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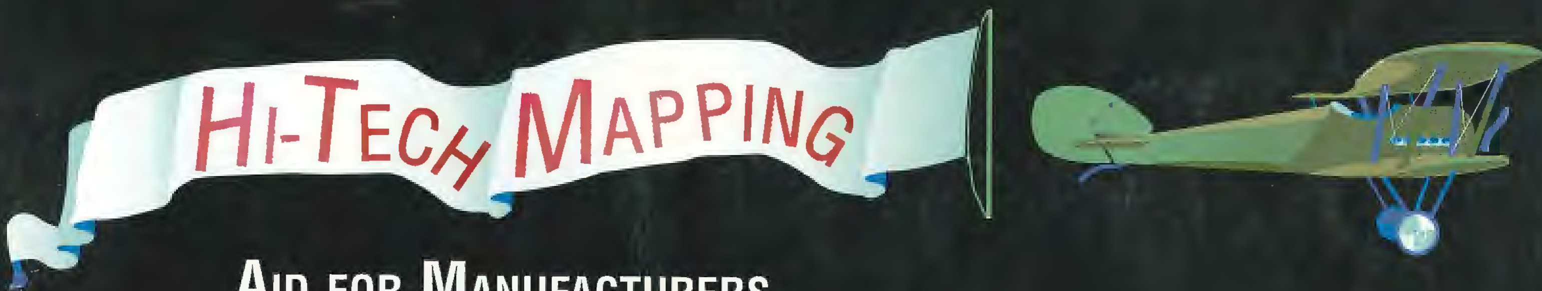

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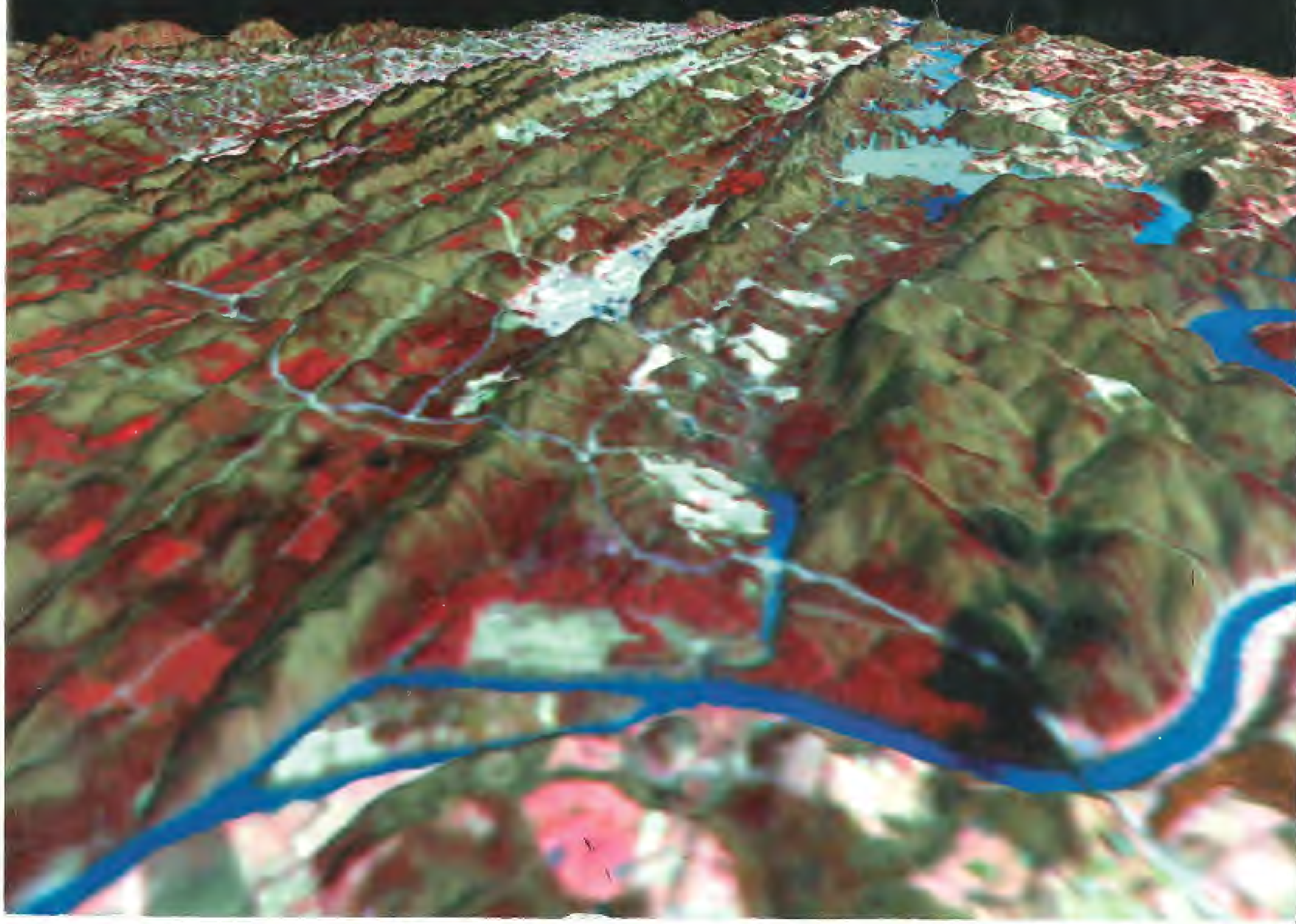
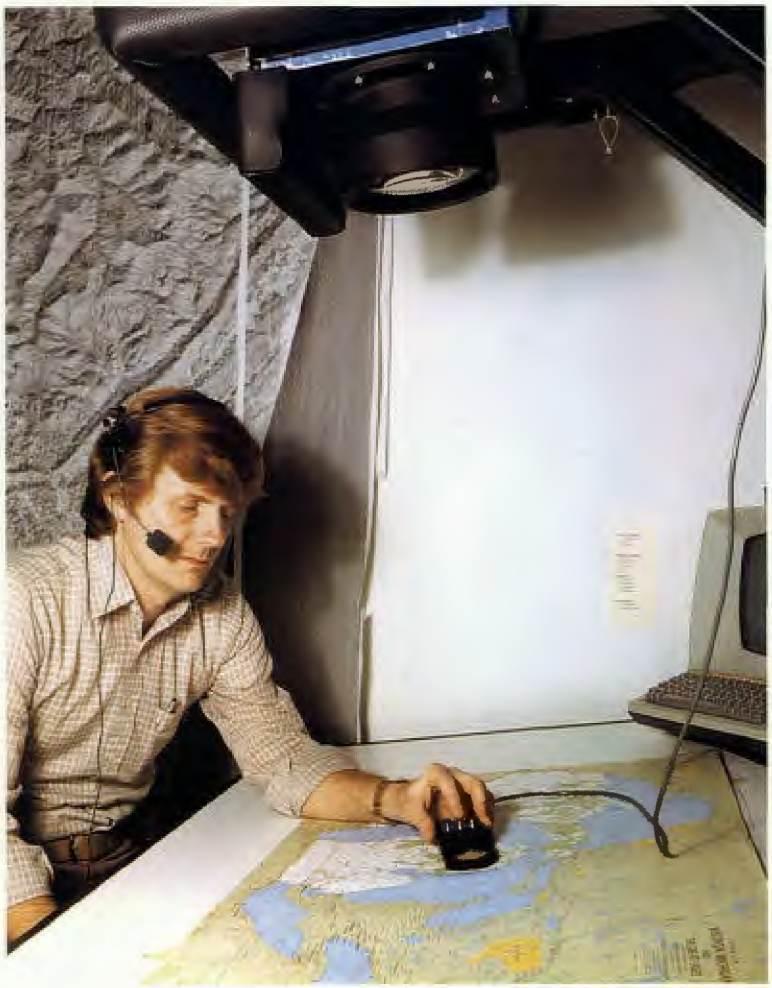


COVER CAPTION

Digital multispectral imagery of the Oak Ridge Reservation, collected in January 1987 by the French SPOT satellite, has been draped over a digital elevation model by the GIS and Computer Modeling group at ORNL to produce a 3-D perspectives image of ORNL and its surroundings viewed from the southwest. The three-band image has been pseudo-colored. Red features generally correspond to active vegetation (e.g., evergreens), light bluish colors tend to depict cultural features such as buildings and roads, and dark blue represents water bodies. See the article on geographic information system technologies (in use in photo below) on p. 46.



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Oak Ridge National Laboratory is a multiprogram, multipurpose laboratory that conducts research in energy production and end-use technologies; biological and environmental science and technology; advanced materials synthesis, processing, and characterization; and the physical sciences including neutron-based science and technology.

The Oak Ridge Solution to Manufacturing Problems

By Bill Wilburn

A small company has a manufacturing problem that it cannot solve because it lacks the in-house resources. Then company officials learn they have easy access to world-class manufacturing and applied research and development facilities that can help them stay in business. This valuable resource is the Oak Ridge Centers for Manufacturing Technology (ORCMT). ORCMT offers the expertise of the Department of Energy's (DOE's) three Oak Ridge sites managed by Lockheed Martin Energy Systems, Inc.—the Oak Ridge Y-12 Plant, Oak Ridge National Laboratory, and the Oak Ridge K-25 Site.

Many of ORCMT's facilities were originally developed for manufacturing components of nuclear weapons. Now, these technologies for defense are being adapted into technologies to help make American industries more competitive in the world marketplace while maintaining national security capabilities.

ORCMT's business is to help business with manufacturing, which is a key to America's economic health. Here's an example of one of its many successes.

Newton A. Solomon owns a small business in Murfreesboro, Tennessee, that makes circuit board prototypes, specializing in fast turnaround of small orders for companies developing new products. Inspection of the boards showed a high failure rate because they were getting burned in the plating process. These failures were costing Solomon's company money and potential business. He needed a quick and cost-effective solution to his manufacturing problem. He got that solution—and immediate results in product improvement—by calling ORCMT at the Y-12 Plant.

Solomon was pleased with the help he received. In a letter of appreciation to the ORCMT staff he wrote, "This is the first time in my more than 30 years in business that a large company has been so helpful to me—a small, minority businessperson."

Newton Solomon's company is just one example of the hundreds of companies that have solved manufacturing problems through interaction with ORCMT. Whether the problem is preventing corrosion of steel plates for electric griddles, certifying a measurement reference master used in building a next-generation space telescope, or developing a way to make cloth faster and cheaper, ORCMT staff members can meet the challenge.

ORCMT's business is to help business with manufacturing, which is a key to America's economic health.

Hybrid Organization

"ORCMT combines the research and development capabilities of ORNL with the unique manufacturing technologies of the Oak Ridge Y-12 Plant and the pollution-prevention research and waste management capabilities at the Oak Ridge K-25 Site to assist American industry," says ORCMT director Dave Beck. "We bridge the gap between ideas and products and between the laboratory and the factory floor. We like to say we solve tough manufacturing problems—and we do. I believe there are very few research or manufacturing problems that someone here at Oak Ridge cannot solve."

The centers—more than 25 in all—are organized through a matrix structure into seven core technology areas, such as manufacturing technology development.

Each center concentrates on a specific technical area, such as coatings and finishing, and may well perform work at several locations linked as a "virtual center." Staffs for the centers are composed of personnel from various Y-12 Plant organizations, several ORNL divisions (including Engineering Technology, Instrumentation and Controls, and Metals and Ceramics), and Central Engineering Services.

Maintain Expertise

ORCMT's efforts form a customer-driven, nationally recognized industrial resource center

Jerry Whitaker of the Y-12 Plant's Testing and Evaluation Center analyzes acoustic emission data from a weld. Acoustic emission technology is used at the Oak Ridge Centers for Manufacturing Technology to understand weld cracking. This center is the most heavily used at ORCMT.

The end of the Cold War continues to drive a national effort to use defense technologies to enhance the nation's industrial competitiveness.

Russ Greeley, a materials joining technologist, watches two parts being welded together by a laser welder in the Materials Joining Center.

for manufacturing technology. ORCMT had at least part of its genesis in the National Competitiveness Technology Transfer Act of 1989. This law encouraged DOE's defense facilities to seek out and work with the private sector. President George Bush's 1992 announcement that the United States would not build any new nuclear weapons, the end of the Cold War, and the dissolution of the Soviet Union brought an abrupt change in the mission of the Oak Ridge Y-12 Plant. Quickly it shifted from weapons production to weapons dismantlement and storage of the nation's enriched uranium stockpile. The end of the Cold War also continues to drive—at increasing speed—a national effort to use defense technologies to enhance the nation's industrial competitiveness while maintaining its capability to support the defense mission.

When it was producing nuclear weapons components during the Cold War, the Y-12 Plant acquired, or developed in-house, some of the most precise machining, process control, and inspection tools in the world. The plant's job was to turn the design ideas of the country's weapons design labs into shop-floor reality. Its staff manufactured items to levels of precision virtually unmatched in either the public or the private sector, and the 500th part produced had to be precisely the same as the first part to ensure the reliability of the nuclear weapons stockpile. ORNL, on the other hand, since its days of producing plutonium for the Manhattan Project, has built an international reputation as a multiprogram laboratory. It is known for its expertise in basic and applied research, isotope production, energy production and conservation, physical and life sciences, technology transfer, and education.

For the taxpayer, ORCMT offers an opportunity to realize a return on 50 years of Cold War investment in defense and energy technologies at DOE's laboratories. Now, the expertise across a broad spectrum of scientific and technological disciplines is available to solve manufacturing problems; create new materials, products, and processes; foster technological innovation; reduce or prevent pollution; and help create high-quality jobs for Americans. Harnessing such expertise is part of DOE's strategic plan to dramatically improve American industrial competitiveness in the world marketplace.

Manufacturing—Key to Economic Growth

Although manufacturing has been shrinking over the past 20 years, it is an enormously important part of the U.S. economy. In 1991 and 1992, the most recent years for which statistics are available, manufacturing accounted for about 18.5% of our real gross domestic product. Although manufacturing is still a mainstay of the economy, production processes are changing. Because of these changes, ORCMT fits well into the manufacturing mosaic.

"People say our economy is changing from a manufacturing economy to a service economy," says Dave Beck. "We don't believe that's true. There is a need for the United States to maintain a strong capability in manufacturing. There is a lot of foreign competition, especially from Germany, France, and Japan, where the companies get a lot of help from their government. This country has a growing need for the government to help the private sector. Manufacturing jobs are high-paying jobs. Manufacturing is the backbone for the whole country."

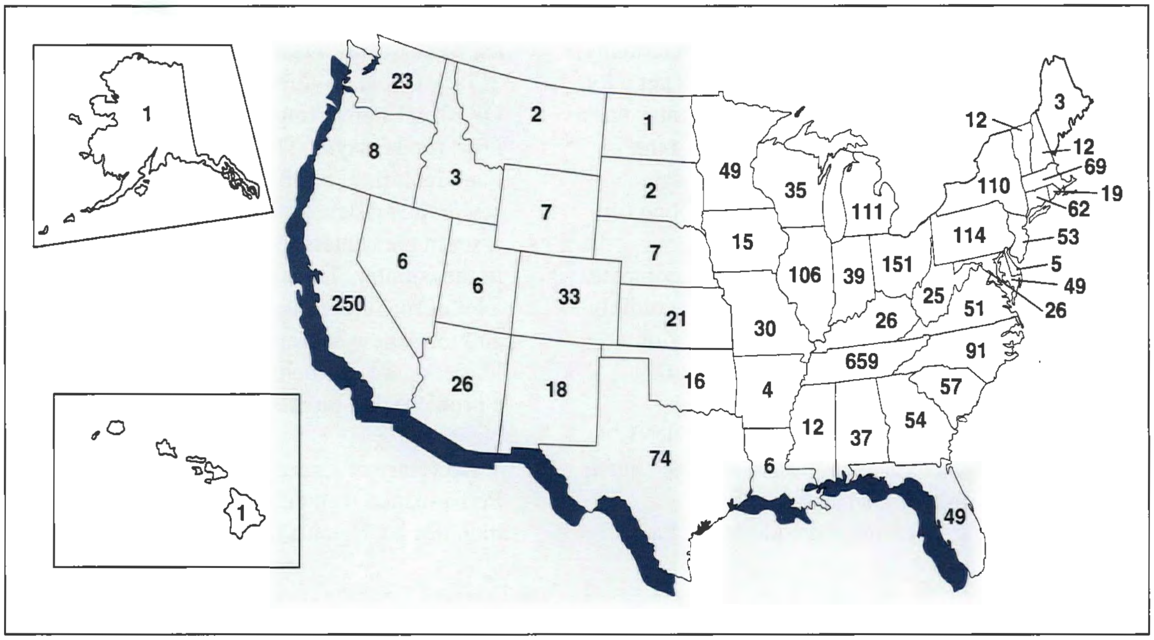
One way that American business can compete in a world where people will work for incredibly low wages is by increasing the efficiency of manufacturing through use of technology. "Unfortunately," says Carl Leitten of the Manufacturing Technology Section of ORNL's Engineering Technology Division (ETD), "much of American industry's capability for manufacturing technology development has disappeared because of tight budgets. Small firms use ORCMT as a research and development arm."

Jack Cook, co-director of ORCMT from ORNL's Engineering and Manufacturing Directorate, says, "The combination of manufacturing capability, technology, and applied research and development is the most valuable asset in the centers, perhaps a unique combination in the country. The umbrella of the centers covers a lot of manufacturing territory. We can develop and test a new coating to make a product last longer or we can help a mom-and-pop shop solve a problem that threatens to put them out of business."

Secretary of Energy Hazel O'Leary's Performance Agreement with the President includes DOE goals that call for "a more

Although manufacturing is still a mainstay of the economy, production processes are changing.

Karen Rogers holds a computer-designed mold for the lug displayed on the screen. The lug created by the mold is an example of the materials that can be produced using ORCMT'S concurrent engineering capabilities.



ORCMT has received requests from numerous businesses in the United States. Numbers on the map represent problems solved for businesses within each of the 50 states. In some cases ORCMT has responded to two or more different requests from a single business.

Small businesses need research and development. ORCMT can be their R&D arm.

productive and competitive economy." Two goals are to "improve industrial competitiveness" and "promote economic growth and the creation of high-wage jobs through access to technical information and research and development partnerships with industry."

Reaching Out

ORCMT helps achieve these goals by aiding its business customers through direct assistance, partnerships, cooperative research and development agreements (CRADAs), user facilities access, and work for others.

Direct assistance transfers know-how on using technology better, more efficiently, or in a unique application.

Direct assistance is a hands-on approach. If problems can't be solved through telephone calls or fax transmittals, Oak Ridge technical experts actually go to company sites to analyze problems and suggest solutions. The funding is limited to a total of $5000 per company request. DOE's Defense Programs National Machine Tool Partnership (NMTP) works in much the same way, except it can provide up to 10 days of technical help to any U.S. machine tool manufacturer or user.

Since it was officially created in September 1993, ORCMT's industrial outreach has generated some impressive statistics. Through the second quarter of fiscal 1995, the centers had assisted more than 1600 businesses nationwide. Industries requesting technical assistance include automotive part production, food product manufacturing, ceramic manufacturing and machining, materials testing and evaluation, and precision measurement. The private-sector impact of this assistance is estimated at more than $150 million—a 400% (4:1) return on investment. It is

Mike Pelfrey (right) a machinist in the Skills Demonstration Center, explains the workings of a computer numerically–controlled three-axis milling machine to John Jordon and Don Garren.

Oak Ridge technical experts go to company sites to analyze problems and suggest solutions.

estimated that between 1994 and 1998, the centers will stimulate over $1 billion of private-sector benefits and create 25,000 high-quality jobs.

While the direct assistance programs and the NMTP allow ORCMT to send its expertise out to businesses, the Deployment/User Facility Program permits businesses and educational institutions to come to ORCMT and use facilities and equipment they might not otherwise be able to access. Feedback on the Deployment/User Facility Program rates the program as excellent. The user facilities, which have been open since August 1993, have entered into 30 user agreements, including 18 with educational institutions, 5 with large businesses, and 7 with small businesses, involving entities in 10 states. Educational institutions can use the centers free if the work will provide economic benefit to small business.

ORCMT staff also have been involved in 87 CRADAs with a value totaling $135.7 million (both DOE and partner contributions) and in Work for Others agreements in which work is performed for specific companies on a reimbursable basis.

Filling Gaps in Training

ORCMT's Manufacturing Skills Campus and the Skills Demonstration Center provide training opportunities for clients ranging from high school and post-secondary vocational school students to professional technicians, designers, and craftspeople. The center provides both classroom instruction and hands-on experience with a wide range of machine tools and testing equipment.

Created to maintain essential manufacturing skills, retrain workers affected by defense program cuts, and transfer skills to local industrial firms to increase their competitiveness, the Skills Campus has served more than 1500 students, including more than 500 from private industry or schools in the region. Projections are for the program to increase private-sector involvement as the program matures, providing training in both manufacturing and maintenance skills. Classes cover subjects ranging from computer numerically-controlled machining to personal computer maintenance and troubleshooting to protecting the environment by proper refrigerant management. The Skills Campus also has prepared a series of highly successful classes that have been broadcast to remote sites by satellite.

Coy Gibson, director of the Tennessee Technology Center at Jacksboro, is involved with a program at the Skills Demonstration Center where local workers are being trained as tool and die makers. The training offered in this field fills a gap in East Tennessee, where no postsecondary tool-and-die programs are offered. Jacksboro's Tennessee Technology Center, which provides vocational and technical training, saw local industry's growing need for tool and die making and began preparing to fill that need. The Technology Center, however, did not have several pieces of high-tech equipment that would enable it to offer a state-of-the-art program.

"We could deliver 85% of what we needed for the program at the center, but we did not have those machines," Gibson says. As a result of the Jacksboro experience, the Skills Campus has recently initiated a user agreement with the Knoxville Tennessee Technology Center to provide a tool-and-die training program for Knoxville similar to the program offered for the Jacksboro campus.

Ray Buttram, at the display board, makes a point during a software applications class at the Manufacturing Skills Campus of the Oak Ridge Centers for Manufacturing Technology. The Skills Campus offers remote broadcasts that reach seven states, and its videotapes of classes are distributed throughout the Southeast.

Another highly visible and highly successful technology training tool is the Mobile Manufacturing Learning Center, which was developed for the state of Tennessee. This facility provides students at Tennessee high schools with a hands-on opportunity in advanced manufacturing technologies. It offers computer-integrated manufacturing devices including robots, milling machinery, a conveyor, a computer, and computer-integrated manufacturing software, all operating on a local computer network in the center.

Strategic Alliances

ORCMT has formed strategic alliances with federal and state agencies to better serve industry. One such alliance with the Department of Commerce's National Institute of Standards and Technology (NIST) resulted in the creation of a NIST-accredited metrology program at Oak Ridge. This agreement allows ORCMT to offer a precision measurement service that previously had been available only from laboratories in Germany. The service is now offered to domestic automobile, aircraft, and farm equipment manufacturers, among others.

Under this agreement, the Dimensional Metrology Laboratory can calibrate end standards and step gauges up to 1.35 meters long to a certified accuracy of 0.7 micrometer per meter (or about one one-hundredth of the diameter of a human hair). Manufacturers use these standards as in-house references to verify the accuracy of their own measurement machines, such as those used to inspect the dimensions of finished parts and assemblies of parts. In fact, the Metrology Center recently completed a contract to certify eight reference masters used in the production of optical elements for the Advanced X-Ray Astrophysics Facility—the next generation space telescope. The service combines NIST's measurement expertise and the Y-12 Plant's advanced technological capabilities, including a high-precision, large-volume coordinate measuring machine, the most accurate machine in its class. The mammoth machine is housed in a room in which the temperature can be controlled to within 0.01°C. The accuracies of the measurements performed at the ORCMT are certified by NIST, the nation's primary measurement and standards laboratory. The ORCMT laboratory recently received the first U.S. accreditation for dimensional metrology under the National Voluntary Laboratory Accreditation Program.

In partnership with the American Society of Mechanical Engineers, the American Gear Manufacturers Association, and Penn State University, NIST and ORCMT are developing a national Gear Metrology Center in Oak Ridge to provide advanced measurement services critical to the manufacture and quality assurance of precision gears.

To illustrate the impact of ORCMT on national competitiveness, gears in German-made helicopters last longer than those in U.S.-made aircraft because the gears are more precise and therefore mesh better. At the Gear Metrology Center, precision measurements will be made on gear masters (or standards). Companies using the center will be able to measure their gears against the gear masters characterized in Oak Ridge to ensure precision and the best possible meshing to lengthen gear life.

A coordinate measuring machine measures volume changes in heat-treated gears as part of the data gathering process for cooperative research conducted by DOE, several American automakers, the National Center for Manufacturing Sciences, and the Gear Research Institute.

Companies using the center will be able to measure their gears to ensure precision and the best possible meshing to lengthen gear life.

NIST experts perform hands-on work in the center, providing extensive engineering support for its calibrations. ORCMT houses the center and provides experience in complex geometry measurement, precision measurement, and associated equipment. Technical staff also address other aspects of gear manufacturing and measurement, including materials testing, nondestructive evaluation, and benchmarking.

The centers provide direct technology assistance through agreements with the Tennessee Valley Authority, the University of Tennessee Center for Industrial Services, the Tennessee Department of Economic and Community Development, and the Southeast Manufacturing Technology Center. This partnership network increases ORCMT's availability as a technology resource for industry in the areas served by the partners.

Areas of ORNL Involvement

ORNL researchers are closely involved with five high-profile ORCMT programs—advanced ceramics, textiles, composites manufacturing, coatings and finishings, and diagnostics.

ORCMT Strengths in Key Manufacturing Industrial Segments	Automotive	Aerospace	Textiles	Transportation	Construction	Machine Tool Builders	Metals/Plastics/Ceramics	Energy Industry	Medical Industry	Paper/Pulp
Manufacturing Skills Campus	●		●	●	●	●		●	●	●
Skills Demonstration	●		●	●		●		●	●	●
Direct Assistance Program	●	●	●	●		●	●	●	●	●
Manufacturing Information Resources	●	●	●	●	●	●	●	●	●	●
Concurrent Engineering	●	●	●	●		●	●	●	●	
Ultraprecision Manufacturing	●	●	●	●		●	●	●	●	
Micro Manufacturing	●	●	●	●		●	●		●	
Thin Film Technology	●	●		●			●	●	●	
Mfg. Prototyping and Demonstration	●	●	●	●		●	●		●	●
Materials Joining	●	●	●	●	●	●	●	●	●	●
Materials Forming and Processing	●	●	●	●	●	●	●	●	●	●
Plating and Cleaning	●	●	●	●	●	●	●	●	●	●
Composites Manufacturing Technology	●	●	●	●	●	●	●	●	●	●
Coatings and Finishings	●	●	●	●	●	●	●	●	●	●
Medical Health Eng. and Manufacturing						●	●		●	
Energy Conservation	●	●	●	●	●	●	●	●	●	●
Pollution Prevention	●	●	●	●	●	●	●	●	●	●
Alternative Refrigerants	●	●		●	●	●		●	●	●
Metrology	●	●	●	●	●	●	●	●	●	●
Testing and Evaluation	●	●	●	●	●	●	●	●	●	●
Diagnostics and Quality Assurance	●	●	●	●		●	●	●	●	●
Measurement and Control Technology	●	●	●	●	●	●		●	●	●
Advanced Photonics	●	●	●	●	●	●		●	●	●
Advanced Ceramic Technology	●		●			●	●	●	●	
Machine Technology Access	●	●	●	●	●	●	●	●	●	●
Advanced Propulsion Technology	●		●	●	●	●		●	●	●
Ceramic Electronic Packaging	●	●		●			●			●

(Industry Segments)

This list indicates the industrial applicability of ORCMT centers' expertise. The centers are listed by core area: manufacturing technology development, manufacturing technology demonstration, manufacturing technology deployment, energy and environmentally conscious manufacturing, manufacturing quality and process assurance, and industry-specific technology. Not shown here is special materials processing.

Organizational lines are blurred, with some project managers located at ORNL for work being done at the Y-12 Plant, center managers on loan from several divisions, and technical support and equipment coming from all three sites. Here is a brief look at each of these programs.

Structural Ceramics

To reduce our nation's dependence on imported oil and cut emissions from vehicles, highly efficient piston and gas turbine engines are being developed. Because they must be run at high temperatures to use fuel most efficiently and emit little pollution, valves and other components of these engines will be made from structural ceramics such as silicon nitride. These ceramics, unlike metal, do not melt or corrode at such high temperatures.

Use of these ceramics is limited by two obstacles: the difficulty of making low-cost ceramic powders and the high cost of machining these hard materials accurately to the critical dimensions required to shape them into engine parts. These problems are being addressed through the DOE-supported Cost-Effective Machining of Ceramics (CEMOC) program.

Ceramics are difficult to machine—the materials are nearly as hard as the diamonds used to grind them. Currently, engine components formed from structural ceramics cost far more than designers can accept. Reducing the cost depends heavily on advances in the nation's machine tool industry. The CEMOC program aims at helping the industry develop improved tools to machine ceramics at lower costs.

The CEMOC program includes CRADAs, subcontracts with industry on ceramic manufacturing in the Ceramic Technology Project, and user projects at ORNL's High Temperature Materials Laboratory (HTML).

Subcontracts have been set up with many companies for demonstrating specific high-accuracy ceramic component manufacturing technology. Other companies are working with Oak Ridge staff to develop better grinding wheels and evaluation instruments.

Numerous projects conducted by industrial users at the HTML concern high-accuracy instrumented ceramic grinding, dimensional analysis, and surface metrology. Industrial firms are also employing tools in the six HTML user centers to characterize candidate materials for their products.

Arvid Pasto, HTML director, cited the creation of the Ceramic Manufacturability Center at ORNL as a model for other types of cross-organizational teams for the future. The center contains state-of-the-art machine tools for use by teams of researchers from industry, ORNL, and the Y-12 Plant. They are working together to determine better ways to grind structural ceramics rapidly and accurately. This center complements the other six HTML user centers, allowing its

We are establishing an integrated set of capabilities for manufacturing structural ceramics.

ORCMT staff are developing ceramic components for highly efficient gas turbine engines that will be operated at temperatures that would melt metal engine parts.

We have created a textile center to help show what ORCMT can do for the textile industry.

users to rapidly and fully characterize their machined materials.

Fred Jones, an Energy Systems Corporate Fellow and Core Manager for Industry Specific Technology, commenting on the working relationship that has developed through CEMOC, says, "The terrifically unique thing about these ceramic projects at Oak Ridge is that they bring together the incredibly strong materials science expertise of ORNL research, the world-class equipment at the High Temperature Materials Laboratory, and the Y-12 Plant staff's unique experience in manufacturing. Those three elements make it go. What is significant is that we are establishing an integrated set of capabilities for manufacturing structural ceramics."

"We don't have this great delineation of us or them," says Bill Barkman, manager of the Ceramic Manufacturability Center. "We view it as an Oak Ridge program. We tap whatever resources are appropriate. We've looked at the whole organization and pulled out the resources that could do the best job for the industrial partner."

Textiles

Textile manufacturing occupies a very large sector of the U.S. economy. The $219 billion textile industry employs 12% of the manufacturing work force and consumes about 6% of the nation's energy. And, like other sectors in the manufacturing economy, textiles have undergone dramatic changes in recent years because of pressure from off-shore manufacturers. The AMTEX program is an agreement between DOE and the textile industry to apply the specific skills of the national laboratories to improve all aspects of textiles—from raw material use to retail sales.

Oak Ridge is participating in three AMTEX projects: Computer-Aided Fabric Evaluation (CAFE), Demand-Activated Manufacturing Architecture (DAMA), and Textile Resource Conservation (TReC). The CAFE laboratory project manager is Glenn Allgood of ORNL's Instrumentation and Controls Division. ORCMT researchers are most closely involved with the CAFE project.

"What we are doing here is building a partnership that supports textile industry needs," Allgood says. "Specifically, we provide a central point for developing and testing new concepts that could lead to rapid development, deployment, and prototyping of new textile technologies. We have created a textile center to test those technologies and to help show industry what ORCMT can do for the textile manufacturers."

Fabric woven from spun yarn and filament on looms may develop defects during the weaving process. After a production run, workers feel and look at cloth in search of defects. If defects are found, the off-quality cloth is discarded. Correcting this inefficiency to reduce financial losses is one of AMTEX's goals.

One purpose of the CAFE project is to develop an on-line inspection system that would detect defects as they occur and remove the bad cloth from the production run to reduce manufacturing waste. Allgood has led the development of an on-loom greige-inspection system that combines optical sensors and machine diagnostics with computers. Greige (French for gray) is unbleached, undyed raw fabric. The system can detect and map structural defects. Information is passed along by computer to the next production step, such as cutting. This information is also fed back to the process to remediate the cause of the defects. The data also provide the basis for process control.

The CAFE project is also developing a system for inspecting color-printed pattern goods. Smart optical sensors are used to ensure that colored patterns on cloth are true and in register. A prototype system now being tested at textile firms

A high-speed weaving machine was provided by Glen Raven Mills for the development, testing, and evaluation of an on-loom greige-inspection system. Glenn Allgood (ORNL), Marty Ellis (Institute of Textile Technology), and Bill Martin of Glen Raven Mills examine the machine at the Y-12 Plant.

Coatings can be designed to protect parts from abrasion, corrosion, and high temperatures.

can "learn" a complicated pattern in the first part of a roll and then inspect the remainder.

Another goal of the project is to develop a system for inspecting knitted fabrics and three-dimensional fabrics such as terry cloth and carpeting. Besides ORNL, DOE facilities involved in the CAFE project are Argonne, Lawrence Berkeley, Lawrence Livermore, and Sandia National Laboratories.

"The basics of weaving have not changed dramatically, but the process has," Allgood says. "The textile industry now is trying to change it. It's one of the few industries in the United States that has developed a plan for competing in the world market. The textile industry is dedicated to seeing that this endeavor is successful."

In this program, ORCMT provides a transition between the laboratory and factory environments, where machines must cope with lint, vibration, heat, humidity, noise, and production schedule demands. The result should be better quality products made at lower cost, with less waste and energy consumption, thus creating more American jobs.

Coatings and Finishing Center

Because of competition from foreign companies, U.S. firms are under increasing pressure to manufacture parts that last longer under trying conditions. Rather than redesigning parts to be made of advanced materials, it is often more cost effective to design coatings for current parts that will give the parts the desired functional surfaces. Coatings can be designed to protect parts from abrasion, corrosion, and high temperatures as well as to make the parts "self-lubricating." As an example, aluminum pistons can be coated to help them better resist corrosion and deterioration brought on by high temperatures.

Manufacturing Technology Areas

More than 25 separate centers form the Oak Ridge Centers for Manufacturing Technology. These centers focus on seven core technology areas that are organized around the Department of Energy's initiative to improve American industrial competitiveness.

Those core technology areas and associated area of expertise are

- **manufacturing technology development**
  - direct assistance programs
  - manufacturing skills campus
  - skills demonstration

- **manufacturing technology demonstration**
  - ultraprecision manufacturing technology
  - manufacturing prototyping and demonstration
  - micromanufacturing technology
  - concurrent engineering environment
  - lithium microbattery technology

- **manufacturing technology deployment**
  - composite manufacturing
  - coatings and finishings
  - materials joining
  - plating and cleaning
  - medical health engineering and manufacturing
  - manufacturing information resources

- **energy and environmentally conscious manufacturing**
  - energy conservation
  - pollution prevention
  - advanced refrigerants

- **manufacturing quality and process assurance**
  - metrology center
  - diagnostics and process assurance
  - testing and evaluation
  - measurement and control technology applications
  - advanced photonics initiative

- **industry-specific technology**
  - advanced ceramics
  - advanced propulsion
  - machine technology access
  - ceramic electronic packaging
  - textiles

- **special materials processing**
  - hazardous materials processing
  - hazardous materials packaging
  - hazardous materials management and storage
  - depleted uranium processing
  - enriched uranium processing

ORCMT's Coating and Finishing Manufacturing Technology Development Center develops and validates environmentally benign, advanced integrated coating manufacturing processes, products, and capabilities. Its equipment applies coatings through various processes—plasma spray, high-velocity oxygen fuel (HVOF) spray, electric wire arc jet, oxygen-acetylene flame spray, and ion sputtering. These processes are often integrated with robotics and computer controls as well as contained in regulated environments, enabling tight control of process parameters and accurately reproducible experiments.

Because of these capabilities, the Coatings and Finishing Center is a primary source of solutions to problems in materials deposition and manufacturing process development. The center experiments with the following materials: metals, alloys, ceramics, cermets (metal alloy composites), composites, intermetallics, polymers, and compounds. Companies from virtually every industry have approached the center for assistance in developing coatings or coating processes for their products. The center provides coating manufacturing test beds that enable development and hands-on validation of integrated coating processes and new coating materials, according to center director Keith Kahl.

"Industry knows how to manufacture parts inexpensively from materials such as aluminum and steel, but these parts may not last very long because of their lack of resistance to wear, erosion, or corrosion," Kahl says. "The center helps companies find coatings that will enhance the performance of parts for specific uses. For example, thermal barrier coatings are used in jet engines to retain heat to increase fuel efficiencies. The turbine blades used in Navy airplanes and seagoing vessels are coated to prevent salt and sulfur corrosion. Typically, there are 500 coated parts in each jet aircraft engine and more than 100 coated parts in each automobile. We've begun to see that almost every industry—every industrial sector in the world—can use coatings to enhance their product performance."

The center is involved in various projects with the government and private industry. Some examples include development of

- coating materials and processes to enable cheaper and faster fabrication of tooling for thermoplastic and thermoset composites,
- a coating for the interior wall of the plasma vessel of the International Thermonuclear Experimental Reactor,
- a dielectric coating to enhance the performance of high-temperature electrostatic chucks for the semiconductor industry,
- coatings to increase corrosion resistance of aluminum alloy components for aircraft,
- a sensor to measure coating characteristics during and after fabrication as well as to detect erosion of in-service air components, and
- a "filling" process for use in manufacturing wood furniture.

In addition to being accessible to outside companies and agencies, "the door is open for anybody in the Oak Ridge complex to work in the center, use its tools, or bring problems to us that we can help them solve," Kahl says. "We've had people from all three plants here. The door is open for interaction, and I see it happening."

Composite research at Oak Ridge has led to significant breakthroughs in development of materials for flywheel energy storage systems.

Composites

High-performance composite materials have a direct impact on daily life in the United States. They are found in automobiles, airplanes, baseball bats, orthopedic devices, tennis racquets, and submarines. New composites are, quite literally, everywhere. Researchers at ORCMT's Composite Manufacturing Technology Center have 30 years of experience in energy, space, and defense programs.

Now, the Oak Ridge composites team is working in partnerships with U.S. industrial firms to develop commercial uses for these advanced engineering materials. Through the Composites Center, U.S. industry gains access to the expertise and manufacturing test facilities needed to

We are trying to find ways to bring composites technology into the commercial marketplace.

Composites winding machine in the Polymer Composites Manufacturing Technology Center.

maintain competitiveness in the use of composite materials. The center has comprehensive capabilities for the development, evaluation, and demonstration of affordable advanced composite materials and structures.

Composite research at Oak Ridge has led to significant breakthroughs in development of materials for flywheel energy storage systems, processing technology for thick-wall structures, and the design and manufacture of large composite structures that can withstand very high compressive loads. Current investigations include innovative processing methods such as electron beam and microwave curing.

"Traditionally," says center manager John Shaffer, "the composites business outside of DOE has been fueled by aerospace and defense, but that market is declining with shrinking defense budgets. Now we are trying to find ways to bring composites technology into the commercial marketplace."

Some specific applications that the composites team helped develop are

- **Advanced technology torpedo**—Oak Ridge was a manufacturing test bed for development of fiberglass hull sections and other composite components in U.S. Navy advanced technology torpedoes.
- **Autonomous underwater search system**—Oak Ridge designed, developed, and built a positive-buoyancy graphite-epoxy pressure hull for the U.S. Navy Autonomous Underwater Search System. The composite pressure hull, which has titanium end caps, is qualified for repeated dives to pressures corresponding to 20,000 feet.
- **Cryogenic fuel tank**—Oak Ridge developed and manufactured lightweight graphite-epoxy fuel tanks for the National Aerospace Plane program. The tanks have aluminum liners and end caps, and they are

designed to hold liquid hydrogen at three atmospheres internal pressure.

- **Aerospace structures**—Oak Ridge has provided guidance to NASA and U.S. Air Force programs in developing new graphite fiber–reinforced thermoplastics for structures in space.
- **Compressed gas cylinder**—Fiber placement methodologies and advanced resin curing processes are being developed at Oak Ridge for manufacturing lightweight storage cylinders for high-pressure natural gas fuels.
- **Centrifugal concentrator**—Oak Ridge is developing a centrifugal concentrator device that extracts trace quantities of heavier-than-air molecules from air samples, enhancing the sensitivity of existing gas detection instruments. A high-speed rotor in the concentrator is made of graphite-epoxy composites.
- **Lightweight automotive materials**—To improve the efficiency and safety of cars and trucks, the structural materials for these vehicles should be light and strong. Oak Ridge is working with private industry and other DOE laboratories, under the direction of the Automotive Composites Consortium, to perform basic materials research and optimize manufacturing technologies for composites in transportation vehicle structures.
- **Flywheel energy storage**—Oak Ridge is working with private industry and the federal government to develop composite components for high-speed flywheel systems for storing energy for later use in automotive vehicles. This work capitalizes on the world-record flywheel rotational speed of 1400 meters per second (3100 miles per hour) set by Oak Ridge in 1985.

