner,"[1] David Rose, the Laboratory's first long-range planner, returned to MIT. Robert Livingston succeeded Rose as head of the program planning and analysis group, which included Calvin Burwell and Frank Plasil. Squarely facing the transition in Laboratory missions, this group proposed a staff education program to retrain fission specialists in broader energy and environmental issues.

Musing on this proposal, Weinberg recognized the dilemma of having experts trained in one field while funding opportunities were becoming more prevalent in other fields. He noted that a similar redirection had marked the experience of Manhattan Project personnel during and after World War II. Wigner, a chemical engineer, switched to nuclear physics. Cosmic-ray specialist Ernest Wollan became a health physicist and neutron diffraction expert, and biochemist Kurt Kraus became highly skilled in plutonium chemistry. Weinberg himself had started his career as a biophysicist, only to become a reactor physicist.

"Enrico Fermi once told me that he made a practice throughout his scientific career of changing fields every five years," Weinberg recalled. He added that, although "there are few Fermis, I think we all easily recognize that the spirit of his advice can well be helpful."

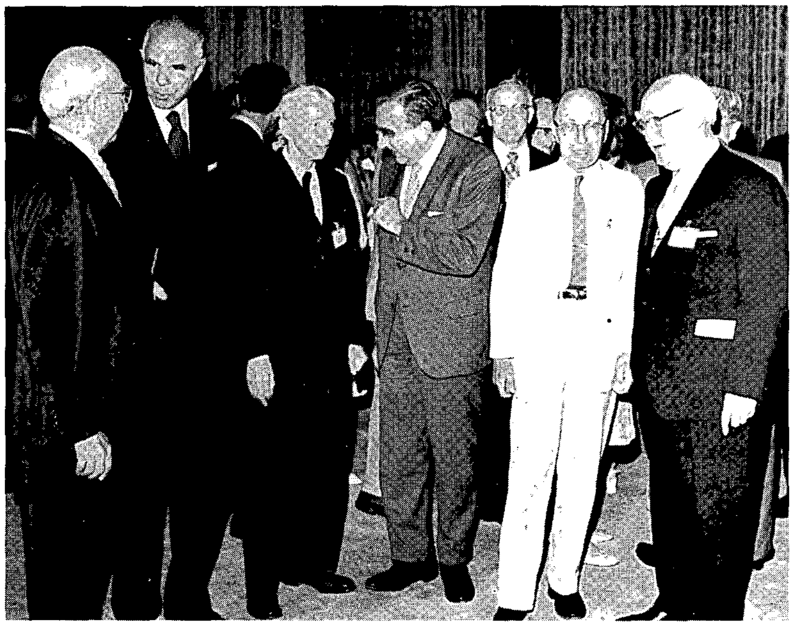
In an effort to enhance internal viability and flexibility, in 1972 the Laboratory initiated a school of environmental effects aimed at producing physical scientists conversant with biology and ecology. This effort stalled, however, because most members of the school were laid off during the massive reduction in force of 1973. Taking cues from his own observations about the Laboratory's future, Weinberg, after a quarter century of service at Oak Ridge, also embarked on a new career.

The long-time Laboratory director joined Herbert MacPherson and William Baker, president of Bell Laboratories, to form a "think tank" dedicated to coherent long-range energy planning. With support from the AEC and John Sawhill of the



Dixy Lee Ray, the AEC's only woman chairman.

Federal Energy Office, they created the Institute for Energy Analysis in late 1973. Oak Ridge Associated Universities served as the institute's contract operator. It opened in January 1974 with Herbert MacPherson as director because Weinberg had been called to Washington to lend his expertise to resolving the national energy crisis.



Lewis Strauss, Glenn Seaborg, Hyman Rickover, Edward Teller, Eugene Wigner, and Chet Holifield celebrate the AEC's 25th anniversary.

Throughout 1973, Floyd Culler served as acting director of the Laboratory. Described as a "muddy boots type," Culler had received acclaim at the fourth Geneva conference on atomic energy in 1971 for objecting to plans by other nations to store liquid nuclear wastes in tanks. He contended that bequeathing radioactive wastes to future generations without providing a permanent, safe disposal system posed serious political and moral questions.

Culler's year as Laboratory director resembled a roller coaster ride, which he later described as a "year of many transitions." In January 1973, Milton Shaw, chief of AEC reactor development programs, mandated a quick end to the Laboratory's molten-salt reactor studies because he was deeply committed to development of the liquid-metal breeder reactor. This decision precipitated what Culler described as the "largest and most painful reduction of employment level at the Laboratory in its history." It also undermined the morale of the nearly 3800 personnel who remained.

In March 1973, President Nixon appointed Dixy Lee Ray, a marine biologist, as AEC chairman to replace James Schlesinger, who became Secretary of Defense. Ray has been credited with saving the Laboratory from those in the AEC and Congress who were bent on destroying it.

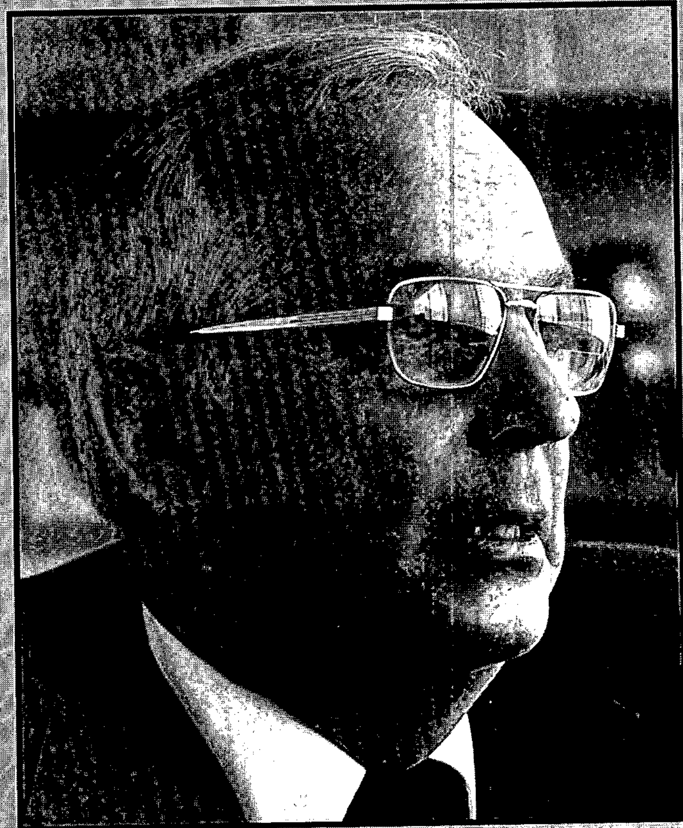
The highlight of Culler's year was the Laboratory's participation in the national energy strategy. When the president asked Ray to review energy research and recommend an integrated national policy, she called on the national laboratories to assist in undertaking these urgent studies. Murray Rosenthal, who was acting as Culler's deputy director, Jere Nichols, and others spent most of the summer in Washington, providing background information for Ray's report.

Titled *The Nation's Energy Future*, it advocated energy conservation to reduce demand as well as research into new technologies and strategies to increase supplies. The report's ultimate goal was to make the nation energy independent by eliminating its need for imported oil by 1980.

The turnaround for Laboratory programs came on the heels of the Israeli-Arab "Yom Kippur War" in the Middle East and the related Arab oil embargo imposed on the United States in October 1973. As disgruntled Americans lined up at filling stations to purchase gasoline, Nixon established the Federal Energy Office. With William Simon as director and John Sawhill as deputy director, the office was responsible for allocating scarce oil and gas supplies during the emergency and for planning long-range solutions to the nation's energy problems.

Floyd Culler

Directed with His Boots On



Acting Laboratory Director Floyd Culler came to Oak Ridge in 1943 from Johns Hopkins University. He worked at the Y-12 Plant during the war and joined the Laboratory in 1947 as design engineer for nuclear-fuel recycling plants. Rising through the ranks, he became section chief and later director of the Chemical Technology Division.

"His team established nuclear fuel reprocessing techniques used worldwide."

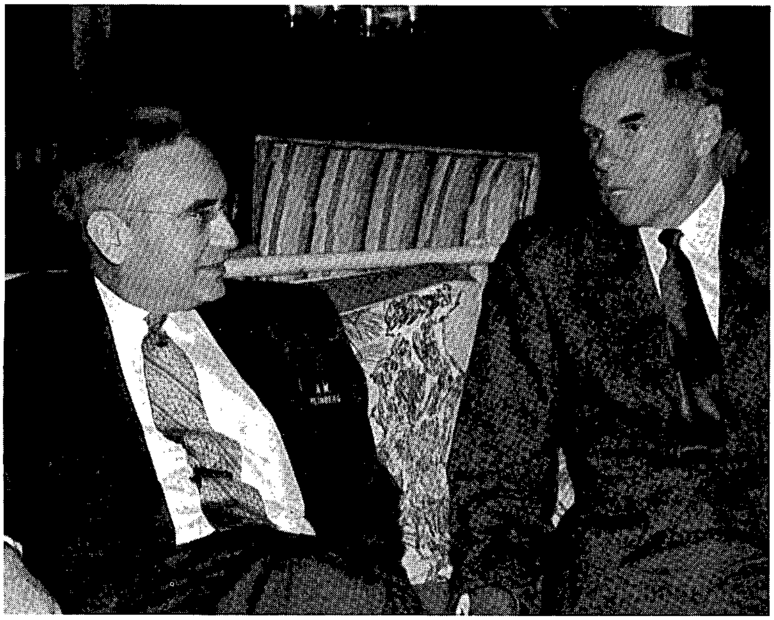
Culler managed the Laboratory's development of solvent extraction and other processes for recovery of uranium, plutonium, and fission products from spent nuclear fuels. His team established nuclear-fuel reprocessing techniques used worldwide.

Culler served as the Laboratory's assistant and later associate director for nuclear technology in 1964 and as its deputy director from 1970 to 1977. When Alvin Weinberg retired in 1972, Culler was appointed acting Laboratory director. In 1977, he moved to California to become president of the prestigious Electric Power Research Institute.

Often described as a "muddy boots type," Culler enjoyed working directly with craftsmen and with the people of Oak Ridge.

"Often described as a 'muddy boots type,' Culler enjoyed working directly with craftsmen and with the people of Oak Ridge."

Active in the community, he chaired the Oak Ridge Regional Planning Commission, which was responsible for the alphabetical naming of the city's streets and helped govern the community before it was incorporated.



Alvin Weinberg and AEC Chairman Glenn Seaborg in 1967.

"Weinberg became science's presence in the White House during the late Nixon and early Ford administrations."

At Sawhill's request, Weinberg went to the White House to head the Office of Energy Research and Development. Because Nixon did not appoint a presidential science advisor as had Presidents Eisenhower, Kennedy, and Johnson, Weinberg became science's presence in the White House during the late Nixon and early Ford administrations.

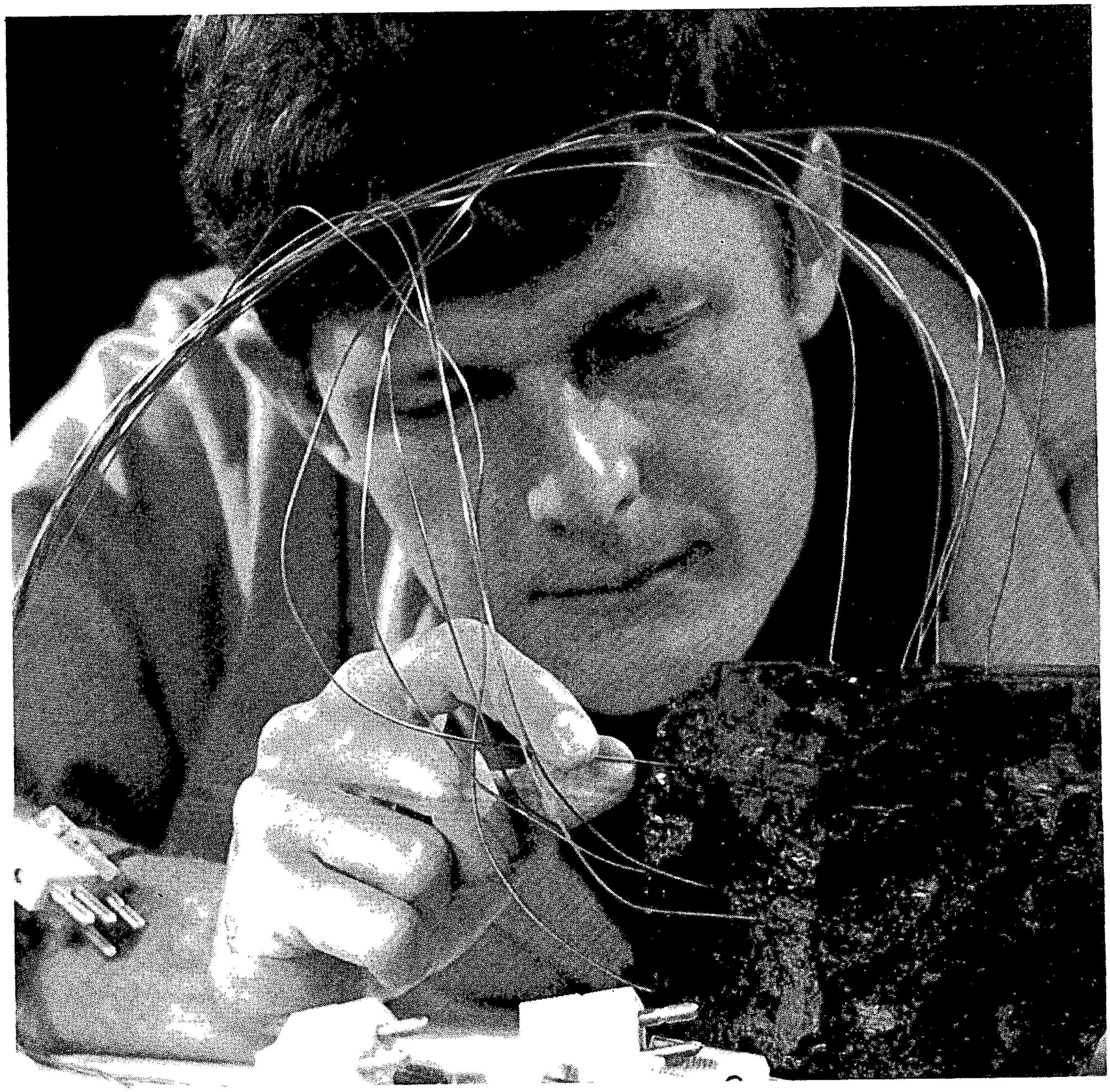
Floyd Culler noted that the oil embargo and energy crisis made the Laboratory "whole again" by the end of 1973. Reacting to this crisis, Congress pumped new funding into energy research and even approved a modest resumption of molten-salt breeder studies at the Laboratory. "Throughout ORNL's evolution, its central theme has continued to be the development of safe, clean, abundant economic energy systems," Culler said at the end of the year. "The Laboratory is now in a uniquely strong position to undertake a multimodal attack on the nation's energy problems."

In December 1973, President Nixon proposed a reorganization of the federal energy agencies. As part of this effort, he divided the AEC into two new agencies. AEC responsibilities for energy research and development went to the Energy Research and Development Administration, while AEC regulatory responsibilities were assumed by the Nuclear Regulatory Commission.

With this new administrative structure in place, Eugene Wigner recommended a Laboratory reorganization paralleling the division of the AEC. He urged that Weinberg be returned to the Laboratory to manage its energy research and development programs and that Culler be assigned responsibility for the Laboratory's safety and environmental programs. "Alvin and Floyd Culler have collaborated for several years," Wigner asserted. "They understand, like, and respect each other." As a result, he said, "conflicts are most unlikely to arise."

Wigner's recommendation was not accepted. Weinberg served the White House until formation of the Energy Research and Development Administration in late 1974 and then became director of the Institute for Energy Analysis in Oak Ridge. Culler stayed at the Laboratory as deputy director under Herman Postma until 1977, when he became president of the Electric Power Research Institute.

Life at the Laboratory may have become more tumultuous during the 1970s, but changes in the Laboratory's workplace were no more—or less—than a reflection of dramatic changes in American society. Isolated in the serene hills of East Tennessee, the Laboratory could not avoid being caught in the vortex of a changed energy world. Its future would depend on how well it could respond to the new world "energy" order that suddenly emerged in the aftermath of the Arab oil embargo of 1973 and the ensuing energy crisis.



Richard Forrester measures heat transfer in coal blocks for coal gasification studies.

Chapter 7

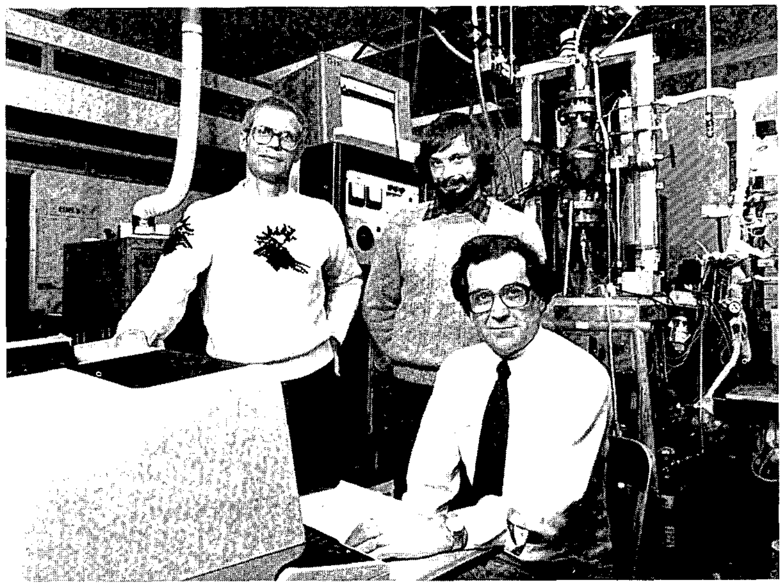
Energy Technologies

"After five years of steady decline, much personal distress, and a deep sense of frustration that obvious national problems were not being attacked," Laboratory Director Herman Postma said, "1974 is the year in which we perceive an end to such dismay." Warnings of energy shortages, Postma added, "finally hit home as the Arab oil embargo began and people had to wait in gas lines."

The 1974 energy crisis and Postma's appointment as director during the same year had far-reaching implications for the Laboratory. Postma had joined the Laboratory's Thermonuclear Division in 1959 and became division director in 1968. He was the first Laboratory director without direct Manhattan Project experience.

In a broader context, his ascent symbolized the arrival of a new generation of scientists—the "young turks." These youthful scientists displayed as much interest in bioreactors, coal reactors, and fusion reactors as the Laboratory's earlier researchers—now the "gray eagles"—had exhibited in nuclear reactors.

Responding to the demands of the younger scientists, Postma launched several management initiatives. Drawing on his professional management training, he initiated attitude surveys, performance evaluations, and other modern management techniques. Adhering more strictly than Weinberg to organizational structure and procedure, he strengthened the administrative role of his associate directors and divested himself of the dual roles Weinberg had filled as both Laboratory director and chief of the Director's Division. Postma replaced the Director's Division with central management offices, under Frank Bruce, associate director for Administration. Postma also supported creation of dual career ladders—one for scientists and technicians and another for managers. (Under earlier career ladders, Laboratory scientists had to become managers to obtain higher salaries.)



Scientists Jim Carter, Scott Hunter, and Loucas Christophorou study the behavior of electrons in liquids and gases.

Although researchers from the old and new schools may have disagreed about the Laboratory's research agenda and its approach to management, both groups were pleased by a broad exploratory studies initiative begun in 1974. Known as the Seed Money Program, it aimed to encourage creative science. "Scientific advances are made by individuals in the privacy of their own minds," observed Alex Zucker in explaining the seed money rationale. "It is one of the functions of a scientific laboratory to discover the unexpected, to develop new ideas, and to explore in an unfettered way areas that may not show much promise to the casual observer."

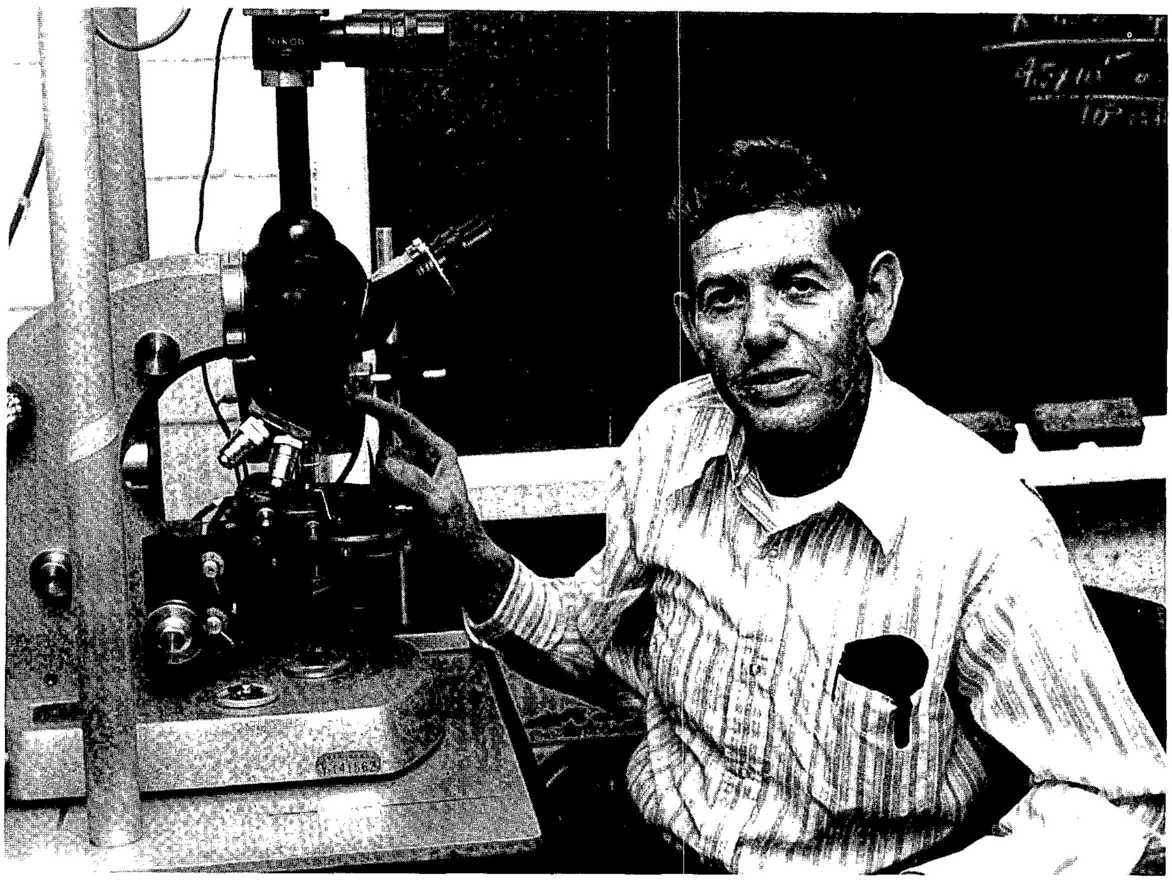
Laboratory overhead funds were used to "seed" research proposals that review committees considered promising, especially initiatives that committee members thought had potential for acquiring additional funding from other federal agencies. Loucas Christophorou's study of the breakdown of insulating gases surrounding power-transmission lines, David Novelli's amino acid research, and Elizabeth Peelle's socioeconomic analysis of power plant impacts on neighboring communities were three successful seed money projects funded in 1974.

By 1977, funding had increased to $1 million, covering startup costs for 15 proposals. The program remains in place today, and it is viewed as one of management's most successful initiatives.

What's in a Name?

To Postma's surprise, in late 1974 he found himself with a new job title. No longer head of Oak Ridge National Laboratory, he became the director of Holifield National Laboratory instead—same job, same place, different title.

Late that year, aides to the congressional committees on atomic energy and government operations memorialized their retiring chairman by renaming the Laboratory after Representative Chet



Howard Adler came to the Laboratory in 1956 and directed the Biology Division from 1969 to 1975.

Holifield of California. Done without consulting Oak Ridge community leaders or Laboratory officials, the name change met local disapproval, although Holifield was a respected friend of Oak Ridge. "I recognize the role Holifield's played," admitted Howard Adler, director of the Biology Division, "but the name ORNL has worldwide significance and recognition that can't be tossed aside lightly."

Responding to this concern, Senator Howard Baker, Representative Marilyn Lloyd, and other members of the Tennessee congressional delegation sought to restore the name Oak Ridge. In the interim, Postma and Laboratory management used Holifield National Laboratory for official government business and the familiar Oak Ridge nomenclature in scientific circles.

This conundrum ended late in 1975, when Congress reinstated the title Oak Ridge National Laboratory and named the national heavy-ion research center, a 150-foot (46-meter) tower under construction for the Laboratory's giant accelerator, the Holifield Heavy Ion Research Facility.

More challenging than the name game was the Laboratory's response to the energy crises of the 1970s. To address the fuel and heating shortages of the winter of 1974, Postma appointed Edward Witkowski and Charles Murphy as Laboratory energy coordinators. Lights were dimmed and thermostats were lowered in buildings throughout the complex, and gasoline was rationed for the Laboratory's fleet of vehicles. Taking these sacrifices in stride, Laboratory employees donned sweaters and joined carpools to get to work. In total, emergency conservation curbed Laboratory energy use 7% in 1974.

Congress responded to the energy crisis by boosting the national budget for energy research, a move that helped warm and brighten (at least symbolically) the Laboratory's cold, dim corridors. Equally important, the energy crisis fueled congressional discontent with the Atomic Energy Commission (AEC), which had already been under fire over questions about how well it was fulfilling its safety oversight responsibilities in nuclear energy.

In 1974, Congress voted to divide the AEC into two separate agencies: the Energy Research and Development Administration (ERDA), which would serve as the federal government's energy research arm, and the Nuclear Regulatory Commission (NRC), which, as the name implies, would be responsible for regulating and ensuring the safety of the nation's nuclear energy industry.

Ending 28 years of service, the AEC closed at the end of 1974. Among AEC staff locking the commission's doors for the last time was Alvin Trivelpiece, later to succeed Postma as Laboratory director.

ERDA absorbed the AEC laboratories, plus the Bureau of Mines' coal research centers, and other federal laboratories with energy-related missions. In all, it inherited 57 laboratories, research centers, and contractors—with approximately 91,000 employees. The Laboratory became one of many ERDA laboratories, although its reactor safety and environmental programs also supported NRC licensing and regulatory activities.

Because no definition of laboratory roles and their relationships to other ERDA responsibilities was in place in 1974, questions about the laboratories' organization, planning, and accounting systems arose.

The ERDA director, former Air Force Secretary Robert Seamans, formed a committee of advisors, including Herman Postma, to help plan the reorganization. Postma soon learned that ERDA would demand rapid applications of technology to improve the national energy posture. An ERDA official warned Postma and other laboratory directors: "If you are not working on energy projects having a good chance of being in the Sears and Roebuck catalog in five years, then you are working for the wrong agency."

ERDA's sense of urgency propelled the Laboratory into a broad range of energy-related research endeavors, dubbed coconuke—conservation, coal, and nuclear energy. At Oak Ridge, ERDA added fossil fuel and energy conservation programs to the Laboratory's traditional nuclear fission and fusion energy missions—an effort that fit nicely into the broad research agenda of the younger scientists.

As part of its response to the expanded mandate, the Laboratory formed an Energy Division in 1974 reporting to Murray Rosenthal, associate director for Advanced Energy Systems. Samuel Beall served as the Energy Division's first

"At Oak Ridge, ERDA added fossil fuel and energy conservation programs to the Laboratory's traditional nuclear fission and fusion energy missions."

Murray Rosenthal, associate director for Advanced Energy Systems, and ORNL Director Herman Postma.

Director Herman Postma

Born of Dutch parents in Wilmington, North Carolina, Herman Postma attended Duke University and earned graduate degrees at Harvard University. He spent the summers from 1954 to 1957 working in ORNL's Electronuclear and Physics divisions and joined the Laboratory staff in 1959, later spending time in the Netherlands as a visiting scientist at the Dutch institute for plasma physics.

"'During his 14 years as director, Postma presided over the broad expansion of ORNL's programs to cover all forms of energy."

As a scientist, he is credited with developing neutral beam injection and stochastic heating methods to heat plasmas in fusion devices and with devising solutions to plasma stability problems standing in the way of achieving fusion goals.

Only 40 years old when appointed Laboratory director in 1974, he was the first director without Manhattan Project experience. His background, moreover, was in fusion energy, not nuclear fission energy on which the Laboratory had traditionally focused. Coinciding with the creation of the Energy Research and Development Administration and the oil embargo crisis, his appointment marked a sweeping change of direction for the Laboratory.

During his 14 years as director, Postma applied professional management techniques to Laboratory administration and presided over the broad expansion of its programs to cover all forms of energy. He provided stability during the turbulent transitions from the AEC to ERDA to DOE and beyond and diversified the research through work for government agencies other than DOE. A significant push to

"He helped forge closer ties between ORNL and regional institutions."

transfer technology to American industry began during this time. He helped forge closer ties between ORNL and regional institutions, especially through the Distinguished Scientist program jointly sponsored by the Laboratory and the University of Tennessee.

Postma became a senior vice president of Martin Marietta Energy Systems in 1988 and retired in 1992.

director; he was followed a year later by Bill Fulkerson. Previously Beall had been director of the Reactor Division; his successor, Gordon Fee, is now president of Martin Marietta Energy Systems, Inc.

The new Energy Division absorbed the environmental impact reports group, the National Science Foundation environmental program, an urban research group, and non-nuclear studies from the Reactor Division under one administrative umbrella.

The Energy Division sought to tie energy research and conservation to broad questions of social and environmental impacts. For example, in 1977 David L. Greene started a transportation energy group in the Energy Division to analyze consumer responses to fuel price changes and more efficient cars on the market and to determine ways to save fuel and cut down on pollutant emissions. In effect, the Laboratory had acknowledged within its administrative framework that energy research could no longer be confined to technical issues.

Energy Conservation

Recognizing that the nation's energy posture could be improved by reducing consumption of existing energy resources and putting wasted energy to use, the Laboratory joined ERDA's national conservation program. Through many small enhancements in energy conservation, the Laboratory and ERDA expected in the aggregate to reduce national energy use by several percentage points annually.

Some conservation research emanated from the Laboratory's earlier studies of potential environmental impacts of nuclear power plants, such as the discharge of waste heat to water and air. Laboratory researchers proposed using waste heat to warm both greenhouses for growing plants and ponds for raising fish for food. As an outgrowth of Laboratory recommendations, TVA and electric power utilities planned to couple greenhouses and related heat-use facilities with nuclear power plants being designed, constructed, and operated during the 1970s.

The Laboratory proposed similar uses for waste heat, called cogeneration, for a modular integrated utility system it blueprinted for the Department of Housing and Urban Development (HUD). In this design for small communities, conducted by John Moyers and others, heat from an electric generating plant could warm buildings and supply hot water.

Using funding from HUD, ERDA, and the National Science Foundation, six Laboratory divisions, including the Energy Division, launched a comprehensive set of programs to foster energy conservation in 1974. Moreover, because of strict personnel ceilings, ERDA asked the Laboratory to act as its program manager for conservation efforts throughout the energy agency's sprawling federal network.

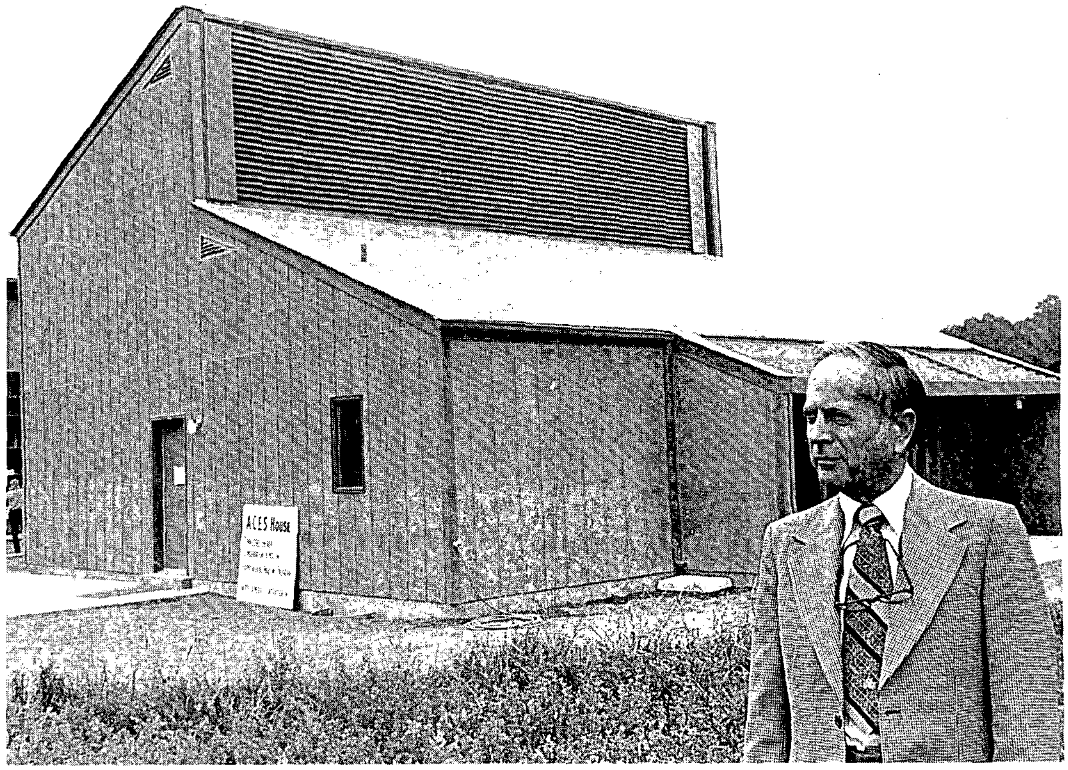
For ERDA, the Laboratory planned conservation programs, awarded subcontracts for research and engineering, and monitored and reviewed the work. Many of these responsibilities were carried out by the Laboratory's residential conservation program headed by Roger Carlsmith. The program supported studies of improved home insulation, tighter mobile home design, advanced heating and cooling systems, and energy-efficient home appliances.

ERDA asked the Laboratory to assess how much energy could be saved by better insulating homes and businesses. The Laboratory emerged as ERDA's prime resource for developing thermal insulation standards, later adopted by ERDA, the Department of Commerce, and building trade associations. These standards helped generate substantial and continuing savings for homeowners while paring national energy consumption. Retrofitting existing buildings to save energy followed when utility systems such as TVA financed improved home insulation, heat pumps, and other energy conservation measures in existing structures.

Manufactured homes promised energy savings that would likely exceed savings in more conventional structures. Laboratory studies, led by John Moyers and John Wilson, sought to determine the full range of potential savings. "Mobile homes are produced in factories," Moyers pointed out, "and should be more susceptible to quality control, unified system design, and engineering than custom-built homes."

"The Laboratory emerged as ERDA's prime resource for developing thermal insulation standards."

"ACES used a heat pump that extracted heat during winter from a large insulated tank of water, changing the water into ice for summer cooling."



Harry Fischer stands before a house built during the 1970s to test his annual cycle energy system.

The Laboratory relied on data obtained from a mobile home equipped with instruments to measure its power use and seasonal temperature fluctuations. Researchers proposed tighter insulation and storm window standards subsequently adopted by the American National Standards Institute and HUD to upgrade mobile home energy efficiency. Those who purchased new mobile homes, often recently married couples or retirees with limited incomes, enjoyed reduced energy costs, and the nation as a whole cut its energy consumption.

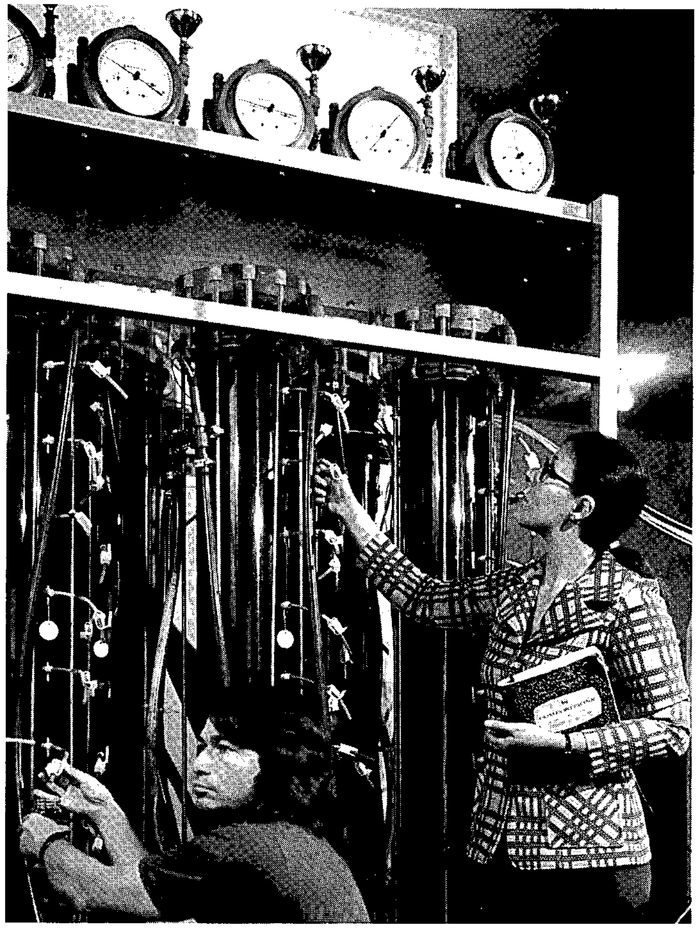
Harry Fischer's annual cycle concept may have been the most publicized Laboratory energy conservation endeavor. A retiree with wide experience in energy engineering, Fischer dropped by the Laboratory in 1974 to tell Samuel Beall, new director of the Energy Division, that he knew how to provide home heating and cooling at half the cost of systems then in use. His annual cycle energy system (ACES) used a heat pump that extracted heat during winter from a large insulated tank of water, changing the water into ice for summer cooling.

A working model for the ACES house was built and operated in two months, using funding from ERDA. Fischer met John Gibbons of the University of Tennessee Energy, Environment, and Resources Center, who was overseeing the university-sponsored construction of experimental houses using solar and conventional heat near Knoxville. Gibbons, a former ORNL physicist who later became director of the Office of Technology Assessment and is now President Bill Clinton's science adviser, offered university land for construction of two ERDA-funded homes, including one heated and cooled by ACES. Jointly managed by the university, the Laboratory, TVA, and ERDA, the houses were completed in a year. ERDA Director Seamans personally inspected them to highlight the fast response to government demand.

As Fischer predicted, the ACES house could be heated and cooled at half the energy costs of conventional systems. However, few ever adopted Fischer's system, largely because of its high initial cost and potential maintenance problems.

ORNL researchers also investigated ways to reduce energy use by industry. Ralph Donnelly, Victor Tennery, and colleagues undertook a study that, in 1976, reported that improved insulation was crucial to improving the efficiency of industrial processes.

Another Laboratory conservation project that received broad media attention was its bioconversion experiment, called ANFLOW. In 1972, Congress mandated secondary sewage treatment for all communities. The Laboratory estimated the new systems would double the energy used for sewage treatment, so it decided to explore technologies that might reduce energy consumption and costs. Alicia Compere and William Griffith, both of the Chemical Technology Division, working with John Googin, a Lawrence Award winner at the Y-12 Plant, devised a bioreactor, known as ANFLOW, to explore its energy-saving possibilities in treating sewage.



Bill Griffith and Alicia Compere examine the anaerobic biological reactor called ANFLOW, tested at the Laboratory during the 1970s.

Conventionally activated sludge sewage treatment used oxygen-seeking aerobic bacteria to digest wastes. In contrast, the ANFLOW system used anaerobic microorganisms that did not require oxygen. This process eliminated the need for energy-consuming pump aerators. Moreover, the ANFLOW system could produce methane gas from sewage for use as heating fuel and recover valuable chemicals from industrial wastes for reuse.

On its own, the Laboratory built an experimental ANFLOW bioreactor, and in 1976 it contracted with the Norton Company to build a pilot ANFLOW bioreactor to be installed at an Oak Ridge municipal sewage treatment plant. The ANFLOW bioreactor pumped sewage through a 15-foot (5-meter) cylinder packed with gelatin-coated particles to which microorganisms attached themselves. The packing, made of crushed stone or ceramics, facilitated the waste flows and provided additional surfaces for the micro-organisms, which thrived and reproduced while consuming wastes.

Skyjack '72

On the morning of Veteran's Day in November 1972, a commercial DC-9 circled over Oak Ridge amid threats that it would be deliberately crashed into the Laboratory or perhaps the Y-12 or K-25 plants. Three men wanted on criminal charges, holding hand grenades with the pins pulled, took over the plane carrying 27 passengers and 4 crew members. If their demands for a $10 million ransom and parachutes were not met, they threatened to crash the aircraft into an AEC facility.

Although few personnel were at the Oak Ridge facilities because of the holiday, the AEC closed the facilities, shut down the reactors, and evacuated personnel except for security forces. After circling Oak Ridge for two tense hours, the plane flew to Lexington for refueling. In less than an hour, it was back over Oak Ridge, with the skyjackers again threatening to crash the plane into the facilities if their payoff demands were not met by 1:00 p.m. that day. Ground investigators, in the meantime, learned that the criminals were from Oak Ridge, Knoxville, and Detroit and were prison escapees and bail jumpers.

After lengthy negotiations by radio, the criminals landed the plane at Chattanooga, where they received part of the cash ransom and left the area headed south. At another refueling stop near Orlando, Florida, waiting FBI sharpshooters shot out the plane's tires in an attempt to prevent its takeoff. The criminals, however, shot the co-pilot and forced the pilot to get the plane airborne. The skyjackers ordered the plane to Cuba, where the pilot made a safe landing, even without tires. There, the skyjackers entered the waiting arms of Communist soldiers. After their return to the United States, the exhausted passengers commented that the highlight of their trip was watching Cuban soldiers take the ransom money from the criminals and march them away under guard.

As the drama unfolded aboard the airplane, the Laboratory and Oak Ridge facilities reopened at 3:00 p.m. that day. The incident, in fact, caused little stir in the Oak Ridge community because both a National Guard airlift to Fort Campbell and a mock Civil Defense disaster drill had been planned and were under way in the town on that holiday. Two days following the incident, the Laboratory restored its nuclear reactors to full operation.

This incident at Oak Ridge was one of the most frightening of more than 150 skyjacking attempts made during the early 1970s, prompting the intense airport security screening instituted in the following years.

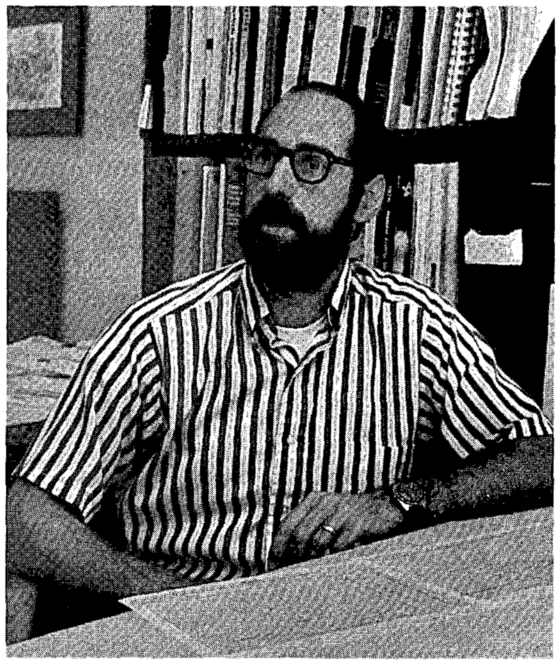
Richard Genung, Charles Hancher, and Wesley Shumate, all of the Chemical Technology Division, managed the ANFLOW program, and in 1978, a subcontract was awarded for design of a larger demonstration plant, which was installed as part of the Knoxville sewage treatment system.

