Oak Ridge National Laboratory REVIEW

Vol. 23, No. 3, 1990

ORNL's Future Missions

Robotics for Hazardous Environments

Search for Ozone-Safe Chemicals

ON THE COVER

This photograph shows a vivid result of materials synthesis and processing by ORNL researchers. It reveals the structure of a nickel/nickel-boride composite material photographed through a microscope using polarized light. In a process called directional solidification, the nickel boride segregates from nickel metal to form a two-phase composite. This segregation is shown by the dark and light colors in the photograph: under polarized light, the Ni_3B phase appears as dark bands in the lighter nickel metal matrix. For a discussion of composite materials, see the editorial on p. 3.

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REVIEW

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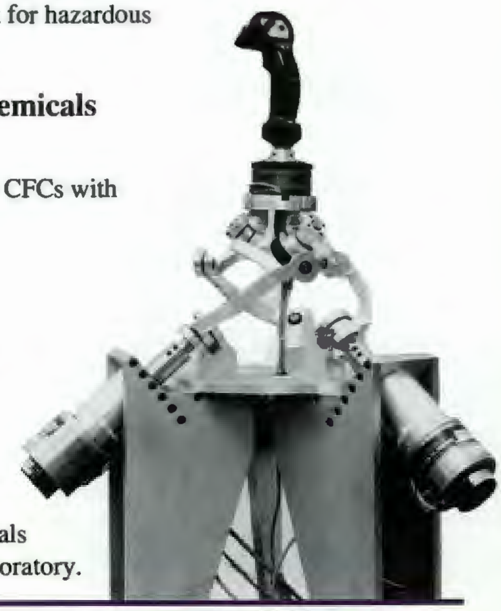
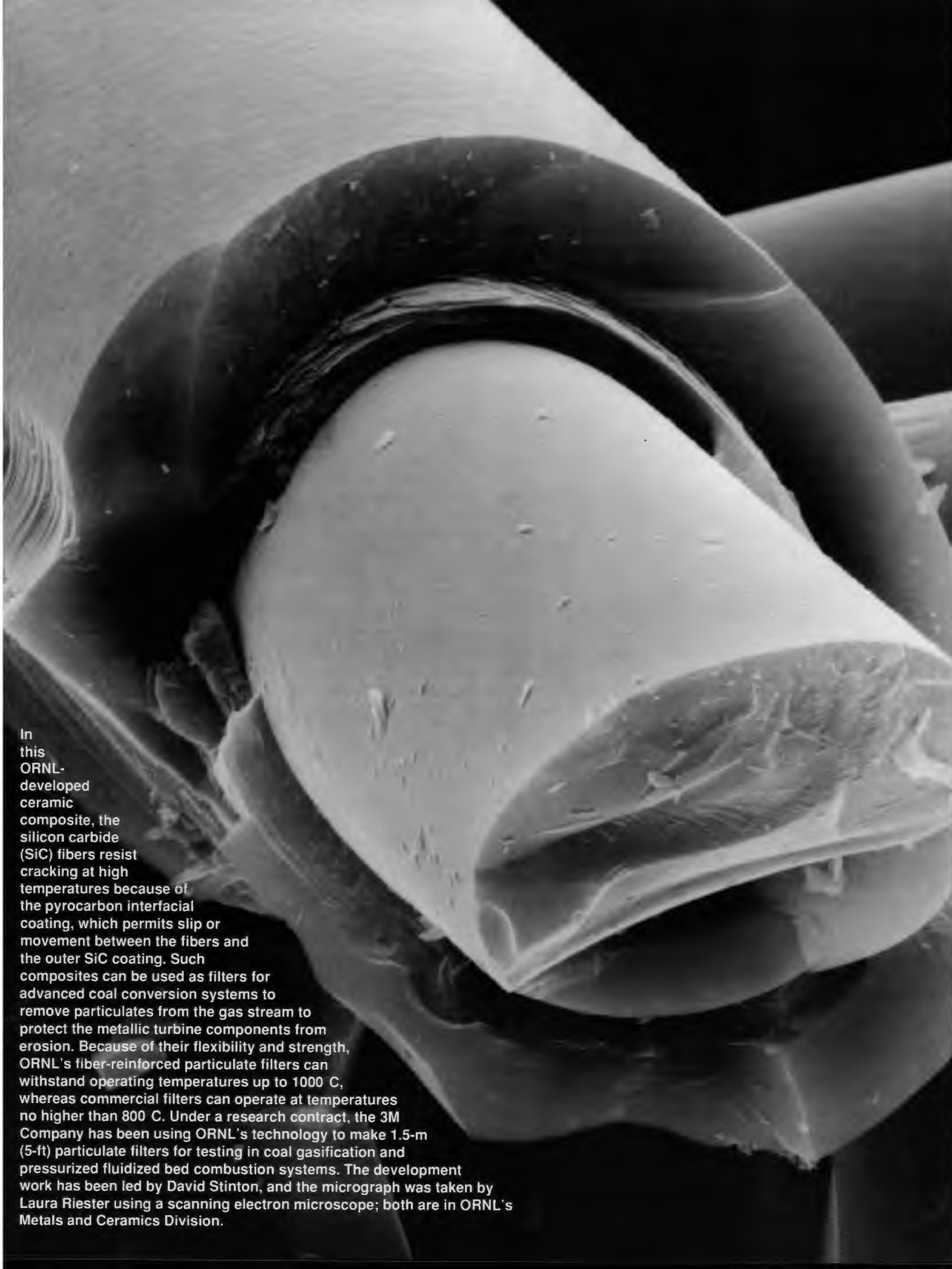
FEATURES



DEPARTMENTS

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



In this ORNL-developed ceramic composite, the silicon carbide (SiC) fibers resist cracking at high temperatures because of the pyrocarbon interfacial coating, which permits slip or movement between the fibers and the outer SiC coating. Such composites can be used as filters for advanced coal conversion systems to remove particulates from the gas stream to protect the metallic turbine components from erosion. Because of their flexibility and strength, ORNL's fiber-reinforced particulate filters can withstand operating temperatures up to 1000 C, whereas commercial filters can operate at temperatures no higher than 800 C. Under a research contract, the 3M Company has been using ORNL's technology to make 1.5-m (5-ft) particulate filters for testing in coal gasification and pressurized fluidized bed combustion systems. The development work has been led by David Stinton, and the micrograph was taken by Laura Riester using a scanning electron microscope; both are in ORNL's Metals and Ceramics Division.

An editorial by Bill Appleton, ORNL associate director for Physical Sciences and Advanced Materials

ORNL Can Create Advanced Materials

In a recent study by the National Research Council (NRC) entitled *Materials Science and Engineering for the 1990s*, synthesis and processing of materials were identified as areas of research and development essential for the future competitiveness of U.S. industry. The study surveyed eight major industry groups—aerospace, automotive, biomaterials, chemicals, electronics, energy, metals, and telecommunications—and concluded that "there are opportunities for progress in areas ranging from the basic science of synthesis and processing to materials manufacturing that, if seized, will markedly increase U.S. competitiveness."

To further define the needs in these areas, four regional meetings, including one in the Southeast, have been held since the NRC study to draft an action plan for use by the Office of Science and Technology Policy in coordinating materials science and engineering at the national level.

ORNL's advanced materials programs have pioneered in several areas of synthesis and processing, including alloy development, surface modification technologies, high-temperature materials, and specialized ceramics. The development of composite materials by our Applied Technology, Chemistry, Engineering Technology, Metals and Ceramics, and Solid State divisions is a good example of ORNL's contributions to advancing materials technologies.

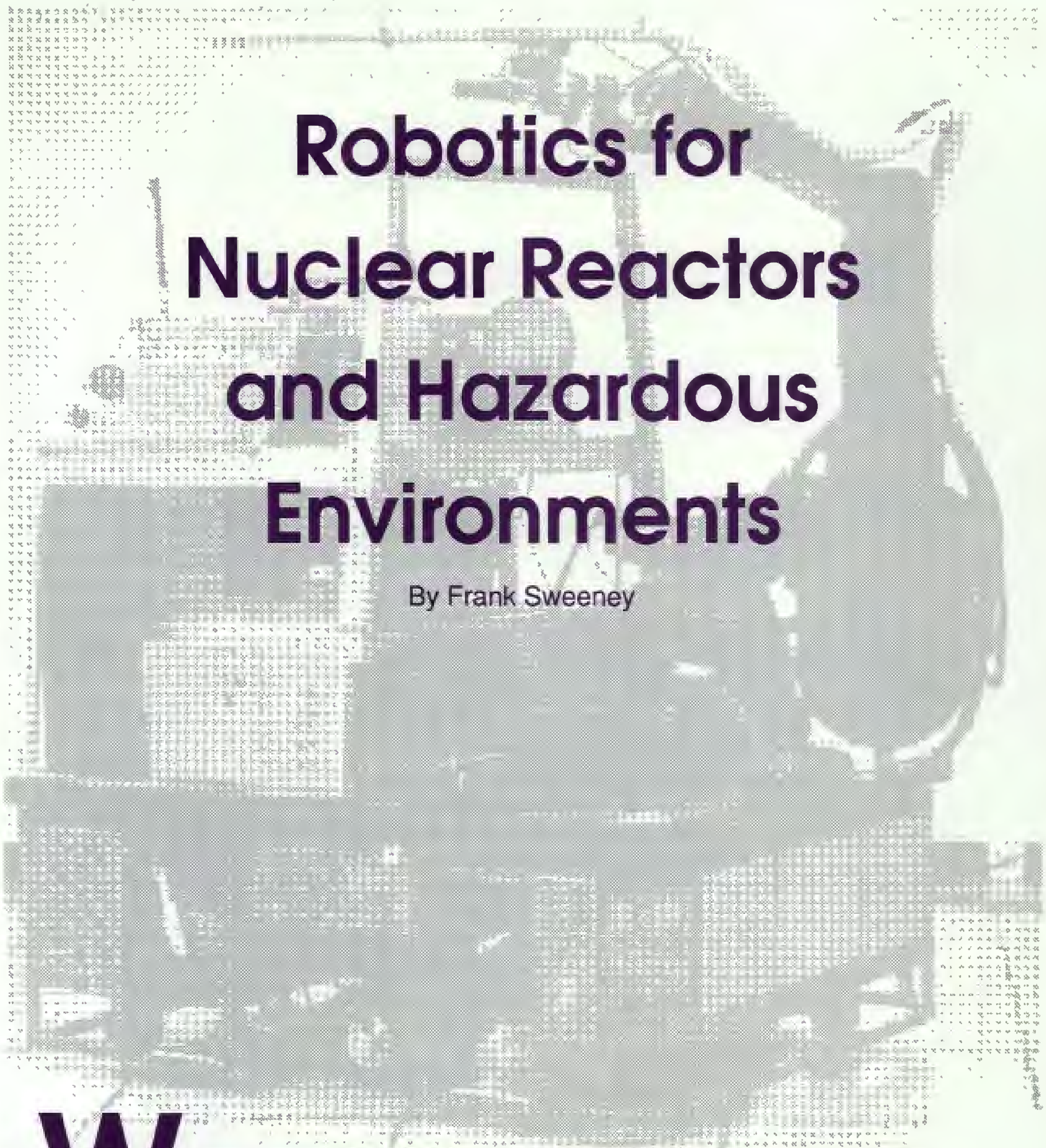
Creating composites is important because they are among the most useful modern materials. Composites consist of a matrix material into which some other material is incorporated to produce enhanced properties such as strength, fracture toughness, and wear resistance. The most familiar composites are metal, ceramic, or polymer materials reinforced with fibers; carbon-fiber–reinforced materials are used in tennis racquets and the American stealth bomber. Another example is the ORNL-developed whisker-toughened ceramic material (various ceramic materials containing silicon carbide whiskers, including the example shown in the micrograph on the facing page) that has been licensed for the manufacture of cutting tools, among other things, because of its superior strength and toughness.

One of the many examples of the increasing emphasis on synthesis and processing by ORNL materials scientists is shown on the cover of this issue of the *Review*. The picture shows the structure of a nickel/nickel-boride composite material photographed through a microscope using polarized light. The composite was formed from a eutectic mixture by a process called directional solidification. A eutectic mixture has a lower melting temperature than either of its separate constituents [in this case, nickel-boride (Ni_3B) and nickel (Ni)]. In directional solidification, a tube or long "boat" containing the molten mixture is slowly moved into a cool zone where the solid phase forms in a controlled fashion. Continued movement of the tube into the cool zone sweeps the solid-liquid interface along the length of the container until the entire mixture is "directionally solidified." In the solidification process Ni_3B segregates from nickel metal to form a two-phase composite. This can be seen from the photograph, where, under polarized light, the Ni_3B phase appears as dark bands in the lighter nickel metal matrix.

In addition to forming composite materials of eutectic mixtures, directional solidification is also used to grow large single crystals of a variety of materials. It can form dendritic crystal turbine blades for use in engines operating under harsh conditions. It may also be used to make materials that are electrically conducting in one direction and highly insulating in another.

The use of composites as advanced structural materials is increasing rapidly in many sectors of the economy, and the yearly product sales have been forecast at as much as $25 billion by the year 2000. Consequently, in the years ahead we can expect more and more research results, such as directionally solidified Ni_3B composites, to find their way to the marketplace.

Several ORNL divisions have established a joint research and engineering venture with the University of Tennessee at Knoxville called the Composite Materials Science and Processing Laboratory. A major strength of the ORNL materials science and engineering programs is that they span the entire range from basic research to development and include effective industry interaction programs and technology transfer efforts. Look for other ORNL developments in the future.



Robotics for Nuclear Reactors and Hazardous Environments

By Frank Sweeney

"ORNL's newest robot is helping researchers design an intelligent, unsupervised machine for performing work in hazardous environments."

When robots are mentioned, many people think of movie characters such as C-3PO and ROBOCOP, which are humanlike robots capable of speaking alien languages or absorbing a hail of bullets without damage and, most importantly, of thinking for themselves. Because of such movie characters, it is generally believed that intelligent machines really exist. However, despite the fantastic growth of electronic and computer technologies, commercially available robots can barely perform the simplest of human tasks, such as moving around without bumping into obstacles or recognizing objects on a table. In most cases, the robot's every action must be guided by a human operator.

This article will explore a strategy to develop a robot that eventually will not require remote operation by humans because it is capable of intelligent and unsupervised operation.

Chernobyl Shows Failures of Current Technology

The misconception that current robots perform like movie characters has resulted in unfulfilled expectations. During the Chernobyl nuclear power plant accident in April 1986, Soviet scientists attempted to employ robots to entomb the damaged nuclear reactor and remove more than 100 tons of contaminated debris from the roof of the reactor building. The Soviets used about 60 remotely controlled machines, but most of the robots quickly succumbed to the adverse effects of high radiation levels on their electronic components. The machines that were able to operate in the high-radiation environments often failed later because of moisture penetration following decontamination with water sprays. Because the robots failed to perform these tasks, Soviet officials eventually gave these jobs to 5,000 workers, who absorbed a total of 125,000 rem of radiation doses. The maximum permitted dose for any one worker was 25 rem, which was five times the normal yearly standard. Altogether, 31 workers died at Chernobyl, 237 had confirmed cases of acute radiation sickness, and many more are likely to eventually suffer adverse effects from their radiation exposure.

Can Humans Be Removed from Hazardous Environments?

Although the robotics experiences at Chernobyl paint a bleak picture, they also challenge researchers to develop advanced technologies that will remove humans from hazardous environments. The Department of Energy, realizing that current robotics technology may not be sufficiently developed to be used effectively in day-to-day operations of nuclear facilities or under accident conditions, has funded a research program involving a team from the universities of Michigan, Tennessee, Florida, and Texas and from Oak Ridge National Laboratory to conduct research leading to the development and deployment of advanced robotic systems. These systems would be capable of performing tasks that are hazardous to humans, that generate significant occupational radiation exposure, and whose execution times can be reduced if performed by an automated system. DOE's goal is to develop a generation of advanced robotic systems capable of performing surveillance, maintenance, and repair tasks in nuclear energy facilities and in other hazardous environments.

Robotics Research for Advanced Reactors

The team adopted a strategy to achieve the program goals efficiently and quickly. It consists of using, and advancing where required, state-of-the-art robotics technology through close interaction among the universities, ORNL, and the manufacturers and operators of nuclear power plants. The approach adopted by the team is a staged transition from robots remotely operated solely by humans (teleoperation) to intelligent and unsupervised (autonomous) operation (see sidebar on pp. 16–17).

An example of how such a staged transition could benefit a robotic application is the simple cleanup of a radioactive chemical spill so that humans can safely enter the work area. Using current technology, a trained operator manipulating a joystick controller directs a robot into the work area, which is viewed on a video monitor. Because the operator has a limited field of view and must avoid running the robot into or over obstacles, the robot is driven at a very slow speed. Once the robot has arrived in the work area, the operator takes control of a mechanical arm (manipulator arm) and uses a sweeping motion to move an attached vacuum cleaning device over the spill area. This cleanup operation is very tedious because of the large number of similar repetitive sweeping motions required. Studies of manipulator arms in laboratory environments have shown that completion of a simple repetitive task such as vacuum cleaning may take up to ten times longer than if done by a human.

First-Stage Solution: Aid Robot Operators

The team attacks a problem like this through a staged approach. In the first stage, techniques could be developed to aid the operator in reducing the time required to complete the task and in making it less tedious. For example, information from sensors could be fed back to the joystick controller to help the operator avoid obstacles. This improvement requires that additional range sensors be mounted on the robot and that a force-feedback joystick be used (see photo on p. 8). As the operator moves the robot closer to an obstacle, the joystick pushes back against the operator's hand, warning the operator to steer the robot in another direction.

Such operator assistance offers these benefits: (1) it would prevent the operator from damaging the robot by inadvertently driving it into an obstacle; (2) it would allow the operator to run the robot at a higher rate of speed because the joystick, coupled with sensors, provides additional information about obstacles that the operator may not see on the video monitor; (3) the tedium of driving the robot is reduced because the operator will not have to concentrate totally on avoiding obstacles and driving the robot at a slow speed for a long time; and (4) the operator may not need as much training and experience to successfully navigate the robot.

Second-Stage Solution: Autonomous Operations

In a second-stage solution, the team would search for ways to make a robot capable of making decisions and performing tasks with virtually no guidance from a human operator. Such highly autonomous robot operations are possible if the robot is equipped with computer intelligence, sensors, a

Photo by Ross Lynn Freeny

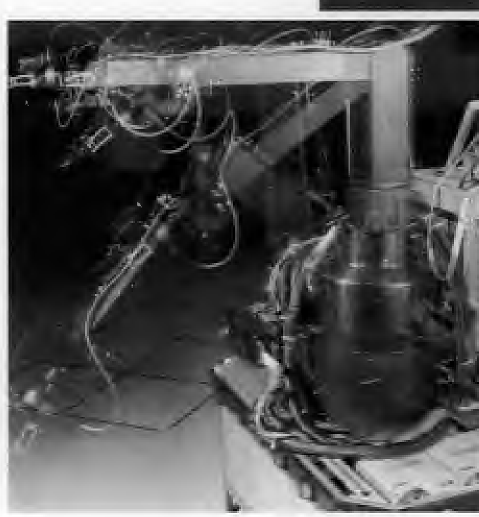
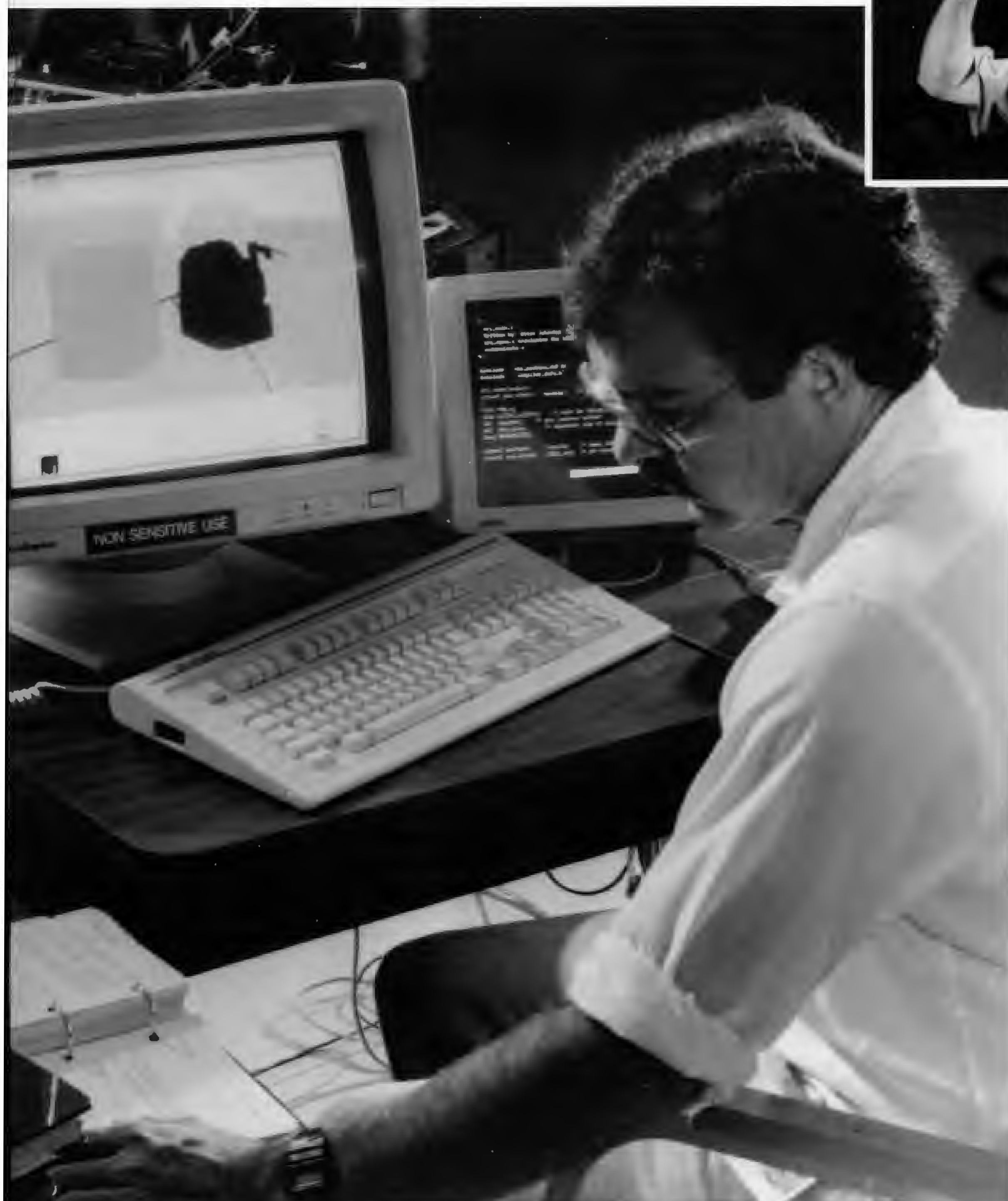


Photo by Ross Lynn Freeny

This time-lapse photograph shows a few of the seven possible positions (degrees of freedom) of the HERMIES-III arm and its joints.

Frank Sweeney inspects a charge-coupled device video camera mounted on the wrist of the CESARm manipulator of HERMIES-III.

Photo by Ross Lynn Freeny



Judson Jones uses the operator-machine interface to control the HERMIES-III robot, shown on the video screen.

"Using current technology, a trained operator manipulating a joystick controller directs a robot into the work area, which is viewed on a video monitor."

dexterous mechanical arm, and motors to move the robot components.

In the case of the spill, an advanced human-computer interface would be developed. The operator first plans the task through this interface by specifying the suspected location of the chemical spill (e.g., the north corner of the room) and the required operation (cleaning up the spill). The robot then uses its own intelligence to plan a path to the suspected spill location and presents it to the operator for his approval. The operator would either approve or modify the plan and then command the robot to execute it. The robot uses its own intelligence to guide it to the work area without running into obstacles. After the spill is located by the robot, it automatically cleans it up. In this solution, a high-level human-machine interface is necessary for communication with the robot because commands such as "clean up the spill" and "go look in the corner of the room" are meaningful only to humans. Such commands must be translated into machine actions for the robot to act upon. The robot must also have sensors to recognize and navigate around obstacles (range sensors that indicate how far the robot is from an obstacle) and detect the spill (radiation detectors and video cameras). Most important, it must have the intelligence to deal with all of these tasks. For example, if the robot encounters an obstacle, it must find a way around it. It must be able to recognize a radioactive chemical spill. The benefits of such a solution are that (1) the operator interacts with the robot only when needed, allowing this person more time to concentrate on more important tasks, and (2) because the operator now must know only how to communicate with the robot, the need for operator training and experience is reduced.

The Price of Autonomy: Cost and Complexity

Because of the sophistication required by these two solutions, the obvious drawbacks of this approach are its high cost and complexity. In the first stage, to achieve obstacle avoidance, the robot must have additional sensors, a force-reflecting joystick, and a computer—all expensive hardware items. In addition, a computer code must be written to obtain the data from the sensors, compute the forces to be fed back to the joystick, and actually generate the forces at the joystick. The robot that was previously driven by only a joystick, actuators (motors to move the

This force-reflecting joystick controller designed and constructed by the University of Texas controls the HERMIES-III robot. Three motors at the bottom of the joystick generate the forces felt by the operator driving the robot.

robot and mechanical arm), and a video camera now has increased in complexity by the addition of a computer, computer code, force-reflecting joystick, and range sensors, all of which have a higher probability of failing while the robot is in a high-radiation environment.

The second-stage solution requires an even higher level of sophistication at correspondingly higher cost and complexity. A human-machine interface is necessary, along with additional sensors, for navigating the robot, detecting the spill location, and cleaning it up. More importantly, the intelligence to support these tasks and deal with unexpected events must be programmed into the robot's computers. Because of the number and complexity of the tasks that must be performed by the robot, multiple computers are needed to accomplish the work in a reasonable amount of time. Again, although the robot is capable of performing tasks without the supervision of a human being, its complexity has been dramatically increased by the addition of numerous hardware items and literally thousands of lines of computer code. Because of such complexity, it is possible that the failure of a single piece of hardware, or a single mistake in a computer program, will cause the robot to become totally inoperative.

A Hidden Problem: Lack of Robustness

When systems such as robots, space vehicles, or nuclear power plants become complex, they may suffer from a problem called lack of robustness. That is, when any such system encounters an unexpected event or uncertainty, or it attempts to operate in a regime not considered by the system designers, the system may fail to operate, sometimes catastrophically. In many cases, lack of robust operation of a system may be caused by internal inconsistencies or conflicts. For example, when one of the three computers monitoring the same subsystems on a space shuttle launch indicated a problem, it generated a conflict that the system was unable to deal with: two computers saying, "Launch," while the third says, "Hold." In this instance, the system failed in a safe manner and the launch was aborted even though the problem was caused by a failed sensor. For robots operating in hazardous environments, such a lack of robust operation can be devastating. If the robot shuts down in a radiation field, humans may have to enter the work area to recover and repair the robot, thereby accumulating radiation exposure. Unfortunately, as the robots become more complex, more intelligent, and, therefore, more likely to be used for complex tasks, the probability of running into situations that will cause a lack of robust operation becomes higher.

ORNL and other researchers believe that many of the difficulties from lack of robust operation can be overcome by improving a robot's ability to sense its environment and interpret the data coming from its sensors. In terms of hardware, sensors must be improved to detect more accurately the object of interest without being adversely affected by other external variables. For example, a video camera is used to detect light reflected from the surfaces of objects in the robot's environment. However, high radiation levels can cause "snow," or noise, in the video signal. How does the robot distinguish between real objects and and the noise created by the radiation field? To achieve more robust operation, one solution is to improve the sensor to minimize the radiation effects. Another solution is to develop software that can intelligently interpret the video signal and disregard the noise. So increased robustness can result from combining improved hardware with software intelligence.