Diagnostics

A couple of decades ago, ORNL developed techniques for diagnosing problems in nuclear reactor operation by spotting abnormalities in noise signatures. A similar technique was developed at ORNL to detect hints of abnormal operations in electric motors. This expertise is now being called upon at ORCMT's Advanced Diagnostic Center, which includes personnel from both ORNL and the Y-12 Plant. Expertise in optical diagnostics, electrical signature analysis, vibration monitoring, chaos theory, neural networks, and other diagnostic techniques are used to address a wide range of industrial needs. The center is working with numerous companies to help improve their operations and products. Applications include condition monitoring of electrical machinery, diagnostics for advanced development of automotive and aircraft engines, predictive maintenance of industrial plant equipment, and improved techniques for disease diagnosis.

Experts in optical diagnostics at ORCMT are studying the potential of using phosphor thermometry as a metrological standard. This method provides an absolute measurement of a material's surface temperature using the fluorescence signatures of certain chemically stable phosphors on the material. An optical material, elastic silicone rubber optical fiber, has been developed at ORNL for weighing vehicles as they roll over high-precision sensing plates placed on roads. This weigh-in-motion measurement technique is expected to play an important role in traffic monitoring and control, truck weighing, and vehicle identification.

The Oak Ridge complex has a combination of capabilities and facilities unmatched anywhere in the world.

Summary

In conclusion, the Oak Ridge complex has a combination of capabilities and facilities unmatched anywhere in the country or even in the world. These resources have been used to help meet the challenges of producing and conserving energy, protecting the environment, and providing for the nation's defense. Now, these resources are being used to meet another important challenge—increasing the nation's industrial competitiveness. Today, Oak Ridge is bridging basic and applied scientific research with manufacturing technology and experience to benefit U.S. industry while maintaining and enhancing DOE capabilities. ORCMT's motto is "We Solve Tough Manufacturing Problems"—Call 1-800-356-4USA.

Bill Wilburn is a staff member of Energy Systems' Office of Public Affairs. ornl

If the results of the experiments on the specialty steels are successful, the company could add more jobs.

Welding Company Samples Oak Ridge Expertise

ORNL recently provided a Fortune 500 company with the tools it needed to obtain steel samples for research. As a result, the company has saved money and may increase its employment.

Lincoln Electric Company of Cleveland, Ohio, is a world leader in welding and cutting products and a manufacturer of industrial electric motors. The company, which has been in business almost 100 years, has about 3200 employees in the United States and annual sales of about $846 million.

Lincoln Electric Company's research efforts had been hampered because it could not purchase small quantities of specialized steels to evaluate for possible welding applications. The smallest samples available for order from commercial steel mills were too large and expensive for the company.

Through a professional association with Stan David, a welding expert in ORNL's Metals and Ceramics (M&C) Division, a Lincoln Electric official visited Oak Ridge. During a tour, he learned about the nonconsumable arc melting facility and rolling capabilities in M&C. With assistance from the Oak Ridge Centers for Manufacturing Technology and the Defense Programs National Machine Tool Partnership, the company was provided access to ORNL's facilities operated by M&C's Materials Processing Group led by Vinod Sikka.

The steels were melted by Joseph Vought and rolled into ten appropriately sized sheets by Ken Blakely and Ed Hatfield. All are engineering technologists in Sikka's group.

In this way, Lincoln Electric obtained the small samples of experimental steels it otherwise could not secure. The company is currently evaluating the samples to determine if they will meet product needs. If the results of the experiments on the specialty steels are successful, the company could add more jobs within the company.

In a June 1, 1994, letter to Stephen Laggis of ORCMT, John Gonzalez, vice chairman of Lincoln Electric, wrote, "Your vacuum melting facility and rolling capabilities...offer us the experimental tool we have sought for years. Your facility has solved a problem that has plagued us for years relative to the production (of) and experimentation on special steels. The knowledge and cooperation of your people have been outstanding."

After the changes were implemented, the company saw an immediate improvement in the outlays.

ORCMT Attracts Magnet Company

Arnold Engineering was looking for a way to make ceramic magnets faster with less waste and fewer defects. Company officials soon were attracted to the expertise in Oak Ridge.

Arnold Engineering, a division of SPS Technologies, Inc., in Sevierville, Tennessee, manufactures hard ferrite permanent magnets for direct-current motors, magnetic separation of metals, and other uses. The company has 100 employees, has been in business for 23 years, and sells about $7 million worth of ceramic magnets each year.

The company wanted to optimize its kiln process used to heat and densify its ceramic magnets. While exploring ways to optimize the sintering process, Arnold Engineering officials contacted the University of Tennessee Center for Industrial Services, which referred them to the Oak Ridge Centers for Manufacturing Technology.

Through ORCMT, two ceramic engineers consulted with Arnold Engineering staff by telephone and then visited the company to see its operation and kiln process first hand. The engineers were Mark Janney of ORNL's Metals and Ceramics Division and T. Gordon Godfrey of the Y-12 Plant's Development Division. After their examination, they recommended that the company make two changes in its sintering process.

After the changes were implemented, the company saw an immediate improvement in the outlays. The amount of scrap and number of defects in the magnets were reduced. The throughput of the kiln tripled because the changes allowed faster operation.

As a result of Oak Ridge's technical assistance, Arnold Engineering retained four employees whose jobs had been in jeopardy, increased sales by 14.3% for the year, and reduced production costs by 2.6%.

Jerry Roberts, plant and facilities engineer, said that Arnold Engineering's experience with ORCMT had been very good for the company. "We received a great benefit through the technology transfer program. It also made us aware of what the Department of Energy's technology transfer program can do, and it will probably result in other projects for us."

As a result of Oak Ridge's technical assistance, Arnold Engineering... increased sales by 14.3%... and reduced production costs by 2.6%.

The immediate result of the ORNL evaluation is that the crystal materials, with some modifications, could be used in remote sensing.

ORNL Helps Laser Firm and Former Soviet Union

Large volumes of natural gas are lost daily worldwide through leaks in pipelines. Considerable energy would be saved if these leaks could be detected and repaired. In addition, less methane would escape to the atmosphere where, as a greenhouse gas, it may contribute to global warming.

In Russia, one of the world's major gas producers, it is estimated that the gas pipeline system is losing from 1 to 15% of the 24 trillion cubic feet of gas annually produced. Even at the lowest leakage rate, Russia would lose a significant amount of gas—240 billion cubic feet per year. Finding and stopping these leaks would help Russia economically because natural gas, which is cheaper than oil, is becoming a favorite fuel of electric utilities.

Pipeline leaks have been detected from small low-flying planes by inspection of vegetation. Because natural gas kills green plants, dead vegetation in pipeline areas indicates the presence of leaks. In cities, a way to detect leaks is to lace the gas with an odorant. When pipelines leak, people smell the gas and report the problem.

A team of Americans and Russians are taking a new approach to the problem by developing an airborne leak detection system. The idea is to use laser light to remotely detect optical absorption caused by the escaping natural gas. Such a laser, which could be operated from an airplane or helicopter, will be built when material that emits laser light of the required wavelength is developed. Just as radar is used by the U.S. Weather Service to spot developing rainstorms, laser "radar" can be made to detect methane and other hydrocarbons. The Department of Energy's Oak Ridge complex is playing a role in the development of such a laser.

LaSen, Inc., of Las Cruces, New Mexico, has been working with a Russian institute on developing an airborne laser radar for detecting leaks of natural gas from pipelines. The company's main product is solid-state mid-infrared tunable lasers for sensing environmental and process changes.

The Institute of Energy Problems of Chemical Physics in Moscow has unique capability for producing custom crystal materials needed for these lasers. LaSen is working with the institute to make a crystal that, when excited, emits infrared light at wavelengths that are absorbed by natural gas. The light is directed from an airplane to the ground through a telescope; the light bouncing back from the ground, minus that absorbed by leaking natural gas, would be captured by a detector onboard the airplane. Through detection of losses in reflected light intensity, gas leaks can be located.

To evaluate the crystals produced by the Russians, LaSen turned to ORCMT at the Y-12 Plant. ORNL researchers were asked to provide technical advice on developing a lasing material for gas detection.

Tom Schmidt of ORNL's Chemical Technology Division leads the effort to cut and polish the Russian crystal samples using Oak Ridge's special materials processing capabilities. Eric Wachter of the Health Sciences Research Division analyzes the optical properties of the crystals using spectroscopic equipment. He measures each crystal's ability to absorb visible and near-infrared light so that he can predict whether it will lase—produce a laser beam of the desired wavelength.

"We are examining crystals made of potassium, titanium, and arsenic," Wachter says. "These KTA crystals are doped at Minsk, Belarus, with small amounts of neodymium. The dopant level of the crystal must be high enough that the material will lase. The current level is 0.1% of the crystal content, but the goal is to achieve 1 to 5% to create a lasing material."

Wachter has provided spectroanalysis data for laser simulation models to demonstrate the material's potential usefulness as a laser medium. Based on these results, LaSen recommended that the Russians grow the crystal material in a larger format with the aim of mass production for long-term projects.

Allen Geiger, president and one of the founders of LaSen, said the immediate result of the ORNL evaluation is that the crystal materials, with some modifications, could be used in remote sensing.

"This promising result," he says, "will keep LaSen's six staff members employed. However, over the next 4 to 5 years, with mass production of the crystal material for laser applications, the company anticipates growing from $1 million in sales to between $15 and $40 million. We could employ up to 100 people to manufacture and tailor the materials for use in photochemical processing, laser arrays, and integrated optical applications."

Wachter says this project involving LaSen, the former Soviet Union, and ORNL/ORCMT, which started out as a Defense Programs Small Business Initiative, has evolved into a larger project under the Newly Independent States Industrial Partnership Program. The first phase of the project, which will end in June 1995, focuses on crystal development. The second phase involves building airborne systems using these crystals for gas leak detection and testing these systems in the field.

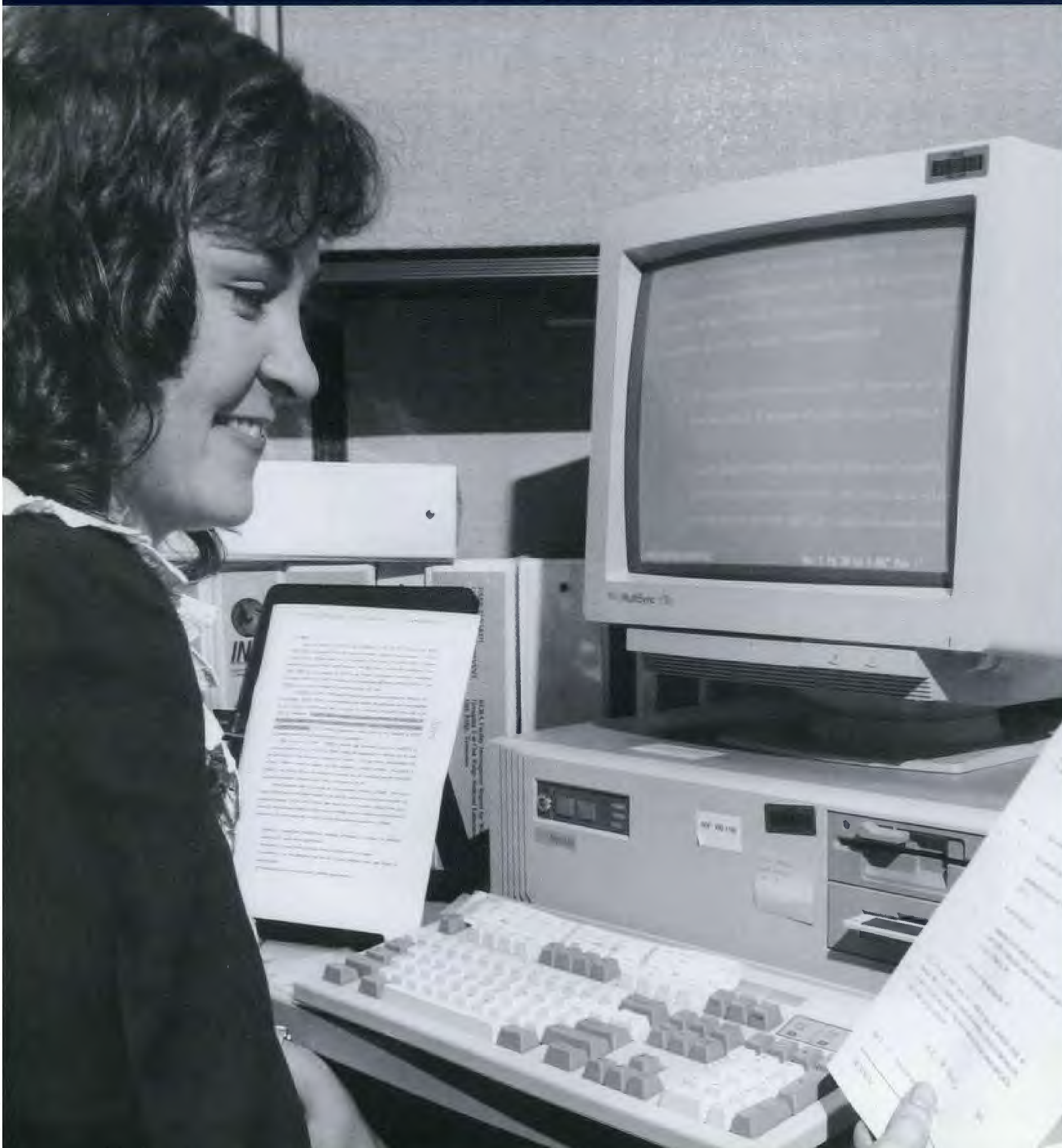
Besides the Moscow institute, the project will also involve the National Scientific and Educational Center of Particle and High Energy Physics, Byelorussian State University, in Minsk, Belarus. This center has considerable experience in development and characterization of crystals for tunable infrared lasers.

The crystal materials program helps the United States meet its goal of helping the former Soviet Union convert its technologies developed for weapons production to the manufacture of commercial products for civilian use. Russia itself would be a good market for gas leak detection systems because it has proven natural gas reserves that total more than 40% of the world supply.

Russia would be a good market for gas leak detection systems.

Risky Business: Assessing Cleanup Plans for Waste Sites

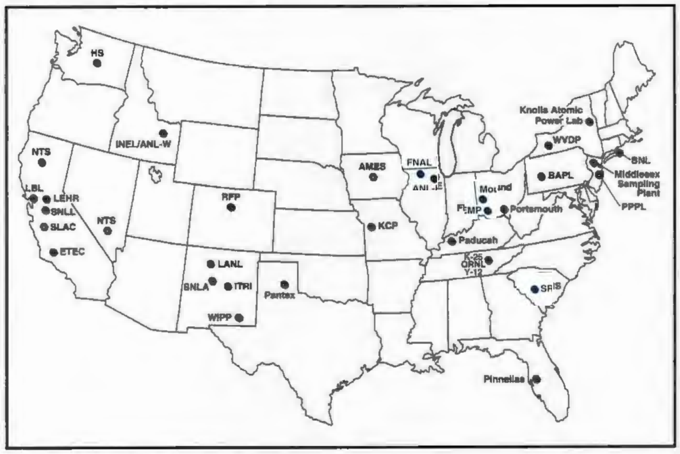
By Bonnie Blaylock



Editor's Note: The U.S. Department of Energy's many production and research sites contain radioactive and hazardous wastes. These waste sites pose potential risks to the health and safety of remediation and waste management workers and the public. The risks, however, vary from site to site. Some sites undoubtedly present larger risks than others and should be cleaned up first. However, before the cleanup begins, DOE is required by law to prepare an environmental impact statement on any actions that may significantly affect the environment—even actions that would clean it up.

The impact statement must also consider the health and safety risks to workers and the public from the cleanup and management of the resulting wastes. In other words, attempts to reduce potential or existing health risks by cleaning up a waste site could produce other risks, altering the benefit-to-risk ratio. For example, cleanup might result in the release of contaminants into the groundwater or air, potentially exposing the public to hazardous substances. Workers removing contaminated soil may be injured while operating heavy equipment. Other cleanup personnel might suffer from heat stress as a result of wearing protective gear. Still other workers risk becoming ill from exposure to radiation or hazardous chemicals.

Clearly, it is a difficult task to weigh the relative risks of leaving wastes at their sites or removing, treating, and disposing of them to restore DOE sites to their original environmental condition. ORNL has taken the lead role in assessing the current risks of DOE waste sites to the public, workers, and ecological systems (i.e., wildlife and vegetation) and in predicting the risks of environmental restoration and management of the wastes produced in the cleanup process. In the following article, Bonnie Blaylock describes ORNL's work in computer modeling and human health risk assessment. In an accompanying article, Larry Barnthouse describes ORNL's ecological risk assessment project in support of DOE's impact statement.

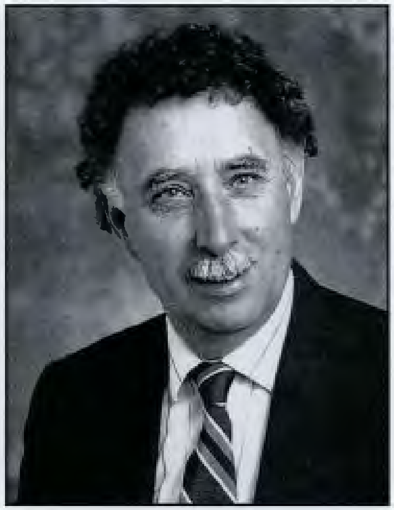


These DOE installations in the United States will require environmental restoration and waste management. Included are three sites in Tennessee—the Oak Ridge Y-12 Plant, K-25 Site, and ORNL.

ORNL was chosen to perform human health and ecological risk assessments for DOE because of its risk assessment expertise.

Since the spring of 1992, Oak Ridge National Laboratory's Center for Risk Management (CRM) has been a key participant in the Department of Energy's Programmatic Environmental Impact Statement (PEIS). The preparation of this statement was mandated by the Secretary of Energy in 1990 to develop and implement an integrated environmental restoration (ER) and waste management (WM) program for DOE sites.

Bonnie Blaylock works at the computer on a health risk assessment document. It will be part of a programmatic environmental statement on DOE's proposed actions to remediate its waste sites and manage wastes from cleanup activities.

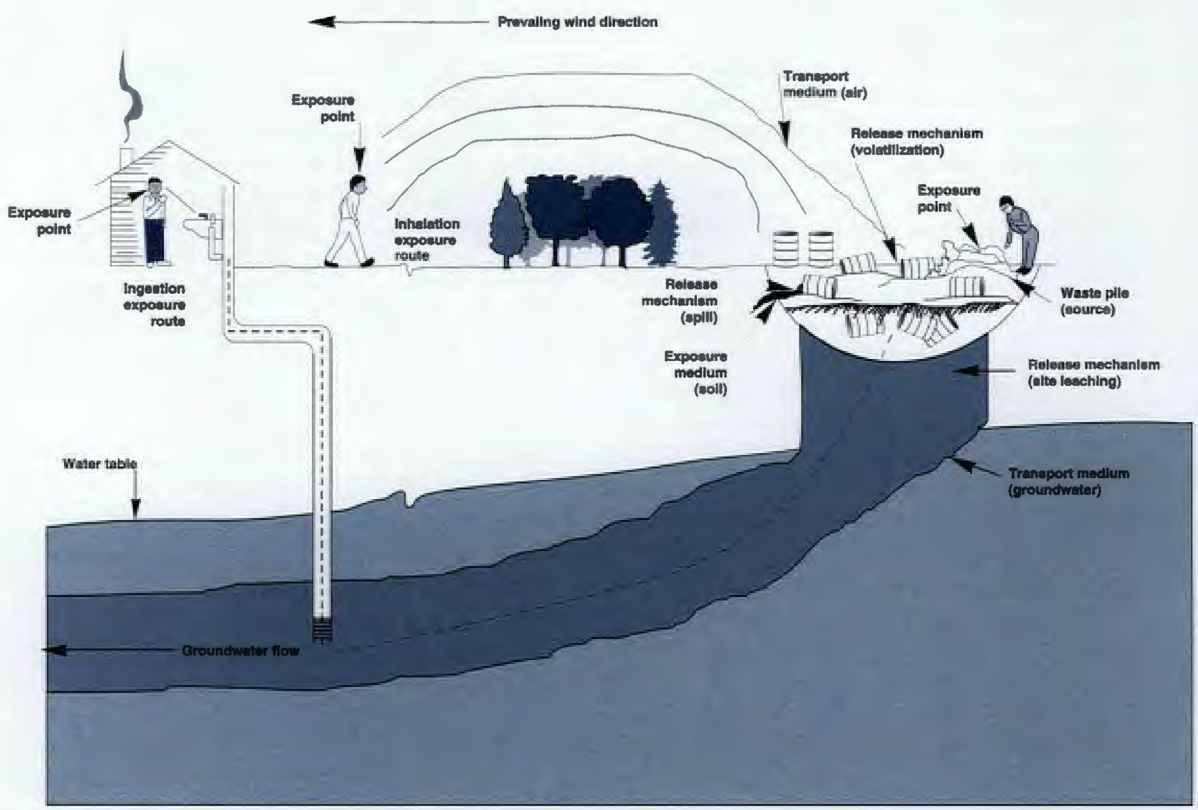


Curtis Travis is director of ORNL's Center for Risk Management.

The PEIS is conducted under the guidelines of the National Environmental Policy Act, which requires that federal agencies prepare environmental impact statements on major federal actions that may significantly affect the environment. The laboratories involved in the PEIS are evaluating several options for environmental cleanup and waste consolidation to trace potential risks from the ER cradle (hazardous waste sites) to the WM grave (storage and disposal facilities).

ORNL was chosen to perform human health and ecological risk assessments for this multi-million-dollar project because of the center's risk assessment expertise. The staff of the CRM (directed by Curtis Travis of the Health Sciences Research Division) performed the human health risk assessment portion of the PEIS, and the staff

The team assessed the risks for the baseline conditions of various categories of waste sites across the DOE Complex.



This schematic shows the various routes by which workers and the public can be exposed to radioactive and chemical contaminants.

of Larry Barnthouse in the Environmental Sciences Division performed the ecological risk assessment portion of the PEIS (see the following article). In addition to health and ecological risks, other impacts evaluated in the PEIS include socioeconomic impacts, air and water quality impacts, costs, and transportation risks. ORNL is responsible only for evaluating the human health and ecological impacts.

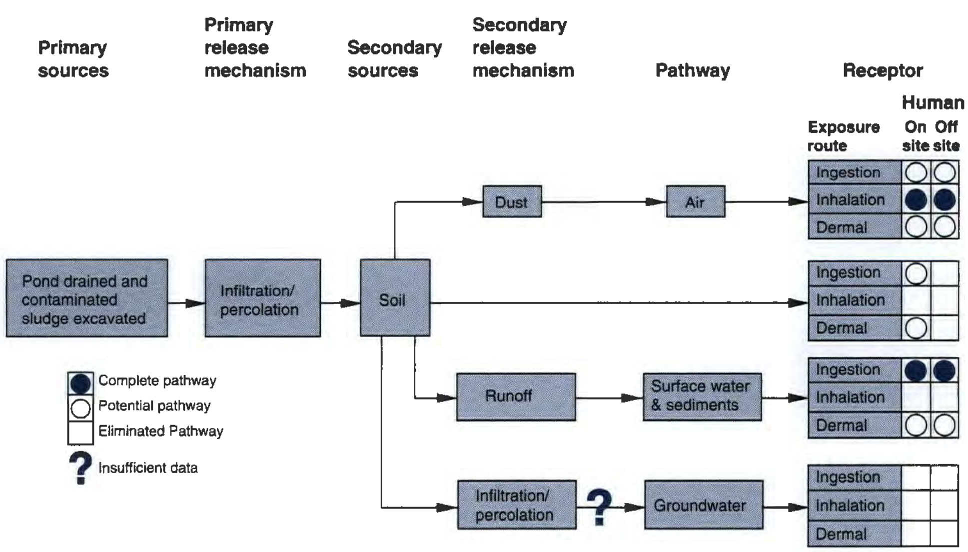
Environmental Restoration, or "The Cradle"

For effective project management, the human health risk assessment was divided into two parts—ER and WM. The ER risk assessment team, led by Jill Morris and Irene Datskou, assessed the risks for the baseline conditions of various categories of waste sites across the DOE complex: facilities, buried waste, contaminated soils, liquid containment structures, surface water, and groundwater.

To manage the huge number of sites and contaminants that exist across the DOE complex, the ER team used a fate and transport model to simulate and predict the transport of contaminants through the environment to different areas where people might be living under both present and future site conditions. The linearity of the computer model allowed the team to use a unit risk approach to estimate risks for numerous exposure scenarios for various times (e.g., living on a waste site 500 years from now) for each of the waste sites being evaluated.

A New Approach to Complex-Wide Risk Assessment

The unit risk approach is a simple concept that was applied on a large scale to yield complex results. ORNL worked with DOE's Pacific Northwest Laboratory, which provided contaminant concentration data for each waste site and many of the environmental parameters needed to run the computer models used for the risk assessment. The ER team assumed that one unit (1 gram or 1 curie) of each contaminant was



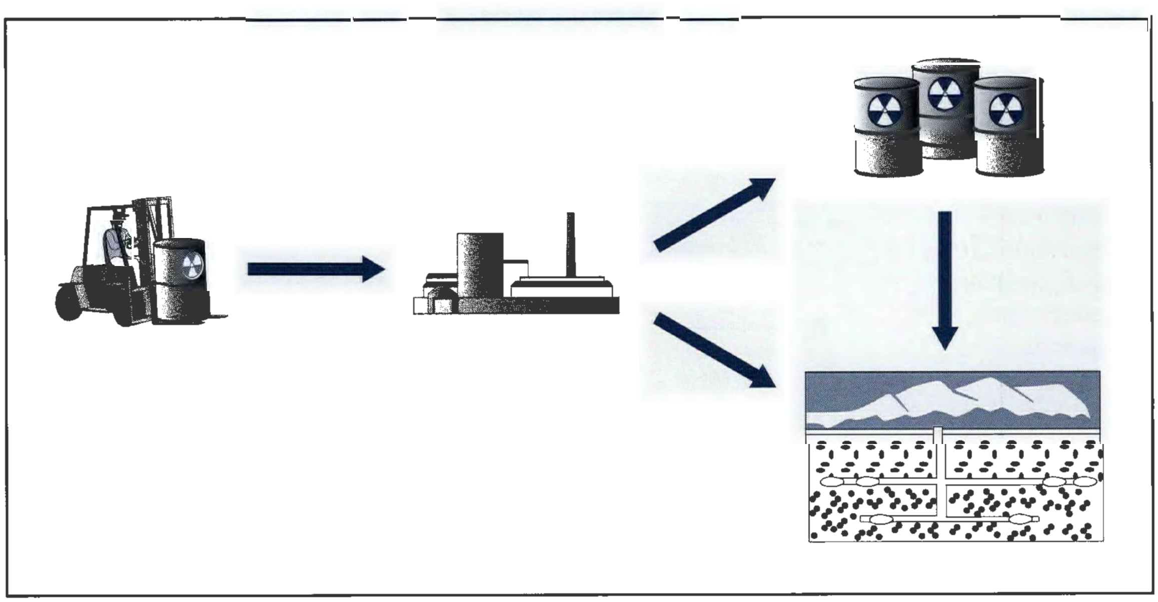
This conceptual model shows the sources, release mechanisms, and worker and off-site public exposure routes for contaminants at DOE sites that will undergo environmental restoration.

The ER team estimated risks during remediation for various remediation alternatives.

present at the site. This one unit was used in the computer simulation of environmental transport for different exposure pathways (such as drinking groundwater and swallowing soil), exposure scenarios (such as on-site resident or off-site population), and time periods (such as present and future). Once the simulation was complete, the analysts could tell how much contaminant remained over time at different locations in the environment. In addition, the ER team could estimate how much of that contaminant might be ingested, inhaled, or absorbed by potential populations or individuals located within a given distance of each site. Once the exposure was estimated, then the potential health risk was estimated using standard U.S. Environmental Protection Agency (EPA) toxicity values and radiation risk assessment methods. The result was a "unit risk," or risk per unit of contaminant for each exposure scenario and pathway. From there, the actual risks posed by a site under given conditions were estimated by scaling up to the actual amount of contaminants at the site. If 50 grams of a contaminant were present, the ER team multiplied the final concentration by 50 and calculated the subsequent exposures and risks. The final risks were presented in terms of cancer fatalities, cancer incidences (the probability of developing fatal or nonfatal cancer), adverse genetic effects, dose, and the potential for health effects from noncarcinogens, known as the hazard index.

For each site, different assumptions about land use were used to estimate the future risks to various receptors (people who may be exposed to contaminants). Land use included restricted use, where the public was denied access to the site; unrestricted use, where a hypothetical homesteader could live on top of the site; and mixed land use, where a combination of both occurred; but the groundwater use remained restricted. The risks to the off-site public within a 50-mile radius of the installation and to a hypothetical homesteader living on the site boundary were examined.

In addition to estimating baseline conditions of each site for different land use scenarios, the ER team estimated risks during remediation for various remediation alternatives. Louis, Berger, and Associates, an engineering firm based in New



In waste management, waste is retrieved, treated, stored, and disposed of in approved facilities.

Jersey, was asked to determine several remediation options for each site based on available technologies and costs. Once the firm selected the technologies, the CRM's ER team used standard emission rates recommended by the EPA for those technologies and performed more extensive computer modeling to estimate potential risks to the public during remediation. For example, radioactive substances could be carried into the air by excavation and removal of contaminated soil.

Using a similar unit risk approach to automate the process, a separate group within the ER team estimated risks to remediation workers performing the remediation activities. The group divided each technology into its composite worker activities and then estimated the number of person-hours the activities required for completion. They then estimated risks to workers from exposure to contaminants using various computer models for inhalation, ingestion, and direct radiation exposure. In addition, the group estimated safety risks such as fatalities and injuries from general construction activities, such as constructing a building or operating heavy equipment. The worker assessment accounted for protective clothing and equipment in the assessment of potential risks, which added another potential safety risk: heat stress fatalities and injuries, often caused when workers become overheated from wearing protective equipment. (See sidebar "Worker Risk Assessment: Breaking Ground" on p. 31).

Waste Management, or "The Grave"

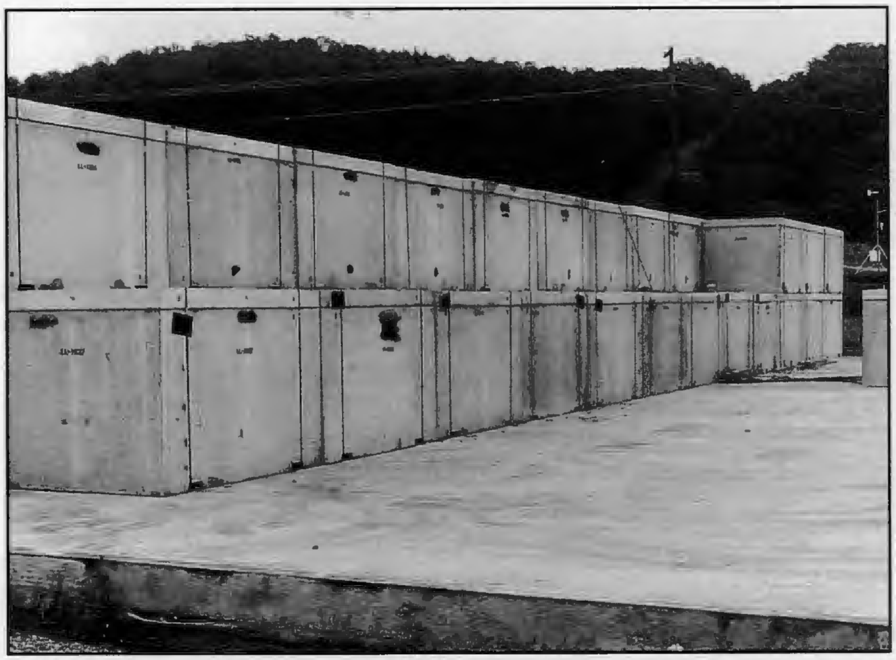
Like the runner in a relay race handing off the baton, the results from the ER assessment feed into the WM assessment. The ER assessment shows the scope of the problems within the environmental management (EM) program. The baseline risks at each site trigger various remediation alternatives, depending on the magnitude of the risk. Cleanup of the DOE waste sites generates volumes of ER waste that must be treated, stored, and/or disposed of within the WM program.

The WM risk assessment team, headed by Pat Pehlman, estimates the potential human health risks posed by various waste consolidation alternatives. In addition to the ER waste that is generated during cleanup, the WM program must address the volumes of various types of waste that are already being treated and stored at various installations throughout the complex. To determine the best ways to treat, store, and dispose of these wastes, the WM team evaluated risks from treatment, storage, and/or disposal of each type of waste at various locations across the complex. The team evaluated risks from high-level waste, low-level waste, low-level mixed waste, transuranic waste, and hazardous waste. Risks were presented in the same terms as for ER (i.e., cancer fatalities, cancer incidences, adverse genetic effects, and a hazard index).

Cleanup of the DOE waste sites generates volumes of ER waste that must be treated, stored, or disposed of.

The WM program focuses on three primary areas of waste handling: treatment, storage, and disposal (TSD). Treatment comprises processes such as incineration, solidification, or vitrification; and treatment processes differ depending on the waste type and treatability classification of the waste. Storage refers to either current or interim storage. Current storage is storage at the installation without waste transfer to another location. However, sometimes waste must be retrieved from current storage and treated or shipped to another location for storage or disposal. Interim storage is a temporary stage when waste is transferred from one location to another to await treatment or disposal. Disposal is a stage of permanent accumulation at DOE sites or at federally prepared facilities such as Yucca Mountain in Nevada or the Waste Isolation Pilot Plant in New Mexico.

The WM team works with DOE's Argonne National Laboratory, which provides contaminant emission rates from treatment processes and potential accident scenarios that were evaluated during the treatment or storage stages. The WM team has developed an automated unit risk approach that works much like the ER approach. For on-site and off-site populations, a unit inventory of contaminant (1 gram or 1 curie) is



One approach to radioactive waste management is to store it in a tumulus facility, like this one at ORNL. Concrete and metal casks are filled with radioactive waste and cement to further immobilize the waste material. The waste casks are transported to and stacked on a concrete pad at the tumulus facility. The casks are then covered with more concrete, plastic liners, and soil to keep water away.

A separate group evaluated the risks to waste management workers who are directly involved with waste handling activities.

first assumed to be released to the air from a treatment or storage facility. For disposal, a unit inventory of contaminant is assumed to be disposed of, and the groundwater pathway is evaluated during the disposal stage. Fate and transport computer models are used to estimate the resulting exposures of individuals living near the facilities and of on-site plant employees. The models simulate environmental transport and account for different exposure pathways and routes. Actual risk calculations for various waste consolidation alternatives are then performed by scaling unit risks according to actual contaminant amounts and then adjusting the results by scenario-specific parameters (e.g., effective stack height, release periods). These calculations are performed in a data base that was constructed specifically for this application.

For the Programmatic Environmental Impact Statement, potential receptors for atmospheric releases are defined as (1) the public within a 50-mile radius of the installation and (2) on-site employees who are not directly involved with waste handling activities. Because the maximum exposure to contaminants released to groundwater can occur several years or lifetimes following the initial release, the receptors analyzed for the groundwater pathway (i.e., disposal) are the most-exposed generation, which is a hypothetical farm family of four.

In addition to the public and plant employees, a separate group within the WM team evaluated the risks to waste management workers who are directly involved with waste handling activities. In many cases, TSD facilities do not exist at an installation and, for the purposes of the PEIS, are assumed to be constructed. Health and safety risks to workers from construction-related hazards are also assessed. The WM worker risks are also estimated using a unit risk approach. Unit doses are estimated per contaminant and exposure route for each WM module or specific TSD task. WM modules can be interchangeably arranged to form a "treatment train." A module is a self-contained waste handling or treatment process where workers are located to treat or handle waste as it is processed through a facility. A treatment train of several modules might include receiving and inspection, sorting, compaction, incineration, solidification, packaging, and shipping. Workers are located inside the building where the module's process occurs, and fugitive emissions from treatment processes may be released into the atmosphere of the building. A facility can contain several treatment modules simultaneously, and a module may contain several subactivities with different unit exposures. The unit exposures are summed to yield the total exposure for a given module, and the exposures for modules are summed to yield the total exposure for a given treatment train.

The WM computer models require many different types of information to estimate risks from TSD facilities. Such information includes facility dimensions, treatment and storage capacities, stored waste inventory, engineered safety controls, storage and disposal criteria, and TSD technologies. For disposal, in most cases, two engineered disposal options are considered: (1) installations in the eastern United States are assumed to use the tumulus option, and (2) installations in the western United States are assumed to use the shallow land burial option. A tumulus is an aboveground, vault-type disposal facility made entirely of reinforced concrete. The waste is placed in a metal and concrete cask and then placed inside the vault. Once the vault is filled, it is closed and covered with a clay soil cap to reduce infiltration of contaminants into the groundwater.

Shallow land burial uses a long, narrow, unlined trench for waste disposal. Waste is stacked on the earthen floor, the voids between the waste containers are filled with earthen material, and the top of the disposal unit is covered with dirt. A third disposal option, a below-ground vault, is also evaluated only for the Savannah River Site in South Carolina.

The WM team estimated risks for normal operating and accident conditions assumed to occur during either the treatment or storage stage. They estimated risks for a variety of scenarios or consolidation alternatives. First, they estimated risks for a no-action scenario, which represents the TSD activities if they were to cease today. Then, they evaluated a current program alternative that represents the WM program in its current state, including planned transportation of waste and planned TSD activities. The remaining alternatives were evaluated to determine the impacts of different waste consolidation options. These alternatives are regionalization, centralization, and decentralization. For each of these alternatives, the WM team evaluated many different "cases" or permutations of waste consolidation. The difference between these alternatives is the number of sites that treat waste, store waste, or dispose of waste.

To determine the potential impacts of regionalizing the handling of hazardous waste, for example, the team might evaluate the impacts of six sites treating hazardous waste, four sites storing the waste, and three sites disposing of the waste. If the alternative mandates that fewer installations across the complex treat, store, or dispose of waste, those installations must take on more of the waste from other installations, increasing the risks at the chosen installations and increasing the transportation risks by requiring more waste shipments. However, if an alternative specifies that many different installations must treat, store, or dispose of waste (i.e., decentralization), then more installations must build facilities to accommodate these processes, and costs and risks will increase at these installations.

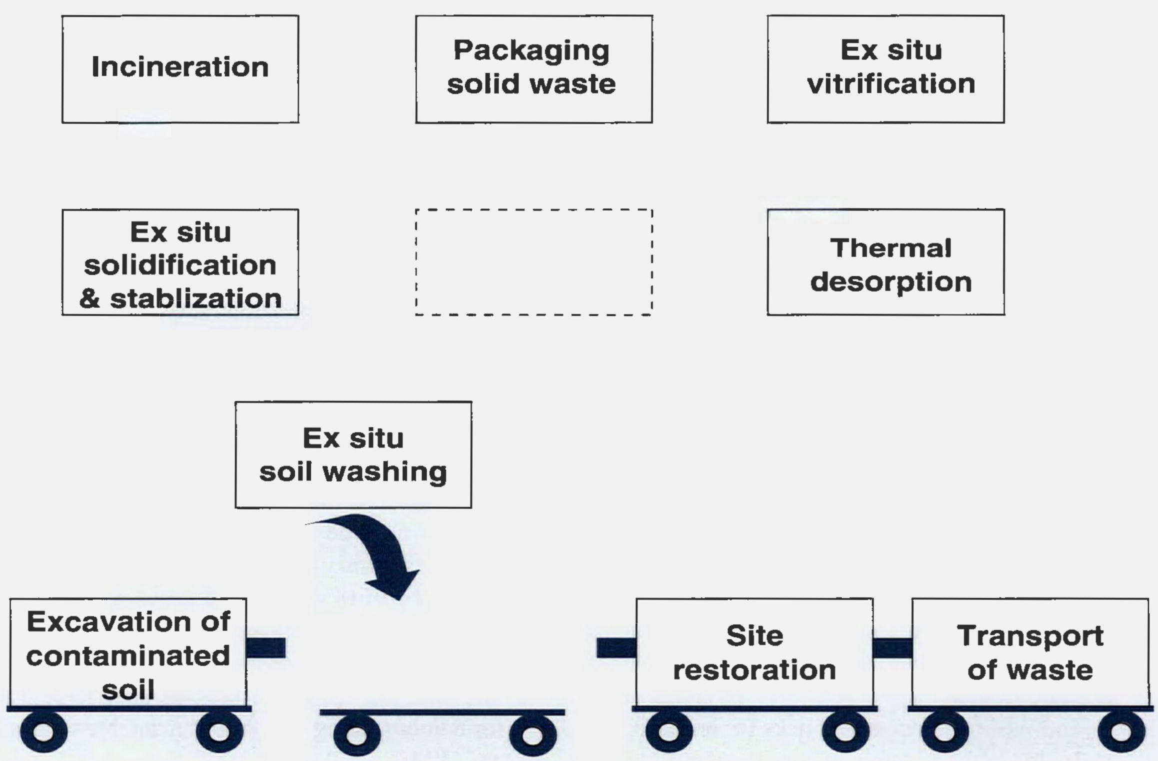
Evaluation of the different waste consolidation alternatives shows the trade-offs between cost and risk that must be weighed by decision makers. The integration of the ER and WM program within the PEIS will present decision makers with a large body of information on different options for cleanup and waste treatment, storage, and disposal. This information is intended to be useful for demonstrating the options available within ER and WM.

The worker risk methodology is a ground-breaking development.