Research on use of organisms to treat waste efficiently, however, has proceeded slowly. Moreover, municipalities seldom build new sewage treatment plants; they are capital-intensive, time-consuming projects that may require a decade or more to negotiate and construct. Therefore, energy savings derived from more efficient sewage treatment would be a long time coming. Despite these obstacles, work on ANFLOW has encouraged broader Laboratory investigations into potential biological solutions to waste disposal problems.

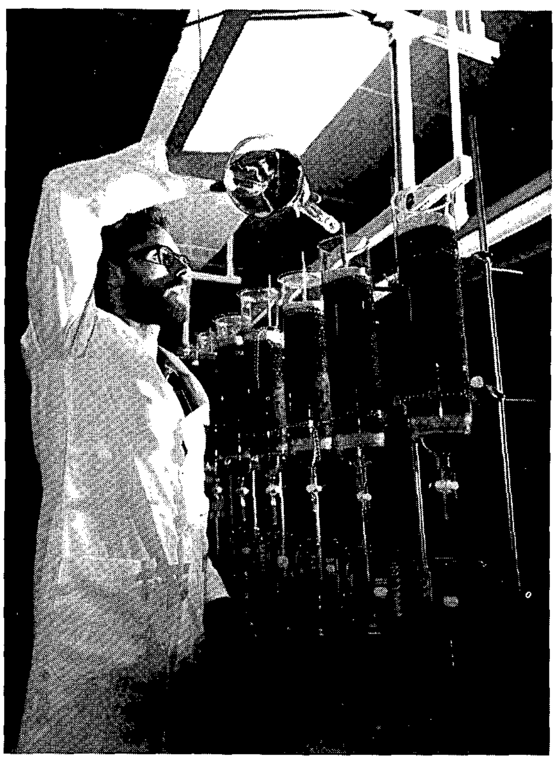
In contrast to long-lived sewage systems, homeowners replace several electric appliances each decade. Believing that aggregate energy savings could be substantial, Laboratory researchers launched detailed studies of ways to improve the efficiency of heat pumps, refrigerators, furnaces, water heaters, and ovens.

Eric Hirst, Robert Hoskins, and their colleagues in the Energy Division gained wide acclaim for computer modeling of home appliances to identify opportunities for greater energy efficiency. Their computer analysis of refrigerator designs, for example, indicated that energy use for these appliances could be halved through installing better insulation, adding an antisweat heater switch, improving compressor efficiency, and increasing condenser and evaporator surface areas.

Laboratory energy-saving recommendations for home appliances were incorporated into the design standards of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers and also into experimental appliances designed by subcontractors under the management of Virgil Haynes at the Laboratory. Out of this applied research came more efficient appliances, notably a heat-pump water heater and refrigerator, that were soon manufactured for commercial markets. By the 1980s, most American homes had at least one appliance that was more energy efficient as a result of the Laboratory's conservation research.



Eric Hirst's work led to more efficient appliances.



Henry Wilson studies contaminants produced in coal conversion processes.

Fossil Energy

With nearly half of the world's known coal reserves, the United States has been called the "Saudi Arabia of coal." In the face of dwindling domestic petroleum supplies, scarce natural gas reserves, and the uncertainty and escalating price of oil imports, it seemed logical in the 1970s to supplement petroleum with fuels produced from coal.

Scientists had long known that applying heat and pressure to coal could produce liquids, gases, and solids for fuel. Efforts to turn scientific theories and blueprints into commercial ventures, however, had been minimal. Then, in 1975, ERDA announced that the United States planned to produce a million barrels of synthetic oil from coal daily by 1985. To create that much synthetic fuel would require as many as 20 plants, so ERDA contracted with industry to plan and design a series of pilot plants and demonstrations. ERDA's Oak Ridge Operations Office managed the contracts and obtained research support from the Laboratory.

In response to this major federal initiative, Murray Rosenthal announced an interagency agreement with the Office of Coal Research that brought the Laboratory into fossil energy research. This agreement culminated in the Coal Technology Program headed by Jere Nichols, later renamed the Fossil Energy Program under Eugene McNeese, and budgeted at $20 million annually. It included fundamental studies of the structure of coal, the carcinogenic properties of coal conversion products, a hydrocarbon reactor, and a potassium boiler to improve the efficiency of producing electricity by burning fossil fuels. Under this program, the Laboratory exchanged personnel and collaborated with the Bureau of Mines' coal laboratories at Bruceton, Pennsylvania; Morgantown, West Virginia; and Laramie, Wyoming.

Planning to fund industrial pilot and demonstration plants that used synthetic refined coal and hydrocarbonization processes, ERDA assigned the Laboratory a major role in evaluating the progress of this broad-ranging initiative. For one project, Henry Cochran and colleagues in the Chemistry and Chemical Technology divisions built a model hydrocarbon reactor that mixed finely ground coal with hydrogen under high pressure and heat to form synthetic oil, plus a substitute for natural gas and a coke-like solid fuel. Modeling experiments identified the optimal combination of pressure and heat for fuel production. Related projects conducted by Richard Genung, John Mrochek, and their colleagues included studies of coal thermal conductivity and recovery of aluminum and minerals from fly ash.

"The Laboratory... looked for ways to reduce sulfur dioxide air pollution from coal combustion."

A bioprocessing group, led by Charles Scott of the Chemical Technology Division, launched a series of studies of bioreactors. The dual goal was to concentrate and isolate trace metals and to produce liquid and gaseous fuels organically. In bioreactors resembling those in the ANFLOW sewage treatment project, microorganisms adhering to fluidized particles in columns could digest toxic compounds from the wastes of coal conversion processes, converting them to harmless substances.

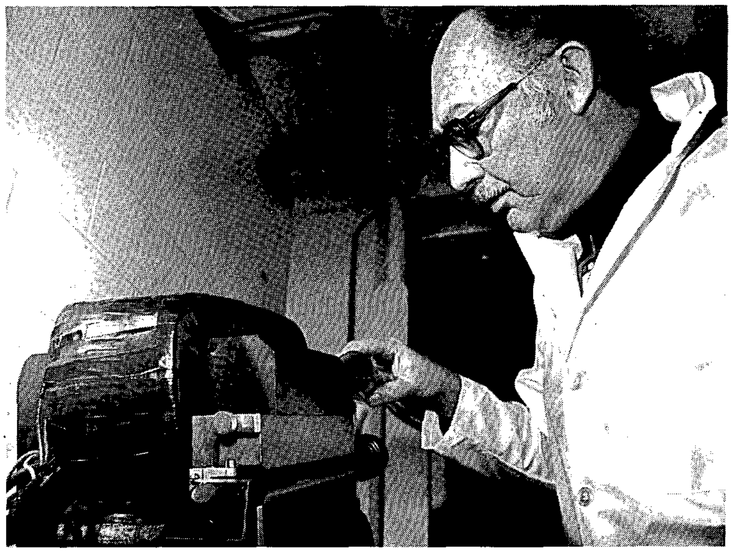
Researcher Chet Francis in the Environmental Sciences Division demonstrated that simple garden soil bacteria in bioreactors could remove nitrates and trace metals from industrial wastes effluents. As a result, the Laboratory built a pilot bioreactor used by the Portsmouth, Ohio, gaseous diffusion plant to treat nitrate wastes, and the Y-12 Plant used Francis's design for a full-scale plant to treat nitric acid wastes.

The Laboratory also looked for ways to reduce sulfur dioxide air pollution from coal combustion. In the Engineering Technology Division, John Jones's team developed a fluidized-bed coal reactor connected with a closed-cycle gas turbine for power generation. Aiming to make high-sulfur Appalachian coal more environmentally acceptable, the system fed coal and limestone particles into a furnace where jets of preheated air agitated them, igniting the coal and thus providing the heat needed to combine the limestone with sulfur dioxide to form harmless gypsum. ERDA sponsored construction at the Y-12 Plant of a prototype to prove that Appalachian coal could be burned cleanly during power generation.

Eugene Hise and Alan Holman devised another method of removing sulfur from coal. Because sulfur-bearing iron pyrites and ash-forming minerals are weakly attracted by magnetic fields and coal particles are mildly repelled, they devised a system for magnetically cleaning coal, using a superconducting solenoid to provide a magnetic field of the required shape and force.

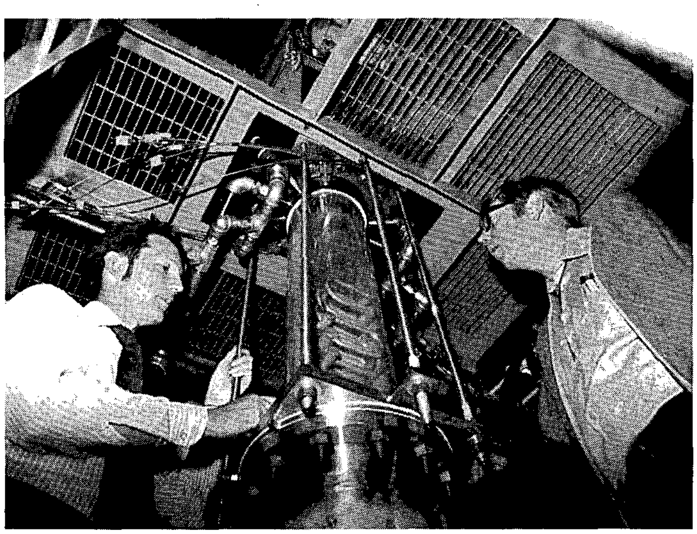
ORNL researchers responded to the need to make components that could withstand the high temperatures of synthetic fuel plants. In 1983 C. T. Liu and his associates in the Metals and Ceramics Division began developing a scientific approach to the design of intermetallic alloys for high-temperature structural uses in advanced heat engines and coal conversion systems. The group developed ductile nickel aluminide alloys that become stronger as temperature increases. The development has been licensed to six companies and is being used in at least two cooperative research and development agreements (CRADAs).

In another coal-related research initiative, the National Science Foundation (NSF) funded a regional evaluation of the economics of strip mine reclamation in Appalachia. Robert Honea and Richard Durfee headed a team in 1975 that used satellite imagery, census data, and regional-scale models to analyze strip mining. Focusing on mining in the New River basin north of Oak Ridge, the study took images from space satellites to classify land cover types, which were then verified with aerial photographs. Researchers could examine strip-mining effects during every overhead pass of the satellite, enabling them to obtain a better picture as the mining unfolded instead of just a snapshot of the impacts once the mining was completed.



Eugene Hise pours crushed coal into a magnetic separator designed to remove contaminants from pulverized coal.

In 1975, ERDA Director Seamans broke ground for an Environmental Sciences Laboratory in Oak Ridge, a two-unit structure that became the first programmatic laboratory in ERDA. It was completed in 1978. The Laboratory's first major laboratory and office expansion since the 1960s, Environmental Sciences was located at the west end of the complex near the Aquatic Ecology Laboratory. The main building was connected by walkways to greenhouses, animal and insect facilities, and chambers for controlled environment experiments.



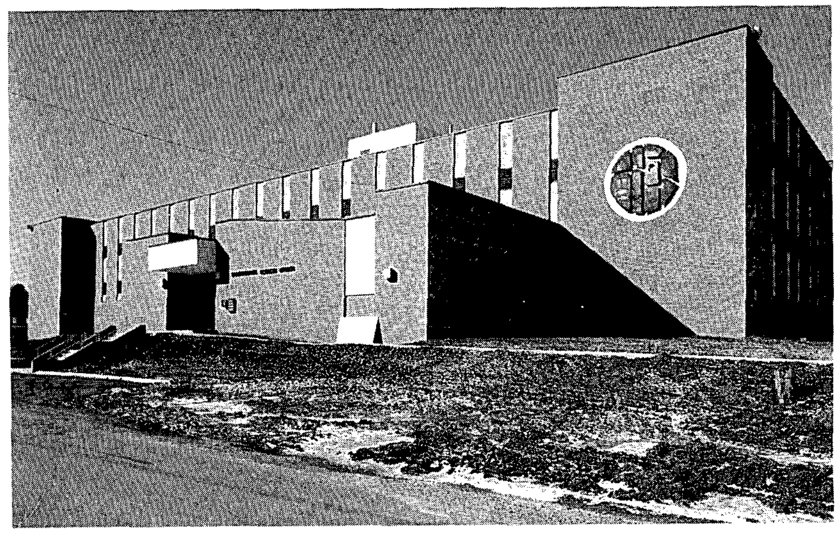
Robert Holcomb and John Jones examine a fluidized bed for coal combustion developed at the Laboratory.

In 1976 Chester Richmond, who succeeded James Liverman and John Totter as the associate director for Biomedical and Environmental Sciences, implemented a life sciences program to support coal conversion technologies. Working closely with the Environmental Protection Agency, the program, led by ecologist Carl Gehrs of the Environmental Sciences Division, examined the chemical and physical characteristics of coal liquids, their biological and health effects, and their transport through ecosystems.

From this program came funding for examining mutagenesis (in the Biology Division), ecological toxicology (in the Environmental Sciences Division), health risk effects (in the Health and Safety Research Division), and coal-liquid constituent identification (in the Analytical Chemistry Division).

For example, in the early 1980s Barbara Walton discovered that cricket eggs exposed to chemicals from synthetic fuels produced insects having abnormalities such as an extra eye, antenna, or head; the discovery received considerable media attention.

These efforts enabled the Laboratory to prove that coal conversion liquids and effluents could be toxic. It also provided information to guide changes in coal chemical processing that would create less toxic products.



Environmental Sciences Division building opened in 1978 at ORNL's west end.

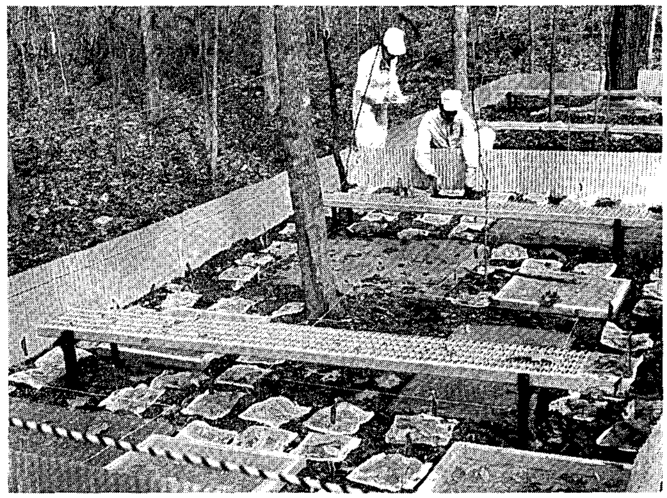
Barbara Walton examines an abnormal cricket from an egg that had been exposed to coal-derived chemicals.

Fusion and Fission Energy

Under ERDA, Laboratory fusion energy research expanded more rapidly than fission research. Although fusion research could not enhance the nation's short-range energy posture, ERDA gave the program substantial support in the hope that it would ultimately provide a long-range solution to the nation's energy problems. With the end of molten-salt reactor research and modest support for high-temperature gas-cooled reactor research, the research agenda of the Laboratory's Manhattan-era researchers had been reduced to the Clinch River Breeder Reactor technology and related fuel reprocessing for plutonium recovery.

Under John Clarke, Postma's successor as chief of fusion energy research, successful testing of the ORMAK and ELMO Bumpy Torus devices continued into the 1970s. The Laboratory also built ISXs—devices called Impurity Study Experiments—to illuminate the behavior of impurities inside fusion reactor plasmas. Researchers, led by Stan Milora and Chris Foster, developed a pellet injection method for firing frozen hydrogen pellets into fusion plasmas to maintain the plasma densities. This refueling technology was subsequently adopted for tokamaks in Europe and the United States.

International fusion research involved many countries, DOE facilities, and Laboratory divisions. A major fusion research problem during the late 1970s was the action of the fusion plasma when it escaped the magnetic field and met the first wall of the vessel containing it. Would it damage the wall? Would it sputter impurities from the wall back into the plasma and "poison" it by radiating away the energy needed to sustain the fusion reaction?



Gladys Dodson and Marvin Shanks check leaf decomposition and isotope release as part of a field ecology study.

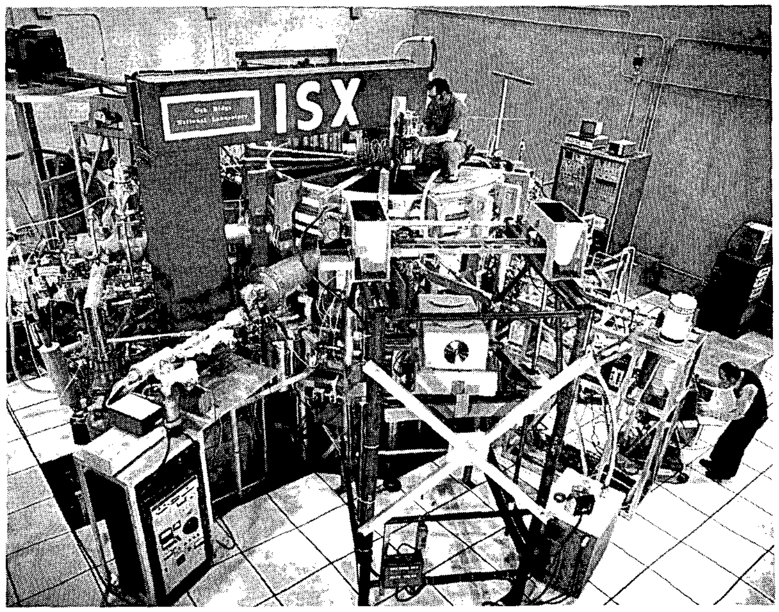
To coordinate studies of these and related questions, the Laboratory joined with four other DOE laboratories in a "first wall interactions" group. Bill Appleton and Jim Roberto, both of the Solid State Division, Bob Clausing of the Metals and Ceramics Division, and Bob Langley and Peter Mioduszewski, both of the Fusion Energy Division coordinated "first wall interactions" studies at the Laboratory.

Other fusion research advances during the ERDA years included the neutral beam technology developed by Bill Morgan's team to heat plasma inside a fusion device. The neutral beam technology helped Oak Ridge's ORMAK and Princeton's tokamak achieve record temperatures that approached what was needed for self-sustaining fusion reactions. Investigations of huge superconducting magnets for containing fusion plasmas began under Hugh Long, Martin Lubell, Fred Walstrom, and William Fietz, leading to selection of the Laboratory in 1977 to build the international Large Coil Test Facility. Managed by Paul Haubenreich, this facility would test supercold magnets, weighing 40 tons each, that were manufactured both in the United States and abroad.

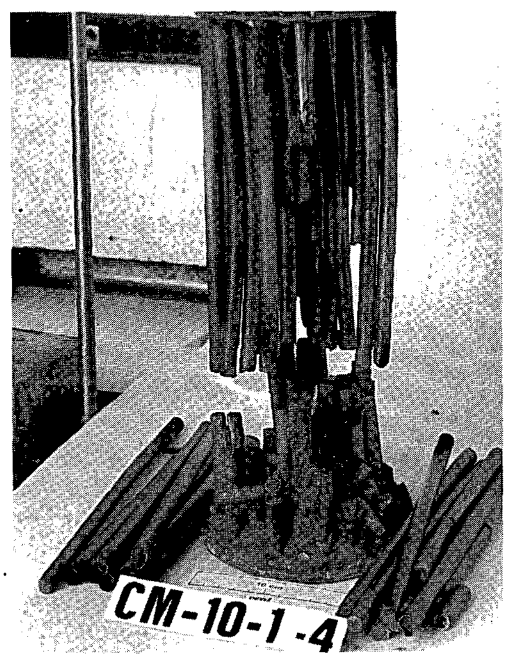
The fusion program also needed large amounts of specialized atomic cross-section data to understand complex plasma interactions. This need was met by a nationally coordinated program started in the Physics Division in 1956 by Clarence

Ernest Bondietti and Roger Dahlman work in the transuranics garden to study the activity of actinides in the environment.

"The neutral beam technology helped Oak Ridge's ORMAK and Princeton's tokamak achieve record temperatures that approached what was needed for self-sustaining fusion reactions."



The Impurity Study Experiments (ISXs) were a focus of Laboratory fusion energy studies of the 1970s.



Nuclear safety experiments at the Laboratory during the 1970s and 1980s included heating bundles of reactor core rods until they melted.

(Barny) Barnett, who ran the program until the late 1980s.

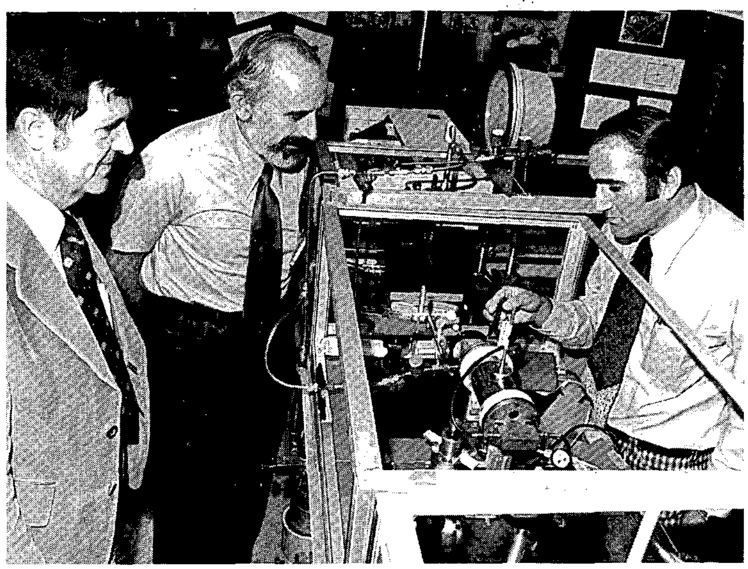
While fusion energy research prospered, the Laboratory built no new nuclear fission reactors during the 1970s. In 1976, the Laboratory changed the name of the Reactor Division to the Engineering Technology Division because its work no longer concerned overall reactor design; instead, it focused on development of engineering systems for both nuclear and non-nuclear facilities. The nuclear safety program for the NRC continued, however, under Fred Mynatt's direction.

After 1976, the Laboratory's nuclear energy research focused largely on the Clinch River Breeder Reactor Project and plans to reprocess its fuel. Design of the steam generator and heat exchangers for the Clinch River reactor was undertaken by Laboratory metallurgists led by Peter Patriarca, who investigated thermal stress and creep in the materials to be used in these systems.

The Laboratory also specialized in devising materials for breeder and fusion reactors that would withstand radiation damage. Jim Weir developed a theory to explain how heated steels swelled and became embrittled during neutron bombardment in reactors, and researchers Jim Stiegler, Everett Bloom, and Arthur Rowcliffe developed low-swelling stainless steel alloys by doping them with silicon and titanium. Despite these advances, support for Clinch River breeder programs faltered after the election of President Jimmy Carter, who opposed the project.

The Carter administration also expressed concern over the possibility of diversion of weapons-grade nuclear materials used in civilian programs to military or terrorist purposes. The Nonproliferation Alternative Systems Assessment Program was initiated to evaluate the problem, which received much attention by DOE. A companion program of broader scope called the International Nuclear Fuel

Cycle Evaluation also was formed by several nations led by the International Atomic Energy Agency at a 1977 meeting in Washington, D.C. The Laboratory had a significant role in both programs, with William Harms as the major participant. These programs focused on potential problems in nuclear fuel-cycle programs and contributed to a decrease in emphasis on breeder reactors. Both programs were unpopular at the time. However, their influence on the direction of the Laboratory's fuel reprocessing program resulted in both improved design concepts and better technology, including the development of robotic systems for use in hazardous operations.

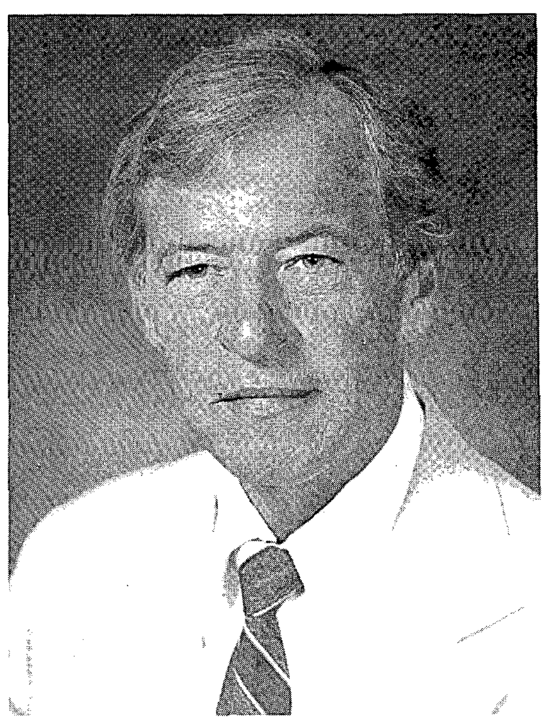


In 1977, Samuel Hurst, Jack Young, and Munir Nayfeh used lasers to detect single atoms of cesium.

Space exploration also received some nuclear energy research funding during the 1970s. The Laboratory designed radioisotopic heat sources to power long-distance space probes and designed materials to contain the heat within the space vehicles and protect the plutonium fuel from the impact of accidentally falling to Earth. Tony Schaffhauser, C. T. Liu, and Roy Cooper, for example, led teams in the Metals and Ceramics Division that developed the iridium cladding and carbon fiber insulation to contain the isotopic heat sources used aboard the *Voyager* and other space probes. Years after their launch, these probes returned spectacular images of the outer planets and their moons to Earth for scientific analysis.

Splendid Crowding

The years of urgent energy research under ERDA were years of expansion for the Laboratory. By 1977, it had acquired lead responsibility for five major ERDA programs and had become involved with the full complement of the nation's energy programs. In addition, it had undertaken work for 11 other agencies, amounting to $35 million in funding annually, and it was subcontracting six times the



James Weir, director of the Metals and Ceramics Division, received an E.O. Lawrence Award for alloy studies.

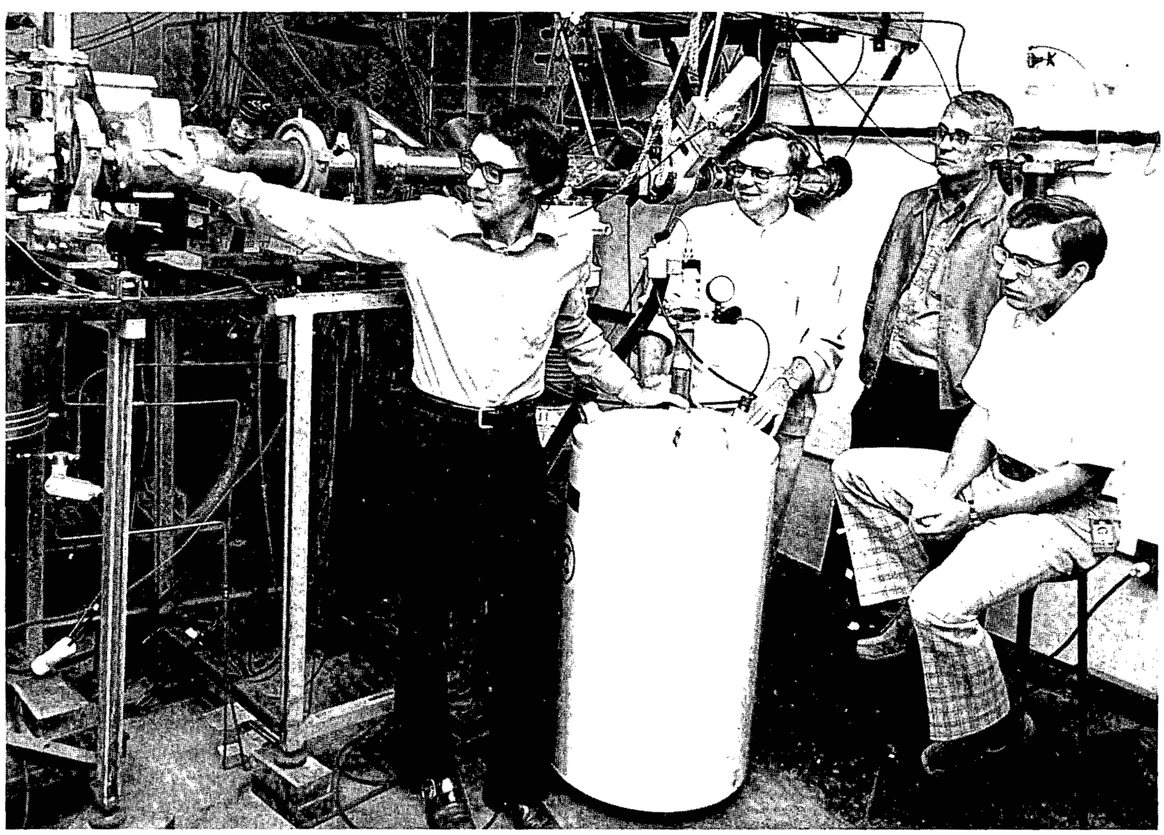
"The Laboratory designed radioisotopic heat sources to power long-distance space probes and designed materials to contain the heat."

amount of outside work it had supported in 1974. The number of Laboratory personnel rose to more than 5000, performing and supporting about 700 scientific and technical projects. The Laboratory also hosted 1250 guest researchers and more than 25,000 visitors annually.

Emphasis by ERDA on developing non-nuclear advanced energy systems proved a boon for materials sciences at the Laboratory. Limited previously to studies of materials related to the fission and fusion energy programs, under ERDA the Laboratory's research in materials sciences advanced into studies of many materials. This new initiative was especially pertinent to the Solid State Division under Mike Wilkinson and the Metals and Ceramics Division under Jim Weir, which experienced significant program expansions.

Although the Environmental Sciences Laboratory and the Holifield Heavy Ion Research Facility were under construction in 1977, the Laboratory had not added significant space to its complex since the 1960s. Existing work space was reduced even more by addition of minicomputers and copying machines during the 1970s. The stereotype of scientists musing in splendid isolation was far from true at the Laboratory in 1977. In fact, conducting research there had become a close-quartered affair.

"The fact is that programs grow faster than buildings can get built or than money can be found for that purpose," lamented Postma. "In practice, the only justification for new buildings is to alleviate crowded conditions that already exist rather than rationally anticipating projected needs," he elaborated. "Thus, in the future there



Developers of low-swelling stainless steels are Arthur Rowcliffe, Jim Stiegler, Jim Leitnaker, and Everett Bloom.

Nuclear Fuel Reprocessing

As the pilot plant for plutonium separation, the Laboratory took the lead in processing nuclear fuel during World War II. Design and operation of its separations building, adjacent to the Graphite Reactor, provided a prototype for the concrete "canyons" built at Hanford, Washington.

After the war, plans called for constructing a plant that would use the wartime precipitation methods to process fuel from the Materials Testing Reactor. John Swartout of the Chemistry Division and Frank Steahly of the Chemical Technology Division insisted, however, that the solvent-extraction method was more efficient and less costly than the precipitation method for recovering uranium and plutonium from spent fuel. As a result, the "25 solvent-extraction process" was adopted and used in the plant built in Idaho.

During the following decades, Laboratory teams headed by Floyd Culler, Frank Bruce, Raymond Wymer, William Unger, and others set the pace in the design and piloting of nuclear fuel reprocessing plants. Their designs became the basis for immense processing plants built at Hanford; Savannah River, South Carolina; and elsewhere throughout the world. Although their plans to recover plutonium from the Clinch River Breeder Reactor were suspended along with the reactor itself, the technology Laboratory researchers developed proved useful in the 1990s when the Laboratory cooperated with Japanese scientists in design of breeder reactor processing plants.

This technology, developed by the Fuel Recycle Division under William Burch, included remotely controlled "servomanipulators" for work in environments too hazardous for humans. The division's growing expertise in remote handling technology led to its change in name to the Robotics and Process Systems Division.

will be more crowding at the Laboratory, more sharing of offices, and far greater need for understanding and cooperation by all members of the Laboratory."

The problem of overcrowding decreased unexpectedly in 1977 when newly elected President Jimmy Carter and his Department of Energy adopted personnel ceilings that capped the number of Laboratory employees. After four years of nearly nonstop additional hiring, the Laboratory's personnel offices suddenly became tranquil and quiet.

President Carter walked to the White House in January 1977 in the midst of one of the 20th century's coldest winters. At the time, the effects of the 1973 oil crisis still rippled through the national economy. Unprecedented cold temperatures generated unanticipated demands for energy supplies, placing additional stress on a national energy system that had not fully adjusted to the new constraints on energy consumption. The result was another energy crisis, although not nearly as severe as the paralyzing events that had gripped the nation four years before. Nevertheless, during the oil and natural gas shortage, the Laboratory narrowly avoided a complete shutdown for lack of heat only because the Oak Ridge Gaseous Diffusion Plant shared its oil reserves during the emergency.

Calling for the "moral equivalent of war" on energy problems, President Carter in the spring of 1977 requested public sacrifices for the sake of regaining control of the nation's energy future. To manage the battle, he proposed establishing a cabinet-level Department of Energy (DOE). Approved by Congress in August 1977, the new

President Carter and Secretary of Energy James Schlesinger participate in a 1978 discussion at ORNL.

DOE absorbed the functions of the ERDA, the Federal Energy Administration, and the Federal Power Commission, plus energy programs from other federal agencies.

Carter appointed James Schlesinger, former AEC chairman and Secretary of Defense, the nation's first energy secretary. In addition, the president announced his opposition to the Clinch River Breeder Reactor Project and stopped the reprocessing of nuclear fuel. These decisions clouded the future of nuclear energy, which, in turn, placed the future of the Laboratory's nuclear divisions on an uncertain path with no clear signposts pointing the way to the future.

Stability amid Transition

The transition from ERDA to DOE proved difficult. The ERDA administrator and assistant administrators resigned before DOE became functional in October 1977, leaving agency program direction unclear. "Whereas we perceive uncertainty and lack of clear direction in Washington, the realities at the Laboratory are quite different," observed Alex Zucker during this transition. "Our programs are productive, our staff is busy. Stability rather than uncertainty characterizes our work; and, if we work now in new areas, we are doing it with the old elan."

Secretary Schlesinger revised the system for managing DOE's eight multiprogram laboratories, 32 specialized laboratories, and 16 nuclear materials and weapons laboratories. For their institutional needs, the laboratories were to report to assistant secretaries in Washington instead of regional operations officers. Invited to Washington to advise Schlesinger on basic research needs, Postma declared that integrating energy development into a single department at last recognized that energy was as important as labor, agriculture, and defense. "There will be studies galore to evaluate everything," Postma predicted. He was confident that the Laboratory would prosper despite the "turbulence represented by the changing political and programmatic winds in Washington."

During 1978 the transition to DOE was completed. Believing that national laboratories had reached optimum size, the Carter administration sought to work more directly with industry, expanding the role of national laboratories as program and subcontract managers. It designated national laboratories as centers of excellence in special fields and imposed ceilings on the number of personnel. Oak Ridge was made the lead laboratory for coal technology and fuel reprocessing, and the Laboratory was told that its staff could not exceed 5165 personnel for 1979.

The Carter administration proved more interested in energy conservation and "soft" energy than in nuclear energy. Taking its cues from Washington, the Laboratory began to emphasize small programs in geothermal and solar energy initiated under ERDA. The Environmental Sciences Division also initiated intensive study of wood and herbaceous biomass—fast-growing trees and grasses that could be converted to a renewable energy resource.

John Michel managed the Laboratory's research on geothermal energy using hot water and steam formed within the earth. This included research in the Chemistry Division on scaling and brine chemistry, in the Metals and Ceramics Division on corrosion, and in the Engineering Technology and Energy divisions on cold-vapor, low-temperature heat cycles. The collective goal of this technical research was to upgrade the efficiency of producing electricity with geothermal energy. A related research program studied ways to improve heat exchangers to capture the oceans' thermal energy. Rather than burning the rocks and burning the seas with nuclear energy—a dream of the 1960s—this research sought to extract low-level energy from the earth and ocean in kinder and gentler ways.

The Laboratory's solar energy research was circumscribed by formation of a special DOE laboratory, the Solar Energy Research Institute in Colorado (now called the National Renewable Energy Laboratory). Robert Pearlstein became coordinator of Oak Ridge's small solar program, which included fruitful research in the three Laboratory divisions. Eli Greenbaum and associates in the Chemistry and Chemical Technology divisions investigated the production of hydrogen from water by using green plant materials to capture and convert the sun's energy catalytically, while the Solid State Division program, directed by Richard Wood, investigated improved photovoltaic solar cells for converting sunlight directly into power.

Funded initially as a seed money project, John Cleland's team in the Solid State Division developed a new method of doping silicon to produce the semiconductors used in solar cells. Instead of using chemical doping methods, a silicon isotope in samples inserted in the Bulk Shielding Reactor was transmuted into phosphorus through interactions with neutrons. This process provided uniform distribution of phosphorus in the silicon, thereby improving the efficiency of solar cells fabricated from this material.

In a related development, the Solid State Division in 1978 used lasers to prepare silicon for solar cell fabrication. To provide good distribution within the silicon, ions of a dopant such as boron were deposited on a silicon surface or implanted among the atoms at the surface using an ion accelerator. Lasers were used for diffusing the boron throughout the silicon and for removing crystal imperfections introduced in the implantation process. This combination of ion implantation doping and laser annealing, which was initiated primarily by Rosa Young and C. W. (Woody) White, spurred fundamental and applied studies in processing solids. The Surface Modification and Characterization Research Center, started by Bill Appleton and later headed by White and David Poker, became the focal point for these studies. Housed initially in the old fanhouse of the Graphite Reactor, the center became a DOE user facility that hosts many university and industry collaborators.

"The Solid State Division in 1978 used lasers to prepare silicon for solar cell fabrication."

Almost a Mecca

To observe firsthand the Laboratory's research achievements and to soothe the Laboratory's ill feelings generated by his decision to oppose the Clinch River Breeder Reactor Project, President Carter visited Oak Ridge in May 1978 at the

The Carter Visit

On May 22, 1978, President Jimmy Carter visited the Laboratory and other Oak Ridge facilities. He was accompanied by Department of Energy Secretary James Schlesinger, Presidential science advisor Frank Press, DOE Research Director John Deutch, and Tennessee Senator James Sasser. His visit attracted many members of the local and national press, including Sam Donaldson of ABC news.

President Carter arrived at the Laboratory in a limousine about noon and walked to a packed Central Auditorium in Building 4500-North. There he sat at a table with managers and researchers for a roundtable discussion. He spoke briefly, and Director Herman Postma introduced researchers selected because their research was thought to be of interest to the president.

Laboratory staff members had mixed feelings about the president. Many were excited about his arrival because he was the first U.S. president to visit the Laboratory while in office. Many were proud because this former governor of Georgia was the first president from the Southeast and because he had worked on a Navy submarine as a nuclear engineer under the supervision of Admiral Hyman Rickover. But many staff members who had long supported nuclear power disagreed with Carter's opposition to the development of breeder reactors. His stance was based on his concern that the plutonium produced in such devices might be diverted by terrorists and outlaw nations to make bombs.

At the roundtable discussion, President Carter told employees, "I think the success that we will strive to achieve in the energy field is heavily on your shoulders." He also spoke of the unsolved problems of safe disposal of nuclear waste and proper storage and use of spent nuclear fuel.

President Carter then listened to the Laboratory researchers at the roundtable: Bob Honea and Patricia Rice, on use of computers to study potential impacts of the president's proposed National Energy Plan; Henry Inouye, on development of alloys that grow stronger as temperatures increase; Pete Lotts, on design of nuclear fuel elements and cycles to prevent diversion of fissionable materials; Sandy McLaughlin, on effects of air pollution on vegetation; Liane Russell, on genetic effects on mice of synthetic fuel compounds derived from coal; and Lee Berry, on magnetic fusion research, including the Laboratory's work in plasma heating and plans for an international test of six superconducting magnetic coils.

President Jimmy Carter (center), with U.S. Representative Albert Gore, Jr. (second from right) donned hardhats for a briefing on Laboratory activities.

The president expressed particular interest in Berry's talk and asked him several questions including, "Is there any limiting characteristic of fusion that causes you the most concern?" Berry replied that his only concern was whether the engineered fusion systems of the future could be integrated to produce power. "We can make a reactor," Berry said, searching for an analogy. "But the question is, will it fly? I mean, will it go under water and come up again?" The audience, and presumably the president, laughed.

After the discussion, the president was escorted to the East Lobby of Building 4500-North, where he was shown several exhibits. He heard about the development of fluidized-bed coal burners (from John Jones); tertiary recovery of oil (from Alicia Compere); use of bioreactors to degrade hazardous substances and produce desired chemicals (from Chuck Scott); and detection of single atoms of target elements using lasers (from Sam Hurst).

How did the researchers feel about the President after his visit? According to *The Oak Ridger*, the researchers were impressed by "the keenness of the President's mind, the perceptiveness of his questions, and the sincerity of his interest in what other scientists were saying." Such a rare dialogue between scientists and a U.S. president will remain a highlight of Laboratory history.

request of Senator James Sasser. The president brought his science advisor and energy staff with him. Remembering his service as an officer in Admiral Rickover's nuclear navy, Carter declared, "Oak Ridge was almost like Mecca for us because this is where the basic work was done that, first of all, contributed to the freedom of the world and ended the war and, secondly, shifted very rapidly to peaceful use of nuclear power."

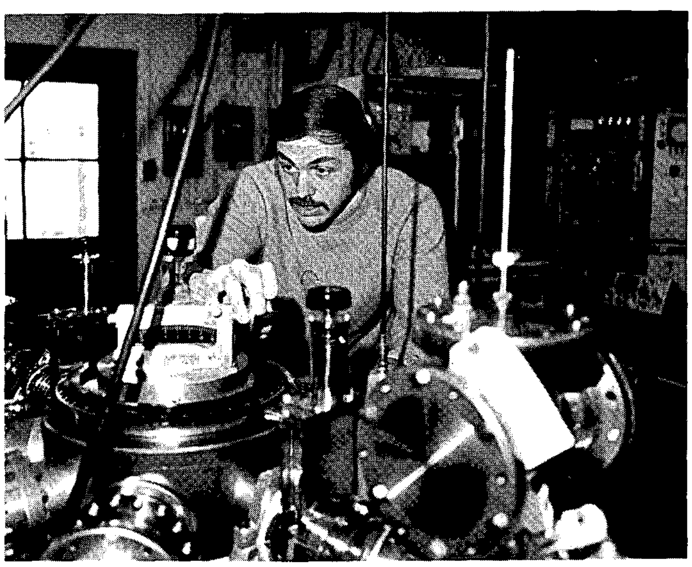
Richard Wood, Rosa Young, and Jagdish Narayan test the efficiency of solar cells made at the Laboratory using laser technology.