Software designed to improve the robustness of robot actions generally must cope with three types of problems: errors (no signal is coming from the sensor), uncertainties (the video image of the room is not clear), and limitations (the room is too dark for a good video image). When these problems occur, the system must be able to compensate for poor conditions and continue to operate. To overcome these problems, ORNL researchers are seeking to obtain the best information from several different kinds of sensors. This technique is called multi-sensor integration (MSI), or sensor fusion, because data from several sensors are combined, or "fused," to give the best interpretation. An example is combining the information from a video camera and an ultrasonic range sensor to produce accurate maps of the robot's environment. The two sensors detect entirely different physical phenomena: the video camera detects reflected light, and the ultrasonic sensors detect sound waves bouncing off objects. From the video camera, discontinuities in surfaces of the environment (edges) can be obtained from the images, but shadows and glare make it difficult to interpret the information. Range data from the ultrasonic sensors can then be used to discriminate among shadows, glare, and true discontinuities.

HERMIES-IIB and HERMIES-III

As part of DOE's Basic Energy Sciences (BES) Program and the University Program in Robotics for Advanced Reactors, two prototype robot test bed facilities for robotics research have been constructed at the Center for Engineering Systems Advanced Research (CESAR) in ORNL's Engineering Physics and Mathematics Division. As a team, the universities and ORNL performed research in robotics on navigation, manipulation, sensing, and human-machine interfaces. The team performed the research to develop a robot capable of carrying out seemingly simple tasks: navigating through the laboratory, finding a control panel, and reading a pair of indicator meters there. Hardware and software developed by the universities and ORNL were integrated into a single experiment by ORNL in the CESAR laboratory. The robot used for the first team experiment in 1988 was called the Hostile Environment Robotics Machine Intelligence Experiment Series IIB, or HERMIES-IIB (see photo above).

HERMIES-IIB weighs about 68 kg (150 lb) and stands ~1.2 m (4 ft) high. Two video cameras and seven arrays of sonar range sensors are mounted on the robot to perform the navigation and panel-recognition tasks. A unique feature of the robot is its tremendous on-board computational power; it contains three computers, one of which is a hypercube architecture parallel processor that has four nodes (central processing units). A human-machine interface developed by the University of Florida and run on a three-dimensional computer graphics work station allows the operator to perform path planning and to communicate with the robot. The robot can be controlled manually through a force-reflecting joystick developed by the University of Texas. The robot uses the sonar range sensors to navigate and algorithms developed at the University of

HERMIES–IIB has been used by ORNL and university researchers in an integrated demonstration of autonomous robot control.

Michigan to avoid obstacles. Recognition and analysis of the control panel by the robot was performed with computer algorithms developed by the University of Tennessee. ORNL integrated each of the computer modules into a single robotic system. Despite the fact that no manipulation was performed in this experiment, more than 20,000 lines of computer code were needed to execute the scenario.

In 1989 the team tackled a more complex problem: developing a robot that can navigate through the laboratory, avoid any unexpected obstacles automatically, locate a simulated chemical spill, and clean it up. Unlike the previous experiment, the new robot's own intelligence was used to avoid obstacles and a manipulator arm was required to sweep a vacuum device over the floor to remove the chemical material (see photo on p. 12). To meet the experiment's requirements for even greater machine intelligence and for a multiple-jointed mechanical arm, the CESARm manipulator robot was built. HERMIES-III is the second-generation robot designed to autonomously perform human-sized tasks. Compared with HERMIES-IIB, its computational and sensing capabilities are awesome. It has 32 sonar sensors and a laser range camera for navigation and obstacle avoidance; three video cameras for locating the spill, including one mounted to the wrist joint of the mechanical arm; and seven on-board computers to control the robot and mechanical arm and to acquire data from the sensors. To support all this equipment, HERMIES-III's size is also awesome; it weighs more than 900 kg (2000 lb) and stands 2 m (6 ft) high. Three of the computers are needed to control the mechanical arm; two control the robot and sensors, and one acts as a "watchdog" by constantly monitoring the operation of the other computers. Over 50,000 lines of computer code were necessary to perform this experiment. The seventh computer is an NCUBE hypercube parallel processor for high-speed computations on laser range and video-camera images.

Lessons Learned

What have we learned from our experiences? Perhaps most important, we have relearned what has been known since the early days of machine intelligence research: emulating human capabilities in machines is not easy. In many cases, basic human capabilities that we take for granted—vision, touch, taste, locomotion, dexterity, balance, hearing, and intelligence—are often the most difficult to achieve in robots. Despite this difficulty, we have found that individual tasks such as navigation and obstacle

The HERMIES-III robot is used by the ORNL-university team to demonstrate autonomous navigation and obstacle avoidance to locate and clean up a simulated spill in the CESAR laboratory.

A seven-degree-of-freedom manipulator arm (CESARm) mounted on the HERMIES-III robot carries a vacuum device to remove simulated chemical spill material from the floor. Three computers are used solely to control the manipulator.

avoidance can be highly or completely automated and that this automation can significantly reduce the human burden of operating robots. Unfortunately, the cost of such automation is very high today because of the expense of hardware and research development and because of system complexity and robustness.

Currently, most autonomous robots operate effectively only in fairly well-characterized environments—that is, environments in which the range of physical variables (lighting intensity, size and location of obstacles, etc.) is fairly well known. On the surface, nuclear facilities are good candidates for well-characterized environments; the challenge lies in the ability of autonomous robots to cope effectively with unexpected events as minor as failed light bulbs in a corridor or as major as explosions in which known environments suddenly become unfamiliar.

Through their research programs and annual demonstrations, ORNL and its university partners have made significant progress in advancing the ability of robots to robustly operate in these types of uncertain environments.

Nuclear Reactors and Robotics

What is the future of robotics for nuclear environments? The rate of growth of robotics for current light-water reactors has been agonizingly slow. Virtually all robots in use at these facilities are teleoperated with few or no autonomous capabilities. Many of the robots at these facilities are of "one-off" construction— that is, designed to perform a single task. Such robots can be very costly to operate compared with general-purpose robots that could perform a variety of tasks.

Despite this slow penetration of robotics technology into the nuclear environment, several bright spots exist. In 1986, the Utility/Manufacturer Robot User Group (UMRUG) was formed to promote technical interaction between utility engineers and robot manufacturers to bring cost-effective utility robotics applications to the marketplace. The group, which includes ORNL participants, meets biannually and circulates materials concerning robotics activities with the minutes of its meetings. ORNL hosted the UMRUG meeting in May 1990 as part of the effort to move advanced robotics technologies into the field.

Another bright spot has been the recent increase in the use of robots by nuclear utilities. In 1986 only 5 utilities reported use of robots in their operations, but in 1989 this figure had increased to 26. An important impetus for robotic development has been the rapid increase in the cost of human radiation exposure. Human radiation exposure costs are estimated to exceed $10,000 per person-rem, and increasingly strict regulations may drive this figure higher, perhaps exponentially. Current robotics technology is capable of reducing radiation exposure, and the degree of success in this endeavor is largely determined by the commitment of the utilities' management to its use.

Although much of the focus of robotics applications is on current light-water reactors, robotics will be needed for advanced reactors now under development. The ORNL-university team has helped define robotics needs for the Power Reactor Inherently Safe Module (PRISM), which is an advanced liquid-metal reactor that may be built in the late 1990s. The team has shown that advanced robotic systems will be needed for safe, efficient operation of PRISMs; other advanced light-water reactors; and modular high-temperature, gas-cooled reactors.

Besides me, members of ORNL's DOE/ Nuclear Energy Robotics Team are Martin Beckerman, Phillip Butler, Ralph Einstein, Judson Jones, and David Reister. The team is guided by Harry Alter of DOE's Office of Advanced Reactor Programs.

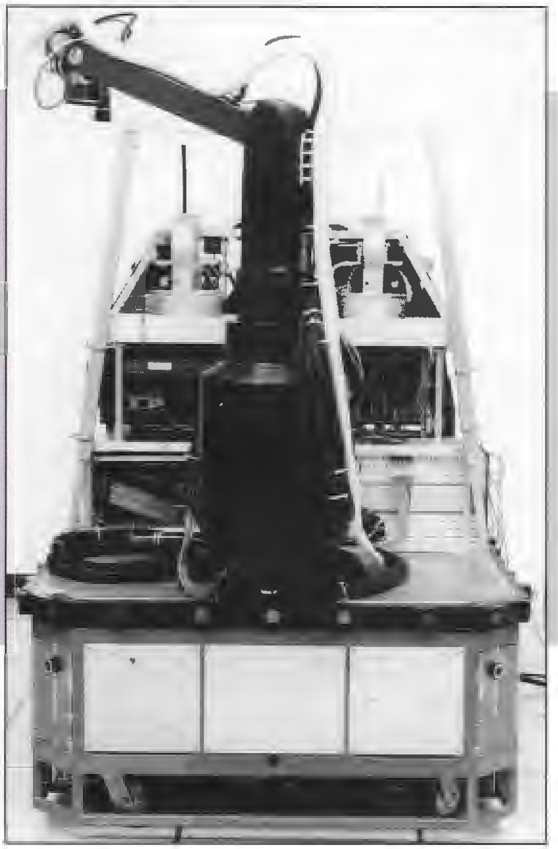
Environmental Restoration and Robotics

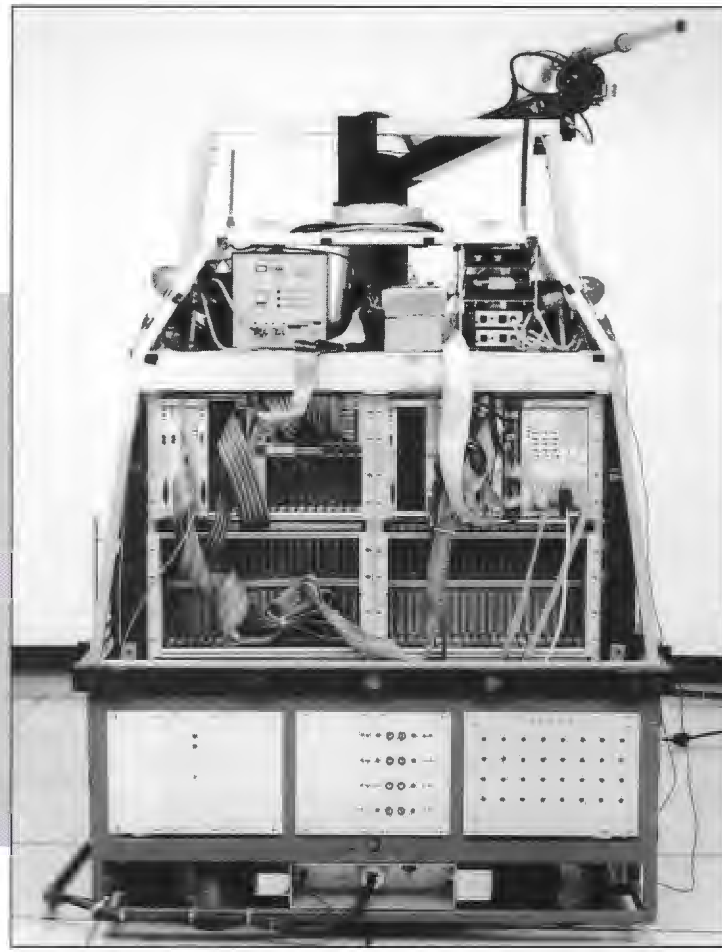
Robotics also has a future in waste management and environmental restoration activities. These efforts are important to the DOE complex in meeting the goals of reducing risks to human health and the environment. Hazardous and radioactive waste materials stored or buried underground since the 1950s as a result of weapons programs now threaten to contaminate

"These researchers must develop robotic systems to perform seemingly impossible tasks, such as operating reliably for years in very high-radiation environments with only remote supervision."

the environment. Because of this imminent danger, DOE launched a 30-year project called the Environmental Restoration and Waste Management (ER&WM) program. This program has recognized the vital need for robotics in reducing human exposure to radiation and hazardous materials, including disease microorganisms and toxic chemicals. Additionally, robotics will be required to make program tasks faster and more cost effective. ORNL has already formed a team of robotics experts from the Robotics and Process Systems and Engineering Physics and Mathematics divisions to develop a national research and development (R&D) plan for robotics in waste management and environmental restoration. The team, along with experts from Sandia National Laboratories, has visited many of the high-priority cleanup sites in the DOE complex.

For robotics researchers at ORNL, the ER&WM program may present the greatest challenge in the next decade. These researchers must develop robotic systems to perform seemingly impossible tasks, such as operating reliably for years in very high-radiation environments with only remote supervision. Although robotics R&D for the environment may be costly, the resulting protection of human health and safety is priceless.





Biographical Sketch

Frank Sweeney is manager of DOE's University Program in Robotics for Advanced Reactors at ORNL. He received his B.S., M.S., and Ph.D. degrees in nuclear engineering from North Carolina State University (1974), the University of Michigan (1975), and the University of Tennessee (1979), respectively. In 1979 he joined ORNL's Instrumentation and Controls Division to work in reactor noise analysis. While a member of the division, he authored more than 30 publications on stochastic signal processing, reactor noise analysis, and space-dependent reactor kinetics calculations. In 1987 he became manager of ORNL's Exploratory Studies Program. In 1989 he joined the staff of the Engineering Physics and Mathematics Division to work in range image analysis.

Telerobots and Teleoperators

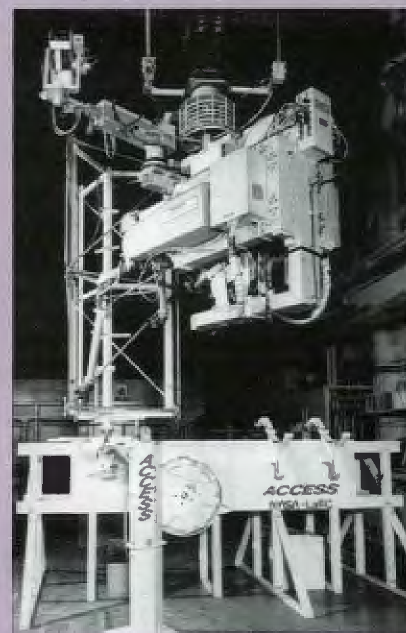
The Andros Mark VI Mobile Tactical Robot (shown above and at right), designed to perform hazardous-duty operations such as nuclear plant maintenance and surveillance, is manufactured and marketed by REMOTEC, Inc., of Oak Ridge. The telerobot, slightly less than 1 m high, can be equipped with accessories and may be used to help police officers and firefighters with their most dangerous work. One of the 25 robots sold so far is being used by officers of the Port of Seattle Police Department (officers shown at right) to detect bombs in packages, carry heavy objects, and drag victims or wounded officers to safety.

Robots used today in nuclear power plants are actually "telerobots" because they combine human remote control with the autonomy of industrial robots, which are programmed to perform one task repetitively, such as spray painting automobile bodies. Because it is guided by a human, a telerobot can perform a variety of tasks. A familiar example is the Jason Junior robot, which explored the Titanic and sent back photographs of objects inside the famous sunken ship.

Because they are both operated by humans, a telerobot is similar to a teleoperator, which consists of a mechanical arm operated by a human for remote manipulation of objects in a hazardous or inaccessible location. A familiar example is the U.S. space shuttle arms that place communications satellites into orbit. ORNL-developed teleoperators include (1) the Laboratory Telerobotic Manipulator developed for the National Aeronautics and Space Administration for

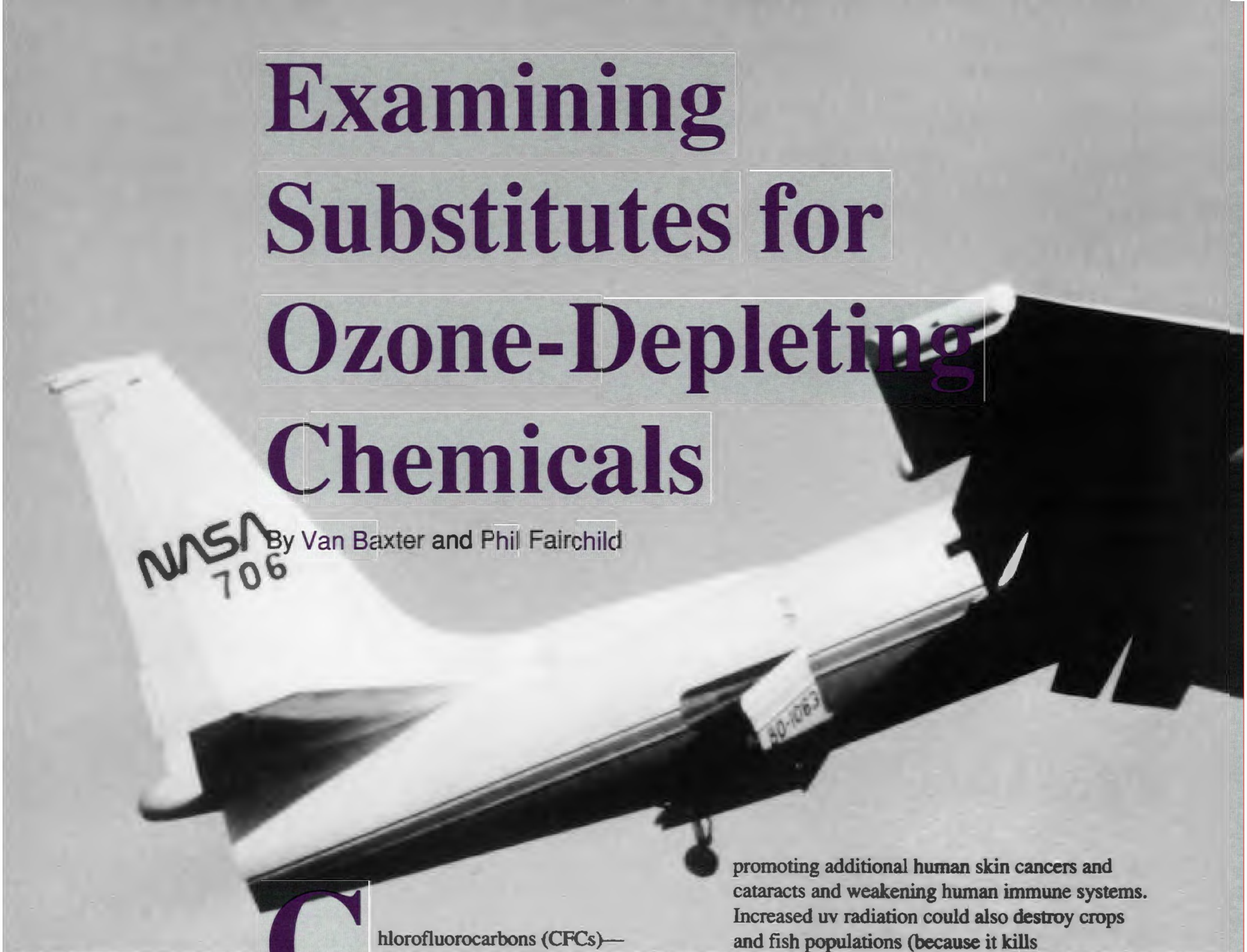
experiments to guide development of intelligent machines for the proposed U.S. space station, and (2) the Advanced Servomanipulator for remote reprocessing work in Japanese nuclear fuel recycle facilities.

ORNL developments in this area prompted the founding of REMOTEC, Inc., of Oak Ridge. The company recently announced the development of the Andros Mark VI Mobile Tactical Robot, designed to perform hazardous-duty operations such as nuclear plant maintenance and surveillance. The telerobot, about 0.8 m (32 in.) high, can be equipped with accessories such as a shotgun, a camera, or a manipulator arm for carrying out tasks in hazardous zones. REMOTEC has sold more than 25 of these telerobots; its customers include the Port of Seattle Police Department, which will use it for various police tasks, and the University of Kentucky, which is exploring ways to use "Little Andros" to fight fires.



Results from NASA experiments at the Langley Research Center with the ORNL-developed Laboratory Telerobotic Manipulator could guide the design of intelligent machines that will assemble, repair, and maintain the proposed U.S. space station.

The Advanced Servomanipulator is operated by Steve Zimmerman (left) and Mark Noakes from this control room at the Robotics and Process Systems Division.



Examining Substitutes for Ozone-Depleting Chemicals

By Van Baxter and Phil Fairchild

This 1988 photograph shows the NASA "rocket with wings" that collected the information indicating that CFCs were indeed the culprit in the depletion of stratospheric ozone, which protects life on Earth from harmful solar ultraviolet radiation.

Chlorofluorocarbons (CFCs)—fluids found in consumer items such as refrigerators, automobile air conditioners, and foam insulations—are widely used because they are effective, nontoxic, nonflammable, and do not decompose easily. Nevertheless, the use of CFCs is being restricted to protect human health and the environment.

In 1974, M. J. Molina and F. S. Rowland, while working in the Department of Chemistry at the University of California at Irvine, presented the theory that chlorofluorocarbons slowly migrate into the stratosphere, where they decompose in sunlight and split off free chlorine atoms that break down ozone (O_3) into ordinary oxygen molecules (O_2). Once liberated, a chlorine atom can destroy about 100,000 molecules of ozone before returning to Earth's surface. It is estimated that 3 to 5% of the ozone layer has been depleted by CFCs.

This thinning of the ozone shield permits more ultraviolet (uv) radiation to penetrate to Earth, promoting additional human skin cancers and cataracts and weakening human immune systems. Increased uv radiation could also destroy crops and fish populations (because it kills phytoplankton, an important food for fish in the oceans). Another environmental concern is that CFCs in the atmosphere are considered "greenhouse gases" because they absorb infrared radiation reflected from Earth; they are thus believed responsible for 15 to 20% of global warming (second only to carbon dioxide).

International Agreement

Recent scientific expeditions to measure stratospheric ozone and odd chlorine concentrations have confirmed the original hypothesis. The evidence led the United States to join more than 30 countries in signing a landmark agreement in September 1987, the Montreal Protocol, to protect stratospheric ozone. Future production and use of five CFC compounds containing chlorine and three chemically related halons containing bromine are now being regulated worldwide.

In the United States, the Environmental Protection Agency (EPA) regulations to implement the protocol took effect on July 1, 1989, imposing stages of cutbacks and mandating an overall 50% reduction in CFCs (based on 1986 production levels) by mid-1998. Periodic review provisions of this protocol together with subsequent results from the second National Ozone Expedition (NOZE-II) have virtually ensured a complete phaseout of regulated CFCs by the year 2000. Numerous companies, including E. I. du Pont de Nemours & Co. and Allied Chemical Corp., the two major U.S. manufacturers of CFCs, have pledged to cease production of refrigerant 12 (R12) and R11 when adequate substitutes are available.

In response to these pressures, research is under way throughout the world to identify suitable, environmentally safe substitutes for the ozone-destroying CFC chemicals. ORNL is making a substantial contribution to this research and technology development effort.

Potential Energy Impacts of CFC Substitutes

The U.S. economy depends on CFCs for many applications because they are effective, nontoxic, nonflammable, and inexpensive. Most of the fully halogenated CFCs (R11, R12, R114, and R115) have energy-related applications. These include the use of R12 as the working fluid in commercial and residential refrigerators and freezers and in automobile air conditioners, and the predominant use of R11 in centrifugal chillers for cooling large commercial buildings. Both R11 and R12 are used as "blowing agents" in producing foam insulation materials for residential and commercial buildings and home appliances. Reductions in production of these chemicals, as mandated by the Montreal Protocol, will result in shortages, probably leading to the use of less-efficient substitutes in insulation and, consequently, an increase in national energy use.

Because the Department of Energy has a goal of increasing energy efficiency (as reflected in government policies and industrial projects), it has been concerned that use of CFC substitutes in building and appliance insulations could reduce energy efficiency, thus increasing energy consumption. So DOE asked ORNL to analyze the potential energy-use impacts of a possible CFC phaseout. Twelve major energy-related applications of CFCs were evaluated for four different scenarios. The study, led by Steve Fischer of the Energy Division, considered a range of scenarios to identify the limits of the energy impacts, assuming the entire equipment stock conformed to the scenario.

Fischer found that if current and nearly ready CFC substitutes are used throughout the American economy, the demand for primary energy would increase by ~0.2 to >2.2 additional quads per year. (One quad of energy is enough to

Photo by Ross Lynn Freeny

Ed Vineyard (left) describes some test results to J. Michael Davis, DOE Assistant Secretary for Conservation and Renewable Energy.

"The Department of Energy has a goal of increasing energy efficiency."

heat 14 million homes for a year and is roughly equivalent to a year's consumption of oil at the rate of 500,000 barrels per day. In dollar terms, that is about $6.6 billion, based on $36/barrel.) The lowest-energy-penalty scenario assumed that the leading substitutes now under study (R123 and R141b for R11, and R134a as a replacement for R12) are accepted, produced commercially, and applied successfully. If they are not, then relying on currently available substitutes, such as R22 and non-CFC foam insulation (a "fallback" scenario), was estimated to result in an increase in national energy use of ~1.0 quad per year.

The "worst case" scenario, in which R22 was excluded as a substitute refrigerant for R12 and fiberglass was assumed as the acceptable insulation alternative, resulted in the more substantial energy use increase of >2.2 quads per year. It should be emphasized that these estimated impacts do not take into account current uses of R22, which is not currently included in the Montreal Protocol because of its low ozone-depletion potential (ODP) of 0.05. R22 is the most widely used refrigerant in the United States for building air conditioners and heat pumps. Because so much home and commercial equipment depends on it, phaseout of R22 is likely to have a much higher economic impact and more severe social consequences than the controls on R11 and R12. Fischer and Fred Creswick (also a member of the Energy Division) found that the single largest impact in each scenario—that is, the greatest decline in energy efficiency from use of CFC substitutes—would be for household refrigerators and freezers in which CFCs are used for both refrigeration and insulation.

In contrast, a fourth scenario, which examined some of the emerging ozone-safe technologies, showed that these could actually reduce current energy consumption by about 0.8 quads annually. More recent research has shown that nonazeotropic refrigerant mixture technology could offer even further energy savings. Therefore, the upcoming CFC transition may well represent an opportunity to introduce new technologies that are not only environmentally safer but also offer energy-efficiency benefits.

Search for Ozone-Safe Fluids

Over the past two years, staff members of ORNL's Building Equipment Research Program have been involved in CFC alternatives research. In addition to the preceding assessment, our various activities have included an exhaustive screening of available refrigerants having low ODP to identify acceptable and environmentally safe fluids and testing of alternative refrigerants in a refrigerator-freezer (RF) and in a laboratory breadboard refrigeration circuit.