Further Results of the PEIS

For this project, the CRM developed risk assessment methodologies for estimating human health risks (for the public and for workers) associated with ER and WM activities. Both methodologies are broad in scope and are useful for DOE risk assessment applications beyond the PEIS. The worker risk methodology, developed in conjunction with Pat Scofield of the DOE Office of Environmental Compliance and Documentation, is a ground-breaking development because DOE has previously had no consolidated guidance for assessing occupational health risks at its waste sites. The risk assessment methodologies have been validated by pilot studies and have been successfully applied in installation-wide risk assessments of ER activities at two DOE installations.

In addition to these methodologies, our staff has automated the unit risk approach for both public and worker risk assessment for ER and WM activities. The automated methodology and data bases developed for the PEIS have applications beyond the PEIS because they provide an efficient, user-friendly method of



Sequential activities required for site remediation form a technology train, which depicts the number, order, and nature of remediation activities that workers must perform to remediate a site.

Worker Risk Assessment: Breaking Ground

Workers who will clean up contaminated DOE sites or handle wastes generated by the cleanup will be exposed to risks to their health and safety. To calculate these risks, scientists must gather data to address several questions.

For example, what types of radiation or pollutants will a worker be exposed to? What are the likely routes of exposure—inhalation, ingestion, or direct radiation exposure through the skin? What is the estimated volume of each contaminant at the waste site? Will heavy equipment be used? In what types of activities is a worker involved—waste incineration, packaging of solid waste, solidification and stabilization of waste, use of heating processes to remove pollutants from soil (thermal desorption) or turn contaminated soil to glass (vitrification), excavation of contaminated soil, soil washing, site restoration, or transport of waste? How many workers engage in each activity and for how many hours?

For DOE's Programmatic Environmental Impact Statement, risks to remediation and waste management workers were estimated using a unit risk approach to automate the risk assessment process. The unit risk approach involves five basic steps for estimating worker risk: (1) identify alternative, (2) identify specific activities and types of workers for each alternative, (3) identify number of workers and hours required for each activity, (4) estimate unit doses for each activity, and (5) estimate unit risks.

Once the remediation method or waste management alternative is selected, the types of activities and workers required to complete site cleanup or waste handling are identified. Both the environmental restoration (ER) and waste management (WM) teams have developed automated user-friendly data bases for choosing typical activities required for a particular remediation or waste treatment method. These activities, occurring sequentially, form a "treatment or technology train" (see drawing on p. 30). The ER data base includes 58 of the most widely used ER technologies, and the WM data base contains 32 possible waste management modules—waste treatment, storage, or disposal activities.

The data bases also include various types of workers such as heavy equipment operators, laborers, supervisors, and waste handlers. It is important to estimate the types of workers involved in an activity because the type of workers affects a worker's exposure. For example, because a laborer is closer to a waste than a supervisor is, the laborer is more likely to be exposed to contamination through inhalation.

An important feature of the automated risk assessment system is its incorporation of levels of worker protection. The more equipment and safety gear a worker uses, the less likely he is to be exposed to contaminants. The ER data base includes various levels of protection that can be selected to ensure compliance with DOE and Occupational Safety and Health Administration protection standards.

Identifying the number of workers and the hours required to complete a WM or ER activity is the next step in estimating worker risks. This information is available from site managers or site or DOE data bases (such as costing data bases).

Once the types and number of workers are identified, potential exposures are estimated using a suite of computer models. Unit exposures (exposure per unit contaminant resulting from inhalation, ingestion, or direct radiation exposure) are calculated using standard Environmental Protection Agency exposure assessment methods.

The ER and WM systems each include 350 of the most common contaminants found within the DOE complex, ranging from cesium and plutonium to mercury and PCBs. Unit risk factors for each contaminant, ER technology, and WM module were developed and stored in a data base developed especially for this purpose. These unit risk factors are multiplied by the unit exposures or unit doses to yield a unit risk (worker risk per unit contaminant) for each contaminant and activity involved in the alternative being evaluated.

Finally, the unit risks are multiplied by the actual inventory of contaminants at a site or waste treatment facility. Risks for each exposure pathway, activity, and contaminant are summed to yield the actual estimated risk for a given alternative or remediation method.

This worker risk assessment will provide information that may be used by decision makers trying to determine how particular DOE waste sites will be remediated and how their wastes will be managed.

estimating site-specific or installation-wide human health risks. In the ER worker risk portion of the package, for example, the user can choose the technologies used to clean up a particular site, the number of personnel involved, the contaminants present, and the level of protective gear the workers are wearing.

The PEIS is an ambitious DOE endeavor. When it is completed (the draft is scheduled for release in September 1995), it will yield complex-wide human health, transportation, and ecological risk estimates that can be used in conjunction with the other evaluated impacts to integrate the ER and WM programs in the most cost-effective manner. The project has provided an opportunity to develop important risk assessment tools for DOE and other agencies, and ORNL's Center for Risk Management expects to continue having a national impact in the risk assessment arena. ornl

The project has provided an opportunity to develop important risk assessment tools for DOE and other agencies.

Biographical Sketch

Bonnie Blaylock joined the research staff of ORNL's Health Sciences Research Division in 1991. She holds an M.A. degree in English from the University of Tennessee at Knoxville. Blaylock was a key member of the team that produced the risk assessment methodologies used for the programmatic environmental impact statement described in this article.

From left, Pat Pehlman, waste management group leader; Bonnie Blaylock, member of the risk assessment team; Jill Morris, environmental restoration group leader; and Irene Datskou, environmental restoration PEIS team leader, discuss the health risks of cleaning up DOE sites.

Ecological Risks of Environmental Restoration

Ecological risks of environmental restoration and waste management activities were evaluated as part of the project of preparing a Programmatic Environmental Impact Statement (PEIS) for DOE sites. Major issues for restoration include current contamination, residual contamination following remedial action, and adverse ecological impacts of remediation and new facility construction. For waste management, the ecological issues evaluated include (1) deposition of atmospheric contaminants on soil and (2) potential spills of radioactive, hazardous, and mixed waste during transport to central storage and disposal sites. The ecological risk assessment team included staff of ORNL's Environmental Sciences Division (ESD) and Advanced Sciences, Inc. Participating ESD staff members included Linda Mann, Lorene Sigal, Jerry Eddelmon, and Dan Jones.

The environmental restoration assessment focused on reservation-wide ecological resources. Of the approximately 30 facilities discussed in the impact statement, 6 were singled out for detailed ecological risk assessments: the Idaho National Engineering Laboratory, the Hanford Reservation, the Fernald Environmental Management Project, the Oak Ridge Reservation, the Rocky Flats Plant, and the Portsmouth Gaseous Diffusion Plant.

To compare impacts among sites, the specific ecological resources on the six reservations were grouped into six categories:

- Threatened and endangered species
- Wetlands
- Recreational fish and wildlife
- Agriculture or timber production
- Parks and other public lands
- General biodiversity

Ecological resources falling into each of the six categories are identified from documents, maps, and contacts with resource management personnel on each reservation. The distribution of each resource on and near the facilities was mapped. These resource distributions were overlaid on the distributions of environmental restoration activities at each facility.

For contaminant exposures, transport media were identified and exposures were quantified using the same data sources and models employed in the human health risk assessments. The area disturbed by remedial action or construction activity was estimated, including both the actual contamination site and the surrounding area expected to be disturbed by road construction, dust, erosion, or noise. Ecological benefits and risks of remedial actions were evaluated by determining whether existing contamination poses a risk to ecological resources, evaluating the reduction in contaminant risk expected from remedial activities, and estimating the fraction of existing ecological resources that would be disturbed by restoration activities. An example of such a disturbance would be loss of habitat for small mammals and birds from excavation of large volumes of contaminated soil.

For waste management (WM), the long-term accumulation of atmospheric contaminants emitted from waste treatment facilities was identified by DOE as a potentially significant ecological issue. These impacts were addressed using the Human Health WM team's atmospheric transport modeling results to estimate deposition and accumulation of radionuclides and toxic chemicals for different WM scenarios. The ecological exposure and effects models developed for the ER ecological risk assessment were then used to determine whether this accumulation could potentially affect plants or small mammals downwind from the facilities.

A "consequence assessment" was performed to evaluate the potential ecological risks of accidents involving radionuclide releases. A consequence assessment involves estimation of the ecological effects of a given size and type of accident but does not include estimation of probabilities of occurrence of accidents. Estimates of maximum credible radiological releases were obtained from Argonne National Laboratory for transportation accidents involving high-level waste, low-level waste, contact-handled transuranic waste (TRUW), and remotely handled TRUW shipments.

The scenario evaluated for the ecological risk assessment involves an accident in which the contents of a rail shipment are spilled into a stream. Assessments were performed for five stream size classes ranging from a small, second-order stream with a flow rate of a few cubic meters per second to a major continental river such as the Mississippi River.

Two alternative assumptions were made about the fate of the spilled material. First, it was assumed that all material remains suspended or dissolved in the water column and is transported downstream. For this scenario, the team estimated (1) the length of stream (m) of each size class that would be affected before longitudinal dispersion reduced the dose rate below the safe level (1 rad/day) recommended by the National Council on Radiation Protection for protection of aquatic life and (2) the time required (h) for this dispersion to occur.

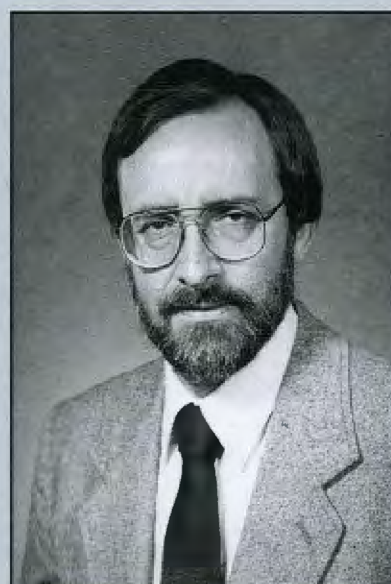
Alternatively, it was assumed that all of the spilled material is immediately deposited on the bottom of the stream at the site of release, where it becomes incorporated in bottom sediment. Biota present at the release site receive radiation exposure over their whole lifetime and can receive both external and internal doses. For this scenario, the team estimated the total number of kilograms of clean sediment required to dilute the spilled material to a sediment activity level corresponding to a 1 rad/day lifetime dose to a large fish residing at the bottom of the stream and feeding on benthic biota. This quantity should be a reasonable estimate of maximum mass of sediment that would have to be removed during a remedial action taken following the spill. The final comparison evaluated the maximum ecological consequence of potential spills for each waste type.

Results of the waste management assessment showed that the physical form of the transported waste is much more important than either the total radiological activity or the size of the shipment in determining the potential ecological consequences of a spill. It now appears that the results of the ER ecological risk assessment will not appear in the PEIS because of scope changes that occurred after most of the work was completed. However, the reservation-wide approach adopted for the PEIS fits well into DOE's new policy of including future land use as a key factor in setting environmental restoration goals for its facilities, land use, and stewardship of its lands. We hope that the results of our assessment will support DOE in implementing this policy. —*Larry Barnthouse*

The physical form of the transported waste is much more important than either the total radiological activity or the size of the shipment in determining the potential ecological impacts of a spill.

Biographical Sketch

Larry Barnthouse is a senior research staff member in ORNL's Environmental Sciences Division. He has an A.B. degree in biology from Kenyon College and a Ph.D. degree in biology from the University of Chicago. He has been on the staff of the Environmental Sciences Division since 1976. Since that time he has been involved in dozens of environmental research and assessment projects involving development of new methods for predicting and measuring environmental risks of energy technologies. Barnthouse has been the author or co-author of nearly 100 publications relating to ecological risk assessment. He has received two Martin Marietta Energy Systems Technical Achievement Awards and was named Energy Systems Author of the Year for 1991.



Larry Barnthouse

The Oak Ridge Reservation: A Nationally Valuable Natural Resource

By Patricia D. Parr and Linda K. Mann

An osprey nests on a platform mounted over the Clinch River bordering the Oak Ridge Reservation. Ospreys are a rare species in the state of Tennessee.

The Oak Ridge Reservation has evolved into a nationally valuable natural resource over the past 50 years. Despite the well-publicized problems of contamination from the Department of Energy's Oak Ridge National Laboratory, Oak Ridge Y-12 Plant, and Oak Ridge K-25 Site on the reservation, the land has a regionally unique diversity of plant and animal species.

Occupying about 14,000 hectares (35,000 acres) of mostly contiguous native forest, the reservation land provides interior habitat for the area's sensitive species of wildlife. It contains relatively undisturbed ecosystems that are important habitats for many species uncommon or absent in surrounding areas. And, perhaps most importantly, it has experienced minimal impact from human land use for the past 50 years, providing an invaluable reference point for determining the effects of human development on natural resources.

When the land was acquired by the federal government in 1942 for the Manhattan Project, it consisted of approximately 1000 individual tracts of land that were primarily farmsteads. This land was a patchwork of forests, wooded pastures, and fields. Aerial photographs taken in the mid-1920s and late 1930s show that about half of the area was cleared. Some clearings for orchards and pastures were on upper slopes, rocky areas, and ridgetops; tillage crops were mostly restricted to lower slopes and bottomlands. Agricultural practices of the time resulted in severe erosion on most slopes. Not surprisingly, erosion gullies are still evident in some areas.

Rare orchids like the one shown here grow in wet areas on the Oak Ridge Reservation.

Linda Mann looks for viable seeds on a member of one of the world's largest populations of tall larkspur.

Twenty-one different species of rare plants occur on the reservation.

Except on very steep slopes, most of the forest was cut for timber, though not necessarily cleared. Many partially cut forest areas were used as rough pasture. After 1942, many previously cultivated fields developed into forests either through natural succession or planted seedlings. Between 1948 and 1954, many of the abandoned fields that were not already well stocked with naturally regenerating timber species were planted with loblolly, shortleaf, and white pine. Some of that pine is still evident today—or was until the spring of 1993. At that time, much of the remaining planted and native pine became infested with pine beetles. Heavily infested areas were cut to prevent their spread and salvage marketable timber. The forest gaps are now filling in by natural regeneration.

To a casual observer, the reservation land may appear wild and overgrown, suggesting that it is not being used to its full potential. The reservation may be compared to a picture that appears to you first as just a pattern of color. But as you relax, rid your mind of preconceived ideas of how the picture should look, and stare at it slightly out-of-focus, you begin to see the hidden picture in the pattern of colors. In this article, we will describe the hidden picture of the Oak Ridge Reservation that shows its value as a natural resource.

Over 1000 Plant Species

Forests, primarily oak-hickory, pine-hardwood, or pine, cover about 75% of the reservation. Contained within the larger framework of mixed hardwood and pine forests on the reservation are many ecological communities that are of special interest because of their unusual species assemblages, which often include rare species. Some of these special communities are more common in mountainous, coastal plain, or prairie regions of the continent, whereas others result from unusual or restricted soil-related and topographic features, such as uncommon soil types, seeps, springs, and river bluffs.

All reservation areas are relatively pristine when compared to the surrounding region, which has been strongly affected by agriculture, cattle grazing, and land clearing during the past 50 years.

More than 1000 different species of plants grow on the reservation, reflecting its diversity. By comparison, 1300 known plant species have been observed in the Great Smoky Mountains National Park, which has greater elevational changes than the Oak Ridge Reservation.

Twenty-one different species of rare plants occur on the reservation—all of them are on the state protected species list, and four of them are under consideration for federal listing. The rare species occur across the reservation in 33 different locations. They are provided protection through National Environmental Research Park Natural Area designations. Additionally, seven of these special habitats have been named State Natural Areas in an agreement between the Department of Energy's Oak Ridge Operations and the Tennessee Department of Environment and Conservation. The presence of 21 species of listed plants and seven State Natural Areas is an important indicator of the unique character of ecosystems on the reservation.

Rare plant population sizes may range from a few individuals to several hundred. Our Oak Ridge population of tall larkspur, one of the species under consideration for federal listing and

The cedar barrens habitat used to be common in East Tennessee. Now, most cedar barrens are found in protected, undeveloped areas. Vegetation seen there is similar to that found in midweastern prairies.

At least two rare plant species grow here at Bull Bluff, a river bluff habitat.

Pat Parr (left) and Barbara Rosensteel, a subcontractor with JAYCOR, survey wetlands.

About 500 acres of wetlands are also found on the reservation.

The New Zion Boggy Area wetland.

listed by the Nature Conservancy as globally threatened, is one of the largest populations (if not *the* largest) known to occur anywhere in the world.

Topographic and geologic features often determine the presence of sensitive plant species. Because these features are discontinuous across the reservation landscape, some plant communities exist as highly patchy systems. These include cedar barrens and river bluffs. Some biotically important wetlands also follow this pattern.

The most widely distributed and perhaps important plant community on the reservation is the cedar barren. Although individually small in area, cedar barrens are fairly common on the reservation—and used to be common across East Tennessee. On the reservation these drought-tolerant plant communities occur only on shallow, flaggy soils, derived from limestone geologic material. Dominant species in the cedar barrens are grasses, such as little bluestem, and a variety of forbs, with some eastern red cedars and stunted oaks. Bare rock is fairly common. Cedar barrens are habitat for several species of rare plants.

Prairie species more common in the midwestern United States are also characteristic of these sites.

River bluffs are found bordering the river reservoir where the Clinch River and Poplar Creek have cut through limestone ridges. River bluff communities contain an assemblage of plant species that flourish in these exposed, rocky environments where the buffering effects of the river provide humidity and some amelioration of extremes in temperature. This rugged environment is home for several rare plant species. Three of the four species under consideration for federal listing—false foxglove, bugbane, and white walnut—are found in this type of habitat.

About 500 acres of wetlands are also found throughout the reservation. Types include emergent communities in shallow embayments on Watts Bar and Melton Hill reservoirs, emergent and aquatic communities in ponds, forested wetlands on low ground along major streams, wet meadows and marshes associated with streams and seeps, and small headwater wetlands that have developed along nearly all seasonal and perennial minor streams.

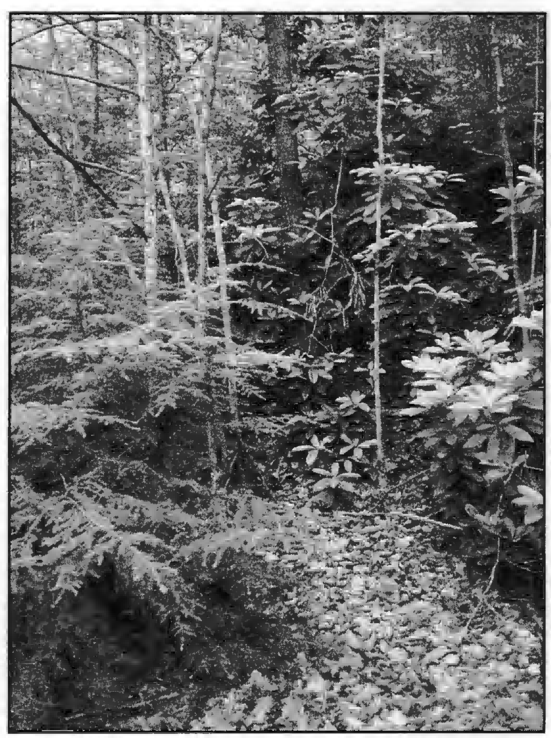
Wetlands on the Oak Ridge Reservation help prevent flooding and flood damage, serve as filters to trap pollutants, and help control erosion. They also provide habitat to numerous species of fish, birds, and other wildlife. Over half of the listed rare plants for the Oak Ridge Reservation occur in wet areas.

Richness of plant species on the reservation that are provided protection by federal law exceeds that of the Great Smoky Mountains National Park on an area basis. (The Great Smoky Mountains National Park has the highest overall diversity of all national parks in the contiguous United States.) Thus, it is one index of the vital role played by our reservation both regionally and nationally in conserving biological diversity. The Oak Ridge Reservation has about four times as many listed species per unit area as the Great Smoky Mountains National Park—an impressive return in species preservation per investment in area.

Approximately one third of the reservation was designated a Department of Energy National Environmental Research Park—one of a network of seven representing seven different ecoregions across the United States.

The Oak Ridge Reservation lies in what is called the Ridge and Valley physiographic province. This area, characterized by the elongated ridges and broad-to-narrow valleys, is between the Cumberland Plateau and the Smoky Mountains. Within this province is a low level of

The rare blue flowering plant *Delphinium exaltatum* grows in cedar barrens. The reservation may have the largest population of this plant in the world.



Hemlock and rhododendron, which are commonly found in the Great Smoky Mountains National Park, also grow in a protected area on the reservation.

land preservation. In contrast, the Blue Ridge physiographic province (where the Smoky Mountains occur) has a relatively large proportion of protected natural vegetation.

The Oak Ridge Reservation was selected to be a Biosphere Reserve in 1988 and is a unit of the Southern Appalachian Biosphere Reserve. It plays an important role as the only representative of the Ridge and Valley physiographic province in the international United Nations Educational, Scientific, and Cultural Organization (UNESCO) Man and Biosphere Program.

Animals on the Oak Ridge Reservation

As would be expected given the diversity of plants and habitat types, the reservation supports a wide variety of wildlife species. Checklists include 60 reptilian and amphibian species; 63 fish species; more than 120 species of terrestrial birds; 32 species of waterfowl, wading birds, and shorebirds; and about 40 mammal species. Habitats supporting the greatest number of species are those dominated by hardwood forests and wetlands.

Ten species of wildlife known to occur on the reservation are state or federally protected.

Mammals present on the reservation range from commonly seen white-tailed deer, groundhogs, bats, and skunks to the more elusive bobcats, red fox, mink, and weasels. Ten species of wildlife known to occur on the reservation are state or federally protected. There are at least 35 more species for which appropriate habitat exists, but their presence has not yet been confirmed. The reservation also provides habitat for numerous species that, although not currently listed, could be listed in the future. A project is currently under way to identify potential habitat for listed species and to survey the areas to determine if the species are present (and if not, to try to figure out why).

The reservation is a Tennessee Wildlife Management Area. Restoration activities by the Tennessee Wildlife Resources Agency (TWRA) with the Oak Ridge National Environmental

These baby black vultures were spotted at an old home site.

Pat Parr holds a tagged wild turkey that was later released to the reservation.

Research Park have resulted in a wild turkey population that is now estimated to have 500 to 600 individuals. TWRA now traps them here to stock other sites. Young turkeys (poults) may be seen in the spring, and groups of 20 to 30 adults are commonly spotted in the fall in favorite feeding places.

The osprey is now successfully nesting and breeding on waterways adjacent to the reservation. Because of restoration programs like this across the state, the osprey has recently been downlisted from "threatened" to "in need of management" in Tennessee. Nesting platforms were put up in 1988. Young ospreys, which are counted and banded by TWRA, were found at three of the platforms in 1994.

Smaller streams and tributaries on the reservation, unlike those in the surrounding area, are minimally affected by sedimentation from construction and agriculture. The Tennessee dace, a fish species listed by the state of Tennessee as "in need of management," is found in numerous streams and tributaries on the reservation. Populations here appear to be stable, in contrast to declining or absent populations in streams outside the reservation. The dace is a pollution-intolerant species that currently inhabits only 45 sites in East Tennessee, and its statewide distribution is concentrated in streams in the Cherokee National Forest in Polk County and on the Oak Ridge Reservation.

We are currently exploring what the role of the Oak Ridge Reservation may be in the migration and nesting of neotropical land birds. Because of the presence of a large forested area that provides important interior habitat, we think that the reservation may play a role in providing refuge for migratory birds (as well as our bird residents).

When the land that is now the reservation was selected to be federal land, the criteria were based on isolation for security reasons. These are not the same criteria used to designate most other public lands such as national forests or national parks. The land did not have breathtaking features such as high mountains, waterfalls, or great stone arches. It was typical East Tennessee land experiencing typical East Tennessee land use.

But because it became federal land 50 years ago, it is no longer typical of East Tennessee. As urban and agricultural development have expanded in the region surrounding the reservation, the types of ecosystems native to our area have become less widespread. Thus, their existence on the reservation has become much more important—on a local, regional, and even national level.

In Oak Ridge we have a natural resource that is of national value. As development in the Ridge and Valley continues, the Oak Ridge Reservation will play an increasingly important role in the understanding and protection of regional ecosystems.

The authors would like to acknowledge assistance in obtaining reference material, data, and manuscript review from the many individuals who work with and care about the natural resources on the Oak Ridge Reservation. Special thanks go to Debra Awl, Rebecca Cook, Hal DeSelm, Jim Evans, Cindy Gabrielsen, Robin Graham, Jim Loar, Jason Mitchell, Larry Pounds, Lon Rathmell, Barbara Rosensteel, Mike Ryon, Andrew Schiller, Beth Schilling, John Smith, Robert Washington-Allen, Warren Webb, and Liz Vail. ornl

Biographical Sketches

Patricia Dreyer Parr, an Oak Ridge native, is currently area manager for the Oak Ridge Reservation and a research staff member in ORNL's Environmental Sciences Division (ESD). She was manager of the Oak Ridge National Environmental Research Park from 1984 to 1994. She joined the ESD staff in 1974 after receiving her B.S. degree in biology from Tennessee Wesleyan College. In 1981, she earned an M.S. degree in ecology from the University of Tennessee at Knoxville. Parr has served on the Oak Ridge Reservation Resource Management Organization (reservation land use planning) since 1984. She is the ORNL representative on the Public Affairs Committee of the Southern Appalachian Man and the Biosphere program. She led the development of the Ecological and Physical Sciences Study Center (ORNL program for precollege education) in 1984. She is a member of the Tennessee Wesleyan College Natural Sciences Advisory Board and vice president of the Association of Southeastern Biologists.

Linda K. Mann, a native of Montclair, New Jersey, who has lived in East Tennessee for most of her life, earned a B.S. degree in botany in 1967 and an M.S. degree in ecology in 1976 from the University of Tennessee in Knoxville. Her career at ORNL started in 1968 in the Biology Division, where she served as a laboratory technician. In 1970, she transferred to ESD, where she worked as a laboratory and field technician and as a research associate in a variety of ecological disciplines, including radiation ecology, effects of air pollutants on vegetation, forest nutrient cycling, soil carbon cycling, and terrestrial ecology in impact assessments. She is the ORNL representative on the Southern Appalachian Man and the Biosphere Natural Resources Management committee. She also serves as secretary-treasurer of the Roane County Soil Conservation Service board of supervisors and as a member of the Ecological Society of America and of the Soil Science Society of America.


Biodiversity in the Oak Ridge
National Environmental
Research Park
Oak Ridge National Park Environmental
Sciences Division, Oak National managed by
Marietta Energy Inc
with the Department of

ORNL and the Geographic Information Systems Revolution

By Jerome E. Dobson and Richard C. Durfee

Explorers from competing teams race to find a mysterious lost city in the heart of Africa. The American team is continuously in touch with its Houston home base through satellite communications. In flight, team leader Karen Ross displays a map of Africa on her computer screen and notes the multicolored lines suggesting different routes from city to city and into the rain forest. Each pathway is accompanied by a precise estimate of travel time to the final destination. Zooming in on the target area, she switches to satellite images and interprets them in shades of blue, purple, and green. At each checkpoint, the team reports its progress and gets a revised estimate of arrival time.

Beset by difficulties, the explorers ask for a faster route, but the computer says the alternative is too dangerous. A simulation model with data representing geology, terrain, vegetation, weather, and many other geographic factors predicts local hazards, including the impending eruption of a nearby volcano. The Americans take the faster route anyway and beat the odds.

This fictional account of emerging geographic information system (GIS) technologies comes from Michael Crichton's 1980 novel *Congo*, which was made into a 1995 movie. The same technologies were highlighted in Clive Cussler's 1988 techno-thriller *Treasure*. In reality, GIS technology began more than a quarter of a century ago at key universities and government laboratories in the United States and Canada. Since 1969, Oak Ridge National Laboratory has been among the leading institutions in this diverse, now booming field. GIS has been evolving through new forms and applications ever since. Consider the following examples of GIS applications that rival and sometimes exceed Crichton's futuristic vision.

For the past three summers, ORNL geographers have monitored the potentially devastating effects of an Alaskan glacier with an annoying habit of rerouting whole river systems. We drive as far as the roads go or fly over roadless terrain with a color laptop computer that displays Ed Bright's interpretation of satellite images. A dot moves across the screen continuously showing our position on the image and thus on the ground calculated from Global Positioning System (GPS) signals from satellites. We've used the same system successfully in helicopters, boats, and even rental cars on the Oregon-Washington coast, the Gulf of Maine, and the North Slope of Alaska.

The roots of our remote sensing and GIS tradition started early at ORNL; more than 20 years ago, ORNL scientists studied some of the first satellite data from Landsat satellites (then called ERTS). By analyzing computer images of the Cumberland Mountains north of Oak Ridge, we were able to compute and display a three-dimensional perspective view of the coal strip mines in the area and superimpose the nearby streams on the terrain (see figure on p. 48). After developing spatial models, we determined which streams were most likely to receive acid drainage from the strip mines. The visual impacts of strip mining on Oak Ridge residents were also predicted.

With or without satellite imagery, GIS is a powerful tool. In 1990, when the United States and other nations responded to Saddam Hussein's invasion of Kuwait, military leaders mounted the largest and most rapid deployment of military personnel and equipment ever attempted. The massive logistics were processed on the Airlift Deployment Analysis System (ADANS) developed at ORNL. ADANS, operating on networked computers, draws on a variety of logistic and spatial technologies to efficiently schedule the transport of U.S military troops and equipment to trouble spots anywhere in the world. Since 1990, ADANS has been used to deploy military personnel and equipment not only to the Persian Gulf but also to Somalia, Rwanda, and Haiti.

Since 1969, ORNL has been a leading institution in developing and using GIS technologies.

In 1995, at ORNL's World Wide Web Showcase, Peter Pace showed a colorful high-resolution image of ORNL buildings and the roads, streams, and forested areas of the surrounding reservation. The view on his computer screen was constructed from a series of aerial photographs that had been scanned and converted to form a digital image. Various computer techniques were used to enhance and blend a series of images, eliminating unwanted elements and bringing out important details. Special photogrammetric techniques were used to remove distortions from the digitized photos. Each pixel (tiny rectangular element) on the screen represents 0.25 square meter (m^2) on the ground. Spatial registration of geographical

Fred Latham demonstrates the use of a video projection digitization system developed as one of ORNL's early (1970s) contributions to geographic information system (GIS) technologies. It projected onto a paper map a light beam that instantaneously followed the operator's mouse as linear features were traced on the map. This development addressed the problem of constantly having to compare digitized features from paper maps with their vector representation on a computer screen. The computer data directly overlaid the paper map in real time. Note the audio input headset.

A three-dimensional perspective view of coal strip mines in the Cumberland Mountains north of ORNL. Streams are superimposed on the terrain. The spatial model computed the geographic relationship between disturbed land and nearby water surfaces, allowing assessment of environmental and visual impacts of strip mines.

features in the image is sufficiently accurate that a highly detailed map can be overlaid on the image. Pace zoomed in on a cooling tower and magnified it enough to see the blades of a fan. He printed out an image of the cooling tower alone. He and other ORNL researchers are preparing geographical data and imagery developed at Oak Ridge for distribution to selected users of the World Wide Web through Netscape, a navigational tool for accessing still and animated images as well as audio and text from the Internet.

Recent growth of GIS markets has been phenomenal. In 1994, GIS was listed under "Whole Systems" in the Whole Earth Catalog. Tens of thousands of people and organizations—universities, research centers, municipal planners, tax assessors, corporations, and resource managers—have come to depend on GIS for geographic data collection, analysis, and display. The commercial GIS industry, which started in the early 1980s, is now estimated to be worth $3.5 billion.

Today's rosy picture sharply contrasts with the situation in 1969 when GIS first began at ORNL. At that time only a few centers—principally Environment Canada, the U.S. Geological Survey, Harvard University, and ORNL—shared a common interest in solving the riddle of geographic analysis. Along with scientists from these centers and a few leading research universities, early members of ORNL's GIS and Computer Modeling (GCM) Group, led by Richard Durfee, contributed many of the developments that made the current boom possible.

These contributions include fundamental development of early geographic computational techniques that supported and accelerated the growth of a commercial industry; development and integration of key GIS data bases and methodologies; and use of geographic and spatial analysis to provide information to help policymakers make decisions on national issues, such as development of energy sources and protection of water resources and fish populations, and to help government agencies assess natural resources and environmentally contaminated sites needing remediation.

Because of the increased use of GIS technology, a new national Spatial Data Transfer Standard (SDTS) has been established. Pioneering efforts by ORNL researchers Durfee, Bob Edwards, Phil Coleman, and Al Brooks helped build a foundation for the exchange of spatial data, and Jerry Dobson served on the Steering Committee of the National Committee for Digital Cartographic Data Standards, which composed most of SDTS. President Clinton's recently signed executive order requires all federal agencies to coordinate GIS data activities and make key data bases available to the public.

What Is GIS?

Many people think of GIS as a computer tool for making maps. Actually, it is a complex technology beginning with the digital representation of landscapes captured by cameras, digitizers, or scanners, in some cases transmitted by satellite, and, with the help of computer systems, stored, checked, manipulated, enhanced, analyzed, and displayed as data referenced to the earth. This spatial information includes earth coordinates and geometric and topological configurations to portray spatial relationships between features such as streams, roads, cities, and mountains. GIS is "a digital representation of the landscape of a place (site, region, planet), structured to support analysis." Under this broad definition, GIS conceivably may include process models and transport models as well as mapping and other spatial functions. The ability to integrate and analyze spatial data is what sets GIS apart from the multitude of graphics, computer-aided design and drafting, and mapping software systems.

Dobson served on a committee that composed most of the new national Spatial Data Transfer Standard.

Typical sources of geographic data for computer manipulation include digitized maps, field survey data, aerial photographs (including infrared photographs), and satellite imagery. Most image data are collected using remote sensing techniques. Aerial photographs are normally taken with special mapping cameras using photographic film. Most commercially available satellite imagery is collected using multispectral scanners, which record light intensities in different wavelengths in the spectrum—from infrared through visible light through ultraviolet light.

Spatial information can be represented in two distinctly different forms. Satellite images, for example, usually appear as raster data, a gridded matrix in which the position of each data point is indicated by its row and column numbers. Each position on a computer screen or map thus corresponds to the position on the ground measured by the satellite as it passes overhead. In contrast, cartographic features such as roads, boundaries, buildings, and contour lines usually are represented in vector form. In digitizing a lake, for example, the shoreline can be indicated as a series of points and line segments. In this case, each point is measured in Cartesian (X, Y) coordinates and each line segment is measured as a vector leading from one point to the next. The

GIS and remote sensing technology can detect changes in land features.

more points recorded, the more detailed the shoreline will be. Both forms, raster and vector, are essential to support environmental restoration projects on the ORNL reservation, for instance, and the software must be capable of rapid conversion from one form to the other.

For such geographic information to be meaningful, it must be accompanied by "metadata" documenting the source, description, specifications, accuracy, time of acquisition, and quality of each data element. As GIS technologies and multitudes of geographic data bases have spread to the desktop in the past decade, metadata have become very important. Good metadata are essential in determining fitness of the geospatial data for each intended use—that is, determining which applications can be accomplished while ensuring the desired quality of results and decisions made from those data.

One of the most exciting applications of GIS combined with remote sensing technology is its ability to detect changes in features of large areas of land over many years by analyzing and comparing past and present landscape images. Each pixel can indicate a type of land cover, such as wetlands, forests, pastures, and developed areas. Such technology is now being used to monitor gains and losses in wetlands along the U.S. coast for assessing environmental impacts on U.S. fisheries. The technology has the potential for monitoring global change. For example, it is possible to detect increases in deforestation, which may alter the climate, or increases in desertification that may result from climate change.

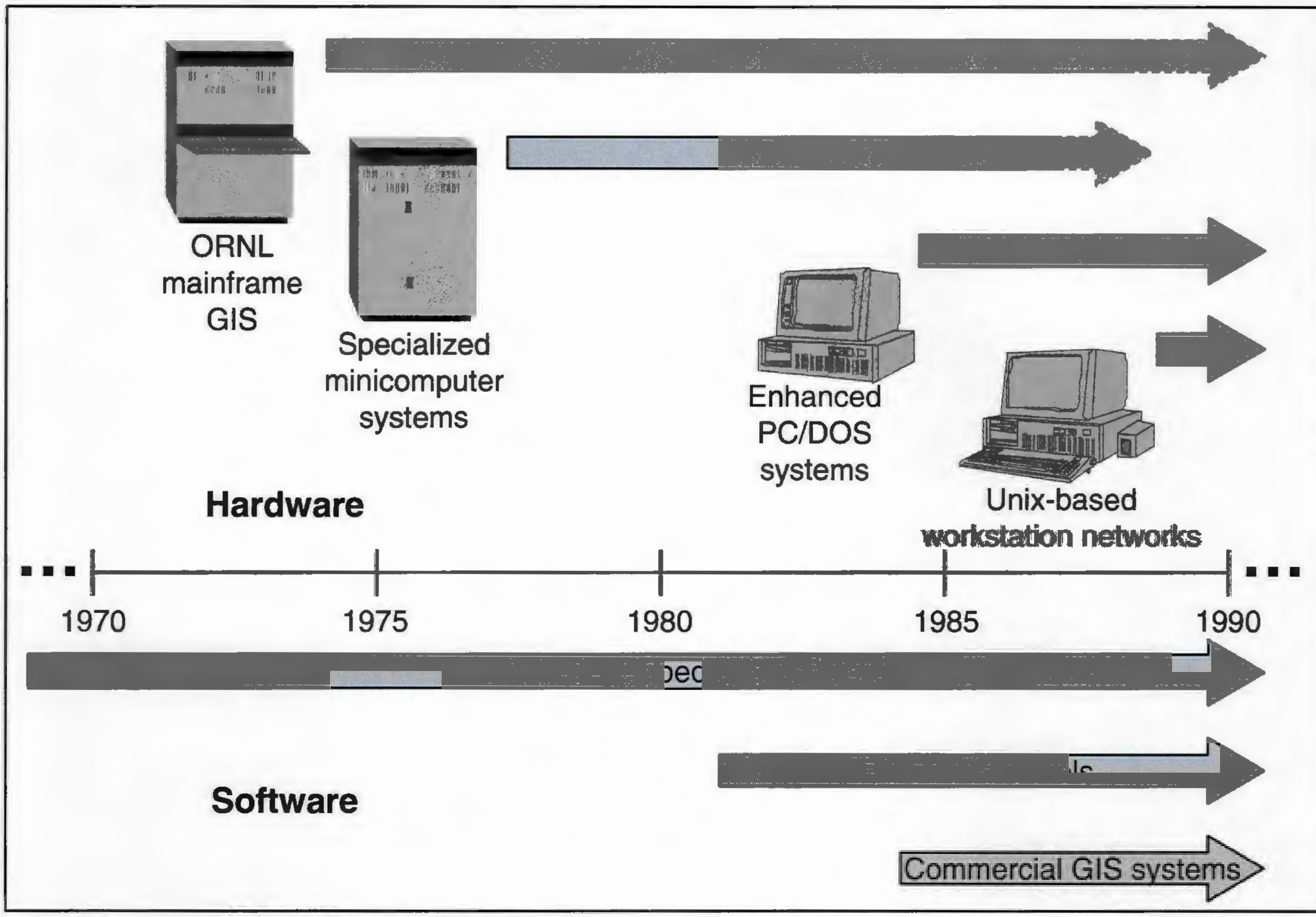
In this article, we focus primarily on ORNL's role in the development and application of GIS to real-world problems over the past 25 years. Over this time, hundreds of projects and tasks involving GIS have been carried out by several organizations at ORNL involving a number of scientists, managers, and sponsors. It would be impossible to mention them all, but we do recognize and appreciate their significant contributions and collective vision for advancing GIS technologies over the years. In addition to the Computational Physics and Engineering Division, the examples of collaborating organizations within Martin Marietta Energy Systems have included the Energy Division, the Environmental Sciences Division, Chemical Technology Division, the Environmental Restoration Program, Biology Division, Data Systems Research and Development, and the Hazardous Waste Remedial Action Program. We highlight several of the larger efforts to illustrate the diversity of applications and techniques. We describe some of the early GIS developments and summarize some of the current systems capabilities. We offer examples in which GIS has proven useful in research and decision support.

History of GIS Development

Actually, the term GIS, though first introduced in 1964, was not extensively used until the late 1970s. The first comprehensive geographic data management system—called the Oak Ridge Regional Modeling Information System (ORRMIS)—was developed in 1974 at ORNL by Durfee. Its purpose was to integrate and support the data management needs of a series of regional analytic models depicting and forecasting land-use, environmental, socioeconomic, and sociopolitical activities in the East Tennessee region.

Many early ORNL developments in GIS that are commonplace today are remarkable primarily because of their dates. Examples from the 1970s and early 1980s include perspective and isometric drawings of cartographic surfaces, integration of remote sensing and statistical techniques with GIS, raster-vector transformation, viewshed calculation, polygon intersections, transportation routing models, and true three-dimensional (3-D) imaging.

ORNL has a long heritage of GIS research, development, and application to complex problems ranging from national issues to site-specific impacts. After presenting an overview of GIS technology development in ORNL's computing environment, we discuss three eras of GIS history at ORNL—regional modeling and fundamental development (1969–1976), integrated assessments (1977–1985), and issue-oriented research and analysis (1986–1995).