The first president to visit the Laboratory while in office, Carter enjoyed technical presentations and a roundtable discussion with a group of scientists in the auditorium of building 4500-North. There, the president seemed particularly interested in Lee Berry's description of fusion research, asking how it compared with Soviet research. Berry responded that the United States may have enjoyed a slight lead in the fusion race. Sandy McLaughlin appealed to the president's environmental interests by describing Laboratory research on the ecological effects of atmospheric pollutants.

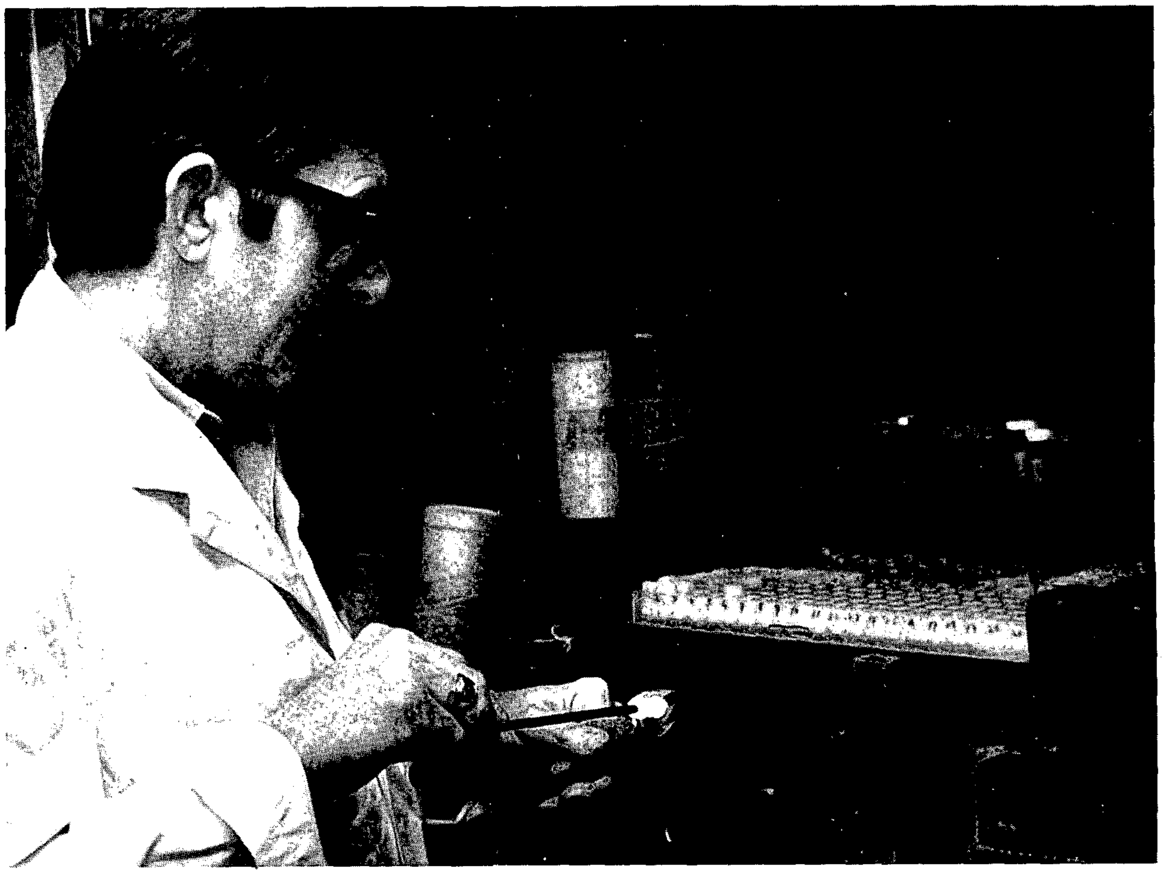
Then in the lobby of Building 4500 North, Postma introduced him to Charles Scott, who described bioreactor experiments; Samuel Hurst, who discussed the ORNL development using lasers to detect single atoms of a target element among millions of atoms of other elements; and John Jones, who explained a fluidized-bed coal burner designed to cogenerate power and heat.

Laboratory personnel greeted the president with respectful cheers, surprising local reporters who thought the president's opposition to the proposed Clinch River Breeder Reactor Project and subsequent political decision to move a centrifuge plant from Oak Ridge to Portsmouth, Ohio, would elicit a less enthusiastic response.

President Carter, however, was near the peak of his popularity at the time of his visit to the Laboratory. Afterward,



Bill Appleton works at the Solid State Division's accelerator facility during early experiments with ion implantation.



Joseph Northcutt loads coolant water from the Three Mile Island reactor after the 1979 accident. He used neutron activation analysis to determine the amount of uranium present to assess the extent of fuel melting.

events, such as the Iranian hostage crisis, plagued his administration, exacerbating the national energy crisis and inevitably affecting Laboratory activities.

Quick Responses

The March 1979 accident at Three Mile Island Unit 2 surprised nuclear experts at the Laboratory and elsewhere. Although nuclear safety research had concentrated on the risks of pipe rupture and the possibility of loss-of-coolant accidents in light-water reactors, the Three Mile Island accident in Pennsylvania resulted instead from a pressure valve that stuck and inaccurate instrumentation and human error that complicated the emergency. Having a national reputation in the safety field, Laboratory staff led by Fred Mynatt became immersed in the Three Mile Island emergency and subsequent analysis.

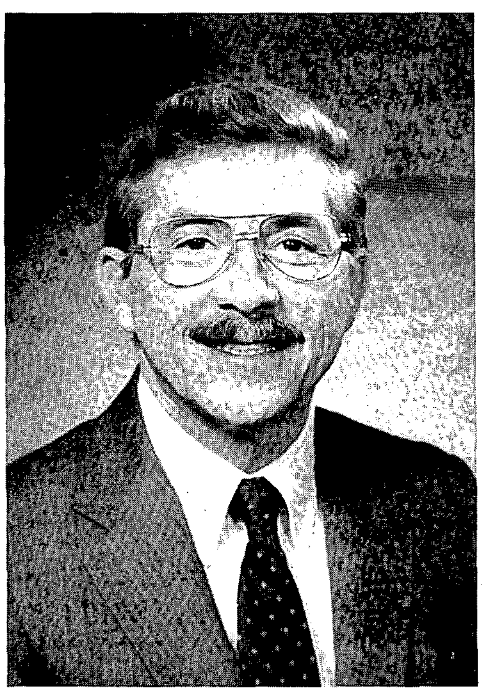
When the company owning the disabled reactor called Floyd Culler at the Electric Power Research Institute for help, Culler (who had just left the Laboratory after 25 years of service, including one year as acting director) contacted Postma and other Laboratory officials, as did the staff of the Nuclear Regulatory Commission. During the emergency, Laboratory personnel served as consultants and on-site analysts. Seventy-five staff members performed technical and analytical research during the emergency or subsequently provided information to the committee appointed by President Carter to investigate the accident.

The Laboratory helped the industry recover from the accident in many ways, including forming several response teams organized by Don Trauger. An Industrial Safety and Applied Health Physics Division team, led by Roy Clark, monitored emissions of radioactivity from the plant after the accident, while Robert Brooksbank's team minimized radioactive iodine releases by adding chemicals to the cooling system and by arranging replacement of the filters used to cleanse reactor gases before their release into the atmosphere. The absence of significant iodine releases was in part a testament to their success.

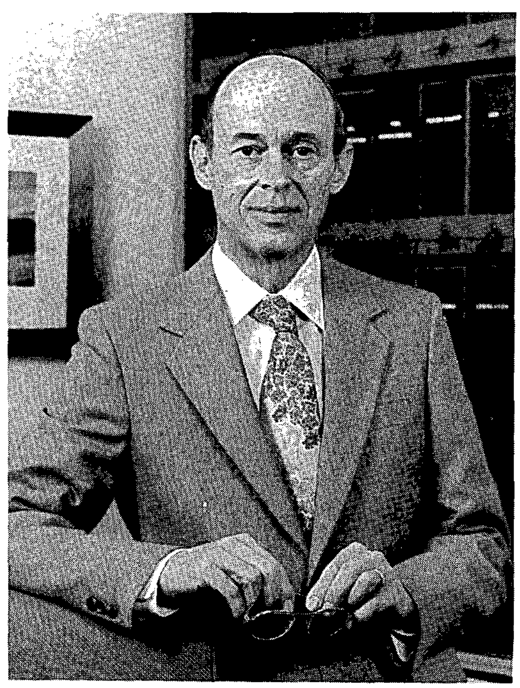
The Chemical Technology Division designed systems to store the contaminated water and remove the fission products. Robert Kryter and Dwayne Frye, both of the Instrumentation and Controls Division, supervised installation of monitors that replaced the damaged sensing systems inside the reactors. Wilbur (Dub) Shults and an Analytical Chemistry team analyzed samples from the accident site to assess the severity of contamination and devise cleanup strategies. An Engineering Technology Division group led by Mario Fontana and a Metals and Ceramics Division team led by David Hobson examined core cooling and debris problems, zircaloy cladding damage, and fission product releases. A group led by David Bartine addressed radiation and shielding issues. Joel Buchanan led the team studying the hydrogen in the reactor, and David Thomas supervised an Engineering Technology Division group that fabricated an electrical core to simulate the accident in the Thermal Hydraulic Test Facility.

Accident investigations and recovery activities continued for years, and the Laboratory took pride in its emergency response. Anthony Malinauskas and David Campbell's review of the issues surrounding releases of radioactive iodine to the atmosphere for President Carter's commission and the NRC proved especially useful. They concluded that the reactor released far less iodine than expected because much of it remained in the reactor.

The accident at Three Mile Island forever changed the public's attitude toward nuclear power. The Laboratory's response, however, helped provide a



Wilbur "Dub" Shults has been director of the Analytical Chemistry Division since 1974.



Associate Director Don Trauger managed nuclear reactor programs at ORNL for 40 years.

Oak Ridge's Environmental Park

Environmental scientists use treetop samplers to study the transport of airborne materials to forests and their soil.

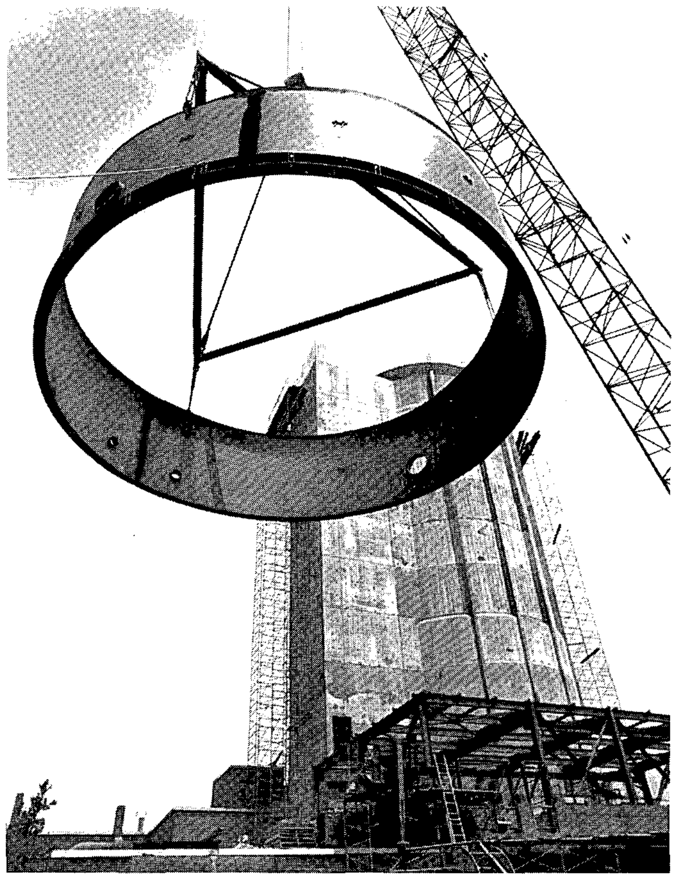
A park nearly surrounds the original X-10 site today. Established in 1980, the Oak Ridge National Environmental Research Park offers 12,400 acres of protected land for environmental sciences research and education. One of six Department of Energy environmental research parks located at sites across the nation, it affords opportunities for scientists to investigate the ecology of the forests of southern Appalachia.

The Laboratory's Environmental Sciences Division for many years has used the park area for research, creating a large base of information that is available to guest researchers. In the park, the Laboratory encourages research relating to energy, ecosystem dynamics, contaminant transport, and bioremediation. Scientists from universities, industrial firms, and other institutions submit their research proposals to the Laboratory for advance review and in selected cases qualify for funding assistance. Visited annually by 20,000 students, ranging in class level from kindergarten to college, the park contributes substantially to environmental education in the United States.

Because it forms a broad forested band nearly encompassing the original X-10 site, the Oak Ridge National Environmental Research Park also guarantees a continuation of the rural flavor that has characterized the Laboratory's history.

sound scientific base for understanding the causes and effects of the most serious mishap in the history of the U.S. commercial nuclear industry.

Later in 1979, the nation and the Laboratory became troubled by the revolution in Iran and the hostage and energy crises that ensued. Visiting Iran shortly before the revolution to discuss training Iranian technicians at the Laboratory, Associate Director Don Trauger observed firsthand the political instability there. He refused, however, to describe the subsequent acute petroleum shortage as another energy crisis. After a decade of energy crises, he believed that it was time for the nation and world to accept the shortages of adequate energy supplies as a persistent and chronic problem. "'Crises' imply unexpected situations that can be set straight by rapid, aggressive responses." Instead, Trauger suggested that "we must hurry to find solutions, but we must not become overly impatient in our quest."



A crane hoists a ring to the top of the Holifield Heavy Ion Research Facility under construction during the 1970s.

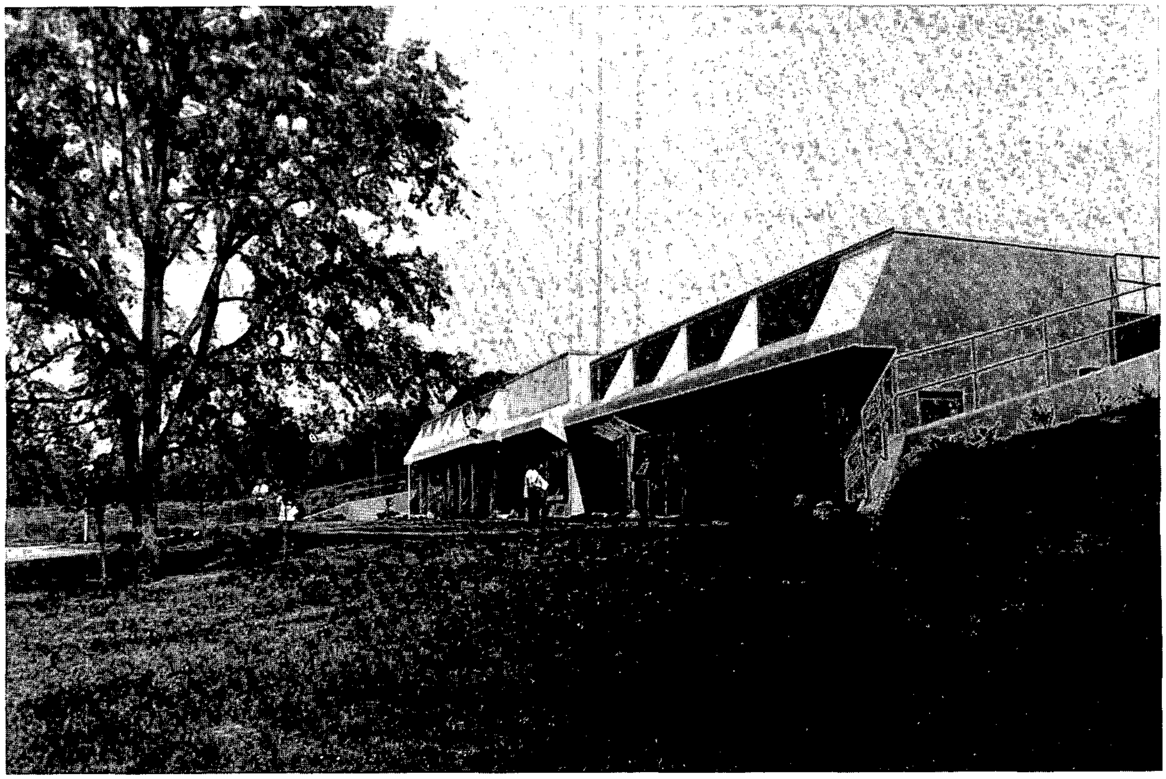
Laboratory energy conservation efforts accelerated during the Iranian embargo. The Laboratory converted its steam power plants from natural gas and petroleum back to coal and turned to gasohol to fuel some of its vehicles. It could not, however, find a local gasohol supplier and had to use its own staff to mix gasoline with ethanol. In addition, the Laboratory's environmental impacts group was commandeered to analyze implementation of the Strategic Petroleum Reserve—a federally sponsored effort to store large quantities of oil that could be tapped in times of emergency. The Strategic Petroleum Reserve later would serve an important role in stabilizing oil prices during the Persian Gulf War of 1991.

Constancy of Change

In 1980, the Laboratory found itself caught in the impasse between Congress and President Carter over the Clinch River Breeder Reactor Project. Funding for the Laboratory's breeder research to support the reactor and fuel reprocessing was slashed significantly—a blow to fission research that further discouraged the Laboratory's dwindling number of Manhattan-era researchers.

"This last defeat has convinced gray eagles like myself that the rainbow we have been following for the past 30 years may indeed not have the long sought-after pot of gold at the end," lamented Peter Patriarca, head of the Laboratory's breeder reactor materials research program. "I feel that I and others like me have accomplished a lot in 30 years of service, but we really haven't achieved the ultimate and that is my disappointment."

Still, 1980 was a banner year for many Laboratory programs. For the first time, the budget exceeded $300 million. Of this total, $20 million



The Joint Institute for Heavy Ion Research was an energy-efficient, earth-sheltered building to provide office space and temporary accommodations for

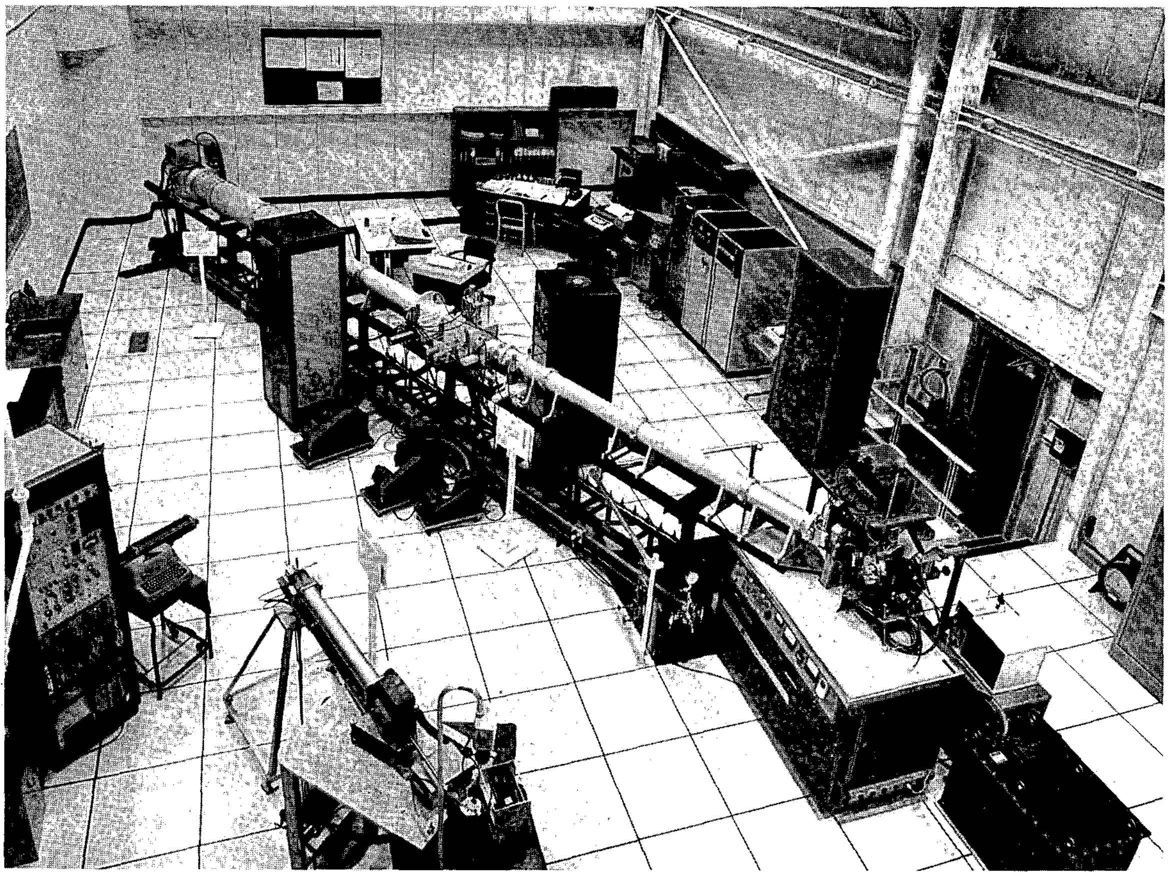
"Like the environmental park, the Holifield Heavy Ion Research Facility was designated a national DOE user facility."

was subcontracted to universities and $60 million to industry to support research and engineering. Completed in 1979, the new Environmental Sciences Laboratory eased staff crowding. Three new user facilities opened in 1980, marking the culmination of three successful programs launched in the 1970s: the National Environmental Research Park, the Holifield Heavy Ion Research Facility, and the National Center for Small-Angle Scattering Research.

The user facility concept evolved from a fundamental change at DOE. Before 1979, many Laboratory personnel collaborated informally with scientists from outside the Laboratory. That year, DOE made it official policy that DOE facilities were to be opened to outside users for cooperative and proprietary research and development.

The Oak Ridge National Environmental Research Park, comprising 12,400 acres of protected land for environmental science research and education, opened in 1980 as the fifth outdoor laboratory of the Department of Energy. Nearly surrounding the Laboratory, it made up about a third of the Oak Ridge Reservation. Here, scientists inventoried plant and animal species; monitored the dynamics behind climate and ecological change; undertook studies of contaminant transport and bioremediation; and cooperated with local, regional, and private agencies to promote science and environmental education. Nearly 20,000 students from kindergarten to high school visited this park annually as part of their science education programs. The Walker Branch Watershed in the park emerged as a key experimental facility for biogeochemical and hydrologic research.

One early research effort in the park tested bird and small animal habitat models later used by the Army Corps of Engineers to prepare environmental impact statements for construction projects. Another



"The National Center for Small-Angle Scattering Research was the Laboratory's third user facility opened in 1980."

The small-angle X-ray scattering device developed by Robert Hendricks became part of the National Center for Small-Angle Scattering Research established in 1978.

early research effort examined atmospheric deposition of pollutants for the National Oceanic and Atmospheric Turbulence and Diffusion Laboratory located in Oak Ridge.

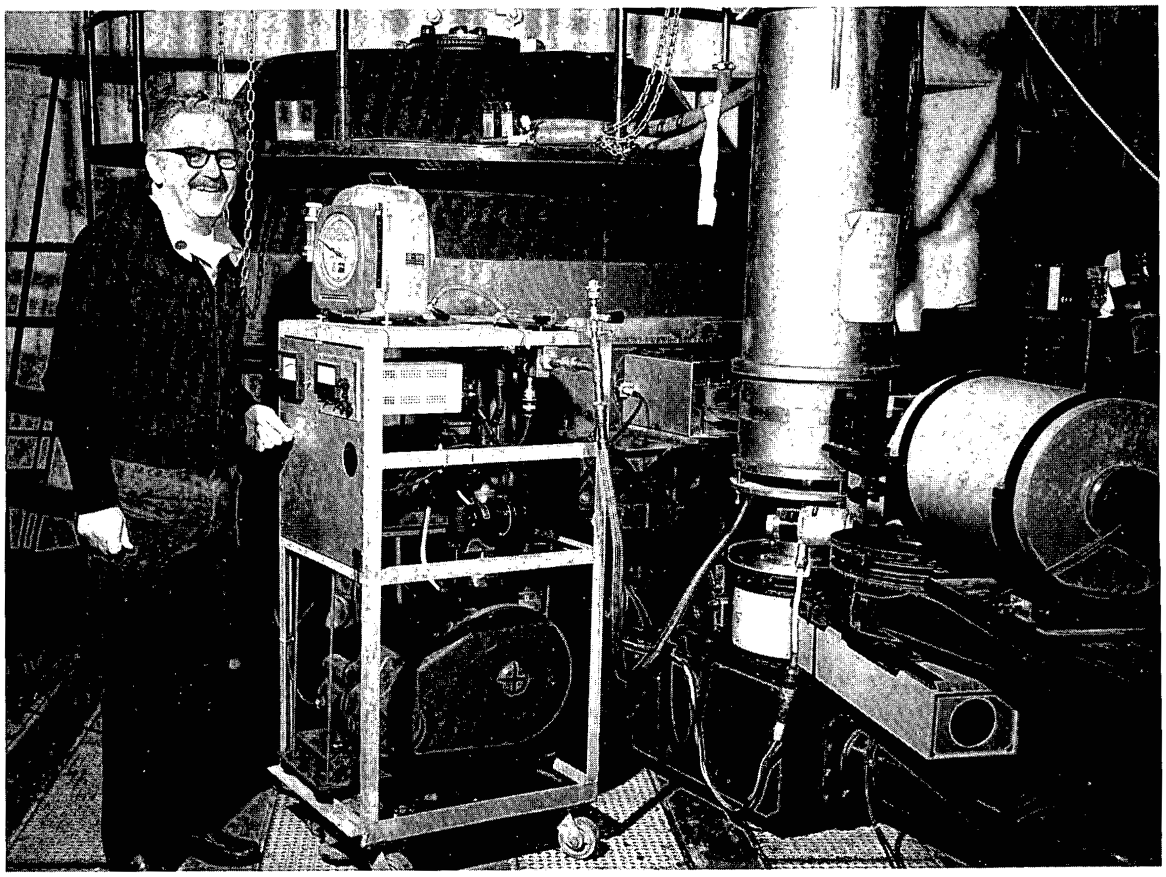
Former Congressman Chet Holifield participated in the December 1980 dedication of the Holifield Heavy Ion Research Facility named after him. "One more curiosity of the scientifically oriented human mind" was Holifield's description of the awesome tower and the pelletron accelerator it housed.

Twice as powerful as any other machine of its type, the accelerator in the tower was coupled with the Oak Ridge Isochronous Cyclotron to convert heavy ions into high-speed projectiles. Colliding with targets, these projectiles produced results that helped to illuminate fundamental nuclear science.

Laymen were more amazed by the spin spectrometer, a clustered array of gamma-ray detectors, dubbed a "crystal ball," used to measure the energies of the gamma rays emitted by the products of the heavy-ion collisions.

Like the environmental park, the Holifield Heavy Ion Research Facility was designated a national DOE user facility. Over the years, it hosted numerous scientists from around the world. By the late 1980s, nearly a quarter of all Ph.D. degrees in low-energy nuclear physics involved work done at this facility. Oak Ridge Associated Universities organized the University Isotope Separator of Oak Ridge (UNISOR) group of universities that conducted studies using an isotope separator at the end of one of Holifield's beam lines. The Physics

"The Laboratory seemed to have adjusted well to its new role as a multiprogram laboratory of the Department of Energy."



Wallace Koehler, who came to ORNL from the Manhattan Project, specialized in neutron scattering research.

Division under Paul Stelson and later Jim Ball formed and built the Joint Institute for Heavy Ion Research on DOE land using funding from Vanderbilt University and the University of Tennessee. The institute has been a model of scientific cooperation. This mostly underground, energy-efficient structure designed by Laboratory architect Hanna Shapira also has served as a visible symbol of the Laboratory's commitment to energy conservation.

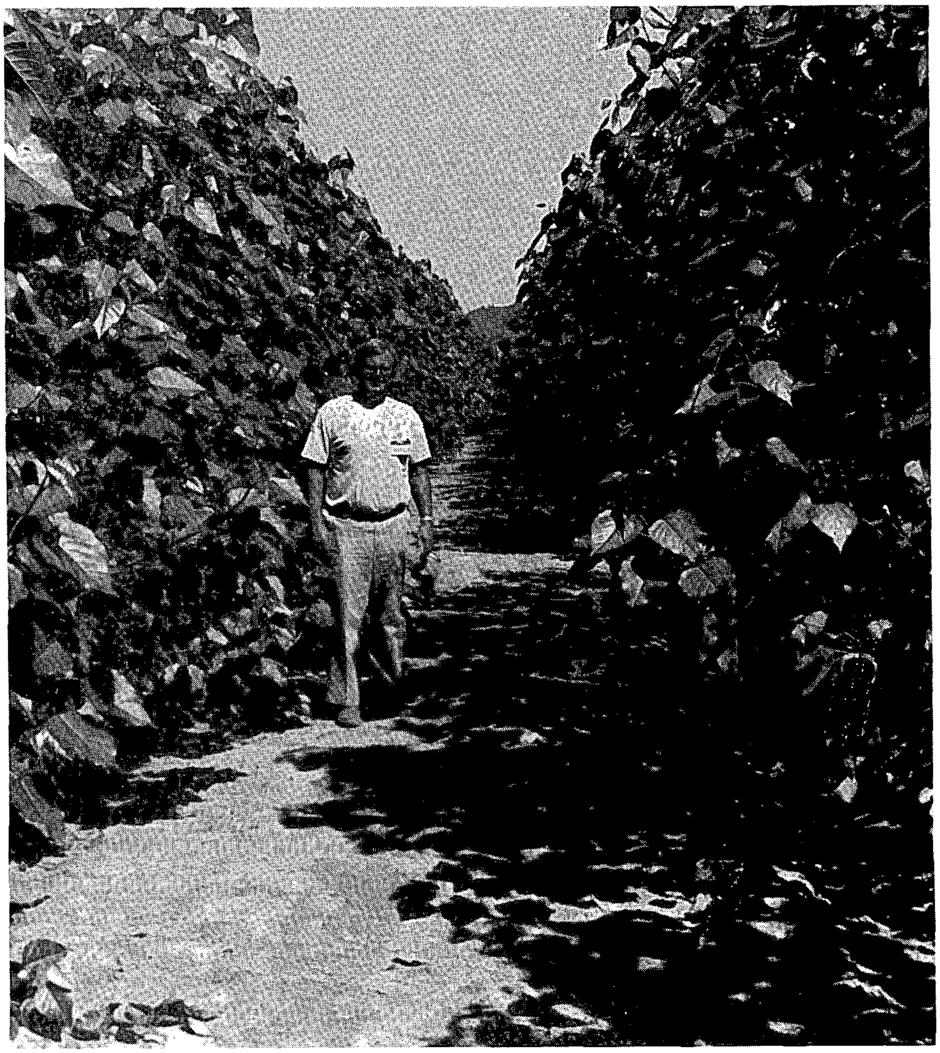
The National Center for Small-Angle Scattering Research was the Laboratory's third user facility opened in 1980. Small-angle neutron scattering blossomed during the 1970s as a way to explore certain types of microscopic structures. Although two laboratories using this scientific technique existed in the United States, they were not readily available to independent researchers. In 1977 the National Science Foundation (NSF) proposed to fund a center for use by scientists nationwide. Wallace Koehler and Robert Hendricks, who had developed a small-angle X-ray scattering instrument, submitted a proposal to establish a user-oriented, small-angle scattering center at the Laboratory. It called for a new small-angle neutron scattering (SANS) facility at the High Flux Isotope Reactor, along with access to the Laboratory's existing small-angle X-ray and neutron scattering devices. Their proposal received NSF approval in 1978.

The new SANS facility, which opened in 1980 at the High Flux Isotope Reactor, included a position-sensitive detector designed by Casimir Borkowski and Manfred Kopp for determining the directions and intensities of the scattered neutrons. Initially directed by Koehler and later by George Wignall, the SANS facility was comparable to the best facilities in Europe, and the center offered a combination of X-ray and neutron scattering that made the Laboratory a mecca for this type of materials research.

With these new facilities, the Laboratory entered the 1980s prepared for its role as a user-oriented institution that could host scientists from around the world. After a decade of energy crises and constant transition, the Laboratory seemed to have adjusted well to its new role as a multiprogram laboratory of the Department of Energy.

During the presidential election of late 1980, however, candidate Ronald Reagan complained that DOE had not produced a single additional barrel of oil and promised to dismantle Carter's creation. By Christmas of that year, Reagan's transition team announced it had profound changes in mind for both DOE and its national laboratories.

In less than a month, they would have an opportunity to put those ideas into practice. Barely having caught its breath from a decade of whirlwind change in energy policy and direction, the Laboratory was poised for yet another transition. The Reagan years were about to begin.



Jack Ranney surveys hybrid poplar trees under study as a biomass energy crop.

Chapter 8

Diversity and Sharing

In the 1970s, the Laboratory moved beyond its war-rooted preoccupation with nuclear power to research fields embracing all energy forms. By the early 1980s, that journey was complete. In the words of Associate Director Alex Zucker, ORNL had become "a multiprogram research and development laboratory having a variety of energy-related missions of national importance."

Emphasis on the Laboratory's multiprogram character was in part a response to the "Reagan revolution" of the 1980s, when fierce debates arose over the proper balance between the public and private sectors. The Reagan administration, in fact, proposed to abolish DOE and severely curtail the activities of the national laboratories. Energy policies, the administration stridently proclaimed, should be shaped by the private sector. If government had any role at all, it should be narrowly confined to questions of basic research.

President Reagan appointed James Edwards, a former governor of South Carolina and oral surgeon with little background in energy policy, to preside over DOE's dissolution as the nation's "last" Secretary of Energy. The president planned to transfer its residual functions to the Department of the Interior under James Watt or to the Department of Commerce under Malcolm Baldrige.

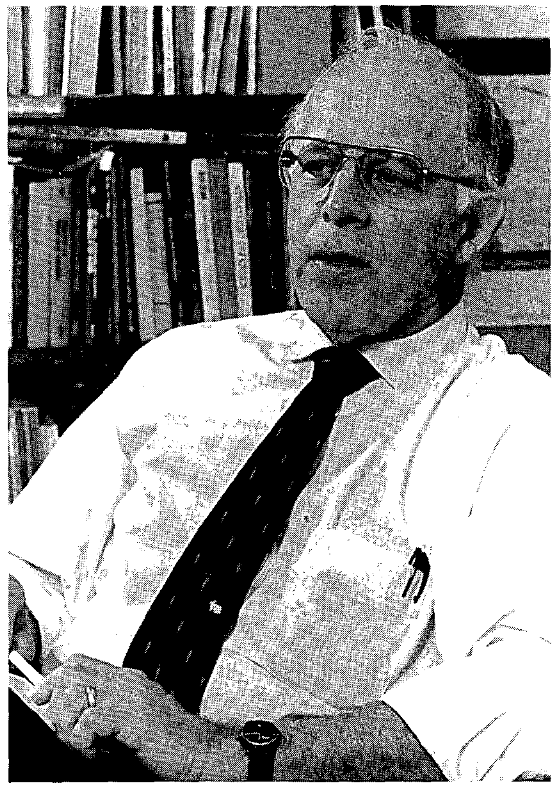
Aiming for major reductions in the public sector, in 1981 the Reagan administration initiated executive reviews of most federal agencies, including DOE laboratories. Kenneth Davis, Deputy Secretary of Energy under Edwards, directed an Energy Research Advisory Board to survey the laboratories' work. Congress conducted similar investigations.

Investigators distinguished among three kinds of laboratories: single-purpose specialty, exclusively weapons, and broadly diverse multiprogram. Oak Ridge, Argonne, and Brookhaven were on the original list of multiprogram laboratories, but it soon expanded to include more than a dozen DOE laboratories.

Vocal criticisms of these multiprogram laboratories arose from universities, consulting firms, and industrial laboratories. Because of the laboratories' excursions during the 1970s into diverse energy research agendas, critics saw them as subsidized competition. One industrial executive, for example, charged: "When I find Oak Ridge planting trees to see if they can't grow them a little closer together and faster, which the paper companies could do; testing solar cells that there are 300 companies already set up to test; and so on, I just wonder if we haven't lost our sense of focus altogether."

Admitting the missions of national laboratories had become diffuse and perhaps "unfocused" during the 1970s, Laboratory leaders asked whether more precise definitions of the roles of all laboratories—national, private, and university—would help clarify the situation and foster a healthier and more robust national research program. Truman Anderson, chief of Laboratory planning and analysis, urged that national laboratories should "assume a broader role in a new partnership with industry and universities." This new partnership was to reshape Laboratory activities throughout the 1980s and into the 1990s.

Program diversity enabled the Laboratory to weather the intense scrutiny of 1981; so, too, did the administration's pronuclear stance, which ameliorated its initially harsh approach to



Jack Gibbons pursued science at the Laboratory and the University of Tennessee's Energy, Environment, and Resources Center before becoming director of the Office of Technology Assessment of the U.S. Congress. He now serves as President Clinton's science advisor.

government-sponsored energy programs. Commenting on the effects of Reagan's policies after his first year in office, Laboratory Director Herman Postma declared: "The impacts so far, while unwelcome and frequently painful, have been rather moderate overall, and certainly less severe than at many of our sister laboratories." Indeed, Postma thought the Reagan policies may have had some salutary effects, notably in restoring an equitable balance between basic science and applied technology.

During the early 1980s the Laboratory staff was reduced by about 700 persons as a consequence of Reagan administration cost-cutting measures. However, the Laboratory's multiprogram character,

Robert Steele and B. J. Sutton evaluate materials in a 1980 flywheel under study for mechanical energy storage in automobiles. Flywheels were also explored as energy storage devices for the Strategic Defense Initiative.

"Oak Ridge endured the loss or retrenchment of some programs and staff reductions during the early 1980s but emerged in a stronger position later in the decade."

together with its ties, through Union Carbide, to the Y-12 and K-25 plants, allowed the cuts to be handled largely by transferring personnel and not filling positions when people retired or resigned.

The first year of the Reagan revolution would prove the most unsettling for the Laboratory. Deep recession in 1982 and growing federal budget deficits soon fostered less hostile views of Laboratory activities within the administration. A national consensus emerged that viewed scientific and technological innovations as the nation's "ace in the hole" for breaking the cycle of budget deficits, high unemployment, and unfavorable trade balances. In 1982, Herman Postma observed that support was building in government for concerted efforts to "encourage high-technology development as the best hope for the nation's economic future."

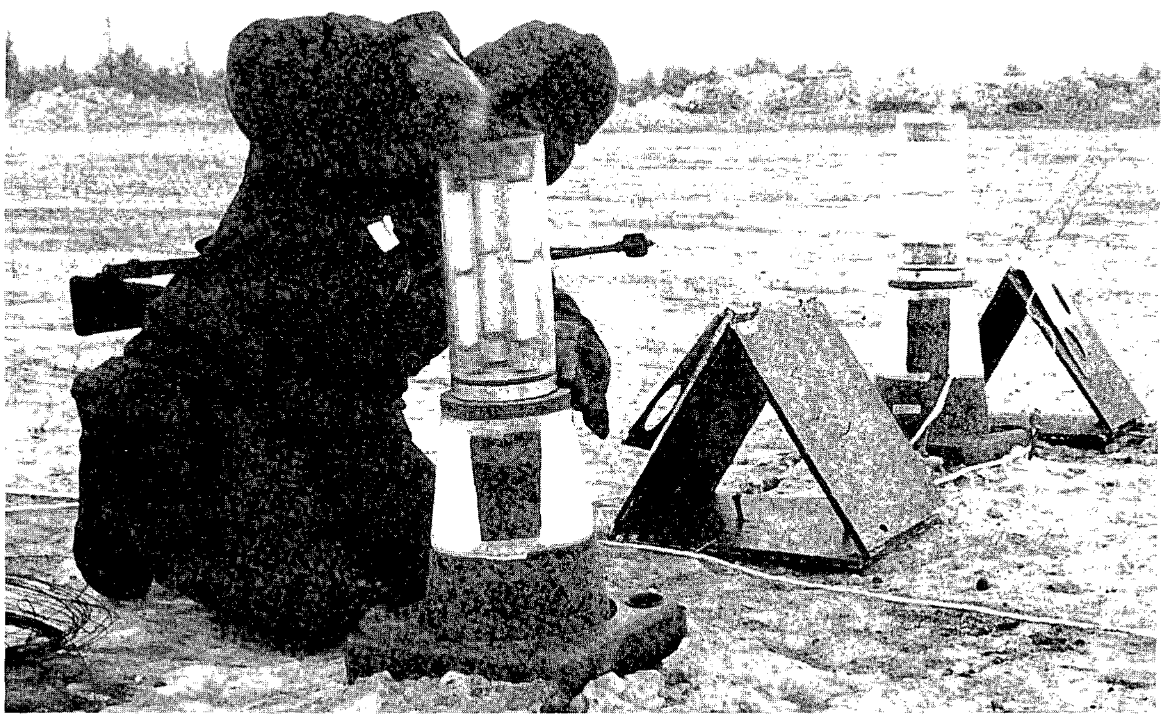
Along with other DOE laboratories, Oak Ridge endured the loss or retrenchment of some programs and staff reductions during the early 1980s but emerged in a stronger position later in the decade. Some ORNL employees took positions in Martin Marietta Energy Systems, Inc., with the Data Systems Research and Development Organization or with DOE's Hazardous Waste Remedial Action Program (HAZWRAP). In time, the Reagan administration abandoned efforts to dispense with DOE, as well, in part because of congressional opposition, in part because of the heavy weight of bureaucratic inertia, and in part because DOE laboratories emerged as critical research centers for the Reagan-inspired Strategic Defense Initiative.

Thus, the Reagan administration's strenuous reform efforts did not seriously sap the overall strength of the Laboratory. These efforts, however, did rearrange Laboratory priorities and programs. For example, Reagan policies forced the Laboratory to reduce the size of its fossil-energy program, and the administration proposed budget cuts that would have scaled back its energy conservation program had the funds not been restored by Congress. When the administration terminated the government-sponsored synthetic fuels program in favor of supply-side, market-driven energy initiatives, funding for the Laboratory's coal research dwindled. To maximize the return on its diminished resources, DOE decided to conduct all its coal research in laboratories linked to the Bureau of Mines. The administration also looked unfavorably on energy conservation, but the Laboratory's energy conservation program survived an early round of cuts and rebounded to eventually enjoy renewed vigor.

Star Wars

In March 1983, President Reagan espoused an antimissile defense initiative that aimed to break the nuclear stalemate by shifting the battlefield to outer space, where an impenetrable defense umbrella would forever protect the United States from nuclear attack. Declaring that the Strategic Defense Initiative would make nuclear weapons obsolete by rendering an attack futile, the president

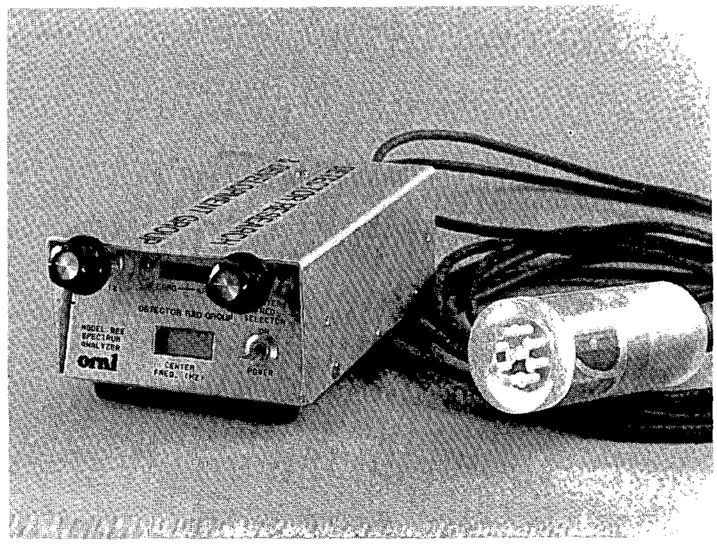
"The Laboratory's energy conservation program survived an early round of cuts and rebounded to eventually enjoy renewed vigor."