As part of a larger ORNL program to investigate the energy-saving aspects of nonazeotropic refrigerant mixtures (NARMs), Ed Vineyard and Jim Sand, both of the Energy Division, evaluated more than 200 potential refrigerants as possible components for a NARM to be used in a residential heat pump. The materials selected from this screening are

Viability of Alternative Insulation Blowing Agents

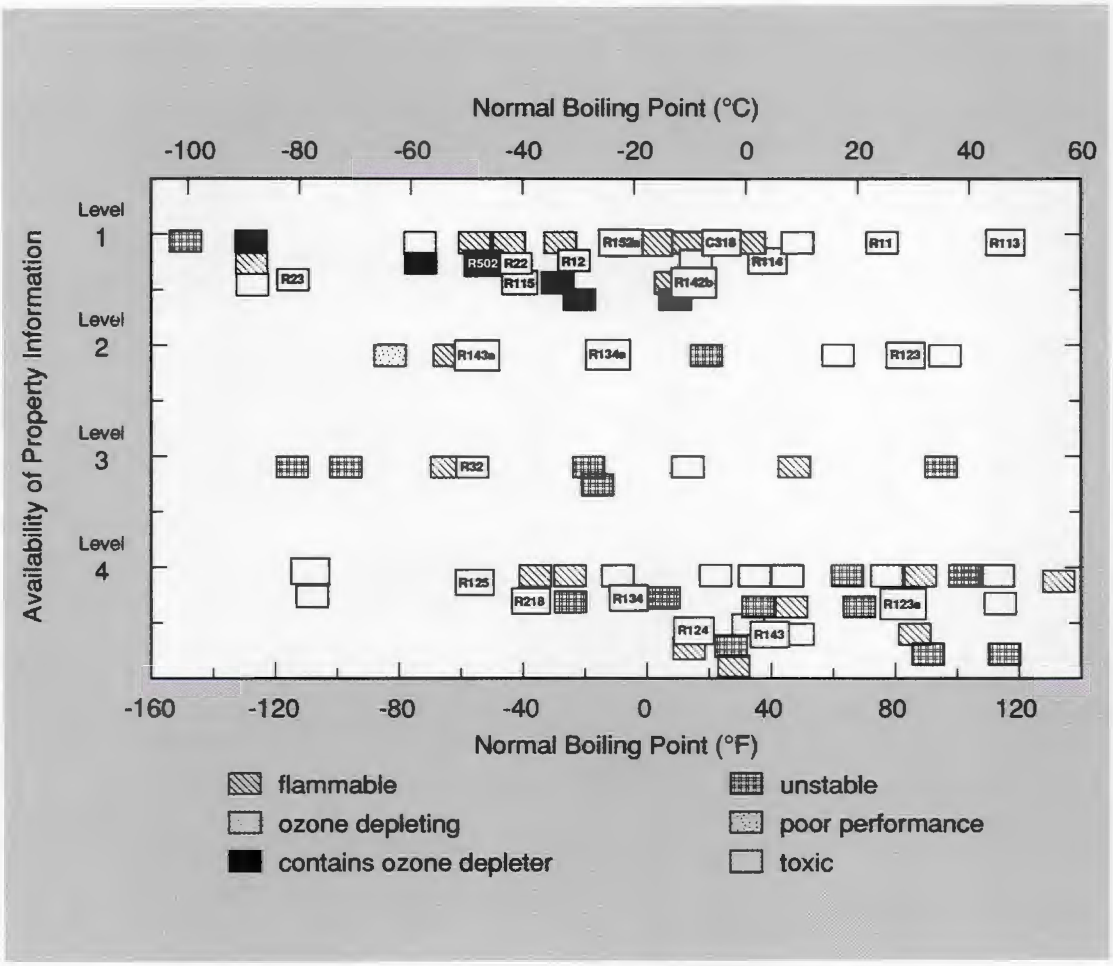
A key question for new forms of insulation is how well they insulate over time. A research team from the Building Thermal Envelope Systems and Materials Program, which spans both the Energy and the Metals and Ceramics divisions, has developed a test to help industry determine quickly how well polyisocyanurate (PI) foam insulation boards for roofs will hold up over their in-service life. The test is for boards containing hydrochlorofluorocarbon (HCFC) "blowing gases," which are possible substitutes for CFC gases.

Roofers spread hot asphalt before putting into place a test roof panel containing hydrochlorofluorocarbon (HCFC) insulating gas at ORNL's new Envelope Systems Research Apparatus. Researchers will compare the encapsulation effect of asphalt with that of a laminated membrane over the long-term performance of these foam insulation boards. The HCFC panels pose less of a threat to the stratospheric ozone layer than do CFC panels.

Over time, oxygen and nitrogen diffuse into the cells of PI boards, and the blowing agent more slowly diffuses out, reducing the boards' resistance to heat flow. Combining laboratory with field tests, the ORNL team compared the thermal aging of boards containing CFC-11, the currently used blowing gas that is being phased out, with four alternatives, including HCFC-123 and HCFC-141b.

After the first year of a three-year exposure test, the researchers found that the PI boards containing four CFC alternatives are thermally acceptable because their resistance to heat flow is only slightly less than that of CFC-11 and because they age at the same rate as boards containing CFC-11. However, the boards being tested are only experimental, and the formulations used to process the HCFC-blown boards have not been optimized.

The test data may provide insights on how industry could change the composition of the best alternatives to improve them even more. The research results could also lead to a testing protocol that would help manufacturers accurately estimate the long-term thermal performance of other foam insulation products.—*Jeff Christian, Manager of the Building Thermal Envelope Systems and Materials Program*



Refrigerant replacements ranked according to normal boiling point and availability of thermodynamic and thermophysical property information. Level 1 indicates readily available, accurate physical property data; Level 4 indicates that few data beyond the normal boiling point could be found. The CFC refrigerants and alternative refrigerants considered good prospects are labeled.

candidates for other refrigeration or air-conditioning applications as well.

A listing of more than 200 compounds that have normal boiling points between –270 and 65°C was compiled from the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Handbook, The Matheson Gas Book, chemical handbooks, tables, and vendor contacts. The figure ranking these chemicals (above figure) suggests that (1) most of the readily available, well-understood compounds have some safety or environmental drawback now that long atmospheric lifetimes are a disadvantage, and (2) property information has not yet been developed for several good refrigerant prospects. Unfortunately, very few compounds have all the desirable characteristics of an ideal refrigerant. Vineyard and Sand received a Best Paper Award from ASHRAE in 1989 for their summary of this work, "Selection of Ozone-Safe Nonazeotropic Refrigerant Mixtures for Capacity Modulation in Residential Heat Pumps" (*ASHRAE Trans.*, Vol. 95, Part 1, 1989, pp. 34–46).

The physical and chemical properties used to select compounds for further consideration were divided between "hard criteria" (inflexible enough

CFC Refrigerants					CFC Alternatives				
Name	Formula	NBP °F(°C)[a]	ODP[b]	GWP[c]	Name	Formula	NBP °F (°C)[a]	ODP[b]	GWP[c]
R113	$CFCl_2CF_2Cl$	118 (48)	0.9	1.4					
					R141b	CCl_2FCH_3	90 (32)	0.08	0.09
R11	CCl_3F	75 (24)	1.0	1.0					
					R123/123a	$C_2HCl_2F_3$	81 (27)	0.02	0.02
					R143	CHF_2CH_2F	41 (5)	0	
					RC318	$CF_2CF_2CF_2CF_2$	21 (-5)	0	
					R142b	$CClF_2CH_3$	16 (-9)	0.06	0.39
R114	$CClF_2CClF_2$	39 (4)	0.8	3.9					
					R124	$CHClFCF_3$	10 (-12)	0.02	0.10
					R134	CHF_2CHF_2	-4 (-20)	0	
					R152a	CHF_2CH_3	-13 (-25)	0	0.03
R12	CCl_2F_2	-22 (-30)	1.0	3.1					
					R134a	CF_3CH_2F	-17 (-27)	0	0.30
R500	CCl_2F_2/CHF_2CH_3	-27 (-33)	<0.8	<2.4					
					R218	$CF_3CF_2CF_3$	-35 (37)	0	
R115	$CClF_2CF_3$	-38 (-39)	0.5	7.6	R22	$CHClF_2$	-42 (-41)	0.05	0.35
					R143a	CF_3CH_3	-54 (-48)	0	0.75
					R125	$CF_3 CHF_2$	-54 (-48)	0	0.60
R502	$CHClF_2/CClF_2CF_3$	-49 (-45)	<0.3	<4.1					
					R32	CH_2F_2	-62 (-52)	0	
					R23	CHF_3	-116 (-82)	0	

[a]Normal boiling point.
[b]Ozone depletion potential relative to R11 = 1.0. Scientific assessment of ozone: 1989.
[c]Global warming potential relative to R11 = 1.0. Scientific assessment of ozone: 1989.

Potential alternatives to current CFC refrigerants.

to eliminate compounds from further consideration) and "soft criteria" (judged as desirable but not essential characteristics). The following hard criteria were applied before a compound was considered an ozone-safe refrigerant: the material must not have any known acute toxicity, it must be chemically stable in the presence of oils and metals commonly used in refrigeration equipment, and it must have an ODP approximately the same as that of R22.

Properties such as flammability, commercial availability, and oil solubility were considered soft criteria. For instance, flammable refrigerants can be blended with other compounds to form nonflammable mixtures that can function as alternatives. The above table lists the potentially useful alternative refrigerants that were chosen using these selection criteria.

The alternative refrigerants listed in the table come from the same fluorinated hydrocarbon family as the CFC refrigerants, but they differ in chemical composition. The alternatives can be broken down into three types. Some, like R22, are called HCFCs because they contain hydrogen as well as chlorine, fluorine, and carbon. The presence of hydrogen causes them to break down

Jim Sand makes adjustments to the Alternative Refrigerants Calorimeter Facility, which is used to measure coefficients of performance and capacities of refrigerants.

in the lower atmosphere more quickly than CFCs, so their ODPs are much lower. Others, like R32 and R134a, are known as HFCs (hydrogen, fluorine, and carbon only). Finally, R218 and RC318 are called FCs (fluorine and carbon only). Both HFCs and FCs are chlorine-free and thus pose no threat to stratospheric ozone.

Testing Efficiency of Candidate Refrigerant Substitutes

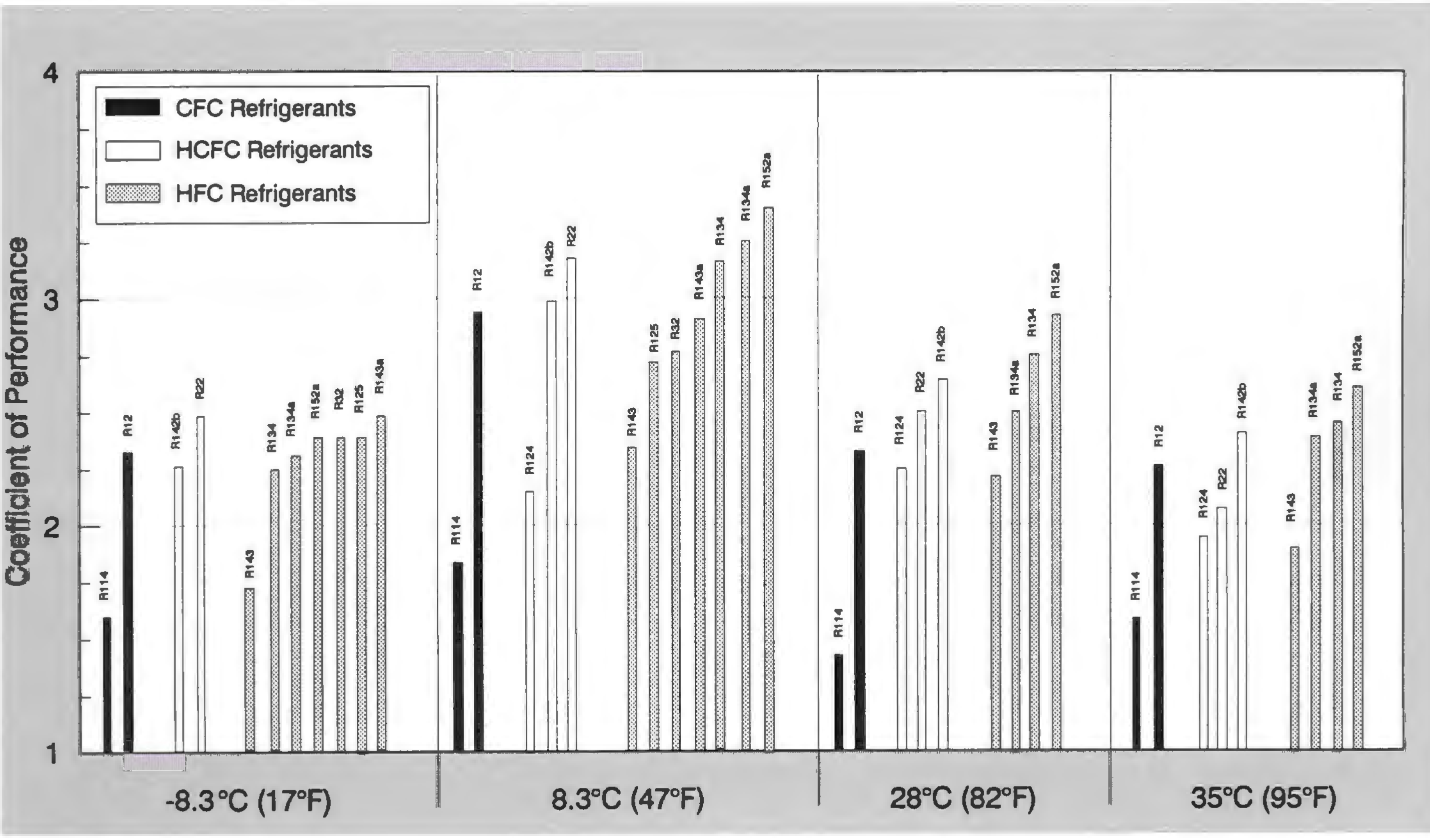
Through our contacts with DuPont and Pennwalt (refrigerant suppliers), we obtained samples of most of the alternative refrigerants. Others were purchased from specialty chemical suppliers. Having these samples put us in the position of obtaining and being the first to publish experimental energy-performance data on several refrigerants.

In examining each refrigerant, ORNL researchers are particularly interested in its energy performance (the electrical energy required to operate the appliance using the refrigerant) and its refrigeration capacity (the ability of the fluid to absorb heat, or a measure of the cooling output). The ratio of the refrigeration capacity to the electrical energy input is the coefficient of performance (COP).

Sand, Vineyard, Charles Hardin of the Energy Division, and Richard Nowak, visiting professor from Purdue University, measured COP and refrigeration capacity for the alternative refrigerants in an instrumented bench-top test rig called the Alternative Refrigerants Calorimeter Facility (see photo on left). Tests were conducted at four different temperatures corresponding to the Air-Conditioning and Refrigeration Institute's rating points for heat pumps. Experimentally measured COPs are given in the figure on the right). The data resulting from these tests have been included in a newly created alternative refrigerants data base set up and maintained by the National Institute of Standards and Technology, formerly the National Bureau of Standards.

Specific conclusions drawn from the data presented in the figure on the right are that

- R152a yielded the best measured performance at all test conditions except the lowest evaporator temperature.
- R143a was the best-performing alternative at the lowest evaporator temperature.
- R134a outperformed R12 at all but the lowest temperature condition.



Coefficients of performance for R12, R114, and alternative refrigerants as measured under ambient temperature test conditions for heat pumps.

- R134 outperformed R134a at the two highest temperature conditions.

Both R152a and R143a are classified as flammable. This characteristic could be ameliorated by combining them with a nonflammable fluid (or fluids) to produce a nonflammable mixture.

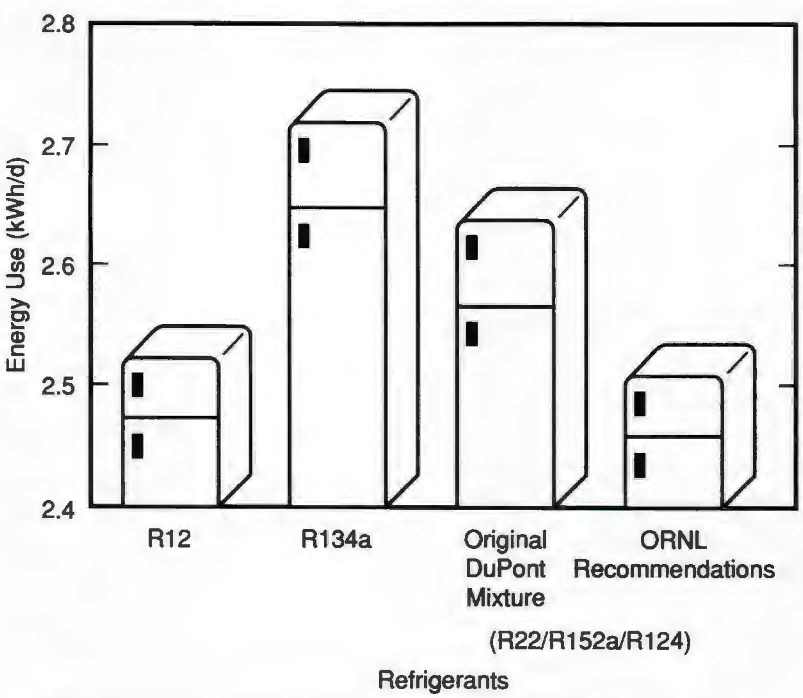
The FC refrigerants R218 and RC318 were evaluated in our test facility as well. However, their performance was much poorer than that of the other alternative refrigerants, and they are not included in the figure.

Vineyard tested several alternative refrigerants in a 0.51-m^3 (18-ft^3) RF in cooperation with DuPont and with RF manufacturers General Electric and Whirlpool. These tests were done in a large environmental chamber in ORNL's Building Equipment Laboratory (see photo on p. 26). A total of six refrigerants, including R12, were tested. The five alternative refrigerants were R12/DME (dimethyl ether), R500, R134a, R22/R142b, and DuPont's new ternary blend R22/R152a/R124. Refrigerants were selected on the basis of their potential for requiring minimal changes in the RF's refrigeration system.

The test results revealed that

- R12/DME and R500 are possible short-term alternatives on the basis of reduced energy consumption. They are only short-term alternatives because they still contain R12, which is being phased out of production. However, test

Ed Vineyard, Van Baxter, and Charlie Hardin observe results from tests of alternative refrigerants in the Building Equipment Laboratory. The large chamber in the center of the picture was used for testing several alternative refrigerants in a household refrigerator-freezer.



ORNL's refrigerant recommendations achieved desirable reductions in energy use for refrigerator-freezers. These closed door tests were done at 32°C (90°F).

results reveal that their use could result in an ODP reduction of about 30 to 35%.

- The use of R134a as an alternative refrigerant resulted in a 7.8% increase in energy consumption compared with R12.

- The mixture of 60 wt % R22 per 40 wt % R142b had an 8.6% higher energy consumption than R12.

The preceding results were for tests in one particular unmodified RF. The possibility exists that some of the results could be altered by changing the system design, either by using a different compressor or optimizing the capillary tube size.

Vineyard worked closely with DuPont in the tests of their ternary blend (results shown in the figure below). ORNL's test of DuPont's initial mixture showed considerably higher RF energy use than with R12. Vineyard suggested that the composition of the blend be changed to increase its refrigeration capacity, and tests of the improved blend showed that it equaled R12's energy use performance. In addition, this blend has only about 1% of R12's ODP.

We are continuing to evaluate alternative refrigerants for RFs using funding from DOE, EPA, and ASHRAE. One part of the work, sponsored principally by ASHRAE, involves improving existing RF systems to maximize energy efficiency with replacements for R12. The other part involves applying advanced refrigeration circuits to RFs to achieve sizeable gains in RF energy efficiency.

In addition to this work, we plan to expand our focus and investigate alternative refrigerants (both single component and mixtures) for both commercial refrigeration and chiller applications. To that end, Steve Fischer has adapted an equation-of-state model obtained from the Federal Republic of Germany, called the Lee-Kesler-Plöcker (LKP) model, to simulate mixtures of three or more compounds. The LKP version has an advantage over the Carnahan-Starling-DeSantis model we have been using because less experimental information is needed to model newer, potentially attractive refrigerants and mixtures.

As the next century approaches, ORNL's research efforts will help ease the world's transition from CFCs to ozone-safe and energy-saving chemicals.

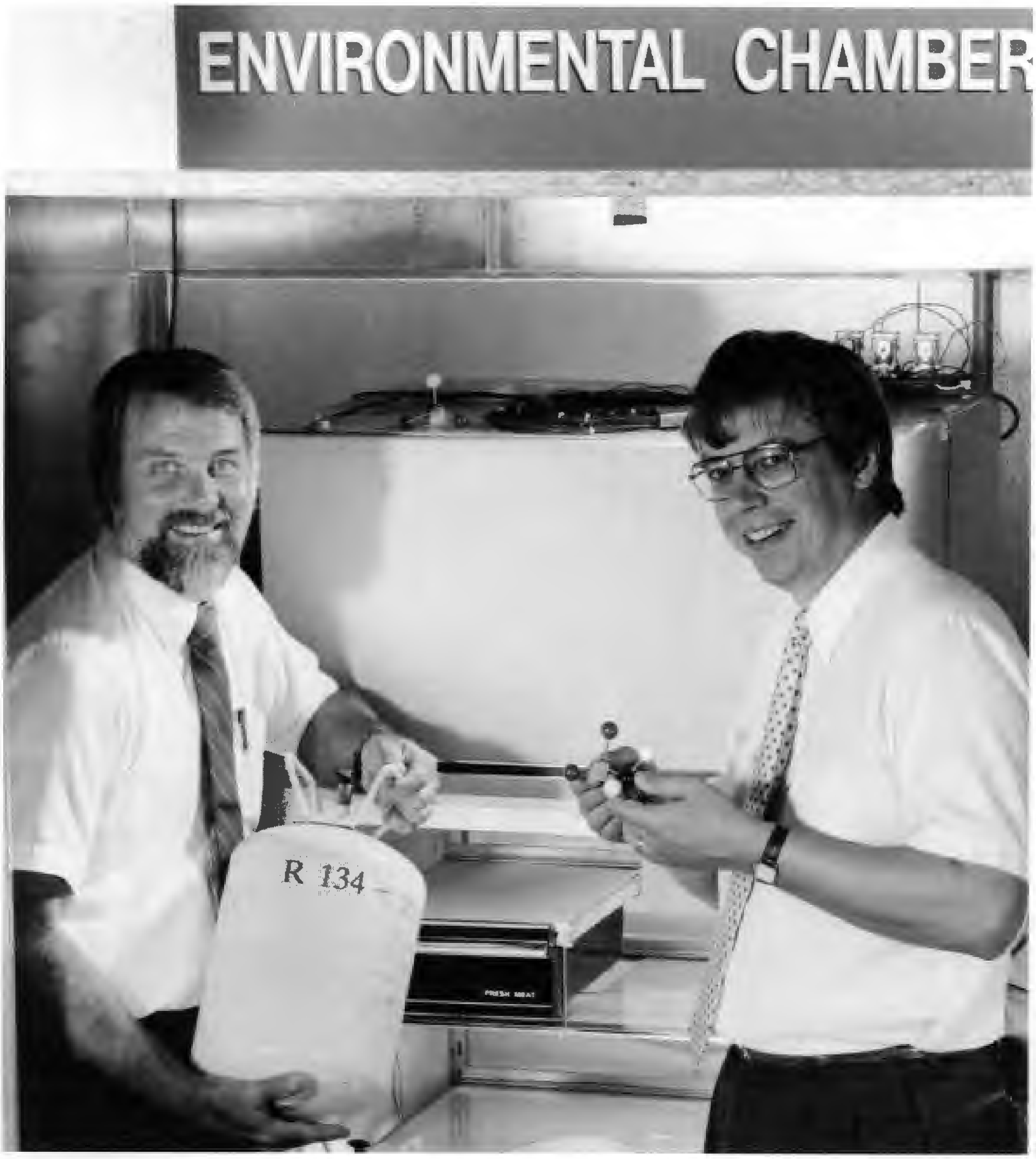


Photo by Ross Lynn Freeny

Phil Fairchild holds a container of R134, one of the alternative refrigerants ORNL is testing. Van Baxter displays a model of a molecule of another ozone-safe alternative, R134a. The household refrigerator in the background is being used to test these alternative refrigerants and several others.

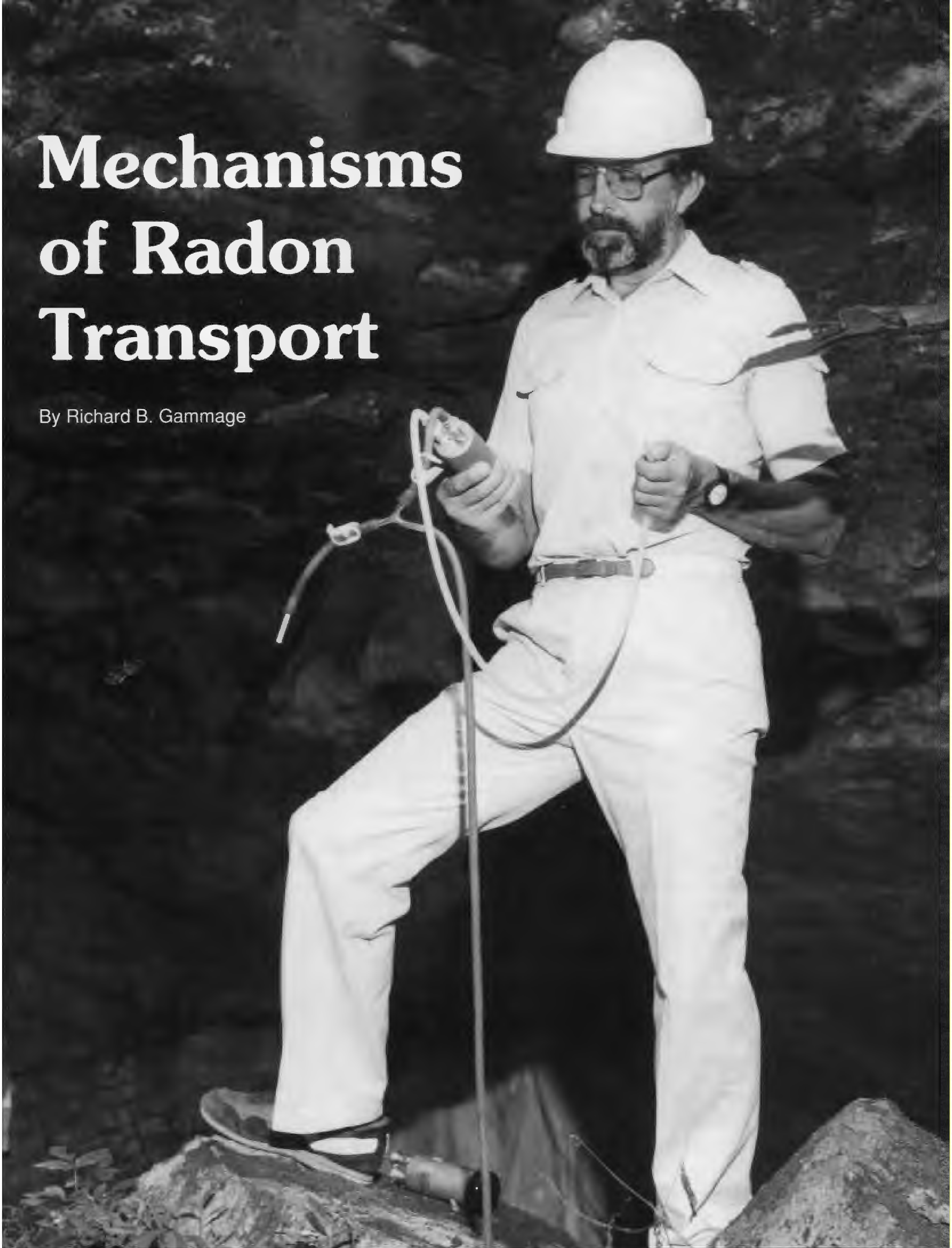
Biographical Sketches

Van Baxter is leader of the Refrigeration Systems Group of ORNL's Building Equipment Research Program in the Energy Division. He has conducted research on innovative heat pump concepts and investigated the field performance of air-source and ground-source heat pumps. In 1982 he received the Willis H. Carrier Award from the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). He joined ORNL in 1977 shortly after receiving his M. S. degree in mechanical engineering from the University of Tennessee.

Phil Fairchild is manager of ORNL's Building Equipment Research Program and an advisor to the Air-Conditioning and Refrigeration Institute's Research and Technology Committee. He has been instrumental in establishing ORNL's research program on CFC alternative refrigerants. In May 1987 he was invited to give testimony at U.S. Senate Joint Subcommittee Hearings on Stratospheric Ozone Protection and Substitutes for Ozone-Depleting Chemicals. Fairchild came to ORNL in 1978 as a project manager. He previously worked for Ebasco Services, Inc., an architectural-engineering firm, where he was responsible for design engineering. He received his M.S. degree in mechanical engineering from Louisiana Tech University.

Mechanisms of Radon Transport

By Richard B. Gammage



Dick Gammage, standing near the mouth of an Oak Ridge cave, examines one of the monitoring devices used to measure indoor and outdoor radon levels. A research team made measurements in basements and living rooms and in damp and occasionally dripping-wet cavities and caves.