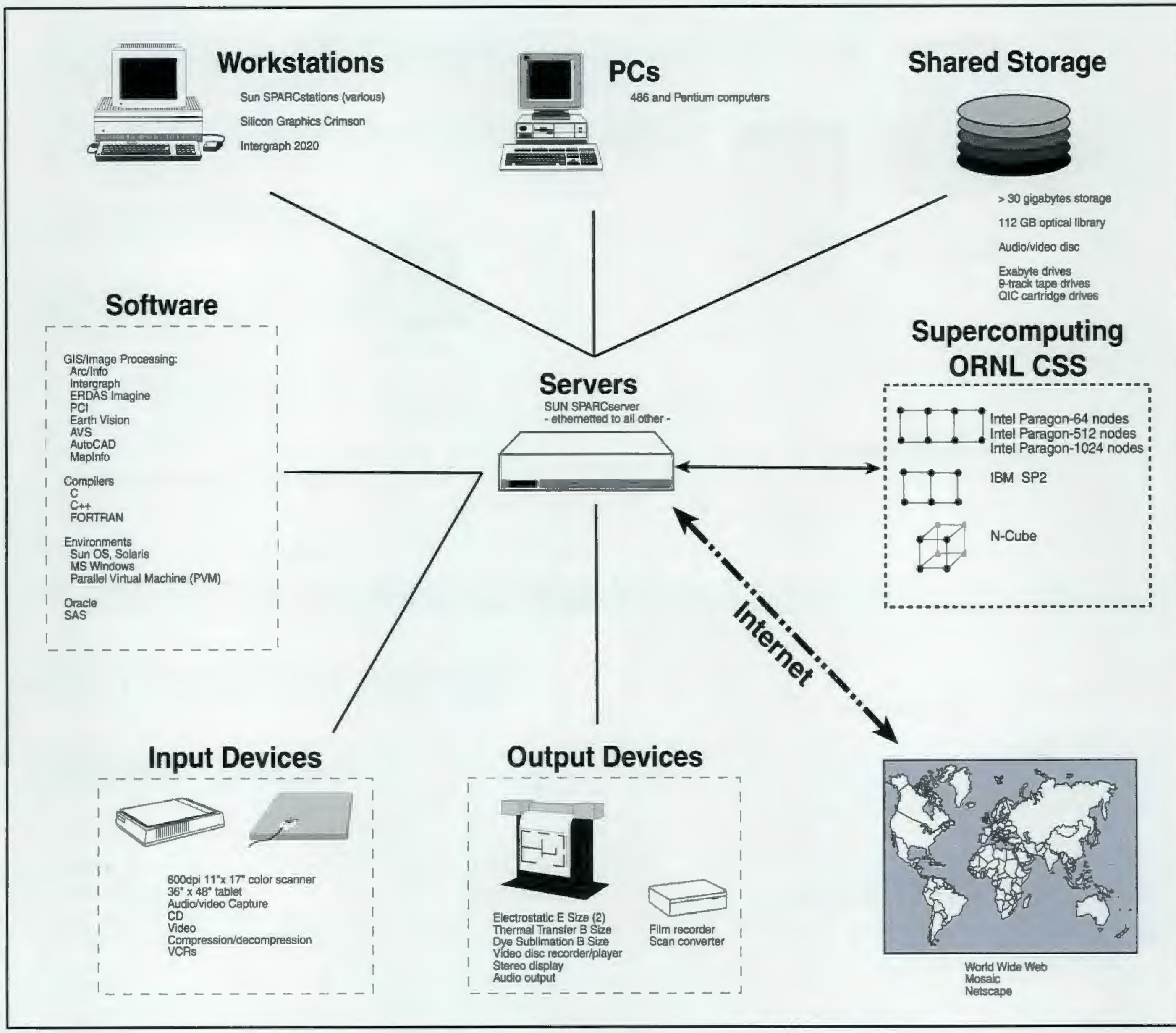
Historical development of GIS computer systems at ORNL, including hardware and software.

Evolution of GIS Technology at ORNL

In the past 25 years (see figure above), GIS software development and applications have migrated from mainframe computers to minicomputers to personal computers (PCs) to networked UNIX workstations (see figure on p. 52). GIS software is now being modified for use on parallel processors and supercomputers, such as the IBM SP2 and Intel Paragon X/PS machines at ORNL.

In the very early 1970s, a technological feat was the development of a computer-generated 3-D perspective movie by Tom Tucker of ORNL. The movie simulated terrain and population changes over a 40-year period in the Norris, Tennessee, area as Norris Dam began operation as a hydroelectric facility.

Over the years, one of the benefits of these spatial technologies has been their applicability to many different types of problems. One example was the development in the early 1980s of electron microscope tomography for 3-D reconstruction of DNA chromosomes as a collaborative effort led by Don Olins and his colleagues in ORNL's Biology Division in cooperation with the GCM group at ORNL. Adaptation and development of hardware and software for a commercial remote sensing system, I^2S, on GCM minicomputers played a major role in the analysis of electron micrographs and display of chromosome structures. When it was determined that more sophisticated true 3-D displays were needed, a special varifocal mirror display was built (see photo on p. 53). Depth visualization was provided by a vibrating mylar mirror synchronized with a monitor mounted above the mirror whose image was reflected to the



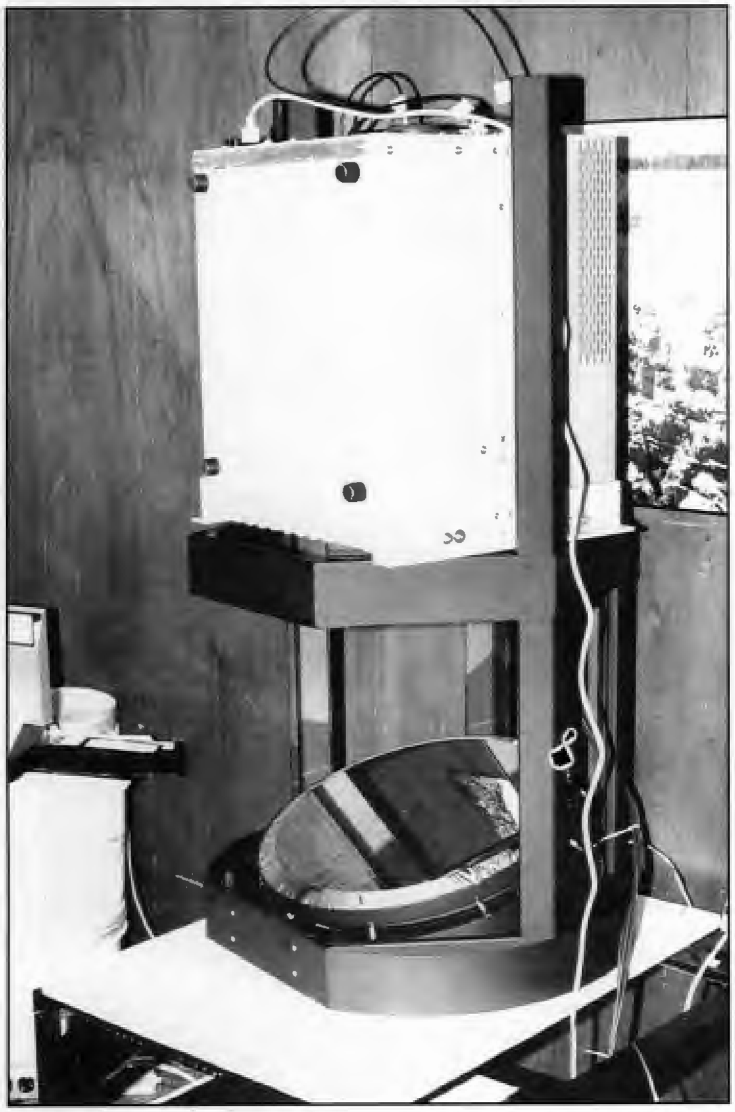
ORNL's GIS and Computer Modeling Group has a variety of computing resources used in support of a number of efforts ranging from natural resource assessments to environmental restoration.

Another technical development in the 1980s was integration of video information with digital data in the computer.

operator. Data at greater depths were displayed when the mirror was at a greater deflection, thus varying the focal length to correspond to the appropriate depth. This occurred at a rate of 60 times per second, so the observer saw a continuous 3-D image.

Another ORNL breakthrough in GIS technology in the mid-1970s was the development of vector-based algorithms and their eventual integration with raster-based grid cell systems. The GCM group used these techniques for all types of water-resource and energy-related studies in collaboration with the Energy Division. In the late 1970s, ORNL developed transportation data bases and capabilities for routing hazardous wastes across the United States. Through use of GIS technology to match proposed routes with population density, the health and safety risks of hazardous waste transport could be estimated.

Another technical development in the 1980s was integration of video information with digital data in the computer by Steve Margle and Ed Tinnel at ORNL. Raster digitization of video signals and the introduction of laser video discs



ORNL researchers, building on earlier work at the University of North Carolina, developed a special varifocal mirror system to provide viewers with a continuous three-dimensional image. This sophisticated technology was used in the display of electron micrographs of chromosome structures and medical computer tomography scan images.

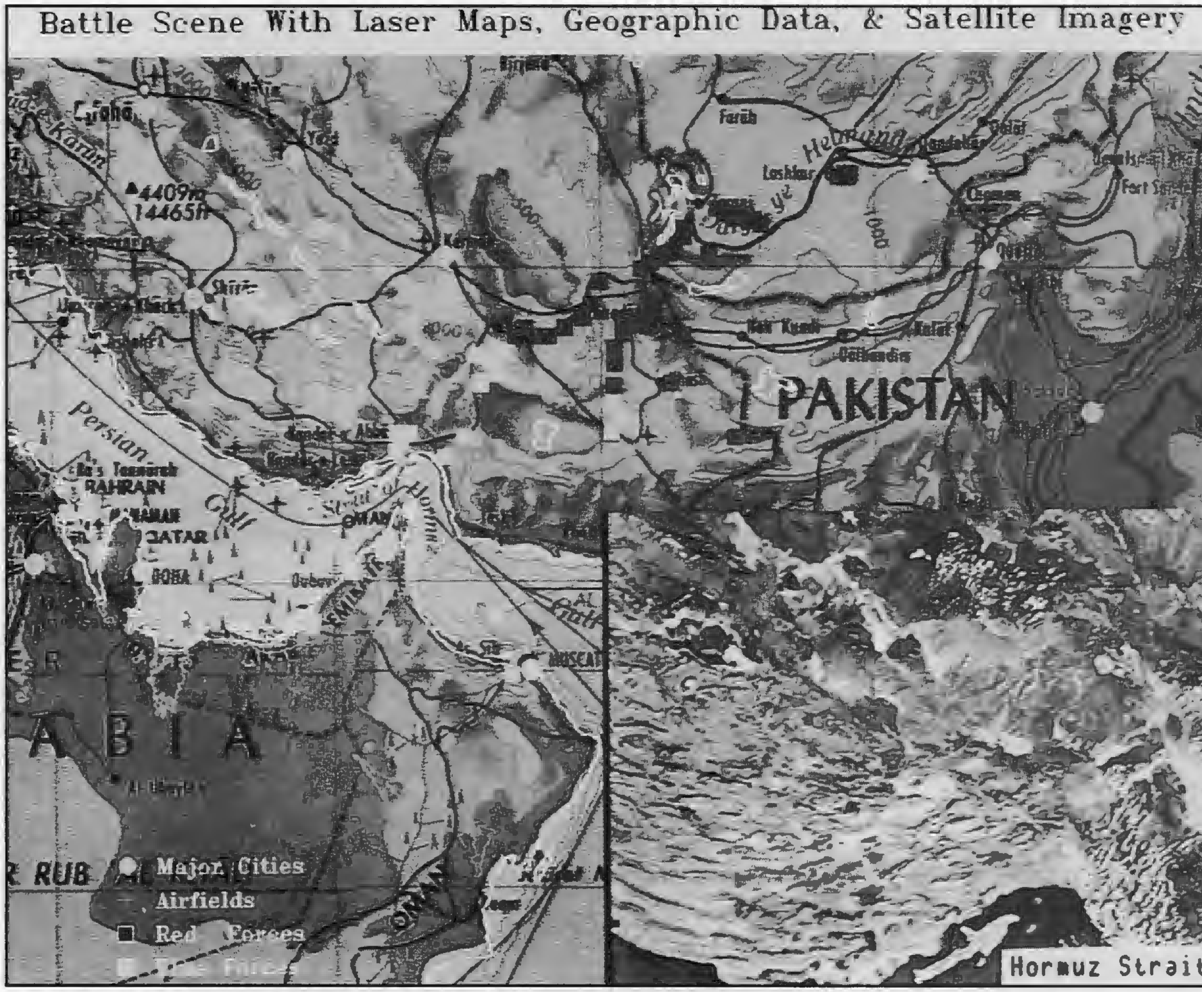
opened up a whole new way of dealing with graphic and map data. Working in cooperation with the Data Systems Research and Development organization, the GCM group demonstrated the feasibility of using video from scanned map images recorded on laser video discs for simulations of war games as training exercises on a high-resolution workstation (see figure on p. 54). In this technique implemented by Beverly Zygmunt, multiple video frames were located, computerized, and combined into large electronic maps that could be roamed and overlaid with other geographic and military information in real time.

Throughout the 1980s and into the 1990s, development of new GIS hardware and software technologies made new applications possible and improved our ability to solve old problems. It is interesting to note that some of our primary GIS applications in the first half of the 1990s have addressed a legacy of environmental problems, just as many initial applications in the early 1970s promoted GIS to help evaluate environmental impacts.

Development of new GIS hardware and software ...improved our ability to solve old problems.

Some of the latest GIS research under way at ORNL involves developing software for use on parallel-processing supercomputers. Very recent work has shown that, by significant improvement of algorithms and by using parallel processors on ORNL supercomputers, the transformation and interpolation (estimation of values between data points) of large GIS data sets can be done 50 to 18,000 times faster than on smaller Sparc workstations. Because of the explosion in data collection from all types of earth sensor systems, workstations and supercomputers must be integrated to handle massive volumes of data.

We are also integrating portable GIS capabilities with GPS in which relative positions



Oak Ridge researchers demonstrated the feasibility of using laser disc video of scanned map images to aid simulations of war games in a workstation environment. In this technique, multiple video frames were combined into large electronic maps (shown here) that could be roamed and overlaid with other geographic and military information in real time.

Real-time airborne GPS techniques have been used in aerial surveys of the Oak Ridge Reservation.

of objects on the earth can be pinpointed in real time by satellite sensors in communication with hand-held devices. As this technology becomes more commonplace, geospatial data will be collected at an ever increasing rate. Real-time airborne GPS techniques have already been used in aerial surveys of the Oak Ridge Reservation to collect high-resolution aerial photography with accurate positioning information. Computerized stereo techniques are being used with special goggles to help generate orthographic images (digital images corrected for camera, terrain, and other distortions) from stereo photography. Also, 3-D subsurface modeling and visualization are being done for hazardous waste studies.

To provide intelligent and efficient access to large amounts of geospatial data, work is under way to prepare and load this information on Internet and World Wide Web servers, which can be accessed by data browsing tools such as Mosaic and Netscape. These capabilities are important to the Oak Ridge user community and to the success of the National Spatial Data Infrastructure (NSDI) during the 1990s.

Regional Modeling and GIS Development (1969–1976)

In 1969, the U.S. Congress passed the National Environmental Policy Act (NEPA), the National Science Foundation (NSF) initiated the Research Applied to National Needs (RANN) program, Ian McHarg published *Design with Nature*, and ORNL delved headlong into regional modeling and GIS. Clearly, NEPA was a major impetus to the other three events.

Before NEPA, research and development, infrastructural development, and resource management decisions had been based almost exclusively on engineering and cost-benefit considerations. Suddenly, NEPA thrust all large enterprises, including the federal government itself, into a new legal and ethical milieu in which comprehensive, interdisciplinary analyses were absolutely essential. Alvin Weinberg, director of the Laboratory from 1955 to 1973, immediately recognized the need and sought to diversify the Laboratory's missions.

For GIS, the most important development in the early days at ORNL was the Oak Ridge Regional Modeling Information System and associated tools that supported spatial data input and display. The primary purpose was "to provide the data management capability for analysis models which forecast the spatial distribution and ecological effects of activities within a geographical region." The land-use modeling efforts became the principal impetus to remote sensing development as well as to the GIS expansions.

Initial GIS software techniques were based on hierarchical grid cell systems. It became apparent that additional capabilities were needed for accurate cartographic representation and analysis of vector-based map data. By the mid-1970s, development of sophisticated polygonal-based GIS systems at ORNL were well under way. Our development of efficient storage and computational techniques for integrating raster-based grid cell and vector-based systems opened the door to addressing larger and more complex problems with a national scope. Incorporation of new algorithms designed by Phil Coleman and Bob Edwards provided a capability for analyzing and displaying large national data bases.

Integrated Assessments (1977–1985)

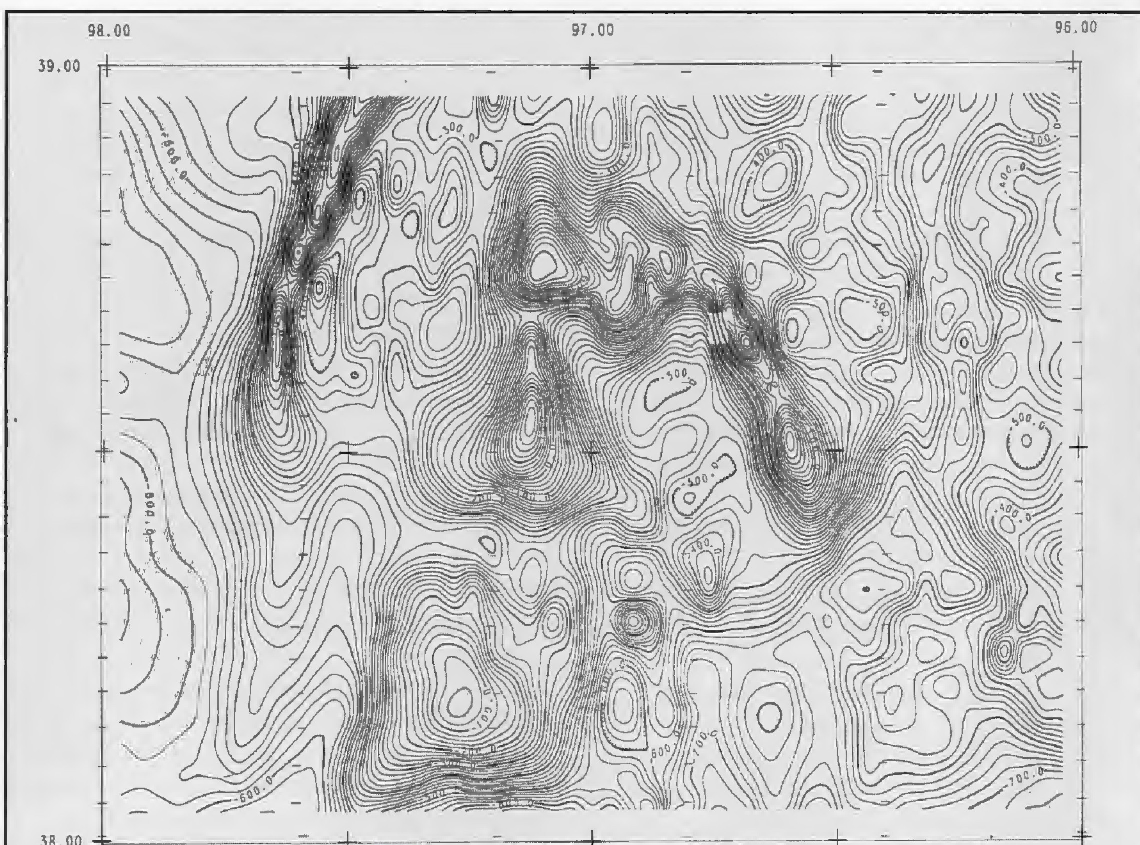
In the mid-1970s, a shift in federal policy greatly reduced NSF funding for the DOE national laboratories. From then on, hardly another penny was received to support basic research, development, or operation of GIS systems at ORNL. The GCM group and the Energy Division shifted to applications-driven research, the funding for which allowed continued development and operations.

We never had the luxury of focusing on a particular technology (remote sensing or computer cartography, for instance) to the exclusion of other technologies. We were then, and are still, comprehensive integrators with analytical purposes paramount in everything we do. In many respects, this approach has been advantageous because (1) the integrated GIS technologies were then applicable to a wide range of spatial problems, and (2) the applications-driven development minimized "ivory-tower" research looking for a problem to solve.

ORNL systems were used...to support conflict resolution in power plant siting.

The first seeds of the new order were sown in 1975 when Richard Durfee and Bob Honea used ORRMIS tools for predictive modeling of coal strip mining and associated environmental problems. Results of this work were presented to Robert Seamans, head of the Energy Research and Development Administration (ERDA), predecessor to DOE. Soon afterward, we became heavily involved in siting analysis. In 1975 and 1976, ORNL systems were used, along with data from the Maryland Automated Geographic Information System, to support conflict resolution in power plant siting. By the late 1970s, these systems were heavily involved in decision support for federal energy policy and resource management. ORNL employed GIS extensively to evaluate the environmental impacts of various proposed National Energy Plans. Later, we predicted the amount of coal that could be produced from federally leased lands and evaluated the impacts on energy supply of designating certain lands as wilderness areas, thus protecting them from exploration for and extraction of oil, gas, and uranium.

During the mid-to-late 1970s, the Laboratory played a major role in the National Uranium Resource Evaluation (NURE) Program. ORNL's Computer Sciences Division (now the Computational Physics and Engineering Division), in cooperation with DOE's Grand Junction Office, was the national repository for all data collected and analyzed to assess the availability and location of potential uranium resources for future commercial nuclear power, research reactors, and other uses. ORNL staff were responsible for overall data management, GIS processing, spatial analysis, and mapping. Al Brooks was director of the Oak Ridge effort to support DOE in surveying the country for potential uranium resources and estimating possible reserves. Through a multitude of subcontractors, DOE conducted both aerial radiometric and geomagnetic surveys and hydrogeologic ground sampling on a quadrangle-by-quadrangle basis across the United States.



This map shows varying magnetic intensities in the Hutchinson, Kansas, region. ORNL helped develop a technique for converting one-dimensional flight line data into meaningful contour maps of regional magnetic data that could help identify anomalies potentially related to geologic deposits.

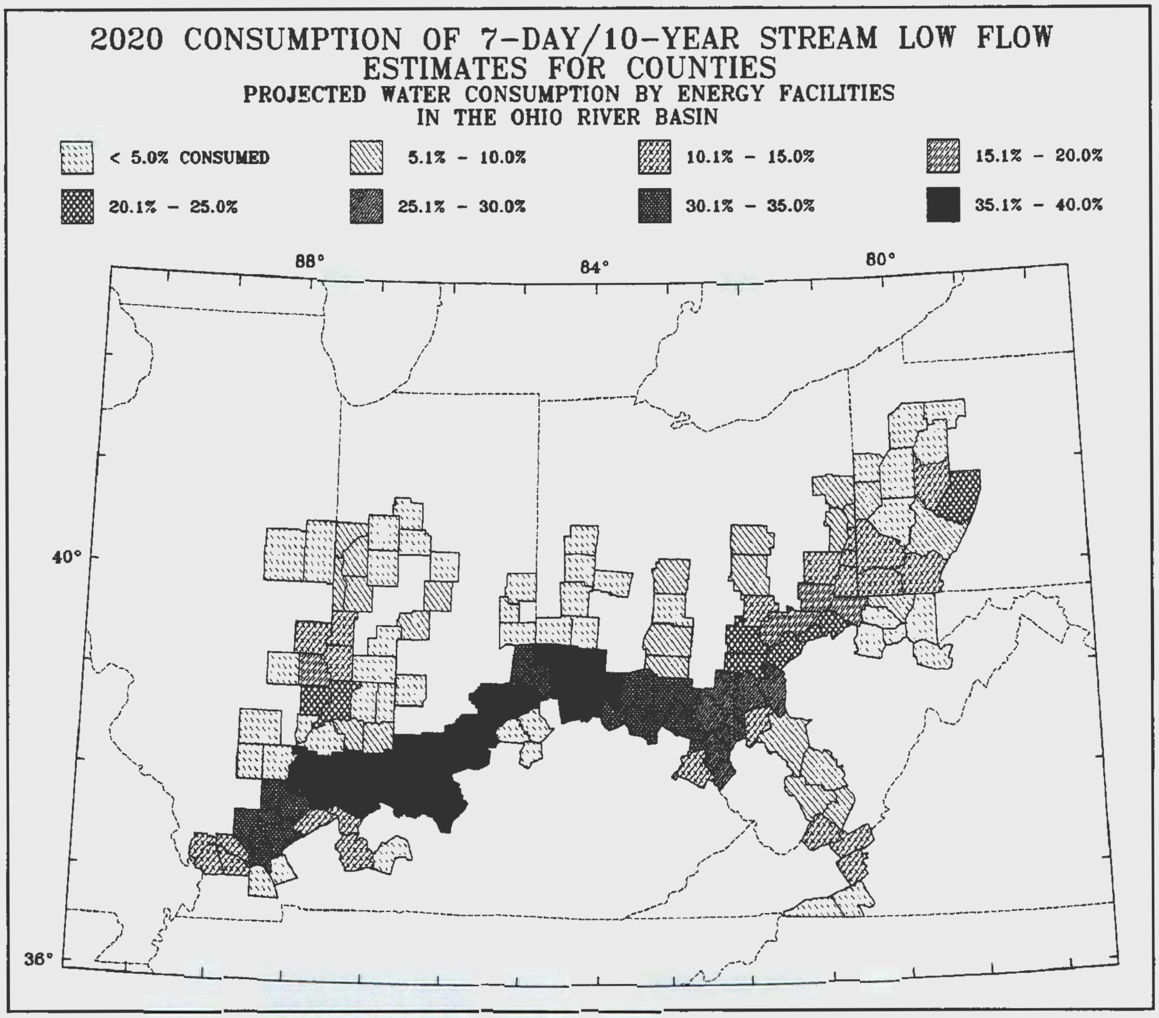
The aircraft had special sensors to detect radioactive isotopes of elements such as bismuth, thallium, and potassium as well as magnetic fields.

One example of highly specialized GIS work at ORNL was Ed Tinnel's development, in cooperation with Bill Hinze of Purdue University, of spatial filtering, interpolation, and contouring techniques to convert one-dimensional flight line data into meaningful maps of regional magnetic data (see figure on p. 56). The purpose was to use these data to help study geologic features and identify magnetic anomalies that might indicate the presence of mineral deposits. These maps were also provided to the U.S. Geological Survey for publication. This was one of the earliest projects that required the handling of massive amounts of spatial, tabular, and textual information of many different types. During this time specialized GIS hardware systems were implemented to provide new ways of digitizing and displaying large amounts of geographic data.

Multiple energy assessments were early examples of policy analysis using GIS. A flurry of activity began each time President Jimmy Carter proposed a new National Energy Plan. Econometric models were run by the Energy Information Administration to project, as far as the year 2000, energy demand and fuel use by type in each major region of the country. These regional projections were passed to ORNL, where energy demand was disaggregated by Dave Vogt to Bureau of Economic Analysis Regions and supply was allocated to counties. Around 1980 Ed Hillsman and others of the Energy Division projected electrical generation from each existing plant and simulated construction or retirement of different plants by fuel type to determine if the president's goals would be met. Dobson and Alf Shepherd projected the amount of water needed for energy production and compared it with the amount of water available in each basin in the United States (see figure below). ORNL's projections of electrical generation for different areas were passed to other national laboratories (Argonne, Brookhaven, Los Alamos, and the Solar Energy Research Institute), which used the information to evaluate effects on air quality, water quality, and labor supply. All results were reported to DOE, which conducted policy analysis of the feasibility of each proposed plan. Results of one GIS assessment of the projected water consumption by energy facilities in the Ohio River Basin (see figure on p. 58) were shown to President Carter in a live presentation using a graphics station when he visited ORNL in 1978.

In short, as early as the 1970s the nation's energy system and many pertinent physical and cultural features were simulated through GIS in linkage with econometric models, location-

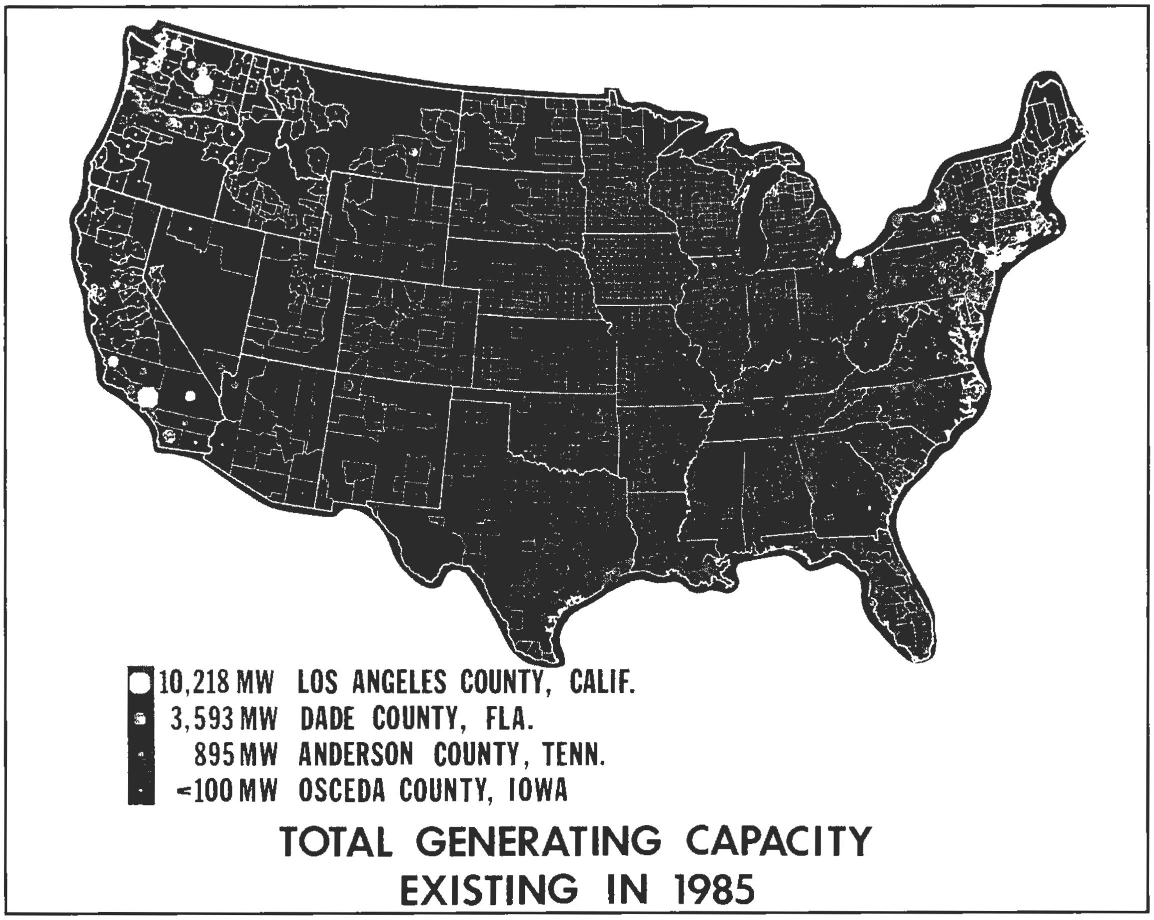
ORNL researchers used GIS and computer modeling techniques to predict the amount of water needed for national energy plans and compared it with the amount of water available in watershed basins across the United States.



Results of one assessment of projected water consumption by energy facilities in the Ohio River Basin were shown to President Carter in a live presentation using a graphics station when he visited ORNL in 1978.

allocation models, environmental assessment models, and spatial data bases. The principal output was by county, but many of the data bases and computations covered details finer than the county level. For example, the data bases included population at the Enumeration District level, all power plants over 10 megawatts in generating capacity (see figure on p. 59), and all U.S. Geological Survey stream gauging station records. The models were as sophisticated as any in use at that time with or without GIS.

Another major multiyear effort involving ORNL researchers in the early 1980s was the development of a national abandoned mine lands inventory for the Office of Surface Mining (OSM) of the Department of Interior. This effort, headed by Bob Honea, was based on federal legislation mandating that abandoned mine lands be reclaimed to protect human health, safety, welfare, and the environment, using funds collected as taxes on mining operations. A national inventory of abandoned mine lands was necessary to determine the affected areas in urgent need of reclamation and to establish priorities for reclamation of other sites. The effort was initially viewed as a technology-based project involving heavy use of remote sensing, GIS, record-based information systems, and statistical tools.



Using spatial techniques and various models and data bases, ORNL researchers displayed a geographic breakdown of the total electrical generating capacity in 1985 in the United States. The information aided utilities and energy agencies in the planning process for meeting projected demands for electricity.

It was anticipated that analysis of Landsat satellite imagery would be a key ingredient for identifying detailed impacts from the disturbed, abandoned lands. However, an interesting turn of events made the project much more difficult than expected. When attempts were made to use results from satellite analyses to meet the mandates in the legislation, we found that the worst threats to human health and safety (e.g., open mine shafts, acid drainage, polluted water supplies) could not be determined from satellite data. Major environmental impacts could be addressed by analyzing satellite images, but health and safety impacts and reclamation cost estimates required field data collection and field assessment efforts. Thus, a major field collection effort, which included on-site interviews with affected populations, was carried out in conjunction with the state agencies of all the coal-mining states (see photo on p. 61). Unique information handling techniques were devised to standardize and computerize textual, tabular, temporal, and spatial data from forms and maps that could then be linked with GIS for spatial aggregation, statistics, and mapping. Don Wilson was responsible for overseeing the computerization of all this information and development of a consolidated data base. These results could then support assessments at the state, regional, and national levels to aid OSM in allocating reclamation funds and overseeing mitigation of the severest problems.

Methodologies developed at ORNL for one application were readily adapted and applied to other problems. For example, our initial demographic work of the late 1970s was extended to compute detailed population distributions for any place or region in the United States (see figure on p. 62).

The technique was used by Phil Coleman and Durfee to compute population distributions around all nuclear power plants in the United States. Our results, including the calculation of population exclusion zones, enabled the Nuclear Regulatory Commission to assess these exclusion areas—regions where additional nuclear power plants should not be built because too many people live or work there—to help make planning and licensing decisions.

ORNL researchers concluded that forest blowdown facilitated the acidification of some lakes.

Issue-Oriented Research and Analysis (1986–1995)

Starting in the mid-1980s, the emphasis shifted again, this time in a very positive direction, as GIS became an important tool in topical research on scientific issues of national interest, as illustrated in these four examples.

Lake Acidification and Acid Precipitation. Acid precipitation can cause water in lakes to acidify, potentially reducing fish populations. Lake acidification and other environmental issues that may be related to acid precipitation were major themes of GIS work at ORNL in the late 1980s. The Environmental Sciences Division (ESD) was involved prominently in the National Acid Precipitation Assessment Program (NAPAP), especially the National Surface Water Survey. Through extensive collaboration with U.S. Environmental Protection Agency (EPA) laboratories and numerous universities and private firms, Dick Olson, Carolyn Hunsaker, and other ESD personnel collected, managed, and analyzed massive geographic data bases for lakes and watersheds throughout the United States. The goal was to characterize contemporary chemistry, temporal variability, and key biological resources of lakes and streams in regions potentially sensitive to acid precipitation.

Simultaneously, the Energy Division approached the same problem from a different perspective. While NAPAP focused on impacts of acid precipitation, this project focused on watersheds and investigated possible causes of lake acidification.

In 1950, a huge storm with heavy rain and 105-mile-per-hour winds blew down numerous trees in 171,000 hectares of forest in the Adirondack Mountains of New York (see figure on p. 63). In the 1980s it was observed that several lakes in the area were acidified, so one hypothesis was that the blowdown of the forest might be a cause. To determine if a relationship existed between the forest blowdown and lake acidification, Dobson and Dick Rush of ORNL and Bob Peplies of East Tennessee State University used an approach that combined GIS and digital remote sensing with the traditional field methods of geography. The methods of analysis consisted of direct observation, interpretation of satellite images and aerial photographs, and statistical comparison of two geographical distributions—one representing forest blowdown and another representing lake chemistry.

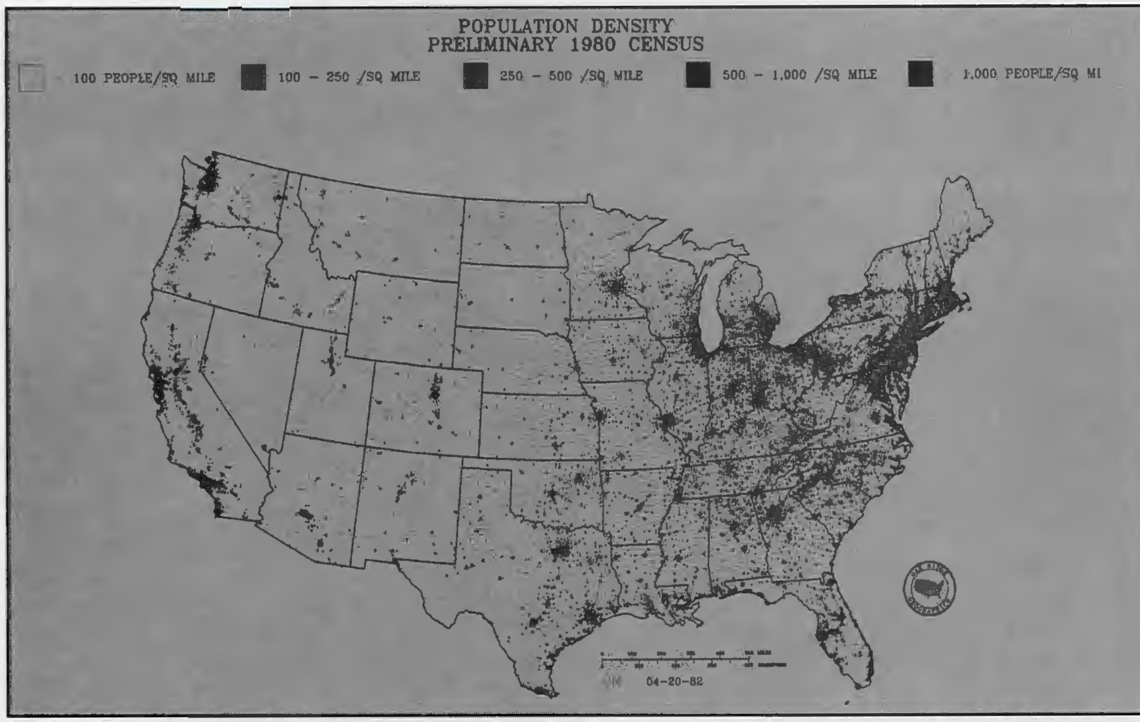
Associations in time and space between surface water acidity levels (pH) and landscape disturbance were found to be strong and consistent in the Adirondacks. Evidence of a temporal association was found at Big Moose Lake and Jerseyfield Lake in New York and at the Lygners Vider Plateau of Sweden. The ORNL researchers concluded that forest blowdown facilitated the acidification of some lakes by altering pathways for water transport. They suggested that waters previously acidified by acid deposition or other sources were not neutralized by contact with subsurface soils and bedrock, as is normally the case. Increased water flow through "pipes"—small tunnels formed as roots decayed—was proposed as the mechanism that may link biogeochemical impacts of forest blowdown to lake chemistry.

ORNL's Al Voelker (now deceased) and colleague Bob Peplies (in back) evaluated the health, safety, and environmental impacts of abandoned mine lands in 1980 for the U.S. Office of Surface Mining.

ORNL has led the technical effort to improve methods for analyses of changes in uplands and wetlands.

Both efforts illustrate an ORNL strength—the ability to assemble multidisciplinary teams and multiple organizations to attack complex problems. GIS, in itself, is an integrating technology because it draws together different sciences that have a common need for spatial data, visualization, and analysis capabilities. Such was the case in the acidification studies just described. Although primary responsibility for these two efforts rested separately in the Energy and Environmental Sciences divisions, the GCM group was heavily involved in both efforts. Thus, considerable interaction took place between the two projects. Since then, ESD, in cooperation with GCM and other groups, has continued to expand its GIS capabilities and resources. ESD scientists now have hands-on access to GIS systems and data bases to support a multitude of research efforts.