Tritium light developed at the Laboratory is installed at an Alaskan airfield by an Air Force employee.

proclaimed that the proposal held promise for "changing the course of human history." Critics dubbed the initiative "Star Wars"—a flight of fancy charted by an ill-informed president that falsely promised to turn the world's fiercest technological force into its most reliable sentinel of peace.

In truth, scientific opinion was deeply divided on the long-term prospects of this proposal. Beyond the huge price tag, however, one thing was certain. Devising space satellites capable of destroying nuclear missiles would require major scientific and technological advances. Resources at DOE's national laboratories—both in skilled personnel and sophisticated equipment—would be vital to any chance for success.


ORNL's Bee Spectrum Analyzer can detect Africanized killer bees in European honeybee hives.

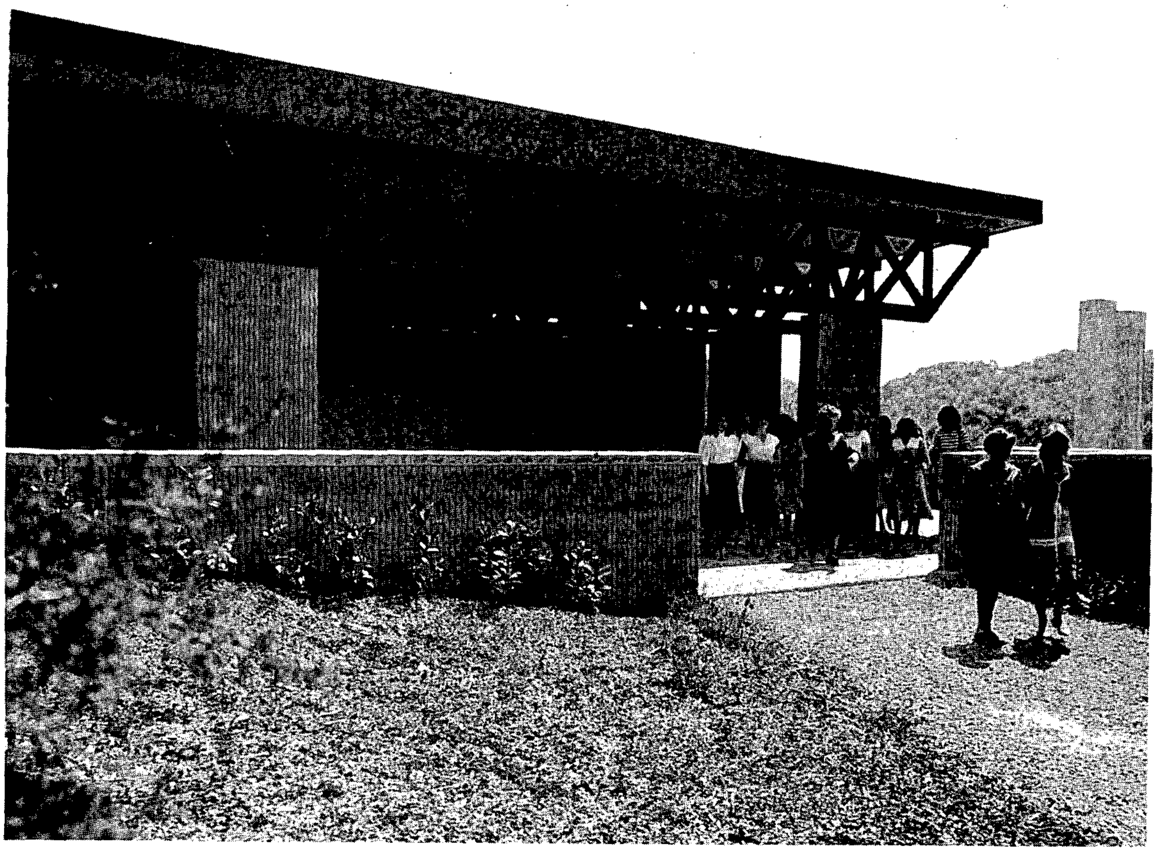
Managed by David Bartine, the Laboratory's Star Wars research agenda, which was set by the Department of Defense, focused on designing reactors to power space satellites and lasers; flywheels for energy storage and pulsed power; and particle accelerators for producing beams to destroy missiles from space. Studies of highly focused beams of hydrogen particles, able to destroy the electronic components of a missile, evolved from the Laboratory's fusion energy experiments in which beams of neutral hydrogen atoms were used to heat plasmas to high temperatures.

"The Laboratory also conducted research that would permit space satellites to sense the heat of missile launches."

John Moyers headed a team from the Engineering Technology Division and other divisions for design of a nuclear reactor to provide power bursts for the lasers and weapons aboard space vehicles. Their concept centered on a boiling-potassium reactor, perhaps with flywheels for energy storage. Even if never needed for national defense, the reactor might power long-distance space exploration to Mars and beyond.

Although some Star Wars research was classified, two of the Laboratory's announced achievements included powerful particle beams and mirrors for surveillance satellites. Taking advantage of the negative-ion sources developed as a result of fusion energy research, Laboratory scientists devised the "world's highest simultaneous current density output and pulse length"—that is, a particle beam that remains tightly focused for thousands of miles, like a spotlight rather than a floodlight. In cooperation with scientists from the K-25 and Y-12 plants and from industry, the Laboratory also conducted research on beryllium mirrors and windows that would permit space satellites to sense the heat of missile launches on Earth. These mirrors and windows were devised, fabricated, and polished in Oak Ridge in cooperation with Martin Marietta Aerospace of Denver. From this effort emerged the Laboratory's Optics MODIL (Manufacturing Operations Development and Integration Laboratories), which has entered into several cooperative research and development agreements (CRADAs) with industrial firms.

The media seemed more interested in the Laboratory's killer bees research than its Star Wars work. At first glance, star wars and bee wars may seem to have little in common, but the efforts of researchers in both fields to track flying objects at long distances enabled them to find a common ground of scientific investigation. Newspaper journalists and television reporters enjoyed reporting Laboratory efforts to detect the migration patterns of



Tourists at the Laboratory Overlook built to host visitors during the 1982 Knoxville World's Fair.

the Africanized bees, dubbed killer bees, that moved north from Central America during the 1980s, posing a threat to national honey production.

Howard Kerr, an experienced amateur beekeeper, became interested in finding ways to detect and track the movements of killer bees. He and his Laboratory colleagues considered tracking them with radioisotopes, spotting them with infrared devices, or identifying their presence in hives by detecting their characteristic buzzing with acoustical devices. This approach would provide scientists with opportunities to disrupt the bees' mating patterns. To Kerr and his colleagues, the threat that killer bees posed to honey production in North America was a serious matter; their research continued as the bees migrated across the Rio Grande River into Texas during the 1990s.

Energy Systems

In 1982, the Laboratory spruced itself up for the Knoxville World's Fair, building a visitor's overlook on a nearby hill and opening some facilities to tell crowds attending the fair and nearby attractions about energy and environmental research taking place at Oak Ridge's national multiprogram laboratory. At the same time, the Laboratory also became an anchor for a proposed technology corridor championed by Tennessee Governor Lamar Alexander.

The corridor was built along Pellissipi Parkway, a highway linking west Knoxville to Oak Ridge. The aim of the corridor was to promote regional economic growth, partially through transfer of Oak Ridge's publicly funded technology to private

"The Laboratory also became an anchor for a proposed technology corridor championed by Tennessee Governor Lamar Alexander."

"Energy Systems could now license the right to manufacture products or provide services based on science and technology developed at the Laboratory."

industrial firms. It was hoped that Pellissipi Parkway, in time, would feature tree-lined industrial parks and glass-encased offices built to market the region's scientific and technological advances. In effect, corridor advocates were seeking to create a Silicon Valley in East Tennessee that would draw on the complementary skills of the region's three major institutions—Oak Ridge National Laboratory, the University of Tennessee, and the Tennessee Valley Authority.

As the World's Fair celebration began, the Laboratory was surprised by news that Union Carbide, after nearly 40 years in Oak Ridge (34 years at the Laboratory) would withdraw as the operating contractor. Three days after the World's Fair opened in May 1982, Union Carbide management announced that the company would relinquish its contract for operating the Laboratory and other Nuclear Division facilities in Oak Ridge and Paducah, Kentucky, although it agreed to serve until DOE selected a new contractor.

The terse announcement read by Roger Hibbs of Union Carbide said the decision not to renew the contract resulted from the company's strategy of "concentrating its resources and management attention on commercial businesses in which it has achieved a leadership position. The corporation has no other defense-related operations."

Seventy organizations, ranging from Goodyear, Boeing, Westinghouse, Bechtel, and the University of Tennessee down to small firms, expressed an initial interest in succeeding Union Carbide. After careful consideration, DOE decided to keep the Oak Ridge and Paducah facilities under a single contractor. A year after Union Carbide's decision, DOE requested proposals for operating the Laboratory and the other facilities, and late in 1983 it received formal responses from a half dozen corporations and companies. It narrowed the field to three—Westinghouse, Rockwell, and Martin Marietta. In December, it accepted the proposal of Martin Marietta Energy Systems, part of the Martin Marietta Corporation, known nationally for its defense and aerospace work.

Martin Marietta Corporation was formed in 1961 by the merger of Glenn Martin's aircraft company with Grover Hermann's American-Marietta Company. Aircraft pioneer Glenn Martin, a partner with Wilbur Wright, built bombers for the Army during World War I; later, the firm built such famous aircraft as the "China Clippers" and the *Enola Gay*. Grover Hermann, an entrepreneur from Marietta, Ohio, had organized one of the first industrial conglomerates in the United States. Known best for its defense and aerospace contract projects, Martin Marietta Corporation managed production of aluminum and construction materials and supervised government-sponsored defense, space, and communications initiatives. With its corporate headquarters in Bethesda, Maryland, it had five operating companies employing 40,000 people at 128 sites throughout the nation. In 1984, it had major contracts for the space shuttle and MX missile designs and research laboratories located in Denver, Orlando, and Baltimore. To administer the Laboratory and other Oak Ridge and Paducah facilities, it formed the subsidiary Energy Systems, Incorporated.

To the relief of Laboratory management and personnel, the transition from Union Carbide to Energy Systems began in January 1984 and proceeded on schedule with minimal impact on Laboratory staff or activities. In April 1984, Energy Systems took full responsibility for Laboratory operations along with the K-25 and Y-12 facilities in Oak Ridge and the Paducah gaseous diffusion plant in Kentucky. Later, DOE added the Portsmouth, Ohio, enrichment facilities to the Martin Marietta operations contract.

Although day-to-day operations remained much the same, the change in administration brought new long-term directions for the Laboratory. Martin Marietta Energy Systems, Inc., was the first contractor-operator at the Laboratory without a chemical engineering background; its roots lay in prompt delivery of high-quality technology under contract with government and other agencies. Its agreement with DOE for operating the Laboratory, moreover, contained innovative provisions, including reinvesting a percentage of its annual fee as venture capital in Oak Ridge, developing an Oak Ridge technology innovation center, and pursuing an aggressive technology transfer program.

To accelerate spin-off of Oak Ridge technology to industry, Energy Systems proposed to license DOE patent rights for technologies developed at

Webb Van Winkle, Pat Mulholland, Jerry Elwood, and Denis Newbold collect samples after releasing a tracer in the Walker Branch Watershed.

the Laboratory. In 1985, DOE approved this proposal. Energy Systems could now license the right to manufacture products or provide services based on science and technology developed at the Laboratory.

This approach would facilitate technology transfer because companies acquiring such rights would not have to face competition. In return, the companies would pay royalties or license fees to Energy Systems, which would be reinvested in product refinement, prototype production, royalty shares for inventors, university programs, or other technology transfer activities. This initiative was in accord with President Reagan's policies encouraging private-sector growth and economic development through transfer of valuable scientific findings to the world of commerce.

Management Challenges

At the time of the 1984 transition, Director Postma had four associate directors administering technical activities. Don Trauger oversaw nuclear and engineering technologies, including the Chemical Technology, Engineering Technology, Fuel Recycle, and Instrumentation and Controls divisions, together with the Laboratory's nuclear reactor, fuel reprocessing, nuclear safety, and waste management programs. Murray Rosenthal supervised the Laboratory's research in advanced energy systems performed by the Energy and Fusion Energy divisions along with the conservation, fossil energy, and fusion programs. Alex Zucker administered the physical sciences research conducted by the Physics, Chemistry, Analytical Chemistry, Solid State, Engineering Physics and Mathematics, and Metals and Ceramics divisions. Chester Richmond headed biomedical and environmental research activities conducted by the Biology, Environmental Sciences, and Health and Safety Research divisions; the Information Center complex also was assigned to him. Support and services divisions reported to the executive director, Kenneth Sommerfeld.

Health and Environment

The Laboratory's biomedical and environmental programs may have had the most direct influence on American life during the 1980s. At least, the environmental and health problems they addressed dominated the news media during the decade. In keeping with trends at DOE, funding for Laboratory environmental and health research increased. As a result, the Laboratory's Environmental Sciences Division, directed by Stanley Auerbach and later by David Reichle, and its Health and Safety Research Division, directed by Stephen Kaye, flourished.

"The Laboratory's study of indoor air pollution, received a great deal of media attention."

By the end of the 1980s, nearly a quarter of the Laboratory's program budget supported environmental and health research.

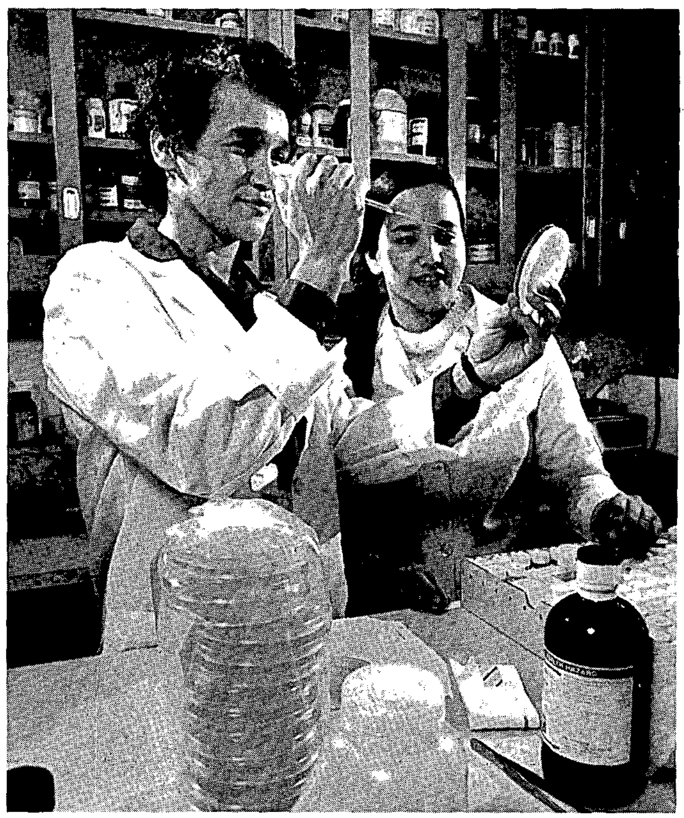
The Laboratory's basic ecological research continued to concentrate on understanding the processes by which contaminants move through the environment and on identifying the ecological effects of energy production. When the National Environmental Research Park opened as an outdoor laboratory in 1980, studies of southern and Appalachian regional ecosystems continued. The Laboratory also expanded its hydrologic and geochemical expertise in support of DOE waste management programs to examine the effects of waste on the environment.

The Laboratory's study of indoor air pollution, started in 1983 by members of the Health and Safety Research Division for the Consumer Product Safety Commission, received a great deal of media attention. Laboratory surveys found that residents of newer homes with tighter construction and improved insulation were exposed to indoor air pollution. Of special concern was radon gas, a decay product of natural uranium in the ground that seeped upward and concentrated in the more tightly sealed homes. If inhaled, it was considered a potential cause of lung cancer. Manufacturers soon were selling radon detection kits to homeowners and urging them to vent the gas from their homes if the levels of indoor radon exceeded government guidelines.

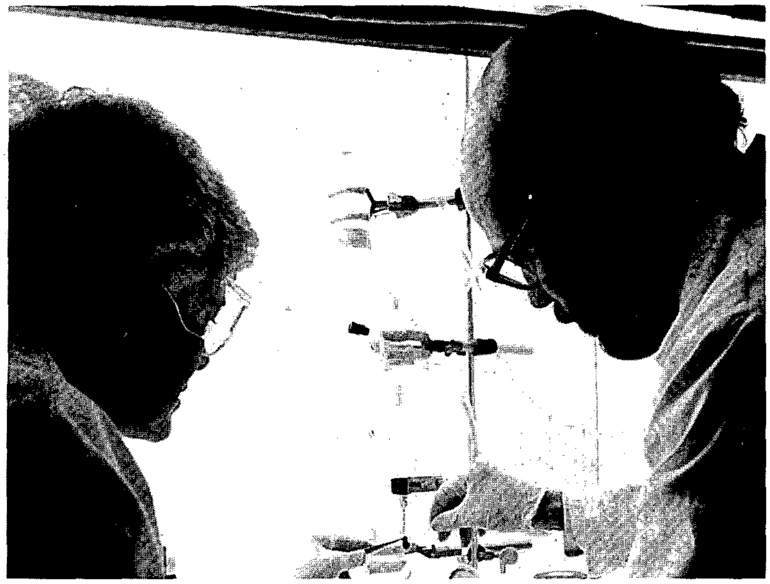
Risk assessment, whose practitioners analyze the potential risks posed by energy technologies and industrial processes, emerged as an important field within the Laboratory. Such assessment involves extensive use of computer modeling, laser optics, and advanced instrumentation to detect and examine the impacts of energy- and chemical-related compounds on ecosystems. Much of this work concentrated on specific chemicals cited as potential agents of contamination by the Environmental Protection Agency.

The ecological challenges presented to the Laboratory during the 1980s extended from the region and nation to the world beyond. Biomedically, long-term studies of carcinogenesis, mutagenesis, and other damages to organisms continued with major support from the National Cancer Institute and other institutes of the Department of Health and Human Services.

Within the Biology Division, research changed dramatically during the 1980s because of the advent of genetic engineering and recombinant DNA technology. Biologists learned to alter genes as simply as they had combined and separated chemicals in earlier times. This expanding capability permitted them to characterize cancer-causing genes, clarify the mechanisms for regulating genes, produce scarce proteins for studies, and design new proteins. Major Laboratory



Margaret Yette and Rise Matsunami pick a recombinant clone from a bacterial plate.



Kathleen Ambrose and F. F. (Russ) Knapp evaluate the properties of a radiopharmaceutical heart-imaging agent.

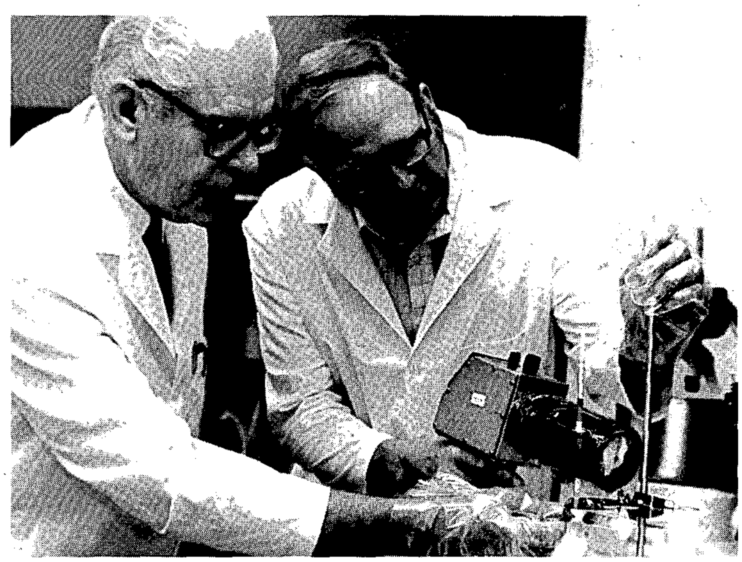
research initiatives included basic studies of proteins and nucleic acids, together with DNA repair, DNA replication, and protein synthesis, which relate to the response of biological systems to environmental stresses.

A Biology Division group led by Fred Hartman, for example, endeavored to use protein engineering to improve crops. Hartman's group sought to alter a plant enzyme so that it no longer used oxygen to break down carbohydrates while synthesizing them from carbon dioxide in the atmosphere. If they could successfully alter this enzyme to improve its efficiency, they might increase the growth and yield of plants useful for food and energy production.

As funding for basic sciences declined in favor of support for the applied sciences, the number of Biology Division researchers shrank during the 1980s to less than half the number employed during the 1960s. It retained a distinguished staff, however, and took pride in the fact that 17 biologists who had worked at the Laboratory were elected to the National Academy of Sciences.

The Laboratory's emphasis on production, development, and use of radiopharmaceuticals contributed to improved public health in several ways during the 1980s. F.F. (Russ) Knapp's Nuclear Medicine Group in the Health and Safety Research Division made news by developing new radioactive imaging agents for medical scanning diagnosis of heart disease, adrenal disorders, strokes, and brain tumors. Stable isotopes produced in the calutrons of the Chemical Technology Division were converted into radioisotopes such as thallium to provide the tracing material for millions of heart scans, which

"The Laboratory's emphasis on production, development, and use of radiopharmaceuticals contributed to improved public health."



Tom Butler adjusts the ORNL-developed iridium generator used to identify infant heart defects while Clarence Guyer monitors the radioactivity with a dosimeter.

Ion Implantation of Materials

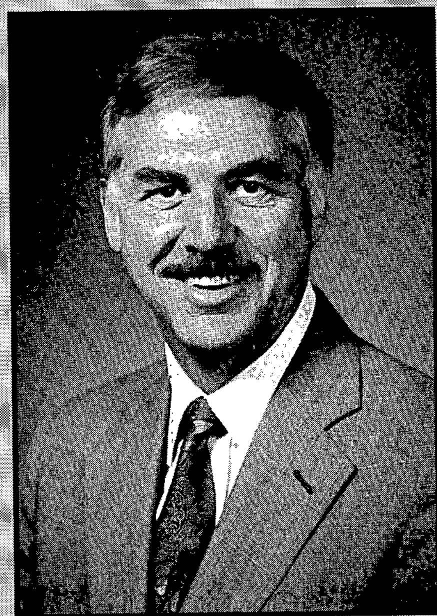
What do computer chips and artificial hips have in common? Both have been significantly improved by the application of ion beam processing, which had its beginnings in Oak Ridge.

Ion beam technology was first employed on a large scale at the Y-12 Plant in the electromagnetic separation of uranium isotopes for the atomic bomb that helped end World War II. Since the mid-1940s, ORNL has made major advances in developing ion sources for physics and fusion experiments and in using ion beams for materials processing. Using calutrons, accelerators, and other devices, researchers developed techniques for producing high-current beams of ions of numerous elements for use by industry for ion implantation—injecting ions (charged atoms) near the surface of a material surface to modify its properties.

"Thousands of semiconductor samples were implanted in Oak Ridge for industry in the early development of integrated circuits for electronic applications."

ORNL helped the electronics industry when Gerald Alton and others used the calutrons to show that electrical junctions can be formed in silicon by the direct implantation of boron and phosphorus ions. Thousands of semiconductor samples were implanted in Oak Ridge for industry in the early development of integrated circuits for electronic applications.

The 1962 discovery by ORNL's Mark Robinson and Dean Oen of ion channeling and its effects in crystals greatly improved the understanding of the interaction of ion beams with solids and advanced the use of ion beams for characterizing, analyzing, and processing materials. The ion channeling effect was discovered theoretically by a computer simulation that showed ions shooting through the "channels" between rows and planes of atoms in crystalline materials. The actual existence of ion channeling was later demonstrated experimentally at a Canadian laboratory and later at ORNL.



Bill Appleton initiated ion implantation experiments at the Laboratory.

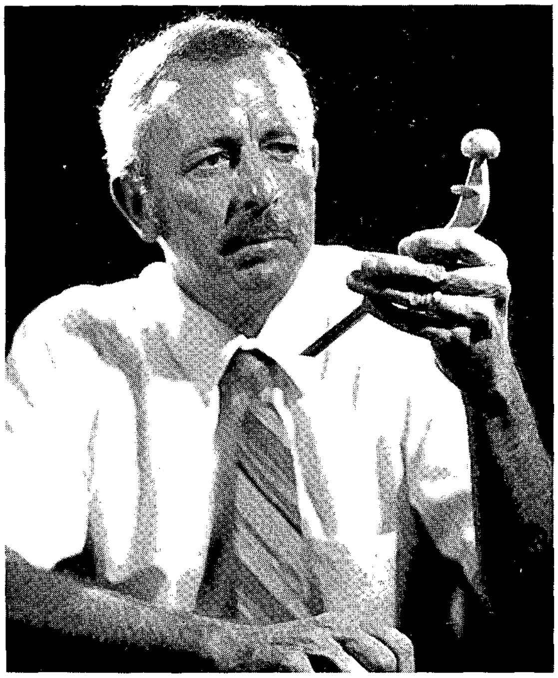
The channeling effect is critical in ion implantation because it affects ion depth in crystals, which is crucial for making effective semiconductor chips that form the heart of laptop computers, automatic cameras, and other electronic devices. Because of the importance of the crystal lattice in the transport of ions in solids and in radiation damage phenomena, Robinson developed the computer code MARLOWE, which continues to be the standard for the simulation of ion beam interactions with crystalline matter.

"ORNL researchers have used ion implantation to produce new materials for electronic, optical, and tribological uses."

In the early 1970s, Bill Appleton initiated an experimental effort using ion beams for implantation and other processes for modifying semiconductors, metals, insulators, and ceramics to improve their surface properties. Since then, ORNL researchers have used ion implantation to produce new materials for electronic, optical, and tribological uses. New implantation techniques have been developed to deposit thin films and fabricate improved optical waveguides.

Artificial hip joints can last much longer if implanted with nitrogen ions, according to ORNL research. Jim Williams, Bill Appleton Ray Buchanon (guest scientist from the University of Alabama at Birmingham), and others in the Solid State Division discovered that implanting surgical alloys used in prosthetic implants made them tougher and more resistant to wear by corrosion. The technology was developed and transferred to industry. By the early 1990s ion implantation was used on about half of the artificial hips and knees sold in the United States, with a potential savings of about $100 million a year by preventing rework of failed joints.

Because of the enthusiastic following of collaborators from universities and industry, ORNL in 1980 formed the Surface Modification and Characterization Research Center. Ion implantation facilities were expanded, and by 1990 the center had four accelerators for high-current, high-energy implantation and low-energy ion beam deposition. Each year about 100 scientists from universities, industries, and national laboratories engage in cooperative research projects at the center. Through research and collaboration, ORNL's work in ion implantation can be expected to be a source of many new exciting applications in science and technology.



James Williams holds an artificial hip joint made from titanium alloy implanted with nitrogen ions using technology he helped pioneer.

contributed substantially to national health care. By the end of the 1980s, DOE estimated that nearly 100 million Americans annually received improved diagnosis or treatment partly as a result of medical isotope research and production at the Laboratory and other DOE facilities.

Another medical advance arose from work at the Solid State Division's Surface Modification and Characterization Collaborative Research Center. Here, various ion-beam and pulsed-laser techniques were used to improve and characterize the properties of materials, giving them harder surfaces, more resistance to wear and corrosion, and improved electrical or optical properties. Applied initially to such semiconducting materials as silicon for solar cells, these techniques later proved beneficial in the development of other new materials, including surgical alloys.

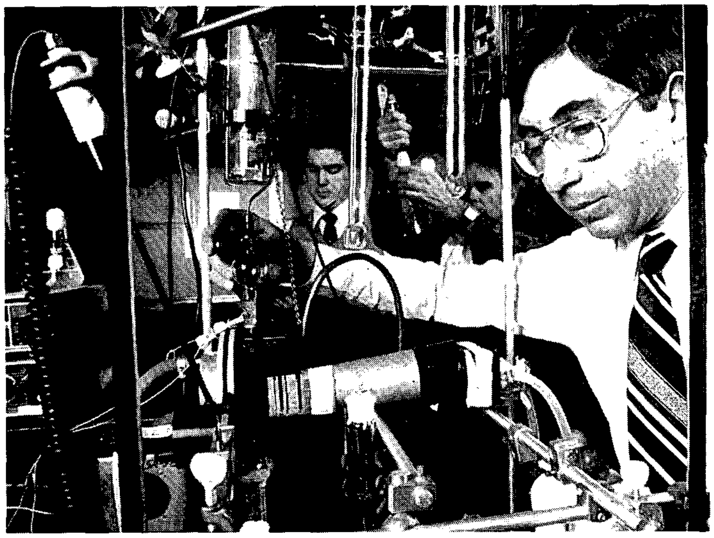
Each year, for example, thousands of patients had been fitted with artificial hip joints made of a titanium alloy. Because body fluids caused corrosion and wear in each implant, they had to be replaced after about 10 years. At the Laboratory, James Williams and collaborators implanted nitrogen ions into the titanium alloy to modify the surface. Ion implantation made the artificial joints much more resistant to wear and the corrosive action of body fluids, significantly increasing the lifetime of such joints. This process was incorporated into a new line of medical products marketed by a private company.

New devices in the Biology and Health and Safety Research divisions made possible the imaging of single atoms and of DNA strands during the 1980s. Scanning tunneling microscopes, developed in 1980 and first used for research on semiconductor surfaces, were built at the Laboratory during the decade. These microscopes, which gave new meaning to the word microscopic, could image supercoiled DNA molecules, showing structural changes and the binding of proteins and other substances to the strands of genetic material. Operated by David Allison, Bruce Warmack, and Thomas Ferrell, the new electron and photon microscopes promised to assist in mapping and determining the sequences of chemical bases in genes, thus opening new frontiers in biological research.

A team of Environmental Sciences and Chemical Technology researchers sought to use microorganisms in bioreactors to rid the environment of PCBs and other toxic wastes. Experiments along Bear Creek in Oak Ridge indicated that aerating and watering PCB-contaminated soil encouraged growth of microorganisms that could digest PCBs and convert them into less toxic substances. This success led to additional investigations into bacterial capabilities for digesting and converting other toxic materials.

For many years, researchers in the Health and Safety Research Division analyzed the accuracy of personnel dosimeters for the Laboratory and outside agencies. Other agencies mailed dosimeters to the Laboratory, and the devices were checked by exposure to measured radiation at the Health Physics Research Reactor. In 1989, the Laboratory opened the Radiation Calibration Laboratory for checking dosimeters, radiobiological experiments, and related purposes. This laboratory helped fill the research needs stymied by closure of the Health Physics Research Reactor.

"Ion implantation made the artificial joints much more resistant to wear and the corrosive action of body fluids."



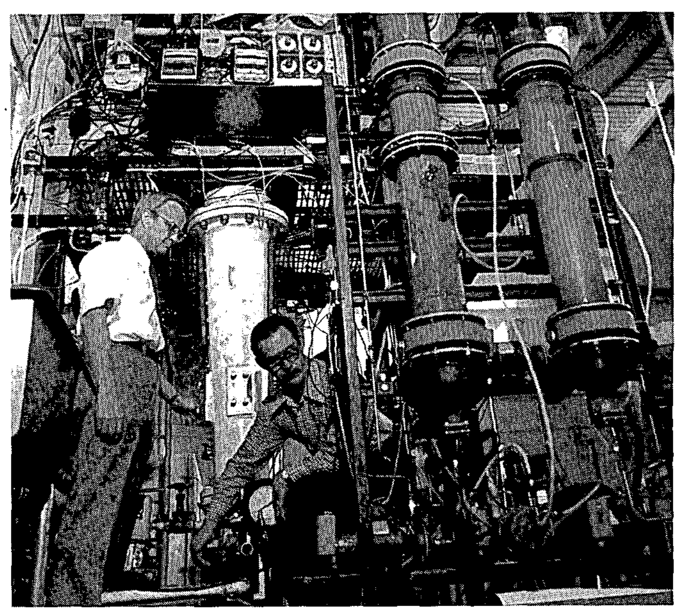
Eli Greenbaum studies photosynthetic water splitting for releasing energy-rich gases and makes bioelectronic materials. Mark Reeves and James Thompson work behind him.

Advanced Energy Systems

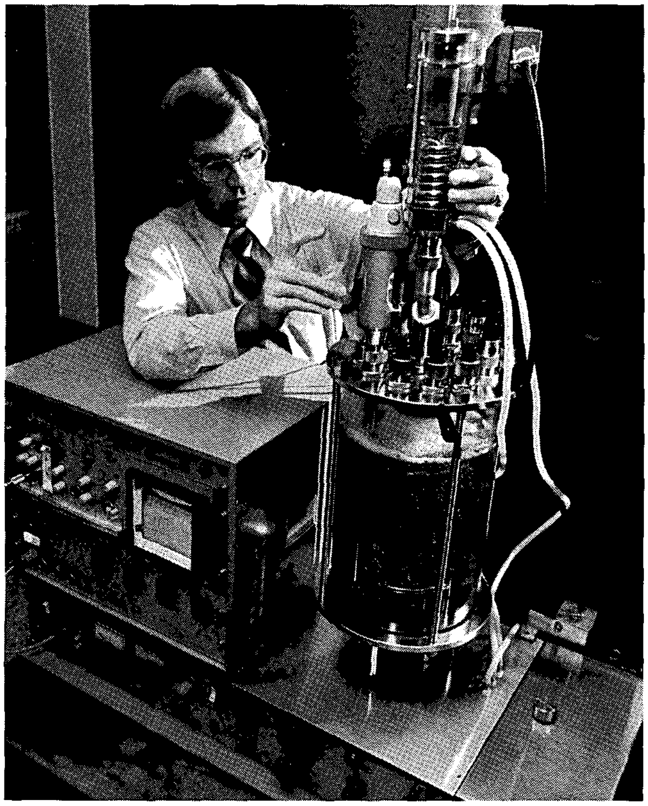
Murray Rosenthal's advanced energy systems activities, including the fossil energy, conservation, and fusion programs, were threatened with loss of program support during the early Reagan years. The Reagan administration dispensed with most of the fossil energy program, severely curbing fossil energy research at the Laboratory. However, after a brief and limited decline, the energy conservation program began to grow again. The fusion program, moreover, continued to progress and received DOE and congressional approval to build two substantial plasma confinement experiments.

One of the ORNL fusion projects, known as the Advanced Toroidal Facility (ATF), was the world's largest stellarator. The stellarator concept had been investigated earlier in the United States at Princeton Plasma Physics Laboratory, but it was difficult both to analyze and build. Most of the U.S. effort was devoted to the newly invented tokamak. However, stellarator development was continued elsewhere in the world, most notably in Germany, Japan, and the Soviet Union. ORNL recommended to DOE that the prospects for this fusion approach were promising enough that the United States should reenter the field. After a period of review, DOE concurred and the ATF was built at the Y-12 Plant on the site of earlier tokamaks using major pieces of equipment remaining from that program.

The other experiment that evolved from the Laboratory's ELMO Bumpy Torus program was known as EBT-II. After a contract to build EBT-II had been awarded, the Fusion Energy Division's refined analysis of the original Elmo Bumpy Torus program indicated that EBT-II's performance would not be as promising as predicted earlier. The Laboratory recommended that its EBT-II program be terminated, and a panel of fusion experts agreed.



Charles Scott and Charles Hancher examine a fluidized-bed bioreactor used to reduce nitrate concentrations in wastewater.



Wes Shumate injects a culture of bacteria into an experimental bioreactor at the Laboratory.

Energy conservation, so popular during the Carter administration, received a cold shoulder from the Reagan administration. One critical official, declaring that energy conservation meant "being too hot in the summer and too cold in the winter," contended that higher energy prices would provide the only incentive needed for conservation. The administration mandated sharp cuts in conservation research funding, forcing the abrupt termination of some energy conservation projects at the Laboratory. Congress, however, restored some of the budget reductions, and the energy conservation program flourished again during Reagan's second term.

In energy conservation research, Eric Hirst and his colleagues in the Energy Division evaluated the benefits and costs of utility and government conservation programs that offered homeowners information on, or even incentives for, cutting the use of electricity. They recommended continuing support for installation of attic insulation and double-pane windows, for caulking and weatherstripping, and for insulating water heaters.

In the 1980s the Laboratory managed a DOE program that developed and tested technologies designed to make electric power systems safer, more reliable, and more efficient. ORNL staff, led by Tom Reddoch and Paul Gnadt, helped plan, design, and conduct a successful automated distribution experiment for Athens, Tennessee. The experiment was a milestone in changing the patterns of electricity use, or load management, which was first explored at ORNL by Hugh Long.

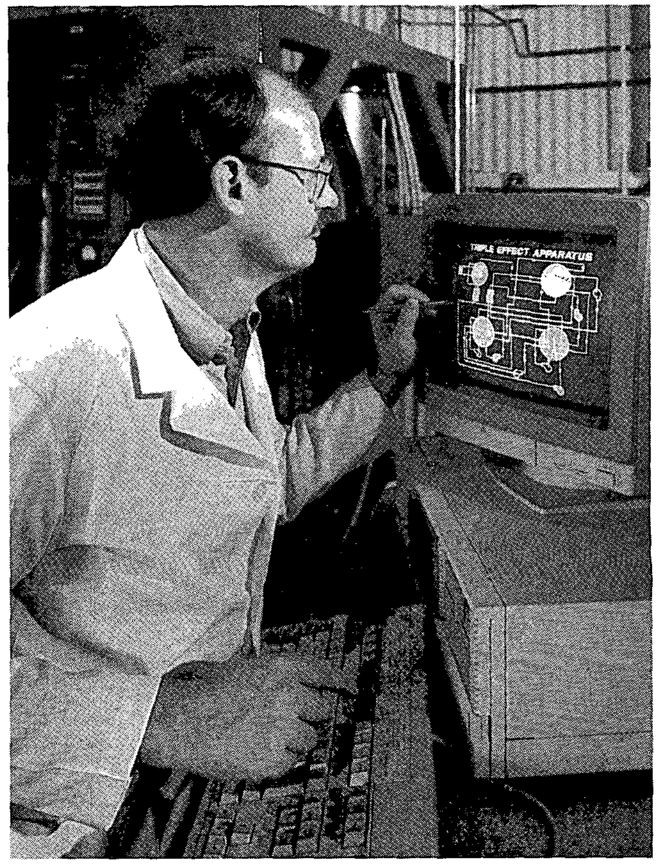
As another example, David Greene and associates in the Energy Division collected data on the use of energy for transportation. They developed models for predicting how much energy would be used under various transportation scenarios, such as increasing fuel efficiency of new cars and using "smart" cars to help drivers avoid congested areas and reach their destinations faster.

Laboratory studies of improved building insulation continued, and George Courville, Michael Kuliasha, and Bill Fulkerson sought the creation of a Roof Research Center. This program, initiated in 1985 as a cooperative effort of DOE and the building industry, measured transfer of heat through roofing structures, assessed how structures reflected or absorbed solar energy, and projected how long the structures would last. In climate simulation facilities added to the Roof Research Center in 1987, instrumented roof structures provided data for computer modeling of roofing designs. At this unique industrial user facility directed by Paul Shipp and Jeff Christian, roofing research identified significant convective heat losses in common blown attic insulation and worked with the building insulation industry to devise more efficient systems.

In cooperation with the National Bureau of Standards and industry, Laboratory studies of improved home appliances produced significant results as well, notably in development of absorption heat pumps for heating and cooling that could be powered with natural gas instead of electricity. The Energy Division's Michael Kuliasha and Robert DeVault managed subcontracts with industrial firms to improve and commercialize these heat pumps. Thanks to these and other innovative ventures, the Laboratory's conservation and renewable energy program recovered its losses; in fact, its annual budget rose from $28 million at the start of the decade to $46 million by 1988.

In the nuclear power industry, proper welding is as critical to safety as it is in most other industries—perhaps even more so. The Welding and Brazing Group established at the Laboratory in 1950, therefore, had many opportunities to improve welding technology and gained worldwide recognition for its contributions.

National energy production has been hampered when poor welds shut down nuclear power plants, coal-fired plants, and petroleum refineries. In 1985, when Alex Zucker asked welding specialist Stan David and physicist Lynn Boatner to review Laboratory research on composite materials, they concluded that a multidisciplinary attack on fundamental welding problems could be fruitful.



Robert DeVault works at a computer model of the gas-fired absorption chiller he invented for cooling large buildings.

Physical Sciences

"The user facility attracting the greatest attention during the 1980s was the High Temperature Materials Laboratory."

The Laboratory's physical science research efforts, under the direction of Alex Zucker and later Bill Appleton, focused on nuclear physics, chemistry, and materials science. Researchers used the Holifield Heavy Ion Research Facility, neutron scattering facilities at the High Flux Isotope Reactor, the Surface Modification and Characterization Research Center, and other new facilities.

Basic research on the chemistry of coal and solvent extraction continued at the Laboratory, but the loss of most of the fossil energy program took several divisions into the field of bioconversion as a potential source of energy and improved waste disposal management.

Bioconversion research sought to use micro-organisms to convert organic materials—sewage, solid wastes, woody biomass, coal, or corn—into fuels. Rather than liquefying coal with heat and pressure, for example, Charles Scott and teams in the Chemical Technology Division turned to bioreactors in which micro-organisms convert coal to liquids. In another case, the Laboratory cooperated with the A.E. Staley Corporation, a corn products company with a plant near Loudon, Tennessee, to improve fermentation of corn using a fluidized-bed bioreactor in which bacteria converted almost all the sugar in corn into ethanol, which can be used as a petroleum substitute.

Materials research rose to the forefront of the Laboratory's efforts in physical sciences during the 1970s and 1980s. The Laboratory was a pioneer in

Raising the Quality of Roof Research

The Roof Research Center and its associated Roof Thermal Apparatus investigate energy-efficient, ozone-safe materials for the national roofing industry. In 1993 the facility's name was changed to the Building Envelope Research Center.

During the mid-1980s DOE established its Roof Research Center at the Laboratory to cooperate with industry in the development of more energy-efficient and durable roofs for homes and businesses. The idea for such a center was conceived at the Laboratory by Jim Robinson, and George Courville and Dick Huntley guided the design, construction, and initial operation of the facility. Researchers at this unique user facility, with industrial sponsors and advisors, test roofing systems in a climate simulator.