In limestone regions in the southern Appalachian Mountains of the United States, indoor levels of radon are often higher in summer than in winter. This surprising effect was discovered in a recent Oak Ridge National Laboratory study of more than 100 homes in Huntsville and Birmingham, Alabama. The opposite effect—higher radon levels in the winter than in the summer—has been observed in the past four years in homes in the Tennessee cities of Chattanooga, Harriman, Kingston, and Oak Ridge and in many other parts of the nation.

It is advisable to have indoor radon levels measured when they are at their highest to determine whether these worst-case levels are hazardous to health and whether costly mitigation measures should be taken to reduce the radon to a safe level. Mitigation is recommended if the indoor radon is above 4 picoCuries per liter (pCi/L). Because indoor radon levels are thought to be generally higher in the winter, the U.S. Environmental Protection Agency and the Centers for Disease Control have recommended that homeowners screen their houses for radon during the cooler months. The ORNL results, however, suggest that wintertime radon screening in some regions of the country could overlook elevated radon levels that prevail for most of the year. In fact, at the Indoor Air '90 conference this past summer (July 29–August 3, 1990) in Toronto, Canada, we recommended that, where certain topological and geological conditions prevail, houses should be screened for elevated radon levels in summer rather than in winter.

Why are indoor radon levels higher in summer in some parts of the nation and lower in others? Why do seasonal variations occur? What are the routes by which radon enters our homes? To answer these questions, a group in ORNL's Health and Safety Research Division has sought to understand the conditions that promote radon migration into houses in particular geological settings during various seasons of the year. The group consists of Charles Dudney, David Wilson, Ralph Saultz, and me.

In our study, we discovered a new subsurface "stack effect" for radon transport into houses that depends on the temperature of the subsurface and outdoor air, topological differences, underground geological structures, and the locations of houses with respect to these topologies and geological structures. But first we need to consider the mechanics of the better known indoor thermal stack effect. Simply put, when a house is heated in winter, warmer indoor air rises toward the roof where some of it escapes. A small negative air pressure is produced at ground level that causes replacement air to be drawn from the understructure into the house. It is this replacement air, drawn from the soil and thus laden with radon gas, that elevates the indoor level of radon. The indoor stack effect occurs in all houses heated during cool weather. The magnitude of the increase in indoor radon, however, varies considerably between houses because no two houses

Why are indoor radon levels higher in summer in some parts of the nation and lower in others?

Photo by Terry Marlar

Gammage inspects the cave that affects the flow of radon into a nearby Oak Ridge house. This home has higher levels of radon in the winter than in the summer.

Photo by Terry Marlar

Ralph Saultz, a member of the research team, dismantles the experiment at the mouth of the Oak Ridge cave. Most of the entrance was blocked off, and a floor fan was used to force air into the cave. The researchers hope that these artificial conditions, created in the summer, will cause the radon measurements in the nearby house to rise to levels usually found in winter.

Photo by Terry Marlar

or their subsurfaces are identical. In summer, when the air is warmer outside, cooler and denser indoor air will usually slow the entry of radon-bearing soil gas. Thus, in many parts of the country, indoor radon levels are highest in winter.

Diffusion and Soil-Gas Flow

The largest source of radon to most houses is underlying soil that contains naturally occurring uranium. As the uranium decays, it produces radon, which may find its way into the house by several routes. A health hazard results when the radon entering a house builds up and decays into radioactive isotopes that damage the lungs and ultimately induce cancer.

In a 1982–83 study of 40 Oak Ridge homes, Alan Hawthorne, Charles Dudney, and I found that those houses built on limestone ridges had generally higher indoor levels of radon than the houses in valleys. Geology was a factor. When we examined the limestone hills of Huntsville in the late 1980s, Wilson, Dudney, Saultz, and I observed that many houses there had high indoor radon levels—and that they were substantially higher in summer than in winter, a surprising finding that prompted our recent research.

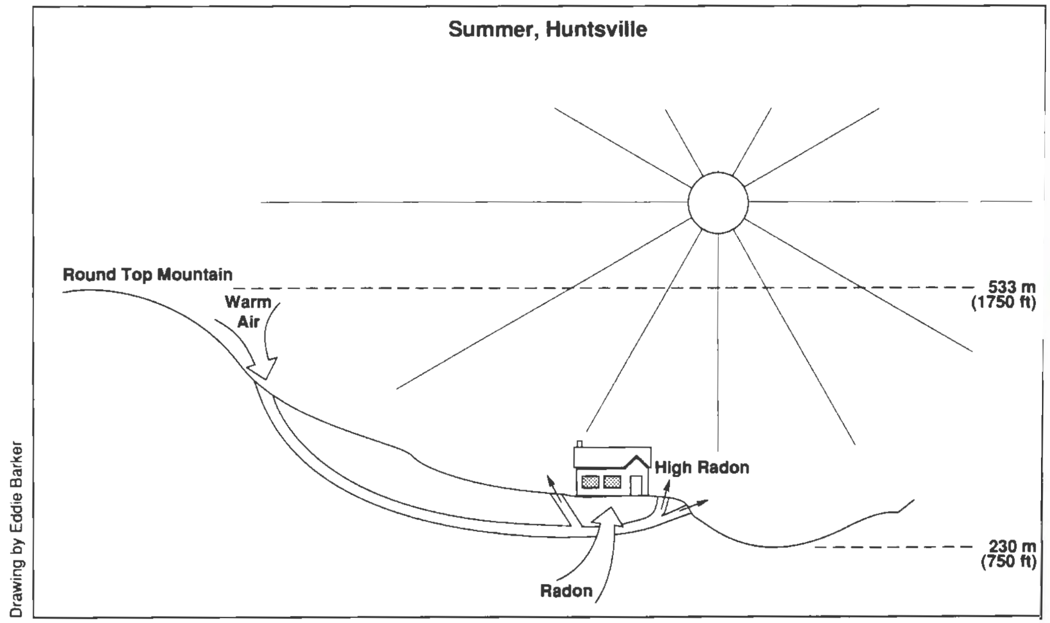
What are some mechanisms for radon entry into homes? At first the scientific community thought that high indoor radon levels resulted from diffusion of the gas from building materials such as granite in stone walls. However, it was found that the amount of radon in most building materials and the rate at which it diffuses through such material cannot generally account for high indoor radon levels.

Then scientists began to realize that most radon entering homes is contained in soil gas, which is drawn into homes through sumps, wall and floor penetrations, cracks, and other openings. The driving force for this flow is a slight pressure difference between the soil and the interior of the house. This drawing pressure can be produced by our old friend, the indoor thermal stack effect, or by wind loading. Another important environmental factor, soil permeability, affects the distance over which radon in moving soil gas is available to be pulled into a house.

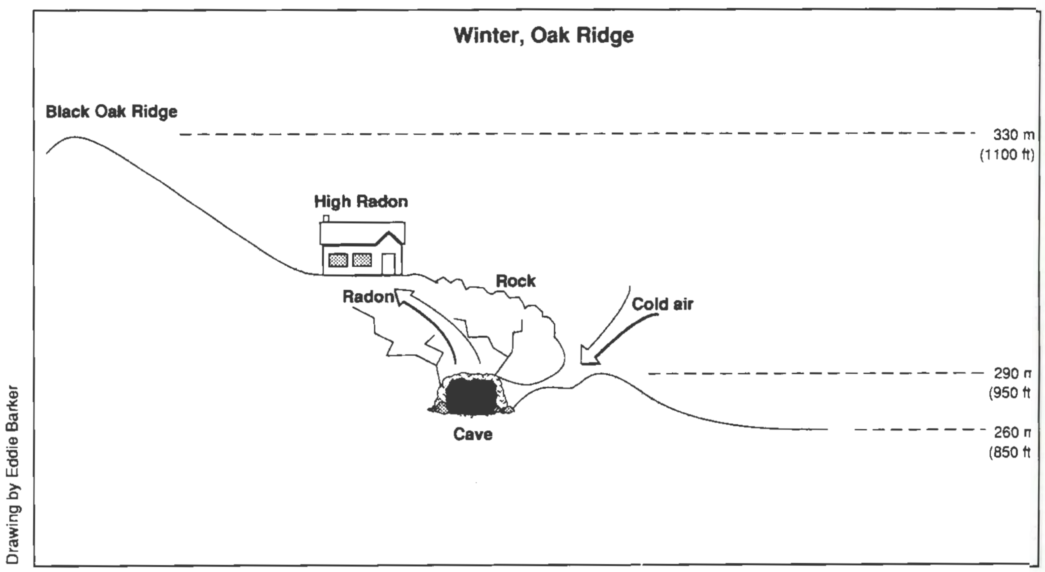
Role of Flowing Air in Underground Cavities

Besides diffusive flow of soil gas, we have found another mechanism for radon transport into houses: a subsurface stack effect involving radon-bearing air in a network of cracks and cavities in underlying limestone. A close look at limestone bedrock in hilly regions reveals that it has a subsurface circulatory system of fissures and "solution cavities"—holes formed when groundwater dissolves the limestone. Columns of radon-rich air can move through this network. We hypothesize that the primary force for driving underground radon-bearing air through a circulatory system, and subsequently up into a house, is the pressure difference created by the difference between the underground and outside air temperatures. This transport mechanism can carry radon rapidly over distances much farther than the 1 or 2 m predicted by diffusion and soil-gas flow mechanisms for low-permeability soils underlying most American homes.

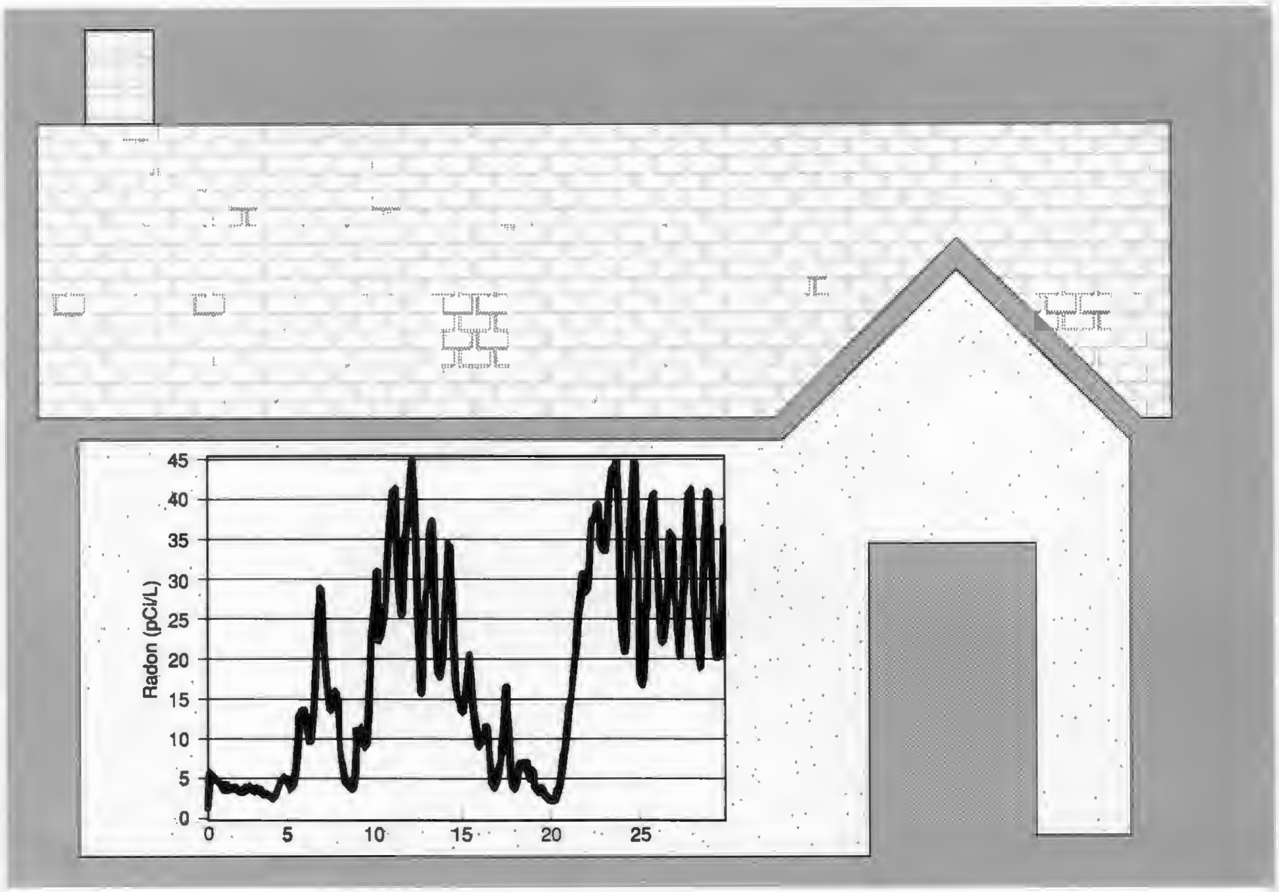
Our proposed radon transport mechanism results primarily from our field studies of two detached houses on karst hills in Huntsville and Oak Ridge. Karst is an irregular limestone region that has sinks, underground streams, and caverns. The Huntsville house has a mixed slab-on-grade and crawlspace.



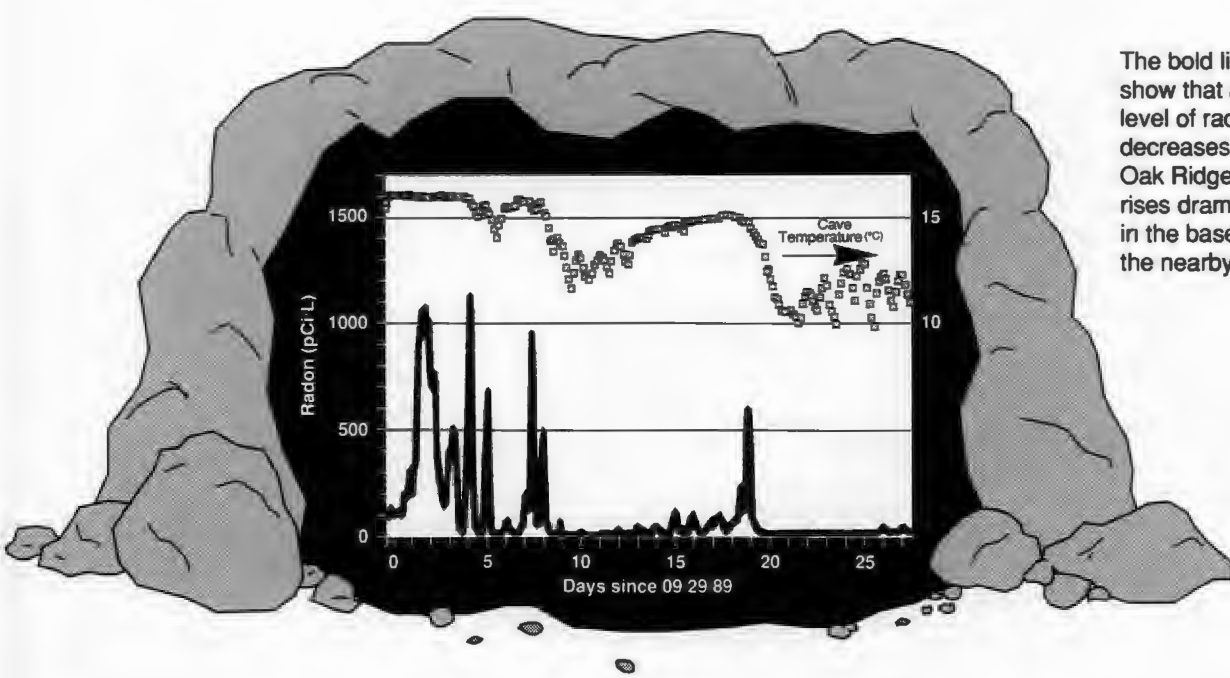
Warm air enters the circulatory system uphill from the Huntsville house; cools, falls, and picks up radon; and vents through holes in the ground into the atmosphere.



Cold outside air pushes the radon from the cave into a system of underground channels; thus, in wintertime the indoor stack effect, now working in unison with the subsurface stack effect, draws an unusually large amount of radon into the house.



Drawings by Eddie Barker



The bold lines show that as the level of radon decreases in the Oak Ridge cave, it rises dramatically in the basement of the nearby house.

Several open solution-cavity holes are evident in the lawn close to the Huntsville house (see photograph on this page). The Oak Ridge home is a basement, slab-on-grade house located 100 m uphill from a cave.

One interesting finding is that, even though the geological settings are similar, the indoor radon levels of the Huntsville house are elevated in summer but those in the Oak Ridge house are highest in winter. How do we account for these observed differences?

The Huntsville house is probably located *below* the point of entry for outside air to the bedrock circulatory system. Although we have detected air exiting the holes in the garden, we have yet to find the entry points in the overlooking hills.

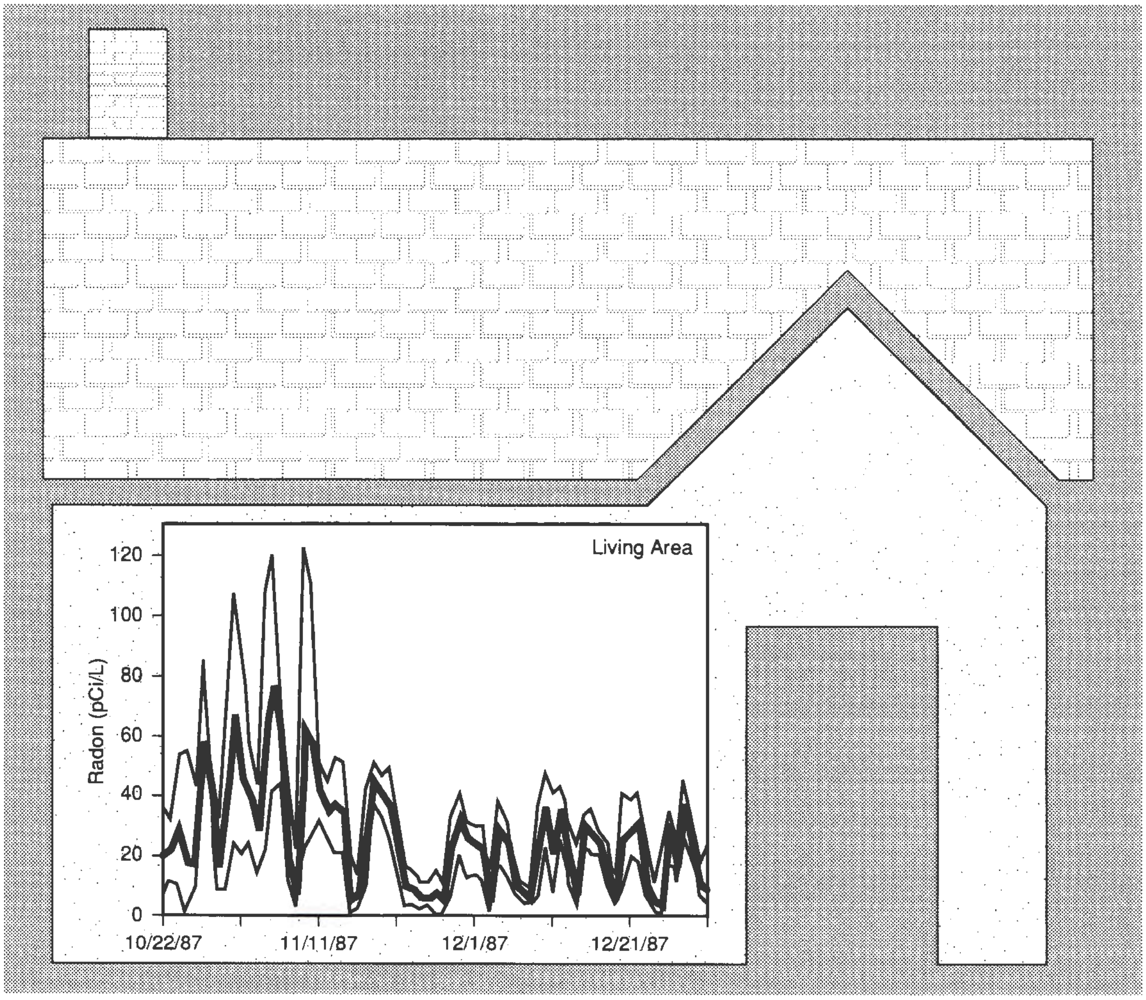
During warm weather, radon gas is emitted from natural holes in the backyard of the Huntsville house, whose indoor radon levels rise correspondingly.

Assuming that the Huntsville house does indeed sit below the point of entry for outside air, we can offer an explanation for its elevated radon levels in summer and for seasonal fluctuations. In summer, warm air entering the circulatory system near the top of the hill increases in density as it cools, and then it sinks downward. The cool, radon-rich air vents from the bottom of the circulatory system and is driven into any house located over emitting fissures. Such emergent fissures in the lawn of the Huntsville house emit copious amounts of radon-laden air in warm weather but nothing in cold weather. Inside this house, the radon levels rise and fall in unison with ventings of radon-rich air from the holes in the lawn.

The Oak Ridge house is located *above* a cave through which air enters the underground circulatory system. We observed that, when the temperature of the cave air drops below 15°C, radon is being pushed out of the cave and into the connecting system of underground channels. Presumably the flushing is produced by cooler, denser, radon-free outside air coming through the cave entrance. As the radon level drops inside the big cave, the radon concentration rises dramatically in the basement of the Oak Ridge house (see drawings on facing page). The topography in this instance is producing a cool-weather, subsurface stack effect that works in unison with the normal indoor thermal stack effect. The result is a particularly high amplification of the indoor radon during the wintertime.

Our radon transport concept is similar to an idea advanced in 1987 by geophysicist E. P. Weekes of the U.S. Geological Survey in Denver, who sought to explain seasonally related intake or exhaust of air from wells in the highly fractured rock on top of Yucca Mountain, Nevada, which is the proposed site for permanent disposal of highly radioactive waste. Weekes explained the air circulation in terms of topological and temperature differentials.

Radon levels vary from day to day, from season to season, and from house to house. This graph shows the maximum, minimum, and (in bold) average radon concentrations in the living area of a Huntsville house. Inside this house, the radon level is higher during warm weather.



Drawing by Eddie Barker

Our goal is to understand the conditions of radon availability and transport that raise indoor radon levels so that we can predict which houses should be screened for radon in summer and which should be screened in winter.

Conclusion

In the hilly karst terrains of the southern Appalachians, whether a house has higher radon levels in winter or summer depends on its location with respect to the point where outside air enters the air-circulating system in the limestone bedrock. If it is located below the entry point for outside air, the house should have higher radon levels in summer because warm air entering the upper end cools, and as it becomes heavier, forces radon-rich air out at the bottom. The levels should be higher in winter if the house is above the air-entry point because cold air entering the ground warms and rises in the underground circulating system. On its upward travels it becomes enriched with radon gas before exiting the ground higher up the hill. Differences in location with respect to the inhomogeneous cavities in underlying bedrock may also explain in part why similarly built neighboring houses often have very different indoor radon levels. The results also suggest that if your house is in a hilly karst area, it would be safest to test for indoor radon in both summer and winter unless you want to thoroughly analyze your home's surrounding geology.

Help for Homeowers

For more information on measuring radon levels and reducing them in homes, read these publications by the Environmental Protection Agency: *A Citizen's Guide to Radon: What It Is and What To Do About It* and *Radon Reduction Methods: A Homeowner's Guide*. Both can be obtained from the EPA regional office for Tennessee: 345 Courtland Street NE, Atlanta, GA 30365, phone (404) 881-3776.

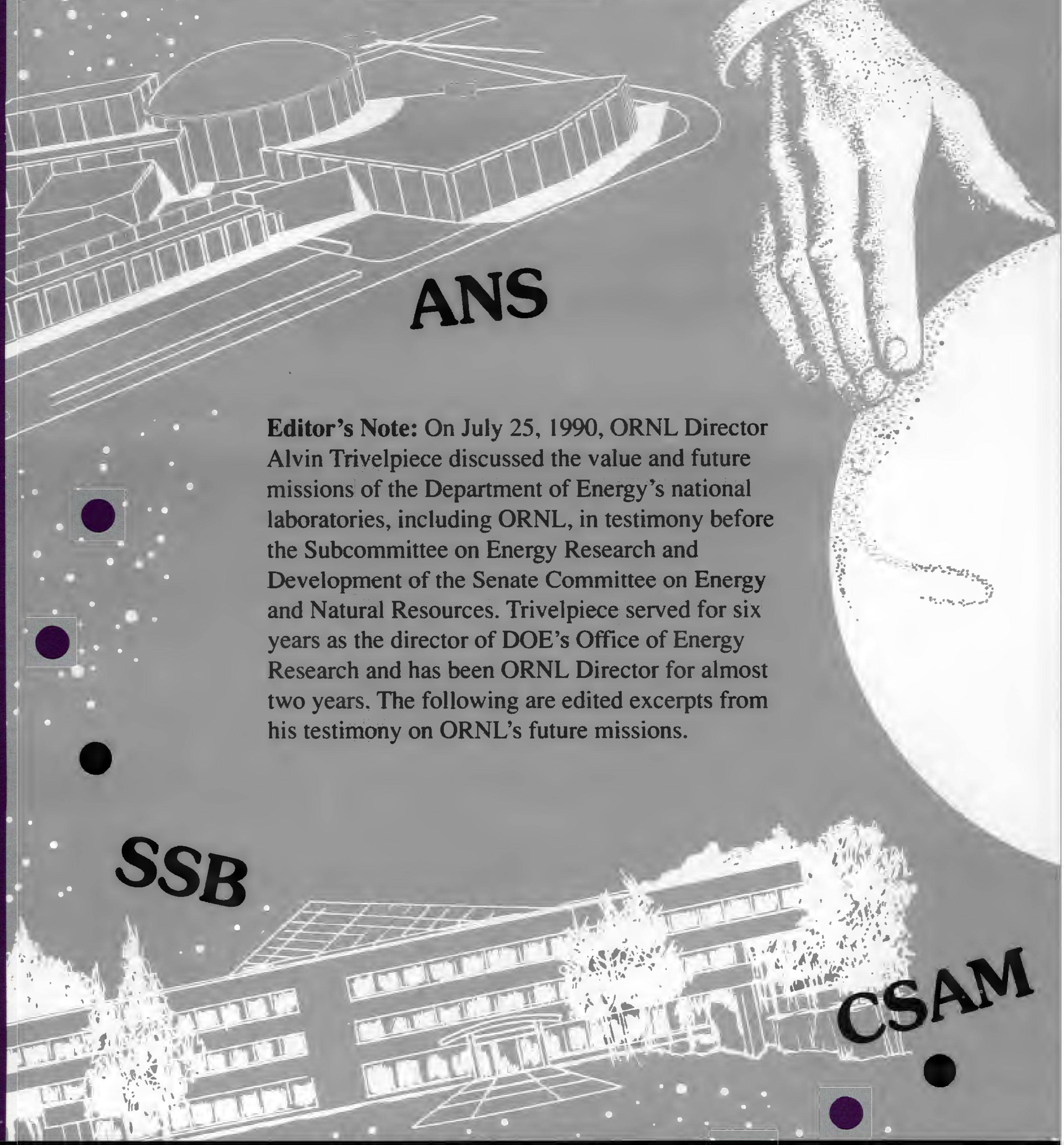
Biographical sketch

Richard Gammage is leader of the Measurement Systems Research Group in the Environmental Measurements and Applications Section of ORNL's Health and Safety Research Division. He has worked at ORNL since 1967 in basic and applied research spanning surface studies of lunar soils, new solid-state radiation dosimeters, and the development of advanced instrumentation to detect environmental contaminants.