Coastal Change Analysis. For decades, the National Marine Fisheries Service (NMFS) of the National Oceanic and Atmospheric Administration (NOAA) has been concerned about declining fish populations in U.S. coastal waters. Suspecting that these declines might be caused by losses of habitat, such as saltmarshes and seagrasses, and increases in pollution resulting from expanding urban and rural development, as well as agriculture, NMFS initiated a research effort to solve the technical, institutional, and methodological problems of large-area change analysis—methods for determining the time, location, and degree of



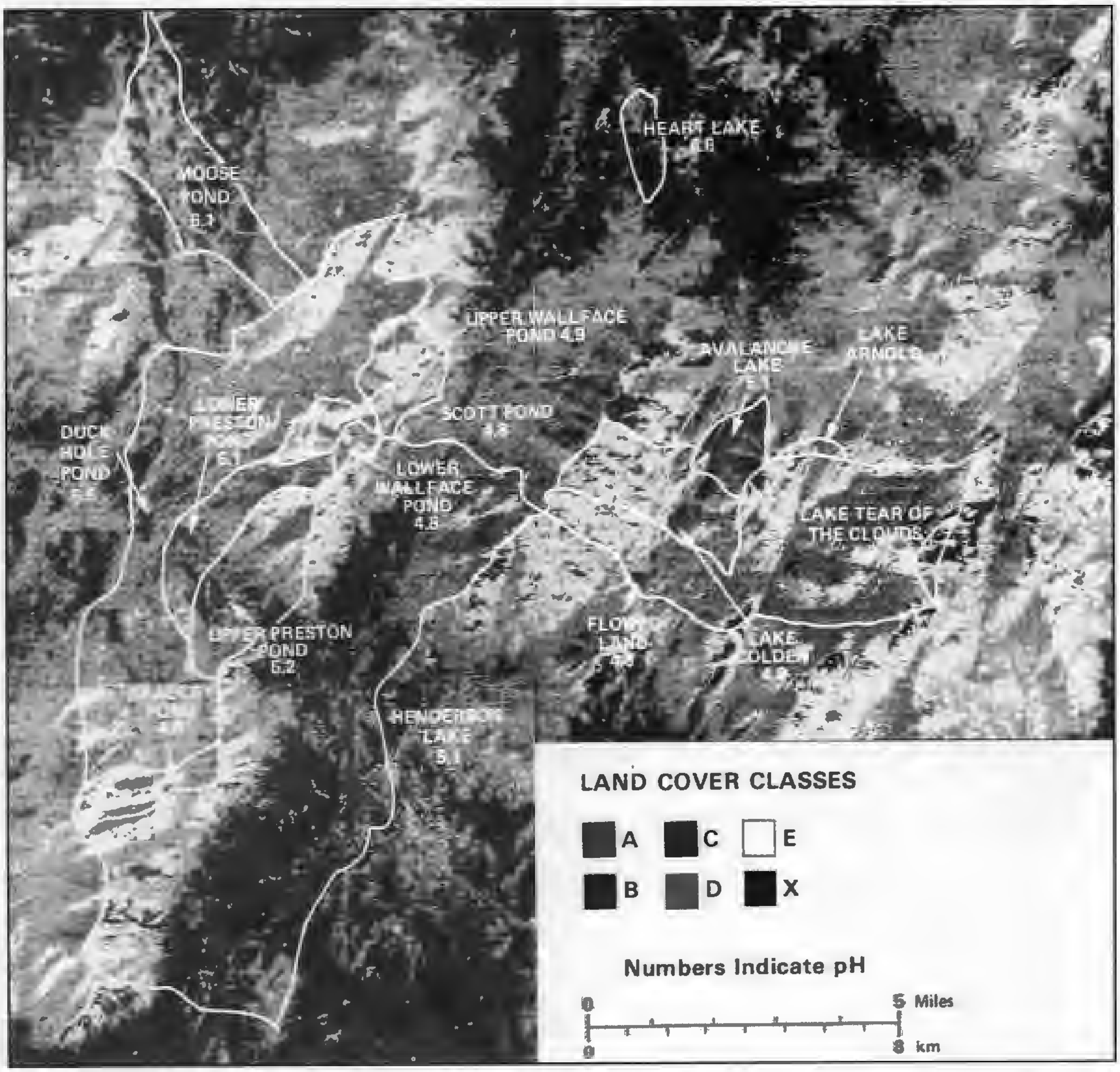
ORNL developed a technique for computing detailed population distributions for any place or region in the United States. The technique was used to compute population distributions around all U.S. nuclear power plants. The Nuclear Regulatory Commission relied on this information to assess future exclusion areas—highly populated regions where additional nuclear power plants should not be built.

We found that marshland in the Chesapeake Bay region increased slightly.

changes in large areas to better understand changes in ecosystems and ecological processes. ORNL has led the technical effort to improve methods for analyses of changes in uplands and wetlands, detected by satellite sensors, and to perform prototype satellite change analysis of the Chesapeake Bay. Integration of these remote sensing and GIS methodologies in a laboratory environment, in field investigations, in workshop settings, and for presentations and briefings in policy and management arenas shows how much this evolving technology is becoming ingrained in all phases of earth-sciences work.

The Coastal Change Analysis Program (C-CAP) is developing a nationally standardized data base of land cover and land-cover change in the coastal regions of the United States. As part of the Coastal Ocean Program (COP), C-CAP inventories coastal and submerged wetland habitats and adjacent uplands and monitors changes in these habitats over one to five years. This type of information and frequency of detection are required to improve scientific understanding of the linkages of coastal and submerged wetland habitats with adjacent uplands and with the distribution, abundance, and health of living marine resources. Satellite imagery (primarily Landsat Thematic Mapper), aerial photographs, and field data are interpreted, classified, analyzed, and integrated with other digital data in a GIS. The resulting land-cover change data bases are disseminated in digital form for use by anyone wishing to conduct geographic analysis in the completed regions.

Land cover change analysis has been completed for the Chesapeake Bay based on Landsat Thematic Mapper (TM) data (see photograph on p. 64). The resulting data base consists of land cover by class for 1984, land cover by class for 1988 and 1989, and a matrix of changes by class from 1984 to 1988–89. We found that, contrary to popular opinion, marshland in the Chesapeake Bay region increased slightly during the period. However, both forested wetlands and upland forests declined significantly, while land development expanded rapidly. At greater detail,



This GIS image of part of the Adirondack Mountains shows the geographical relationship between forested areas where trees were blown down by strong winds in 1950 and acidified lakes (numbers on lakes show acidity level, or pH). The forest blowdown has been linked to acidification of the lakes.

we observed the formation of a new barrier island and recorded lateral movement of portions of its tip by almost a kilometer.

Although the Chesapeake Bay prototype focused on a single region, its purpose was to provide a technical and methodological foundation for change analysis throughout the entire U.S. coast. Four regional workshops (Southeast, Northeast, Great Lakes, and Pacific) addressed a full range of generic issues and identified the issues of special interest in each major coastal division of the United States.

Ed Bright develops and views results of land-cover change analysis of wetland changes in the Chesapeake Bay region based on data from Landsat satellites.

In studying satellite images, we have looked for changes in land cover...and tried to quantify these changes on a regional basis.

Ultimately, the protocol development effort involved more than 250 technical specialists, regional experts, and agency representatives.

During the summer of 1994, field work was conducted in the Gulf of Maine, along the Oregon and Washington coast, and in Alaska. The Alaskan study is especially interesting.

In 1986, the Hubbard Glacier moved, closing the narrow opening between the glacier and Russell Fiord's Gilbert Point on the coastline of Alaska. The ice dam later burst as the fiord's water rose, and the narrow opening was restored. The event was worrisome to salmon fishermen because the fiord's alternative outlet to the sea could destroy the unique stock of sockeye salmon that spawn in the Situk River. The glacier is poised to move again, and the new, more permanent ice dam that is expected could cause the fiord to empty through the Situk watershed, drastically altering its ecosystem.

Using satellite images of the Alaskan coastline from various years, we are identifying changes in the Alaskan coastline that will help predict the impacts on fisheries when the glacier closes the gap again. If the Situk River salmon are threatened, it may be necessary to transplant some of them to less vulnerable streams.

In studying satellite images, we have looked for changes in land cover from 1986 on and tried to quantify these changes on a regional basis. For example, we have looked at changes in the size and shape of woodlands, wetlands, grasslands, and bare ground over a period of years to characterize coastal changes. We are trying to model the direct relationship between land-cover changes and ecological processes.

To verify the accuracy of our interpretations of the satellite data, we visit the imaged sites. In 1993 and 1994, Ed Bright and Dobson went to Alaska to conduct field verification of a 1986 land-cover classification in the Yakutat Foreland and Russell Fiord. Now, when we do field work, we use a hand-held GPS device linked directly to a color laptop computer. Commercial software integrates the live GPS location coordinates with raster images representing land cover and with vector images representing other features such as roads. The device has more than doubled productivity in the field. We are currently designing a modeling approach that will link GIS, transport models, and process models to address the linkage between land-cover change and fisheries.

Environmental Restoration. To clean up a legacy of environmental contamination and to comply with environmental regulations, U.S. government facilities must locate, characterize, remove or treat, and properly dispose of hazardous waste. In the 1980s, ORNL researchers helped develop geographic workstations, spatial algorithms, 3-D subsurface modeling techniques, and data base systems for handling hazardous waste problems at Air Force installations. Later, this work provided a foundation for supporting environmental restoration activities at DOE facilities. Since the late 1980s, environmental restoration has become a major theme for GIS activities at ORNL. The integration of GIS with other technologies provides an important resource to support hazardous waste assessment and management, remediation, and policy formulation for environmental cleanup at DOE facilities. The locations of waste areas (i.e., surface operable units) across the DOE Oak Ridge Reservation (ORR) are represented by the bold polygons shown on the map at the top of p. 66.

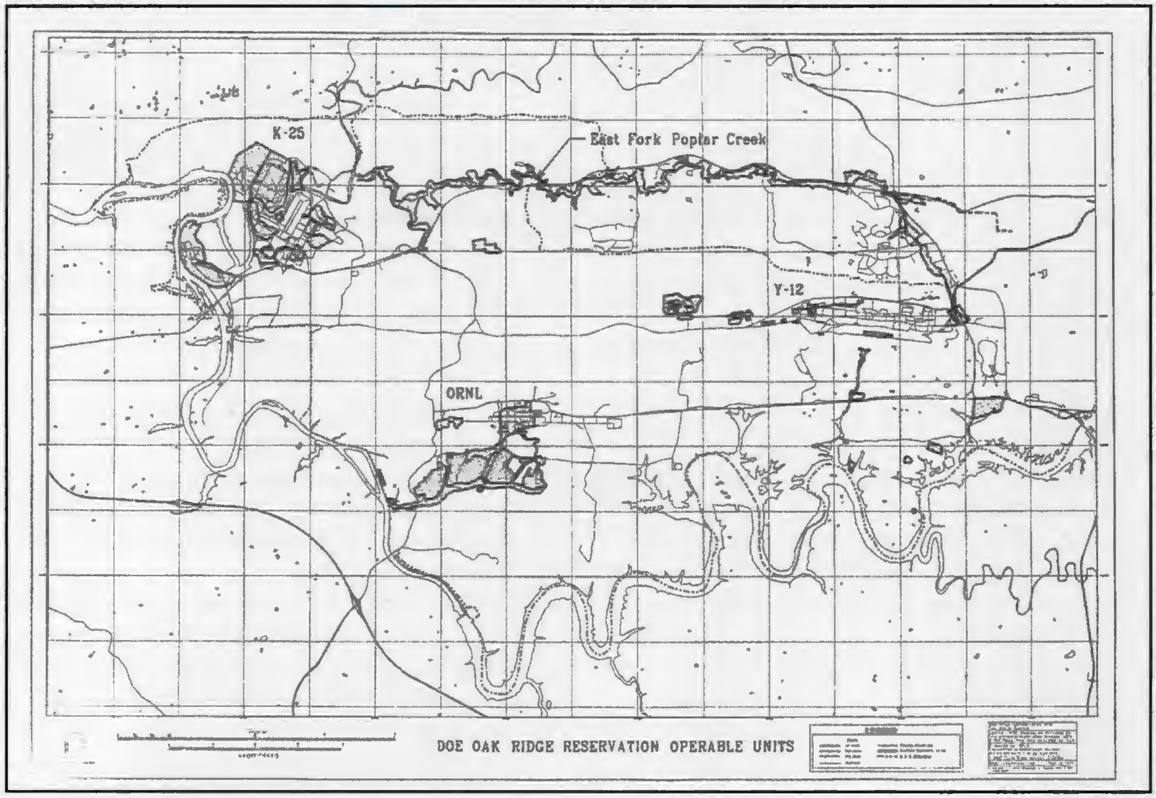
In conducting successful cleanup efforts and meeting regulatory requirements at these facilities, GIS can assist in many ways. Key aspects include investigation of the types and characteristics of contaminants; the location of possible pollutant sources; previous waste disposal techniques; the spatial extent of contamination; relationships among nearby waste sites; current and past environmental conditions, including surface, subsurface, and groundwater characteristics; possible pollutant transport mechanisms; efficient methods for analyzing and managing the information; effective cleanup strategies; and mechanisms for long-term monitoring to verify compliance.

GIS technologies support environmental monitoring and cleanup.

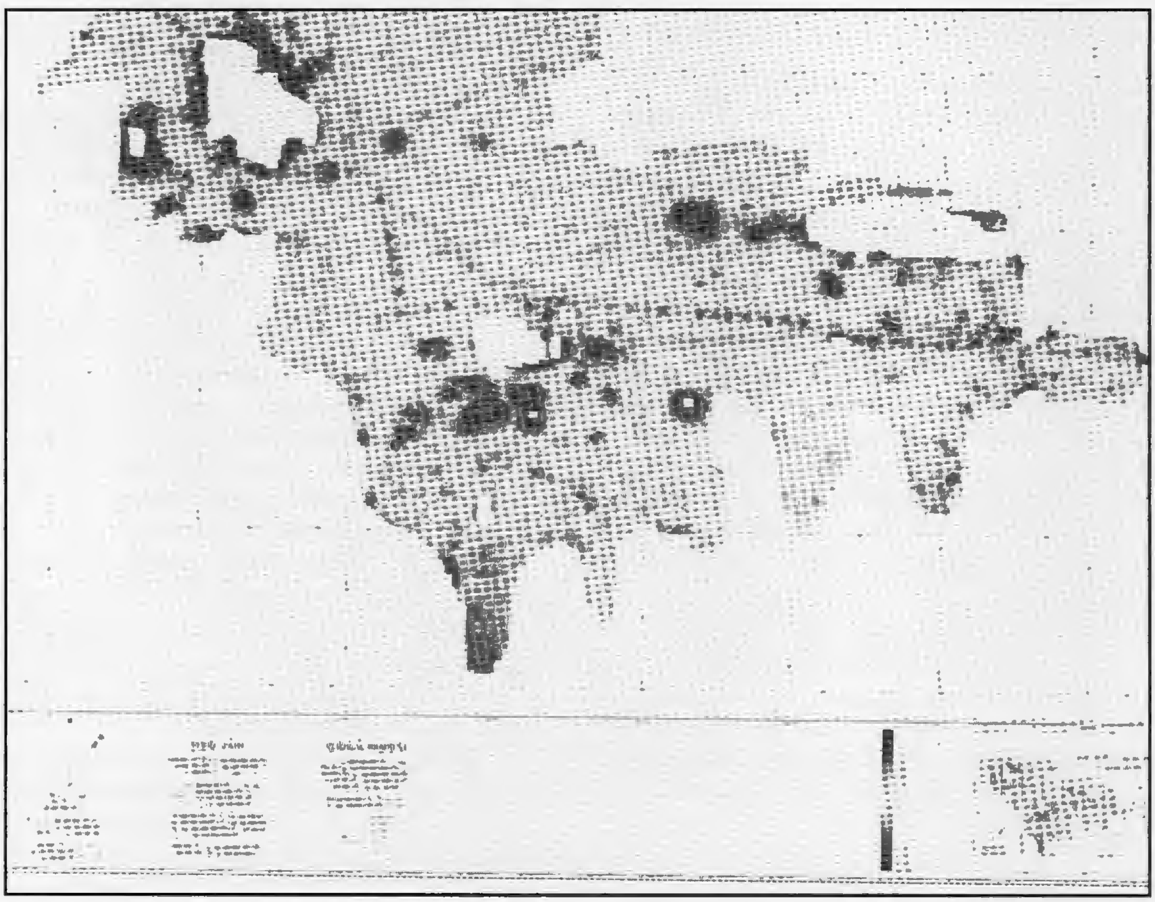
Three programs that involve significant GIS activities in support of environmental restoration (ER) in Oak Ridge include the Oak Ridge Environmental Information System (OREIS), the Remote Sensing and Special Surveys (RSSS) Program, and the GIS and Spatial Technologies (GISST) Program. The OREIS effort is designed to meet environmental data management, analysis, storage, and dissemination needs in compliance with federal and state regulatory agreements for all five DOE facilities operated by Lockheed Martin Energy Systems. The primary focus of this effort has been to develop a consolidated data base, an environmental information system, and data management procedures that will ensure the integrity and legal defensibility of environmental and geographic data throughout the facilities. The information system is composed of an integrated suite of GIS, relational data base management, and statistical tools under the control of a user-friendly interface. Examples of some of these tools are shown on the inside back cover. The OREIS effort, previously led by Larry Voorhees and Raymond McCord, is now being directed by David Herr.

OREIS's data have been combined with other site-specific information to study a variety of environmental problems. ORNL has modeled contaminant leakage from underground waste lines and used historical aerial photos to assess potential pollutant migration.

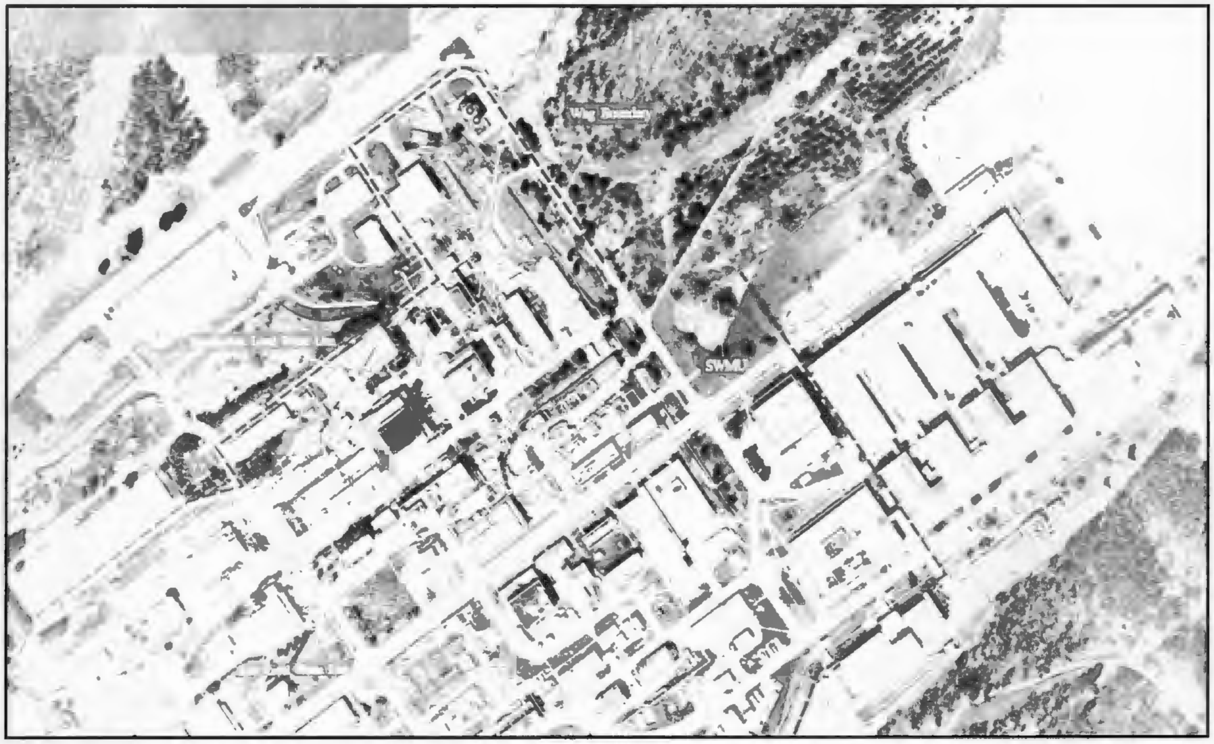
The RSSS Program under Amy King supports ER site characterization, problem identification, and remediation efforts through the collection and analysis of data from aircraft and other remote sensors. One example has been helicopter



Waste areas designated as surface operable units on the DOE Oak Ridge Reservation.



ORNL geophysicists led by Bill Doll perform spatial analysis and mapping of magnetic and electromagnetic data from airborne surveys to provide information that may aid in locating potentially contaminated areas on the Oak Ridge Reservation. Integration of this information with other types of remotely sensed data can help identify waste areas in burial grounds that may be a source of waterborne contaminants.



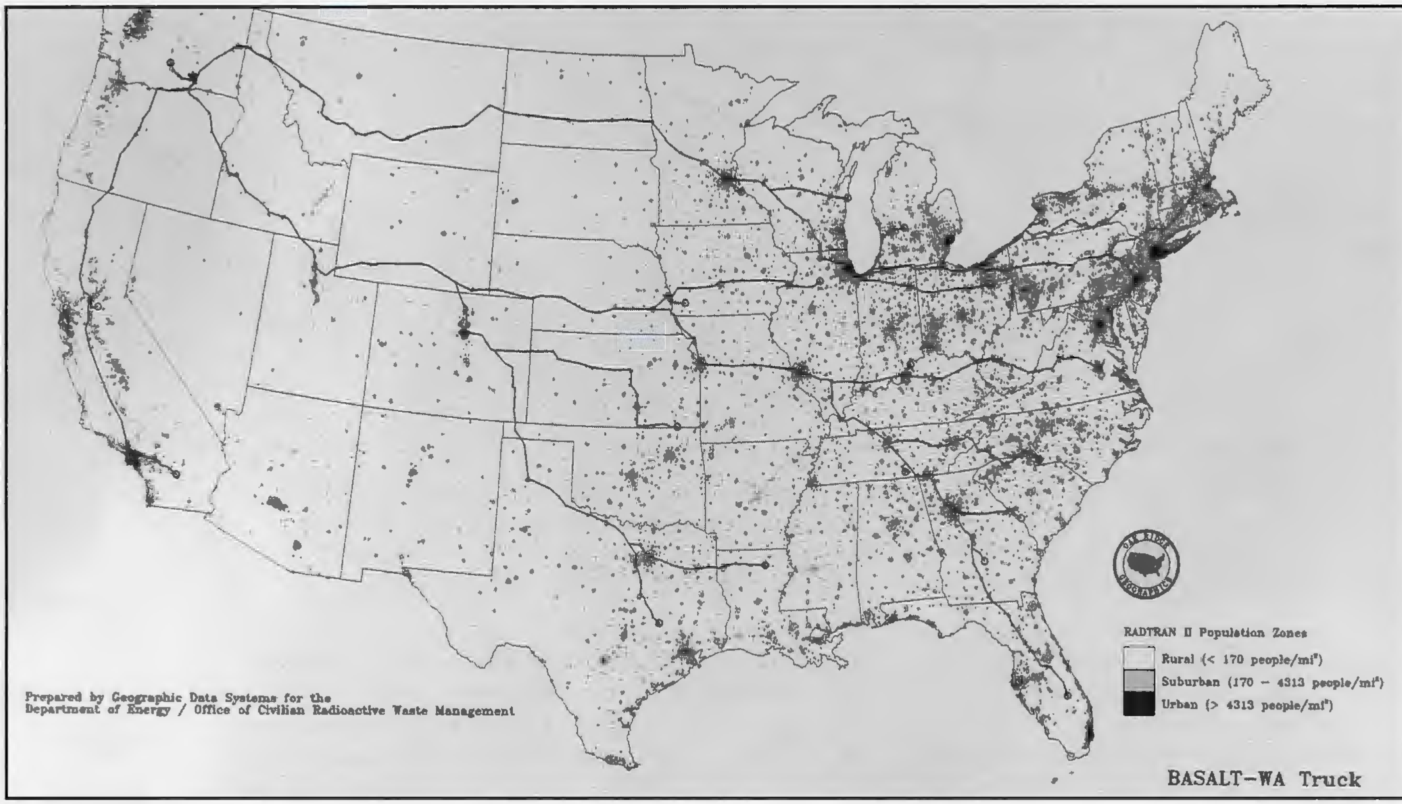
ORNL's fusion of orthoimagery with all types of spatial data on the Oak Ridge Reservation (note waste lines, operable unit boundaries, and solid waste management units in this figure) can help improve the identification and understanding of relationships among contaminant sources, support environmental monitoring activities, and assist in various types of facility management and land-use planning.

Results from such analyses are useful in locating potentially contaminated ...areas.

radiometric surveys to determine gamma radiation levels across mapped areas of DOE facilities. GIS and remote sensing techniques also aid in the interpretation and visualization of airborne multispectral scanner data, thermal imagery, infrared and natural color photography, and electromagnetic and magnetic survey analyses. The back cover, inside back cover, and map at the bottom of p. 66 show examples of these types of processed information. Integrated results from such analyses are useful in locating potentially contaminated and affected areas, as well as possible underground structures that may be pertinent to hazardous waste burial and migration. Another example has been the delineation of waste trenches in burial ground areas that may be a source of waterborne contaminants requiring remediation. The RSSS Program is also responsible for surveys of environmentally sensitive areas on the ORR.

The GISST effort, under Durfee, promotes the development, maintenance, and application of GIS technology, data bases, and standards throughout the ER Program. The largest activity currently under way is the development of base map data, digital orthophotos, and elevation models for all Energy Systems facilities using advanced stereo photogrammetric techniques based on real-time airborne GPS. When completed, these terrain data will be the most comprehensive GIS and orthoimage coverages of any DOE reservation. This project, under the technical direction of Mark Tuttle, is being carried out in cooperation with the Tennessee Valley Authority. Desktop mapping systems are being integrated into the daily operations of many Oak Ridge staff devoted to monitoring and cleaning up the ORR. To support these activities, a repository of the resulting data from this project is being made available to users networked into a local file server, which will soon be accessible as a World Wide Web server. These GIS data provide a consistent, current, and accurate base map that can be integrated with all other types of environmental and pollutant data for analysis and reporting.

The fusion of all types of spatial data is an important tool for any environmental activity on the ORR (see photo above). Through these and other ER programs, facility data and environmental data bases have been developed to improve understanding of relationships among pollutant sources, surface and subsurface pathways, and receptors of environmental contaminants. Three-dimensional modeling, data management, and contaminant analysis have been enhanced through integration of computer tools



Results from Paul Johnson and Dave Joy's work depict the computation and display of possible truck routes for transporting radioactive waste material from groups of nuclear reactors to a candidate repository site. These routes are superimposed on zones of computed population densities across the United States.

and geospatial data. All these resources are becoming an integral part of the remediation planning and cleanup process, supported through communication networks linking scientists, engineers, and decision makers with analytical software and data bases.

GIS is used increasingly to plan, develop, and manage transportation infrastructures.

Transportation Modeling and Analysis. Transportation systems and networks are crucial to the U. S. economy and way of life. GIS is used increasingly to plan, develop, and manage transportation infrastructures (e.g., highway, railway, waterway, and air transport networks) with the goal of improving efficiency in construction and operation.

Three main centers heavily involved in transportation modeling and geographic networks are the Energy Division (ED), the Chemical Technology Division (CTD), and the Computational Physics and Engineering Division (CPED). CTD has been primarily supporting DOE transportation needs in collaboration with CPED; ED has been supporting the Department of Transportation; and both ED and CPED have been supporting the Department of Defense. Collectively, the three groups have developed detailed representations of highway, railway, and waterway networks for the United States and military air transport networks for the entire world. ED, for example, is the developer and proprietor of the National Highway Planning System and the initial INTERLINE railway routing model. CTD has had a major responsibility for routing and assessing hazardous materials on the nation's highway and rail systems for many years (see figure at left). They have enhanced and adapted the INTERLINE and HIGHWAY routing models to assist in this work. CPED has been a major developer of the Joint Flow and Analysis System for Transportation (JFAST), which is a multimodal transportation analysis model designed for the U.S. Transportation Command (USTRANSCOM) and the Joint Planning Community.

Operations Desert Shield and Desert Storm (1990–1991) involved the largest airlift of personnel and equipment from region to region ever accomplished. The U. S. Air Force's Military Airlift Command, now the Air Mobility Command (AMC), was responsible for this movement from the United States and Europe to the Persian Gulf region. Prior to that event, ORNL had worked with AMC to develop the Airlift Deployment Analysis System (ADANS), a series of scheduling algorithms and tools that enabled AMC to schedule missions to and from the Persian Gulf more rapidly and efficiently than ever before. ADANS is currently being used 24 hours per day by AMC to schedule peacetime, exercise, and contingency missions, as well as peacekeeping relief and humanitarian operations. Some of the key members of the ADANS team have included Glen Harrison, Mike Hilliard, Ron Kraemer, Cheng Liu, Steve Margle, and Irene Robbins.

The ADANS architecture is based on a relational data base management system, which operates on a network of powerful, UNIX-based workstations stretching across the United States with current installations at ORNL; Scott Air Force Base, Illinois; and Travis Air Force Base, California. PCs are used to perform some functions. The configuration includes a data base management system, a form generation tool, graphical display tools, a report generation system, communication software, a windowing system, and more than 500,000 lines of ADANS-unique code. All modules exchange data and run asynchronously. Thus, schedule planners can use the windowing system to keep track of and to modify multiple pieces of information. The three main components of the user interface are movement requirement and airlift resources data management, schedule analysis, and algorithm interaction.

All data and algorithms are geographically explicit. The user inputs data on a station-by-station basis with the textual network editor; the graphical network editor allows the user to establish a network and to enter or to edit information directly on a world map. With this system, it is easy to determine how cargo and passengers were moved, how many were moved as required, and to what aircraft they were assigned.

The JFAST effort, initiated by Bob Hunter, is designed to determine transportation requirements, perform course of action analysis, and project delivery profiles of troops and equipment by air, land, and sea. JFAST was used in Desert Shield to analyze the airlift and sealift transportation requirements for deploying U.S. forces to the Middle East and predict their arrival dates in-theater. These deployment estimates provided input for establishing concepts and timing for military operations. Under Brian Jones' direction during Desert Storm, JFAST was also used to track ships, provide delivery forecasts, and analyze what-if scenarios such as canal closings and maintenance delays. In addition to analyzing support for humanitarian efforts such as those in Rwanda and Somalia, USTRANSCOM and the Joint Planning Community use JFAST to determine the transportation feasibility of deployment plans.

JFAST incorporates a graphical user interface that makes significant use of geographic display of transportation data as well as other graphic displays to aid the planner in understanding the output from the flow models. To assist in preparing briefings, all JFAST screens and graphic displays can be captured and inserted directly into presentation software while JFAST is running. Data from JFAST can also be sent directly to other Windows™-compliant applications, such as spreadsheets and word processing packages.

ADANS is currently being used...to schedule... peacekeeping relief and humanitarian operations.

ORNL's Role in the GIS Revolution

ORNL has advanced the use of GIS within our national infrastructure.

After a quarter of a century, how have GIS developments and applications at ORNL advanced science and served the national interest? ORNL has played an instrumental role in the GIS revolution by establishing and implementing a coherent vision that has been welcomed by scientific, policy, and management communities. ORNL has advanced the use of GIS within our national infrastructure. Today, commercial GIS products address many of the technical needs that required so much of our effort in the past, and the research frontiers have moved on to more complex methodological issues. However, no single commercial product today will handle all the current needs for GIS and related spatial technologies. One of our ongoing roles will be integration of multiple products with in-house technologies to best meet real-world needs that arise.

For the future, we envision linkages of GIS with environmental transport models and process models traditionally used by biologists, ecologists, and economists; implementation of GIS and digital remote-sensing techniques on supercomputers; 3-D GIS visualization and analysis; temporal analysis in a spatial context, and improved statistical analysis capabilities for geographic and other spatial data. The use of supercomputers will become even more important as new data collections—for example, the next generation of high-resolution satellite imagery—inundate the scientific community with terabytes of information. Justification for collecting and using these data will depend on the ability to extract meaningful information using supercomputer technology. We are currently addressing these and other technological issues, such as GIS animation, telecommunications, and real-time GPS and video linkage with GIS.

We hope to maintain a leadership position through continued advancement of hardware and graphics systems, GIS software, and data bases that will more effectively solve complex spatial problems. We think that knowledge-based expert systems will play a role in advancing future development and use of GIS technologies. We intend to assist the GIS community in improving standards and quality assurance procedures, and we look forward to assisting in enhancement of the National Spatial Data Infrastructure.

Ultimately, we view GIS as an integrating technology with the potential to improve all branches of science that involve location, place, or movement. Consider, for example, that most of the advances in medical imaging have been based on visual analysis. Imagine how much greater the potential would be if the images were enhanced by data structures, models, and analytical tools similar to those employed in analysis of the three-dimensional earth. We envision that certain technological thresholds will open the door to entire fields. For example, true 3-D analysis (more than visualization) and temporal GIS should provide new insights to geophysicists studying plate tectonics and the dynamic forces operating beneath the earth's surface. The single advancement of linking GIS with environmental transport models and process models will suddenly enable scientists and professionals in numerous other disciplines to incorporate spatial logic and geographical analysis alongside their traditional approaches. As these and other developments take place, a truly revolutionary new form of science should emerge. ornl

Biographical Sketches

Jerome E. Dobson (left) is a senior research staff member in ORNL's Computational Physics and Engineering Division. He currently serves as chairman of the Interim Research Committee of the University Consortium for Geographic Information Science, scientific editor of the *International GIS Sourcebook*, and a contributing editor and member of the editorial advisory board of *GIS World*. He holds a Ph.D. degree in geography from the University of Tennessee. He joined the ORNL staff in 1975. He is a former chairman of the Geographic Information Systems Specialty Group, Association of American Geographers, and member of the Steering Committee of the National Committee for Digital Cartographic Data Standards. He previously served as leader of the Resource Analysis Group in ORNL's Energy Division, as visiting associate professor with the Department of Geography at Arizona State University, as a member of the editorial board of *The Professional Geographer*, and as a member of the Steering Committee of the Applied Geography Conferences. Dobson was co-founder and first chairman of the Energy Specialty Group of the Association of American Geographers. He proposed the paradigm of automated geography, and he was instrumental in originating the National Center for Geographic Information and Analysis and in establishing the Coastal Change Analysis Program (C-CAP) of the National Oceanic and Atmospheric Administration. Employing geographic information systems (GIS) and automated geographic methods, he has proposed new evidence and theory regarding the mechanisms responsible for lake acidification and regarding continental drift and plate tectonics.

Richard Durfee is head of the Geographic Information Systems and Computer Modeling Group (GCM) in ORNL's Computational Physics and Engineering Division. He is also program manager of the GIS and Spatial Technologies Program for Environmental Restoration supporting DOE's Lockheed Martin Energy Systems facilities. He is responsible for an advanced GIS Computing and Technology Center at ORNL with special facilities for analyzing and displaying all types of geospatial information. Previously, he was head of the Geographic Data Systems Group in the former Computer Applications Division and section head in the former Computing and Telecommunications Division. He joined ORNL in 1965 as a member of the Mathematics Division. He has an M.S. degree in physics from the University of Tennessee. An expert in GIS and remote sensing technologies, he served on the initial steering committee for the DOE Environmental Restoration GIS Information Exchange conferences and for the early DOE Interlaboratory Working Group on Data Exchange. He was also an early member of the Federal Interagency Coordinating Committee on Digital Cartography. He is coauthor of many publications and presentations, including a GIS-related presentation to President Carter during his visit to ORNL in 1978. For more than 25 years, he has researched and directed a wide range of GIS technologies supporting hundreds of applications for more than 15 different federal agencies.

Oak Ridge Pays Tribute to its Nobel Prize Winner

Nobel Laureate Clifford Shull examines the neutron diffractometer now on display at the American Museum of Science and Energy in Oak Ridge. Shull used this instrument for his neutron-scattering research at ORNL's Graphite Reactor.—*Photograph by Kelley Scott Walli.*

Joy, pride, and hope. These were the emotions that Oak Ridge residents and ORNL employees felt October 13, 1994, when it was announced that Cliff Shull had received a Nobel Prize for physics. These emotions were rekindled on April 10 and 11, 1995, when Shull came home from Massachusetts to be honored for his achievements and to describe them in a replay of his Nobel Prize lecture.

The professorial Shull—diminutive in stature but a giant among scientists—had been a resident of Oak Ridge from 1946 to 1955. He and his wife Martha lived on Kentucky Avenue, and his children played with the children of former ORNL Director Alvin Weinberg. He conducted his pioneering research using neutron scattering with Ernie Wollan at the Graphite Reactor of Oak Ridge National Laboratory. He is the first person to receive a Nobel Prize for research conducted in Oak Ridge.

Shull shared the 1994 Nobel Prize in physics with Bertram Brockhouse of McMaster University in Hamilton, Ontario. Shull and Wollan used neutron scattering to determine where atoms are in a crystal, and Brockhouse used this tool to learn how atoms move in a material. Neutron scattering has been used at ORNL reactors and research reactors throughout the world to probe the structure and dynamics of materials. The research has led to development of high-strength plastics and improved magnetic materials used for small motors, credit cards, computer disks, and compact discs.

"This award was greeted with great joy in the neutron science community because of the respect we have for both men and in Oak Ridge because Cliff Shull did the work here that earned him the prize," said Ralph Moon, Shull's first doctoral student at the Massachusetts Institute of Technology (MIT), where Shull spent his career after leaving ORNL in 1955. Moon was master of ceremonies for an April 10, 1995, program at the American Museum of Science and Energy in Oak Ridge, where Shull was honored. Sharing the stage was the original neutron diffractometer that Shull had used for his prize-winning research and that was brought to Oak Ridge from the Smithsonian Institution in Washington, D.C., as a new exhibit for the museum's future ORNL room.

At the ceremony, Oak Ridge Mayor Ed Nephew said the city is proud of Shull's achievements. He presented the scientist with a proclamation declaring April 10, 1995, as "Clifford G. Shull Day" in Oak Ridge.

Shull's Nobel Prize also raised the hope that the Advanced Neutron Source research reactor to be built at ORNL would stay in the president's budget as a construction item and receive congressional funding. That did not happen, but Oak Ridge was named the preferred site for a proposed spallation neutron source, an accelerator to replace the reactor as a future facility for neutron scattering research.

On April 11, before Shull gave his Nobel Prize lecture "Early Development of Neutron Scattering" at ORNL, Tennessee Representative Zach Wamp pledged to Shull that he would support funding for neutron science and would educate fellow congressmen about the need to support activities in neutron science to which Shull had dedicated his life. For neutron scientists, there was still hope for more research opportunities ahead.

This instrument was designed by a Nobel Prize winner, and it was used by another Nobel Prize winner.

The neutron diffractometer now on display in the Oak Ridge museum was built at the University of Chicago using a 1915 design by Arthur Compton, Nobel Prize winner under whom Wollan had done his doctoral research in scattering of X rays from solids and gases at the University of Chicago. "This instrument was designed by a Nobel Prize winner," Moon said, "and it was used by another Nobel Prize winner."

A frequently used photograph of Wollan and Shull with their second instrument was first published in the April 8, 1949, issue of *The Oak Ridge National Laboratory News*. The photograph is displayed with the original instrument as part of the museum exhibit.

"I last saw this diffractometer in England in 1982 during the celebration of the 50th anniversary of the discovery of the neutron by James Chadwick," Shull said. "Since I last used it, it's been gilded and nicely polished.

"The years I spent in Oak Ridge were really exciting. I left Oak Ridge because of the prospect of teaching at MIT and starting a research

Shull goes through the motions of operating his old neutron diffractometer, now a museum piece. Looking on are, from left, ORNL Director Alvin Trivelpiece; Ralph Moon, Shull's first doctoral student at MIT; and Mike Wilkinson, one of Shull's collaborators at ORNL in the 1950s. *Photograph by Curtis Boles*

program using the new reactor there. Our years at MIT were as wonderful as the earlier period in Oak Ridge."

During his Nobel lecture at ORNL (similar to the one he gave in December 1994 in Stockholm, Sweden, during the Nobel Prize ceremonies), Shull traced the history of the neutron, from its discovery in 1932 to the discovery of fission in 1939 to the demonstration of the first neutron chain reaction in December 1942 in Chicago. He then talked about his collaboration with Wollan that ORNL Director Alvin Trivelpiece called "unusually productive."

"My biggest regret," Shull said, "is that Ernie Wollan did not live long enough to share in the honors that came to people in this field."

"My biggest regret," Shull said, "is that Ernie Wollan did not live long enough to share in the honors that came to people in this field."

Wollan joined the Manhattan Project at the University of Chicago during World War II to work in radiation protection and detection. He developed the first reliable film badge, a pocket radiation dosimeter, and a gamma ray meter that recorded the startup of the Graphite Reactor. Then known as the Clinton Pile, this air-cooled, graphite-moderated reactor was built in 1943 as a pilot plant for the production of plutonium to aid in the design of the plutonium-producing Hanford, Washington, reactors. These reactors produced the nuclear material used in the second atomic bomb dropped on Japan. Wollan came to ORNL in 1944 as associate director of the Physics Division.

In 1945 when the war was over, Wollan and other scientists pondered some possible scientific uses for the Graphite Reactor. Wollan, who had studied X-ray scattering from solids and gases, considered using neutrons from the reactor for scattering studies. In late 1945, he obtained a neutron beam of a single wavelength by passing reactor neutrons through a crystal. He arranged for a neutron spectrometer to be sent to Oak Ridge from Chicago. The spectrometer made possible measurement of the angles at which neutrons are scattered from atoms in a target material and the intensities of the scattered neutrons; such information is useful in determining material structure.

Wollan and Robert Sawyer showed that they could get a "powder pattern" by scattering neutrons in a beam from powder ground from a sodium chloride crystal. They then showed that neutron scattering could do what X-ray scattering could not—detect hydrogen atoms in hydrogen-containing materials. The definitive experiment showed that neutrons scatter differently from water (H_2O) than from deuterium oxide (D_2O), which contains heavy hydrogen, because of differences in the nuclear properties of the two hydrogen isotopes. Thus, they proved that hydrogen contributes to neutron scattering patterns in a recognizable way.

Shull learned of these results when he first visited Wollan in April 1946 at the Graphite Reactor. A native of Pittsburgh, Pennsylvania, Shull earned a B.S. degree from the Carnegie Institute of Technology and a Ph.D. degree in nuclear physics from New York University (NYU). He was there when O. Halpern and M. H. Johnson of NYU developed the theory of magnetic scattering of neutrons. During World War II, Shull became an expert in X-ray diffraction through his research at Texaco on catalysts being developed for production of high-octane aviation gasoline. Impressed by Wollan's research, Shull came to Oak Ridge to collaborate with him in June 1946, about the time that Sawyer left for Lehigh University.