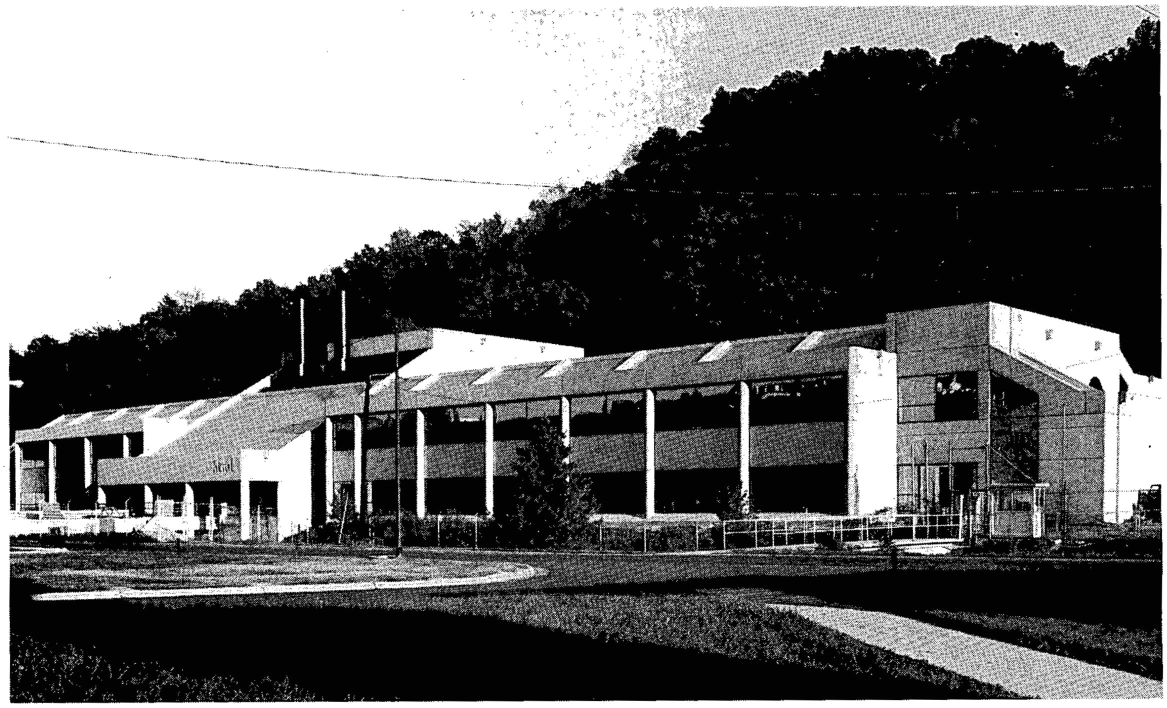
The Center's research improves understanding of the thermal and physical characteristics of various roofing systems and insulating materials. This information helps identify roofing materials and insulations that last longer, hold more heat, and use materials that are less damaging to the environment.

For example, ORNL researchers have determined that some types of blown-in insulation in buildings in the northern United States permit air movement within the insulation, resulting in natural convection. Compared with conduction, convection allows more heat to escape from within a building to the outside. The researchers confirmed that natural convective heat loss in some loosefill fiberglass insulations can be responsible for as much as half of the heat loss at very low temperatures. As a result of this Roof Research Center achievement, the private firm Energy Savings Solutions developed a thin plastic-wrapped fiberglass batt that can cover existing insulation to nearly eliminate convection losses. In addition, Minnesota improved its state building code to require insulation manufacturers to guarantee the performance of their products during the coldest weather expected.

The Roof Research Center is also being used to determine how ozone-safe roof insulation responds to aging as heat flows through it. The roof foam used for thermal tests contains hydrochlorofluorocarbons (HCFCs), which do not persist nearly as long in the stratosphere as ozone-depleting chlorofluorocarbons (CFCs). One outcome of this work may be an improved HCFC-blown roofing insulation that is nearly as efficient as CFC-blown insulation in keeping wanted heat in and unwanted heat out. As a result, it may be possible to speed the elimination of CFC insulation for roofs and help preserve the stratospheric ozone layer that protects humans from hazardous solar radiation.

Providing industry with unparalleled opportunities for testing roof system responses to precipitation, stresses, and energy flows, the center establishes new standards for roofing research. Owners of new buildings or new roofs benefit directly from the new standards and the nation gains an improved energy and environmental outlook.

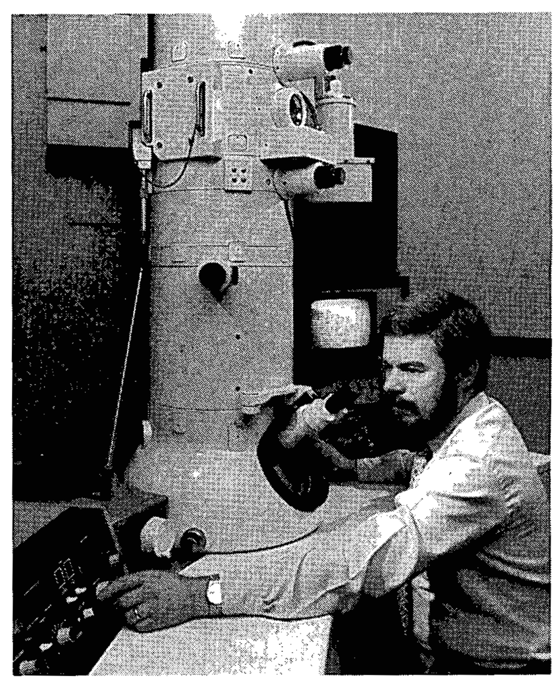
"The award-winning HTML building, which houses 49 laboratories and 72 offices for staff and visitors, opened in April 1987."



The High Temperature Materials Laboratory was completed in 1986.

the development of new alloys, high-temperature materials, specialized ceramics, and composite materials. It also developed new techniques to modify surfaces of materials, improving their properties. These successes placed it in a position to contribute directly to industrial technology applications.

The user facility attracting the greatest attention during the 1980s was the High Temperature Materials Laboratory (HTML). First proposed in 1977 as part of DOE's Basic Energy Sciences Program, it required a decade of efforts by Alex Zucker, Fred Young, John Cathcart, Victor Tennery, James Weir, James Stiegler, Carl McHargue, Ted Lundy, and associates to get the $20 million user facility completed. Deferred by the Reagan administration in 1981, persistent academic and industrial interest overcame the administration's initial resistance and abruptly shifted the project to the front burner. In that shift, the HTML was funded in 1983 by DOE's Energy Conservation Program, which had become a major supporter of materials development. The award-winning HTML building, which houses 49



Larry Allard operates a high-resolution, transmission electron microscope to study high-temperature superconducting materials.

laboratories and 72 offices for staff and visitors, opened in April 1987.

The High Temperature Materials Laboratory fostered exactly the sort of scientific research the Reagan administration demanded. Its modern instruments, microscopes, furnaces, and other research equipment have made possible the characterization, testing, and processing of ceramics to help develop materials for the most energy-efficient engines. Heat-resistant ceramic or intermetallic components may be used for advanced highly efficient engines that operate at elevated temperatures that would melt ordinary metal alloys. The Laboratory's research in these fields promises to help maximize the fuel efficiency of vehicle, aircraft, and rocket engines. These materials also could promote development of superconducting magnets, advanced electronic components, and lightweight armor for tanks and other military applications.

In 1985 when President Reagan visited the University of Tennessee in Knoxville, ORNL Director Herman Postma had an opportunity to tell the president about Laboratory activities. Using its development of wear-resistant artificial hip joints by ion implantation as an example, Postma emphasized the Laboratory's new role as a center for cooperative research with universities and industry. Instead of closeting its research behind a fence, the Laboratory had become a place that opened its doors to collaboration and innovation. "We have large and unique facilities in Oak Ridge, and we open them to users from throughout the country," he told the president. "We have also helped the University of Tennessee to establish centers of its own that are privately funded by industry. Perhaps most importantly, we share accomplishments."

Laboratory management made a bold decision in the mid-1980s that changed the face of computing at ORNL. At the time Energy Systems had a centralized Computing and Telecommunications organization, and each division at ORNL assumed responsibility for its own computers and scientific needs. Only the Engineering Physics and Mathematics Division, directed by Fred Maienshein and later Robert Ward, was conducting research on computing. ORNL management decided to look beyond the supercomputers of the day and initiate an aggressive program in the new architecture of parallel computing. This decision laid the groundwork for the Laboratory to become a winning competitor for a center of collaboration to solve computer problems of national interest when parallel computing became the wave of the future in the 1990s.

The Laboratory's responsiveness to a new set of national needs brought it out of the doldrums of the early 1980s into renewed prosperity. After setbacks during Reagan's first term, the Laboratory's overall operating budget rose to $392 million in 1988, slightly larger in constant dollars than it had been in 1980.

"Laboratory management made a bold decision in the mid-1980s that changed the face of computing at ORNL."

Seed Money Spreads

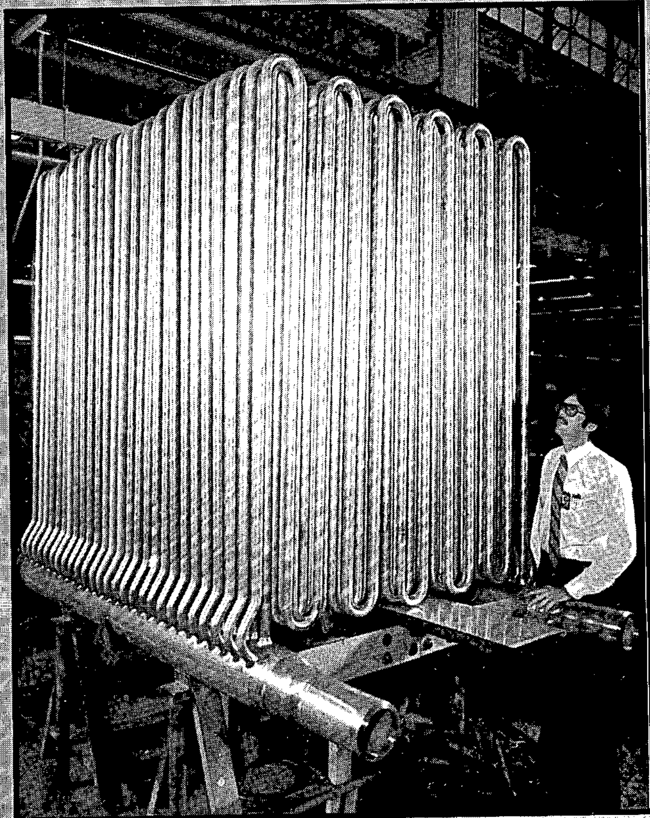
Postma viewed the seed money program for exploratory studies as an undiluted success. Since the program's beginnings in 1974, seed money projects had brought about four dollars in new research funding to the Laboratory for every dollar invested internally.

To build on this success, the Laboratory in 1984 established two new exploratory research funding opportunities: a Director's Research and Develop-ment Fund for larger projects and a Technology Transfer Fund to encourage commercially promising research. It is our "strong view," Postma asserted, "that the best judges of technical opportunities are those doing the work and their peers."

Seed money projects provided grants of up to $100,000 for one year's work, long enough for the work to produce results that could attract attention and funding from a sponsor. The Director's Research and Development Fund created in 1984 supported larger projects, ranging from $100,000 to $600,000, selected from proposals submitted by Laboratory divisions.

Among early projects supported by the Director's Fund was a project managed by Don Trauger and James White to assess the commercial feasibility of smaller, safer nuclear reactors. Promising designs under study included liquid-metal–cooled reactors; process-inherent ultimately safe (PIUS) reactors; small boiling-water reactors; and high-temperature, gas-cooled, prismatic, and pebble-bed–fueled reactors.

Quest for Fail-Safe Reactors



Tom Conley inspects a heat exchanger later installed in the Component Flow Test Loop, a key experimental facility for DOE's High Temperature Gas-Cooled Reactor Program.

Light-water reactors require redundant and expensive emergency systems to prevent fuel melting if they lose coolant. During the 1980s, citizens worldwide expressed increased concerns about the reliability and safety of emergency cooling systems.

"Laboratory researchers concluded that complex cooling systems would be unnecessary in high-temperature gas-cooled reactors."

Laboratory researchers concluded that complex cooling systems would be unnecessary in high-temperature gas-cooled reactors. In 1988 John Cleveland of ORNL's Engineering Technology Division found merit in this conclusion when he participated in landmark safety tests at Germany's Arbeitsgemeinschaft Versuchs Reaktor (AVR). To observe gas-cooled reactor performance after sudden coolant loss, researchers deliberately stopped the coolant flow to the reactor. The reactor ran for five days without any coolant other than natural convection and conduction to its steam generator and through its walls. The test demonstrated the reliability of an inherently safe reactor.

This demonstration augured well for fundamentally safe and economical nuclear power, although a commercially viable unit remains years away. Oak Ridge and German scientists continued to collaborate on designing larger modular high-temperature gas-cooled reactors based on the inherently safe principles illustrated at the AVR.

"The test demonstrated the reliability of an inherently safe reactor."

In the United States, the Department of Energy has initiated studies of 350-megawatt (thermal) modular high-temperature gas-cooled reactors to produce electricity and tritium for defense purposes.

Robotics

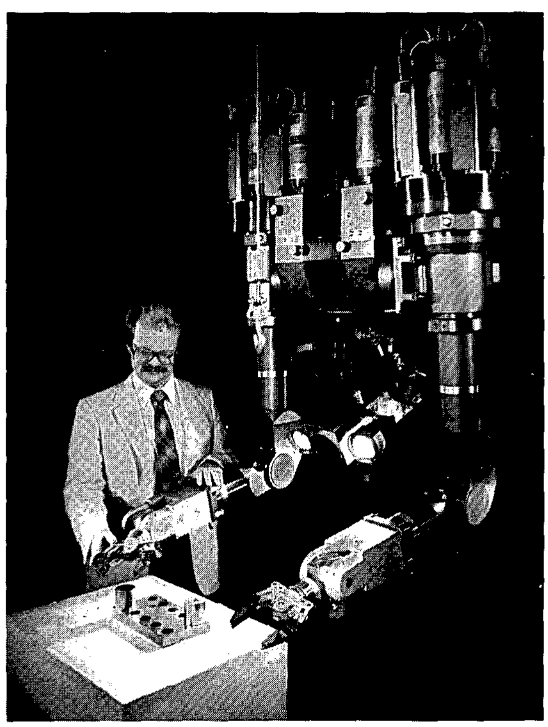
Katie Vandergriff checks a gear pump module used in a servomanipulator developed for remote operations in fuel reprocessing.

"Remote control of operations in hostile environments had been a Laboratory specialty."

Another Director's Fund project of 1984 was the Center for Engineering Systems Advanced Research (CESAR), which was established in the Engineering Physics and Mathematics Division. Headed by Charles Weisbin, this center focused on computer problem solving through artificial intelligence resembling human reasoning. The "reasoning" generated by machine-produced artificial intelligence was to be exercised through remotely controlled robots capable of working in such hostile environments as outer space, battlefields, areas contaminated by radiation, or coal mines.

Since the days when the Laboratory recovered plutonium from the Graphite Reactor and Waldo Cohn initiated radioisotopes production, remote control of operations in hostile environments had been a Laboratory specialty. Elaborate servomanipulators had been designed and built to accomplish work from behind the protection afforded by concrete or lead walls. Moreover, Mel Feldman, William Burch, and leaders of the Fuel Recycle Division had become interested in using robots to accomplish nuclear fuel reprocessing through teleoperations from a distance—or, as Feldman put it, to project human capabilities into hostile workplaces without the actual presence of humans.

In the mid-1980s, the Laboratory formed a TeleRobotic task force, managed by Sam Meacham, to acquire new programs and sponsors for research in robotics and teleoperations. For this effort, the Laboratory received support from NASA to develop the Man-Equivalent TeleRobot for satellite refueling and space-station construction. It also received funding from DOE's new Office of Civil



Joe Herndon checks the advanced servomanipulator.

"The Laboratory created one of the world's most computationally powerful robots."

Radioactive Waste Management to assess applications of robotics and remote technology for the proposed Monitored Retrievable Storage facility that was intended to provide temporary storage for high-level nuclear waste.

Members of the Fuel Recycle, Instrumentation and Controls, and Engineering divisions contributed to the robotics program. Also, the Engineering Physics and Mathematics Division broadened its technological bases in robotics and artificial intelligence. These initiatives led to the Robotics and Automation Council, the precursor of the Laboratory's Robotics and Intelligent Systems Program headed by Charles Weisbin and then by Joseph Herndon.

In 1985, the Laboratory began tests of a motor-driven robot that could sense its surroundings through sonar and machine vision and respond to computer commands relayed by radio. Investigators Reinhold Mann, William Hamel, and associates improved the basic design to create one of the world's most computationally powerful robots. Nearly the size of a small car, it could sense its surroundings, deal with unexpected events, and learn from experience.

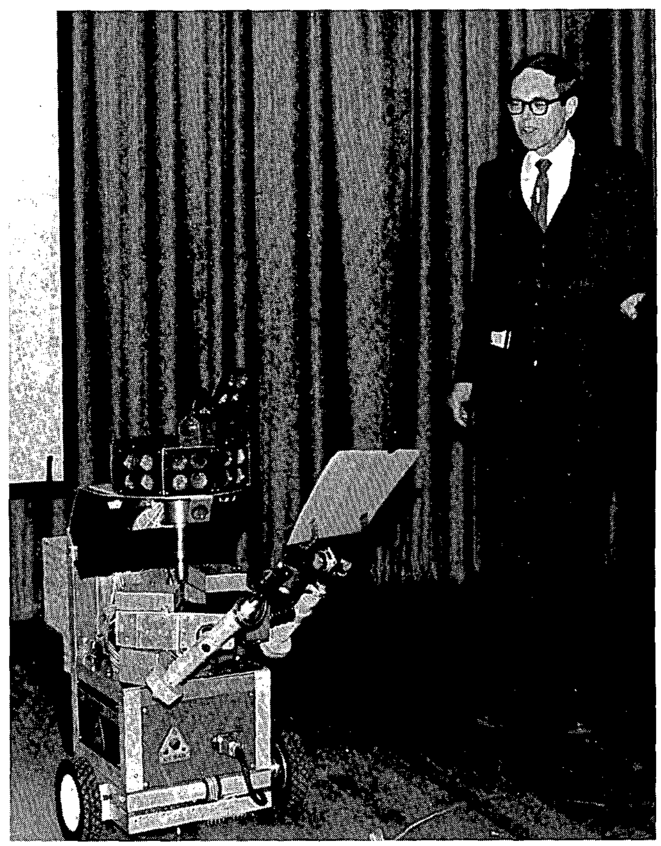
Acquiring funding from DOE, the National Aeronautics and Space Administration, the Army, and the Air Force for robotics research, the Laboratory formed the Robotics and Process Systems Division in the early 1990s and initiated research aimed at devising remotely controlled robots with "common sense." One early accomplishment was the robotic mapping of waste-filled silos at DOE's Fernald, Ohio, facility. The robotic effort helped DOE complete the project on schedule and saved millions of dollars in the process.

In related work, the Engineering Physics and Mathematics Division also engaged in "human factors" research to understand how to ease the operator's mental work load to minimize errors in the control of nuclear reactors. Such research was later used to evaluate driver response to intelligent vehicles and highway systems.

In the words of one Laboratory scientist, robotics research resembled a "Buck Rogers adventure." For children of today's generation, *Star Trek*, not Buck Rogers, may be a more apt analogy from the world of entertainment. But for both young and old, the effort again proved science's unique ability to enliven the imagination by turning the fantastic into reality.

Chernobyl's Fallout

Oak Ridge, America, and all the world watched and worried in April 1986 as a radioactive cloud from the massive reactor failure at Chernobyl in the Soviet Union circled the globe. The Three Mile Island accident in Pennsylvania had taken place seven years before but remained a fresh memory for



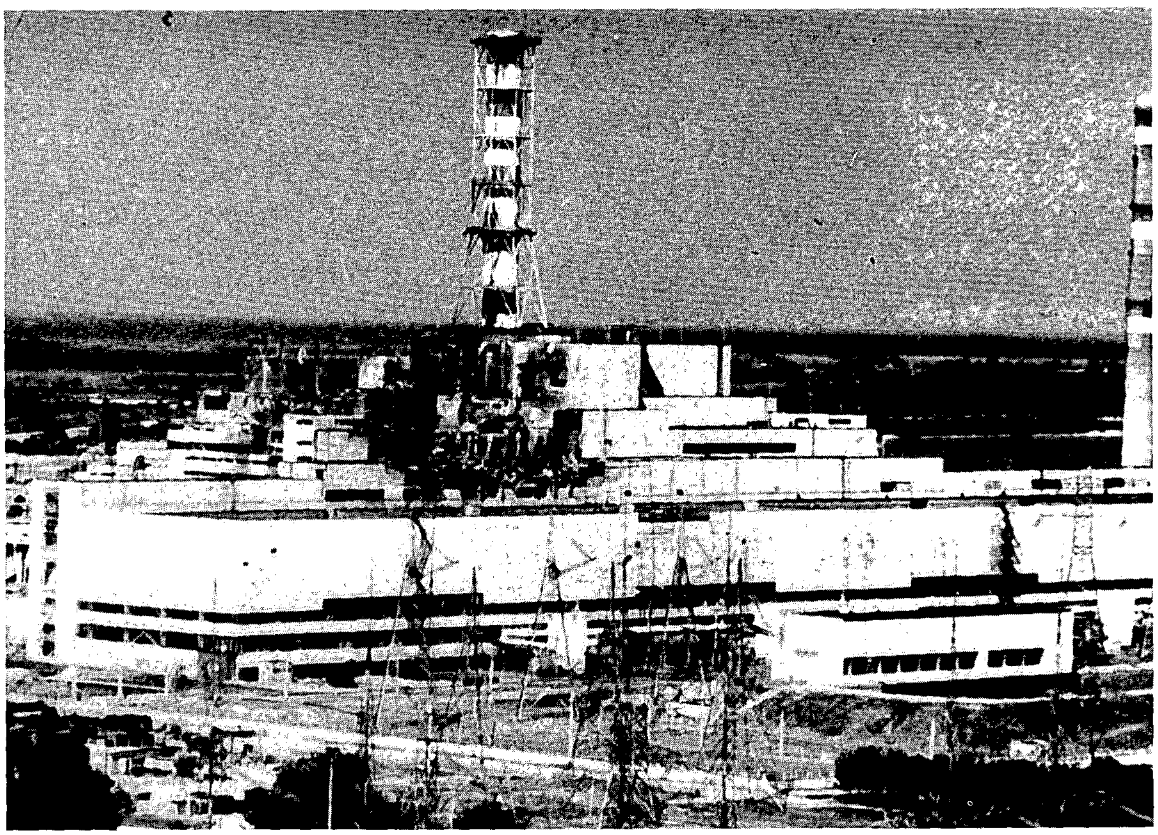
An ORNL experimental robot delivers the 1985 State of the Laboratory address to Director Herman Postma.

many people concerned about the safety of nuclear power. The far more serious accident at Chernobyl renewed public fears and further dampened hope of reviving commercial nuclear power in the United States. The Soviet tragedy also caused a massive DOE reexamination of reactor safety throughout the nation, including detailed inspection of reactors at the agency's nuclear facilities. An industry that had been reeling from mistakes and mishaps for two decades now went into a tailspin.

DOE funding for nuclear power research at the Laboratory had been severely curtailed during the 1980s, even before the Chernobyl accident. "ORNL used to be thought of as a nuclear energy laboratory, a facility whose main mission was fission," Postma remarked in 1986. "That obviously is not the case now." ORNL's reactor research budget plummeted from $50 million in 1980 to $13 million in 1986, representing only 3% of the Laboratory's total budget.

A few weeks after Chernobyl, Postma appointed a committee chaired by Don Trauger to review safety at the aging High Flux Isotope Reactor. After locating and assessing the data, the committee learned the reactor's vessel had been embrittled more than predicted by 20 years of neutron bombardment. In November 1986, the Laboratory shut down the reactor and DOE kept it idle to conduct a thorough investigation because of safety and management concerns.

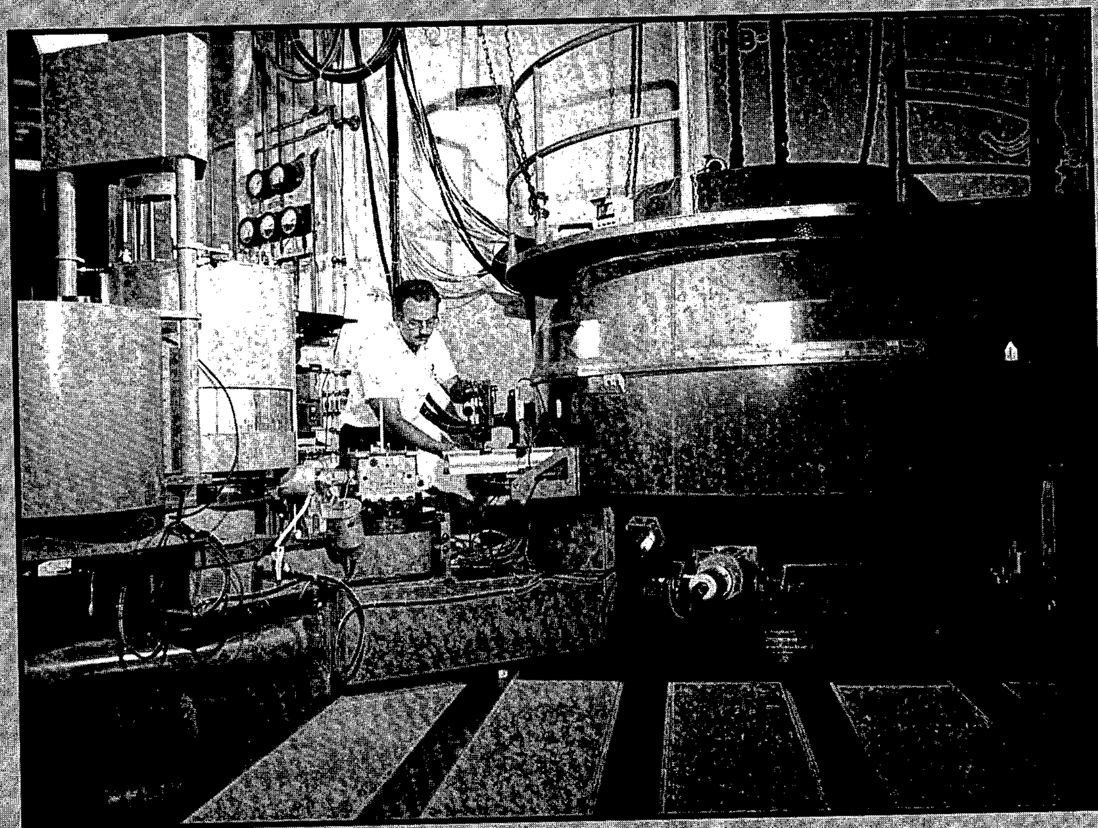
These precautionary steps had severe impacts: they delayed neutron scattering research and neutron activation analysis, slowed irradiation testing of Japanese fusion reactor materials, and



The April 1986 explosion at the Chernobyl nuclear power plant in the Soviet Union stimulated intense investigations of reactor safety throughout the world.

Neutron Scattering Research

Born in Oak Ridge



Bob Nicklow installs a remotely controlled diaphragm that limits the size of the neutron beam in experiments with the triple-axis spectrometer at a beam port of the High Flux Isotope Reactor.

The use of neutron scattering to obtain valuable information on the properties of materials was pioneered in Oak Ridge. Ernest Wollan installed a modified two-axis X-ray diffractometer at a beam port of the Graphite Reactor in November 1945, and he was joined in this work several months later by Clifford Shull. The research by these two scientists and their associates laid the foundation for widespread application of neutron scattering techniques throughout the world and for the preeminent position of these techniques in many areas of scientific research. Their first two-axis neutron diffractometer is now on display at the Smithsonian Institution in Washington, D.C.

"The use of neutron scattering to obtain valuable information on the properties of materials was pioneered in Oak Ridge."

Wollan and Shull, both of the Laboratory's Physics Division, were well prepared for their pioneering efforts in this new field of research. Both had strong backgrounds in X-ray physics and X-ray diffraction techniques, and they quickly recognized the potential of neutron scattering for nuclear and solid-state studies. Within a few years, they and their associates had established neutron scattering as a very valuable, quantitative experimental technique; demonstrated the importance of neutron scattering in determining the positions of hydrogen atoms in materials; observed the existence of ferromagnetism and antiferromagnetism; reported fundamental results on ferromagnetic materials; and measured the nuclear scattering amplitudes for more than 60 elements and isotopes.

The determination of hydrogen positions in materials was of such interest to ORNL crystallographers that a separate program was established in the Chemistry Division under Henri Levy to study hydrogen bonding in crystals. Levy and Selmer Peterson were pioneers in developing the neutron scattering technique for detailed structural analysis of single crystals. Bill Busing, Harold Smith, Ray Ellison, Dan Danford, George Brown, Carroll Johnson

Paul Agron, Bill Thiessen, and Al Narten joined the Chemistry Division program at later dates. As the program moved to more advanced reactors, the experiments shifted to more complicated materials and to more sophisticated equipment. Automatically controlled instruments to orient samples and to position detectors were designed and built, and significant information was obtained on atomic structure and bonding in a large number of materials. The first minicomputer-controlled diffractometer was used in this research, and computer programs were developed for data analysis, which were rapidly adopted by crystallographers throughout the world.

"When the ORR began operating in 1958, ORNL had a brief edge over other research facilities in neutron source intensity."

In the Physics Division, Wollan and Shull were joined by Wallace Koehler in 1949 and Mike Wilkinson in 1950, and this group helped to explain a variety of phenomena in magnetic materials. Shull left ORNL for the Massachusetts Institute of Technology in 1955, and shortly afterward Joe Cable and Ray Child joined the program. In the late 1950s and early 1960s, this group discovered the rich array of exotic magnetic structures in the rare earth metals and alloys—one of the most significant and exciting achievements in the history of neutron scattering. Ralph Moon joined the group in 1963, shortly before Wollan retired and the group was transferred into the Solid State Division.

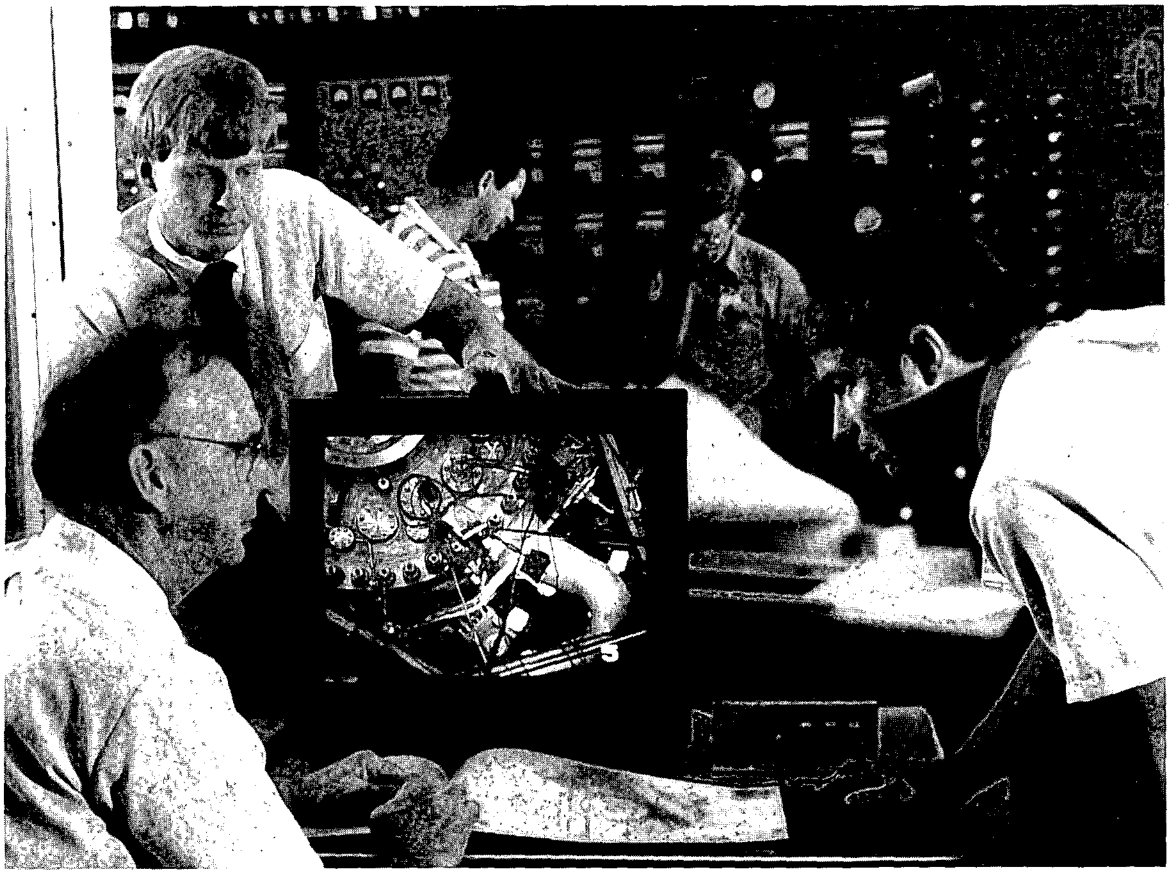
When the Oak Ridge Research Reactor (ORR) began operating in 1958, ORNL had a brief edge over other research facilities in neutron source intensity. In addition to the programs in crystallography and magnetism, in 1962 Mike Wilkinson and Harold Smith, both then in the Solid State Division, initiated a program of inelastic scattering to investigate the dynamic properties of atoms in solids. They were soon joined by Robert Nicklow and Herbert Mook. The group constructed a triple-axis spectrometer at the ORR, which was based on an instrument developed at the Chalk River Laboratory in Canada.

With the startup of the High Flux Isotope Reactor (HFIR) in 1966, ORNL once again had the most intense neutron source for research in the world. This high intensity, together with state-of-the-art instrumentation at the four HFIR beam ports, allowed experiments to be performed that had not been possible previously. Eventually, each of the beam ports was equipped with at least two instruments, and some of them at the time of installation were unique in the world.

In the late 1970s and early 1980s, strong efforts were made by ORNL and DOE to permit scientists from other organizations to use the HFIR facilities for both cooperative and proprietary research. The National Center for Small-Angle Scattering Research, which was strictly for the benefit of users, was established under an interagency agreement between DOE and the National Science Foundation (NSF); it included the design, construction, and operation of a sophisticated small-angle neutron scattering (SANS) facility at the HFIR using NSF funds. Wallace Koehler and Robert Hendricks were leaders in the project, and Koehler became the first director of the national center. George Wignall, who later became the national center's director, and John Hayter, who is scientific director of the Advanced Neutron Source project, came to ORNL to use the SANS facility for the study of polymers and colloids. In addition to the national center, a more formal user's program was initiated for all ORNL neutron scattering facilities, a special cooperative program was started with scientists from Ames Laboratory, and DOE established a cooperative neutron scattering program at ORNL with Japanese scientists as part of the U.S.-Japan Agreement on Cooperation in Research and Development in Science and Technology. The programs hosted about 150 users a year until late 1986.

In November 1986, the HFIR was shut down for more than three years because of concerns about safety and management of the reactor. The user programs were suspended until the summer of 1990, but interest in performing research on the HFIR instruments has increased rapidly since then. Unfortunately, the neutron scattering instruments are old, and the best facilities for research are found in Western Europe. The Advanced Neutron Source, which is planned for ORNL, would provide the highest-intensity neutron beams in the world, furnish new state-of-the-art instruments, accommodate over 1000 users annually, and undoubtedly return leadership in this very important field to the United States. The neutron is a unique and remarkable probe for studying materials, and neutron scattering research provides information that is essential in development of new and better materials for many technologies. The Advanced Neutron Source would permit these important investigations to continue well into the next century.

"With the startup of the HFIR in 1966, ORNL once again had the most intense neutron source for research in the world."



Ken Belitz, Michael Farrar, Greg Kickendahl, Robert Cupp, and William Hill monitor tests of the High Flux Isotope Reactor pressure vessel in 1987.

"Concerned about reactor safety management, DOE shut down all reactors at the Laboratory in March 1987."

reduced radioisotope production for medical research. The halt in production of californium-252, an isotope vital for cancer research and treatment and industrial uses, was especially critical.

Concerned about reactor safety management, DOE shut down all reactors at the Laboratory in March 1987. To oversee a safe restarting of at least some of the reactors, Fred Mynatt became the associate director for Reactor Systems, and responsibility for reactor operations was assigned to a new Research Reactors Division. For the first time since its inception in 1943, however, in 1987 ORNL had no nuclear reactors in operation.

For the Laboratory, the fallout from the Chernobyl accident had a positive side because it stimulated reactor research supported by DOE. ORNL scientists, for example, made calculations to determine the time of the accident—information the Soviets would not reveal. Relying on data on fission-product concentrations in Europe, Laboratory researchers correctly predicted the chemical conditions affecting the two releases of radioactivity from the stricken reactor. In July 1986 ORNL assembled a team from several DOE laboratories to model the Chernobyl reactor systems to better understand the causes, course, and consequences of the accident. The team concluded that the accident might not have happened if the Soviet operators had thoroughly understood their reactor system.

The States of the Laboratory

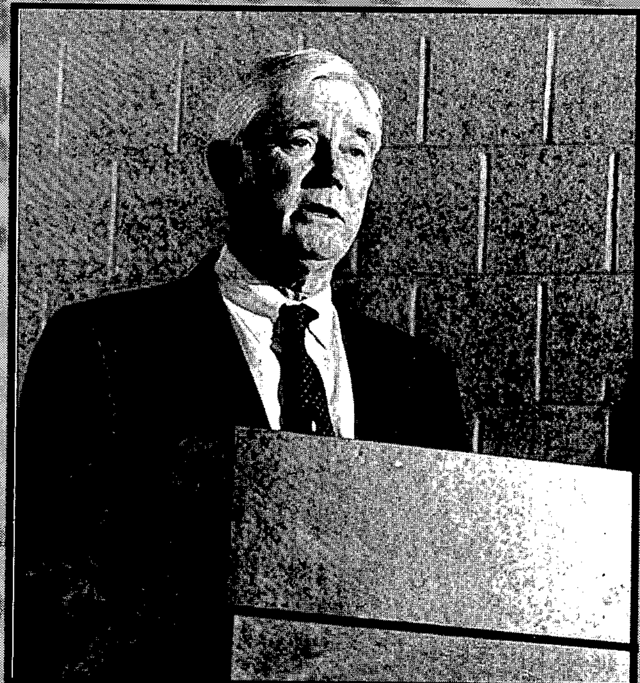
In 1951, while serving as ORNL's research director, Alvin Weinberg offered the first "State of the Laboratory" address. Since then, Laboratory directors have mused over the Laboratory's accomplishments, direction, people, and future in an annual talk that has become a tradition. Early addresses were classified, subsequent addresses were attended by invitation only, and in 1966, the public was invited for the first time.

If the directors were to collectively ponder the activities and nature of the Laboratory, they might agree on the maxim, "The more things change, the more they stay the same."

Consider, for example, the Laboratory's history of concern for environmental management discussed by directors Weinberg and Herman Postma. Commenting on Laboratory activities in 1969, "the year of the environment," Weinberg wrote:

> *The nuclear energy laboratories have, for obvious reasons, been concerned with the environment since the beginning of the Manhattan Project. Handling large quantities of radioactivity without endangering the biosphere and particularly without endangering man was part of our task in 1943 when ORNL was started, and it remains an important part of our job. Our concern with the environment gradually broadened, and now some 10 percent of everything we do at ORNL is related to the environment.*

Postma, given the benefit of hindsight, later reflected on these same environmental management activities. In 1989 he said:



Alvin Trivelpiece delivers a "State of the Laboratory" address.

> *[There is] growing concern about environmental abuses that occurred over the years...We understand the problems (and) we now know how to solve them. . . Our ability to understand, manage, and resolve environmental problems has been demonstrated but it has required a tremendous effort and has been costly.*

On another score, Acting Director Floyd Culler called 1973 the "time of transition" and spoke about the following changes that had rippled through the Laboratory in the wake of the energy crisis.

> *If I believed in destiny, I would be tempted to think that ORNL was predestined to play its most important roles in the next scenes of the great energy dilemma. Destiny or not, we now have the challenge to participate in the most difficult and complex research and development program ever to be proposed. I think that we are ready for the task, but ready or not, we shall be asked.*

Change is not always easy, however. When in 1972 the Laboratory was increasingly in the public eye, Weinberg wrote:

> *We find ourselves increasingly at those critical intersections of technology and society which underlie some of our country's primary social concerns. During 1972 these involvements have boiled over into a series of incidents that make many of us long for the good old days when what we did at ORNL was separate plutonium, measure cross sections, and develop instruments for detecting radiation.*

Twenty years later, Alvin Trivelpiece offered a similar observation in his 1992 address but with an additional proviso: "You can't go back again."

> *Many of us look back with certain fondness or nostalgia for the good old days of the AEC, but I don't think there is any way we can work as we did back then. The Laboratory staff has learned to operate in its present circumstances. The AEC and the ERDA are gone, and the old ways of doing business are not coming back.*
>
> *The American public is more concerned about the environment than ever before. Today, the public does not trust DOE. Members of the public want independent verification of the many facts we generate, and their demand for more audits and oversight will continue. Such audits are intrusive, invasive, and a fact of life. We are going to have to learn to work in this climate and compete for scientific and technical programs at the same time. It is not easy now, and it is not likely to get any easier.*

Fred Mynatt, William Burch, and John Jones led reactor programs at tthe Laboratory during the 1980s.

From Arsenal to Engine

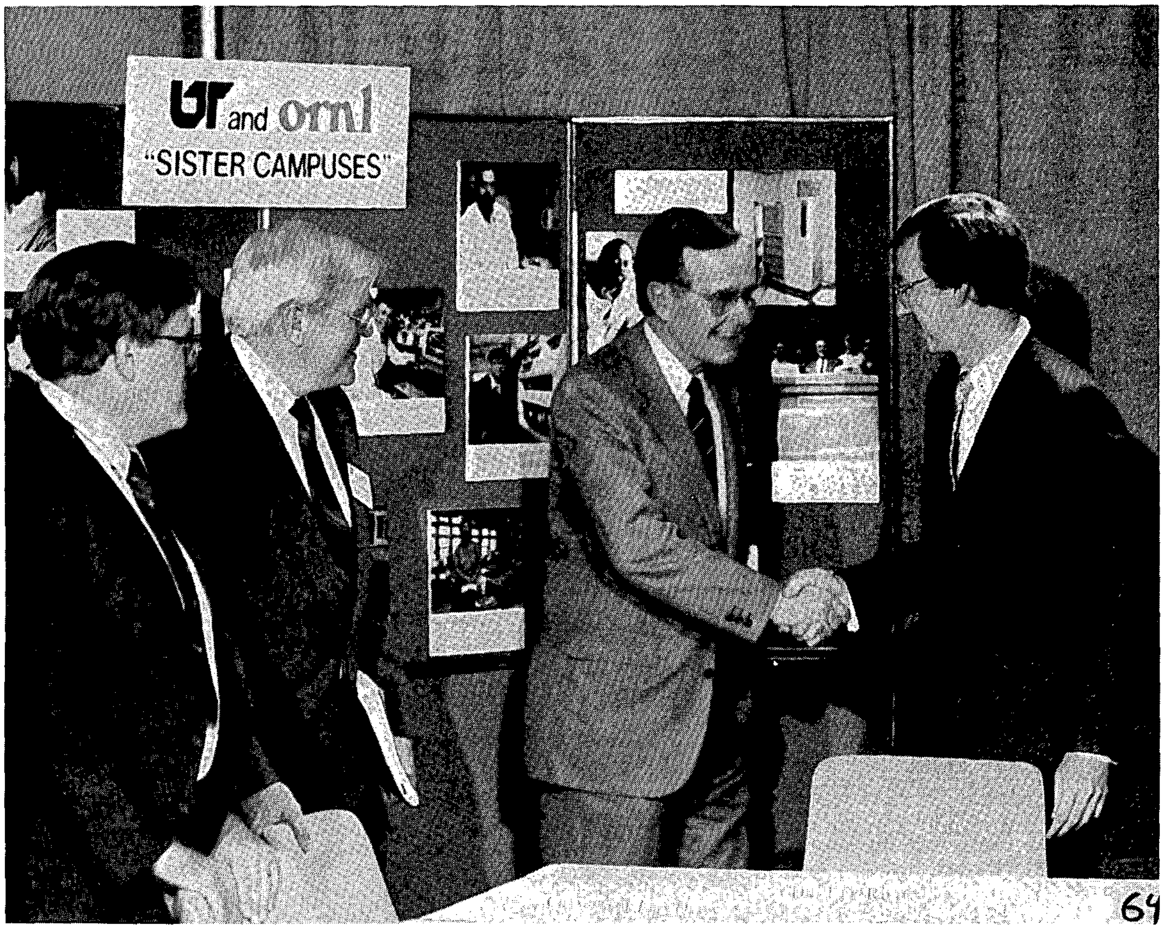
Although no longer strictly a nuclear laboratory, the multiprogram laboratory at Oak Ridge during the 1980s savored its inheritance in scientific research and experimentation. "The essence of a laboratory is that it experiments," Postma said. "It explores, it hurls itself against the limits of knowledge. In short, it tries. Often it fails."