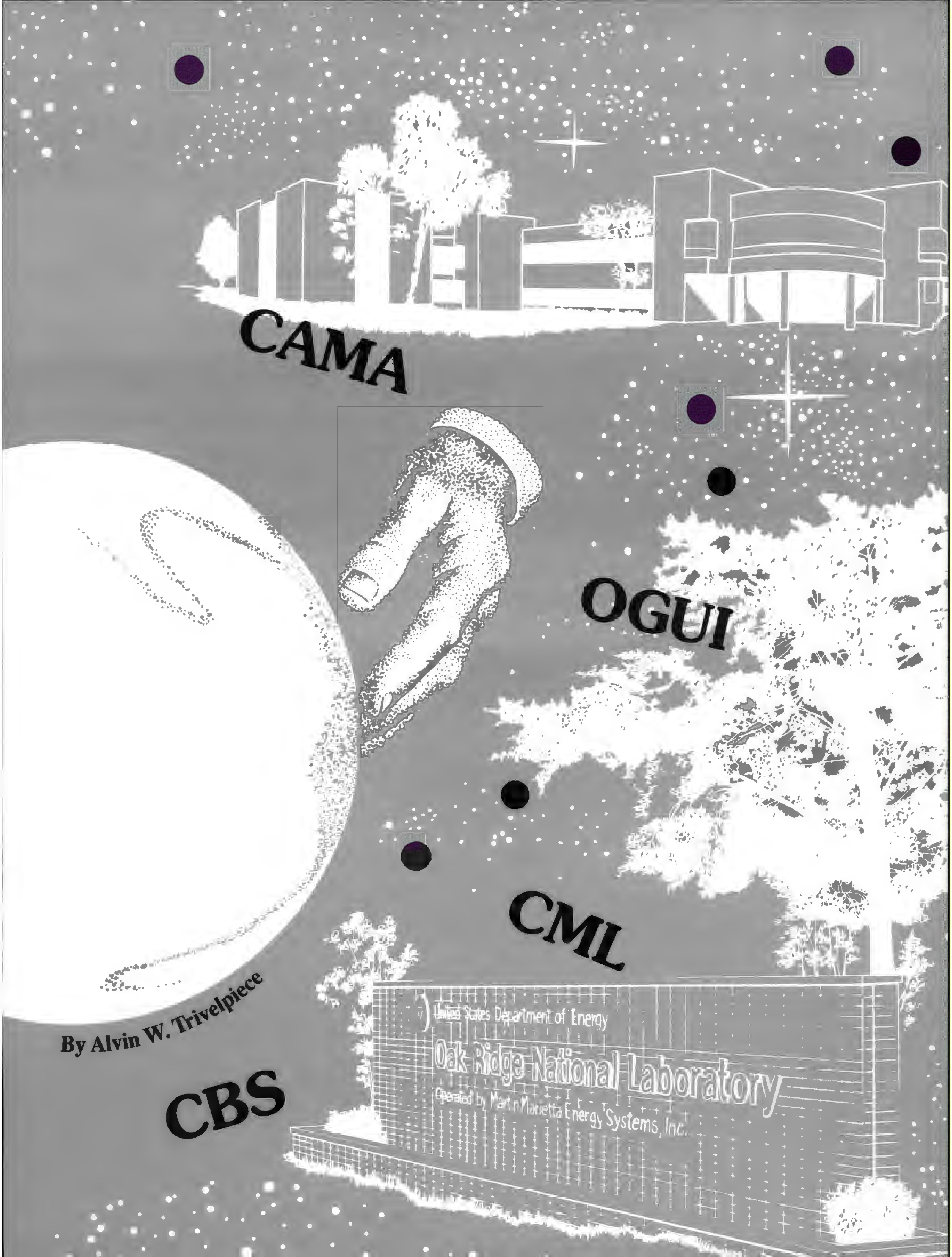
Recently, Gammage has led a research group that measures a multitude of indoor contaminants in programs supported by the Department of Energy, the Environmental Protection Agency, Consumer Products and Services Commission, and the Tennessee Valley Authority. The focus is currently on radon assessment and mitigation in residences and federally owned buildings.

Gammage's research group also produces screening and in situ monitoring devices for the cost-effective evaluation of hazardous chemical wastes. The objective is to provide ORNL with the best state-of-the-art field evaluation capabilities. Gammage has authored about 140 open literature papers and book chapters and chaired or organized several conferences.

ORNL's Future Missions



Editor's Note: On July 25, 1990, ORNL Director Alvin Trivelpiece discussed the value and future missions of the Department of Energy's national laboratories, including ORNL, in testimony before the Subcommittee on Energy Research and Development of the Senate Committee on Energy and Natural Resources. Trivelpiece served for six years as the director of DOE's Office of Energy Research and has been ORNL Director for almost two years. The following are edited excerpts from his testimony on ORNL's future missions.



CAMA

OGUI

CML

CBS

By Alvin W. Trivelpiece

"ORNL has established itself as a leader in technology transfer."

Laboratory Director Alvin Trivelpiece (right), Sen. Jim Sasser of Tennessee, and Joe La Grone, manager of DOE's Oak Ridge Operations, are briefed on the High Flux Isotope Reactor's fuel elements by Jack Richard, director of Reactor Operations at ORNL.

Senator Jeff Bingaman of New Mexico: *What trends do you foresee at Oak Ridge National Laboratory for meeting the challenges posed by issues of national concern?*

Dr. Trivelpiece: I look forward to the next decade as a period of revolutionary change in many areas of science and technology in which ORNL is involved. It will also be a period of considerable challenge. Reflecting national trends, the issues addressed by ORNL programs during the next several years will be energy, the environment, and international competitiveness.

Because of the challenge to improve the U.S. competitive posture in the world, collaborative research at our major user facilities will become a very important component of the Laboratory's intellectual output. Already ORNL hosts over 2300 guest researchers each year. By the turn of the century, we expect that number to double. Much of the increased collaboration with outside researchers will be linked to the expansion of 13 existing user facilities and the addition of new facilities at ORNL.

Major new user facilities we hope to put in operation over the next decade include the world's most powerful research reactor, the Advanced Neutron Source; the Materials Science and Engineering Complex; and the Center for Biological Sciences. The Advanced Neutron Source alone is expected to accommodate 1000 users annually.

As another element of our competitiveness mission, the Laboratory will expand its already **substantial educational programs**. The present educational activities encompass over 30 programs involving precollege, undergraduate, graduate, and postgraduate students and faculty. I am particularly enthusiastic about the potential for our precollege program.

To a growing extent, the exceptional scientific and technical developments coming from ORNL are being translated into new American products, markets, and jobs. The catalyst for this expansion in the Laboratory's traditional role of technology developer is an aggressive technology transfer program, one that recognizes the importance of face-to-face interaction between ORNL researchers and their industrial counterparts. Our technology transfer program, managed by Martin Marietta Energy Systems, Inc., really got going in 1985. As of mid-year 1990, Energy Systems had in place 46 licensing agreements with American industry (of which 43 were from ORNL). The cumulative product sales associated with these agreements is $30 million and growing rapidly.

ORNL has established itself as a **leader in technology transfer**. In its November-December 1989 issue on "Technology Hits and Misses of the 1980s," *High Technology Business* featured three DOE-funded developments in what it considers the 20 key technology developments of the last decade. One of DOE's developments was Brookhaven National Laboratory's National Synchrotron Light Source, and the other two came from ORNL—nickel aluminide alloys and whisker-toughened ceramics.

ORNL has been extremely successful in attracting industry to participate in our **High Temperature Superconductivity Pilot Center**. In two years, 15 joint cooperative research agreements have been signed. This program has provided increased flexibility and streamlining of the business interface between DOE and U.S. industry to enable cooperative R&D on the technology development and applications of these materials. The end result will be accelerated commercialization of this important technology.

Senator Bingaman: *What do you envision the future direction of energy technologies to be?*

Dr. Trivelpiece: The future emphasis of energy R&D at ORNL will be on energy efficiency improvements and nonfossil energy supply technologies—including fusion and fission energy.

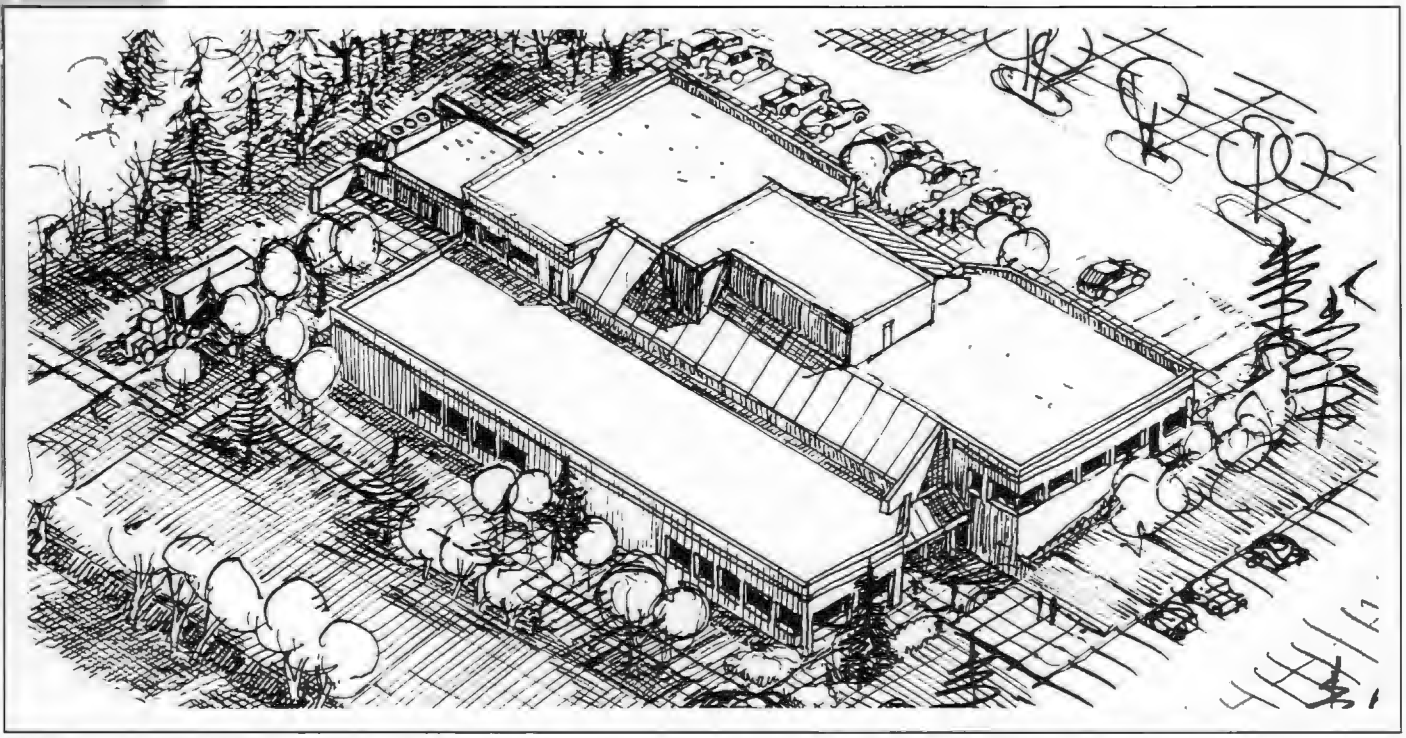
The Laboratory will continue to conduct the nation's largest and most diverse R&D program in **conservation and renewable energy**. The current program emphasizes research on high-temperature materials, R&D on advanced electric power transmission and distribution systems, technologies for increasing the efficiency and economical use of energy in buildings and industry, and energy storage. Our renewable energy R&D focuses on techniques to reduce the cost and increase the productivity of woody and herbaceous biomass in many regions of this country and in developing nations.

Energy supply technology development at ORNL will continue to concentrate on **fusion and fission**. The energy released when light elements are "fused" offers mankind the potential for a limitless source of energy. ORNL plays an important role in the international quest to transform this potential into reality. The Laboratory's long-term strategy for fusion is to strive for scientific and engineering excellence in a broad program emphasizing technology and materials. In particular, work will continue to make possible advances in toroidal confinement, plasma heating, fueling systems, superconducting magnets, first-wall and blanket materials, and applied plasma physics.

ORNL's nuclear fission activities support DOE's civilian nuclear power program and provide technical assistance to the New Production Reactor Program, which will provide materials for nuclear weapons. Planned future directions for ORNL in fission energy R&D include assuming lead roles in developing modular high-temperature gas-cooled reactor technology, nuclear fuel reprocessing, and reactor safety research. The Laboratory will also support all other reactor concepts through its work on strategic nuclear technologies including advanced instrumentation, control, and automation; robotics and teleoperations; and high-temperature materials and structural design.

I believe that the nation would be ill-served if the DOE laboratories were to substitute for

"The goal of the ORNL materials program is to continue as a world leader."



ORNL's proposed Solid State Sciences Building will replace obsolete solid-state laboratories and offer an acceptable environment for conducting synthesis and processing science; studying surfaces, interfaces, and films; and fabricating improved semiconductors, superconductors, and magnetic and optical materials.

private sector R&D or to compete with the private sector in commercializing new energy or environmental technologies. The nation is well served with the improvements in the technology transfer process that Congress has enacted and DOE has implemented. Industry-laboratory interaction is important for our national competitive posture. The **cooperative research and development agreements** that are implemented as part of the National Competitiveness Technology Transfer Act of 1989 will provide excellent foundations for future interactions.

Senator Bingaman: *I am aware of the strong basic science programs at your institution. What do you foresee as their long-term direction?*

Dr. Trivelpiece: The Laboratory will maintain vital programs in both the physical and the life sciences. The science programs serve two important purposes: they add to the storehouse of fundamental knowledge, and they create a strong scientific base of support for the Laboratory's technology programs.

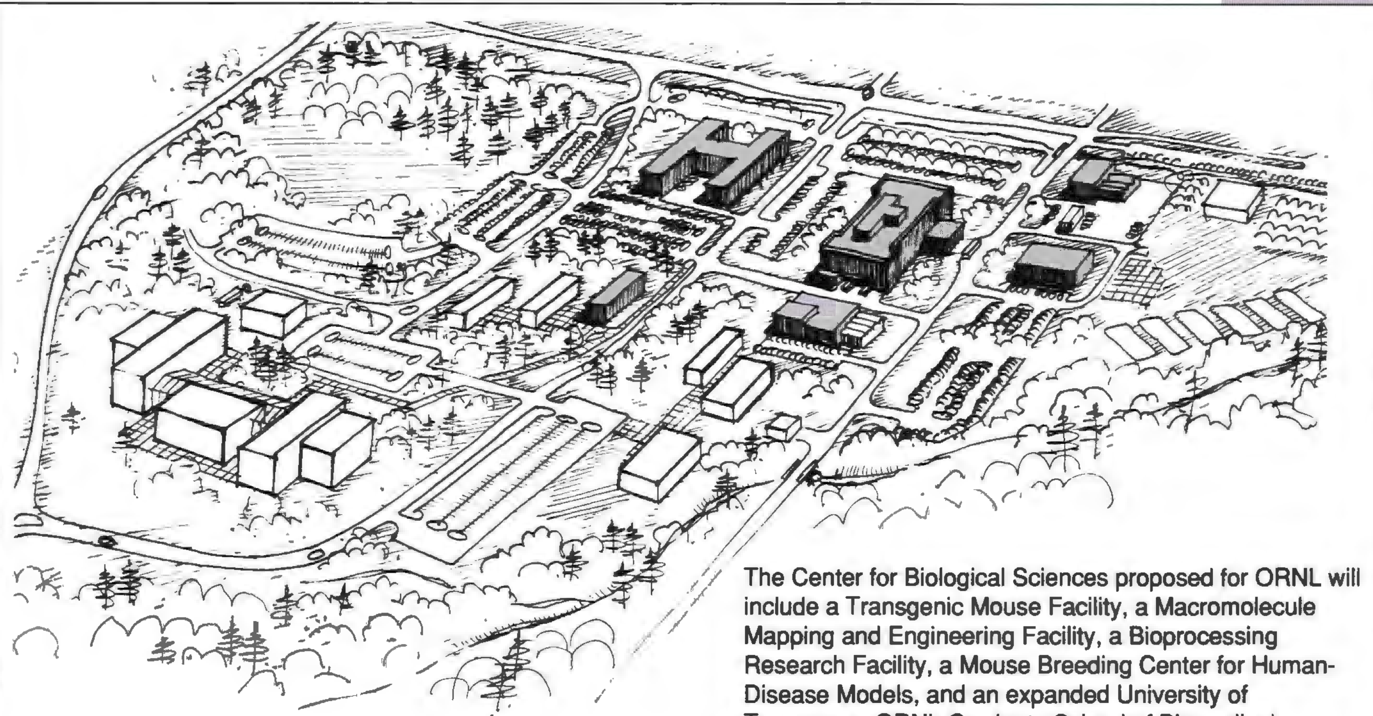
Areas of research in the **physical sciences** will include materials; computations; robotics and intelligent systems; and atomic, nuclear, and high-energy physics. The goal of the ORNL materials program is to continue as a world leader in high-temperature materials development and in solid-state physics, including surface research, preparation of new materials, advanced materials processing, and neutron scattering. Advances in neutron scattering research depend heavily on our building the Advanced Neutron Source.

In the 1990s, our already strong efforts in basic **materials science** will be strengthened further by the construction of the future Materials Science and Engineering Complex. In computations, research on parallel processing will continue to be one area of emphasis. Research topics in robotics and intelligent systems will include teleoperations and autonomous systems with man-machine symbiosis as the ultimate goal.

In physics, the addition of new instruments to the **Holifield Heavy Ion Research Facility** will make ORNL the world center for nuclear structure research into the next century. This user facility provides world-class opportunities for nuclear structure research for investigators from across the nation. It is also an important national facility for promoting undergraduate and graduate education in nuclear physics.

The **life sciences**—biology and environmental sciences—will continue to grow as essential elements of the Laboratory's research programs. In biology, the plan is to build on the core areas of mammalian genetics, radiation carcinogenesis, and protein engineering. In addition, multidisciplinary research in structural biology and genome mapping will be expanded. The proposed new **Center for Biological Sciences** will provide important new research tools for the ORNL staff, as well as for users from universities and industry.

In the **environmental sciences**, the broad goal is to retain the Laboratory's status as one of the world's premier ecological-environmental research centers. The environmental sciences program will cover both energy-related environmental issues and global science. An important program objective is to study and understand the interactions of physical and chemical agents with living organisms, including the ultimate consequences of these interactions for humans and the environment. Global environmental studies will be directed toward understanding how to deal intelligently with the major global change issues, including global warming. One of the goals of these studies is to provide practical input to leaders making technology and policy decisions.



The Center for Biological Sciences proposed for ORNL will include a Transgenic Mouse Facility, a Macromolecule Mapping and Engineering Facility, a Bioprocessing Research Facility, a Mouse Breeding Center for Human-Disease Models, and an expanded University of Tennessee–ORNL Graduate School of Biomedical Sciences. The shaded buildings form the existing Environmental Sciences Division Complex.

"Today's R&D problems are sufficiently complicated that no single technique is likely to solve them."

Senator Bingaman: *How would you summarize the role of neutrons in the national and international R&D arena? Why is the Advanced Neutron Source important to our competitiveness?*

Dr. Trivelpiece: To be technologically preeminent, we need to dominate the field of developing advanced materials. Almost everything we use for fabrication, maintenance, and protection, and a substantial portion of what we eat, is made from a synthetic or processed material. Amazingly often, that synthesis or process has been improved over the past few decades because of our increasing ability to modify natural processes on a finer and finer scale.

When this industrial evolution began, neutrons and X rays were still being used to study atoms. In the intervening period, we have learned to use these tools to study increasingly larger objects. In the past decade or so, the size range that can be studied using neutrons and X rays has finally overlapped with the most important size range for industry. The resulting research has been spectacular.

Neutrons and X rays are often complementary, but for most practical applications, **neutrons have a decisive and often unique advantage.** For example, neutrons can be used much more easily than X rays to study lightweight materials, which are usually of the greatest technical importance. Aerospace materials obviously should be as light as possible, and low-weight automobile components are needed to reduce fuel usage and costs.

Another advantage is that neutrons can be used much more readily than X rays to study pieces of material large enough to be representative, preferably under end-use conditions. Plastics are one of the most important materials where neutron research can aid present understanding and future development. If you've ever tried to tear the paper-thin foil of an airline peanuts bag somewhere other than the precut starting point, then you have experienced firsthand the importance of this research.

Today's R&D problems are sufficiently complicated that no single technique is likely to solve them. It is possible that a particular technique, using neutrons such as in the instances I just mentioned, may provide a breakthrough in fundamental understanding that will allow progress to be made across the board. The problems are often cross-disciplinary; thus, one specific feature of neutron user centers has made them remarkably fruitful for attacking such problems. Although neutron experiments tend to be essentially "small science" of the type found in university laboratories, the need for a centralized neutron source brings all types of neutron experimentalists together at one site. Many of the best results have come from the meetings of people who would not normally interact professionally and who subsequently have found new ideas in common.

Neutrons are used for a wide variety of applications beyond materials research. These uses extend from fabricating silicon for use in computer chips to therapeutic medical radioisotopes. Geologic maps of strategic minerals were constructed using data obtained from neutron activation analysis. The research reactors at ORNL are a resource shared by universities, national laboratories, and industries throughout the country. The fundamental scientific studies that were once the exclusive domain of neutron research are still performed, more widely than ever, but they now take place beside nondestructive testing of oil drills, pipelines, aircraft wings, and jet engines. Neutrons are being used for finding expanded reserves of petroleum and strategic minerals to help guarantee our future industrial independence, and for trace element analysis of soil to help guarantee our present and future food supply. As D. Allan Bromley, science adviser to President Bush, once put it, "Neutrons have had a revolutionary impact on much of science and technology."

The United States can take great pride in the invention, at ORNL, of reactor-based neutron research. Evidently, we showed the rest of the world the importance of this field all too well. In recent years, the lessons learned in this important research field have been applied more extensively overseas than at home. For the past 15 years, the 1989 Nobel Laureate in Physics, Norman Ramsey, has had to go to Europe to continue the neutron research he once performed in this country. Our facilities have not kept pace with new developments. Researchers in Japan are preparing for the startup of their newest research reactor. In Malaya, new neutron facilities are being built because of the practical importance of neutron scattering to understanding rubber. Investments in new facilities, such as the Leon Brillouin Laboratory in Paris, has given Europe a commanding lead in neutron research. An investment in facility upgrades has additionally benefited Europe by providing a training ground for the many new scientists entering the field. New advances in neutron technology are now being exported from Europe some 30 years after this country's most recent research reactor was designed.

Thirty years ago, Japanese cars were almost unknown, color television was a novelty, and ballpoint pens leaked. The technology behind fiber-tipped pens and polymer-based mechanical pencils was still awaiting the understanding that would come from neutron-based studies of these materials. Imagine what your workplace would be like if your most essential tools were 30 years old and you had to try to recruit staff. If we do not rejuvenate this field soon, a later injection of capital of any amount may still fail to increase our competitive posture. We will no longer have enough scientists trained in neutron science, and other countries will advance still further while we train new people.

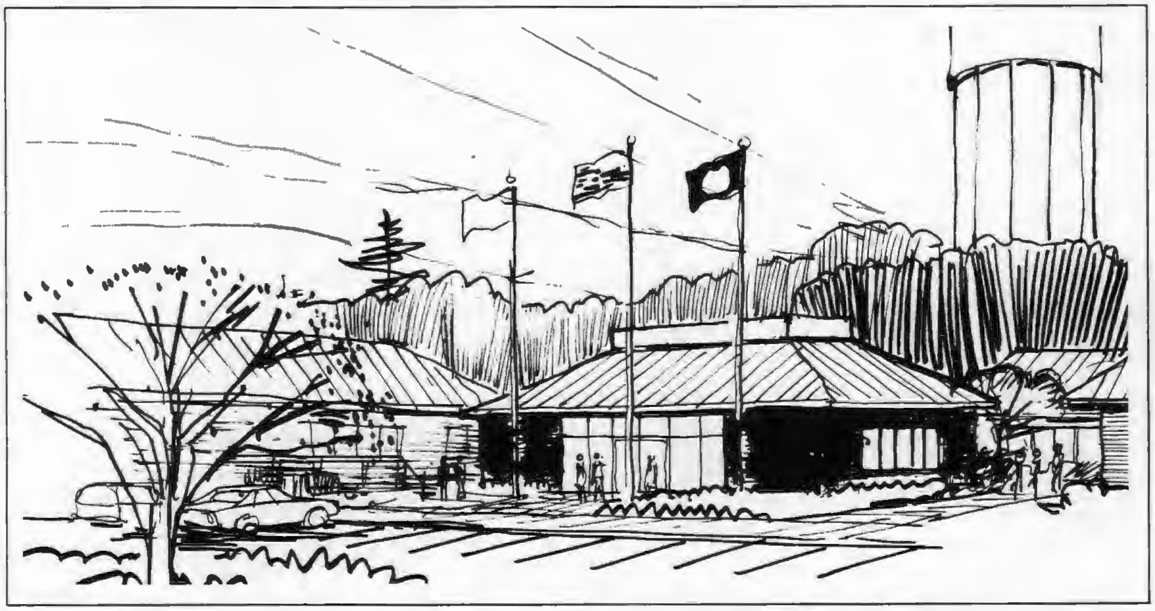
The **Advanced Neutron Source** (see drawing of ANS on p. 36) planned for ORNL will be the world's most exciting center for neutron research. It will allow us to regain the lead that we lost to western Europe a decade ago, and it will attract a new generation of researchers while it serves the needs of the present generation. The centerpiece of the ANS will be the finest research reactor ever built, incorporating every advance made since our last generation of research reactors was designed, to ensure safe and reliable performance. We project that 1000 scientists and engineers annually will use the 30 instruments that the ANS will provide for experiments on materials and for basic nuclear science. The neutron analytical facilities incorporated into the ANS will permit extremely sensitive and precise chemical analysis of environmentally important chemicals and pollutants. The ANS is the top scientific priority at ORNL, reflecting the importance that DOE, the National Academy of Sciences, and others attach to this project as an essential element of our national R&D strategy.

Senator Bingaman: *Would you expand on the capabilities you are planning for the future ORNL Materials Science and Engineering Complex? Why is this facility needed at Oak Ridge National Laboratory?*

Dr. Trivelpiece: The proposed Materials Science and Engineering Complex will consolidate a number of existing ORNL programs in new buildings and facilities that will meet new standards and enhance collaborative interactions in materials science. The Complex also would meet a critical need to replace deteriorating, substandard buildings and to alleviate severe crowding in current materials facilities at the Laboratory. It is planned that this Complex will address identified national, regional, and local needs for materials R&D and support our rapidly expanding user programs and technology transfer activities.

The **Materials Science and Engineering Complex** will include a new Solid State Sciences Building (SSB), a Center for Advanced Microstructural Analysis (CAMA), a Center for the Study of Advanced Materials (CSAM), a Composite Materials Laboratory (CML), and an Office of Guest and User Interactions (OGUI). (See drawings on pp. 36–37.) The existing OGUI will be sited in the Complex to coordinate the initiative of the Southeastern Universities Research Association (SURA) to encourage joint materials research activities with ORNL by establishing a university/industry presence at the Complex.

Materials R&D is the cornerstone of high technology, and ORNL has one of the strongest materials programs among DOE's national laboratories. Indeed, our programs in high-temperature alloys, ceramics, composites, and superconductors are unparalleled successes. The Materials Science and Engineering Complex is a recognition of the need to both perform and exploit materials R&D to make our nation more competitive in world commerce.