In his Nobel lecture, Shull said he and Wollan irradiated sodium chloride, calcium chloride, and

In a nostalgic moment, Shull examines the control room in the Graphite Reactor, where he conducted his Nobel Prize–winning research. *—Photograph by Curtis Boles.*

carbon in diamond dust and graphite powder. They were trying to match intensities of scattered neutrons with material structures. But they failed to find quantifiable relationships; instead, they obtained discrepancies that they called diffuse scattering anomalies.

Eugene Wigner, ORNL research director who received a Nobel Prize in physics in 1963, listened quietly to their problem. Recalls Shull: "Wigner said, 'Maybe there's something brand new here.' He urged us to keep trying to quantify the effects. Eugene had more faith in our experiments than we did." They later determined that they had multiple scattering effects that could be sorted out, allowing neutron intensities to be correlated with structure.

In their neutron scattering experiments with sodium hydride and sodium deuteride, Shull said he and Wollan got their "first clear indication of where the hydrogen atoms are." They also obtained scattering patterns showing the locations of hydrogen atoms in ice balls made of water and deuterium oxide. " We used an ice ball machine," Shull said, "but we omitted the flavoring."

By accident, Shull and Wollan were the first to obtain a neutron radiograph, similar to an X-ray radiograph. They had set up an experiment to observe the first neutron Laue diffraction pattern using a single crystal of sodium chloride and a white (all wavelengths) neutron beam from the Graphite Reactor. The diffracted neutrons were detected using an indium sheet, which converts neutrons into photons, followed by a sheet of X-ray film. They had used Scotch tape to piece together strips of indium, and the images of these pieces of tape are clearly visible in the background of the Laue pattern.

Shull said he spent the rest of his career at ORNL using neutron scattering to probe the structure of alloys and magnetic materials. His work in magnetic scattering led to the development of improved magnetic materials that have proved important to the recording and computer industries. ornl

One of the jobs of a Nobel Prize winner is to talk to news reporters. Here, Shull explains neutron scattering to Frank Munger, science writer for the *Knoxville News-Sentinel*, while ORNL physicist Herb Mook listens in.*—Photograph by Curtis Boles.*

Tribute to Alvin M. Weinberg

Former ORNL Director Alvin Weinberg (left) chats with Nobel Laureate Cliff Shull, who performed his prize-winning work at ORNL when Weinberg was Laboratory research director.—*Photograph by Curtis Boles.*

Review of the Weinberg Years at ORNL

He asked penetrating questions and made tough requests. That's how former Laboratory staff members remembered former ORNL Director Alvin Weinberg at his 80th birthday celebration on April 20, 1995. Bill Fulkerson, former ORNL associate director, called Weinberg "our spiritual leader."

In honor of the occasion, ORNL Director Alvin Trivelpiece announced the inauguration of the annual Alvin M. Weinberg Lecture Series. The first lecture, "On Plutonium" (summarized below), was presented by Wolf Häfele, scientific director of the Research Center at Rossendorf-Dresden, Germany.

Several persons recalled that Weinberg used to sit in the front row at ORNL division information meetings and ask the first question after each scientific talk—often a very penetrating question. For a young scientist giving his first information meeting presentation, the experience was frightening but also exciting and stimulating.

Trivelpiece acknowledged that he is not always able to attend information meetings and ask questions. "How did you find the time?" he asked Weinberg. The former ORNL director replied in jest, "We didn't have a DOE in those days."

Sam Beall, director of ORNL's old Reactor Division, recalled Weinberg's requests that led to the development of several new reactors and "criticality parties" when the reactors were started. "Fifty years ago, I was called to his office and asked, 'Can we convert the Materials Testing Reactor mock-up to a real reactor?' He wanted something for nothing." The result was ORNL's Low Intensity Test Reactor (LITR), or the "Poor Man's Pile." Experiments at the LITR supplied data that aided the design of both pressurized-water and boiling-water nuclear reactors, the dominant reactor types in commercial nuclear power plants.

Weinberg then asked the reactor engineers to design a reactor that used fluid fuel instead of solid fuel. It was called "Alvin's 3P reactor" because it required a pot, a pipe, and a pump. The Homogeneous Reactor Experiment (HRE), as it was called, went into operation in 1950. At the criticality party, Weinberg pulled a bottle with a black label from his briefcase. Beall recalled that Alvin told him, "Sam, when piles go critical in Chicago, we celebrate with wine. When piles go critical in Tennessee, we celebrate with Jack Daniel's."

The HRE had a 105-day run and then was closed despite Weinberg's attempts to sell the merits of the reactor to powerful people in Washington. In fact, Weinberg even invited Senator Jack Kennedy and Jackie Kennedy and Senator Albert Gore, Sr., to visit the reactor. Weinberg recalled the event: "I invited John Swartout to be in charge of Jack Kennedy so I could be in charge of Jackie."

Information gained from operation of the HRE and the Aircraft Reactor Experiment (for 100 hours) led to the design and operation of the Molten Salt Reactor Experiment. It set a record for continuous operation of a reactor, and it was the first reactor to use uranium-233 as fuel.

Reactors were the centerpiece of the Laboratory in the Weinberg era.

Ellison Taylor, former director of ORNL's old Chemistry Division, said, "Reactors were the centerpiece of the Laboratory in the Weinberg era." But he called the Molten Salt Reactor Experiment "a chemist's reactor" because the "make-or-break problems" of the reactor required chemical solutions.

Howard Adler, former director of ORNL's Biology Division, recalled that under Weinberg this division was the largest, "five times the size of the next largest division." Its mission, he said, was to understand how radiation interacted with living things and to find ways to help organisms survive radiation damage, such as with bone marrow transplants.

Fulkerson remembered Weinberg as an environmentalist. "He viewed national laboratories as tools for achieving social progress." Fulkerson said that once the nuclear era was under way, Weinberg thought that ensuring sufficient food, clean water, and biological survival were important missions. Thus, in the 1960s Weinberg pursued new missions for the Laboratory, such as using nuclear energy to desalinate seawater and "make the deserts

Weinberg performs classical music during his 80th birthday celebration in Oak Ridge.

Weinberg offers birthday cake to his wife Gene.

bloom." Philip Hammond was recruited to the Laboratory from Los Alamos to push this mission.

Weinberg then invited David Rose from the Massachusetts Institute of Technology to come to ORNL and provoke discussion of the future of national laboratories. One result was a controversial publication "A Case for a National Environmental Laboratory." U.S. Representative Chet Holifield, chairman of the Joint Congressional Committee on Atomic Energy, opposed the idea. "Holifield," Fulkerson said, "didn't want nuclear labs tainted with the environmental brush."

Under Weinberg's leadership, the first big ecology project in the United States was started in 1970 at ORNL as the National Science Foundation–Research Applied to National Needs Environmental Program. Rose was the first director; when he left, his successor was physicist Jack Gibbons, now President Clinton's science adviser. Concerning this program, Gibbons has said, "We were ahead of our time."

"The exciting activity that Alvin stimulated in the late 1960s and early 1970s transformed the Laboratory," Fulkerson said. "Now, a quarter of a century later, another Alvin—Alvin Trivelpiece—suggested to the Galvin Commission that the new mission for the national labs should be sustainable development in the areas of the three E's—energy, the environment, and the economy."

Häfele, who in 1959–60 was a guest scientist with ORNL's Neutron Physics Division and an assistant to Weinberg ("a highlight of my professional life"), spoke on plutonium as a future resource, a future investment. Some people, he said, are "religiously against plutonium" because of its toxicity and potential for use in weapons. Because 200 tons of scrap plutonium exist in the United States (80 tons) and former Soviet Union, people are looking for ways to deal with it. One proposal is to burn it in reactors; another is to "hide it" by isolating it permanently from the environment.

Häfele sees plutonium as a resource to be guarded and proposes subsurface storage of plutonium. He said it should be kept in this "bank" for later use when nuclear power becomes more acceptable and energy needs necessitate a second nuclear era. Various countries would withdraw the plutonium they own from the bank as they need it for reactor fuel in accordance with international guidelines. Nuclear power will be more acceptable, he says, once waste disposal is addressed by an international group and once people have experienced problems in using alternative nonnuclear energy sources and the adverse environmental and climatic impacts of fossil fuel use.

"Plutonium is neither waste nor fuel," Häfele said. "It is an endowment."

In his remarks at the end of the birthday celebration, Weinberg complimented Häfele on his proposal for a global plutonium regime. He then spoke of the previous day's car bomb explosion at the federal office building in Oklahoma City, which killed or injured hundreds of adults and children. The worst bomb attack ever in the United States, he said, raises "grave questions and concerns for a world that finds existence of plutonium to be threatening. How does the world deal with senseless acts if nuclear bombs come into the possession of people like that? I don't really have an answer."

He noted that a possible solution to the scrap plutonium-238 problem is to blend it with plutonium-240 so that the nuclear material could not be used to make an atomic weapon. But he did not know if enough plutonium-240 exists to fully "denature" plutonium-238.

"Ultimately, the issue is organizational," Weinberg said. "Is the regime of terrorism the bitter fruit of today's technology? Is there no longer order in our society? It has been said that if society has a choice between freedom and order, it will choose order. Is it possible to have both?" More penetrating questions from Alvin.

Weinberg called for the strengthening of the International Atomic Energy Agency and for defensive systems as the number of nuclear weapons for each superpower drops from the thousands to a few hundred.

The main job of the Laboratory director, Weinberg said, is to keep money coming in to support research, not to sit in the front row at scientific meetings and ask questions. He noted that the recent publication of the Clinton administration, *Science in the National Interest*, proposed that 3% of the national budget be allocated to support research and development. But, he said, this report is not being taken seriously as was Vannevar Bush's report 50 years ago that called for strong government support for science.

The main job of the Laboratory director is to keep money coming in to support research.

Now that he is 80, Weinberg said he looks to the next generation to take over. "The problems they will face will be monumental. They will have large opportunities to deal with problems and bring on the second nuclear era. I hope they will make a better world than we oldtimers were able to produce."

So spoke Weinberg, whom former Tennessee Senator Howard Baker called "the master of the majestic concept" and whom Oak Ridge Associated Universites President Jon Veigel called "a citizen of the world who is our neighbor and friend." Even on his 80th birthday, Weinberg made sure we had some intellectual meat to chew on before we helped him eat his birthday cake. ornl

Confessions of a Nuke: A Book Review

Alvin M. Weinberg, *The First Nuclear Era: The Life and Times of a Technological Fixer*, American Institute of Physics, New York, 1994, 291 pages.

By Alex Zucker

We at ORNL think of Alvin Weinberg as our first long-time Laboratory director with a vision: to make nuclear power practical, to ensure cheap and clean electrical energy for the immediate and distant future. We saw a Laboratory director who cared, who knew all our names, and who set high standards for us and for himself, and we tried to live up to those standards. It was a matter of pride: we were all working for Alvin.

The astonishing thing is that in all these fields he was near the top, honored, sought after, respected, and listened to.

Weinberg's new book, *The First Nuclear Era: The Life and Times of a Technological Fixer*, is a personal memoir of his life in the world of nuclear technology. It begins with the first nuclear chain reaction at the University of Chicago and ends with a search for the rebirth of fission reactors as an acceptable energy source.

It soon becomes obvious how much more than a laboratory director Weinberg was. In approximate chronological order, he was a reactor physicist, a pioneer in nuclear energy, a reactor builder, a laboratory director, a lecturer, a writer, a thinker, a policymaker. The astonishing thing is that in all these fields he was near the top, honored, sought after, respected, and listened to. The book, then, describes a life full of accomplishment but also a life that contains its measure of disappointments and, at least during one period, despair.

The book starts with a very personal account of Weinberg's origins, his early education and his youth. By an accident of circumstances he is drawn into the Manhattan project at the University of Chicago, where he has earned a Ph.D. degree in what his adviser called mathematical biophysics. At this point personal history is narrowed to the technical and political domains, and purely personal reactions appear far too seldom. On finishing the book I am left with the thought that there is yet another book in Alvin Weinberg, a book about the private thoughts of a very public person.

After Chicago comes his 26-year career as research director and then director of ORNL. Weinberg had the simple idea that the management function at the Laboratory was "first, to maintain standards, and, second to show that it (management) cares." Hence Weinberg's unbroken record, sitting in the front row at division information meetings, asking penetrating questions, and making comments that could well influence the direction of an entire research program. I recall that, when I gave reports at information meetings, I always felt that I was speaking directly to Weinberg and that I had better have something interesting to say and be prepared to answer difficult questions.

Weinberg used his position at ORNL as a bully pulpit for nuclear energy. He was carried away when in 1964 General Electric "published . . . a catalog listing guaranteed prices of boiling water reactors ranging from 50 to 1000 megawatts." Cheap nuclear power seemed to have arrived, and Weinberg embarked on two quests. One was to ensure mankind unlimited energy for a very long time through development of the breeder reactor, which in large numbers would provide fissionable material far beyond what was then thought to exist in natural uranium deposits. The other was the application of nuclear energy to solve social or political problems—the technological fix. The most ambitious such fix was the agro-industrial complex, which would use giant reactors to supply cheap electricity and desalted seawater to overpopulated and underfed regions of the world and thus ensure peace and plenty to their struggling peoples. Clearly, Weinberg was going for the long ball. Big problems have always tempted him, and in the 1960s he was captured by a nuclear euphoria and became one of nuclear energy's most eloquent exponents.

But the devil is in the details. Fermi saw a problem as early as the Chicago days. In the book, Weinberg quotes him as saying, "It is not clear that the public will accept a source of energy that produces so much radioactivity or that might be subject to diversion of bomb material by terrorists." As in so many other cases, Fermi turns out to be right. Perhaps nuclear energy was developed too rapidly. Because of the pressing need for a nuclear navy, reactors became an article of commerce before engineers could examine in depth such issues as nuclear waste, reactor safety, fuel reprocessing, and the economics of energy production and use. Weinberg points out that the choice of the light-water reactor system was really driven by the naval reactor programs, and that other systems, and there are plenty of them, never had a chance. In their euphoria, reactor entrepreneurs forgot Fermi's warning. "During my years at ORNL," Weinberg says, "I paid too little attention to the waste problem. Designing and building reactors, not nuclear waste, was what turned me on . . . had I to do it over again, it would be to elevate waste disposal to the very top of ORNL's agenda."

When Weinberg became convinced that reactor safety was an issue of the greatest importance, that loss-of-coolant accidents were not unthinkable, he was punished by the nuclear advocates. In the book Weinberg quotes what, to me, is the most bizarre statement of the whole story. In a conversation about reactor safety, Chet Holifield, then chairman of the Congressional Joint Committee on Atomic Energy, told him, "Alvin, if you are concerned about the safety of reactors, then I think it might be time for you to leave nuclear energy." Soon after, Weinberg was fired from his job as director of ORNL. That was in 1972. In 1979 Three Mile Island fully justified Weinberg's concern, setting in motion events that led to much enhanced safety of U.S. reactors but also leading to cancellation of many reactor sales. No new reactor orders have been placed by U.S. utilities since then.

Did Weinberg acknowledge defeat? Not at all. From his position as director of the Institute for Energy Analysis at Oak Ridge Associated Universities, he redoubled his efforts to make nuclear energy a viable source of power. He initiated among the first government-funded studies of global warming caused by increased atmospheric levels of carbon dioxide from burning fossil fuels to produce electricity. He examined a new class of reactors, the so-called inherently safe reactors, whose safety does not depend on engineered systems but rather on processes based on laws of nature. His intellectual curiosity led him into arms control issues, high-level waste storage, and eventually to the nub of the question: Why are people afraid of nuclear energy? And, why are they so averse to certain very small risks?

Weinberg used his position at ORNL as a bully pulpit for nuclear energy.

There is much to read in this book for those who are interested in the history of ORNL. Buy the book and get the inside scoop on the X-10 pile (Graphite Reactor), the Aircraft Nuclear Propulsion program, the Materials Testing Reactor and its progeny, the thermal breeder, the Homogeneous Reactor Experiment, the Experimental Gas-Cooled Reactor, the Molten Salt Reactor Experiment, and other projects nuclear.

On the whole, Weinberg thinks nuclear energy has done reasonably well, progressing in "50 years . . . from a miraculous dream into a major source of electric energy." But he recognizes that there is a pause in its further development and that not much is likely to happen in the next several years. Weinberg is ever the optimist, especially when it comes to the ability of mankind to rise to the occasion. "To deny rebirth of nuclear energy is to deny human ingenuity and aspiration. This I cannot do. During my life I have witnessed extraordinary feats of human ingenuity. I believe that this struggling ingenuity will be equal to the task of creating the Second Nuclear Era." Whenever it comes, Weinberg's labors will be there to light the way.

Alex Zucker, now retired, was acting director of ORNL in 1988 and ORNL associate director for the Physical Sciences and later for the Reactor and Engineering Technologies for many years. He has taught courses at Roane State Community College. He is writing a book about scientific literacy.

Designing and building reactors, not nuclear waste, was what turned me on . . . had I to do it over again, it would be to elevate waste disposal to the very top of ORNL's agenda.

A Glimpse at Weinberg's Career

1915	Born in Chicago in 1915
1939	Received Ph.D. degree from the University of Chicago in mathematical biophysics
1942	Worked at the Metallurgical Laboratory at the University of Chicago
1946	Named director of ORNL's Physics Division
1948	Appointed research director at ORNL
1955	Named director of ORNL
1958	Weinberg and Nobel Laureate Eugene Wigner's classic *The Physical Theory of Neutron Chain Reactors* is published
1959	Elected president of the American Nuclear Society
1960	Began service on President's Science Advisory Committee
1965	Appointed vice president in the Union Carbide Corporation's Nuclear Division
1973	Became director of energy R&D in the White House
1975	Founded and became director of Institute for Energy Analysis at Oak Ridge Associated Universities (ORAU)
1985	Retired from ORAU and became ORAU distinguished fellow
1992	Named chairman of International Friendship Bell Committee

A Chat with Alvin Weinberg

In anticipation of Alvin Weinberg's 80th birthday in April 1995, Bill Cabage, editor of *Lab Notes*, and Carolyn Krause, editor of the *ORNL Review*, recently interviewed the former ORNL director (1955–73) in his home in Oak Ridge. Our edited interview with Weinberg follows.

Q: Emphasis on reduction of U.S. budget deficits may threaten the survival of many scientific programs and even some Department of Energy national laboratories. What is your view on this situation?

WEINBERG: Today's situation is analogous to the situation 50 years ago. The issue 50 years ago was what would be the future of the entity then known as Clinton Laboratories. What the Oak Ridge laboratory is for and where the money will come from have always been central issues.

Weinberg is author or coauthor of these books: *The Physical Theory of Neutron Chain Reactors*, *Reflections on Big Science*, *The Second Nuclear Era: A New Start for Nuclear Power*, *Continuing the Nuclear Dialogue*, *Strategic Defenses and Arms Control*, *Stability and Strategic Defenses*, *Nuclear Reactions: Science and Trans-Science*, and *The First Nuclear Era: The Life and Times of a Technological Fixer*.

Among the honors he received were the Atomic Energy Commission's E. O. Lawrence Memorial Award and its highest award, The Enrico Fermi Prize.

Famous Weinberg phrases: Big science, little science, first nuclear era, second nuclear era, trans-science, Faustian bargain, technological fix, burning the rocks and burning the seas.

Weinberg and Eugene Wigner stroll up the aisle of Oak Ridge High School after one of Weinberg's State of the Laboratory addresses.

It was an awful error on the part of the government to cancel the ANS.

Norris Bradbury, director of Los Alamos Scientific Laboratory for a long time, used to scare other lab directors by saying, "Suppose an earthquake destroyed your laboratory. Would the AEC or DOE decide to rebuild it?" The implication was that he wasn't sure.

The contract between the scientific establishment and the government is being reviewed again. In 1945 Vannevar Bush wrote a paper that set forth why science should be supported by society. That provided the underlying understanding for why these big laboratories and science are supported. Well, 50 years later, we seem to be reopening that question. The advantage today is that we have people very adept at exploiting the political process. Why should science be supported? Only the government can decide the proper role of science and the labs.

Q. What was your reaction to the decision to terminate the Advanced Neutron Source research reactor, which would have been built at ORNL to produce medical isotopes, test materials, and provide beams for neutron-scattering research?

WEINBERG: It was an awful error on the part of the government to cancel the ANS. A dreadful decision. The government is prepared to spend $30 billion on an international space station, but it won't spend one-tenth of that on something of central importance.

Q: Do you think scientists have lived in a golden era that may be ending?

WEINBERG: For 50 years, the contract between scientists and government has been firmly in place, and it has been very generous. We scientists were very lucky people. It is a much colder world today. Perhaps it will mean that scientific careers will revert to the way they were in the 1930s, some 60 years ago. In that time, scientists didn't have large sums of money. College professors were poor then. They lived a life of genteel poverty. It was a trade-off—you did something you enjoyed doing, but you had to pay by living a life of genteel poverty. I hope this does not happen. I hope people realize that science must be pursued and that government must have a dominant role in supporting it.

Q: Your mentor, Nobel Laureate Eugene Wigner, always seemed to be two steps ahead of everyone. Was that really so?

WEINBERG: Eugene Wigner was smarter than anyone else by a good deal. No one at the Laboratory was in the same intellectual class as Eugene Wigner. That was so evident during a scientific discussion. His intellectual power was phenomenal.

His aptitude as an engineer was remarkable. He would argue details of design for the Hanford plutonium-producing reactors, invoking common engineering principles. Yet he was not a trained engineer or physicist. He started out as a chemist. In his eulogy on Wigner (who died January 1, 1995), Frederick Seitz recalled that Wigner knew how to prepare every known inorganic chemical compound. Isn't that extraordinary?

Wigner attributes much of his excellence in science to having gone to the best high school in the world. It was a Lutheran high school in Budapest. His classmate and best friend, John von Neumann, was a genius like Wigner.

ORNL is wonderfully fortunate in having had this close interaction with a great genius. Even the people there who didn't know him are aware of Wigner's influence on the Laboratory. He had a tremendous influence on me.

Q: One-third of the DOE budget is devoted to environmental restoration. What is your position on the goal to remediate all hazardous sites even though many of them may pose no more of a health risk than areas where most people live and work?

WEINBERG: I think it's nonsense. We've gone crazy. I have argued at various times that one of the prices of nuclear energy is the commitment of certain pieces of real estate in perpetuity to nuclear activity, including waste disposal. This is not all that big a commitment because there are only 85 reactor sites and 50 other nuclear-related sites throughout the United States. That's the price we pay, and I'm prepared to pay that price. Not that these sites are not useful. They are.

Recently, Donna Cragle, director of the Center for Epidemiologic Research at Oak Ridge Associated Universities, led a study at the Savannah River Plant in South Carolina that found that long-term exposure to low-level radiation may increase workers' risk of leukemia. (The study found that workers exposed to higher doses had a higher rate of leukemia deaths than workers exposed to lower doses; however, the study did not find a significant increase in leukemia cases over the expected rate for the general population.) The study also showed that the Savannah River worker population had a lower risk of developing certain other cancers and a lower death rate than the national population. Overall, life expectancy is rather long for nuclear workers.

Q: Why do you think people worry so much about the hazards of nuclear power plants and hazardous waste sites when greater health risks are closer to home in the form of cigarettes, food, alcoholic beverages, and cars?

WEINBERG: You look around and Americans are fat. This is the fat generation. I think eating the wrong foods in large amounts is a more serious risk to health than smoking. Not everybody smokes, but everybody eats.

Q: In your book *The First Nuclear Era: The Life and Times of a Technological Fixer*, you come across as a man of integrity. You have spoken out on your beliefs, even when your views were, as we say today, politically incorrect. Should researchers at government laboratories speak out truthfully about their findings and concerns even if their careers could be jeopardized?

WEINBERG: Karl Morgan, once director of ORNL's Health Physics Division, disagreed with the way reactor development was going. He thought the thorium cycle (breeding uranium-233 in a reactor by neutron bombardment of thorium) should be pursued because the waste disposal problem was simpler to handle. We had some difficult times there. The problem that Laboratory management always faced was that our survival depended on our ability to get money, mostly from the Atomic Energy Commission's Reactor Division under Milton Shaw. Karl Morgan's dissenting views on reactors placed ORNL in an awkward position, but Karl's career didn't suffer. He's going strong even though he's close to 90. Milton Shaw had a singleness of purpose. In many ways I admired him, and in many ways he drove me nutty. He had a single-minded commitment to do what he was told to do, which was to get the Clinch River Breeder Reactor built. My views were different from his. I think the Commission decided that my views were out of touch with the way the nuclear industry was actually going.

I hope people realize that science must be pursued and that government must have a dominant role in supporting it.

Q: Which views were these?

WEINBERG: I wasn't a great believer in the liquid metal fast breeder reactor (which was designed to breed plutonium using neutrons from the plutonium fuel). I pushed for the molten salt breeder reactor, which used the thorium cycle. Also, I was outspoken on how much effort should go into developing safety systems for reactors.

Q: In your book, you mentioned that Rep. Chet Holifield, chairman of the congressional Joint Committee on Atomic Energy, said, "Alvin, if you are concerned about the safety of reactors, then I think it might be time for you to leave nuclear energy."

WEINBERG: I did include that anecdote in my book, but I'm not quite proud that I'd done that because Chet Holifield was a remarkable man. He, perhaps more than any other person, was responsible for the government spending billions and billions of dollars on nuclear energy. It was kind of odd. Toward the end, he and I did disagree in 1970 when the establishment of national environmental laboratories was proposed. I had worked with senators Howard Baker and Edmund Muskie on this issue, and we advocated that ORNL become an environmental laboratory. That really caused Chet Holifield to blow his stack.

I'm pleased that we came up with this idea of a solar energy national laboratory.

Q: Speaking of national environmental labs, you wrote in your book that you proposed the idea for a solar energy national lab, which became the Solar Energy Research Institute, or SERI, which has since been renamed the National Renewable Energy Laboratory. Are you in favor of making more labs single-subject labs?

WEINBERG: Not necessarily. I guess I feel that the establishment of SERI was the one thing I was really proud of in that year (1974) I spent in Washington (as director of the Energy Research and Development Office of the Federal Energy Administration). We were to have a think tank in Washington, but no one told us what to think about. I'm pleased that we came up with this idea of a solar energy national laboratory. Most people are unaware of where the idea for that got started.

What the focus of the national labs ought to be for the future is very difficult for me to say. I think a big environmental component is inevitable. I still have this notion that nuclear energy will reemerge. Although we spent 50 years and an awful lot of money on the development of nuclear energy, I don't see the development as completed. If I had my druthers, I would say, "Let's take out a clean sheet of paper and let's design a new category of reactor that avoids all difficulties and is inherently safe."

Q: Do you think that nuclear energy is less popular in the United States than in France and Japan because there is more reverence for human life in this country? Does this reverence make us overly concerned about health risks of environmental agents?

WEINBERG: I don't think so, the main thing is that we have enormous amounts of coal. It has always been problematic whether nuclear energy can compete with coal.

Q: But someday we'll run out of the coal.

WEINBERG: Yes, someday we'll run out of the coal. That's when many of us say a second nuclear era may begin. But we don't really know when.

In the meantime, the problem with coal is that burning it produces carbon dioxide, which can intensify the greenhouse effect and may produce undesirable climate changes. I was the first to alert the Energy Research and Development Administration, AEC's successor, to the carbon dioxide question. The head of ERDA then established a carbon dioxide effects office in 1975. ERDA gave the new Institute for Energy Analysis that I had established in Oak Ridge the responsibility of assessing the impacts of increased atmospheric concentrations of carbon dioxide. From 1976 to 1984, IEA became the nation's center for studies of the carbon dioxide issue.

Q: Do you think the United States will ever be energy independent?

WEINBERG: It depends on the time scale you are talking about. How long will the oil and gas last? 100 years? 200 years? In a sense the question answers itself. When I worked on Project Independence in 1975 under AEC Chairman Dixy Lee Ray, the goal was that we would be energy independent by 1980. It was utter nonsense.

The question is, is energy independence all that important? When I was in Washington it was of central concern. It is no longer regarded as a central concern except that it contributes a lot to our trade imbalance.

Weinberg shows the Oak Ridge Research Reactor control panel to King Hussein of Jordan.

Weinberg points out a feature of the Oak Ridge Research Reactor to Senator John Kennedy (left of Weinberg) and Sen. Albert Gore, Sr., and Jackie Kennedy. Looking on at far left is Sam Hurt.

Weinberg shows the controls of ORNL's Molten Salt Reactor to Glenn Seaborg, Nobel Prize winner, discoverer of plutonium, and once a chairman of the Atomic Energy Commission. Seaborg was at the controls October 8, 1968, when the reactor started its successful operation using uranium-233 as a fuel. Weinberg called this reactor ORNL's greatest technical achievement.

Weinberg prepares to give his State of the Laboratory address in 1971 at Oak Ridge High School's auditorium.

My contribution to the philosophy of scientific administration is probably the most important and original thing that I did in my life.

Q: Dixy Lee Ray claimed in her autobiography *Is It True What They Say about Dixy?* (by Louis R. Guzzo) that she saved the Laboratory back in 1972. Is that a realistic claim?

WEINBERG: Let me read to you what she said in her book: "One of the notions he (Milton Shaw) had was his stated desire to destroy the Oak Ridge National Laboratory. I never really knew exactly why but I was equally determined that that fine American institution should live forever. At one time he (Milton Shaw) could have accomplished his goal, because he had Congressman Holifield on his side and both of them detested my old friend, Dr. Alvin Weinberg, who ran the Oak Ridge lab. To this day I don't understand the Holifield-Shaw dislike of Oak Ridge, but I had to believe it had no place in the Holifield nuclear empire."

So she fired Milton Shaw. Her claim that he was out to destroy the Lab is not realistic because the Lab is a big place. Shaw was out to get me fired, and I did get fired. But, in looking back, I think I had outlived my usefulness at Oak Ridge National Laboratory. I left at an appropriate time. I had been director and research director for 26 years, which is an awfully long time.

Q: What contributions are you most proud of as a scientist, scientific administrator, and writer and thinker?

WEINBERG: My career as a practicing scientist was really quite short. But the formulation and codification of the theory of nuclear reactors culminated in the book I coauthored with Wigner called *The Physical Theory of Nuclear Chain Reactors*. That's probably my most important contribution to science.

I'm known as the person who proposed to Admiral Rickover that the *Nautilus* submarine be powered by a pressurized-water reactor. We were working on the Materials Testing Reactor at the time, so it was easy enough for me to say, "Take the MTR and put it under pressure and put it in your submarine." (After that, the pressurized-water reactor was used in many commercial nuclear power plants throughout the world.)

As a scientific administrator, I am proud that under my leadership, ORNL became a very viable entity.

But my contribution to what I call the philosophy of scientific administration is probably the most important and original thing that I did in my life. The philosophy of science is concerned with how you decide if a scientific finding is correct or true. You have to establish criteria to determine if the finding or theory is valid. Validity is a fundamental problem in the philosophy of science, but the fundamental problem in the philosophy of scientific administration is the question of value. Two scientific activities are equally valid if they achieve results that are true. Now, how do you decide which activity is more valuable? The question of value is the basic question that the scientific administrator asks so that decisions can be made about funding priorities. Criteria for measuring value of competing scientific ventures that I set forth in a series of papers have been accepted by people in the National Science Foundation.

Another thing I've done is to promote the Friendship Bell now in Oak Ridge as a way to live with the bomb. (Weinberg showed us his miniature copy of the replica of the Hiroshima *bonshoo* friendship bell now in Oak Ridge; he chaired the International Friendship Bell Committee, which raised money for the project.) It's pretty controversial, and I'm prepared to live with the controversy.

In my most recent book, I wrote about what I call the sanctification of Hiroshima. People ask, 'Was the Hiroshima bomb justified?' Well, it was justified on two accounts. I believe that Hiroshima really did end World War II, that it saved many lives. I was a signer of several petitions urging that the bomb not be dropped on Japan, just demonstrated by blowing up a tower in the desert. I've come to decide that dropping the bomb actually saved lives.

The other justification is that we will have to live with bombs for the rest of time. Is there some way we can invest in the bomb some "aura of forbiddenness" so people won't use it again? We should look upon an event such as Hiroshima as one to be remembered 1000 years from now because it killed a lot of people like the Holocaust in Germany, which is passing into the Jewish tradition as a religious tradition. This bronze bell, which was made by the same bellmaker who cast the original Hiroshima bell, will last 1000 years. Years from now, people seeing the Oak Ridge bell will have forgotten the controversy and remember the lesson of Hiroshima—we have to live with the bomb, but we must avoid using it. Through sanctification of Hiroshima, we will establish a tradition of non-use.

Q: You have been concerned with the proliferation of scientific information. We are even more aware of it on the Internet, which offers researchers a "virtual lab" in which they can communicate with each other. What is your view of new trends in communicating scientific information?

WEINBERG: I was on the President's Science Advisory Committee from 1959 to 1961. The panel I chaired produced the report *Science, Government, and Information*. I acquired a reputation for my leadership in dealing with burgeoning scientific information.

As for the Internet, I tend to have profound doubts about the value of this communication advance to science. I wonder if, in an era of the Internet, we can have somebody like Eugene Wigner. Eugene Wigner's genius manifested itself in his ability to concentrate for a long time on a single idea. If you are constantly beset by outside ideas, can you really get to the true heart of the matter? It's a very different way of doing science. Things have changed a lot in 50 years. ornl

Weinberg chats with Dixy Lee Ray, former chairman of the Atomic Energy Commission and later governor of Washington. Weinberg introduced her to an ORNL audience in 1992 before she gave a talk on environmental research and regulation.

Doug Lowndes

Tuan Vo-Dinh

Phil Thompson

Steve Lindberg

Lockheed Martin Energy Systems has conferred one of its highest honors, the rank of corporate fellow, on Oak Ridge National Laboratory scientists **Douglas H. Lowndes** and **Tuan Vo-Dinh** and the Oak Ridge K-25 Site scientist **Michael J. Stephenson**. In announcing the selections, Martin Marietta Energy Systems President **Gordon Fee** said such recognition is accorded on an extremely limited basis to individuals whose contributions have been both significant and continually high over a number of years.

Alvin Trivelpiece has been named the Outstanding Engineer of 1995 by region 3 of the Institute of Electrical and Electronic Engineers, Inc.

Arvid E. Pasto has been named director of the High Temperature Materials Laboratory in ORNL's Metals and Ceramics Division.

Michael Kuliasha has been appointed director of ORNL's Computational Physics and Engineering Division.

Steve Lindberg and **Roger Clapp** assisted in the production of a special 30-minute episode of the television series *The Heartland Series* entitled *From the Mountains to the Ocean.* This production, which traces the Little River from its headwaters in the Great Smoky Mountains National Park to the Gulf of Mexico, was awarded an Emmy for the Mid-South Region by the Academy for Television Arts and Sciences.

Philip B. Thompson has been named director of Central Engineering Services for Lockheed Martin Energy Systems. Thompson, who has served as engineering manager for the Advanced Neutron Source Project since 1989, succeeds **Don Cannon**, who has retired.

Tony Schaffhauser has been appointed director of ORNL's Energy Efficiency and Renewable Energy Program, succeeding **Roger Carlsmith,** who has retired.

Steven E. Lindberg will chair the 1996 International Conference on Mercury as a Global Pollutant to be held in Hamburg, Germany.

Jane G. Mural has been selected to participate in the Antarctic Biology Training Course sponsored by the National Science Foundation.

Robert V. O'Neill has received the Distinguished Statistical Ecologist Award from the International Association for Ecology.

Don Trundle has received the 1995 Professional Leadership Award from region 3 of the Institute of Electrical and Electronic Engineers, Inc.

Andrew F. Diefendorf will serve as the president-elect of the Tennessee Section of the American Institute of Professional Geologists in 1995 and will assume the role of president in 1996.

Pat A. Scarbrough was elected chair of the Southeast Regional ARC/INFO User's Group for 1995.

Po-Yung Lu has been presented the Tillmanns-Skolnick Award by the Chemical Health and Safety Division of the American Chemical Society.

During the latest ORNL Director's Awards ceremony, the **Metals and Ceramics Division** received the ORNL Award of Excellence in Research and Development; the **Health Division** received the ORNL Award of Excellence in Operations and Support; and the **Research Reactors Division** received the ORNL Award for Excellence in Environment, Safety, and Health.

Rufus Ritchie, a retired senior corporate fellow, was honored with a symposium covering the major themes of research in which he has been involved.

Noel Nachtigal has been honored by the Society for Industrial and Applied Mathematics for coauthoring a paper designated as one of the two most outstanding papers published on linear algebra between 1991 and 1993.

Charles A. Flanagan has been presented the Distinguished Career Award by the Fusion Power Associates Board of Directors.

Nancy L. Gray has been named ORNL Protocol Officer.

Joe Culver has been appointed manager of ORNL's Public Affairs Office.

Jack Cook, formerly of ORNL's Engineering Technology Division, has been named co-director of the Centers for Manufacturing Technology at the Oak Ridge Y-12 Plant, replacing Dave Bartine, who retired.

Tony Schaffhauser

C. J. Sparks

Philip Maziasz

Marshall Adams

Laura Toran has been appointed to the American Geophysical Union's Ground Water Committee.

A poster presentation titled "Laboratory Evaluation of the In Situ Chemical Oxidation of Contaminated Soils," prepared by **D. D. Gates, R. L. Siegrist,** and **S. R. Cline,** received a first-place award in the R&D category at the Water Environment Federation's annual conference.

John B. Bates' research on rechargeable Thin-Film Lithium Batteries was judged to be a "Significant Implication for the Department of Energy Related Technologies Accomplishment" in DOE's annual Materials Science Research Competition.

Robert Siegrist has been named chair of the Task Force on Contaminated Sites under the International Committee of the Water Environment Federation.

Nic Korte has been appointed to the editorial review board of the journal *Groundwater Monitoring and Remediation.*

Cullie J. Sparks has been elected a fellow of the American Physical Society.

James R. Sand, Edward A. Vineyard, and **Van D. Baxter** have received the 1993 American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc., (ASHRAE) Symposium Paper Award for their paper "Laboratory Evaluation of an Ozone-Safe Nonazeotropic Refrigerant Mixture in a Lorenz Meutzner Refrigerator Freezer Design."

Two ORNL entries won Second-in-Class awards in the annual International Metallographic Competition sponsored by ASM International and the International Metallographic Society. These were an entry by **J. Sipf, Stan David, Lynn Boatner, Mary Jane Gardner,** and **A. Baldwin** entitled "Development of Microstructures in Single Crystal Stainless Steel Spot Welds" and another entry by **Stan David, John Vitek, Lynn Boatner, Robert Steele,** and **A. Baldwin** entitled "Dendritic Growth in a Nickel-Based Superalloy."

Richard P. Woychik has been named head of the Mammalian Genetics and Developmental Biology Section in ORNL's Biology Division.

Laura Toran has been appointed to the American Geophysical Union's (AGU) Ground Water Committee.

Larry Barnthouse and **Marvin Poutsma** have been elected fellows of the American Association for the Advancement of Science.

Linda L. Horton has been appointed associate director of the Metals and Ceramics Division.

Johnnie B. Cannon has been appointed director of the Office of Planning and Management.

Philip J. Maziasz has been named a fellow by the American Society of Metals International.

S. Marshall Adams has been awarded the annual prize from the Association of American publishers for the outstanding book of the year in biological sciences. Adams served as co-editor of the book *Biodiversity of the Southeastern United States: Aquatic Communities.*

Carolyn Krause has been named an associate fellow of the international Society for Technical Communication.

Theodore M. Besmann has been elected vice president of corporate and external affairs for the American Ceramic Society.

Michael J. Saltmarsh has been named director of the Fusion Energy Division and the fusion program at ORNL.

R. J. Michael Fry has been selected as the 32nd Failla Memorial Lecturer by the Radiation Research Society.

Tommy Phelps received a Certificate of Appreciation from the Department of Energy's Office of Energy Research for his work in determining the origins of microbial communities in the deep subsurface.

Max Morris has been elected editor of *Technometrics.*

ORNL's **Energy Efficiency and Renewable Energy Program** has been included in Renew America's *Environmental Success Index*, a data base communities can use to learn about successful environmental programs.

Environmentally Safe Bullets Developed

Rick Lowden shoots an ORNL-made lead-free environmentally safe bullet at a target on a local private shooting range.

The Laboratory has developed lead-free, environmentally safe bullets that may keep new shooting ranges from becoming hazardous waste sites.

Lead shot and bullets may present a double threat to ducks and geese. They can be killed by ammunition from hunters' guns during waterfowl season. Or, if they eat near recreational shooting ranges tainted with lead from bullets, they may die from lead poisoning. Lead bullets are not environmentally safe.

ORNL has found a solution that may prevent this environmental problem from getting worse. The Laboratory has developed lead-free, environmentally safe bullets that may keep new shooting ranges from becoming hazardous waste sites.

The new bullets, which are being developed to replace lead bullets used for training and security at DOE's production and research sites, are made of mixtures of tungsten and other metals or alloys. The composite-metal bullets are called environmentally safe projectiles, or ESP™.

DOE is committed to reducing environmental pollution from lead ammunition. Each year DOE expends approximately 17 million rounds of small arms ammunition, depositing more than 300,000 pounds of lead and copper on DOE ranges. DOE estimates that for each dollar spent on ammunition, $100 is spent for cleanup and reclamation of shooting ranges contaminated with lead.