"In 1991, 4400 guest researchers worked at the Laboratory; 30% of these guests came from industry, compared with 5% in 1980."

Still, the change in national administrations in 1981 and the switch of contractor-operators in 1984 sparked a new phase of research within the Laboratory. The cornerstone of this new age of accomplishment was the expanding partnerships with industries and universities. Between 1980 and 1988, the list of official DOE user facilities at the Laboratory increased from 3 to 12 and the number of guest researchers tripled. In 1992, 4400 guest researchers worked at the Laboratory; 30% of these guests came from industry, compared with 5% in 1980.

Technology transfer became the second highlight of the Laboratory's surprising renaissance during the Reagan and then Bush administrations. By transferring the Laboratory's scientific and technological advances speedily into the private sector, the administration and Martin Marietta Energy Systems, Inc., hoped to boost the national economy and improve the competitiveness of U.S. products in international markets. As President George Bush summed it up during a 1992 visit to Oak Ridge, the multiprogram laboratory was being transformed from "the arsenal of democracy into the engine of economic growth."

As the Cold War fades into history, the Laboratory's ability to negotiate the challenging transformation from military arsenal to economic engine is likely to determine how well it serves the nation's interest in the 21st century and beyond.



The cooperation of the University of Tennessee with the Laboratory was emphasized during President George Bush's 1990 visit to Knoxville. From left, David Joy, John Quinn, Bush, and Lee Riedinger.

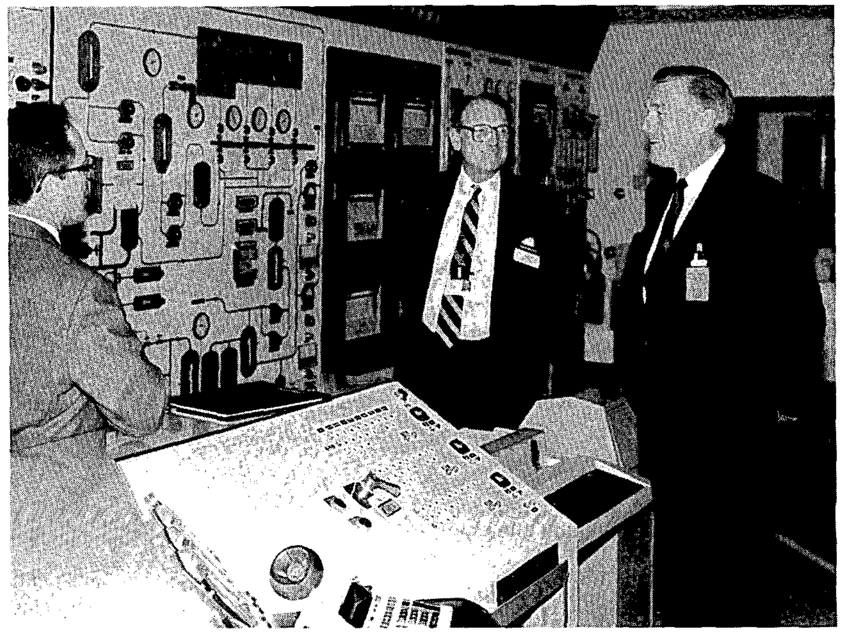
Chapter 9

Global Outreach

As the Laboratory approached its 50th anniversary, science—always an international enterprise— assumed even broader global dimensions. Just as national boundaries were drifting away for the business world, the interests of basic and applied scientists transcended national concerns. Events at the Laboratory during the 1980s and early 1990s reflected this global transition.

The Laboratory's energy-efficiency expertise generated an international demand for its assistance. The U.S. Agency for International Development called on the Laboratory to help Third World countries. These countries have growing appetites for fuels but face shortages of reliable and affordable energy services. To keep energy prices down and to minimize carbon dioxide emissions, as called for by the 1992 United Nations Conference on Environment and Development—the Earth Summit in Rio de Janeiro—these countries must find ways to supply and use energy more efficiently. Laboratory researchers are providing them with technical assistance and energy planning guidance.

In its quest for abundant fusion energy, the Laboratory intensified its scientific cooperation with laboratories in other nations. Its environmental research, which focused originally on nuclear power plant effects, expanded to encompass worldwide environmental threats. Its life sciences divisions united with an international program to map and sequence the human genome. Technology transfer, the Laboratory's keynote of the 1990s, aimed to improve the economic well-being of the United States by increasing its competitiveness in world markets. In short, starting as a national scientific laboratory in 1943, the Laboratory had evolved by 1993 into a global science center.



Secretary of Energy James Watkins, right, visits the High Flux Isotope Reactor's control room.

As its global missions proliferated, the Laboratory's top management underwent transition, paralleled by changes at the national level. George Bush, who became president in 1989, had spent most of his career as a federal employee. Unlike Reagan (and even Carter), opposition to the federal government was neither the rallying cry of his campaign nor the centerpiece of his administration. Bush proposed to use government agencies, including DOE laboratories, to advance his goals.

Specifically, Bush augmented the duties of his science advisor; to advance that goal, the president appointed D. Allen Bromley, who became the assistant to the president for Science and Technology and director of the Office of Science and Technology Policy. Having ready access to the president enabled Bromley to rejuvenate many existing committees that had ceased to function effectively—notably the Federal Coordinating Council for Science, Engineering, and Technology and the President's Council of Advisors for Science and Technology.

"By 1993 the Laboratory had evolved into a global science center."

A new approach to science research and development, called the "Presidential Initiative," also was launched. When such initiatives were announced in global climate modeling, high-performance computing, advanced materials and processing, mathematics and science education, manufacturing technology, and biotechnology, the Laboratory responded with proposals and programs.

To lead DOE, Bush selected Admiral James Watkins, a veteran of Rickover's nuclear navy. Watkins had attended the Oak Ridge reactor school during the 1950s and later recalled that "it was the bright minds of the academics at Oak Ridge, not the blue suit people, who inspired me to go forward in the Navy." From nuclear submarine and ship commander, he rose to chief of operations before retiring from the Navy to become secretary of Energy.

This national transition was accompanied by changes in Laboratory management. After 14 years at the helm, Herman Postma transferred to the executive ranks of Martin Marietta Energy Systems, Inc., in early 1988. While Associate Director Murray Rosenthal chaired a committee to recommend Postma's successor, Alex Zucker served as acting Laboratory director throughout

1988, and Bill Appleton served as acting associate director for Physical Sciences. A nuclear physicist, Zucker had come from Yale University to the Laboratory in 1950 to launch its cyclotron program. A naturalized citizen born in what is now Croatia, he offered an international perspective that inspired closer association with the global scientific community.

Although not troubled by severe budgetary constraints like those of the early 1980s, Zucker inherited several "crises" demanding Laboratory attention. The least troublesome crisis focused on fears that international terrorism might extend into the United States, even to Oak Ridge. Charles Kuykendall, Laboratory Protection Division director since 1979, marshaled his division's resources to protect the Laboratory against potential terrorist assaults, adding an emergency preparedness department and opening a center for high-technology security. Although ORNL has never been even remotely threatened by international terrorism, the new safeguards proved useful, especially when the 1991 Persian Gulf War heightened concerns about terrorism and again when President Bush visited the Laboratory in 1992.

A second and longer-lived crisis of the late 1980s and 1990s involved environmental, safety, and health issues at DOE facilities. Under new, more stringent laws and regulations, federal and state environmental officials monitored both remedial and preventive measures designed to protect human health and the environment on the Oak Ridge Reservation and in the surrounding communities and counties. At the Laboratory, scores of air- and groundwater-monitoring devices were installed, and dozens of environmental safety and health physics specialists were hired to ensure that ORNL complied with the stricter standards. As part of this initiative, the Laboratory also investigated and tested new methods of treating and managing waste.

Estimates indicated that environmental restoration costs at the Laboratory could reach $1.5 billion and that the costs of restoration over 30 years at all DOE installations could exceed $300 billion. The Laboratory's long-standing leadership in environmental restoration technology, it was hoped, could partially offset these staggering costs and provide the Laboratory with new areas of research. Officials even suggested that Oak Ridge might become an international center of excellence in waste management.

A third crisis afflicting the Laboratory in 1988 involved ensuring the safety of its nuclear reactors. In the aftermath of the Chernobyl accident in the Soviet Union, DOE closed the Laboratory's five reactors in 1987 for comprehensive safety reviews. The Oak Ridge Research Reactor had been scheduled for decommissioning, and Laboratory officials thought it imperative that the High Flux Isotope Reactor (HFIR) and Tower Shielding Facility (TSF) be reactivated quickly to alleviate radioisotope shortages and permit resumption of scientific experiments. Officials also identified important Laboratory research programs that depended on the Health Physics Research Reactor and Bulk Shielding Reactor, but the costs of the prescribed environmental, safety, and health improvements precluded their future operation.

Pressed by DOE, Zucker initiated a campaign to improve quality assurance. The Laboratory's Quality Department (formerly Inspection Engineering) increased its work force to 28 people. This staff helped clear the way for the restart of the HFIR and TSF reactors, prepared quality assurance documentation in accordance with new standards, and corrected deficiencies identified by internal and external quality assurance audits by DOE, Energy Systems, and other sponsors.

During Zucker's year at the helm, the Laboratory continued to boost its position as an international leader in materials research by integrating applied materials research, lodged chiefly in the Metals and Ceramics Division, with basic research, found mostly in the Solid State and Chemistry divisions. In the process, the Laboratory hoped to achieve a broader understanding of surface phenomena and physical properties. Such knowledge, in turn, could be applied in many ways—from improving the efficiency of electricity trans-mission to enhancing the speed and safety of ground transportation.

In addition to coping with the challenges facing the Laboratory in 1988, ORNL management concentrated on reassuring the staff

"Air- and groundwater-monitoring devices were installed, and health physics specialists were hired to ensure that ORNL complied with the stricter standards."

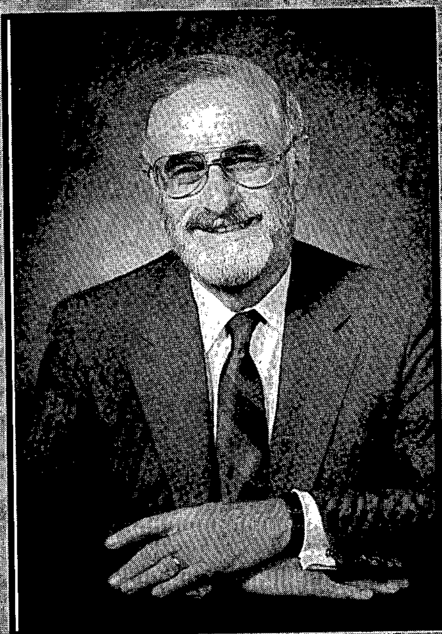
Alex Zucker

From Cyclotrons to Central Administration

Alex Zucker served the Laboratory for more than 40 years both as an eminent physicist and a skilled administrator. His career culminated in 1988 when he was appointed acting Laboratory director, replacing his long-time associate Herman Postma, who assumed the post of senior vice president of Martin Marietta Energy Systems, Inc. Before becoming acting director, Zucker had been an associate director for the physical sciences for years.

"He conducted pioneering research in nuclear physics in the early 1950s at ORNL's 63-inch cyclotron, which he helped design."

Zucker left his mark on the Laboratory in many ways. As a physicist, he conducted pioneering research in nuclear physics in the early 1950s at ORNL's 63-inch cyclotron, which he helped design. There they observed 20 new nuclear reactions, such as the fusion of nitrogen nuclei and the formation of the heavier nuclei of fluorine, sodium, and aluminum by bombardment of oxygen and carbon targets with beams of nitrogen nuclei. The results of their nitrogen fusion studies eased the fear that detonation of a hydrogen bomb might set Earth's atmosphere on fire.



As a manager, he was instrumental in bringing many Laboratory projects to fruition, helping to overcome formidable administrative and budgetary hurdles. His managerial skills, for example, helped bring into being the Holifield Heavy Ion Research Facility and the High Temperature Materials Laboratory. Zucker also lent an administrative hand to acquiring funding for the Laboratory's proposed new research reactor, the Advanced Neutron Source.

A native of what is now Croatia, he received a B.A. degree in physics from the University of Vermont and M.S. and Ph.D. degrees in physics from Yale University. He came to the Laboratory in 1950 and spent his first 20 years conducting nuclear physics experiments and studying reaction mechanisms and the scattering of heavy ions and protons.

Throughout his career, Zucker has influenced not only the Laboratory's specific agenda but broad trends in U.S. science. He served as executive director of the Environmental Studies Board of the National Academy of Sciences/National Academy of Engineering between 1970 and 1972, has been a member of the editorial advisory board of *Science* magazine, is chairman of the American Society of Mechanical Engineers National Laboratory Technology Transfer Committee, and is a fellow of the American Physical Society and the American Association for the Advancement of Science.

"Throughout his career, Zucker has influenced not only the Laboratory's specific agenda but broad trends in U.S. science."

Zucker left the Laboratory in the spring of 1992 to become special advisor to Clyde Hopkins, president of Energy Systems at the time (and also a former ORNL administrator). He retired in January 1993.

that advancing science and technology would remain the Laboratory's principal goal. Concern existed among scientists that the Laboratory's preoccupation with the environment, health, and safety, coupled with the prime consideration given to compliance in setting contractor-operator award fees, would render Laboratory research more conservative and less rewarding. To alleviate this concern, the Laboratory initiated planning and program development efforts for science and technology that emphasized the Laboratory's user facilities and opportunities in technology transfer.

Jack Richard (left) briefs Joe La Grone, Senator James Sasser, and Director Alvin Trivelpiece on the High Flux Isotope Reactor.

By the time Alvin Trivelpiece became the new Laboratory director in early 1989, the Laboratory had improved its emergency response system, promoted innovative waste management technologies, and stood ready to resume reactor operations. There would be no quick fix, however, to the waste management and reactor operations crises, both of which would help define the Laboratory's agenda in the 1990s.

Trivelpiece Reorganizes

In his first address as director in 1989, Trivelpiece outlined the themes of his administration. "As a national laboratory, we need to be able to respond both to inflicted change and to the changes we may cause to occur," he declared. "We need to be a competitor; we need to be serious about competing and to be taken seriously as a competitor in the world's research and development efforts."

Preparing to meet these challenges, Trivelpiece reorganized Laboratory management. Zucker was appointed associate director for Nuclear Technologies, a post he held until moving to the Energy Systems executive staff in 1992. (Jim Stiegler replaced him, and his directorate was renamed Engineering and Manufacturing Technologies.) Murray Rosenthal was named deputy director and found himself drawn heavily into urgent efforts to upgrade the Laboratory's health, safety, and environmental activities. Bill Fulkerson succeeded Rosenthal as associate director for Advanced Energy Systems, later renamed Energy and Environmental Technologies. Chester Richmond continued as associate director for Biomedical and Environmental Sciences, and Bill Appleton was designated associate director for Physical Sciences and Advanced Materials.

As part of the reorganization, Trivelpiece supported several program initiatives and organizational changes to nurture new Laboratory missions and directions. He breathed new life into the Advanced Neutron Source project, which the Laboratory hoped would lead to construction of its first new research reactor in more than 25 years. He divided project responsibilities into reactor operations and scientific research, corresponding to the two major challenges Laboratory staff faced in justifying federal expenditures: how reliable the reactor would be and what kind of research it would support. With Colin West as project director and John Hayter as scientific director, the Advanced Neutron Source became a top Laboratory priority.

"The Advanced Neutron Source became a top Laboratory priority."

"Another Trivelpiece initiative enhanced scientific computing at the Laboratory."

A strong proponent of the Superconducting Super Collider, Trivelpiece also encouraged vigorous Laboratory participation in that project's design and development, largely through creation of an Oak Ridge Detector Center. Acknowledging worldwide scientific concern for the potential impact of global warming, Trivelpiece also encouraged creation of a Center for Global Studies.

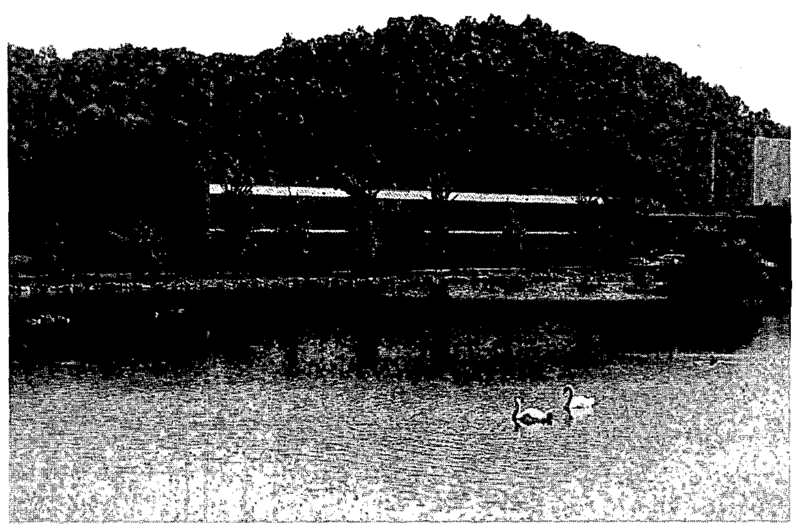
The new director also strengthened the Office of Planning and Management under Truman Anderson. To meet the needs of the increasing number of outside guest scientists and users and to coordinate the cooperative research and development agreements (CRADAs) involving ORNL and industrial groups, an Office of Guest and User Interactions was established.

Another Trivelpiece initiative enhanced scientific computing at the Laboratory. He established an Office of Laboratory Computing under Carl Edward Oliver to coordinate Laboratory interactions with central computing and to stimulate improvements in scientific computing. Citing the expertise developed in parallel computing in the Engineering Physics and Mathematics Division under Fred Maienshein and Robert Ward, DOE designated the Laboratory as a High-Performance Computing Research Center—one of only two laboratories granted this responsibility.

The Laboratory was selected partly because of the wide recognition its researchers have earned for their achievements in computational science, especially in parallel computing. For example, Malcolm Stocks and Al Geist received the 1990 Gordon Bell Prize and a Cray Gigaflop Award for a materials properties code, and Geist was co-winner of the IBM Superconducting Competition First Prize for Parallel Virtual Machine software, which enables computers nationwide to be linked together to solve complex problems.

To promote the use of high-performance computing, a new Center for Computational Sciences was established at ORNL. In partnership with universities and other laboratories, these supercomputers, it was hoped, would help Oak Ridge confront key scientific challenges of the late 20th century—the unknown frontiers in global climate research, human genome sequencing, high-energy heavy-ion physics, materials sciences, and environmental issues such as the transport of groundwater contaminants.

In 1989 Secretary Watkins solicited views and started a consensus-building process to develop a new national energy strategy. ORNL researchers led by Bill Fulkerson and Roger Carlsmith helped formulate this plan by contributing ideas on improving energy efficiency, tapping renewable energy, understanding global climate change, developing energy technologies for Third World countries, and transferring technology. The final report, produced after many public hearings, was the



In 1991, the Laboratory opened a new Computer Science Research Facility to support expanding and interactive mathematical computing, modeling, and analysis.

Malcolm Stocks and Al Geist examine a physical model of the electronic structure of a superconductor that they had computed on a new Intel parallel processor at the Laboratory.

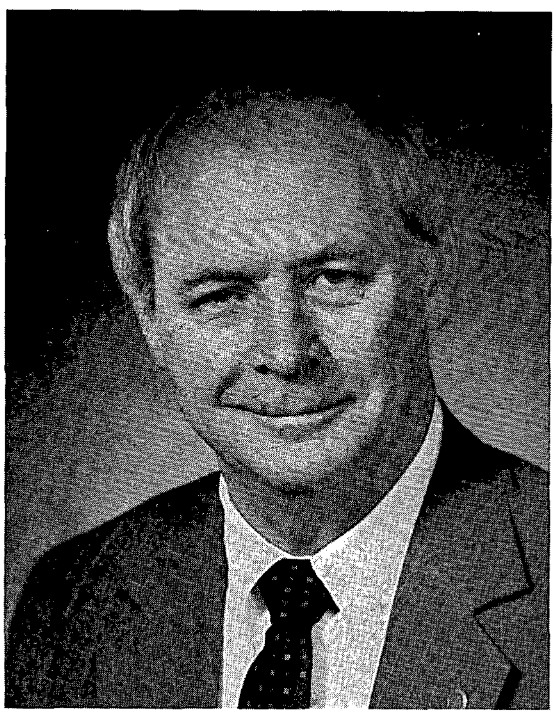
basis for legislation that was debated in Congress and passed as the Energy Policy Act of 1992.

Trivelpiece also enlisted the Laboratory in a campaign spearheaded by Secretary Watkins and President Bush to foster science and mathematics education. In February 1990, he appointed Chester Richmond director of the Laboratory's science and math education programs, an announcement that coincided with President Bush's visit to Knoxville to boost public support for science education.

"The Laboratory expanded its educational programs designed to foster elementary and secondary science education."

Under this initiative, the Laboratory expanded its educational programs designed to foster elementary and secondary science education, largely through hosting student workshops and teacher training seminars. In an effort to attract new students into the world of science, the science education program further strengthened Laboratory cooperation with minority educational institutions. More than 16,000 precollege students visited the Laboratory in 1991, many participating in weekend academies for computing and mathematics.

When Richmond moved to science and mathematics education programs in 1990, David Reichle succeeded him as associate director for Biomedical and Environmental Research, later expanded to include the Energy Division and renamed Environmental, Life, and Social Sciences. By 1992, this directorate had experienced significant growth and led Laboratory advances into research on global environmental change, economic competitiveness, and human health.



Chester Richmond, former associate director for Biomedical and Environmental Sciences and now director of Science Education and External Relations.

Reactor Management

Restarting its reactors was at the forefront of the Laboratory's agenda. After extensive review and improvements of the HFIR's safety and

"The HFIR was brought back on line in April 1990."

management, DOE's Oak Ridge Operations manager, Joe La Grone, recommended reactivating the reactor in late 1988. And, in March 1989, Admiral Watkins surprised a Senate committee by announcing that HFIR operations would resume at Oak Ridge.

The long process of restarting the reactor was managed by Robert Montross, Jack Richard, Pete Lotts, and Hal Glovier. As a result, the HFIR was brought back on line in April 1990 at 85% of its original power. The Laboratory also restarted its Tower Shielding Facility reactor in December 1989, allowing shielding studies for breeder reactors funded by DOE and Japan to proceed. This reactor had been used for many years for shielding experiments developed, designed, and analyzed by Dan Ingersoll and others. The Laboratory mothballed its Bulk Shielding Reactor, Health Physics Research Reactor, and Oak Ridge Research Reactor, however, and initiated steps to decommission them, although Jack Richard and the Laboratory believed the Health Physics Research Reactor deserved retention as a national asset.

Age of Materials

In 1989, the National Research Council published a comprehensive study titled *Materials Science and Engineering: The Age of Materials*. It provided a detailed assessment of the critical roles materials science and engineering would play in the future economic competitiveness and prosperity of the United States. ORNL staff played a major role in this study, and the systematic development of multidisciplinary materials science programs at ORNL served as a case study of why materials were technologically and economically important, and why the 1990s seemed destined to become the "age of materials."

Materials science, which had begun in earnest during the Laboratory's nuclear airplane project in the 1950s, had slowly evolved from a program defined by disparate agendas into a cohesive and comprehensive research initiative. The Solid State Division, launched in 1950 under Douglas Billington, initially examined radiation effects on materials, but expanded over the decades to explore the physical properties of many types of materials needed for new technologies. This work was directed by Mike Wilkinson, Bill Appleton, Fred Young, and Jim Roberto. The Metals and Ceramics Division, begun in 1948, steadily moved into broad research and development efforts that included advanced alloys and ceramics, under the leadership of John Frye, Jim Weir, Jim Stiegler, and Doug Craig.

The interaction of these two divisions, together with support from the Chemistry, Chemical Technology, and Analytical Chemistry divisions, provided a broad multidisciplinary research organization with unparalleled capabilities for characterizing and analyzing materials. Alloys developed to withstand severe radiation damage in reactors were found to have valuable commercial applications. Ion beam facilities built to simulate radiation damage to materials were found useful for the fabrication of solar cells and semi-conductors. Furthermore, the fundamental understanding of

Mike Wilkinson, a pioneer in neutron scattering investigations, directed solid-state physics research at the Laboratory during the 1970s and 1980s.

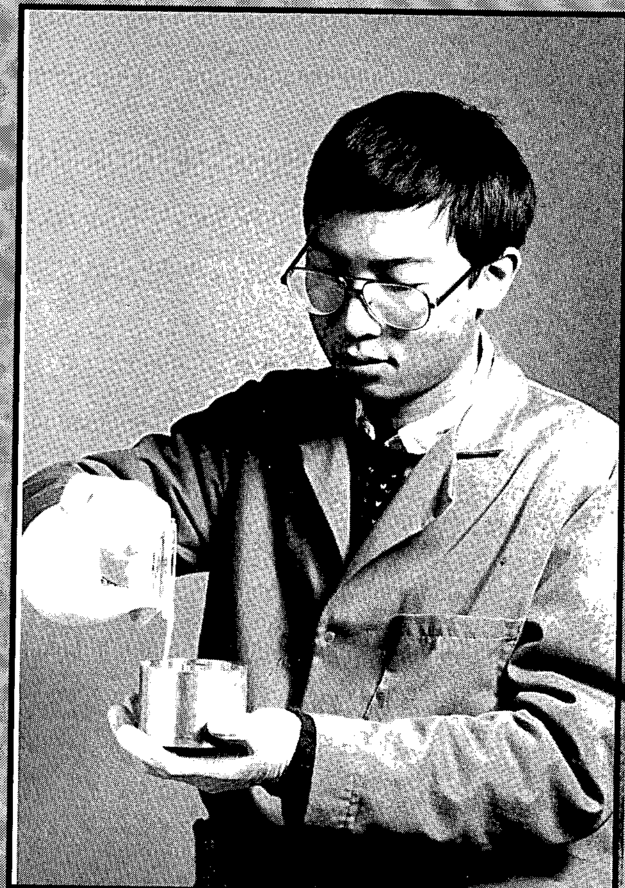
Ceramics and Energy

It's a Materials World

Created by John Frye in 1952, the ceramics research group at the Laboratory was later managed by Lou Doney, Bill Harms, Jim Scott, Walt Eatherly, and Vic Tennery. During the early decades, this group concentrated on developing ceramic fuels for nuclear reactors. Unlike metal fuels, ceramic fuels would not melt during high-temperature reactor operation. The early ceramics research contributed to the adoption of ceramic uranium dioxide pellets inside zirconium alloy tubes as the standard fuel in light-water reactors worldwide. For gas-cooled reactors, ceramics research developed tiny spheres of nuclear fuel with special coatings to prevent release of fission products into the helium coolant.

Studying ceramics for nuclear reactors led the Laboratory ceramic research team into related fields. While studying uranium dioxide during the 1960s, for example, Wayne Clark and Ted Chapman invented a method for growing single crystals of this material incorporating tungsten metal fibers. This ceramic matrix composite proved useful in electronic devices.

When the Laboratory became involved in broad energy research during the 1970s, ceramics research was applied to materials in addition to nuclear fuels. As industry shifted from imported oil and natural gas to coal burned in hotter, more energy-efficient furnaces for many manufacturing processes, it became interested in identifying corrosion-resistant materials for high-temperature furnace liners and heat exchangers. Ceramics were a logical choice for such applications, and Laboratory ceramics researchers led by Vic Tennery focused on meeting these needs.



Albert Young pours a slurry of aluminum powder and pre-gel solution into a mold, the first step of ORNL's "gel casting" process of forming a ceramic part.

They learned that silicon nitride and silicon carbide could maintain their strength and resist corrosion at the high temperatures of advanced gas turbines and heat exchangers. On the other hand, these brittle materials can fail at high temperatures because of internal flaws produced during their manufacture.

Using electron microscopes to reveal ceramic structure, Laboratory researchers studied ways to improve the processing of these materials to make them more uniform and fracture resistant. They learned how to reduce ceramic brittleness by reinforcing the materials with silicon carbide whiskers, just as straw was used to reinforce the adobe clay used in Pueblo houses. Whisker-reinforced ceramics now are used in high-speed cutting tools.

In 1985, DOE approved a program at the Laboratory to develop ceramics for advanced heat engines, which will use fuel more efficiently than current engines. Led by Tennery, Tony Schaffhauser, Ernie Long, and Ray Johnson, Laboratory research developed structural ceramics for use in the high-wear parts of large diesel engines and experimental gas turbines being developed for transportation and electricity production.

With strong support from industry, the Laboratory opened a High Temperature Materials Laboratory in 1987. Here, Laboratory scientists and engineers cooperate with industrial and university researchers exploring ceramics and other materials development. The presence of this unique user facility has encouraged several industrial firms to build plants in Oak Ridge.

Recently, Laboratory and industrial researchers have discovered how to make silicon nitride materials self-reinforcing, thereby achieving the same goals as whisker-reinforced ceramics. The latest silicon nitride materials have found use in engines for cars and trucks. These and other new ceramics developed at the Laboratory will find wide use in industry.

Claudette McKamey inserts a corrosion-resistant iron aluminide specimen into a furnace to test its strength and ductility.

researchers continue to study carbon. For example, Bob Clausing and Lee Heatherly research thin diamond films that can be used as abrasives and cutting tools in the electronics industry. Laboratory scientists Bob Compton and Bob Hettich have observed that large all-carbon molecules, called buckyballs, can take on additional electrons, which suggests they may find applications in batteries and superconductors. Compton and Hettich also have studied fluorinated buckyballs that may be used as a lubricant.

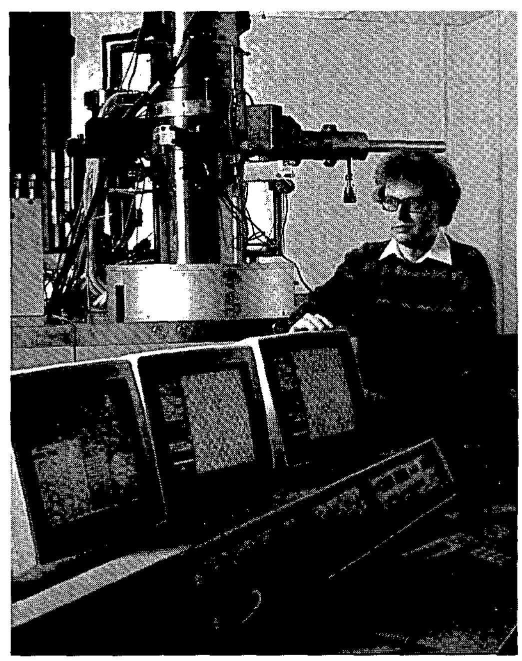
Carbon is only one source of material investigations at the Laboratory. In alloy development, C.T. Liu, Claudette McKamey, and Vinod Sikka have forged iron

materials obtained in previous investigations and the ability to apply a variety of techniques to major projects were the ingredients needed to help meet the research and development requirements of U.S. industry.

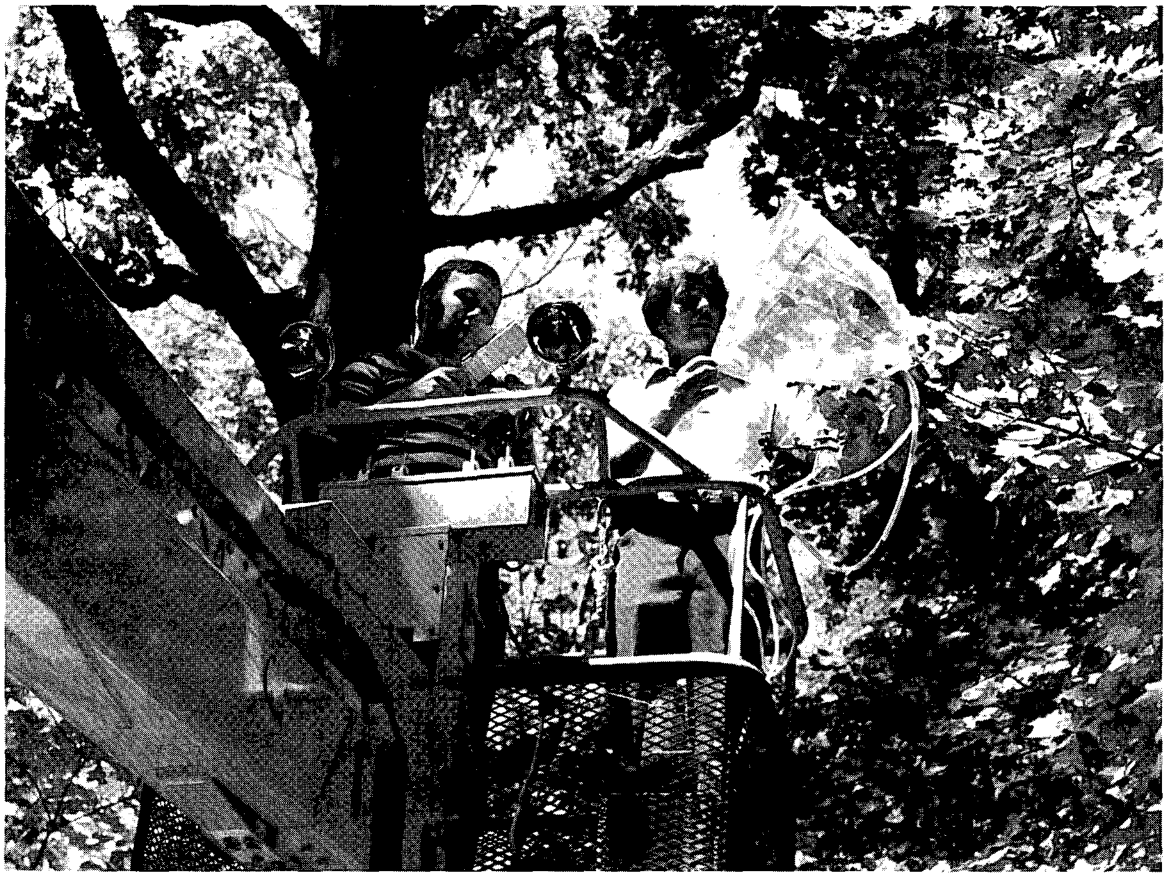
Laboratory staff also contributed significantly to the National Research Council's assessment of materials science. Bill Appleton, for example, chaired the council's solid-state sciences committee, which coordinated the report, and Jim Stiegler co-chaired an assessment panel. Moreover, the Laboratory hosted one of four regional meetings requested by the Office of Science and Technology Policy to follow up the report, edited the combined report, and helped to obtain a Presidential Initiative on Advanced Materials and Processing.

In the late 1980s and early 1990s, Doug Lowndes and his colleagues used laser technology to make high-temperature superconducting films. Steve Pennycook, in turn, used a new imaging technique with a scanning transmission electron microscope, which he developed at the Laboratory, to view the step-by-step development of these films in an effort to advance the process and improve the product.

Following in the footsteps of the laboratory's original Graphite Reactor researchers, today's ORNL



Using a scanning transmission electron microscope modified to exploit his innovative technique, Steve Pennycook obtains unusually sharp images of columns of atoms in high-temperature superconducting material.



In 1976, Ron McConathy and Sandy McLaughlin examined foliage at ORNL to explore effects of atmospheric deposition on forests.

aluminide alloys that can be used in corrosive, high-temperature environments.

In ceramics, George Wei, Ron Beatty, Paul Becher, and Terry Tiegs have shown that silicon carbide whiskers effectively reinforce many ceramics and keep them from cracking at high temperatures. Tiegs and his colleagues also developed a potentially tough cutting material—tungsten carbide bonded by nickel aluminide—which may find many industrial uses. And Laboratory researchers are now guiding development of improved silicon nitride for use in high-temperature engines, such as gas turbines.

Using polystyrene, the main ingredient of styrofoam cups, ORNL researchers led by Al Mattus in the Chemical Technology Division developed a strong, deterioration-resistant superconcrete that could be used for bridge supports and toxic waste containers. Solid State Division researchers led by John Bates developed thin films for advanced microbatteries to provide backup power for computer memory chips. These developments show that the Laboratory will continue to play an important role in the Age of Materials.

The Global Environment

Laboratory efforts to quantify and resolve threats to the global environment began as early as 1968, when Jerry Olson of the Environmental Sciences Division initiated studies of carbon dioxide levels in the world's atmosphere. David

"This ORNL proposal was one of several that encouraged DOE to launch a major global carbon dioxide program."

Rose, who spent a few years at ORNL before returning to the Massachusetts Institute of Technology, stimulated studies of ways to control carbon dioxide emissions. In 1976, Alex Zucker expressed concern about global warming—that is, the potential for Earth's surface temperatures to rise largely because of increased carbon dioxide levels in the atmosphere—and he assembled a team composed of Olson, Charles Baes, and Hal Goeller, all of ORNL, and Ralph Rotty of Oak Ridge Associated Universities' newly formed Institute for Energy Analysis to study the problem and recommend appropriate Laboratory actions. Observing that carbon dioxide concentrations in the air had increased steadily since the Industrial Revolution, the team identified the sources and sinks of carbon dioxide, pinpointing the crucial role of oceans in absorbing carbon dioxide from the atmosphere and the great uncertainties connected with the problem.

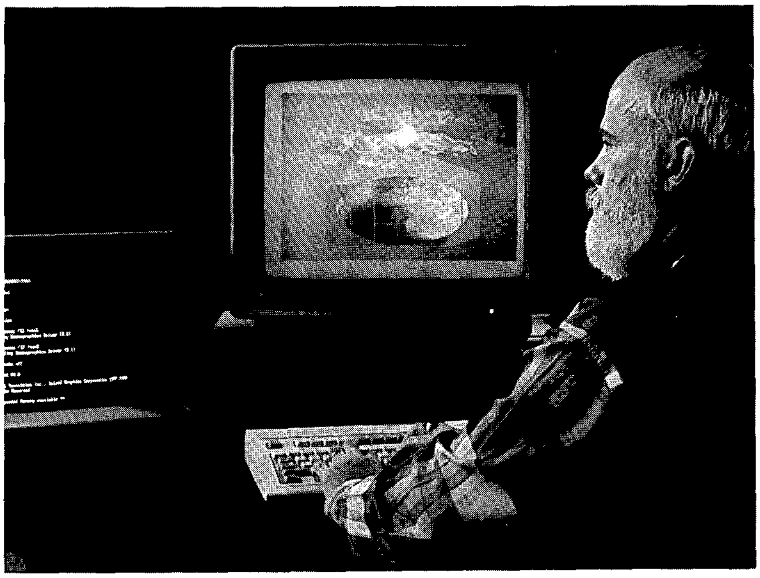
With DOE support, the Laboratory began analyses of emerging global environmental concerns related to energy use. The burning of fossil fuels and forests was cited as the prime cause of the steady buildup of carbon dioxide in the atmosphere. Fossil fuel burning also was linked to the formation of acids in the atmosphere, which rain down on forests hundreds of miles from their diverse sources.

During the late 1970s, Henry Shugart and David Reichle proposed to DOE a study of the global carbon cycle and its relationship to fossil fuel burning. This ORNL proposal was one of several that encouraged DOE to launch a major global carbon dioxide program. With Reichle, John Trabalka, and Michael Farrell of the Environmental Sciences Division providing leadership, the Laboratory adopted an inter-disciplinary research strategy to identify the sources, distribution, and consequences of global warming and acidic rain deposition. This effort, in turn, sparked vigorous experimentation at the Laboratory on global biogeochemistry.

David Shriner examines bean plants in a rainfall simulator to assess the effects of acid rain on vegetation.

Laboratory scientists used computer modeling to estimate how additional accumulations of carbon dioxide in the atmosphere might induce future global climate changes. Some models predicted intense global warming, with potentially devastating effects on trees and crops. In the field, Laboratory scientists examined tree rings and fossil pollen grains taken from lake sediments to detect past climatic conditions and trends. For example, using fossilized pollen recovered from sediment taken from Tennessee ponds, Hazel Delcourt and Allen Solomon reconstructed changes in regional vegetation over 16,000 years. With this paleoecological evidence, they estimated the future effects of carbon dioxide concen-trations on vegetation and the climate.

The greenhouse effect and acid rain were truly global challenges, and quantifying their results and devising potential solutions required an understanding of complex physical, chemical, and biological processes on a global scale. The Laboratory's approach, therefore, expanded to include global monitoring, measurement, and modeling using the largest, fastest computers available. The Laboratory took the lead in formulating global carbon simulation models and became responsible for managing the DOE research effort, subcontracting studies to universities and other laboratories and establishing the National Carbon Dioxide Information and Analysis Center to compile and disseminate data.



Michael Farrell, director of Laboratory research on "greenhouse effects," views global computer image.

"In July 1989, Trivelpiece announced formation of a Center for Global Environmental Studies."

To investigate acid rain and its effects, the Environmental Sciences Division installed rainmaker simulator chambers in a greenhouse and programmed them to control raindrop size, intensity, and chemical composition; for comparison purposes, they built an identical system using unpolluted water. These experiments examined the consequences of prolonged ecosystem exposure to rain polluted by sulfur and nitrogen oxides, ozone, and other materials. The accumulated data helped set regulatory standards for environmental protection.

In the late 1980s, the Electric Power Research Institute and other agencies funded Laboratory studies of the effects of acids on streams in the Appalachian, Great Smoky, and Adirondack mountains. Ernest Bondietti managed this project, which sought the cooperation of a dozen universities in the eastern forest region. Early results indicated that acids in mountain streams had natural geologic sources in addition to human-induced sources created largely by industry and transportation.