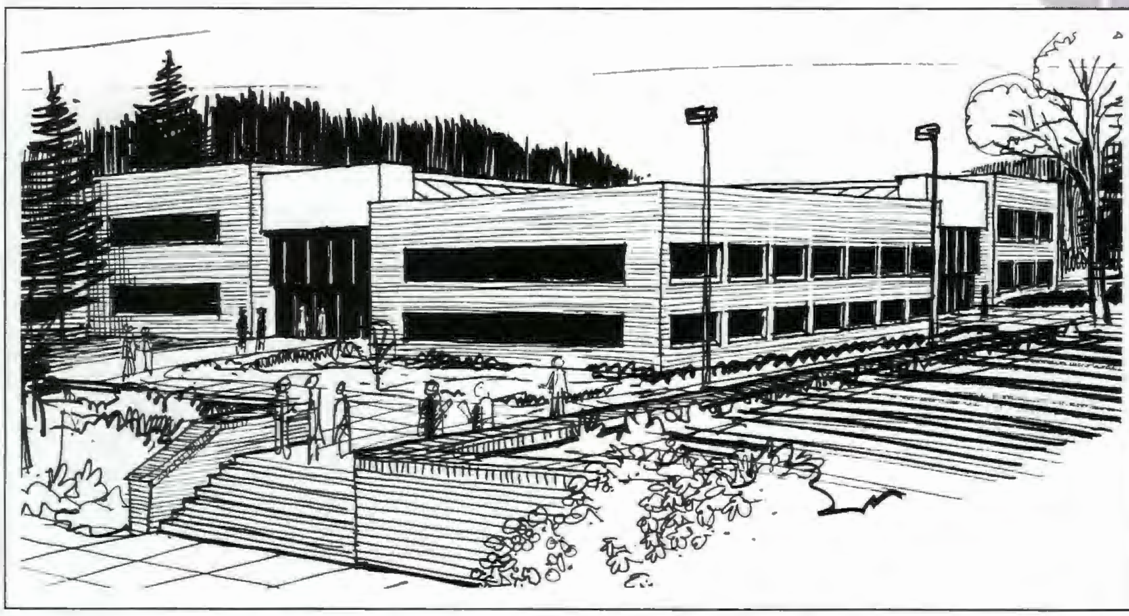
A new building is proposed for the Office of Guest and User Interactions, which offers visitors and guests access to collaborative research facilities at ORNL. The office serves 13 user centers and several collaborative research programs, negotiates legal agreements on research interactions, and handles more than 2300 researcher visits annually.

"In the 1990s, ORNL's strong materials science efforts will be strengthened further by the construction of the proposed Materials Science and Engineering Complex."

Universities and colleges in the southeastern United States have numerous innovative materials R&D programs that collectively span a broad range of disciplines from materials chemistry to materials physics and materials engineering and testing. During the last few years, SURA and Oak Ridge Associated Universities (ORAU) have explored ways to simplify and encourage joint materials research activities with ORNL.

As a result of a SURA materials science workshop and other organizational meetings between SURA and ORAU, the establishment of a campus-like presence at the Laboratory in the form of a Center for the Study of Advanced Materials has been proposed. This center would focus the materials science and engineering talents, facilities, and capabilities in the Southeast on nationally significant materials problems important to both DOE and the university participants—problems that cannot be solved by any one institution. The center would support the research and graduate education programs of the southeastern universities by (1) providing a site at ORNL where students and faculty could be located while participating in joint research; (2) utilizing the Laboratory's user facilities and staff; (3) holding workshops; and (4) benefiting in numerous other ways from the enhanced interaction with other university/industry and national laboratory researchers. The Center will provide positions for visiting scholars, faculty, and graduate students for research and study.

Another part of the proposed Materials Science and Engineering Complex is the **Solid State Sciences Building**, which will allow the consolidation of research activities now located in 15 separate buildings. Providing approximately 100 offices and 40 laboratories for state-of-the-art materials research, this new facility will replace aging structures that cannot be upgraded either to accommodate modern research or comply with environmental, safety, and health standards at acceptable costs. The building will provide a modern environment for conducting synthesis and processing science; studying surfaces, interfaces, and films; and fabricating improved semi-conductors, superconductors, and magnetic and optical materials.



The proposed Composite Materials Laboratory will be the home for work in developing polymer, carbon-carbon, metal, and ceramic-matrix composites. It will attract university and industrial experts in processing, structural mechanics, design and analysis, manufacturing science, and tests and evaluation.

The proposed **Composite Materials Laboratory** will be the home for work in developing polymer, carbon-carbon, metal and ceramic-matrix composites. It will attract university and industrial experts in processing, structural mechanics, design and analysis, manufacturing science, and tests and evaluation.

The **Center for Advanced Microstructural Analysis** will be a national resource for the user community. As microanalytical instrumentation becomes more sensitive, performance of these devices is limited not by the instruments themselves but by the environment in which they are situated. Electromagnetic fields, building vibrations, and even low levels of acoustic noise can degrade performance. Most of our existing facilities were designed as general-purpose laboratories, with little attention paid to the environmental issues that now restrict performance. The Center for Advanced Microstructural Analysis will provide a state-of-the-art site for the microanalytical instrumentation available at ORNL, including analytical and high-resolution electron microscopes, atom probes and field ion microscopes, surface analysis instrumentation, X-ray diffraction equipment, and mechanical property microprobes.

The **Office of Guest and User Interactions** facilitates guest and user access to collaborative research facilities at the Laboratory by disseminating information about designated user facilities, identifying user facility and other opportunities for collaborative research, providing assistance with the access and approval procedures required for visits to ORNL, negotiating legal agreements on research interactions, and assisting visitors with local needs such as transportation and housing.

Senator Bingaman: *You mentioned the proposed Center for Biological Sciences. What functions would this facility serve?*

Dr. Trivelpiece: For more than four decades, ORNL's Biology Division has steadily expanded the frontiers of life science. The work there began with studies of the biological effects of radiation and then continued with pioneering methodologies for radiation and chemical risk

"The new Center for Biological Sciences will greatly improve the accessibility of the Laboratory's research facilities and allow for expanded educational opportunities."

assessments. More recently, efforts have been focused on exploring the most basic life processes, including genetic replication and repair and protein structure/function relationships.

In the next century we have the opportunity to unlock the detailed secrets of DNA and the human genome to help us discover the causes and cures of many of our gravest human health problems, including birth defects, developmental abnormalities, and many forms of cancer. Today's research tools are tomorrow's hope for better chemotherapies, high-yield biomass for food and energy, and new ways of diagnosing and treating genetic disorders.

By establishing the Center for Biological Sciences, ORNL will continue to play a pivotal role in advancing these exciting frontiers. The facility will be structured, physically and organizationally, to promote accessibility, collaborative research, and user interaction. As a result, the Center itself will become a powerful new tool for bringing ORNL's expertise to life.

The **Center for Biological Sciences** will bring together several key components, allowing new interactions and synergies. These include a Transgenic Mouse Facility, Macromolecule Mapping and Engineering Facility, a Bioprocessing Research Facility, a Mouse Breeding Center for Human-Disease Models, and an expanded University of Tennessee–ORNL Graduate School of Biomedical Sciences.

The **Transgenic Mouse Facility** will be a world-class center for producing and breeding new mutant mouse strains. We are the world's leader in producing transgenic mice with insertional mutations—that is, mutations triggered by inserting foreign DNA "markers" into mouse zygote chromosomes. Some transgenic mice exhibit mutations that can be correlated with disease-producing mutations in humans. By developing many lines of transgenic mice, ORNL's breeding center will give researchers throughout the world powerful tools for deciphering the structure and function of the human genome.

As a user facility, the **Macromolecule Mapping and Engineering Facility**, coupled with ORNL's existing research reactors and the planned Advanced Neutron Source, will allow researchers from universities and other institutions to probe the three-dimensional structure of proteins and other complex hydrogen-containing molecules. It will shed light on protein function, through studies of "designer proteins," created by genetic engineering. Our ANS will reveal a new level of molecular detail, inaccessible to X-ray techniques and beyond the reach of today's neutron scattering equipment.

The **Bioprocessing Research Facility** develops advanced bioreactor systems to convert biomass into fuels and chemicals; to turn conventional fossil fuels into clean-burning liquids and gases; and to treat solid, liquid, and gaseous wastes. By bringing the Laboratory's biological researchers and analytical equipment into closer contact with this user facility, we will forge strong new bonds, both within the Laboratory and with additional guest researchers.

In addition to breeding transgenic mice, the new Center will house a **Mouse Breeding Center for Human-Disease Models**. These mutant strains, including strains mutated by radiation and chemicals, will provide animal models for exploring serious human diseases, including skeletal deformities, kidney disease, some forms of diabetes, and immune system malfunctions, including AIDS and arthritis.

For nearly a quarter century, the **University of Tennessee–ORNL Graduate School of Biomedical Sciences**, a collaborative program of ORNL and the University of Tennessee, has trained some of the nation's brightest biological researchers. Graduates of this school have later directed major laboratories, headed corporate and university research departments, and earned national-level science awards. Five of the Laboratory's seven National Academy of Sciences members have come from the Biology Division.

In keeping with Secretary of Energy James Watkins' science education initiative, the new Center for Biological Sciences will greatly improve the accessibility of the Laboratory's research facilities and allow for expanded educational opportunities. The biologists at ORNL represent a rare educational resource, one that we are committed to sharing with the scientists of tomorrow.

The Mouse House at ORNL, the world's foremost center for genetics research, is an irreplaceable international resource in urgent need of better facilities. This facility and the Biology Division's other facilities are badly aged, energy inefficient, and increasingly difficult to maintain. A continuing drain on resources, they pose an increasingly serious threat to our ability to sustain high-caliber biological research. The Center for Biological Sciences will allow us to take critical steps both toward protecting our research investment and toward meeting Secretary Watkins' environmental compliance goals.

Based on the results of recent studies by high-level committees, it may soon be recommended that the allowable limits for radiation exposures be reduced. The need for animal experiments to help determine safe exposure limits is vital. This is another example of research that will be supported in the proposed Center for Biological Sciences.

Senator Bingaman: *In his opening remarks, Secretary Watkins mentioned the national need for research in environmental restoration. How could ORNL assist the national effort to better understand the phenomena associated with both environmental restoration and waste management?*

Dr. Trivelpiece: In the last few years, the magnitude of the effort to clean up our nation's contaminated sites has increased dramatically. Vast economic and personnel resources are being devoted to **environmental restoration**. In some cases, problems can be addressed with available technology, so progress can be achieved in a short time. In many other cases, however, our level of understanding of the complex systems associated with remediation of certain disposal sites and the environmental behavior of wastes is either nonexistent or poorly developed. In either case, an appropriate base of knowledge is needed to develop solutions. This demands foresight in identifying future needs, as well as a relatively long-term commitment toward research directed at fundamental science issues related to environmental restoration. Goals for this effort are laid out in terms of decades rather than a few years. The challenge is for multidisciplinary teams of scientists to develop the fundamental knowledge required to ensure that environmental restoration activities are successfully undertaken, cost effective, and environmentally safe. Basic research and development support today will help ensure timely and cost-effective technologies for tomorrow.

What are the basic R&D challenges for environmental restoration? We need to understand better the physical and chemical factors that control the movement of radioactive, hazardous, and mixed wastes in the subsurface and surface water systems. We must also develop the capability to quantitatively model contaminant behavior. New remediation technologies—physical, chemical, or biological—must be developed for environmental restoration. In addition, they should be accompanied by recommendations for future waste management. The impact of remediation technologies on human and environmental health must be assessed, and new models must be developed and validated for assessing the health and environmental risks associated with previous disposal operations. Finally, performance assessments and post-remediation technologies and capabilities must also be developed.

These broad objectives will demand a wide variety of technical disciplines, and a highly interactive structure in which to operate. For instance, significant emphasis must be placed on modeling capabilities, including those related to geochemistry and hydrology, as well as to risk analysis. The interactive relationships between wastes of different types and natural processes of varying nature must be studied. These studies should emphasize microbial transformations that can be used in remediation, as well as other biological parameters that can effectively serve as risk and performance assessment evaluators. Inherent in this initiative will be the need for enhanced computational ability and the use of artificial intelligence and expert systems to aid restoration decision making. Basic research issues important to the waste R&D effort will change as technologies develop and as new problems are encountered.

"The time is right for the nation and the DOE to take advantage of the multi-disciplinary expertise and experience in waste R&D at ORNL."

The time is right for the nation and the DOE to take advantage of the multidisciplinary expertise and experience in waste R&D at ORNL. The setting of this Laboratory provides a unique opportunity for field-testing projects running the gamut from characterization to remediation.

Because the cost of remediating environmental insults is high, a vigorous R&D program is needed to minimize cleanup costs, to quantitatively understand the risks posed by the contaminated sites, and to help establish remediation priorities. At ORNL, the purpose of our waste R&D initiative is to develop and demonstrate advanced technologies that will significantly reduce the costs of environmental restoration and waste management while meeting requirements of public acceptability.

One component of this program is to determine methods and develop techniques for identifying and characterizing the wastes and waste sites associated with the various DOE operations, particularly those within the eastern half of the United States. As part of this characterization effort, more useful, cost-effective tools need to be developed that will facilitate our response to compliance requirements at minimal cost. These include modeling hydrologic systems and developing advanced field measurement, sensing, and data analysis techniques. The Ultrasonic Ranging and Detection System, developed at ORNL, has been successfully transferred to industry. Effective modeling requires greater understanding of contaminant behavior and its response to remediation techniques. A large cost of any remediation effort is the required qualitative and quantitative analysis. Improved and cheaper analytical techniques should be developed that are in situ and real time. Field-oriented methods that allow both site and contaminant characterization with minimal cost and health impact are necessary.

A second component of the applied waste R&D initiative involves assessing existing waste management methods and evaluating, developing, and demonstrating new potentially effective technologies for waste treatment. Some of these potential effective technologies may currently be in use in other industries, but they have not been considered for application to waste management. These technologies will be needed to address the three frontiers of restoration and waste management: the cleanup of existing sites, better techniques for handling wastes currently being generated, and process modifications to minimize future waste generation.

Several technologies are currently being evaluated for these purposes, along with their potential for future development. Bioremediation and biotechnology may provide organisms that fix, degrade, detoxify, or accumulate organic and selected inorganic species either in situ or in process. Bioindicators may continuously monitor environmental quality. Robotic systems and remote technology may enhance environmental restoration and waste management operations. These waste-handling techniques would remove workers from contact with hazardous materials, increase the speed and productivity of operations, and reduce life cycle costs of these operations.

Waste reduction in volume or toxicity may be achieved by developing waste minimization technologies ranging from fundamental chemical reactions to engineering and process design. Advanced separation technologies would improve waste concentration efficiency and effectiveness.

Although these technologies are to some extent already developed, additional refinement is necessary for them to be cost effective in addressing a wider range of waste problems. It is expected that industry will be heavily involved in this program, particularly in the demonstration phase. Because of ORNL's impressive record in technology transfer, close working relationships are anticipated both within and outside the DOE community.

At any site undergoing cleanup efforts, two questions are frequently asked: How clean is clean? At what level of contamination is toxicity negligible? These questions are directly related to risk. Successful support of our national remediation efforts depends on the fundamental knowledge base provided by basic research. It will take decades to complete remedial investigations, feasibility studies, and actual site remediation at DOE and other government sites. It is the management of health and environmental risks that is of primary concern to the owners of the contaminated sites and the funders of the remediation efforts. Achievement of a given level of compliance is not the sole criterion. Fundamental operational questions of risk and risk management require new approaches that are generated by basic research, along with the application of site-specific human health and ecological effects data bases for model development, validation, and uncertainty analysis.

Concern over a lack of qualified, trained scientists and engineers to solve future problems has led to an increased emphasis on education within DOE. ORNL is responding to this concern by developing joint research projects with major universities and historically black colleges and universities to encourage students to study in the various fields of waste management.

Senator Bingaman: *You've mentioned your educational programs several times in your comments today. Would you please describe some of the educational programs conducted at Oak Ridge National Laboratory this summer? I also understand, Dr. Trivelpiece, that you are the chairman of the Mathematical Sciences Education Board. What role does this group have in national education?*

Dr. Trivelpiece: ORNL's educational programs are part of DOE's effort to arrest the trend toward fewer numbers of American students in science and engineering. From June 13 to July 3, the first National Teacher Enhancement Program was conducted in Oak Ridge under a three-year, $2 million National Science Foundation grant. ORNL administers this grant on its own behalf and on behalf of four other DOE laboratories—Fermi, Argonne, Brookhaven, and Livermore. Forty-six elementary-level teachers and principals from ten East Tennessee counties participated in this three-week session. More than 25 area teachers as well as ORNL research staff members acted as resource persons.

Under the May 19, 1990, DOE Memorandum of Understanding with the Appalachian Regional Commission, activities were initiated with two pilot science education programs in July for 17 middle and high school students and 3 teachers from school systems in southwest Virginia. These hands-on learning experiences were based on the curriculum of our Ecological and Physical Sciences Study Center.

Under ORNL's Memorandum of Understanding with the University of Puerto Rico, a one-week hands-on precollege study program was conducted from June 25 to July 3 in Oak Ridge for 17 Puerto Rican students and two teachers. The one-week program included an opportunity for interaction with the Hispanic SEED students here on summer-long research appointments.

Our core program in the precollege area, the Ecological and Physical Sciences Study Center, served some 16,000 youths and adults during the September 1989 to June 1990 academic year. This number represents a 60% increase from the total of 10,000 participants during the previous year. The Study Center offers more than 20 different half-day, hands-on study experiences, both for visiting groups and through classroom visits from the Center's staff.

A total of 40 elementary- and secondary-level teachers participated in this year's eight-week Summer Teacher Research Program at ORNL. This total more than triples the number of appointees at the Laboratory under DOE's nationally administered Teacher Research Associates program. Additional support for teachers has been provided through several sources: the Laboratory's research divisions, the Department's Waste Management Education Initiative, initial Department funds for Project SMART (Science/Math Action for Revitalized Teaching), local funds to support minority teachers under the STAR Program (Summer Teachers As Resources), and the first appointment under a new initiative to provide national laboratory research experience for prospective teachers during their undergraduate or graduate study.

Working through the newly organized Clinch River Environmental Studies Organization, the 130-acre Anderson County Wildlife Sanctuary is being developed as an environmental study site by three area school systems. Money provided by

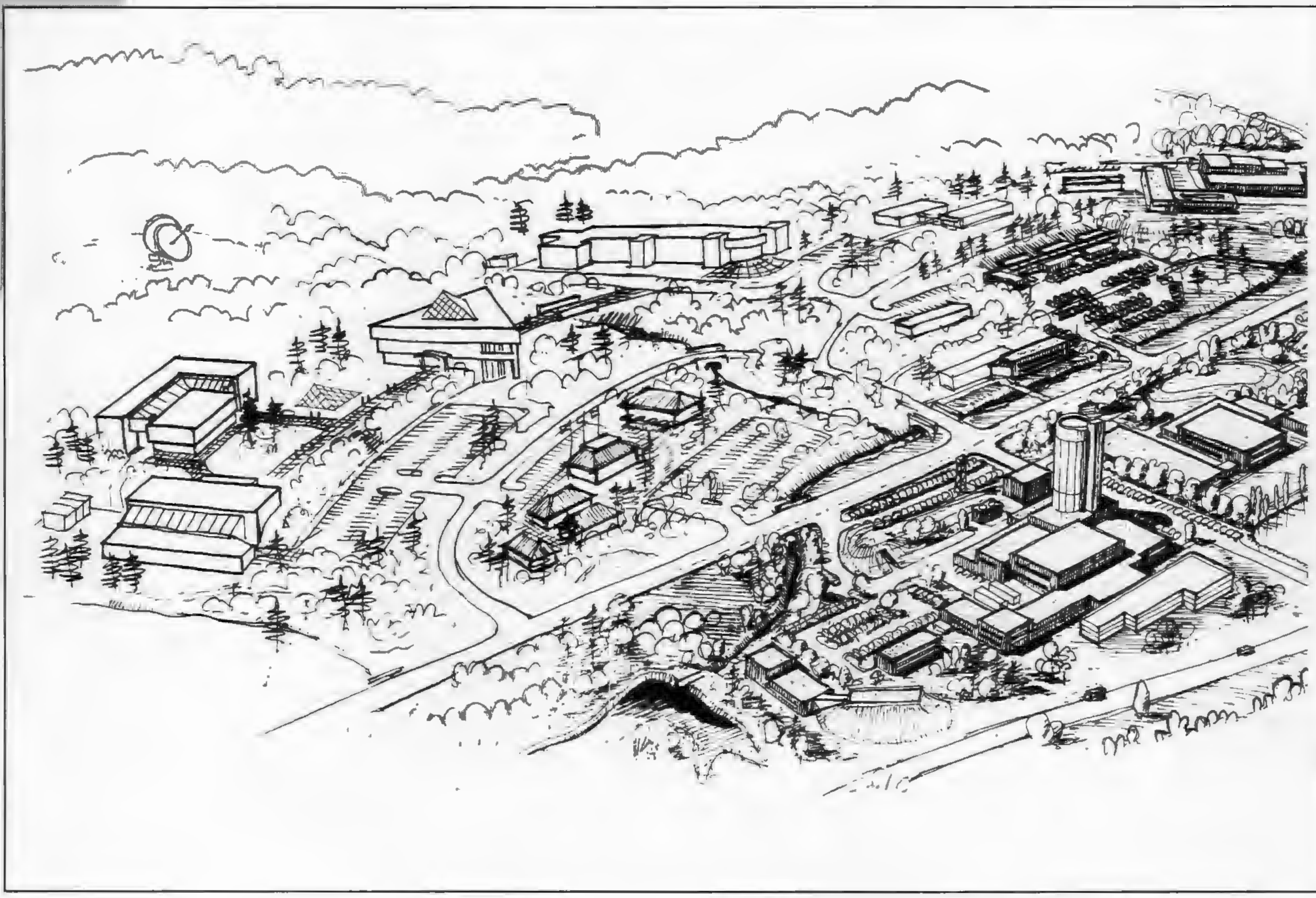
Katherine Capps, a 1990 graduate of Clinton High School, completed her second summer as a Project SEED student working with Jonathan Woodward's biotechnology group in ORNL's Chemical Technology Division.

DOE's Waste Management Education Initiative has helped to support initial survey and curriculum development activities at the site. This has been accomplished through a program of "student environment problem grants," which enabled upper-level students to develop and carry out research projects during the spring and summer. Two supervising teachers were supported under our Summer Research Program. On-site study experiences for class groups from the participating schools are to begin this fall.

The Service Academy Research Associate program brings science, mathematics, and engineering majors from military academies to ORNL to work with staff scientists in a research

Louise Dukes, biology teacher at Marshall County High School in Lewisburg, Tennessee, was one of 42 teachers who carried out eight-week summer research assignments in 1990 at ORNL. She worked with Brenda Faison in the Chemical Technology Division.

Chet Richmond, director of Science Education Programs and External Relations at ORNL, enjoys a winning poster, "It's Their Earth, Too," in the local Earth Day Poster Contest. The winner (shown here) is Colette Boudreaux of Knoxville, who entered in the Grade K–2 category.



Architectural drawings by Ron Barstow

environment for two to six months. This summer three undergraduate and six graduate students are participating. Other programs include the Science and Engineering Research Semester for college undergraduates and the Nuclear Engineering Training Program for top students at historically black colleges and universities.

To respond to the second part of your question, the Mathematical Sciences Education Board was created in 1985 by the National Research Council to stimulate and coordinate national reform of mathematics education. The Board is a coalition of national leaders from the mathematical sciences, education, government, parent groups, and the corporate sector. In its first major publication, *Everybody Counts: A Report to the Nation on the Future of Mathematics Education*, the Board sets forth a compelling argument for fundamental mathematics education changes starting in kindergarten. The Board will work toward a consensus on the goals of mathematics education and will promote national standards. Structures for facilitating change will be established, and prototypes of content and instruction will be developed. The Board will report to the nation on the status of mathematics education and will define a national strategy for implementing change.

The Mathematical Sciences Education Board is engaged in a wide variety of activities in its effort to improve mathematics education at all levels and for all students. Several of these activities are well advanced, such as coordinating the work of professional organizations that are developing professional teaching standards, as well as a national strategy for reaching out to groups that are traditionally underrepresented in the mathematical sciences. The Board is disseminating the results of international comparisons of mathematical achievement and creating materials that encourage young children to be successful in mathematics. A national network of state-level mathematics coalitions is being established, and mathematics education is being promoted as a priority concern for a wide range of national organizations. The Board is beginning to organize a national corporate council to link business and industry with the reform movement in mathematics education. Also, U.S. schools are beginning to adopt successful international practices in mathematics education.

In short, if the nation is to regain its leadership in international commerce, we need to influence the nation's best and brightest young people to pursue scientific, technical, and mathematical careers. ornl

RE: Awards & Appointments

Loucas Christophorou

Herb Mook

Donald Batchelor

Victor Tennery

Mark Kohring

Loucas Christophorou and **Herb Mook** have been elected chairman and vice chairman, respectively, of the Corporate Fellows Council, recently formed to advise ORNL Director Alvin Trivelpiece on matters concerning ORNL's scientific and technical welfare.

P. C. Srivastava has received the United Nations Distinguished Scientist Award, which encourages Indo-U.S. collaboration through projects, seminars, and workshops. During his stay in India, he will perform research at the central Drug Research Institute in Lucknow and participate in the Transfer of Knowledge Through Expatriate Nationals Project.

Steiner J. Dale has been elected a fellow of the Institute of Electrical and Electronics Engineers.

Donald Batchelor has been elected a fellow of the American Physical Society.

James C. Mailen has been elected a fellow of the American Institute of Chemical Engineers.

For the 14th consecutive year, ORNL received the DOE Award of Excellence for its safety performance. ORNL also received the National Safety Council Award of Honor for operating 7,413,451 employee hours without occupational injury or illness involving days away from work, from October 14, 1988, to August 18, 1989.

The East Tennessee Chapter of the Association for Women in Science recently presented awards to **Karen Von Damm,** for distinguished achievements in science; **Mary Emrich,** for distinguished achievements in technology; **Linda Cain,** for being an outstanding leader and advocate; and **Janet Cushman,** for service to the local chapter.

Victor J. Tennery has been given an Award for Excellence in Technology Transfer by the Federal Laboratory Consortium for Technology Transfer.

Robert D. Hatcher, Jr., has been appointed to the National Research Council's Board on Radioactive Waste Management.

G. Daniel Robbins has received the Watson Davis Award of the American Society for Information Science for outstanding contributions and dedicated service to the society.

James R. Sand and **Edward A. Vineyard** received a 1989 Best Paper Award from the American Society of Heating, Refrigerating and Air-Conditioning Engineers for co-writing "Selection of Ozone-Safe, Nonazeotropic Refrigerant Mixtures for Capacity Modulation in Residential Heat Pumps."

The newly created Office of Operational Readiness and Safety, headed by **Mark Kohring,** has two new sections: the Operational Readiness Section, headed by **Jeff Hedges,** and the Self-Assessment and Appraisal Section, headed by **Betty Dagley. Mike Murray** has been named review and appraisal manager for the office.

Paul H. Hughes has been named training and procedures manager of the Research Reactors Division.

Paul F. Reeverts is Occupational Safety and Health Administration (OSHA) program manager at ORNL.

Paul Kanciruk has been named DOE representative to the Committee on Earth Science's Task Group on Earth System Measurements and Data Management by DOE's Atmospheric and Climate Research Division.

B. Gordon Blaylock has been elected to the National Council of Radiation Protection and Measurements.

Jeffrey E. Christian has been appointed to the Board of Direction of the Building Thermal Envelope Coordinating Council.

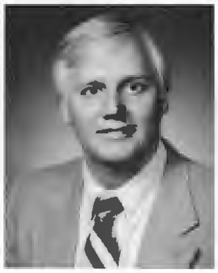
Darlene Lasley has been awarded the 1990 Research Support Award of the Oak Ridge Chapter of Sigma Xi.

Ajay K. Rathi has been named to two committees of the Transportation Research Board of the National Research Council: Traffic Flow Theory and Characteristics Committee and Committee on Expert Systems.

Elizabeth B. Peelle received an honorary degree from Miami University for "her outstanding contributions to the nation's environmental consciousness."

Donald B. Hunsaker, Jr., has been elected to the Board of Directors of the National Association of Environmental Professionals.

Tuan Vo-Dinh has been named to the Committee on the Curriculum for Biomedical Technology for the Tennessee Department of Education.



Curtis Olsen

David Hobson

Leo Holland

Dorothy Skinner

Sankar Mitra

He also is serving on the Senior Research Associate Board of the Environmental Research Center at the University of Nevada, Las Vegas.