Powell River Laboratories, Inc., of Oak Ridge has been granted the right to manufacture ESP™ bullets in a licensing agreement with Lockheed Martin Energy Systems, Inc., which manages ORNL for DOE. ORNL is working with Delta Defense, Inc., in Alexandria, Virginia, in a cooperative research and development agreement to test the bullets to ensure that they meet all appropriate standards.

Tens of billions of lead bullets are fired each year in the United States. It is estimated that 400 to 600 tons of lead per day are used to produce bullets.

"The grounds of some of the nation's 8000 public and private recreational shooting ranges are contaminated with hundreds of tons of lead from bullets," says Rick Lowden, chief developer of the ESP™ bullet and a metallurgist in ORNL's Metals and Ceramics Division. "The most contaminated ranges pose a threat to humans and wildlife. Duck and geese have been found poisoned in lakes polluted by lead shot. Shooting ranges could be declared hazardous waste sites by the Environmental Protection Agency when they are shut down, and it will cost millions of dollars to clean them up.

"DOE recognizes the contamination problem that exists at its own shooting ranges, which are used by security personnel. So it plans to switch from lead bullets to ESP™ bullets for training and security."

At this time, each ESP™ bullet costs about five times more than a lead bullet—a quarter instead of a nickel per bullet. However, Lowden says, the ORNL bullet offers several advantages over lead bullets. It has been proven to be nontoxic. The ESP™ material is completely recyclable. In addition, the bullets can be made to be both lethal and "frangible"—that is, they will break apart upon impact, minimizing property damage and the risk of accidents at facilities containing hazardous materials.

The ORNL metallurgist and his colleagues started on this project in early 1993 when ORNL was asked by DOE to evaluate a plastic-metal bullet developed by Delta Defense for training purposes. A group led by Tom McCoig in ORNL's Safeguards and Security Division found the bullets wanting. "The plastic-metal bullets were half as dense as lead bullets," Lowden says, "so they did not function as well as lead bullets from the security guards' guns."

McCoig and Joe Dooley of the Special Projects Office of Energy Systems met with Lowden and asked him if he could make ceramic bullets to replace lead bullets. Lowden replied that ceramic bullets would be too light in weight and too hard to adequately replace lead bullets. He proposed using powder metallurgy techniques to make a metal-composite bullet that has the same weight, density, and mechanical properties as a lead bullet.

"We set out to make a metal-composite bullet with the same density as a lead bullet. We mixed hard, heavy, high-density metals like tungsten with soft, low-density metals or alloys and found compositions that worked.

"We used a powder metallurgy technique in which we press powders of the metals into a solid cylindrical core at room temperature in a cylindrical die. Then we squash them into the shape of a bullet using a technique called swaging. Major manufacturers would have to make only minor changes in their equipment to add the powder metallurgy step to mass produce the metal-composite bullets."

ORNL's Industrial Hygiene Department checked the hazard ratings for the individual metals and alloys in the ESP™ material. It determined that the metal composites for the bullets are environmentally safe. "By changing the composition, shape, and size of the bullet and the amount of heat treatment," Lowden says, "we can control its penetration and optimize its performance for any specific use. We can meet DOE's request to make bullets that don't ricochet off indoor range targets."

Norm Vaughn shapes a lead-free bullet using commercially available equipment.

DOE plans to switch from lead bullets to ORNL's lead-free bullets for training and security.

"For the future," Lowden says, "We hope to learn how to make fine shot for skeet shooting using metal composites." In 1986 lead was phased out as a material for shot; steel shot is now being used, and bismuth-tin may be approved as a replacement for steel. "We also hope to learn how to manufacture our bullets using casting instead of swaging to give industry another production option."

Lowden has been assisted in the laboratory by Norman Vaughn, a co-op student at Tennessee Technological University in Cookeville. The development and testing of the bullets at ORNL is supported by DOE's Office of Safeguards and Security.

Ducks may not feel any safer, but they could be now that Americans are no longer ducking the issue of the environmental harm posed by bullets.

Self-Lubricating Coating for Engine Parts Developed

A self-lubricating composite coating that could make engine and other moving parts last longer has been developed at ORNL.

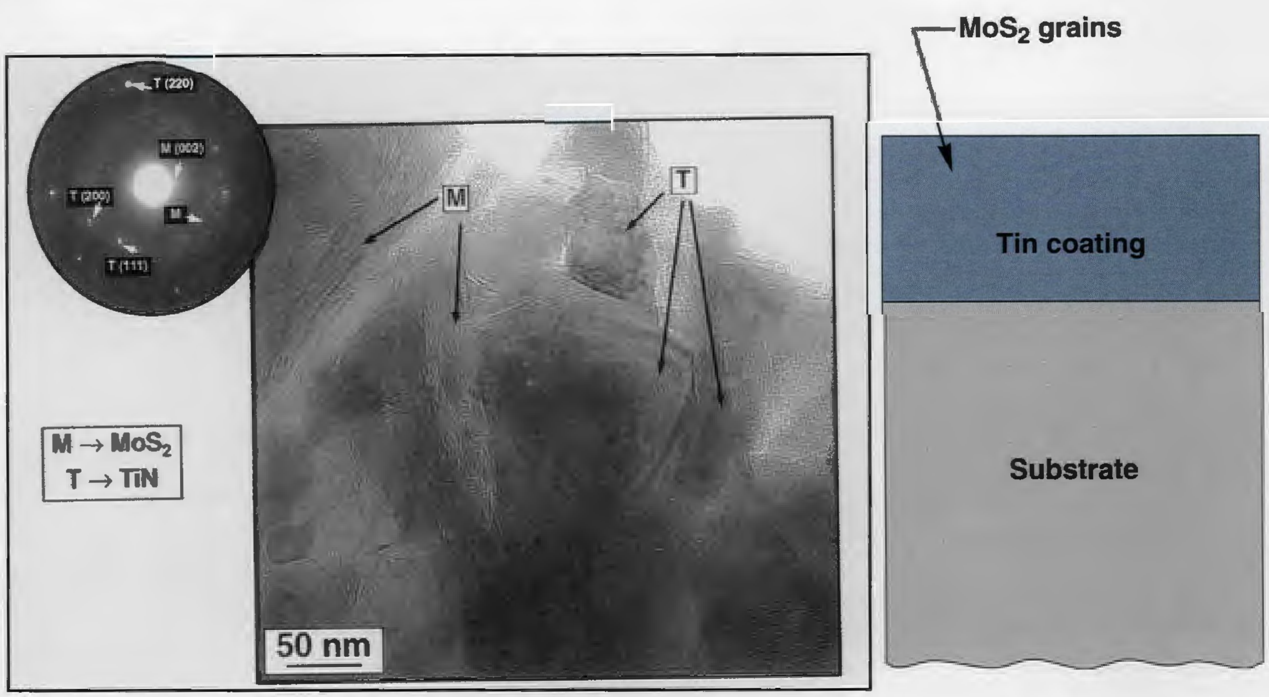
"Oil-based lubricants break down at high temperatures," says Ted Besmann, a scientist in ORNL's Metals and Ceramics Division and one of the developers of the new coating. "As a result, components of engines that are run at high temperatures to improve their fuel-use efficiency tend to wear rapidly and require replacement. Our composite coating should help engine parts last longer because it incorporates a solid lubricant that makes them slide more easily."

Our composite coating should help engine parts last longer.

The self-lubricating coating may be used for high-speed bearings, piston rings, cylinder linings, valve guides, and other parts in jet and internal combustion engines. Coated samples from ORNL are now being tested at the General Electric Company's Aircraft Engines Division in Cincinnati, Ohio.

Metals and Ceramics Division staff members Woo Lee and Peter Blau, postdoctoral scientist Y. Bae, and Besmann developed a composite coating made of titanium nitride, a hard, wear-resistant material at high temperatures, and of molybdenum sulfide, a solid lubricant. Electron micrographs of the composite coating show that separate grains of the solid lubricant are dispersed near the surface of the titanium nitride coating.

To make the coating, the researchers at ORNL used chemical vapor deposition (CVD). In this process, vapors or gases are allowed to flow over a heated solid surface (called a substrate), react, and form a solid coating.



Electron micrograph and drawing show how molybdenum sulfide lubricant is incorporated in a titanium nitride structure, making a self-lubricating, wear-resistant coating for engine or other parts in sliding contact.

The researchers simultaneously deposited the desired materials on substrates such as silicon and graphite. Then they deposited the composite coating on a titanium alloy used for parts in engines.

"To make the coating for a titanium alloy substrate," Besmann says, "we flowed several gases at a temperature of 800°C and low pressure into a reactor containing the heated substrate. To get the best coating composition, we varied the composition of the gases, which included molybdenum hexafluoride, hydrogen sulfide, ammonia, and argon, that carried the titanium organometallic vapor into the reactor."

Researchers elsewhere have used CVD, sputtering, or plasma spraying to deposit films of titanium nitride and of molybdenum sulfide. But the ORNL group is the first to co-deposit the two materials to form a composite coating.

"Solid lubricating films of molybdenum sulfide have been deposited on moving parts, but the lubricant tends to be worn away quickly," Besmann says. "Our composite coating increases the sliding life of the molybdenum sulfide lubricant by incorporating it in a hard material."

Besmann proposed that CVD could be used to develop a low-wear, low-friction composite coating. The development of the coating was carried out primarily by Bae and Lee.

Other division members who contributed to the work are Blau and Charles Yust, who measured the coating's friction and wear characteristics; Karren More, who took electron micrographs of the experimental coatings to reveal their structure; and David Braski, who analyzed the coating structure using Auger electron spectroscopy.

"Through the analytical work," Besmann says, "we are determining which coating structures and compositions are lowest in wear and friction. We have found that the friction of our best coatings containing titanium nitride and molybdenum sulfide is three times lower than a titanium nitride coating alone."

The coating development was supported by the Division of Advanced Energy Systems Projects in the Department of Energy's Office of Basic Energy Sciences.

ORNL Software for Salt Solutions Saves Time and Money

Highway maintenance crews battle icy roads by salting them. But how much salt should be sprinkled on the ice to melt it as quickly as possible? Moonis Ally of ORNL can provide the answer in a few minutes using a personal computer program he helped to write.

"If you add just the right amount of salt," Ally says, "the freezing point of the ice will be lowered as much as possible, and the ice will melt faster. But if you add too much salt, compounds called hydrates will form, raising the freezing point. The salt then becomes a burden instead of a benefit. In fact, too much salt not only wastes taxpayers' money but also can be toxic to roadside vegetation."

The result is a labor-saving software package that rapidly and inexpensively predicts the properties of various water-based salt solutions.

To develop the software, Ally, a researcher in ORNL's Chemical Technology Division, and retired consultant Jerry Braunstein developed the theory and algorithm, a step-by-step method for arriving at answers using available information; Andrea Sjoreen, a programmer in ORNL's Computational Physics and Engineering Division, converted the algorithm into a computer program. The result is a labor-saving software package that rapidly and inexpensively predicts the properties of various water-based salt solutions. Called Aqueous Electrolytes (AE), the software eliminates the need for researchers to measure such properties in the laboratory—a time-consuming, laborious, and expensive process.

"In only one day," Ally says, "AE can predict the thermodynamic properties of mixtures of different salts in water that would take chemists several months or even a year to obtain in the laboratory. These properties include boiling and freezing points, density, and vapor pressure as a function of solution temperature, salt concentration, and salt composition.

"In addition, our software can predict the properties of aqueous electrolytes that have higher salt concentrations than those treated by competitive programs. Also, it can be used on

The patented software already has had several important applications at ORNL in waste treatment and energy conservation research.

ORNL researcher Moonis Ally (left) and consultant Jerry Braunstein developed a computer program that saves time and money by analyzing salt solutions in minutes instead of days.

difficult problems such as predicting when a salt solution will form solid crystals."

The patented software already has had several important applications at ORNL in waste treatment and energy conservation research.

For example, results obtained by the new software have confirmed that ORNL has selected the correct design for an evaporator. This device must supply enough heat to remove water from low-level liquid radioactive wastes in ORNL's eight Melton Valley storage tanks. The evaporator, which was ordered in October 1994 and will be installed in May 1995, will further concentrate these wastes to make space for recently generated waste.

"The wastes are salt solutions, and their boiling points depend on the salt concentration," Ally says. "If a solution is 30% salt, its boiling point is higher than that of a solution that is 10% salt. Salt concentration also affects freezing points."

"Using the software, Ally also helped us determine whether the liquid wastes might freeze in the aboveground transfer lines if the evaporator is run in the winter," says Vic Fowler, a contractor with ORNL's Chemical Technology Division. "He found that the wastes will not freeze in winter, so costly heating equipment is not needed."

In another example at ORNL, a proposal was made to use a wiped film evaporator to evaporate water from some hazardous wastes containing zinc bromide that are stored in several ORNL buildings. But before a final decision was made on treating the wastes, a decision was made to determine the thermodynamic properties of the waste solution.

"It would have taken too much time to get the answers in the laboratory," Ally says, "so we were asked to determine the properties of the waste solution using AE. We did it in 15 minutes. We found that boiling the wastes would require a higher temperature than the proposed evaporator could achieve. So that method was abandoned, and an alternative method was later used."

Ally also has used AE to help ORNL's Energy Division screen salt solutions in the search for the best refrigerants for absorption heaters and chillers—refrigerators under development that do not require energy-hungry compressors. Such refrigerants remove heat from the refrigerator cabinet at lower temperatures and reject it to the outside at higher temperatures. To make such machines more energy efficient, developers are trying to identify aqueous salt mixtures that have even better heat-transfer properties than the more fully understood mixtures of lithium bromide and water and of ammonia and water. Several potential salt combinations have been identified by AE for advanced absorption machines.

ORNL Researchers Test Trash-Based Fuel Cubes

The paper you throw away at ORNL may someday be used to heat your office, reducing the need for coal and landfill space. ORNL researchers have begun work on a pilot project to demonstrate the feasibility of burning fuel cubes made of shredded wastes collected from DOE facilities in Oak Ridge.

The pilot project will allow testing of air emissions and ash from various fuels and fuel mixtures to determine if refuse-derived fuel (RDF) is suitable for use in steam plant boilers. The project will proceed with a full-scale ORNL steam plant demonstration if the pilot demonstration identifies no air emission or ash problems as a result of burning the RDF fuels and fuel mixtures.

Tens of millions of pounds of sanitary waste are produced on the Oak Ridge Reservation annually. A successful RDF program would reduce both the amount of waste placed in landfills and the amount of coal burned at the ORNL steam plant, with possible savings of more than $300,000 per year.

The Oak Ridge project may be a model for other DOE facilities. Municipalities across the country already are implementing similar programs to comply with new Environmental Protection Agency and state mandates to reduce the volume of waste placed in landfills.

World Record Set for System Size in Molecular Dynamics

A team of researchers from ORNL, Brookhaven National Laboratory (BNL), and the State University of New York (SUNY) at Stony Brook have set a new world record for system size in molecular dynamics, using the 1024-node Intel Paragon XP/S 150 supercomputer at ORNL.

Molecular dynamics, a field of study that models the interactions among atoms in a chemical, biological, or solid-state system, is a cornerstone of applications ranging from the study of DNA-protein interactions to the design of new materials.

A new record has been set using the Intel Paragon supercomputer at ORNL.

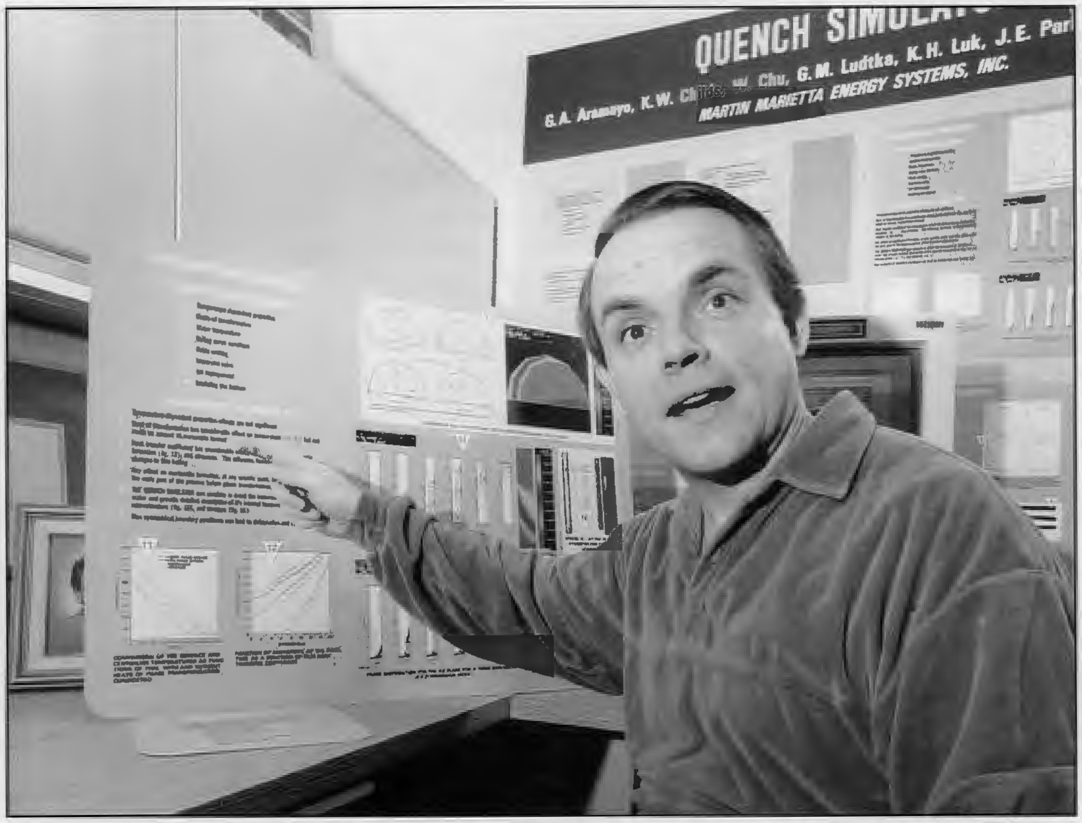
In two record-breaking runs, members of the Partnership in Computational Sciences (PICS) consortium performed molecular dynamics simulations for systems of 200 million and 400 million particles, with each simulation step taking 80 and 160 seconds, respectively. These results far exceed recently reported simulations of 10 million particles on the 512-node Intel Touchstone Delta system at the California Institute of Technology at Pasadena and 180 million particles on a 1024-node Thinking Machine CM-5.

"This breakthrough is yet another example of the High Performance Computing and Communications program bearing fruit for U.S. science and industry," said Ken Kliewer, director of the Center for Computational Sciences (CCS) at Oak Ridge. "It demonstrates the ability of key molecular dynamics algorithms to scale up to the large sizes needed for biologically interesting problems. This achievement should lead to major breakthroughs in molecular biology by permitting the simulation of realistic systems over significant time scales."

The computer code used to achieve this feat was developed by Osman Yasar of ORNL's CCS, Robert B. Marr and Ronald F. Peierls of BNL, and Yuefan Deng and R. Alan McCoy of SUNY. All three institutions are members of the PICS consortium, which uses the large Intel Paragon system at ORNL.—*Jennifer Ball*

RE: R&D Updates

Lawrence Award for Gerard Ludtka



Gerard Ludtka, an ORNL researcher who recently won one of DOE's E. O. Lawrence Memorial Awards, explains results from a computer simulation using the Quench Simulator code he developed.

Gerard Ludtka, a metallurgist in ORNL's Metals and Ceramics Division, received the Department of Energy's E. O. Lawrence Memorial Award in 1995. He led a multidisciplinary team that developed a computer code for weapons components production that is now being adapted for use in the automobile and steel industries.

Ludtka was cited for "significant contributions to materials technology through the development and implementation of superplastic forming of uranium alloys and through development of a method to predict the effects of quenching on microstructure and residual stresses." Ludtka is one of seven winners of the E. O. Lawrence Award, given out to researchers whose work applies to the development, use, or control of nuclear energy. It is named after E. O. Lawrence, inventor of the cyclotron.

While at the Y-12 Plant from 1982 to 1991, Ludtka developed a process that revolutionized the manufacture of hemispherical weapons components. He recognized that uranium alloys could be "superplastic" at high temperatures—that is, flat sheets of the materials could be shaped into half spheres and other geometric shapes for weapons components.

After characterizing the superplastic behavior of uranium alloys, Ludtka developed simple superplastic forming equipment that was scaled up for component production runs. The equipment fabricated the parts much closer to the desired final shapes, significantly reducing the amount of waste material and cost of manufacturing.

Ludtka also developed a computer simulation code to predict the effects of component shape and rapid cooling, or quenching, on the microstructure and internal stresses produced in heat-treated uranium weapons parts. The parts are heated and then rapidly cooled to room temperature with cold water or oil to strengthen them and to achieve the desired internal structure and other properties. But the cooling rate must be right for a given shape to make the desired product, or cracking will occur.

Ludtka's Quench Simulator code predicts the cooling rate that will produce a heat-treated component with the best possible features. Use of this code eliminates the need for trial-and-error experiments in part design, resulting in significant savings.

The Quench Simulator code is now being applied to nonmilitary tasks, such as helping the automobile and steel industries. Ludtka, now a staff researcher in the Materials Modeling Process Group of ORNL's Metals and Ceramics Division, is a principal investigator for a three-year, $20-million cooperative research and development agreement (CRADA) that is based on the success of the Quench Simulator code. CRADA participants include DOE and four of its national laboratories, the National Center for Manufacturing Sciences, General Motors, Ford Motor Company, and Torrington Bearing Company.

For the CRADA, Oak Ridge, Lawrence Livermore, Los Alamos, and Sandia national laboratories are producing customized software based on concepts used in the development of the Quench Simulator code. For the automobile industry, the software will be used to improve the efficiency of design of gears for transmission systems. When gears are heat-treated to increase their strength, their volume will increase, affecting gear tooth size and shape. The software will predict the starting geometry that will give the desired gear design and properties.

This CRADA is also developing software to predict the effects of trace impurities on the heat treatment of recycled steel. Recycled steel from old cars is used to make new cars. But the steel from car parts may have impurities such as copper from wire for electric circuits. The software will predict the quality of the recycled steel product based on its impurities and manufacturing cycle.

Quantitative Leap: Dedication of New Computer and User Center

The latest quantitative leap at ORNL provided a reason to jump for joy. A new parallel computer now being used at ORNL has over four times the peak computing power of its predecessor of the same type and, as of April 1995, was the world's fastest computer. This was one of two high-performance computing developments celebrated at the Laboratory on April 21.

The other was the opening of ORNL's new computer-based facility for users from industry. Joining in were distinguished guests representing Intel, the Department of Energy, other agencies of the federal government, the state of Tennessee, U.S. industry, ORNL, Lockheed Martin Energy Systems management, and users at ORNL's Center for Computational Sciences (CCS), one of two DOE High Performance Computing Research Centers.

The first development was the completion and installation of the Intel Paragon XP/S 150, which has 1024 MP-nodes (two computer processors and one processor for message passing per node), or a total of 3096 processors. This machine passed acceptance tests and was made available to CCS users January 20, 1995. It is the fourth in a series of massively parallel machines developed for ORNL by Intel. The other Intel Paragon machines are the XP/S 14 (96 MP-nodes), the XP/S 35(512 GP-nodes, each with one computer processor and one message-passing processor), and the XP/S 5 (66 GP-nodes). The processors working together on complex problems can do more than 150 billion calculations per second (150 gigaflops). The goal of future machines is one trillion calculations per second (one teraflop).

At the April 21 event, the Paragon XP/S 150 was dedicated at a ceremony at ORNL's Central Auditorium in which the speakers simultaneously flipped switches for the symbolic ribbon cutting. As a result, the lights on the face of the new Intel machine displayed the words ON TO TERAFLOPS (as shown to the audience on closed-circuit television).

In addition, the new DOE national user facility, the Computational Center for Industrial Innovation (CCII), was inaugurated with a ribbon cutting by a Remotec robot (seen at the auditorium by closed-circuit TV). The purpose of the center is to promote and encourage industrial participation in mutually beneficial, computationally intensive collaborative projects with ORNL scientists and engineers.

Participants at CCII include Reynolds Metals, Weyerhauser Technology Center, and the U. S.

DOE's new Computational Center for Industrial Innovation at ORNL will help U.S. companies become more competitive. The center's staff is working with paper and aluminum companies.—*Photograph by Bill Norris.*

Department of Transportation (DOT). Reynolds Metals is interested in demonstrating through computer simulations that structurally strong bridges could be designed using aluminum, which does not corrode, to replace steel bridges, which eventually are weakened by corrosion. Weyerhauser researchers are interested in optimizing the design and operation of recovery boilers used in kraft pulp mills. They anticipate that computer simulations of the fluid dynamics phenomena in these boilers will lead to increased co-generation of energy (currently 40% of the energy used by the paper industry comes from burning chemicals recovered in these boilers) and to reduced air pollution. DOT supports design of highly efficient cars made of lighter materials, but it wants to ensure that these cars are crashworthy. Car crash modeling can be done on a Cray supercomputer in 48 hours, but the Intel Paragon XP/S 150 at ORNL can perform a car crash simulation in 2 hours. So DOT has a car crash safety project at CCII.

The Intel machines are also being used to solve "grand challenge" problems in the areas of space exploration, fusion power, climate prediction, environmental remediation, materials science, human genome analysis, and high-energy physics.

At the ceremony, CCS Director Ken Kliewer acknowledged the contributions of the Department of Energy and ORNL Director Alvin Trivelpiece to the development of the center. He said that Trivelpiece's "recognition of the need for high-performance computing made possible the emergence of ORNL as one of the premiere computational centers in the world." Trivelpiece noted that DOE national laboratories are distinguished by their user facilities and that CCII, ORNL's newest user facility, will use "one of the latest state-of-the-art computers."

James Decker of DOE's Office of Energy Research noted that CCS and other centers have been established to improve the nation's competitiveness in world commerce. He challenged computer scientists and engineers to build machines capable of petaflops, or a quadrillion calculations per second. He then mentioned two trends: partnerships and strategic alliances are being formed for many megascience projects, and computational science is moving into business and industry.

Ed Masi, the Intel manager responsible for the Intel Paragon machines built for ORNL, said that building parallel computers is technically and financially difficult. He noted that the U.S. government has given considerable support in the past to the development of big computing machines, especially in 1983 with the inauguration of the National Science Foundation's four supercomputer centers and in 1989 with the High Performance Computing and Communications (HPCC) initiative pushed by then Tennessee Senator Albert Gore and President Bush. "Big computing machines, like giant telescopes, are enormously important tools because they lead to new discoveries," Masi said. He challenged the government to continue support for the development of faster computing machines, and he challenged ORNL scientists "to make great use of this outstanding tool" and get results to justify continued government funding.

Malcolm Stocks, an Energy Systems corporate fellow and an ORNL materials scientist who uses the Intel Paragon, said it is being used to model transport of contaminants in groundwater and simulate properties of materials calculated from first principles. For example, a computer simulation of several hundred atoms of copper and nickel can improve understanding of magnetism in a copper-nickel alloy. Or simulation of several thousand atoms of carbon can aid understanding of the melting behavior of diamond—information nearly impossible to get experimentally. Stocks noted that understanding interactions among nuclei and electrons in materials took a leap forward in the 1980s with the introduction of vector computers and another leap in the 1990s with the introduction of parallel computers.

ORNL's newest user facility will use one of the world's fastest computers.

Thomas Zacharia, CCII director, said that the new user facility offers a classroom, computers, and visualization capabilities. He called CCII "a focal point for industrial interactions and partnerships in the critical area of high-performance computing." CCII was made possible by support from DOE's Office of Scientific Computing and Ron Hultgren, DOE site manager for ORNL. Hultgren said, "Let's officially open CCII and let the good times roll."

Gordon Fee, president of Lockheed Martin Energy Systems, called the construction, installation, and programming of the latest Intel supercomputer "a great accomplishment" for DOE and the country.

Other distinguished guests at the ceremony included Walter Ermler, David Nelson, and Ed Cumesty of DOE; Jose-Marie Griffiths of the University of Tennessee; Robert Sugar of the University of Santa Barbara; David Daugherty of the University of Vermont, who is a member of the CCS Advisory Committee; Faris Bandak of the National Highway Traffic Safety Administration; and Peter Gorog of Weyerhauser.

Ron Tipton of Reynolds Metals Company is optimistic that CCII will help his company find ways to better use aluminum for building cars and bridges. "When you know where people are coming from and they know where you're coming from," he said, "you can get a lot done." It is hoped that CCS and CCII will smooth the way for a quantum leap in cooperation between industrial firms and national laboratories.

U.S. Proposes a Different Neutron Source for ORNL

DOE supports replacing the canceled ANS with a new spallation neutron source at ORNL.

For 20 years U.S. scientists have sought an advanced source of neutrons for research. Debate centered on whether to build a reactor or accelerator as the primary source. The most recent scientific consensus favored building a reactor first—the Advanced Neutron Source (ANS) proposed for Oak Ridge—and a complementary accelerator source second.

However, because of the push to reduce the national deficit and because a reactor could cost three times as much as an accelerator, the Clinton administration in January 1995 canceled the $2.9 billion ANS, which had been in the president's budget as a construction item for the past two years. To replace the ANS, the Clinton administration proposed an accelerator option called a spallation neutron source and designated ORNL as the preferred site.

In an April 4, 1995, internal workshop at ORNL to discuss plans for designing a spallation neutron source, Bill Appleton, ORNL associate director for the ANS, said, "The design for the ANS was the best and most complete design of any recent Department of Energy project." He noted that the design, which was done under the leadership of the ANS Project Office in Oak Ridge, may still be useful in the future and that efforts will be made during closeout activities to properly preserve the ANS design for DOE.

The ANS, Appleton said, was canceled mainly because of its cost. A secondary reason was a political consideration related to the U.S. government's nonproliferation goal. Some people in the Clinton administration were concerned that, because the ANS was originally designed to use highly enriched uranium (although designs were in progress for making use of low-enriched uranium), the government would have a problem urging other nations to avoid using nuclear materials that could be made into weapons.

Because the Department of Energy had promised to provide new facilities to ORNL and other national laboratories under its facilities revitalization plan, Appleton said that DOE supports replacing the canceled ANS with a new spallation neutron source at ORNL. The pulsed spallation source would provide neutrons for neutron scattering research but, unlike the ANS, would not produce radioisotopes or steady-state beams for materials irradiation experiments. Neutrons from the spallation source would be used primarily to address questions in fundamental and condensed-matter physics, structural chemistry, materials science, and molecular biology.

Appleton said ORNL was also chosen for the spallation source to maximize use of the Laboratory's neutron source design expertise and to take advantage of its experience in operating particle accelerators and in conducting neutron scattering research. He noted that expertise in particle source design resides in ORNL's Fusion Energy, Metals and Ceramics, Engineering Technology, Solid State, and Research Reactors divisions and in the ANS Project Office.

"We are doing about $120 million worth of studies in neutron science," Appleton said. "We have a strong neutron science competency. We also have complementary neutron science facilities, such as the High Flux Isotope Reactor (HFIR), Radiochemical Engineering Development Center, the Oak Ridge Electron Linear Accelerator, and hot cells. Also, we have a strong materials science and engineering program. What is missing is experience in high-energy accelerator design."

Appleton said that ORNL will team with accelerator design experts from Europe and from U.S. national laboratories and universities to come up with the best accelerator design. The goal is a 5-megawatt (MW) source. However, because the best available technology will now permit the operation of only a 1- to 3-MW source, Appleton said the spallation source would be built in stages while new technology is developed to contain such a high-energy beam in the target area.

Another option, Appleton said, would be to upgrade ORNL's HFIR to make it more suitable as a neutron research facility. To become a complementary capability to a spallation source, the HFIR would receive modest upgrades, such as the addition of a cold neutron source in existing beam tubes, and it would continue to be used for isotope production and materials irradiation experiments. If for some reason the spallation source were not funded, he said, improvements could include a new reactor vessel and moderator, a high-flux cold source, increased power level (HFIR's power level is now 85 MW but will return to 100 MW; ANS would have been operated at 330 MW), and new neutron-scattering instruments. He noted that any options would have to be consistent with available funding.

"There are significant problems involved in the spallation source project," Appleton said. "We have to get it through Congress to maintain funding in the fiscal-year 1996 budget. The big problem is bringing the neutron science community together and getting a consensus on the best spallation source design, a steady-state neutron source such as an upgraded HFIR, and an affordable integrated facility.

"Argonne, Brookhaven, and Los Alamos national laboratories have already done designs for a complementary spallation source, so people there think their lab should be the site for the Spallation Neutron Source. But DOE supports building it at ORNL."

A spallation neutron source consists mainly of an ion source, a linear accelerator, a synchrotron or storage ring, a target area, and neutron beam lines. A continuous beam of negative ions of hydrogen is obtained from an ion source and accelerated by the linear accelerator. At the Los Alamos spallation source, the ion beam passes through the linear accelerator's radiofrequency quadrupole (RFQ), where it is bunched into pulses and accelerated by RF waves; then it is focused by quadrupole magnets into the storage ring. There the negative ions pass through a foil, which strips all electrons from the negative hydrogen ions, converting them into positive ions, or protons.

The pulsed proton beam is guided around the ring by a series of magnetic fields; when some fields are turned off, the beam is "dumped" out of the ring and directed to a target made of a heavy metal, such as lead, tantalum, tungsten, or uranium. As a result of the intense interaction between the high-energy protons and neutrons in the target, many neutrons are knocked out. As the neutrons spray out in different directions, they are slowed down as they pass through a moderator—liquid methane or deuterium, for example. Then they enter various beam lines for neutron scattering studies.

According to workshop speakers, one advantage of the spallation source over the ANS is that, because the beam is intermittent rather than steady, more accurate measurements can be taken between pulses when the source of background radiation is off. In addition, the pulsed beam can be used to measure scattered neutron energies by time-of-flight techniques. A third advantage is that measurements can be made without moving equipment, permitting the use of many time-of-flight neutron spectrometers around the target area. Additional physics experiments possible with a spallation source include studies of neutron oscillation and of particles such as muons and neutrinos.

The chief disadvantage of the spallation source, compared with the ANS, is that the pulsed source's repetition rate limits the possibilities for cold, or slow, neutrons. "By the time slow neutrons get through the system," ORNL physicist Herb Mook said, "the next pulse will be upon us." Cold neutrons are particularly useful for probing the structure of polymers in plastics and biological materials.

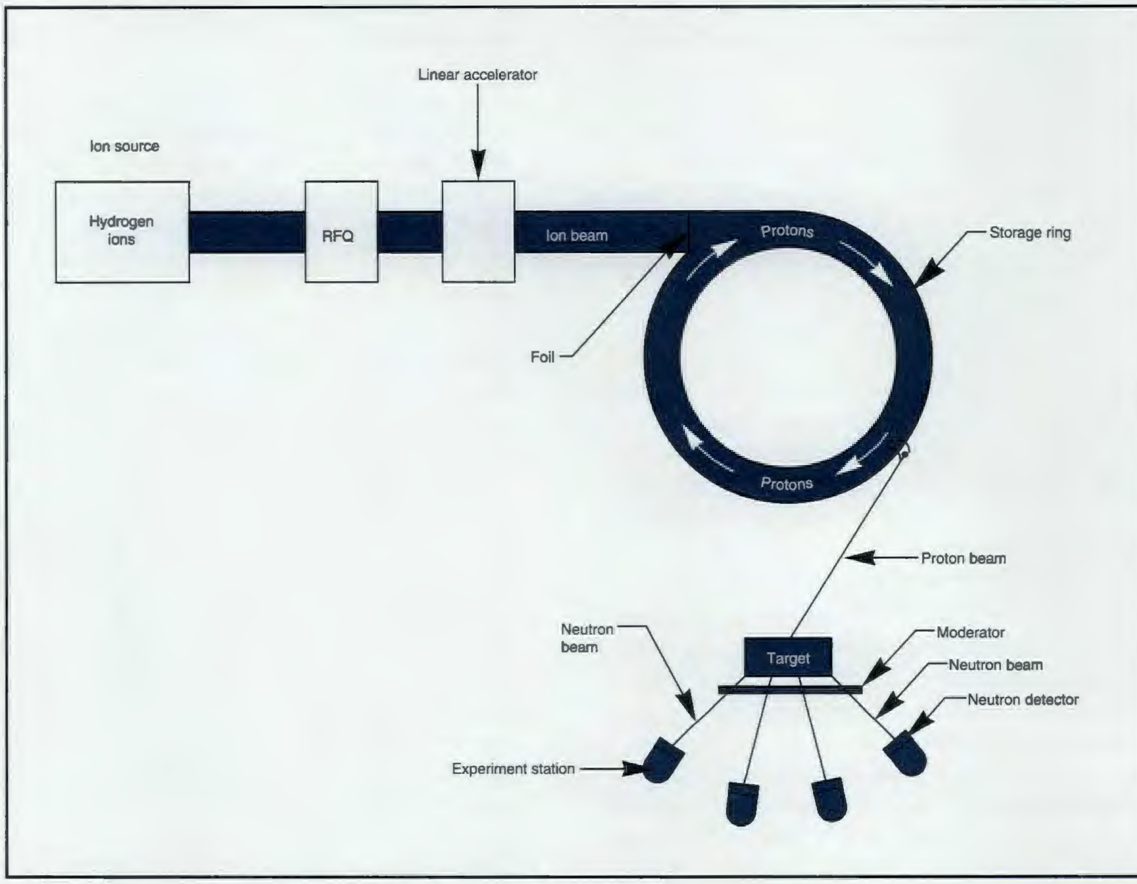
Designers of a spallation source must overcome at least two problems. One problem is the possibility of losing control of the beam, allowing it to irradiate and damage magnets and other accelerator parts. Second, proton beams can cause materials in the accelerator and target to become highly radioactive.

"We can shield high-energy accelerators to protect workers from activated parts," said ORNL physicist Tony Gabriel. "ORNL has developed shielding codes that have helped other accelerator facilities solve their shielding problems."

ORNL has developed shielding codes that have helped other accelerator facilities solve their shielding problems.

ORNL physicist John Whealton noted that the Laboratory's expertise in RF technology and computer analysis has been used to help Los

The spallation source would be built in stages while new technology is developed to contain such a high-energy beam in the target area.



In one concept, a spallation neutron source consists mainly of an ion source, a linear accelerator that includes a radiofrequency quadrupole (RFQ), a storage ring, a target area, and neutron beam lines that end at experiment stations. A continuous beam of negative ions of hydrogen (H^-) is obtained from an ion source and accelerated by the linear accelerator. When the ion beam passes through the RFQ, it is bunched into pulses and accelerated by RF waves; then it is focused by quadrupole magnets into the storage ring. There the negative ions pass through a foil, which strip all electrons from the negative hydrogen ions, converting them into positive ions, or protons. The pulsed proton beam is guided around the ring by a series of magnetic fields; when some fields are turned off, a proton beam is directed to a heavy-metal target. As a result, neutrons spray out from the target in different directions. After being slowed by a liquid moderator, they pass through various beam lines for neutron scattering studies.

Alamos solve two problems with the linear accelerator of its spallation source. RF technology and computer modeling will also be needed for the advanced spallation source planned for ORNL.

Whealton says the spallation source will present ORNL staff with research opportunities in such areas of development as RF technology, better negative ion sources, longer-lasting foils, and computer programs to enable designs to reduce beam halo (spreading of the beam, which can cause accelerator parts to become radioactive) and to sort out and make sense of the information in detectors.

Clearly, ORNL has its foot in the spallation source door. With the right resources, it should be able to go full speed ahead.

State of Laboratory Address by ORNL Director

The Advanced Neutron Source (ANS) research reactor proposed for ORNL was quashed because of its $2.9 billion cost, but a $1 billion accelerator for neutron scattering may be built here in its place. Some 200 scientists and engineers left the Laboratory last year under the Special Retirement Incentive Program, but ORNL now has more opportunities to hire younger researchers to energize its staff. A former ORNL researcher won the Nobel Prize, but ORNL's most famous Nobel Prize winner died.

This mixture of good and bad news marked the annual State of the Laboratory address that ORNL Director Alvin W. Trivelpiece presented on March 3, 1995, at the Laboratory. He noted that, although ORNL's future is uncertain, he believes ORNL will survive and continue as a world-class institution.

ORNL is the preferred site for DOE's proposed accelerator for neutron scattering research, Trivelpiece noted, because of the Laboratory staff's experience in particle accelerator operation and neutron scattering research. Because the ANS reactor will not be built, steps will be taken to extend the operational life of ORNL's High Flux Isotope Reactor for production of radioisotopes.

Trivelpiece said that 433 ORNL staff members took the special retirement in 1994 as part of ORNL's downsizing in response to a reduced budget. He called the loss of 200 researchers a major event. "The good news here is that it brings an opportunity to recruit young staff members," he said. "The bad news is that many of the people who left were the ones writing the proposals, maintaining contacts with program managers in Washington, and bringing in funding."