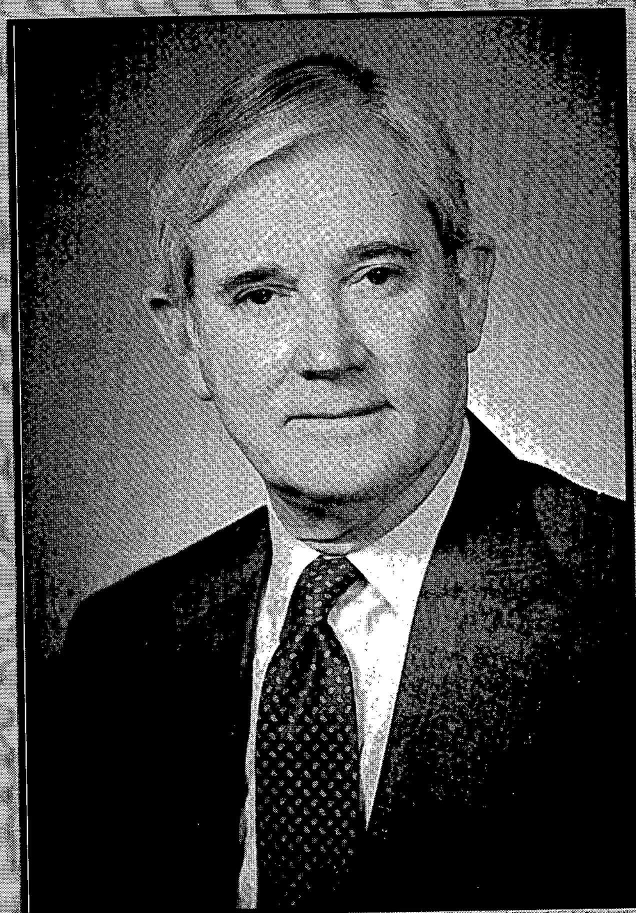
ORNL acid-rain researchers made important contributions to the National Acid Precipitation Assessment Program (NAPAP) as well as the Integrated Forest Study. They found that atmospheric deposition of sulfur and nitrogen oxides is twice as high in the Great Smoky Mountains as in the New Hampshire mountains. They observed that acidic cloudwater is linked to reduced growth in high-elevation trees. They learned that ground-level ozone is more damaging than acid rain to U.S. crops. Relying partly on ORNL research, NAPAP concluded in 1990 that acid rain has harmed only a small number of lakes and forests; even so, the amended Clean Air Act called for stricter controls on U.S. emissions.

At the Laboratory's Walker Branch Watershed, Dale Johnson and Daniel Richter conducted forest-nutrient cycling research on the soil-leaching effects of acid deposition, and in 1992 the Laboratory announced the watershed would be the site of the first large-scale field studies of the effects of global warming on forest growth.

This and other research supported a steady growth in the Laboratory's environmental sciences program. With about 200 full-time employees and more visiting university faculty and students than other divisions, the Environmental Sciences Division built an international reputation.

In July 1989, Trivelpiece announced formation of a Center for Global Environmental Studies to be

Director Alvin Trivelpiece



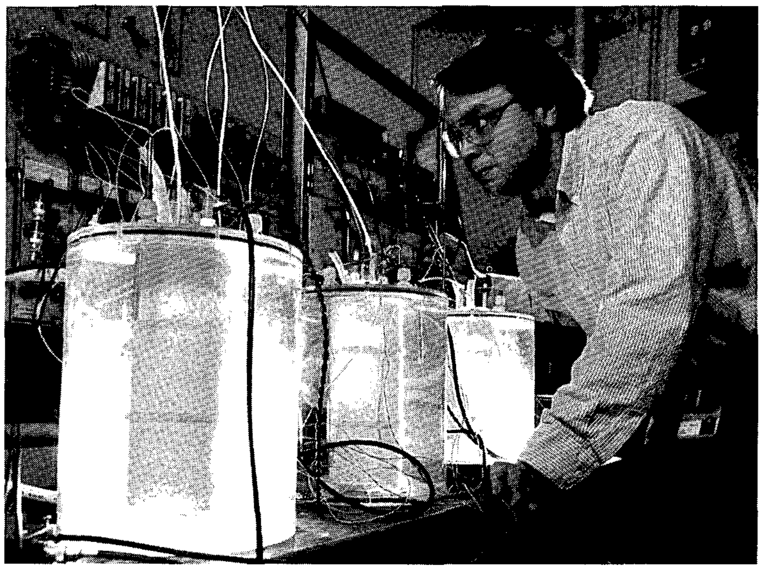
Selected in 1988 to succeed Herman Postma as Laboratory director, Alvin Trivelpiece shared the dual expertise of Eugene Wigner and Alvin Weinberg before him. A chemical engineer, Wigner had become a physicist; biophysicist Weinberg had become a nuclear physicist. Trivelpiece was an electrical engineer who became a physicist.

Trivelpiece earned his doctorate in electrical engineering in 1955 and taught the subject at the University of California for years. In 1966, he went to the University of Maryland as a professor of physics and then became the assistant director of fusion research for the AEC. After working in private laboratories and technological companies in California, he returned to Washington in 1981 as director of the DOE Office of Energy Research. He was serving as an executive officer of the American Association for the Advancement of Science when selected as Laboratory director.

Extensive knowledge of both engineering and science is important in managing such an amalgam of science and technology as Oak Ridge National Laboratory.

Extensive knowledge of both engineering and science is important in managing such an amalgam of science and technology as Oak Ridge National Laboratory. Trivelpiece had that depth of knowledge and, in addition, had worked in government, academia, and industry. This broad experience was excellent preparation for leading the Laboratory into new partnerships with universities and industrial firms in efforts to achieve faster technology transfer to the commercial marketplace.

managed by Robert Van Hook and Michael Farrell from the Environmental Sciences Division. "Its goal," Trivelpiece said, "will be to achieve better understanding of global air, land, and water environments and more accurately predict the consequences of human activities on the world's ecological balance." The center would concentrate on the causes and effects of such global challenges as greenhouse warming, ozone depletion, acid rain, and deforestation.



Charles Bennett, visiting researcher in 1989 from the University of North Carolina, examines three "cold fusion" tests cells at the Laboratory.

"Reports from ORNL and other national laboratories discredited the discovery of cold fusion."

By the early 1990s, the Laboratory had conducted major studies of ways to avoid ozone depletion, or what the media commonly call the "ozone hole." In cooperation with industry, the Laboratory joined the search for acceptable substitutes for chlorofluorocarbons (CFCs) in refrigerants, insulation, and commercial solvents. Studies at the Laboratory's Roof Research Center in the Energy Division, for example, focused on testing foam-board insulation made with ozone-safe CFC substitutes.

Hot and Cold Fusion

Fusion energy researchers were shocked when two chemists from the University of Utah announced in a March 1989 press conference that they had achieved cold fusion, or fusion at room temperature. By passing electricity through chunks of palladium metal immersed in jars filled with electrically charged heavy water, they said they had produced heat and the neutron by-products of a fusion reaction. If true, the discovery offered an inexpensive alternative to "hot" fusion as an unlimited energy source.

Trivelpiece learned of this announced accomplishment from the front pages of his weekend newspaper. "I used the only scientific tool available to me that weekend—a push-button telephone," he later remembered, "and called everyone I knew who might be able to help me and I tried to find out as much as I could."

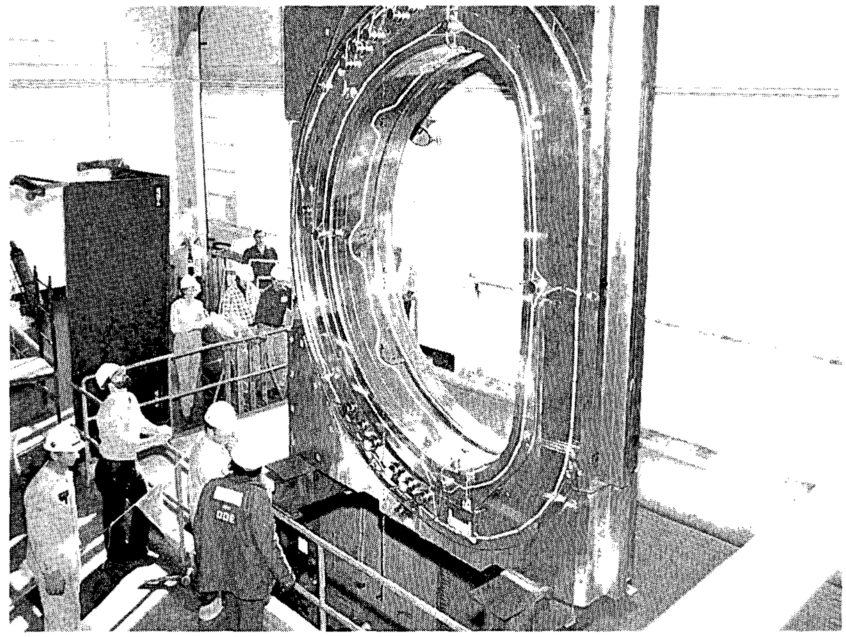
His discussions with Laboratory colleagues revealed they thought the chances were slim for cold fusion but that the Laboratory should investigate it fully. The Laboratory accelerated studies of cold fusion the following week. Teams in the Physics, Metals and Ceramics, Chemical Technology, and Engineering Physics and Mathematics divisions energized a dozen electrochemical cells to test the claims of cold fusion researchers, using more sensitive neutron detection devices than those available to the purported discoverers of this energy source.

Michael Saltmarsh of the Fusion Energy Division chaired a Laboratory committee compiling information on these experiments, and within a month, he testified before a House science committee that the Laboratory had been unable to detect excess heat or radiation in its cold fusion experiments.

This and reports from ORNL and other national laboratories discredited the discovery of cold fusion. Frank Close, an ORNL–University of Tennessee

Distinguished Scientist, published a critique of the short-lived cold fusion events, emphasizing the importance of following accepted scientific procedures when "new" phenomena are reported. Still, limited experimentation continued in the hope that some yet-to-be-explained phenomenon was occurring.

Achieving magnetically confined hot plasma, therefore, remained a major technological challenge at the Laboratory and throughout the world of science. This pursuit assumed cooperative global proportions during the 1980s, especially at the Laboratory's large-coil test stand named the International Fusion Superconducting Magnet Test Facility.



Fusion Energy Division researchers view the Japanese superconducting magnetic coil in 1982.

All major industrial nations conducted research on fusion power during the 1980s and on the superconducting magnets to be used in fusion energy production. In cooperation with the International Atomic Energy Agency, DOE approved construction of a large magnetic coil facility at Oak Ridge to test huge superconducting magnets—three designed and fabricated in the United States by General Electric, General Dynamics, and Westinghouse and three overseas in Japan, Germany, and Switzerland. All used specifications written at the Laboratory so that the magnets would fit into the test facility.

The Laboratory installed the six magnets, weighing 45 tons each, in the toroidal (doughnut-shaped) facility. When its stainless steel vacuum chamber lid was lowered into place atop the magnets and the proper vacuum was achieved, its liquid helium refrigeration system chilled the magnets to almost absolute zero. Paul Haubenreich, assisted by Martin Lubell, managed comparative testing of the magnets during 1986 and 1987, checking their ability to withstand thermal, mechanical, and electrical stresses and determining whether superconducting coils were practical for confining the plasma of fusion reactors.

The magnet test facility operated reliably during 22 months of testing, and the magnets performed well, setting records as the largest superconducting magnetic coils in size, weight, and energy ever operated. This project marked the first time that four nations—the United States, Germany, Japan, and Switzerland—had submitted unique versions of similar equipment to collaborative testing for evaluation of their performance, reliability, and costs.

The 1988 report on the experiment stated that the magnetic coils in operation had exceeded their design parameters, indicating that much larger magnets could be built using similar design methods. The report observed that the successful international cooperation marking the large coil tests boded well for other cooperative global ventures in fusion research.

These conclusions proved useful in the design of the International Thermonuclear Experimental Reactor (ITER) planned as a joint effort of the United States, Russia, Japan, and the European Community. This thermonuclear reactor was being planned as the first fusion reactor in which studies of ignited and burning plasmas could be conducted.

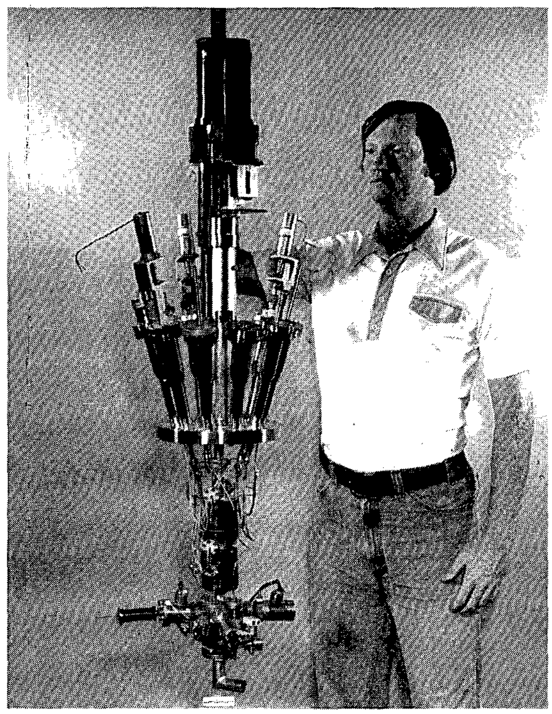
Within the political and scientific communities of the United States, some observers recoiled at the costs of long-term fusion research, fearing that federal research funds would not be available for the long haul. After all, scientists projected that successful fusion energy generation would not occur until the mid-21st century. "Let us not grow weary while doing good," warned William Happer, chief of DOE's Office of Energy Research. Quoting a letter from the Apostle Paul to the Galatians, Happer continued, "For in due season we shall reap if we do not lose heart."

The Laboratory expected to play a significant role in the ITER program, and Paul Haubenreich, manager of the large coil tests, went to Europe for several years to work in that program. Charles Baker of ORNL is now leading the U.S. effort in designing the ITER.

After completing the large coil tests, Martin Lubell and the Laboratory's superconductivity team turned to potential commercial investigations of motors using low- and high-temperature superconducting materials. A team that included Bob Hawsey of the Applied Technology Division, Bill Schwenterly of the Fusion Energy Division, Keith Kahl of the Engineering Technology Division, and Ben McConnell of the Energy Division built and operated the first superconducting motor by 1990. Tests and improvements of this device could lead to development of smaller, lighter, more energy-efficient motors.

Stellar Performance

Other Laboratory advances in fusion energy research during the late 1980s and early 1990s included improved plasma fueling and heating devices and construction and testing of the Advanced Toroidal Facility (ATF), a stellarator fusion reactor shaped more like a cruller than a doughnut. Much of this work was done under the supervision of John Sheffield, director of the Fusion Energy Division.

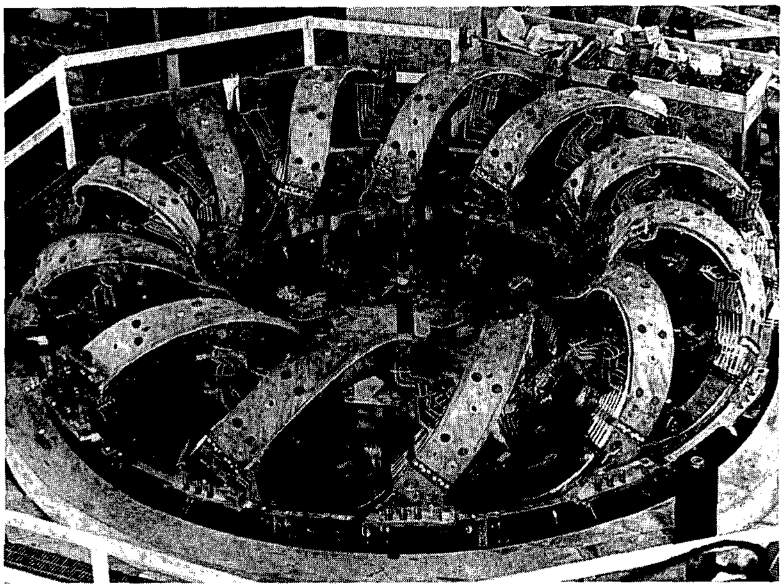


Stephen Combs adjusts a pneumatic injector developed at the Laboratory to shoot pellets of frozen deuterium into the plasmas of fusion reactors.

Pioneered by Stanley Milora and Chris Foster at the Laboratory, fueling fusion plasmas by freezing deuterium and later tritium into pellets and firing them into reactors became the standard fueling method worldwide. The Laboratory became DOE's lead agency for this plasma fueling technology. For the ever-larger fusion reactors, the Laboratory fabricated bigger pellets, discharging them into plasmas using an electron beam accelerator to vaporize their back ends and provide a rocketlike forward thrust. The Laboratory also completed a radiofrequency facility in 1985 to test the use of radio waves for heating fusion plasmas, and it joined with Japan's energy institute to conduct collaborative testing at Laboratory reactors of the structural alloys that are candidates for fusion devices.

"The Laboratory became DOE's lead agency for this plasma fueling technology."

"Aiming to create more stable plasmas, the ATF afforded a steady, rather than a pulsed, operation, which utility systems prefer for electric power generation."



The coils of the Advanced Toroidal Facility, an experimental fusion reactor, which was completed in 1987 and produced its first fusion plasma in 1988.

The Laboratory designed and built the ATF to supplant its Impurity Study Experiment tokamak of the 1970s. Called a torsatron or stellarator, the ATF had a helical field for plasma confinement provided entirely by external coils, instead of relying on currents within the plasma as the tokamaks did. Aiming to create more stable plasmas, the ATF afforded a steady, rather than a pulsed, operation, which utility systems prefer for electric power generation.

After four years of construction, the Laboratory in 1988 completed its precision-crafted stellarator, with more than twice the plasma volume of previous stellarators. Its principal purpose was to determine the plasma pressure and stability limits for improved toroidal designs. Testing soon identified a "second stability" phase in the plasma, which was termed a major advance in fundamental plasma physics. The Laboratory sought funding during 1992 for a restart and continued testing of this stellarator, which was the only fusion machine in the United States capable of operating in a steady state.

Funding shortages in fusion energy motivated some Laboratory researchers to apply their technologies in other arenas, such as space applications, materials development, and environmental cleanup. Theorists employed computer modeling to design an ion thruster that one day may be used on space missions to Mars and the other planets. Beam experts studied etching technology for improving semiconductor chips, and pellet-injection researchers tried cleaning surfaces with dry ice pellets at high velocities. Fusion researchers Hal Kimrey and Terry White, who used microwaves to heat fusion plasmas, collaborated with other researchers in using microwave processing to sinter ceramics, to treat radioactive waste, and to clean contaminated concrete.

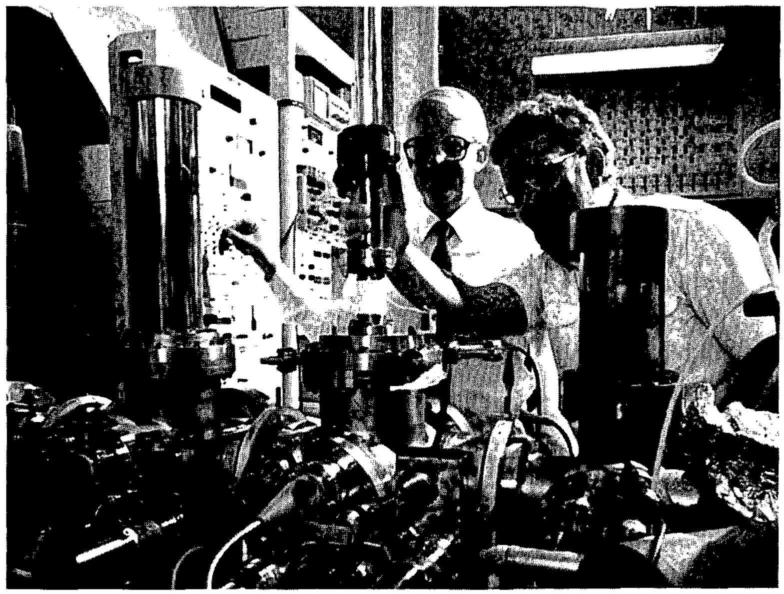
Interest in microwave technology spread to other Laboratory divisions. Bob Lauf of the Metals and Ceramics Division and Don Bible of the Instrumentation and Controls Division, for example, invented a variable-frequency microwave furnace that employed the same technology used for jamming Iraqi radar during the Persian Gulf War.

Although scientists had not achieved a self-sustaining controlled fusion reaction by 1993, clearly the Laboratory's fusion research was producing dividends in a number of practical applications.

Particle Accelerators

Global scientific cooperation is a two-way international highway. In the 1980s, ORNL's Physics Division dispatched two of its large calorimeters and 10 of its scientists under Frank Plasil to the European Laboratory for Particle Physics (CERN) in Switzerland to participate in experiments aimed at observing individual quarks outside nuclei. The experiment fired oxygen nuclei into target nuclei of carbon, copper, silver, and gold at ultrahigh energies, dramatically demonstrating the conversion of energy into matter. The Laboratory calorimeter team saw particles bombarding the gold nuclei multiply into many more particles.

Trivelpiece was credited with persuading the Reagan administration to explore mysteries of the nucleus through construction of a Superconducting Super Collider (SSC), a 53-mile oval track to be built underground in Texas where two opposing beams of protons would circle and collide. Scientists seeking to determine whether quarks are the fundamental units of matter or whether they can be further subdivided will run experiments on this huge proton racetrack. It will be the world's most powerful accelerator, if Congress agrees to fund the project to its completion.



Lynn Boatner and Brian Sales adjust the controls of a particle accelerator at the Surface Modification and Characterization Collaborative Research Laboratory.

"Funding shortages in fusion energy motivated some Laboratory researchers to apply their technologies in other arenas, such as space applications, materials development, and environmental cleanup."

Laboratory participants in the SSC project have worked on the design of detectors needed to determine the results of particle collisions. In 1989, the Laboratory formed an Oak Ridge Detector Center, directed by Tony Gabriel. The center hoped to be at the forefront of developing central-system particle detectors for the SSC that could track and measure the directions and initial energies of secondary particles produced by the collisions. Recognizing the value of these devices to global science, the Laboratory consulted physicists from many nations for the detector designs, which were still under development in 1993.

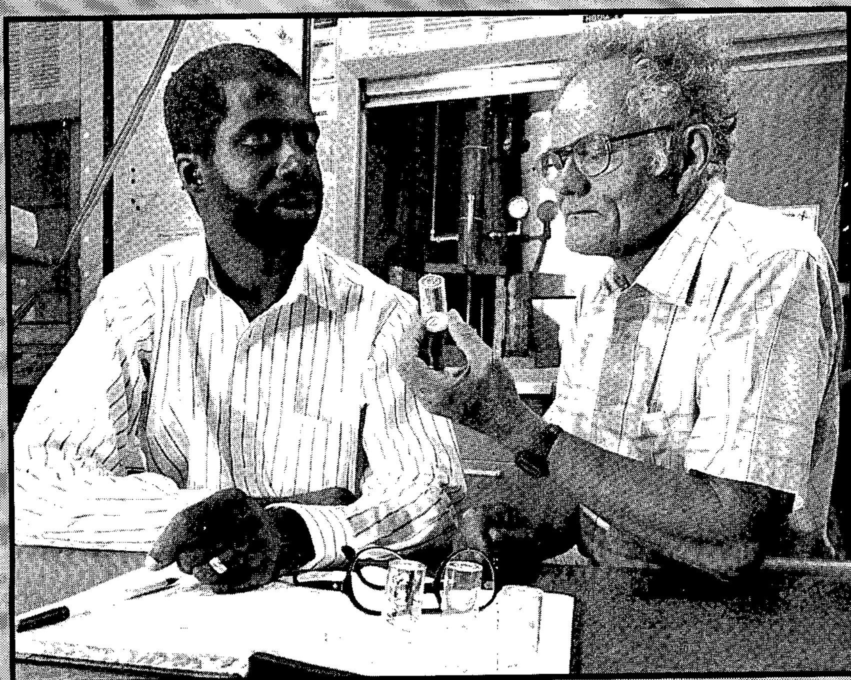
Mapping Genes

Inspired by an Office of Technology Assessment report on detecting inherited mutations in human beings, the DOE Office of Health and Environmental Research in 1987 launched an international campaign to map and sequence the three billion chemical base-pairs in human DNA. Charles Cantor and colleagues at Columbia University had mapped the *E. coli* bacterium, and Larry Hood and fellow researchers at the California Institute of Technology had developed automated sequencing equipment. Among the practical benefits of sequencing the human genome could be new diagnostic tests and therapies for genetic diseases.

Through participation in long-term international studies of the survivors of the Hiroshima and Nagasaki bombs, Laboratory researchers had obtained experience in human gene studies. During the 1970s, the Biology Division had devised gene-mapping techniques for the study of mutagens and carcinogens. Searching for genes that might inhibit cancer, they had identified individual genes and assigned them to specific chromosomes. Laboratory capabilities were further enhanced by development during the 1980s of improved scanning tunneling microscopes that could obtain images of DNA strands. These microscopes could help determine the locations of genes on cell chromosomes (mapping) and the arrangement of DNA bases in the genes

President Zachary Taylor and the Laboratory

Presidential Visit from the Grave



Larry Robinson and Frank Dyer examine a sample of hair removed from the body of President Zachary Taylor. Using neutron activation analysis on this and other samples, they determined that Taylor had not died of arsenic poisoning.

Shortly after breaking ground for the Washington Monument on July 4, 1850, President Zachary Taylor, a hero of the Mexican War, fell ill. When he died suddenly a few days later, the cause was listed as gastroenteritis—inflammation of the stomach and intestines.

Some historians suspected that Taylor's death may have had other causes, and in 1991 one convinced Taylor's descendants that the president might have suffered arsenic poisoning. As a result, Taylor's remains were exhumed from a cemetery in Louisville and Kentucky's medical examiner brought samples of hair and fingernail tissue to Oak Ridge National Laboratory for study.

In the Analytical Chemistry Division, Larry Robinson and Frank Dyer headed the Taylor investigation, using neutron activation analysis to measure the amount of arsenic in the hair and nail samples. After placing the samples in a beam of neutrons from the High Flux Isotope Reactor, Dyer and Robinson looked at the gamma rays coming from the samples for the distinctive energy levels associated with the presence of arsenic. Arsenic is among the easier elements to identify through neutron activation and can be detected in a few parts per million. Most human bodies contain traces of arsenic, so the essential issue in the Taylor case was whether the samples from Taylor contained more arsenic than would be normal after 141 years in the crypt.

After reviewing the test results, the examiner announced that the arsenic levels in the samples were several hundred times less than they would have been if the president had been poisoned with arsenic.

Working late in the evenings, Dyer and Robinson in a few days calculated the arsenic levels in the samples and sent them to the Kentucky medical examiner for his decision. After reviewing the test results, the examiner announced that the arsenic levels in the samples were several hundred times less than they would have been if the president had been poisoned with arsenic. This finding acquitted several of Taylor's prominent contemporaries of the suspicion of murder and proved that history and science share a common quest for truth.

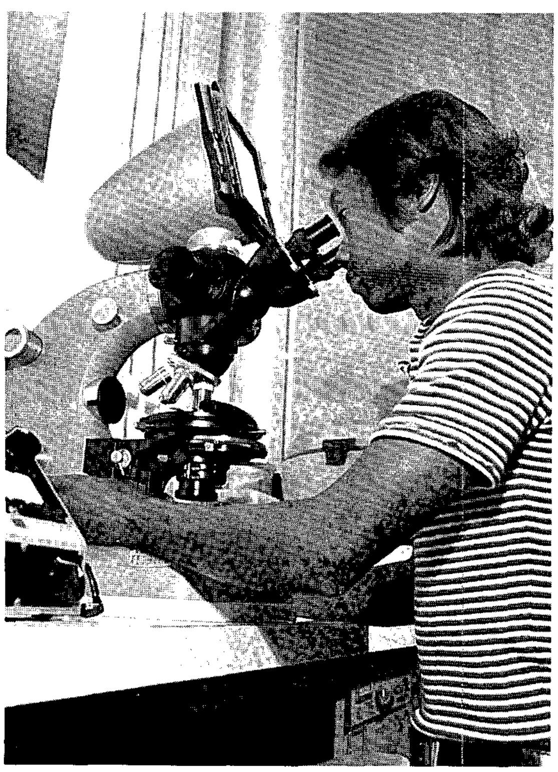
(sequencing) of the human genome. Sponsored by DOE and NIH, the human genome initiative, an immense computer-intensive investigation, became global in scope, with several nations sharing the research and its costs.

The Laboratory, however, had no externally funded human genome projects when the director of DOE health and environmental research programs visited Oak Ridge in 1990. Several "seed" money research projects set the stage for convincing DOE that the Laboratory should be involved in the genome challenge. Six Laboratory divisions were subsequently participating in genome research, focusing on learning the order of chemical bases that make up DNA and locating specific genes to determine their functions.

Using mass spectrometry, gel electrophoresis, radiolabeling, laser ionization, and other research techniques, the Laboratory obtained information on the genome. It also provided a forum for international exchange of genome information through its Human Genome Management Information System, located in the Health and Safety Research Division. In addition, ORNL developed a computer program called GRAIL (Gene Recognition and Analysis Internet Link) that helps researchers identify genes from DNA sequence data.

Tony Gabriel has directed the ORNL effort to design detectors for the Superconducting Super Collider.

"Trivelpiece was credited with persuading the Reagan administration to explore mysteries of the nucleus through construction of a Superconducting Super Collider."



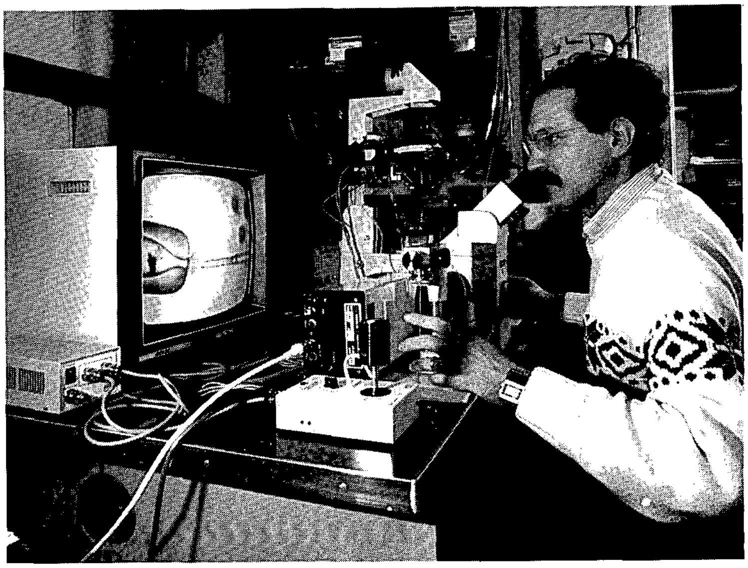
Waldy Generoso discovered a genetic repair mechanism in female germ cells.

The Laboratory also received funding for human genome research because it has been a gold mine of knowledge about mouse genetics, starting with the research of William and Liane Russell. More recent work, in fact, has been particularly relevant for human health. ORNL mouse studies led by Waldy Generoso in the mid-1980s showed that ethylene oxide, which is widely used by health care workers to sterilize medical supplies, can cause mutations in mice. The findings led to regulatory limits on occupational exposure to the gas. The research also suggested that, under certain conditions, women exposed to mutagenic chemicals soon after conceiving may be unwittingly putting their future children at risk. In the 1990s Generoso and his

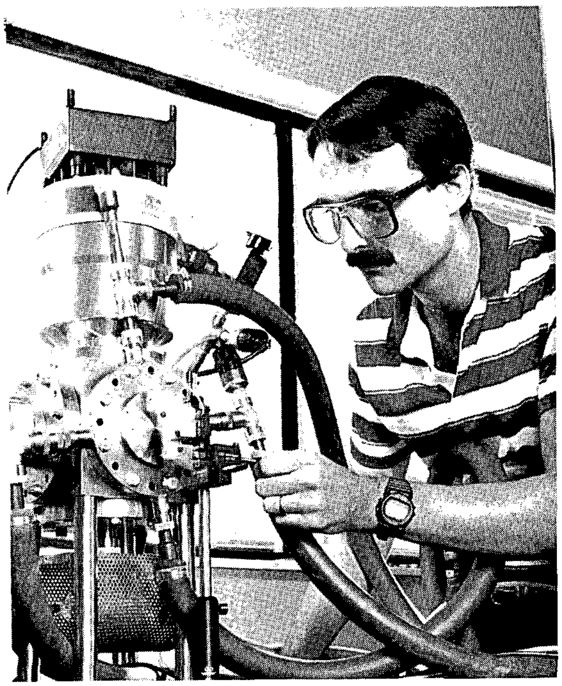
"During the 1970s, the Biology Division had devised gene-mapping techniques for the study of mutagens and carcinogens."

colleagues found that male and female mice respond differently to certain chemicals, and they identified several female-specific mutagens. Their results suggest that certain anticancer drugs pose genetic risks to women but not to men.

DOE encouraged collaboration between the Laboratory's mouse experts and the genome research centers. A Biology Division program led by Richard Woychik and Gene Rinchik, for example, used transgenic mice for genome research. These mice had genetic material with deliberately inserted foreign DNA to help ascertain the locations, functions, and molecular structure of human genes. In time, this research would advance the understanding of human genetic disorders.



Rick Woychik injects foreign DNA into fertilized mouse eggs as a molecular tag to locate and characterize the structure and function of the genomic region.



Scott McLuckey adjusts an ion trap for analyzing ionized DNA fragments.

The Laboratory, DOE, NIH and, more generally, the international life sciences community hoped to obtain information on genes that would help them determine, for example, which genes are responsible for polycystic kidney disease, cystic fibrosis, and Huntington's disease. With this information, scientists might be able to devise methods for repairing these genetic disorders. Program advocates implied this information might contribute eventually to ameliorating mental health problems by identifying genetic causes of manic depression, schizophrenia, and Alzheimer's disease. The most avid proponents asserted that successful completion of this global project could place humans in control of their genetic destiny, although critics questioned the wisdom and ethics of this goal.

Environment, Safety, and Health

In June 1989, Admiral Watkins outlined a "new culture of accountability" for DOE to regain its credibility in environmental restoration compliance. He approved providing state agencies access to DOE installations to monitor DOE

"ORNL developed a computer program called GRAIL that helps researchers identify genes from DNA sequence data."

Reinhold Mann, Ed Uberbacher, and Rich Mural in 1991 developed the GRAIL computer system to identify genes in DNA sequence data.

compliance with environmental standards and regulations. DOE also emphasized environmental, safety, and health compliance in awarding fees to contractor operators of its facilities, mandated full compliance with Occupational Safety and Health Administration standards, and formed "tiger teams" to assess field agency compliance and corrective measures.

These measures were a belated response to the 1984 amendments to the Resource Conservation and Recovery Act, which stipulated that facilities handling hazardous wastes must reduce the generation of such wastes and remediate areas containing waste. It soon became apparent that remediating hazardous wastes would be time-consuming and costly and that no cheap, quick fix would be available. John Gibbons, former staff member of ORNL and director of the Office of Technology Assessment and now President Clinton's science adviser, recently declared, "Decades will be required for cleanup of certain sites while others will never be returned to pristine conditions."

As an incentive to reduce wastes, the Laboratory adopted a charge-back policy, billing waste disposal costs to the division that generated the waste. Thereafter, Laboratory research and development proposals incorporated waste disposal into their estimated project costs, encouraging researchers to avoid using toxic substances in their experiments. "It's a new mentality, a cultural change," Tom Row insisted.

"Low-level liquid wastes, once disposed of using underground hydrofracture, are now concentrated and compacted to reduce the volume, then solidified and stored aboveground."

To speed mapping and measurement of contamination, the Laboratory improved a remotely operated vehicle for survey of waste sites.

In 1988, about 15% of the Laboratory budget was devoted to waste management and remedial actions—and this was only the beginning. To reduce waste management and remediation program costs, the national laboratories were challenged to find ways to treat the contamination without moving it. One ORNL response involved in situ vitrification, which uses electric currents to heat underground radioactive wastes to high temperatures, thereby converting them into glasslike solids impervious to groundwater. Developed at the Pacific Northwest Laboratory, in situ vitrification was tested by Brian Spalding and colleagues at ORNL to isolate strontium and cesium. Although still an expensive technique, in situ vitrification may be used at some future date to treat the pits and trenches that served as waste repositories during the Laboratory's early years.

Another innovation was bioremediation, which uses microorganisms to degrade hazardous chemicals. Laboratory teams developed methane-consuming microorganisms to break down gasoline and other solvents in soil. Additional research was under way in 1992 to identify or modify microorganisms that consume other types of toxic wastes.

Support also was given to environmental monitoring to determine the extent of contamination and the success of the cleanup. Tuan Vo-Dinh and Richard Gammage, both of the Health and Safety Research Division, developed various light-emission and -detection technologies, including fiber-optic technologies, for applications such as health and environmental monitoring and enhanced computer memory storage. Alan Witten of the Energy Division developed an acoustic tomography system that uses sound waves and computer analysis to image buried objects at waste sites; the technique also has been used in New Mexico to locate the bones of a Seismosaurus, the world's longest

Row, who in 1991 became director of ORNL's Office of Environmental, Safety, and Health Compliance, described major changes in Laboratory waste disposal methods reflecting the new corporate culture. Historically, the Laboratory had placed solid low-level hazardous and radioactive wastes, such as contaminated glass and cloth, into unlined trenches; now it packaged such waste in steel cans placed inside concrete vaults that are eventually entombed in earth berms equipped with monitored drainage systems. Low-level liquid wastes, once disposed of using underground hydrofracture, are now concentrated and compacted to reduce the volume, then solidified and stored aboveground. The Laboratory's high-level spent reactor fuel went to the Idaho or Savannah River complexes, which had storage facilities for reactor fuel that required reprocessing. The Laboratory's transuranic wastes were stored on site in specially designed bunkers for eventual disposal at a DOE centralized facility, perhaps the Waste Isolation Pilot Plant in New Mexico. One measure of the Laboratory's commitment to environmental, safety, and health programs was its increase of program personnel from 240 in 1988 to 390 in 1990.

dinosaur. Other ORNL staff monitored air, soil, surface water, and groundwater of the entire Oak Ridge Reservation in support of remedial action projects. They provided new information and analytical methodologies to support environmental restoration and waste management.

ORNL wastes are now classified and isolated in engineered storage facilities such as this "tumulus " site.

Tigers on the Prowl

To ensure full compliance with environmental, health, and safety programs, Admiral Watkins dispatched "tiger teams" to DOE field organizations for thorough operational and management inspections.

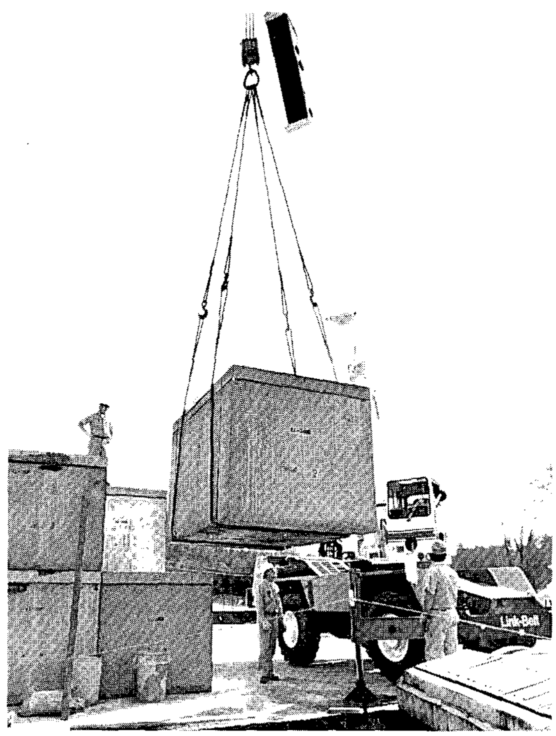
Within a month after the lengthy inspection, the Laboratory's response team had corrected 366 deficiencies identified by the tigers.

Trivelpiece declared the tiger team inspection largely a success, although he also pointed out that the Laboratory had not received a completely clean bill of health. "We did not come through unscathed," he admitted. "There are a lot of problems: legacy wastes from past practices and management deficiencies in meeting environmental safety and health regulations." Yet, he thought the tiger team inspection had served as a catalyst for improvement.

Defense Challenges

Visiting the Laboratory in 1992, President Bush referred to it as an "arsenal of democracy." Although it is not a weapons laboratory, the Laboratory has supported national defense at every opportunity. In addition to assisting the Strategic Defense Initiative, the Laboratory undertook research during the 1980s for the Defense Department that included investigations of defense materials, battlefield logistics, robotics, instruments and controls, and electromagnetic interference.

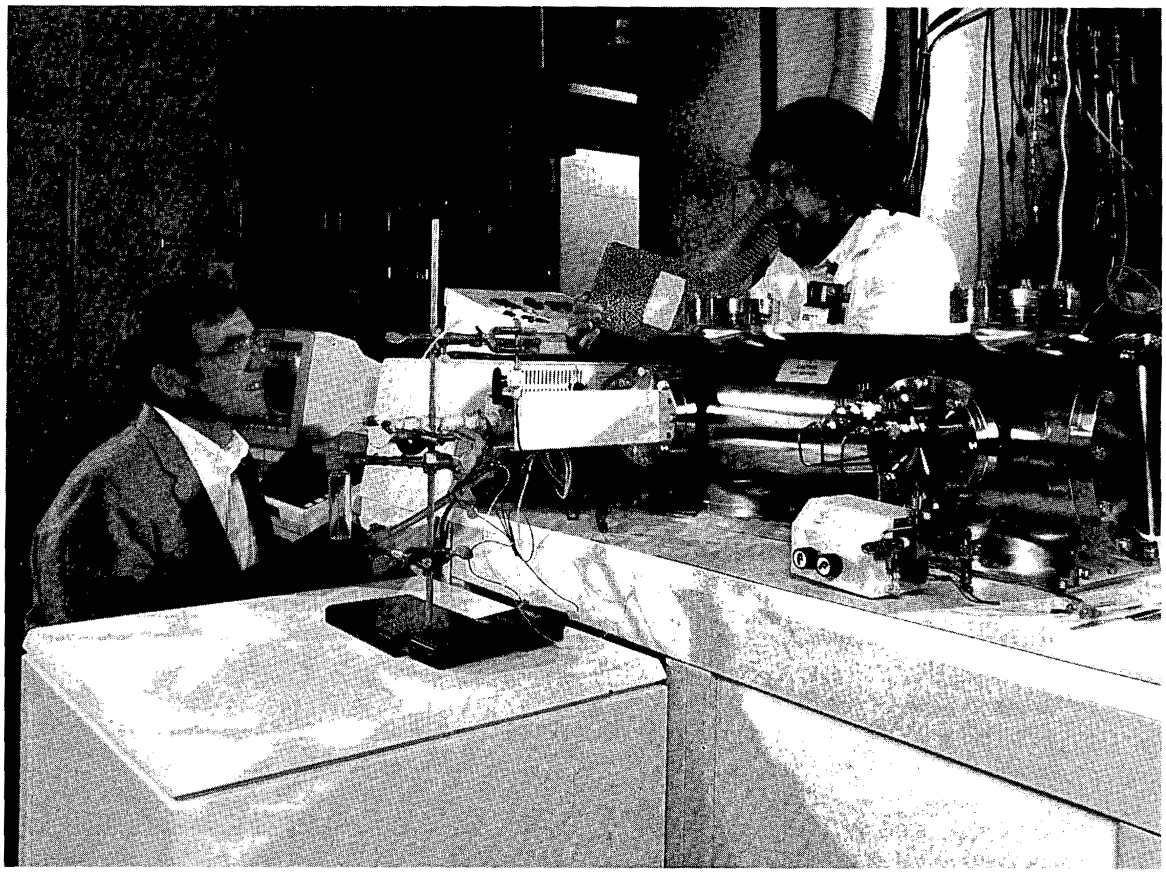
Also for the Defense Department, the Laboratory's radioisotopes group directed by Neil Case developed isotope-powered lights using



Crane hoists concrete vault containing radioactive waste into place at one of the Laboratory's engineered storage facilities.