Janice Henderson has been appointed manager of administrative support for the Instrumentation and Controls Division.

Numerous ORNL employees were honored at the annual Awards Night of Martin Marietta Energy Systems, Inc., held April 12 in Knoxville. Awards were presented in recognition of outstanding contributions to the company or the community during 1989. Awards were presented in four categories: technical achievement, community service, operations and support, and management achievement.

Three ORNL employees singled out for top awards who later received the Jefferson Cup Award at Martin Marietta Honors Night Ceremonies were Inventor of the Year **Wayne F. Johnson,** for 30 years of distinguished technical innovation associated with the science and technology of automated analysis instruments for use in medical laboratories; Author of the Year **Curtis R. Olsen,** for publication of "Plutonium, Lead-210, and Carbon Isotopes in the Savannah Estuary: Riverborne Versus Marine Sources"; and Operations Improvement Award recipient **Thomas H. Row,** for outstanding leadership as manager of the successful Technical Safety Appraisal of ORNL for DOE.

ORNL employees who received a Technical Achievement Award, which recognizes excellence in contributions in research, development, engineering, publications, or inventions, are **Steve L. Allman,** for exemplary research and development of the laser technique for ultralow-level detection; **Archibald C. Buchanan III,** for significant achievements in the research of reaction mechanisms relevant to the thermal processing of coal; **Loucas G. Christophorou,** for outstanding research on and development of the dielectric-liquid pulsed power switch; **Robert E. Clausing** and **L. Heatherly, Jr.,** for successful research and development in the growth of oriented diamond thin films that have excellent optical properties; **Dwight A. Clayton, Robert R. Bentz, James M. Jansen, Jr., Russell B. Rochelle,** and **R. Wesley Wysor,** for research and development leading to a state-of-the-art, unique system for the acquisition and processing of acoustic signatures from submarines; **Diedre D. Falter, Gary T. Alley, Kelly G. Falter, Pamela H. Fleming, Gerald E. Jellison, Jr., James M. Rochelle,** and **Russell D. Westbrook,** for outstanding work in developing a solar-powered infrared microminiature transmitting system; **Christopher A. Foster, Thomas C. Jernigan, Darrell W. Simmons, Carl W. Sohns,** and **John C. Whitson,** for significant research leading to the development of a centrifuge-type cryogenic pellet injector for the Tore Supra device; **Dennis W. Heatherly,** for exemplary technical support in the development of a technique for reencapsulating previously irradiated specimens and for sustained high performance in the Material Irradiation Programs; **David O. Hobson,** for research and development leading to three inventions, with patents granted or filed, on the use of magnetohydrodynamic forces to purify, atomize, or fabricate metals and alloys; **Patricia R. Hunsicker,** for vital technical support in the research of the Mammalian Genetics Section; **Deborah J. R. Huntley,** for publication of "Adsorption and Reactions of Methanethiol on Clean and Modified Ni(110)"; **Stephen J. Kennel, Linda J. Foote,** and **Claude D. Stringer,** for publication of "Analysis of the Tumor-Associated Antigen TSP-180"; **Terrence Lindemer, J. Brynestad, J. E. Gates, Camden R. Hubbard, John F. Hunley,** and **Alfred L. Sutton, Jr.,** for publication of "Experimental and Thermodynamic Study of Nonstoichiometry in $\langle YBa_2Cu_3O_{7-x} \rangle$"; **Douglas H. Lowndes, John D. Budai, David B. Geohegan, Douglas N. Mashburn, J. W. McCamy,** and **David Norton,** for significant research and development of the laser ablation processing of thin-film superconductors; **Sankar Mitra,** for research and development in devising and successfully exploiting a method for cloning genes for human DNA-repair proteins and for subsequently isolating substantial quantities of the encoded protein; **Mark Mostoller, Robert M. Nicklow,** and

Doug Lowndes

Patricia Hunsicker

Stephen Kennel

David M. Zehner, for publication of "Bulk and Surface Vibrational Modes in NiAl"; **Curtis R. Olsen, Norman H. Cutshall, Ingvar Lauren Larsen, Patrick J. Mulholland,** and **Myint Thein,** for publication of "Plutonium, Lead-210, and Carbon Isotopes in the Savannah Estuary: Riverborne Versus Marine Sources"; **Charles R. Schaich,** for technical support through sustained contributions to the development and operation of microwave heating systems for fusion plasmas; **Dorothy M. Skinner,** for outstanding research and development leading to the transcription of a satellite DNA; **Rajendra S. Solanki,** for publication of "Approximating the Noninferior Set in Linear Biobjective Programs Using Multiparametric Decomposition"; **Michael R. Strayer** and **Christopher Bottcher,** for publication of "Electron Pair Production from Pulsed Electromagnetic Fields in Relativistic Heavy-Ion Collisions"; and **Madge C. Woody,** for sustained and outstanding contributions in technical support of the coal chemistry program.

An ORNL employee who received a Community Service Award, which recognizes voluntary activities of benefit to the community, is **William R. Busing,** for outstanding devotion and personal commitment in working with the Alliance for the Mentally Ill on local, state, and national levels.

Four ORNL employees received a Management Achievement Award, which recognizes management contributions characterized by exemplary performance in leadership, planning, organization, staffing, and control functions; dealing with resource limitations and other constraints, meeting or exceeding schedules, attaining mission goals, training and motivating people; and specific accomplishments that demonstrate outstanding management performance. They are **Truman D. Anderson,** for outstanding leadership in strategic planning and management directions for ORNL; and **Leo B. Holland, F. Eugene Muggridge,** and **Roger L. Stover,** for exemplary performance in management efforts and problem resolutions that were principally responsible for successful restart of the Tower Shielding Reactor.

ORNL employees who received an Operations and Support Award, which recognizes exceptional administrative, technical, or operations support characterized by improvements to efficiency, major cost avoidance or reduction, enhanced programmatic operations, or extraordinary personal effort, are **Kimble G. Edgemon, Jr., James E. Bacon, A. L. Herrell, C. Yvonne Horton, J. L. Johnson, Claude G. McCuiston, R. E. Shepherd, Jr.,** and **L. C. Wilson, Jr.,** for outstanding performance of the Hazardous Waste Operations Group in preparing for audits, in dealing with changing compliance regulations, and in upgrading equipment and facilities; **J. Harold Greene,** for innovative leadership in planning, staffing, and bringing on line the Laboratory Emergency Response Center; **James T. Hargrove,** for exceptional sustained management of the ORNL Nuclear Materials Management and Materials Control and Accountability Programs; **Paul B. Hoke,** for pioneering efforts and developing procedures to structure a quality assurance program for the Laboratory's R&D activities; **Dawn C. Human,** for distinguished secretarial support to the Engineering Physics and Mathematics Division, particularly in guiding efforts to secure a site license for the Arnold Engineering Development Center; **Mariann Huskey,** for unselfish administrative and office support in coordinating three major environmental projects for the Energy Division; **Charles Kirkpatrick,** for exemplary performance as a general supervisor and Technical Safety Appraisal and Environmental, Safety, and Health Upgrade coordinator in the Plant and Equipment Division; **Virginia N. Lee,** for exemplary and highly professional performance in administrative and office support throughout 30 years; **Lana K. McDonald,** for sustained excellent performance and productivity as secretary for the Regional Resources Group; **Patrick N. Rader,** for extraordinary competence and farsightedness and for demonstrated commitment to excellence and continuing improvement in management of the ORNL Materials Department; and **Marjorie N. Skipper,** for outstanding contributions in administrative and office support for the Laboratory Shift Superintendent organization.

EDITOR'S NOTE

Last Column

This is Ram Uppuluri's last "Take a Number," a regular column that first appeared in the Review *in the Fall 1970 issue. On November 16, 1990, he retired from ORNL's Engineering Physics and Mathematics Division. While at ORNL, he studied decision-making techniques and knowledge systems, helped found the Society for Risk Analysis, and motivated efforts to improve mathematics education in Tennessee. We wish him well and gratefully acknowledge his 20 years of fine contributions to our readers' mathematics education and appreciation.*

Take a Number

By V. R. R. Uppuluri

Paper Folding and the Square Root of 2

The standard size of paper in the United States is different from that of paper in Europe and Japan. In the United States, a sheet of letter-size paper measures 8 1/2 by 11 in., or 215 by 275 mm. In Europe and Japan, letter-size paper measures 210 by 297 mm.

The dimensions of the foreign paper are intriguing, as I learned from a recent discussion with Yohta Nakai of Tokaimura, Japan. If you divide 297 by 210 to obtain the ratio of the longer side to the shorter side, your answer is 1.414286, close to the square root of 2, which is 1.414214.

Now, if you fold the sheet of paper in half along the longer side, the new dimensions are 148.5 by 210 mm. The ratio of the longer side to the shorter side (210 divided by 148.5) is 1.414141. Fold the paper in half again along the longer side, and its new dimensions are 148.5 by 105 mm. Divide the longer by the shorter side and you obtain 1.414286. Both answers are close to the square root of 2.

Not surprisingly, dimensions resulting from repeated foldings of paper this size have ratios that are always close to the square root of 2.

Unique Only for a Few Cases

By increasing each digit of certain perfect squares by 1, another perfect square is created.

Consider the perfect square 25 (= 5^2). By increasing each digit by 1 (25 + 11 = 36), we obtain another perfect square (= 6^2).

Next, consider the perfect square 289 (= 17^2). By adding 111 to 289, we obtain 400, which is also a perfect square (= 20^2).

Similarly, by adding 1111 to the perfect square 2025 (= 45^2), we obtain 3136, another perfect square (= 56^2).

The perfect square 13,225 (= 115^2) has the same property. Add 11,111 to 13,225 to obtain 24,336, which is also a perfect square (= 156^2).

The solutions given above are the only squares fived digits or less that have this property. In other words, no other square containing five digits will yield a perfect square when 11,111 is added to it. However, at least two six-digit squares, when increased by 111,111, will produce perfect squares.

Science and Technology Alliance

Carmen Varcla, a secondary science teacher in Puerto Rico, was one of two supervising teachers for seven outstanding Puerto Rican students who carried out ten-week summer research projects at ORNL through the Science and Technology Alliance.

In the ever-expanding effort to draw more minorities into science and engineering, DOE has taken the quite practical approach of establishing the Science and Technology Alliance. The program connects national laboratories with universities that have large minority student bodies, allowing the laboratories' expertise, enthusiasm, and equipment to entice the students into technical careers.

ORNL, Sandia National Laboratories, and Los Alamos National Laboratory were chosen as the national laboratory participants, and the Ana G. Mendez Educational Foundation in Puerto Rico, New Mexico Highlands University, and North Carolina A&T State University were the chosen universities. The universities will create competitive scientific and engineering programs through enhancements of the faculty, curriculum, and research and through equipment loans and special programs. The laboratories will reap the benefits of increased numbers of qualified scientists and engineers, research opportunities, and universities capable of DOE research.

The program began operation in 1988 through summer research projects, workshops, and seminars by the Alliance for faculty members; staff loans from the national laboratories to expand the courses offered at Alliance universities; and acquisitions of equipment and materials by the universities. ORNL staff conducted a workshop in computer program design at the Ana G. Mendez Educational Foundation and provided technical assistance to their computer center. ORNL also invested more than $1.5 million in its collaborative research efforts with North Carolina A&T's materials science program on the testing and evaluation of advanced ceramics at high temperatures. ORNL's interaction through the Metals and Ceramics Division with NCA&TSU dates back several years and includes collaborative research subcontracts totaling more than $1.5 million.

ORNL is part of a collaboration with the other two national laboratories to develop both a technical library for engineering technology and a degree-granting program in environmental sciences at New Mexico Highlands University. ORNL is helping the Ana G. Mendez Educational Foundation establish a five-year plan for its computer center by providing a staff member as consultant.

These activities were expanded in 1990. One program will establish joint research and development (R&D) projects and programs between Alliance laboratories and universities, helping the universities to develop the capability to perform major R&D and gain Accrediting Board for Engineering Technology (ABET) accreditation. North CarolinaA&T will aid in this effort, given its existing School of Engineering's ABET-accredited departments. The successful summer research programs at the laboratories will be expanded by increasing the number of university participants in the three-month program.

ORNL's closest ties are with North Carolina A&T, whose 6100 students form the largest minority university in the state. David Gain, a student there, was pleased with his participation in a summer research program at ORNL. "I feel that it was a great asset to my career. It gave me an opportunity to experience things in an industrial setting that I haven't had a chance to experience at school."

Plans are being made for the first cooperative educational programs, and opportunities will expand for minority faculty members to work on research projects with colleagues at the national laboratories. Furthermore, precollege programs in science, engineering, and technology have been developed at the universities.

An interesting feature of the Science and Technology Alliance is its industry affiliate members. AT&T, the first affiliate, provided an engineer as a professor in the School of Engineering to the Ana G. Mendez Educational Foundation and will assist the Alliance laboratories in obtaining ABET accreditation. Hewlett-Packard, although not a formal industrial affiliate, has given a UNIX computer system to New Mexico Highlands University. Martin Marietta Corporation has been asked to become an industry affiliate. The goal is to increase industry support, eventually allowing the program to become less dependent on government funding.

The following are other long-term goals in FY 1990 for the Alliance, listed by educational institution.

Ana G. Mendez Educational Foundation

- Continue development of an engineering school, to include ongoing loan of staff from Sandia National Laboratories to design curricula and to create a technical library. The Foundation hopes to open an engineering school within five years that will offer B.S. degrees in manufacturing engineering and mechanical engineering.
- Continue development of a master's degree program in computer science and biology, tied to upgrading and modernizing current computer science programs.
- Develop programs in electronics engineering technology.
- Develop precollege programs in engineering.

New Mexico Highlands University

- Continue development of B.S.-degree programs in engineering technology.
- Expand a two-year program in computer science to a four-year BS-degree program.
- Further develop the Science Education Resource Center for precollege and in-college assistance.

North Carolina A&T State University

- Expand the UNIX network for educational programs.
- Establish a free-standing computer science department and simultaneously develop an M.S.-degree program in computer science.
- Continue to develop M.S.-degree programs in civil engineering and chemical engineering.

Reggie Hall (right) of ORNL's Chemical Technology Division was the summer mentor for Edmundo Rivera-Santos, a rising senior at Irving High School in Carolina, Puerto Rico.

Students from three high schools in Smyth County in southwest Virginia participated in the first Math/Science Summer Experience conducted at ORNL under a new memorandum of understanding between DOE and the Appalachian Regional Commission. Instructor Kris Light leads the group in a "Fallen Tree" study.

- Continue to develop "free-standing" doctoral programs in electrical engineering and chemistry.
- Expand environmental sciences programs within the School of Agriculture.
- Develop research programs in microelectronics.

Memorandums of Understanding

A memorandum of understanding (MOU) is a formal agreement between two institutions that establishes the bases for a collaboration. The agreement provides for mutual support and interactions in a number of areas that will strengthen resources in science and technology. In education, ORNL is usually exchanging its staff and research capabilities for the fresh approach of university faculty and students. MOUs can also be an excellent way to recruit minorities for careers in science and technology.

ORNL has MOUs with several minority education institutions. The MOU with Southern University made possible faculty and student research appointments at ORNL and the Oak Ridge Y-12 Plant during the summers of 1989 and 1990, and R&D contracts totaling $413,000 were committed to the university. ORNL continued its collaborations with Tuskegee University through R&D contracts totaling $118,000 and support of two students and one faculty member for summer internships during FY 1989. In FY 1990, $60,000 supported faculty members at ORNL as summer interns.

ORNL has committed $90,000 to Clark Atlanta University (CAU, formerly Atlanta University). The major collaboration links ORNL's expertise with hazardous materials to a Hazardous Materials and Waste Management Consortium comprising 12 Historically Black College and University/Minority Educational Institution institutions. This consortium, led by CAU, was successful in obtaining funding ($4.3 million) from DOE.

The University of Puerto Rico

The MOU between ORNL and the University of Puerto Rico (UPR), signed in 1987, is a step toward increased interactions between the Laboratory and Hispanic institutions. ORNL's ties to Puerto Rico date back to the establishment of the Puerto Rico Nuclear Center in 1957 and its subsequent operation of the Center for Energy and Environmental Research under a contract administered by Oak Ridge through a Puerto Rico area office. In 1989 the MOU provided a mechanism to support eight faculty members and students conducting research at ORNL. This relationship strengthens UPR's capabilities in energy-related research and enhances the training of students in science and engineering disciplines. As a part of this collaboration, the two institutions will support

- collaborative research projects;
- research participation appointments for faculty and students;
- short-term visits to ORNL by UPR faculty and students to conduct research and use equipment and facilities;
- short-term visits to UPR by ORNL staff to conduct research, teach classes, consult, and give seminars;
- technical assistance in preparing research proposals to federal agencies; and
- assistance to UPR in developing a "Visiting Lecturers Program" to attract prestigious scientists in energy-related disciplines.

In FY 1990, as a part of one UPR program, 15 Puerto Rican high school students plus two high school teachers, two graduate students, and one professor spent three weeks at the university and one week at ORNL studying energy-related topics.

Foreign Institutions

"We're establishing international agreements," said Chet Richmond, director of Science Education Programs and External Relations at ORNL. Recently, the Laboratory has signed MOUs with the Universidad Nacional Autónoma de México (UNAM) and the Gesellschaft für Strahlen- und Umweltforschung mbH München (GSF).

UNAM, which has 12,000 faculty and lecturers and 130,000 students, asked ORNL to establish an MOU with them. Besides promoting better north-south relations, the agreement could give UNAM access to ORNL's advanced scientific equipment and ORNL access to resources such as two oceanographic research vessels (one in the Gulf of Mexico and one in the Pacific Ocean). This potential access to ocean study may be of help in ORNL's global environmental studies.

GSF, a national research laboratory established and operated by the German federal government and the Bundesland Bavaria, is a center for health and environmental sciences. GSF provides ORNL with a basis for rapid international collaboration in response to research opportunities or emergency situations. "Because of the global nature of many scientific problems," says Richmond, "and the scarcity of resources to perform R&D, it will become increasingly important to develop international collaborations."

GSF's research activities are concentrated on the impact of radiation and chemical pollution on the environment and on human health. ORNL's collaboration with them will contribute to the overall national goal of strengthening energy-related research by taking mutual advantage of the research facilities and scientific instrumentation at both a national laboratory and at an excellent research laboratory in Germany.

Premier Institutions Program

An advisory committee once pointed out that most of ORNL's university interaction is with the University of Tennessee (ORNL has $14 million contract with them for the 1990 fiscal year) and that ORNL should not neglect to interact with the many other outstanding U.S. universities. In response to this comment, ORNL created the Premier Institutions Program, which provides joint steering committees to identify areas for collaboration. ORNL has established MOUs with Duke University, because of its general excellence, and with the University of California at Santa Barbara, because of its studies of global environmental concerns, geographic information and analysis systems (GIAS), and its interests in applying artificial intelligence systems to GIAS systems. Several other universities have expressed interest in establishing formal alliances with ORNL.

RE: User Facilities

The Bioprocessing Research Facility

Photo by John Avery Emison; reprinted with permission of the *Oak Ridger*.

Brian Davison takes a sample from the 500-L stirred-tank fermentor, the centerpiece of the Bioprocessing Research Facility.

"Bioprocessing efforts thus far at ORNL have led to innovative, promising results."

Providing a place and the equipment to research problems and produce innovative solutions to our nation's environmental and energy problems is the mission of the Oak Ridge Bioprocessing Research Facility. Bioprocessing uses living microorganisms to make chemical and physical changes in a material, often creating new products, such as fuels and enzymes.

Bioprocessing efforts thus far at ORNL have led to innovative, promising results. A method of fermenting corn sugars that uses microorganisms trapped in gel beads has yielded ten times as much fuel alcohol as have other methods (*Review*, Vol. 20, No. 2, 1987). Coal may be liquefied more cheaply and safely with microbes rather than the conventional methods of heat and pressure, yielding products that could be suitable for fuels and industrial chemicals (*Review*, Vol. 19, No. 2, 1986). These biofuels derived from corn and coal will become increasingly important as petroleum reserves are depleted or become inaccessible, and they could be a means of lessening U.S. dependence on foreign countries for oil.

Bioprocessing concepts may also offer some solutions to waste problems. Bioprocesses are being developed to remove pollutants from coal-conversion wastewater, and it may be possible to use biological techniques to remove hazardous materials from coal-derived liquids and petroleum products.

Several types of research and production are being performed at the Bioprocessing Research Facility. Audrey Stevens of the Biology Division uses the facility's centerpiece, the 500-L stirred-tank fermentor, in her basic research. The large fermentor grows more than 10 kg of yeast paste in a single run, which is enough to supply the needed enzymes and proteins for her experiments for six to nine months. If she used a smaller system, she would have to grow the yeast paste every few weeks. Stevens is studying how ribonucleic acid, an essential chemical of life, is formed and maintained in the cells.

Basic research is also done by researchers from ORNL, the University of Tennessee, Oak Ridge Associated Universities, and Selma College, a historically black college, when they use the facility's smaller analytical equipment, such as the high-performance liquid chromatograph (HPLC) and gas chromatographs.

On the other hand, production of large amounts of bacteria is the priority when the company Oxyrase uses the facility. While a member of the Biology Division, Howard Adler developed an oxygen-absorbing product that makes it possible to cultivate anaerobic organisms in petri dishes exposed to air. Ordinarily anaerobic organisms, which cannot live in the presence of oxygen, must be cultivated in special oxygen-free chambers. Using the oxygen-absorbing membrane makes it possible to observe the organisms more closely and easily and to move them from flask to flask without killing them. Adler bought the patent for his discovery from the government and started Oxyrase, a company that markets the technology. Oxyrase still grows the *Escherichia coli* needed for the oxygen-absorbing membrane at the Bioprocessing Research Facility.

Brian Davison, a biochemical engineer in the Chemical Technology Division, runs the facility. "Some people just need help with the unfamiliar area of bioprocessing," says Davison. "For example, a person in Hawaii has requested a sample of alcohol containing fermentation broth, or 'beer.' He's working with supercritical extraction of alcohol, and he wants to test his method on an actual feedstream rather than just create a mixture of alcohol and water. Because his background is in experimental thermodynamics, he isn't familiar with bioprocessing technology, or biotechnology.

"We've also done a lot of work in immobilizing microorganisms. For instance, a professor at North Carolina A&T asked us to send immobilized microorganisms for testing in a modified bioreactor. He has the equipment to do the testing, but not to do immobilization."

The facility was established about five years ago and is open to university, national laboratory, and industrial scientists and engineers. Besides the flagship 500-L stirred-tank fermentor, it includes a smaller fermentor, stirred-tank and advanced columnar bioreactors, continuous centrifuges and homogenizers, large chromatography equipment, and other analytical equipment such as gas chromatographs, spectrophotometers, an HPLC, a "cold lab" (which is like a room inside a refrigerator), and an autoclave. This equipment can be used for research in areas such as microbial culture selection and improvement, genetic manipulation, microbial and enzyme immobilization, advanced bioreactor concepts, process feasibility and scaleup, biomass pretreatment and fractionation (for ultimate conversion into fuels), bioprocess monitoring and control, and biochemical separation.

The 500-L stirred-tank fermentor is the centerpiece of the facility because of its size. Davison explains the huge fermentor in terms that make the gleaming equipment seem much less imposing. "It's really just an automated, giant stirred pot. You add sugar and vitamins to water and then sterilize (autoclave) it, which is similar to using a pressure cooker to sterilize food at home. It's more efficient and well defined, but similar. Next you carefully innoculate the mixture with a small amount of the living microorganism, allow it to grow, and produce the products in a controlled environment. Our job is to keep the solution well mixed, aerated, and sterile while controlling the temperature, the acidity level, and other parameters."

"The conversion of wood to fuel is one example of how bioprocessing uses living micro-organisms to make chemical and physical changes in a material."

One potential biotechnology project for the facility is to convert wood to fuel. A fermentor would produce large amounts of the cellulase enzyme to convert the cellulose in waste wood and paper into sugar, which could be fermented into alcohol fuels. Not only would the alcohol be more useful than wastepaper, but less paper would go into our landfills. In another planned project, biomass could be produced to adsorb trace metals from water. This technology could be used to remove heavy metals, including radioactive substances, from wastewater. A third project is investigating the production of lactic acid, a commodity chemical that is used commercially as a food preservative. It's being considered as an ingredient to make biodegradable polymers.

Davison calls the equipment at the facility "tools to help people do research projects more efficiently." These tools may help solve some of our energy and waste problems.—*Cindy Robinson*

New Findings on Attic Insulation and Heat Loss

"The findings are expected to affect the insulation industry."

At the Roof Research Center, experiments performed on this Attic Test Module may lead to changes in the testing and characteristics of loose-fill, fibrous glass insulation. Heat flow was measured using a guarded hot box and thermocouples distributed throughout the module, and photographs taken with an infrared camera (through the triangular gable vent shown detached from the module) suggested that convection is more responsible for the heat loss than originally thought.

Researchers at DOE's Roof Research Center at ORNL have found a way to reduce heat losses from attic insulation. The results could influence the insulation industry and cut homeowners' energy bills.

ORNL researchers have been trying to determine how effectively attic insulation keeps heat in houses in the winter and out during the summer. In studying this question for Attic Seal, Inc., an industrial sponsor of the Roof Research Center, ORNL researchers reconfirmed a little known discovery: loss of heat through certain, commonly used types of blown, loose-fill fibrous glass insulation is not entirely the result of conduction and radiation. Convection, they found, may be responsible for as much as half of the heat loss at very cold temperatures—for example, an attic temperature of –12°C (10°F).

It had been thought that radiation was responsible for about 60% of the heat loss through the insulation and that the remaining loss resulted from conduction. Radiation is the emission and propagation of waves transmitting thermal energy through space or some medium. Conduction is the transmission of energy through a fixed medium; in

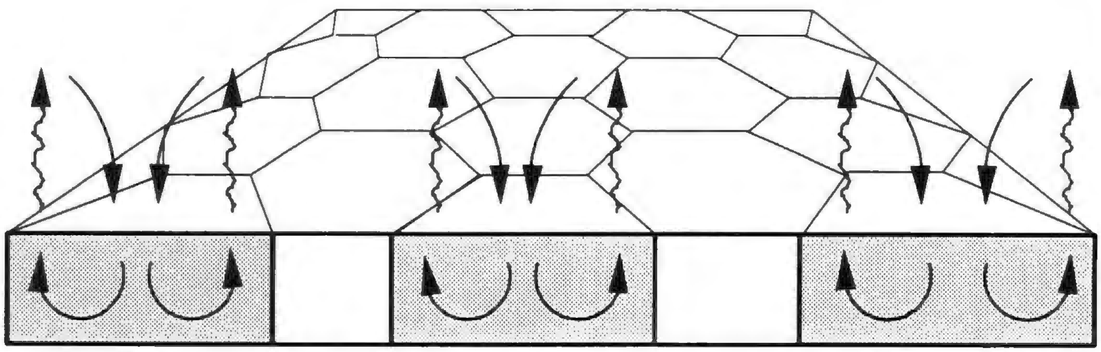


Diagram of the hexagonal Benard cell pattern for fluid layer heated from below.


This photograph taken by an infrared camera shows the top surface of insulation in an attic having a temperature of –20°C (–5°F). The light areas in this hexagonal pattern are warmer than the dark ones.

"If cost-effective convection-retarding products can be developed, energy losses through ceilings could be reduced as much as 33%."

the attic insulation tested, the media include trapped air and glass fibers. Convection is the transfer of heat by the natural circulation of air or some other fluid.

Because the commonly used insulation tested by ORNL was subject to heat loss by convection and because the standard test procedures for thermal performance do not measure convection losses, the Roof Research Center's findings are expected to affect the insulation industry. Impacts could include changes in test procedures and the physical characteristics of some of the loose-fill, fibrous glass insulations available.

"The insulation industry has shown substantial interest in our findings," says Bob Wendt, director of the Roof Research Center, "and has expressed interest in testing additional products to determine whether they may be subject to convective heat loss."