Because the new Congress is focusing on deficit reduction and middle-class tax cuts, the Department of Energy, to save itself from abolishment, pledged to cut $14.1 billion over five years. But because the fiscal 1996 budget is so far along, Trivelpiece said, the cuts may occur over only four years, forcing ORNL to tighten its

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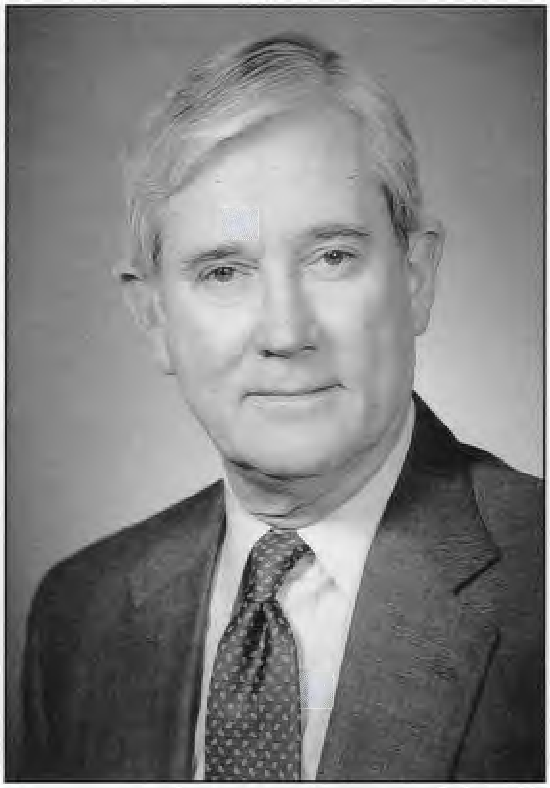


Alvin Trivelpiece

fiscal belt even more. "The budgets we have to deal with," he added, "are the lowest science and technology budgets since 1975 in terms of gross domestic product."

A number of government councils and task forces—including the Galvin Task Force—will also influence ORNL's future, as will the recent change in congressional representatives. To face such an uncertain future, Trivelpiece recommended that the Laboratory sharpen its focus with R&D strategic planning, produce high-quality proposals, market its capabilities effectively in Washington, and ensure top-quality work.

ORNL would continue to become better known... through... Community Day.

He also urged that the Laboratory become more "user friendly" for the benefit of the 4400 guest researchers and 24,000 students who spend time at ORNL each year. He said that ORNL would continue to become better known to the community through another Community Day planned for the fall.

In 1994, he noted, former ORNL researcher Cliff Shull received a Nobel Prize for physics for his neutron scattering research, and ORNL geneticist Liane Russell won the Fermi Award for her biological research. Two ORNL innovations received R&D 100 Awards from *R&D* magazine, and ORNL researchers Doug Lowndes and Tuan Vo-Dinh were named Corporate Fellows by Lockheed Martin Energy Systems.

On a sad note, Nobel Laureate Eugene Wigner, a former ORNL research director, died at the age of 92. Trivelpiece said that as a memorial to the famed physicist he hoped to rename Central Auditorium after Wigner.

Trivelpiece's choice of research highlights for 1994 included the acquisition of the 1024-node Intel Paragon, which is one of the world's most powerful massively parallel supercomputers; the introduction of ORNL to the Internet and World Wide Web; ORNL work in collaboration with others to make cars and textile production more efficient; use of ORNL-developed nickel aluminides for longer-lasting furnace trays for making parts for the automobile industry; the acquisition of a recoil separator from England for use with the Holifield Radioactive Ion Beam Facility; and ORNL's entry into forensics research by analyzing the chemical composition of children's fingerprints, which vanish from surfaces more quickly than do adult fingerprints.

Trivelpiece said that the Laboratory is well positioned to support DOE's new mission of developing and deploying technologies and influencing social systems to ensure a sustainable future for the world. Such work could help sustain ORNL through an uncertain future.

Environmental Restoration Magmas Studied

What happens when molten volcanic rock cools in a lava lake or below the surface of the earth? How are large granite masses formed? Answers to these questions may be emerging from volcano-free Tennessee.

A soil-to-glass environmental restoration process used at ORNL can mimic some of the processes of magma formation and cooling. That's the conclusion of geoscientists from around the nation.

The process, in situ vitrification (ISV), is a patented technology developed for DOE by Battelle Pacific Northwest Laboratory. It uses electrodes to heat soil contaminated with radioactive elements to temperatures up to 1600°C (2900°F). Upon cooling, the molten soil transforms to a mixture of glass and crystals in the ground, trapping the radioactive material.

ISV has been tested with and without radioactive materials at ORNL. It will be used in September 1995 to produce 600 tons of glass at an ORNL waste pit. In this melt, 4 megawatts of electrical power will heat and melt the soil.

"ISV melts," says Mike Naney, a geochemist with ORNL's Environmental Sciences Division (ESD), "can provide artificial magmas in a controlled, monitored environment. The molten rock, crystals, and gases produced by the melting are formed at temperatures similar to those in

An in situ vitrification (ISV) test was performed at ORNL in 1991. In September 1995, ISV will be used to turn the soil in a radioactive waste pit into 600 tons of glass, immobilizing the contaminants.

crustal magma chambers that supply lava to volcanoes.

"But the ISV melts are not subjected to the explosively high pressures of volcanoes. By studying the cooling and crystallization in artificial magmas, we can learn more about what happens during the cooling of crustal magma chambers and lava lakes."

These magmatic processes include extraction of metals and their deposition as mineral ores, heating and circulation of water that can be tapped as geothermal energy, and venting of gases to the atmosphere that affect global climate.

The idea of using ISV technology to develop large-scale melts for scientific studies was spawned before ORNL's 1991 ISV test. In the fall of 1989 Rick Williams, of the University of Tennessee's Geology Department, and Jon Nyquist of ESD were interested in using geophysical methods developed for near-surface environmental studies to obtain acoustic images of the artificial magma produced during an ISV test planned for 1991. They asked Gary Jacobs of ESD and Naney to join them to identify petrological and geochemical studies that might be complementary to the geophysical studies and then to write a proposal for funding.

"The proposal was successful," Naney says, "and we were able to take advantage of a unique opportunity to advance understanding of magmas and magmatic processes by 'piggy-backing' interesting studies on the 1991 ISV test." The test of this technology for environmental remediation was sponsored by DOE's Office of Technology Development.

We were able to take advantage of a unique opportunity to advance understanding of magmas.

Using thermocouples, the ORNL scientists measured the temperature profile of the 1991 ISV magma. Temperatures ranged from 100°C several feet away from the melt to 1500°C in the molten soil. They observed vigorous bubbling and rapid convection of heat by circulation of heated liquid and gases at the melt surface. After the artificial magma cooled, they obtained samples by diamond core drilling the rocklike product. Then they analyzed the textures and chemistry of the minerals that formed during crystallization of the melt.

Our studies of artificial magmas help us understand how igneous rocks form.

"Our studies of artificial magmas during and after cooling," Naney says, "help us understand how igneous rocks form during the cooling of pools of natural magma and lava lakes. The ORNL soils that we studied melt to form a basalt-like liquid, rich in calcium, magnesium, iron, and silicon. As the molten basalt cools, minerals containing calcium, magnesium, and iron precipitate out, leaving a liquid rich in silicon. As the last remaining liquid cools, it solidifies into a mixture of glass and crystals having the composition of granite.

"Our observation of small amounts of granite filling spaces between the larger feldspar and pyroxene crystals that form the predominantly basalt-like rock provides information on granite formation in the crust of the earth," Naney says. "The same phenomenon in natural magmas would trap granite liquid between interlocking crystals of a basalt, preventing migration and coalescence of the granite liquid to form large masses."

What conclusions have the ORNL researchers made from their observations? Says Naney: "The existence of some large bodies of granite, of the size exposed at Stone Mountain, Georgia, or in Yosemite National Park, may require multiple cycles of melting and squeezing of solidified basalts. These processes extracted the small amounts of granite liquid required to form granite masses as large as hundreds of cubic kilometers."

This idea is not new to geologists. "But," Naney says, "the ORNL studies provide a large-scale example of the 'fractionation' process that generates granite from a 'parent' basalt magma."

The ORNL researchers noticed an interesting phenomenon 20 hours after the ISV power was shut off. "The cooling of the artificial magma halted for 24 hours," Naney says.

The high temperatures needed to generate and maintain the ISV molten rock are the result of adding heat energy through electric-resistance heating of the soil and resulting melt. After the electrical power is turned off, the magma begins to cool. Radiative, convective, and conductive processes all constantly remove heat, cooling the magma.

The observed halt in cooling, a thermal arrest, was produced by the generation of sufficient heat within the magma to counterbalance the three heat-removal processes. The source of this energy was heat liberated during growth of crystals in the magma. This is a well-known thermodynamic phenomenon—an exothermic phase change.

The same phenomenon benefits fruit growers when they mist citrus groves with water during cold weather. The water droplets are cooled by cold air and freeze to form ice crystals. In the process of freezing, the water crystallizes (a phase change), giving off heat to the surfaces of fruit and the surrounding air. For air temperatures near 0°C (32°F), this heat can be sufficient to prevent the temperature of fruit from falling below 0°C and destroying a crop.

"In the case of the ISV test," Naney says, "thermal arrests were anticipated, but the magnitude and duration of the effect was surprising. The temperature and duration of the thermal arrest provide information about crystallization processes within the melt that could not be directly observed."

Although basalt is a common rock at volcanoes in the Cascades in the western United States and in Hawaii, it is not present in East Tennessee. The common rocks at the ORNL site are limestone and shales. "But," Naney notes, "the chemical compositions of basalt and the combination of shale and limestone are similar, so ISV melts in Tennessee can provide useful information on volcanic processes."

Naney and Jacobs pursued the idea of using ISV melts as artificial magmas at a meeting of geologists in San Francisco and later in Boston. In the spring of 1994, he and Gary Jacobs organized a workshop on this subject in Oak Ridge. It was attended by 23 geoscientists from universities, research institutions, and national laboratories across the country.

"The participants concluded that ISV technology can produce large silicate melts whose makeup and properties provide unique analogs for natural magmas," Naney says. "They agreed that ISV melts are useful for testing theories that cannot be investigated through direct observation using bench-top experiments or uncontrolled studies of natural systems such as lava lakes."

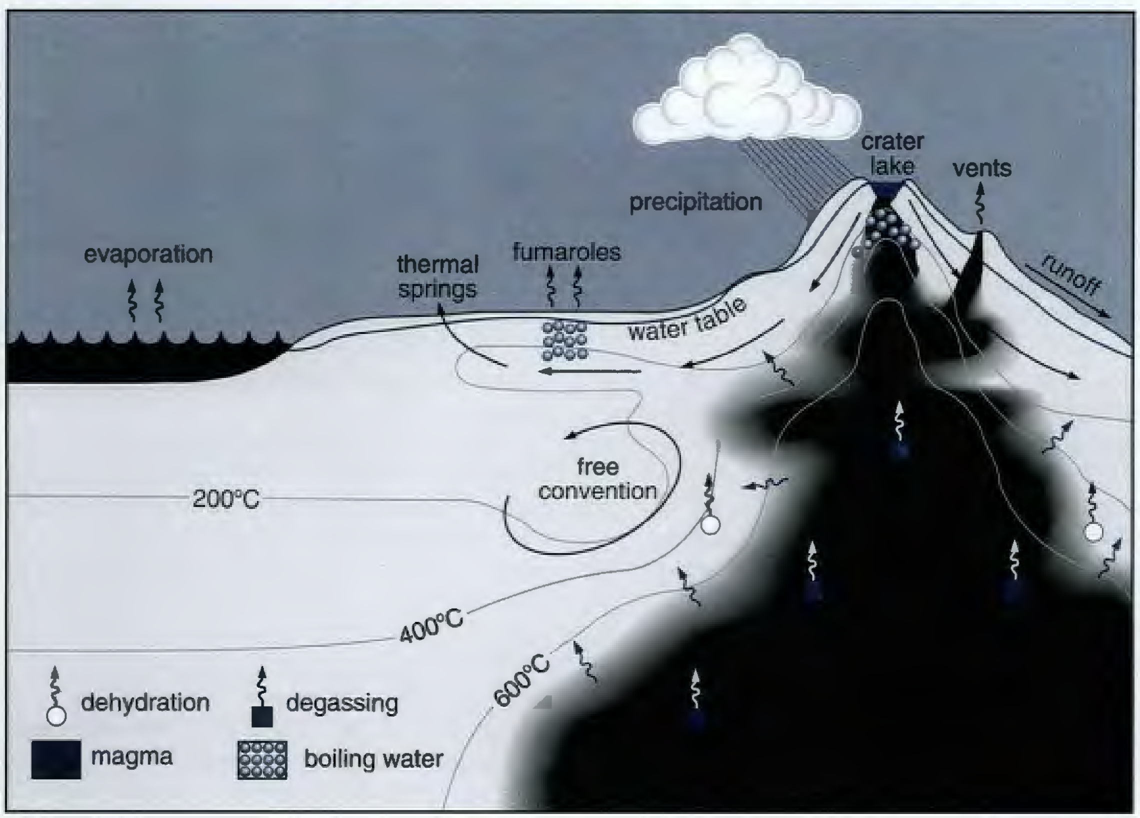
As volumes of soil up to 300 cubic meters undergo melting, Naney says, a "magma chamber" is created. "Such a melt is large enough for field-scale geophysical instruments to be used but small enough to be controlled and monitored like a laboratory experiment," he says. "We can determine the chemical composition and physical properties of the materials before and after melting. In addition, we can follow the history of the melting and cooling by using sensors and taking samples of magma, gases, and particle emissions from the ISV melts."

The workshop and other ISV magma research were supported by the Geosciences Research Program of the Department of Energy's Office of Basic Energy Sciences.

Real Cost of Power from Coal Explored

What is the real cost of electricity? Is it simply the total cost reflected in our electricity bills? This issue is addressed in the recently published second and third of a series of eight reports on the external costs and benefits of electricity fuel cycles. The reports, which cover analytical

Our observation provides information on granite formation in the crust of the earth.



Artificial magmas created by in situ vitrification processing provide analogs for the thermal and chemical processes associated with the intrusion and solidification of magma, as shown in this illustration. (*Figure courtesy of J. G. Blencoe, ORNL's Chemical and Analytical Sciences Division.*)

methods and the coal fuel cycle, were written by ORNL and Resources for the Future (RFF) as part of a study sponsored by DOE.

According to the report on coal power, the real cost includes the social costs of all activities involved in the production of electricity—that is, of the fuel cycle. These social costs are the financial costs plus the external costs and benefits (externalities) of extracting fuel, processing it, transporting it, burning it to generate electricity, and disposing of wastes. These external costs include injuries, illnesses, and environmental damage.

Surprisingly, the report found that the external costs at one coal-fired power plant are much lower than expected.

Surprisingly, the report found that the external costs at one coal-fired power plant that was studied are much lower than expected—about 2 to 3% of the total cost of generating electric power from coal. Some external costs, however, cannot be reliably estimated (e.g., global warming) and are not included in this estimate.

ORNL prepared the report in collaboration with RFF and with DOE and the Commission of the European Communities (EC). In this project, methods were developed for analyzing the externalities of electricity production. ORNL and RFF are applying the methodology to estimate the social costs of coal, biomass, hydropower, oil, natural gas, and nuclear fuel cycles. EC is using the methodology to estimate the costs of photovoltaics, wind fuel cycles, and energy conservation options in addition to its studies of these other fuel cycles.

DOE's and EC's interest in this study stems from their desire to assess the full costs of alternative energy technologies. "Total energy cycle assessments" are needed to guide research and development and facilitate deployment of energy-efficient and renewable energy technologies in the marketplace. Their interest also stems from the fact that the impact of energy production on the global environment is considered an important issue for years to come.

The methodological foundation for the study was developed largely by Robin Cantor, formerly of ORNL and now at the National Science Foundation, and Alan Krupnick, an RFF researcher who was with the President's Council of Economic Advisers. Russell Lee, a geographer with ORNL's Energy Division, took over the Laboratory part of the study when Cantor left in 1991. In 1995, Lee was honored for the report on coal fuel cycles by the Association of American Geographers.

The full social cost of producing electricity, Lee says, includes two components. The first component is the price reflected in electric bills; it covers labor, capital, fuel, insurance, regulatory compliance, and taxes. The second component covers costs to people other than producers and consumers. For example, sulfur and nitrogen oxides emitted from coal plant stacks may cause lung disease, reduce fish populations, and damage crops in some regions.

"From mining to transportation to generation and transmission of electricity, the coal fuel cycle imposes burdens on the environment that can harm ecosystems and human health," Lee says. "Individuals place some value on preserving ecosystems, good health, and materials and are, therefore, implicitly willing to pay to avoid damage to them. These values are reflected in the full social cost, or externalities, of providing electric power from coal."

Lee noted that the coal fuel cycle also has some benefits that must be accounted for in estimating the full social cost. An example is fertilization of soil in some areas by deposits of sulfur and nitrogen.

The methodology developed at ORNL and RFF includes the "damage function approach," which is considered by most researchers the preferred method for estimating most coal fuel cycle externalities. Lee says that the work also resulted in several new analytical methods.

"We developed new models for estimating concentrations of ground-level ozone from coal plants at various locations and of sulfur and nitrogen oxides, lead, and particulates at distances from coal plants that are not treated by other models," Lee says. "In addition, we developed new methods to estimate nonenvironmental impacts such as damages to roads by coal trucks and reduction in unemployment because of power plant construction and operation."

In the study, a coal power plant in the southeastern United States and one in the Southwest were examined. The researchers looked at specific impacts of various stages of the coal fuel cycle.

"Mining coal can lead to injuries and deaths from accidents and to lung disease from emissions of radon and coal dust," Lee says. "Transporting coal can lead to injuries and deaths from rail and truck accidents.

"Generating electricity by burning coal results in the emission of gases and heavy metals that have environmental impacts. The most notable are carbon dioxide, which contributes to global warming; nitrogen oxides, which contribute to ground-level ozone; and sulfur oxides, which form acid rain. These pollutants can cause harm to crops, forests, fish, wildlife, materials, and human health."

Lee said the study made several conclusions after evaluating the two reference sites. Some findings showed that costs are generally site specific—for example, health effects of airborne pollutants emitted from the coal plant in the Southeast are 100 times greater than those associated with the plant in the Southwest.

"We estimate that the externalities are considerably less than some people expected," Lee says. "For the power plant in the Southeast, the externalities amount to little more than 1 mill, or 0.1 cent, per kilowatt-hour, which is only about 2 to 3% of the total cost of generating electric power using coal."

However, Lee notes, damage from potential global warming is not part of the estimate. "It could be 1 cent, or more, per kilowatt-hour," he says.

"One problem is that ecological damages are difficult to estimate and are not all included in the 1-mill estimate. Also, if a coal power plant is located in a more populated area, then damages might be several times greater."

"We found that precise social costs are difficult to estimate," Lee concludes, "because of differences from site to site and because of uncertainties in estimating ecological impacts, including global warming effects."

The coal fuel cycle also has some benefits that must be accounted for in estimating the full social cost.

DOE's Inventions Programs Saves Energy and Money—ORNL

The news media claim that some government programs "rip off" American taxpayers. However, an ORNL report shows that taxpayers clearly benefit from a government program called the Energy-Related Inventions Program (ERIP).

This federal government program for stimulating energy-related inventions has generated commercial products that are saving Americans energy and money, creating jobs, boosting tax revenues, and slowing global warming. That's the conclusion of a recently published report prepared by Marilyn Brown, C. Robert Wilson, Charlotte A. Franchuk, Stephen M. Cohn, and Donald W. Jones, all with ORNL's Energy Division.

The report, *Economic, Energy, and Environmental Impacts of DOE's Energy-Related Inventions Program*, examines the results of ERIP, which has been jointly operated since 1974 by DOE and the National Institute of Standards and Technology (NIST). This program solicits and selects invention ideas, and from 1975 through 1992, it provided $41 million in grants to inventors to develop the most promising concepts.

"The value of sales of ERIP inventions is 19 times the value of ERIP grants awarded and 7 times the appropriations for the program," Brown says. "In 1992, the last year covered by our evaluation, ERIP technologies launched new businesses, created more than 650 full-time jobs, and provided the U.S. Treasury with $2.7 million in individual income taxes.

"The commercial success of three ERIP projects has saved more than half a billion dollars in energy expenditures over the past decade," Brown says. "In addition, the energy savings cut greenhouse gas emissions by nearly one million metric tons of carbon." Carbon dioxide and other greenhouse gases contribute to global warming, which may have undesirable environmental effects.

The three highly successful ERIP projects were (1) replacement rings for steam turbines, which prevent the gradual loss in efficiency that characterizes conventional packing rings; (2) an ignition control system for automotive internal combustion engines; and (3) a high-efficiency gas-fired water heater for industrial applications.

ERIP has brought prosperity to some inventors. "By the end of 1992," says Brown, "at least 129 of the 625 inventions recommended by DOE for support had entered the market, generating total cumulative sales of $763 million. In 1992, ERIP inventors earned an estimated $1 million in royalties. Over the lifetime of the program, royalties have totaled $18.6 million."

The commercial success of three ERIP projects has saved more than half a billion dollars in energy expenditures over the past decade.

The authors obtained the report's information by designing and distributing a 16-page questionnaire to the 557 inventors who had been recommended for program participation by NIST prior to October 1991. (It was judged that more recent participants would not have had enough time to complete their projects and develop a successful new product.) They measured an invention's progress primarily in terms of market entry, level of sales, and length of time in the market.

50-Year-Old Calutrons Resume Isotope Production

After being idle for three years, 8 of ORNL's 36 calutrons were restarted by DOE on January 3, 1995, beginning the year that marks the 50th anniversary of stable isotope production in Oak Ridge. The reason for the restart: DOE changed its policy, recognizing that some customers that have been buying low-priced stable isotopes from Russia require a more stable supplier.

On December 22, 1994, Trace Sciences International of Ontario, Canada, signed a three-year contract with DOE to buy stable isotopes in large quantities at a volume discount. These stable, or nonradioactive, isotopes will be distributed to 14 countries for medical, industrial, research, and agricultural uses. In the United States alone, radioisotopes, some of which are produced from stable isotopes, are used for medical diagnosis or treatment of 30,000 to 40,000 patients a day.

ORNL's calutrons at the Oak Ridge Y-12 Plant are high-current mass spectrometers that use magnetic fields to separate isotopes by charge and mass. Some 1152 calutrons were used during World War II to produce fissionable uranium-235 for the atomic bomb.

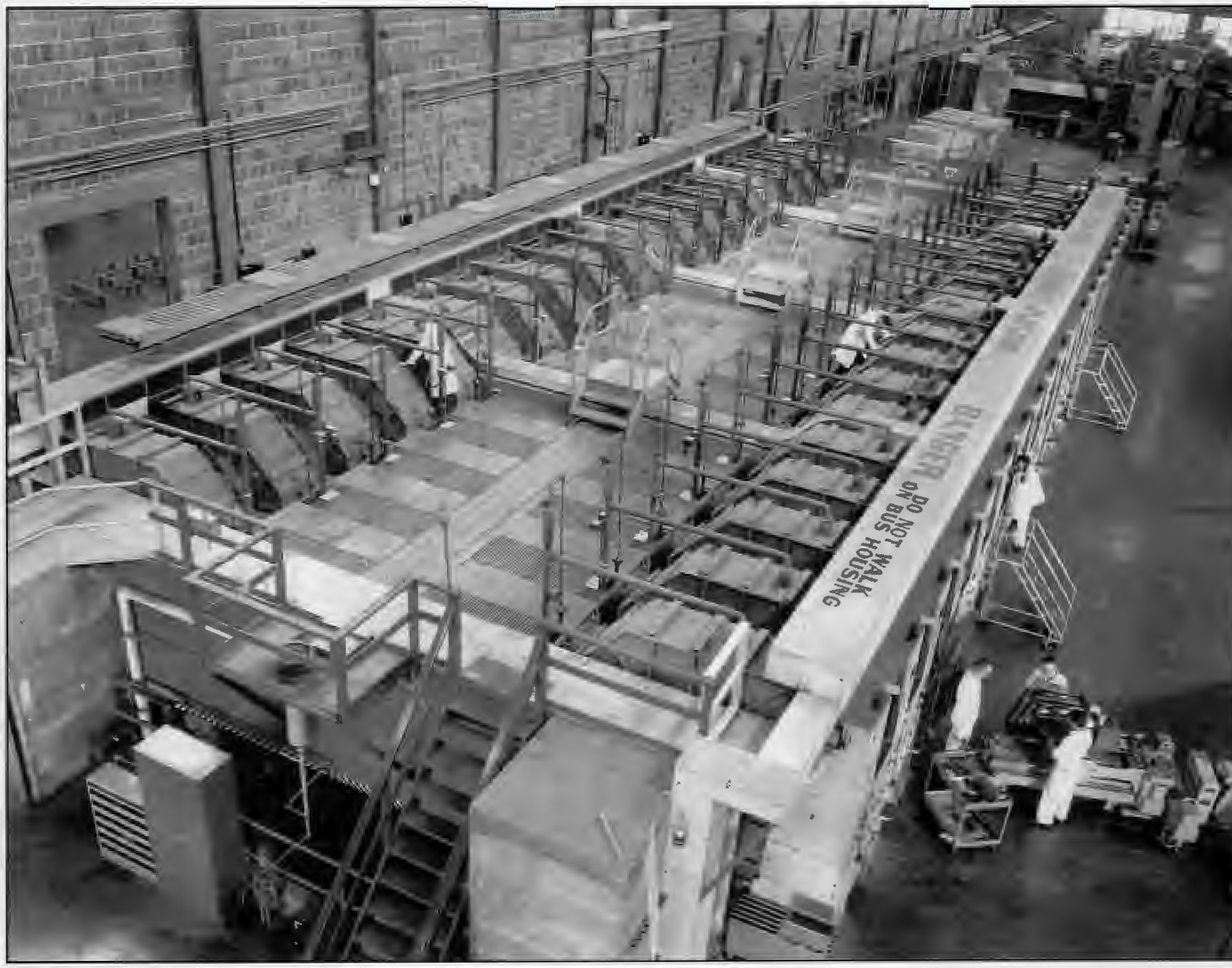
In the current facility (Building 9204-3) of ORNL's Isotope Enrichment Program, a track of 36 calutrons began separating uranium-235 from other uranium isotopes on December 13, 1944; another track of 36 calutrons started uranium separations on January 30, 1945. Production of stable isotopes commenced November 11, 1945, with the separation of copper-63 from copper-65 in the Building 9731 pilot plant at the Y-12 Plant.

In the fall of 1959, ORNL took over operation of the calutrons in Building 9204-3 for its stable isotope production program. Over the years it has operated 30 calutrons for 4 million hours, producing a total of 250 kilograms (550 pounds) of material enriched in 232 different stable isotopes.

The eight restarted calutrons are now used to produce material enriched in thallium-203 for Trace Sciences International. This feed material goes to the isotope supplier, which uses proton beams in cyclotrons to convert thallium-203 to thallium-201, a radioisotope. Thallium-201 is used worldwide to diagnose heart disease.

ORNL had been producing thallium-203 until 1991 when its customers turned to Russia because it was selling the isotope for 10 to 20% less. So the calutons were shut down. However, during the shutdown, the program began selling its reserve supply of strontium-88 to Amersham International, a pharmaceutical company in England that produces strontium-89 chloride for relieving cancer-induced bone pain.

The calutron is based on an invention by E. O. Lawrence and associates at Berkeley, California. In early 1942, this group converted a 37-inch cycloton to a production mass spectrometer and



ORNL uses these calutrons at the Y-12 Plant to produce thallium-203, a stable isotope that is converted to radioisotope thallium-201 for heart scans. The calutrons were recently restarted after being idle for three years.

showed that electromagnetic separation of uranium-235 is possible.

The ORNL calutrons are the only source of stable isotopes in the United States. The only other operating calutrons in the world are in China and Russia.

Calutrons were built and operated in Iraq in support of Saddam Hussein's fledgling nuclear weapons program. In 1986, Iraqis operated their first experimental electromagnetic separator at the Tuwaitha Nuclear Research Center near Baghdad; in 1987, they operated two experimental separators there. Iraq planned to deploy 70 calutrons at one site and 20 at another. In 1990, eight separators were installed and operated at Tarmiya; they were shut down for modifications

The restarted 8 calutrons are now used to produce material enriched in thallium-203 for Trace Sciences International.

The ORNL calutrons are the only source of stable isotopes in the United States.

A technician adjusts a calutron ion source used for stable isotope production.

in 1991. Iraq's separator facilities were destroyed by February 1991 air attacks during the Persian Gulf War.

ORNL's stable isotope production program has a staff of 45 persons, including 25 technical employees ranging from chemists and physicists to electrical and chemical engineers. Says Joe Tracy, manager of ORNL's Isotope Enrichment Program, "Producing isotopes is a beneficial peaceful use of wartime technology. And it is popular with the U.S. government because it brings in revenue."

ORNL's Battery Technology Gains More Recognition

This Hazard Card, being designed to warn workers of the presence of hazardous gases, will be powered by ORNL's thin-film lithium battery. The battery technology has been licensed to Teledyne Electronic Technologies.

ORNL's development of rechargeable thin-film lithium batteries continues to attract attention. The technology is being used in the Department of Energy's 1000th cooperative research and development agreement (CRADA), it received a prestigious DOE award, and the rights to commercialize it have been granted to Teledyne Electronic Technologies.

A Hazard Card, a badge that will warn workers of the presence of hazardous gases, is the expected product of DOE's 1000th CRADA. The electronically operated gas sensor will be powered by the award-winning thin-film lithium battery developed at ORNL.

The participants in the CRADA are Research International of Woodinville, Washington, and John Bates, Nancy Dudney, and Chris Luck, all of the Ceramic Thin Films Group that Bates heads in ORNL's Solid State Division. The group's development of rechargeable thin-film lithium batteries also received a Significant Implication for Department of Energy–Related Technologies Award in the Solid State Physics category in DOE's 1994 Materials Sciences Research Competition.

The 1000th DOE CRADA was signed in September 1994 in Washington, D.C. Present at the signing were Secretary of Energy Hazel O'Leary; Elric Saaski, president of Research International; and Alvin Trivelpiece, ORNL director. This agreement was one of 87 CRADAs signed in fiscal-year 1994 by Martin Marietta Energy Systems, Inc.

The goal of this CRADA is a credit-card–size device in which a gas sensor detects hazardous gases and special electronics warn the badge wearer of the presence of these gases through light and sound signals. The electronics would be powered by a rechargeable lithium microbattery half as thin as plastic wrap.

The lithium-vanadium oxide battery used for the Hazard Card is one of several types of thin-film rechargeable lithium batteries developed by the ORNL group. These solid-state batteries, which can be cycled thousands of times, can be fabricated in virtually any size and shape to meet the needs of a variety of electronic devices.

"For the Hazard Card," Bates says, "a battery measuring 9 square centimeters and 5 microns thick will supply the current required—between 2.5 and 3.5 volts—to operate the card continuously for more than 8 hours before recharging."

The ORNL battery can operate at higher voltages and currents than previously developed thin-film batteries.

The ORNL battery can operate at higher voltages and currents than previously developed thin-film batteries. The key to this improvement was the group's discovery in 1991 of an effective solid electrolyte, called amorphous lithium phosphorus oxynitride, or Lipon. The electrolyte separates the reactive electrodes (the lithium and vanadium oxide film layers), enabling the conversion of the battery's chemical energy into electrical energy.

Bates' group participated in an earlier CRADA in 1992 with Eveready Battery Company. In this project the researchers developed a protective coating for thin-film lithium batteries.

Currently, the group is involved in a CRADA with Teledyne Electronic Technologies. Researchers are working to apply the sensing device first to the electroencephalogram (EEG), a test that monitors activity in the brain. The technology may later be applied to the electrocardiogram (EKG), a test for detecting abnormal activity in the heart.

In these tests, extremely low-level electric signals received from the body are relayed by sensors across electrical wires to a machine that amplifies the signal for a reading. "During that trip, motion and other environmental factors can distort and even swamp out the signal," says Bob Steenberge, a researcher at Teledyne. "The technology we're developing puts the amplifier right at the head of the source, making for a clearer signal, and the lithium battery may provide just the power source we need to operate it."

Several companies have shown interest in ORNL's thin-film lithium battery for these applications: backup power for computer memory chips in case of a power outage, backup power for solar-powered devices in space, notebook computers, miniature hearing aids, and ultrathin watches. Bates' group is also exploring the use of thin-film batteries for powering micromachines.

Sensors will allow staff at computer control centers to monitor the pace of traffic and identify slowdowns.

ORNL Sensor Research To Aid Traffic Flow for Atlanta Olympics

ORNL is involved in a CRADA with an Atlanta, Georgia, company to improve the traffic flow during the Summer Olympic Games to be held in 1996 in Atlanta. Steve Allison, David Howell, and Gary Capps, all of ORNL's Engineeering Technology Division, will work with Supercond Technology, Inc., to develop a traffic monitoring system.

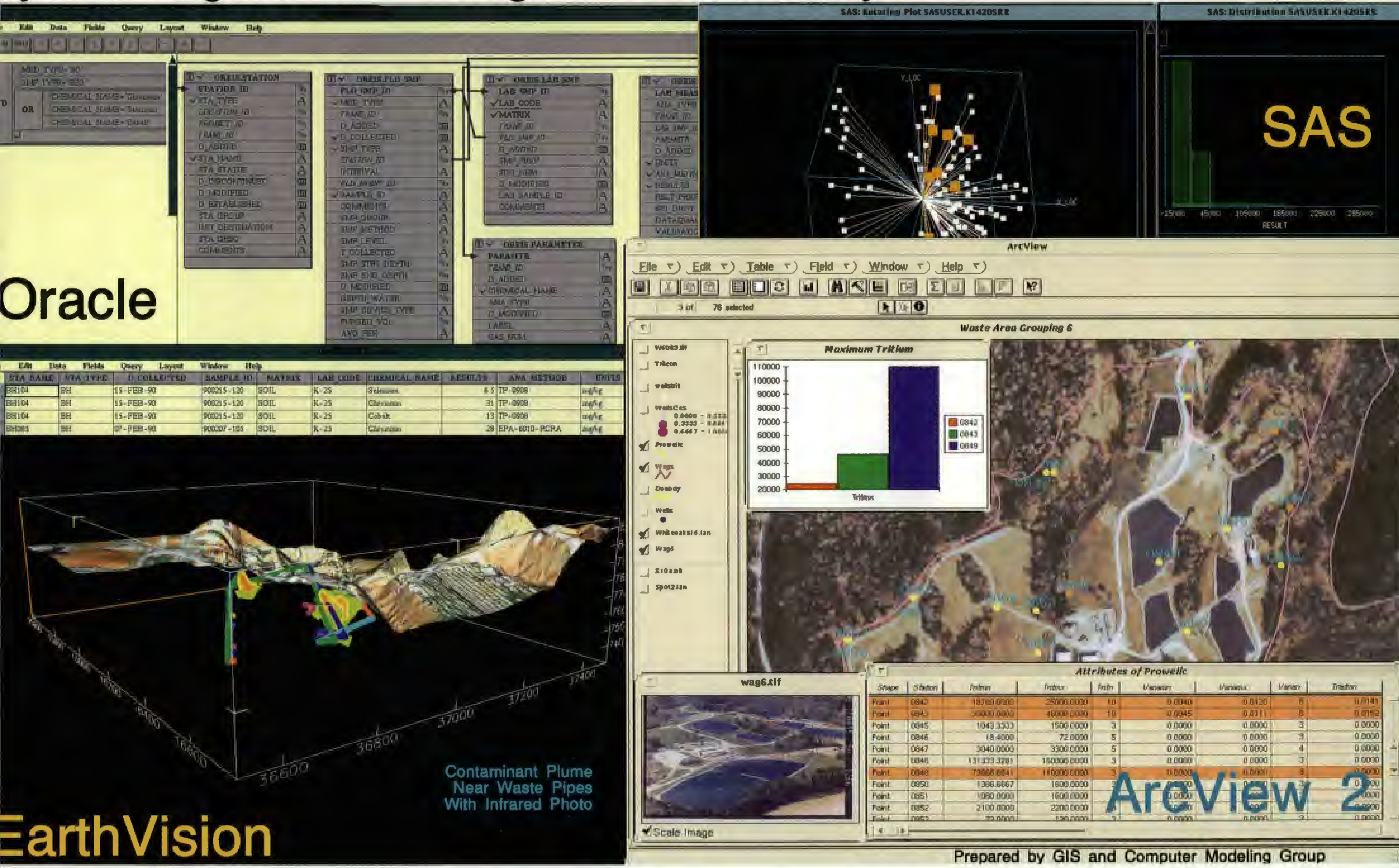
Sensors embedded in road materials — called "smart structures"— for use in major highways will allow staff at computer control centers to monitor the pace of traffic and identify slowdowns or other problems. The ORNL researchers must determine the compatibility of the sensors with road materials, such as asphalt and concrete, before they can develop smart structures. They will test the effects of extreme temperatures and other conditions on the sensors to determine their durability.

Another project is to develop and implant silicone rubber fibers into reusable shipping containers made of polymer-based composite materials. The fibers will serve as sensors for quickly and easily monitoring the containers' structural integrity.

Supercond Technology, a minority-owned company, specializes in defense technology conversion focusing on smart-materials development and advanced communication systems for aerospace and other commercial applications.

Thomas Mensah, president of Supercond, said the research is expected to have applications far beyond the 1996 traffic flow in Atlanta.

Systems Integration at Oak Ridge National Laboratory for Hazardous Waste Studies



Various computer tools that support studies of hazardous waste sites on the Oak Ridge Reservation include GIS, statistical tools, relational data-base management systems, subsurface modeling, and visualization techniques. These resources are important for managing, analyzing, storing, displaying, and disseminating environmental and geographic information throughout the DOE complex.

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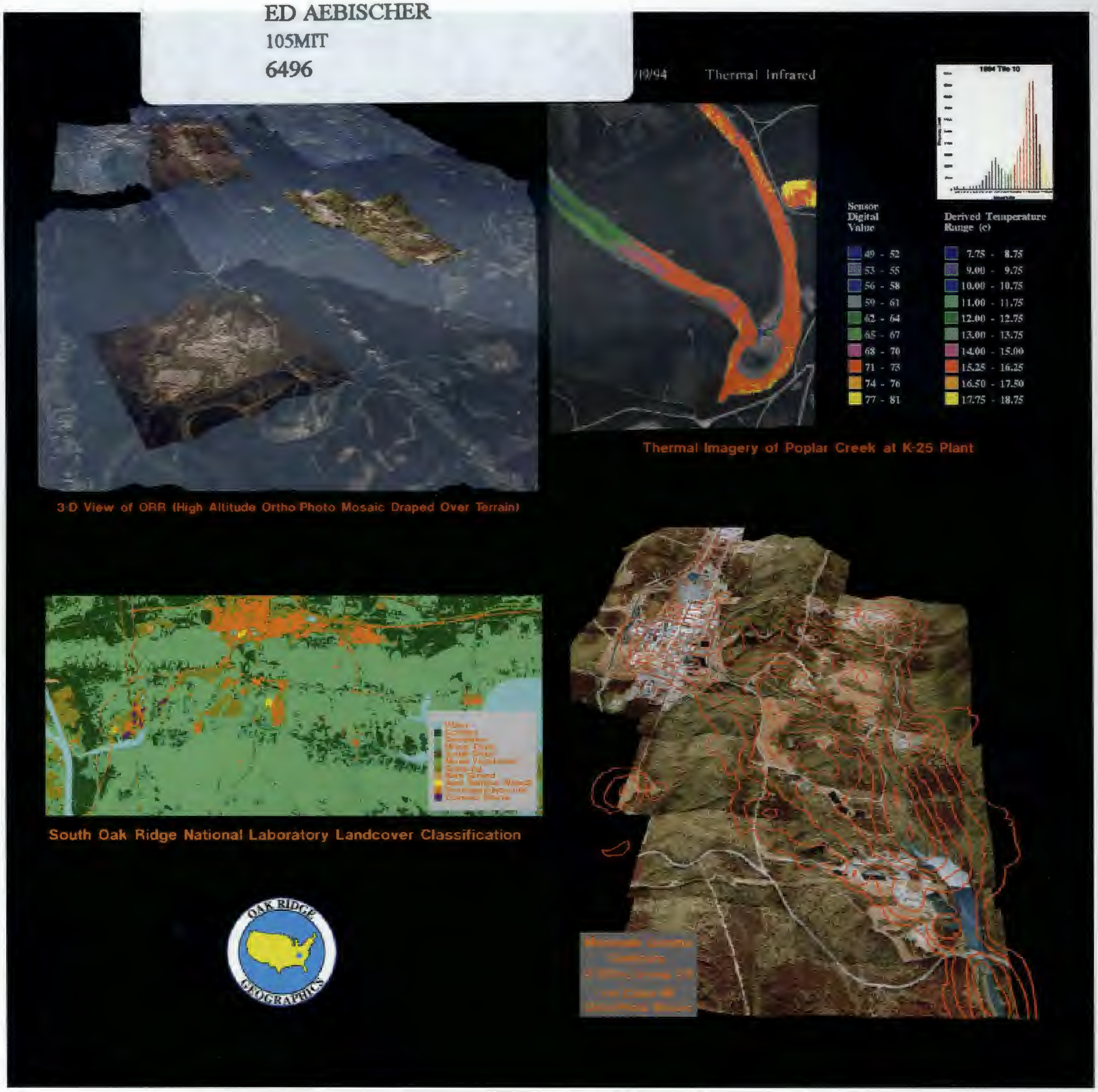

3-D View of ORR (High Altitude Ortho Photo Mosaic Draped Over Terrain)

Thermal Imagery of Poplar Creek at K-25 Plant

South Oak Ridge National Laboratory Landcover Classification

All types of remotely sensed information are analyzed and integrated to characterize DOE facilities. Examples from John Smyre's work are shown here including mosaics of rectified aerial photography over the Oak Ridge Reservation, airborne thermal studies of water bodies at the Oak Ridge K-25 Site, gamma radiation contours computed from helicopter surveys superimposed on digital terrain models of ORNL, and land-cover patterns across the ORNL burial grounds as computed from airborne multispectral scanner surveys.

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