"Support also was given to environmental monitoring to determine the extent of contamination and the success of the cleanup."

"The Laboratory has had a major impact on mass spectrometry, emerging as a world leader in the field."



Mike Guerin and Mark Wise work at an ion-trap mass spectrometer used for quickly identifying and quantifying pollutants. A portable version of the ORNL system provides on-site soil, water, and air analyses.

radioactive emissions from krypton and tritium to excite phosphor pellets, causing them to glow in the dark. These "plugless" lights provided landing and distance markers for military and civilian pilots in remote areas. In another case, Cabell Finch and Lynn Boatner, both of the Solid State Division, developed doped crystals for room-temperature promethium lasers. These crystals were suited for satellite-to-submarine communications because their light can be transmitted through water.

Led by the Energy Division's Samuel Carnes, in 1987 a Laboratory team completed the final programmatic environmental impact statement for disposal of the Army's stockpiled chemical weapons. The team identified on-site incineration as the environmentally preferred method of disposing of weapons.

When terrorist bombings plagued aircraft during the 1980s, a team in the Analytical Chemistry Division devised an explosives sniffer using mass spectrometry to test the air for suspect chemicals, thereby determining in seconds whether explosives were present. This development interested airport security firms, and Energy Systems licensed the "sniffer" to a private company for commercial use.

In addition, the Laboratory developed a direct-sampling ion-trap mass spectrometer. Installed in a van, this equipment has served as the basis of a mobile laboratory for rapid detection and measurement of concentrations of organic pollutants in air, water, and soil at sites targeted for cleanup.

Providing test results much faster than conventional methods, the device is expected to produce substantial savings for the cleanup programs of both DOE and Department of Defense sites.

Since 1946 when it assumed operation of the electromagnetic separators at the Y-12 Plant, the Laboratory has had a major impact on mass spectrometry, emerging as a world leader in the field. Like an electromagnetic separator, a mass spectrometer uses electric and magnetic fields to separate chemical elements, enabling scientists to identify elements and measure the amounts present. Applications have included safeguarding nuclear materials by determining whether plutonium and uranium have been diverted illegally from facilities for making nuclear weapons. Recently, thanks to the work of Joel Carter, Scott McLuckey, and others, the Mass Spectrometry Laboratory was completed at ORNL for developing and conducting experiments with mass spectrometers.

Computer models developed by the Laboratory's Center for Transportation Analysis in the Energy Division saw useful application during the 1991 Persian Gulf War. The U.S. Transportation Command used the software to schedule deployment of troops and equipment to the Middle East for Operations Desert Shield and Desert Storm in the largest airlift operation in history.

Successful national defense ultimately rests on economic prosperity, and during the 1990s the Laboratory increasingly focused its resources and staff on environmental and economic, not military, matters. The key words for this operation were "technology transfer" and "national competitiveness."

Tech Transfer

Laboratory efforts to transfer its technological advances to industry began in 1962, when Weinberg established an Office of Industrial Cooperation to reduce the time required for the civilian economy to adopt scientific advances. Carol Oen and Don Jared headed Laboratory technology utilization offices during the 1970s and found partial success through spin-off firms often launched by former Laboratory personnel. ORNL and other Energy Systems sites also helped lure Science Applications International Corporation, System Development, TRW, Exxon, Bechtel, and other corporations to Oak Ridge by increasing public awareness of local technical capabilities.

Legal barriers involving patents and nonexclusive licensing, however, hampered quick technological transfer. Corporate executives were reluctant to invest in technology without the marketplace advantage of holding the exclusive rights to a particular technology.

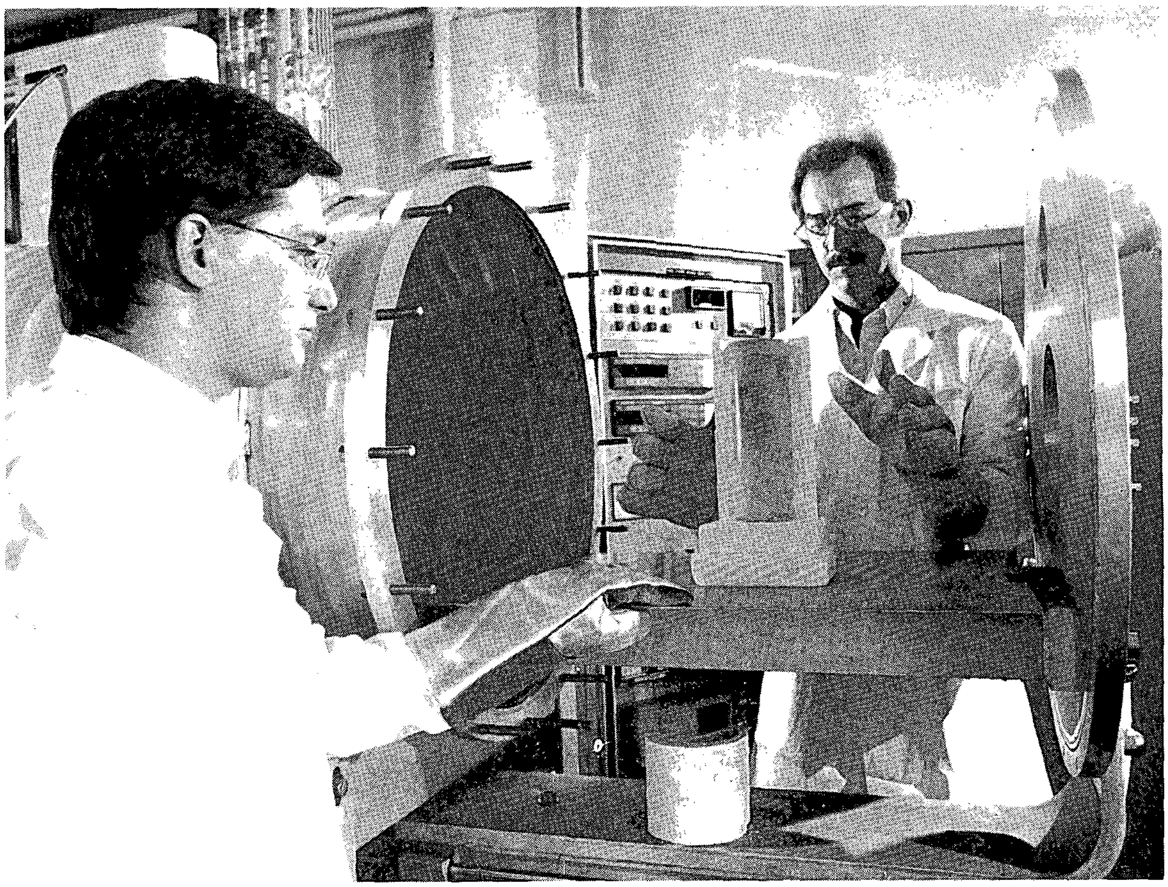
Recognizing these difficulties and the frustration of industry, DOE initiated a technology transfer pilot project centered around newly discovered high-temperature superconductors with the intention of streamlining legal requirements at DOE laboratories. Oak Ridge, Los Alamos, and Argonne national laboratories were designated as High-Temperature Superconductivity Pilot Centers, and the three worked closely with DOE under industry's watchful eye to devise procedures that would accelerate transfer of supercon-ducting technology from the laboratories to industry. ORNL's Tony Schaffhauser, Louise Dunlap, Jon Soderstrom, and Bill Appleton helped establish the collaborative arrangement that became a model for the CRADAs legislated by Congress.

Aware of the latent economic potential of the national laboratories, Congress passed the National Competitiveness and Technology Transfer Act of 1989 to encourage technology transfer. The Laboratory's new contractor-operator, Martin Marietta Energy Systems, Inc., vigorously promoted this initiative. In 1985, for example, Energy Systems signed an exclusive license with Cummins Engine Company for use of modified nickel aluminide alloys in diesel engines. The alloys were developed by C.T. Liu and his colleagues. Energy Systems offered financial incentives to Laboratory personnel who applied for patents as well. Laboratory inventors received the first royalties for their innovations in 1987.

ORNL's successful collaboration with industry at the Roof Research Center, High Temperature Materials Laboratory, and elsewhere quickened the pace of transferring information on ceramics, semiconductors, electronics, computer software, insulation, and other commercially promising technologies. As a result, the Laboratory led other

"The Laboratory led other DOE facilities in technology transfer, and its program became a model for other government agencies to emulate."

"Energy Systems issued its first royalty-bearing license in nuclear medicine to Du Pont in 1989."



Hal Kimrey and Mark Janney inspect a silicon carbide ceramic tube that has been heated by microwaves.

DOE facilities in technology transfer, and its program became a model for other government agencies to emulate.

Industrial firms expressed great interest in the Laboratory's development of ceramic gel casting and ceramics reinforced with whiskers made from silicon carbide. By 1989, 11 companies had obtained licenses to use durable whisker-toughened ceramic composites in metal-cutting tools. A gel-casting technology for shaping ceramics, invented in the Metals and Ceramics Division, was licensed to Coors Ceramics, Inc., which built a plant in Oak Ridge to pursue this and related technologies.

Trane Company, a worldwide manufacturer of air-conditioning and refrigeration systems, acquired a license for gas-powered absorption chillers invented at the Laboratory by Robert DeVault. These gas chillers were more economical and much more efficient than electric chillers; the new devices could reduce primary energy requirements as well as summer demands for electricity by shifting commercial building air-conditioning loads to natural gas.

Energy Systems issued its first royalty-bearing license in nuclear medicine to Du Pont in 1989. Prem Srivastava and associates in the Health and Safety Research Division synthesized a chemical compound to make radiolabeled monoclonal antibodies more useful for cancer detection. Du Pont expected to market this development to medical research institutions.

Open for Business

The National Competitiveness and Technology Transfer Act of 1989 amended the Atomic Energy Act to make technology transfer a principal mission of DOE and its laboratories. The act allowed contractor-operated laboratories such as ORNL to work directly with industrial firms, universities, and state governments on jointly sponsored research and to share information through CRADAs. "The labs are now open for business," proclaimed William Carpenter, Energy Systems' chief of technology transfer.

In 1990, the Laboratory entered its first CRADA, joining an international chemical consortium to study chemicals that could serve as alternatives to chlorofluorocarbons. More CRADAs followed. During his February 1992 visit to the Laboratory, President Bush highlighted this technology transfer program at the signing of a CRADA with Coors Ceramics to develop precision machining of ceramics.

Touring the High Temperature Materials Laboratory and addressing a crowd in front of the building, President Bush praised the $3.6 million CRADA with Coors as an excellent way to take technology directly to markets and create new jobs. "The High Temperature Materials Laboratory is a world-class facility," he declared, "and in the race with other nations in making precision parts, America will get there first." After Trivelpiece and Joseph Coors signed the CRADA, the Coors executive presented the president with a ceramic golf putter as a light-hearted sample of the products that could flow from the materials research.

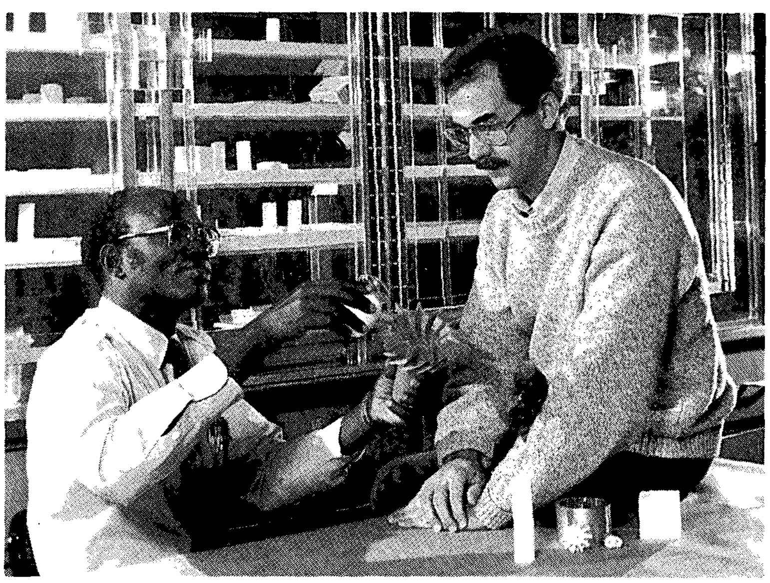
Speaking in Knoxville later that day, the president promised significant increases in funding for science education and the National Science Foundation. Thus, the president's brief visit to Oak Ridge and Knoxville framed, in national terms, two of the Laboratory's most important initiatives of the 1990s—technology transfer and science education.

Future Challenges

When listing the future priorities of the "broadest based and most multidisciplinary of the DOE national laboratories," Alvin Trivelpiece highlighted his hope that the Laboratory will become the center for excellence in research reactors. Its HFIR and TSF reactors were back in service, although the latter, which was funded primarily by a Japanese-sponsored program for breeder reactor shielding studies, was shut down in October 1992.

In 1992 the Laboratory continued to press for funding to design and construct a major new reactor to replace the aging HFIR. Named the Advanced Neutron Source (ANS), studies of this proposed reactor had begun in 1984 as a Director's Fund project, with initial funding from DOE coming in 1987. Leadership in neutron scattering research had passed from the United

"The labs are now open for business."



O. O. Omatete and Mark Janney demonstrate the "gel casting" process they invented to mold ceramic components for engines.

Industrial-Strength Science

The relationship between science and technology is a subject in which historians and policymakers take great interest. In the classic paradigm, scientists seek knowledge of basic physical principles or natural laws and technologists apply this knowledge to invention. Albert Einstein exemplified 20th-century scientists. He identified general and specific physical laws that subsequently were verified by experiments. Thomas Edison, Henry Ford, and the Wright brothers were epitomized 20th-century technologists.

Science, to borrow a phrase, is the mother of invention, according to theory. Einstein's theories certainly led to inventions, the atomic bomb and nuclear reactor counted among them. But did the Wright brothers know anything about

"Science, to borrow a phrase, is the mother of invention, according to theory."

science? How about Thomas Edison or Henry Ford? Who or what were the scientific mothers of their inventions?

The issue has affected policy decisions for decades. If science is the mother of invention and technology is only applied science, then pumping funding into science will produce inventions useful to a society and profitable for business. It has happened: nylon, radar, radio, television, transistors, and lasers are examples.

If, on the other hand, useful inventions and technological improvements can be produced without increased scientific knowledge, then why not take the short cut? Allocate funding directly to technology to achieve quick results and reduce or eliminate funding for science.

"Sometimes technology becomes the mother of science. Scientists apply new technology to their own research."

Differing science-technology paradigms adopted during the Laboratory's first 50 years have had a major influence on its budget and activities. Funding for basic sciences, especially nuclear science, was strong during the Laboratory's early years. During the 1960s and 1970s, substantial increases in the Laboratory budget for technology development came in response to demands for more "socially relevant" science and for solutions to the national energy crisis; and in the 1980s, the policy pendulum swung back toward "high-risk, high-return" basic science.

Yet, the traditional distinction between science and technology is, and always has been, blurred at the Laboratory. When Arthur Compton sent Enrico Fermi to Oak Ridge in 1942, he wished him success with his "greatest of all practical physics experiments."

The Laboratory's leadership throughout its first 50 years has come from managers with multiple areas of expertise. Eugene Wigner was a chemical engineer who became a physicist. Alvin Weinberg was a biologist and a physicist. Floyd Culler was a chemical engineer who acquired great understanding of science. Herman Postma and Alex Zucker were scientists who worked closely with the engineering design of fusion and cyclotron devices. And Alvin Trivelpiece is an engineer who became a physicist. These men managed the application of the Laboratory's industrial capabilities to the solution of scientific challenges.

To reverse the classic paradigm, sometimes technology becomes the mother of science. Scientists apply new technology to their own research. In astronomy, as a prime example, telescopes, radios, rockets, and satellites have provided astronomers new insights into the functioning of the distant universe. Swift application of technological innovations to scientific research also has marked the Laboratory's history.

The Laboratory represented, at its founding in 1943, a merger of science and technology, and this diversity has been one of its great strengths

"The Laboratory represented, at its founding in 1943, a merger of science and technology, and this diversity has been one of its great strengths throughout its history."

throughout its history. The emphasis placed on one aspect or the other of the Laboratory's character has changed over the years, but the effort has always had the same goal: a melding of theory and application that serves as a catalyst for advancement.

States to Europe during the 1970s when a reactor was built at Grenoble, France, with a neutron flux and experimental facilities superior to those at Oak Ridge and other DOE laboratories. Backed by reports of several important national committees, Laboratory management insisted that building the ANS would regain world leadership for the United States by providing the most intense steady-state neutron beams in the world and state-of-the-art neutron scattering facilities. The ANS research reactor would also be used for isotope production, neutron activation analysis, and research on radiation effects in materials.

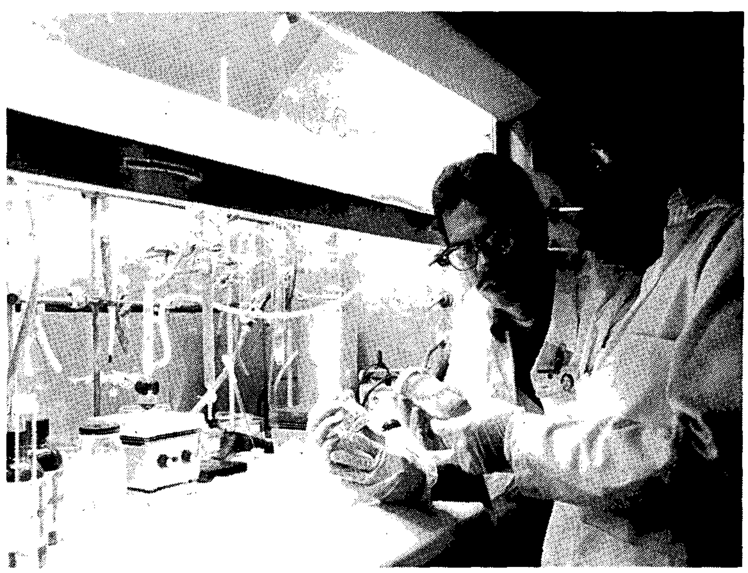
Managed initially by Ralph Moon and David Bartine, the project was later placed under Colin West, who directed the conceptual design of the ANS with the aid of prominent scientists throughout the world. Surrounding the reactor would be a national research center, with adjoining structures housing laboratories for neutron scattering and other experiments, as well as offices for scientists from both the Laboratory and elsewhere.

The initial ANS design called for heavy water to cool the reactor fuel and reflect neutrons back into the core. (The High Flux Isotope Reactor uses ordinary water as coolant and beryllium as a neutron reflector.) Studies by the Laboratory and the Idaho National Engineering Laboratory led to selection of a split-core configuration with uranium silicide fuel in aluminum-clad plates. These features would permit a 200- to 350-MW powerhouse, compared with the original 100-MW rating of the High Flux Isotope Reactor.

Noting that the Laboratory had built and operated 14 nuclear reactors (counting the 1955 Geneva conference reactor and the Pool Critical Assembly), Murray Rosenthal observed that the proposed ANS would become the Laboratory's 15th reactor and the first one built since 1966. Colin West estimated that the 350-MW reactor and modern beam facilities would provide neutron beams with intensities at least 10 times those of the HFIR and at least 10,000 times greater than those available to Ernest Wollan and Clifford Shull at the 1943 Graphite Reactor. John Hayter, scientific director for the project, said that plans for the new reactor include about 30 beam lines and beam guides, many of which would serve more than one instrument. The facility would have special features such as neutron mirrors for beam delivery and two cold sources (tanks of liquid deuterium) to slow some of the neutrons before they are transported to the "guide hall" for experiments.

The conceptual design involved personnel from national laboratories, industries, and universities, plus researchers from Germany, Japan, and Australia. More than a thousand non-Laboratory scientists are expected to conduct research annually at the ANS when it becomes operational. With the aging High Flux Isotope Reactor operating at slightly reduced power to prolong its life, early completion of the ANS seems vital. "When the HFIR reaches the end of its useful life, we will need a new reactor to enable U.S. scientists to conduct neutron scattering studies to make progress in certain

"Colin West directed plans for the conceptual design of the ANS with the aid of prominent scientists throughout the world."



P. C. Srivastava and John Allred developed new techniques for radiolabeling antibodies to detect cancer.

The Bush Visit

Molding the Future

During his February 1992 visit to ORNL, President Bush speaks to Laboratory Director Alvin Trivelpiece as Secretary of Energy Admiral James Watkins (left) and Secretary of Education Lamar Alexander (right) look on. Joseph Coors, president of Coors, signs a CRADA on ceramics with ORNL.

On February 19, 1992, President George Bush visited the Laboratory to witness the signing of a $3.6 million, three-year cooperative research and development agreement (CRADA) between the Laboratory and Coors Technical Ceramics Company. The agreement, co-signed by Joseph Coors, Jr., president of Coors, and Director Alvin Trivelpiece, could lead to precisely shaped ceramic parts for multiple uses, including the highly efficient and durable high-temperature engines of the future.

"You're pointing our country toward the next American century," President Bush told the 800 Laboratory employees who attended the signing ceremony. "This agreement," he said, "combines in one place the resources of government with the energy and inventiveness of private enterprise." He added that the future of U.S. competitiveness in the world marketplace depends on research and development.

President Bush was only the second U.S. president to visit the Laboratory (unless you count Zachary Taylor, whose remains were analyzed for arsenic in 1991). President Jimmy Carter visited ORNL in 1978.

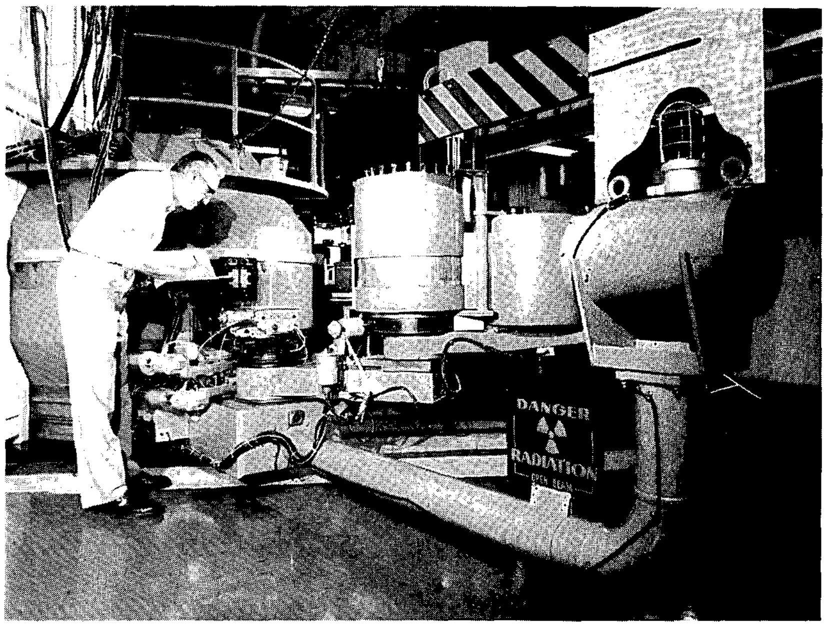
President Bush delivered his message in front of the High Temperature Materials Laboratory, which he toured. He cited this CRADA as one in a series of pathbreaking initiatives that would help overcome the obstacles government currently faces in sharing its technology with private industry. CRADAs are research partnerships between government laboratories and private companies made possible by the National Competitiveness Technology Act of 1989.

President Bush called the High Temperature Materials Laboratory "a world-class advanced materials testing facility" that would be instrumental in helping "American industry...take a world lead in making precision ceramic parts. We're in a race with other nations in this multimillion-dollar market, and we will get there first with the best product, thanks to the hard work of the people right here and the imagination of your scientists."

The president said that the Laboratory and Coors researchers would "attack one of the obstacles to wider use of durable, efficient, and lightweight ceramic parts—machining ceramics without destroying their desirable qualities." The collaborative work, which will also involve staff members of the Oak Ridge Y-12 Plant, will take place largely in the new Ceramic Manufacturability Center in the High Temperature Materials Laboratory.

key fields," Trivelpiece asserted. "I think we need to make a full court press, and I regard this project as the highest-priority technical facility pursued by the Laboratory."

Other ongoing reactor programs at the Laboratory included the modular high-temperature gas-cooled reactor research program, promising safety and investment protection features unavailable in other efficient reactor concepts. The Laboratory also provided research and design review support for the liquid-metal fast reactor with potential for greatly extending the nuclear fuel supply, and it reviewed and researched DOE's work with improved light-water reactors of modular size and improved safety characteristics. Laboratory work on advanced controls for reactors for DOE and renewal of the licenses of aging nuclear power plants for the Nuclear Regulatory Commission was expected to continue.



Ralph Moon at a triple-axis neutron spectrometer of the High Flux Isotope Reactor. His principal research concerns neutron scattering to study magnetic materials.

"How well it performs in a variety of energy and environmental fields could well determine the Laboratory's future."

Established in 1943 as a nuclear reactor site, chemical separations facility, and scientific laboratory, the Laboratory continues to build upon these traditional strengths in 1993. Nevertheless, ORNL's broadening investigations of alternative energy sources; environmental, safety, and health concerns; and strategies for improving national economic competitiveness absorb ever-larger portions of the Laboratory's budget and energies as it approaches the end of the 20th century. The Laboratory's future seems to lie not so much in its ability to do research in specific nuclear projects as in its deeply rooted ability to undertake large-scale, complicated projects that address national and international needs and concerns. How well it performs in a variety of energy and environmental fields could well determine the Laboratory's future. These efforts, in turn, could help chart America's future, helping the nation retain its leading role in an increasingly complicated and competitive world.

In recent years elementary schoolchildren have used Laboratory facilities and interacted with its staff to learn about science. Science education for all ages is a new mission of DOE laboratories, including ORNL.

Epilogue

Nearing retirement in 1992 after 50 years of service to the Manhattan Project and the Laboratory, senior staff advisor Don Trauger reflected on the lessons of a half century. "The Laboratory and science at large," he urged, "should expand their strategic planning to longer time spans." Rapid political changes on both the national and international scene have limited effective implementation of some programs to four years or even two years, he noted. And industry as well is shortening its planning to as little as two years because of high capital costs and demands for early returns on investments. "Perhaps," Trauger suggested, "the national laboratories can effectively consider the time spans that are really desirable. Even 100 years is not as distant as we might have thought."

Laboratory management, as always, devotes considerable attention to planning the institution's future research and proposing the acquisition of equipment and design and contruction of facilities needed to support world-class science. The Department of Energy, in fact, requires the Laboratory to prepare institutional plans looking five years into the future, and in 1990 ORNL Director Alvin Trivelpiece formed a planning group to analyze the Laboratory's long-term corporate strategy.

In addition to assigning the highest priority to the Laboratory's proposed Advanced Neutron Source (ANS) and other nuclear reactor studies, Trivelpiece emphasized the global importance of the work of Energy Division teams, who by 1992 had assisted 21 nations with development of their energy and environmental technology policies. Pointing out that events in these nations have ramifications for the environment worldwide, Trivelpiece urged Congress to support Laboratory efforts to assist other nations in meeting their energy needs while reducing the strains on the environment and world oil markets.

To improve science education, Trivelpiece advocated greater cooperation with Oak Ridge Associated Universities, the University of Tennessee, Pellissippi State Technical Community College, Roane State Community College, Tennessee state government, and regional school systems. He was particularly interested in designing classrooms for the 21st century, using reasonably priced electronic teaching aids and student workstations.

Haitians purchase charcoal for cooking and carry it home. ORNL has assessed the potential for Haitians to use a clean-burning briquette made from coal to help save the nation's forests, the source of charcoal.

"Trivelpiece urged Congress to support Laboratory efforts to assist other nations in meeting their energy needs."

For the 1990s and beyond, Trivelpiece and the strategic planning group expected Laboratory directions to be dominated by four major themes: education, energy, environment, and economic competitiveness. They proposed to support these efforts with three new major user facilities the Laboratory hopes to complete within a decade: the ANS and its adjoining research facilities, a materials science center on the east end of the Laboratory, and an environmental and life sciences center on the west end.

The increasing importance of materials science to the Laboratory's efforts to improve national economic competitiveness is demonstrated in the proposed Materials Science and Engineering Complex, which the Laboratory hopes to construct near the Holifield Heavy Ion Research Facility tower. Consolidating existing programs in new facilities to enhance scientific interaction, the complex would include centers for solid-state research and processing, advanced microstructural analysis,

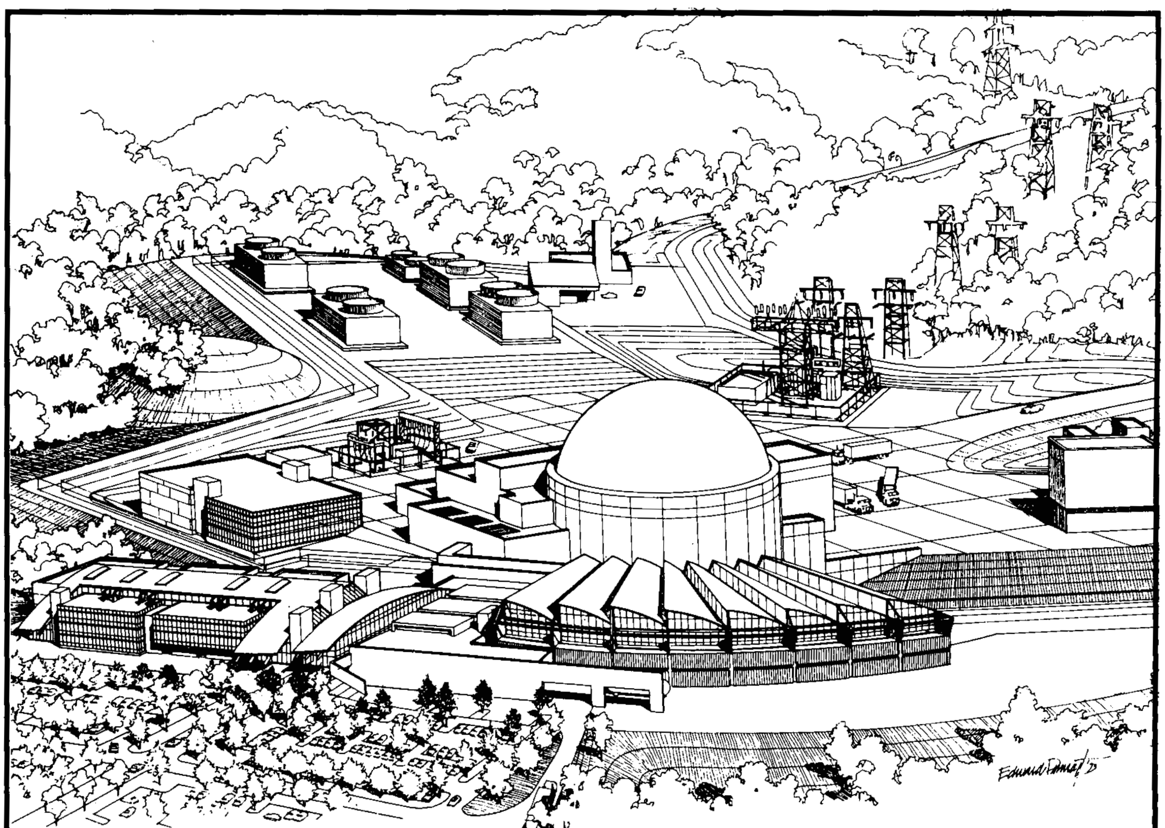
Operators of bicycles, horse-drawn carts, cars, buses, and trucks battle for space in this congested Chinese city. The problems of developing countries have drawn increasing attention from ORNL.

advanced materials research, and composite materials investigations.

Explosive growth in the materials sciences and their role in the Laboratory's technology transfer programs since 1980 has severely overcrowded existing laboratories. Building a new complex is considered more economical than upgrading older structures to meet modern environmental and safety standards. The proposed new complex would make possible more on-site participation of university and industrial researchers in cooperative projects in ceramics, composites, superconductors, and high-temperature metals and alloys. This complex, therefore, enjoys support from universities and industrial firms in the Southeast.

At the western gate, near the existing Environmental Sciences and Aquatic Ecology laboratories, the Laboratory proposes to develop an Environmental, Life, and Social Sciences Complex. The complex would include centers for biological sciences and Earth systems and a biological imaging and advanced photonics laboratory. Its completion would concentrate the Laboratory's programs in structural biology, biotechnology, human genome, global environmental studies, risk assessment and management, environmental restoration, social sciences, energy technologies for developing nations, energy efficiency, and transportation systems research.

As with the materials science divisions, research in the environmental, life, and social sciences in 1992 was scattered throughout the Laboratory in older facilities. For example, the Biology Division had been housed since 1946 in obsolete facilities at the Y-12 Plant, eight miles from the X-10 Laboratory complex. With much of the Laboratory's global research centered in the newly formed Environmental, Life, and Social Sciences Directorate, the



Artist's concept of proposed Advanced Neutron Source at ORNL.

"*Trivelpiece expected Laboratory directions to be dominated by education, energy, environment, and economic competi-tiveness.*"

The White Oak Creek Embayment Sediment Retention Structure was built to stop releases of radioactive contaminants into the Clinch River.

collaborative interactions facilitated by concentrated research in this new complex would help open new horizons for the solution of global challenges.

One noteworthy problem area for the Laboratory lies in nuclear physics. Although the Holifield heavy-ion research accelerator was only 12 years old in 1992 and had set new records for beam energies in 1992 that were 60% higher than those achieved in 1982, it had fallen on hard times. New European accelerators provided even higher energies, and budget cuts reduced the operating time available for researchers at the accelerator.

To reverse these trends, the Laboratory proposed using the Holifield facility to accelerate radioactive ion beams, a unique capability that would make the facility more valuable to nuclear physicists, especially those interested in astrophysics. If this proposal is approved, a recoil mass spectrometer, jointly funded by the Laboratory and universities, would be acquired to complement the radioactive beam capability.

While applying cost constraints to facilities such as the Holifield accelerator, DOE began to devote vast resources during the 1990s to improving scientific understanding of the transport of wastes in the environment and the remediation of waste disposal sites. As a result, Trivelpiece expected the Laboratory to expand its waste management and remediation work.

Back to the Future

As the Laboratory approached the beginning of its second half century, Alvin Weinberg was

"If the Laboratory's past is its prologue, then its next 50 years should be as demanding, rewarding, and surprising as its first half century."

preparing Eugene Wigner's papers for publication. His effort to uncover and organize the Laboratory's past gave Weinberg an opportunity to reflect on Wigner's legacy. The Laboratory's most renowned scientist not only set a standard of performance for Oak Ridge, Weinberg observed, but he also provided a vision of the future that speaks as directly to the uncertainties of the 1990s as it did to the uncertainties of the 1940s. In a simple statement of truth, Wigner once remarked, "Every moment brings surprises and unforeseeable events—truly the future is uncertain."

Weinberg himself viewed aging and the future with equanimity. He has wryly concluded that scientists improve with age because their knowledge broadens as they become older. Much of science, he said, comes not out of brilliant flights of fancy but from viewpoints and techniques growing out of a lifetime of scientific inquiry.

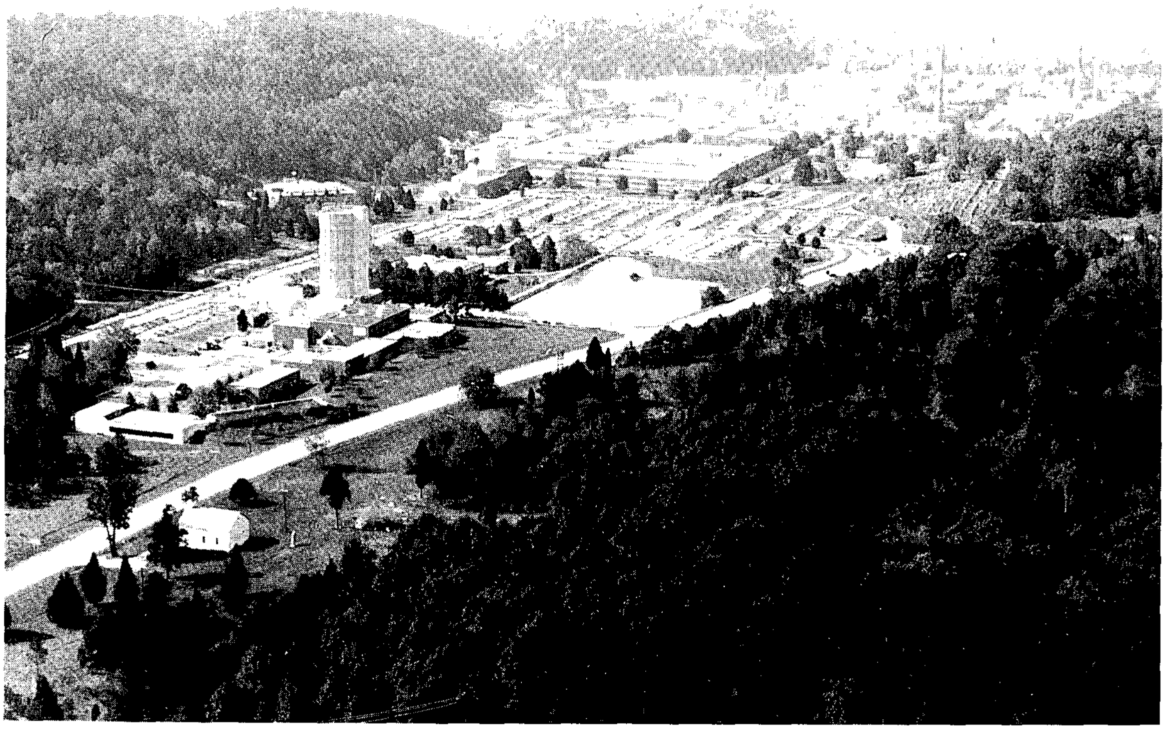
The same sentiment might well apply to an institution that reaches the half-century mark. Its corporate experience and accomplishments should serve as a foundation of strength upon which to build a vigorous future of inventiveness and purpose.

Although the Laboratory, like science generally, seems more interested in the future than the past, it sometimes turns to its past for hope, inspiration, and understanding. When drafting plans for Laboratory initiatives during the 1990s, the strategic planning group admitted that improving national competitiveness through technology transfer and science education might be "more difficult than the Manhattan Project, which birthed the national laboratories nearly a half century ago."

In the 1940s, the nation's attention and resources were riveted on the war, and Laboratory efforts on behalf of the atomic bomb received the highest priority. Today, the enemies are less clearly defined and Laboratory initiatives must share the political spotlight with other government priorities and needs. Thus, the Laboratory will have to work even harder to justify public investment in its research activities. As Weinberg recently suggested, if the Laboratory is to become a prime engine of the national economy, its people must "adopt the same high standards and dedication shown during the four years of the Manhattan Project."

And so the experience of the Laboratory has come full circle. Amid the complex of buildings, intricate equipment, piping, test tubes, roads, reactors, accelerators, robots, and supercomputers, one force stands above all others in explaining the institution's success: the dedication of the people who work there. That dedication reached its first peak during the war years, when secrecy prevailed. Fifty years later, the Laboratory is determined to open its doors to the future, drawing

The Laboratory has taken a variety of measures to keep employee exposure to radiation as low as possible.



An aerial view of Oak Ridge National Laboratory including its focal point, the towering accelerator of the Holifield Heavy Ion Research Facility. The Graphite Reactor is at the top right, to the right of the stacks.

on its storehouse of knowledge and skills to serve the public interest.

The purposes to which the Laboratory can now apply its talents are more varied. But for the Laboratory, the future has always been uncertain. Its staff has seized opportunities and redefined the Laboratory's purposes time and again to fit changing circumstances. As the Laboratory celebrates its 50th anniversary and as it stands on the threshold of the 21st century, there is little doubt that it will marshal its resources and talents to meet the challenges of tomorrow. At the dawn of a new era, this much is certain: if the Laboratory's past is its prologue, then its next 50 years should be as demanding, rewarding, and surprising as its first half century.

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TECHNOLOGY	LICENSEES
Nickel aluminide alloys (for wear parts, engine parts, heating elements)	Harrison Alloys, Metallamics, Armco, Hoskins (Armada Corp.), Cummins Engine, Valley Todeco
Whisker-toughened ceramic composites (for wear parts, cutting tools, engine parts)	Keramont; Kennametal, Inc.; GTE; Valenite; Hertel; Cercom, Inc.; Iscar; Dow Chemical; American; Matrix; High Velocity Corp.; Advanced Composite Materials (2)
Fiber-optic luminoscope	Environmental Systems (2)
Sewage treatment system	Anflow, Inc.
Radioactive material shipping design	Ontario Hydro
Ceramic gripper for testing	Instron
Quality control program for chemical laboratories	Future Tech
Advanced servomanipulator	Remote Technology (2)
Ultrasonic ranging data and telemetry system (USRADS)	Chemrad Corp.
Atmospheric sampling discharge ionization source (for detecting explosives at airports)	Finnigan Corp.
Analis software to manage volume chemical analyses	Chemical Research Labs, Inc.
Motor current analysis method (for detecting abnormal motor operation)	Wyle Labs, Predictive Maintenance Inspection, Inc., Performance Technologies, Inc., Spectrum Technologies USA, Inc.
Novel ternary ceramic alloy	3M Co.
Radioiodinated maleimides (for tumors)	E. I. du Pont de Nemours & Co.
Identifying killer bees in honeybee hives	B-Tec
Triple-effect absorption chiller (for gas-fired air-conditioners)	Trane Company, Apache Corp.
Blood rotor (health monitor)	Abaxis
Gel-casting method for making complex ceramic shapes	Coors Ceramics, Inc.
Soil corer/sampler	Associated Design and Manufacturing Co.

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Layered protection system	Micro Safe-T Systems
Electrically driven solvent extraction to recover chemicals	Analytical Bio-Chemistry Labs, National Tank Co. (NATCO)
Microwave plasma source for etching computer chips	Sematech
Groundwater Cerenkov radiation detector	Sorrento Electronics
Alpha spectroscopy software	Canberra
Iron aluminides for corrosive environments	Amatek, Harrison Alloys, Hoskins Manufacturing
Integrated graphics system	Abkowitz & Assoc.
Alpha radiation detector	Dosimeter Corp.
Check-valve monitoring system	Valvision, Inc.; ITI Movats, Inc.; Southern California Edison Co.
Atom probe software for field ion microscope	Microscience, Inc.
Iridium generator for imaging heart defects	Scintillation Technologies Co.
Surface-enhanced Raman spectroscopy (SERS) for environmental monitoring	Gamma-Metrics, Inc.
Variable frequency microwave furnace	Microwave Laboratories, Inc.
Ceramic fiber-reinforced composites	Advanced Innovative Technologies
Amoeba-bacteria consortia (for treating waste)	EODT Services, Inc., and Associated Companies
Ultralight electromagnetic interference shielding	Sigma Electromagnetic Shielding Technologies, Inc.