The Roof Research Center also tested a patented product developed by Attic Seal, Inc., and determined that it effectively retards convection in the loose-fill, fibrous glass attic insulation. This product, which resembles a thin fiberglass batt covered with two perforated plastic membranes, was found to significantly reduce energy loss through the insulation. These test results are helping Attic Seal improve the product and determine its market potential.

If changes in loose-fill fibrous glass insulation can be made to reduce the energy loss from convection or if cost-effective convection-retarding products can be developed, energy losses through house ceilings could be reduced as much as 33%, depending upon the climatic conditions, thus lowering energy costs.

The research was performed by Ken Wilkes, Bob Wendt, and Phil Childs, all of the Energy Division, and Agnes Delmas, a visiting postdoctoral student from France.

"The loudest single message was to increase energy efficiency in every sector of energy use."

ORNL Contributing to National Energy Strategy

In terms of energy efficiency, the United States has come a long way but still has a long way to go, according to one of five "white papers" commissioned by Secretary of Energy Admiral James Watkins. One of the paper's authors is Roger Carlsmith, manager of ORNL's Conservation and Renewable Energy Program.

In *Energy Efficiency: How Far Can We Go?*, Carlsmith and three co-authors from other national laboratories write: "The United States has made remarkable progress in efficient energy use since the 1973 oil crisis. In 15 years energy use increased only 8%, while gross national product increased 46%. Thus we are now using 26% less energy to produce one dollar's worth of goods and services. Some of this reduction came from structural changes in the economy, but most of it resulted from increases in energy efficiency. The experience shows that threats of shortages, rising prices, and government policies can make major changes in the operation of the economy."

The paper concludes that (1) U.S. energy efficiency may improve by 12% by 2010 in response to market forces if fuel prices rise as projected; (2) if extensive government policy changes take place, cost-effective measures could be taken to improve the nation's energy efficiency by an additional 14%; and (3) the additional potential for efficiency improvements beyond 2010 is very large, but much of it will not be realized without concerted research and development efforts by government and industry.

Carlsmith's report is one of those cited in DOE's *Interim Report on the Development of a National Energy Strategy*, which is permeated with the belief that "government and industry could do more to solve energy problems." This compilation of public comments, released April 2, 1990, summarizes input from 15 regional hearings across the country, testimony from 375 witnesses, and 1000 written comments. ORNL researchers were sources for some of the statements in the report and helped with the editing of the environmental chapters.

According to the report, "The loudest single message was to increase energy efficiency in every sector of energy use. Energy efficiency was seen as a way to reduce pollution, reduce dependence on imports, and reduce the cost of energy."

The report, said Secretary Watkins, "summarizes what a broad spectrum of American people had to say about problems, prospects, and preferences in energy. It is an important step in building a national consensus." The report includes publicly identified goals, obstacles, and options in increasing energy efficiency, securing future energy supplies, respecting the environment, and fortifying American science and engineering research and technology transfer.

Among the editors of the "Respecting the Environment" chapter (which explores the relationship between energy and air quality, global environmental issues, waste management, and water and land use) was John Reed of ORNL's Energy Division. Many other ORNL employees, mostly in the Energy, Environmental Sciences, and Engineering Technology divisions, also provided support to the document.

Besides Carlsmith, other ORNL researchers and managers cited in the *Interim Report* are David L. Greene (*CAFE or Price? An Analysis of the Effects of Federal Fuel Economy Regulation and Gasoline Price on New Car MPG, 1978–1989*), Gregg Marland ("Fossil Fuel CO_2 Emissions: Three Countries Account for 50% in 1986," *CDIAC Communications*), T. Randall Curlee (*The*

Economic Feasibility of Recycling: A Case Study of Plastic Wastes and "Source Reduction and Recycling as Municipal Waste Management Options: An Overview of Government Actions, *Proceedings of the Workshop on Research Needs for Waste Reduction*), Elizabeth Peelle ("Beyond the NIMBY Impasse II: Public Participation in an Age of Distrust," *Proceedings of Spectrum '88, International Meeting on Nuclear and Hazardous Waste Management*), and William Fulkerson (*Energy Technology R&D: What Could Make a Difference?*).

Several ORNL researchers are also listed as contributors to *Energy and Climate Change: Report of the DOE Multi-Laboratory Climate Change Committee*, another "white paper" cited in the *Interim Report*. They are Robert Cushman, Donald DeAngelis, William Emanuel, Michael Farrell, Edward Hillsman, Carolyn Hunsaker, Gregg Marland, and Steve Rayner.

The final report on the national energy strategy will be published in 1991. It is said that this strategy will be the first national energy policy "built from the ground up" because it will be based on public input. It will be a "road map for the future," using 1990 as a baseline point of reference and containing short-term, mid-term, and long-term recommendations for the next 40 years.

Intel Computer Here Breaks Record for Calculation Speed

To understand the electronic structure of a superconductor, ORNL scientists and their University of Tennessee colleagues recently turned to their newest supercomputer—and broke a record for calculation speed.

In June 1990, using the Intel iPSC/860, they achieved an execution rate of 1.8 billion arithmetic operations per second on a supercomputer problem, solving it 10% faster than did the YMP/8, Cray Research's most powerful supercomputer and previously the fastest machine for this computation.

The Intel machine, a parallel computer having 128 high-performance microprocessors, costs an order of magnitude less than traditional supercomputers such as the Cray models. It was installed in January in ORNL's Engineering Physics and Mathematics Division. It is being tested by the Advanced Computing Laboratory, an organization sponsored jointly by ORNL's Mathematical Sciences Section and the Computer Science Department of the University of Tennessee.

The Intel computer allows scientists to perform in a few hours complex calculations that previously required weeks at ORNL. These calculations should aid scientists in designing superconductors capable of operating at near room temperatures. Existing superconductors operate only at temperatures lower than –150°C, requiring expensive cooling techniques. Determination of these materials' electronic structure should help theorists better understand the behavior of superconductors.

Scientists in ORNL's Metals and Ceramics and Engineering Physics and Mathematics divisions believe that the same code will run well over two billion operations per second on problems involving more difficult superconductor materials. Their goal is to apply this code toward the study of these complicated alloys.

Besides modeling superconductors, the Intel machine is also being used for other ORNL "grand challenge" problems, such as global climate modeling, gene sequencing, atomic physics, and plasma physics, and some computationally intensive problems from other organizations, such as the Superconducting Super Collider Laboratory in Texas.

Nuclear Winter and U.S. Civil Defense

In the event of a nuclear war, would the ensuing "nuclear winter" kill most Americans and prove that the U.S. civil defense program is unworkable? A recent ORNL study for the Federal Emergency Management Agency (FEMA) indicates that nuclear war is survivable

"ORNL was asked to recommend any changes needed to improve the ability of U.S. civil defense to deal with the threat of nuclear winter."

and that the U.S. civil defense program would cope with the threat of nuclear winter, given adequate funding and time to implement the plans.

In 1983, a study was published on the effects on climate of a large nuclear war. It was predicted that nuclear explosions would inject hundreds of millions of tons of smoke and dust into the atmosphere, leaving survivors to shiver in the dark and do without rain for months. The study, whose most famous co-author is astronomer Carl Sagan, was entitled *Nuclear Winter: Global Consequences of Multiple Nuclear Explosions* and was nicknamed TTAPS, from the initials of its authors, Turco, Toon, Ackerman, Pollack, and Sagan.

Because the TTAPS study predicted that nuclear war could cause the atmospheric temperatures to drop by as much as 40 to 60°C, some people concluded that nuclear war is not survivable and that the U.S. civil defense program is unrealistic. So ORNL was asked by FEMA to review the literature on nuclear winter and recommend any changes needed to improve the ability of U.S. civil defense to deal with the threat of nuclear winter.

Conrad Chester and A. M. (Bud) Perry of ORNL's Energy Division and B. F. Hobbs of Case Western Reserve University reviewed the most recent results of calculations by global circulation models at the National Center for Atmospheric Research, Los Alamos National Laboratory, and Lawrence Livermore National Laboratory. One conclusion from the review is that in a worst-case scenario, depression in the northern hemisphere temperature would average about 15°C for a July war that injects 100 to 200 million tons of smoke into the atmosphere. A winter war might produce a temperature depression of only a few degrees.

Drawing on ORNL studies of U.S. food reserves and the vulnerability to drought of the nation's water systems, the researchers concluded that

- Neither cold nor drought is likely to be a direct threat to human survival for populations with the ability to survive normal January temperatures;

- The principal threat from nuclear winter is to agriculture, with a high likelihood of the loss of a crop year in the event of a very large spring or summer war, but the United States can deal with this problem because it has at least a year's supply of stored grain;
- The threat of nuclear winter does not require changes in the U.S. civil defense program other than those already needed because of inadequate funding.

However, the researchers say, the threat of nuclear winter "does provide an incentive to remind people to take their winter clothing with them if they evacuate in summertime, to encourage people to store food, to sustain agricultural policies that maintain large reserves of grain, and to provide backup electric power for water supplies."

ORNL Sales of Tritium End

"ORNL was a leader in DOE's research program to develop self-powered lights with tritium."

In October 1990, ORNL halted its shipments of tritium, and DOE's tritium sales program was transferred to its Mound Facility near Dayton, Ohio.

Since 1946, ORNL handled the commercial sales of the radioactive material for the federal government. DOE is the sole U.S. producer of tritium, which is used for biological research, for increasing the power of nuclear weapons, and for manufacturing radioluminescent products, such as runway lights for remote airports.

ORNL was a leader in DOE's research program to develop self-powered lights with tritium. The Laboratory built and tested a number of tritium lights that glowed in the dark on airport runways in Alaska.

ORNL's tritium program was scrutinized in 1989 following reports that some of the gaseous material shipped to customers could not be accounted for, suggesting that it might have been stolen or diverted to foreign interests. Investigations revealed that no tritium had been stolen but that equipment deficiencies and other problems made it difficult to accurately track the material.

However, DOE states that its tritium sales program was moved primarily to centralize the activity and reduce costs. Other reasons given for

the move were the age and deterioration of ORNL's nuclear processing facilities and its use of shielded hot cells and other laboratory processing areas that fail to meet new standards.

ORNL Models Aid Desert Shield

About a dozen researchers at Oak Ridge National Laboratory have developed four computer models that have helped the U.S. Department of Defense make decisions about the transportation of American troops and equipment deployed in Saudi Arabia.

"In response to requests by the Department of Defense, ORNL has designed decision-support systems that offer a revolutionary new way to solve complex transportation problems," says Bill Fulkerson, ORNL associate director for Advanced Energy Systems.

The deployment for Operation Desert Shield, which began shortly after Iraq's invasion of Kuwait on August 2, required a massive amount of complex scheduling of aircraft, ships, trucks, and trains to move troops and equipment from the United States to Saudia Arabia. Most of the troops are transported by commercial aircraft, and most of the equipment is moved by fast Navy ships and commercial ocean vessels.

To meet U.S. military objectives, extensive analysis must be done to determine the number of active/reserve transportation units, pieces of equipment, and vehicles required to move the troops and their equipment. Analyses are also needed to ensure that trucks and trains meet with departing aircraft and ships in time, determine the

An ORNL researcher checks the computer screen for information about possible routes for military aircraft traveling between the United States and Saudi Arabia for Operation Desert Shield (see inset). The computer model ADANS is being refined for use in scheduling military transportation by a team that includes researchers from ORNL, Data Systems Research and Development, and the Computing and Telecommunications Division at ORNL.

number of commercial transportation vehicles required to support military transportation, and project arrival dates in the Middle East.

The ORNL models will be providing automated assistance in scheduling buses, trucks, trains, aircraft, and ships so that these vehicles arrive at the proper time to meet follow-on transportation without congesting ports and support bases.

Since August 2, 1990, Energy Systems researchers at ORNL helped the Crisis Action Teams at Scott Air Force Base in Illinois run the deployment models. The experience will lead to design modifications and improvements to make the models more responsive to users' needs.

ORNL staff members have been involved in the development and testing of four models—dubbed ADANS, STRADS, SAIL, and FAST—for the U.S. Transportation Command (TRANSCOM), which is responsible for deploying U.S. troops and military equipment anywhere in the world.

The Airlift Deployment and Analysis System (ADANS) is being developed for TRANSCOM's Military Airlift Command (MAC), located at Scott Air Force Base. Since October, ADANS has been used to schedule thousands of MAC Desert Shield and Desert Storm airlift missions bound for the Middle East. ADANS also will provide many new capabilities for automating airlift planning and analysis tasks.

According to one of its developers, "ADANS revolutionizes the way transportation scheduling and analysis are conducted by the Department of Defense. The system advances the state of the art in airlift scheduling and provides MAC with new tools for schedule analysis. ADANS is being used daily to analyze how best to organize the airlift system for efficient operations and to evaluate and establish concepts of operation for Operation Desert Storm airlift."

ADANS team members include staff from Energy Systems' Data Systems Research and Development (DSRD) organization and the Computing and Telecommunications Division, the University of Tennessee at Knoxville, and various subcontractors, such as Logicon, ASI, and Science Applications International Corporation.

The Strategic Deployment System (STRADS) prototype was developed by ORNL in conjunction with research centers at the University of Tennessee. STRADS provides TRANSCOM's Military Traffic Management Command with automated assistance in scheduling trucks, buses, and rail cars to pick up troops and their equipment at their place of origin and move them to the appropriate airports and seaports for deployment overseas. Continued development of STRADS is now being managed by the DSRD organization.

The Scheduling Algorithm for Improving Lift (SAIL) computer model will replace the sealift scheduler used for war planning by the U.S. TRANSCOM's Military Sealift Command. This model will schedule and route ships based on the planned usage of the Panama and Suez canals and will match the cargo to the ship capable of moving it at the lowest possible cost.

The Flow and Analysis System for Transportation (FAST) was developed by a team of four ORNL researchers and operated during the Desert Shield deployment. The ORNL team has incorporated the other transportation models to develop a transportation analysis tool.

Within a few hours after receiving data on the troops and equipment to be deployed, FAST can provide detailed information about their projected military movements by air, land, and sea. FAST is designed to stay 10 to 25 days ahead of the deployment to determine transportation requirements, show the amount of equipment and number of troops that have been deployed and remain to be deployed, and predict bottlenecks that need to be addressed.

The ORNL researchers say the military decisionmakers have increased their confidence in these models because model results often agree with the manual projections of experienced military planners.

Philip J. Maziasz (right) and Robert W. Swindeman, both of ORNL's Metals and Ceramics Division, developed lean austenitic steels for harsh environments.

ORNL Wins Five R&D 100 Awards

In the fall of 1990, five ORNL developments received R&D 100 Awards from *Research & Development* magazine. The magazine's editors selected these developments as among the top 100 new technology advances. Since 1967, Energy Systems facilities in Oak Ridge have received 71 of these awards.

The winning entries and researchers were the lean austenitic steels for harsh environments developed by Philip J. Maziasz and Robert W. Swindeman, both of the Metals and Ceramics Division; ductile iron aluminides for components in corrosive environments, developed by Claudette McKamey, Vinod K. Sikka, and Chain T. Liu, all of the Metals and Ceramics Division; an ultrahigh-resolution scanning transmission electron microscope, developed by Stephen J. Pennycook of the Solid State Division; a powerful radiolabeling tool with applications for early cancer detection, developed by P. C. Srivastava and J. F. Allred, both of the Health and Safety Research Division; and a radiation dosimeter system, developed by ORNL's A. B. Ahmed and M. A. Buckner and by R. S. Bogard of the Oak Ridge Y-12 Plant.

Lean austenitic steels. As a result of studies of the effects of altered microstructures on metallic properties, ORNL researchers have developed a "lean" austenitic stainless steel that is strong, tough, and ductile at high temperatures. It is also resistant to creep rupture—the long-term tendency to stretch and crack at high temperatures under an applied stress.

This new high-temperature-ultrafine-precipitate-strengthened (HT-UPS) steel rivals the high-temperature strength and creep-rupture resistance of the best superalloys and nickel aluminides. Thus, it is particularly useful as a structural material for fossil-energy steam boiler tubes and for components of fast breeder and fusion reactors.

Until Phil Maziasz and Bob Swindeman's development, the best creep strength in a lean stainless steel was found in 17-14CuMo, a "poor-man's superalloy" made of copper and molybdenum that was developed by ARMCO, Inc., during World War II. The new HT-UPS steels have a rupture lifetime up to 13 times longer than 17-14CuMo and up to 1700 times longer than type 316 at 700°C and 170 MPa (24.7 kpsi).

The ORNL steel is also resistant to radiation-induced swelling and helium embrittlement during exposure in fast-breeder or magnetic-fusion reactors. The improved resistance to degradation stems from special ultrafine and stable precipitate

"Research & Development *magazine's editors selected these developments as among the top 100 new technology advances."*

Chain T. Liu, Claudette McKamey, and Vinod K. Sikka, all of the Metals and Ceramics Division, developed ductile iron aluminides for components in corrosive environments.

microstructures that develop during either high-temperature creep-aging or lower-temperature neutron irradiation.

The HT-UPS steel, which contains chromium, nickel, molybdenum, and manganese, is referred to as a 14Cr-16Ni-2.5Mo-2Mn-based austenitic stainless steel having a unique combination of minor solute additions. Trace elements introduced to and dissolved in the material are titanium, niobium, vanadium, carbon, boron, and phosphorus. During use of the material, they produce ultrafine carbide and phosphide precipitates in the matrix for strength and grain-boundary carbides for ductile and tough fracture behavior at high temperatures. (For a history of this development, see "Designer Steels for Advanced Energy Applications," *ORNL Review*, Vol. 21, No. 3, 1988.)

Ductile iron aluminides. ORNL researchers have developed a low-cost iron aluminide (Fe_3Al) structural material that is strong, ductile, and resistant to corrosion and oxidation at temperatures up to 800°C. The material shows promise for use in structural components for highly corrosive environments, such as those in advanced fossil-energy conversion systems, chemical-production systems, and heat engines.

Fe_3Al has not been used as a structural material because it is brittle at room temperature and weak at temperatures above 600°C. The material, however, is particularly desirable because of its excellent resistance to oxidation and corrosion.

To improve the material's properties, the ORNL researchers added small amounts of chromium, zirconium, boron, molybdenum, carbon, and niobium. The typical composition is Fe-28Al-5Cr-0.1Zr-0.05B, with 0 to 2% Mo and/or 0 to 1% Nb added for specific properties.

The ORNL researchers also improved the ductility dramatically by controlling the surface composition, microstructure, and grain-boundary cohesion. And they increased the material's strength both by solid solution hardening and particle strengthening.

The newly developed iron aluminides exhibit excellent oxidation and corrosion resistance at temperatures up to 1000°C, especially in sulfur-containing atmospheres, because of their ability to form an aluminum oxide coating, which protects the underlying material. Because they possess improved room-temperature tensile ductilities, fabrication of structural components from iron-aluminide–based materials is now easier. A history of the alloy's development is described in "Iron Aluminides and the Inventor of the Year," *ORNL Review*, Vol. 23, No. 1, 1990, pp. 24–29.

Ultrahigh-resolution STEM. A scanning transmission electron microscope (STEM) has been modified to ORNL specifications to provide atomic-resolution images of the structure and composition of materials. This improved instrument uses a fundamentally new approach to transmission electron microscopy and offers advantages for research in solid-state physics and the materials sciences.

A high-power instrument manufactured by VG Microscopes of England is used to scan a fine beam of electrons across a thin sample. This new technique differs from the conventional STEM in that electrons passing straight through the sample are ignored and only those electrons scattered through large angles are detected—by a ring-shaped detector.

A computer receiving information on the detected electrons builds up a map of the scattering power of the sample, which is directly related to its composition. If the beam is made finer than the atomic spacings in the material, the resulting map yields images having atomic resolution. The ORNL technique has achieved a resolution as small as 2.2 Å.

Because atoms are imaged using this technology with a brightness depending on their atomic number, normally referred to as Z, developer Steve Pennycook calls the new technique Z-contrast imaging. (Applications for this technique are described in his article, "Toward a One-Angstrom Electron Microscope," *ORNL Review*, Vol. 23, No. 1, 1990, pp. 54–61.)

Stephen J. Pennycook of the Solid State Division developed an ultrahigh-resolution scanning transmission electron microscope.

Iodophenylmaleimide radioimmunoconjugator. Because of their ability to locate and bind to proteins on tumor surfaces called antigens, radioiodinated antibodies can be used to detect and treat cancer. However, such "magic-bullet" antibodies have not been effective because the radioactive iodine that could reveal or destroy targeted cancer cells is rapidly lost from the antibody.

Inventor P. C. Srivastava and laboratory technologist John Allred have overcome this problem by developing a powerful radiolabeling tool for attaching and retaining radioactive iodine on proteins and tumor-specific antibodies without interfering with their intended functions. The development could make possible the increased use of radioiodinated antibodies for early detection of cancer, especially cancer cells that

P. C. Srivastava (front) and J. F. Allred, both of the Health and Safety Research Division, developed a powerful radiolabeling tool with applications for early cancer detection.

have metastasized from undetected primary tumors.

In January 1989 the patented ORNL reagent technology was licensed to E. I. du Pont de Nemours & Company (see "Nuclear Medicine Research," *ORNL Review*, Vol. 22, Nos. 2 & 3, 1989). A history of its development is described in "New Radiolabeling Technique May Aid Early Cancer Detection," *ORNL Review*, Vol. 21, No. 1, 1988, pp. 34–35.

The new reagent has two important structural features: (1) an iodophenyl moiety, which has a strong iodine-benzene chemical bond to inhibit rapid loss of iodine from the antibody after its injection into the body, and (2) the maleimide moiety, which binds to the antibody through a thioether (sulfur) or an amide (nitrogen) linkage. The reagent is readily prepared using an iodine-reactive mercury acetate maleimide kit, also developed as a part of this invention.

The ORNL agent is labeled with iodine-123 for diagnostic applications and with iodine-131 for therapeutic applications. ORNL animal studies showed that the reagent is efficient as a protein- and antibody-conjugator and as an inhibitor of in vivo deiodination.

Radiation dosimetry system. ORNL and Y-12 Plant researchers have jointly developed a thermoluminescent dosimetry (TLD) system that automatically measures the amount and type of ionizing radiation to which personnel and the environment are exposed. In addition, the turnkey system analyzes, stores, and reports this information. The system is now in use at Martin Marietta Energy Systems, Inc.

This innovation, which has advantages over the commonly used film badge for radiation monitoring, is called the Harshaw Model 8800 TLD System™. It is manufactured and marketed by Harshaw Crystal & Electronic Products of Solon, Ohio, a subsidiary of Engelhard Corporation.

TLD is based on the ability of phosphors and certain other solids to store the energy they absorb from exposure to radiation and later release this energy as a luminescent glow when heated. The intensity of this glow is proportional to the exposure received. The dosimeter attached to the badge consists of radiation-sensitive material sandwiched between Teflon™ sheets mounted on a card and inserted in a plastic holder having various filters covering the sensitive areas.

The advantages of TLD badges over film badges are that they are reusable, can be read by an automatic process, can permit detection of very low

Rhonda S. Bogard (left) of the Oak Ridge Y-12 Plant and ORNL's Mark A. Buckner and Abu B. Ahmed developed a radiation dosimeter system used by Energy Systems.

exposures, and offer more information on the types of radiation that caused the dose. The filters are used to distinguish among the types of radiation—beta rays, photons, neutrons, for example—and their respective energies to estimate doses to various organs.

The Model 8800 TLD System™ features a self-contained, integrated system of hardware and software capable of both routine production dosimetry and research measurements. The major components of the system are the automatic card reader; the dosimeters; dose computation algorithms; and the PC-based Radiation Evaluation and Management System (REMS) package, which integrates the operation of the reader, handles the data, and implements a set of quality assurance procedures to maintain the hardware and ensure data traceability, reproducibility, and integrity.

The Model 8800 TLD Card Reader™ automatically processes up to 1400 dosimeter cards at a rate of approximately two per minute. Each dosimeter is heated by a separate stream of hot nitrogen gas under precise temperature control. As the card is heated, the emitted light is measured by four photomultiplier tubes, digitized, and reported to the host computer as a glow curve of 200 ordered pairs of thermoluminescence intensities and corresponding temperatures.

The thermoluminescent materials in the dosimeter and filtration materials are selected to be as equivalent in density to human tissue as possible, so that their response to radiation resembles that of a human. According to the developers, this dosimeter design coupled with the algorithms are improvements over competitive products offered by other commercial suppliers. Also, this system successfully meets all the criteria of the Department of Energy Laboratory Accreditation Program.

A Scheme for Producing Pure Proteins Continuously

An ORNL researcher has devised a separation scheme for continuously producing very pure proteins and other biological materials. Further development of this concept could help the pharmaceutical industry manufacture pure drugs having reduced side effects. This technique would be an improvement over currently used batch separations because it would yield more product over time.

Jack Watson of ORNL's Chemical Technology Division has conceived of a "continuous annular electrophoresis" technique, for which a patent application has been filed. A prototype, if built, would continuously separate the large molecules of a biological material of interest from impurity molecules, producing a very pure substance.

Such biological materials could include viruses used for making vaccines and proteins used for making many drugs. The fewer the impurities in vaccines and drugs, the fewer the side effects.

Electrophoresis is a process in which large molecules or larger particles having an electric charge move in one direction in a solution or gel in response to an electric current.

Watson's proposed device would be a cylinder inside a cylinder, and the separation would occur between the walls of the two cylinders, or the "annular region." There particles in solution would be subjected to an electric field produced by electrically charging one cylinder so that each cylinder acts as an electrode.

"The particles will move under the influence of the electric field," said Watson, "and separation is accomplished because the small particles move faster than large ones and highly charged particles move faster than weakly charged ones."

To improve separation, Watson's device would reverse the electric field and rotate the inside cylinder wall in alternate directions to make the particles move in rectangular paths—alternatively parallel to the electrode surfaces and then perpendicular to the electric field. The separated biological material would be collected by washing it out of the top end of the unit by a liquid that continuously flows in an upward direction.

Watson says that this device would produce larger amounts of purified substances than conventional "blot" electrophoresis because the feed material can be separated continuously rather than one batch at a time. Also, he adds, it would make a purer product than a similar British annular prototype, which moves the particles and removes the products in different ways.

Radiation Detector for Groundwater

An ORNL-developed submersible device for detecting radioactivity in groundwater and shallow surface water has been licensed by Energy Systems to Sorrento Electronics of San Diego, California. A wholly owned subsidiary of General Atomics, Sorrento Electronics plans to add environmental monitoring to its activities as a result of the acquisition of rights to ORNL's in situ Cerenkov radiation detector.

The ORNL device was developed for field surveillance of groundwater. When lowered into groundwater surveillance wells as small as 7.6 cm (3 in.) in diameter, it gives immediate warning if radioactive contamination is present. However, it also can be used for continuous monitoring of water treatment plants and of waters receiving industrial waste effluents and discharges from facilities processing nuclear materials.

The radiation detector monitors beta radiation from radionuclides, such as strontium-90, by measuring the bright blue Cerenkov radiation emitted from the high-energy beta particles passing through the water sample. It also can measure gamma-ray emissions.

Robert Kamensky, product manager for Sorrento Electronics, said the company plans to refine the technology to be more sensitive and more easily manufactured and then to market it to DOE facilities for use in characterizing contaminated sites and in contamination-prevention programs. Other potential markets are the Environmental Protection Agency and oil exploration and recovery industries that use tracer injection testing.

The ORNL developers of the technology are I. Lauren Larsen of the Environmental Sciences Division and Marion M. Chiles and Clint Miller, both of the Instrumentation and Controls Division.

New R&D Agreements

Energy Systems has become the first DOE management contractor to receive authority to implement cooperative research and development agreements (CRADAs) under the National Competitiveness Technology Transfer Act of 1989.

Such agreements provide additional means by which DOE can share its capabilities, facilities, and technologies with U.S. industry, universities, and other R&D organizations to help improve our nation's competitiveness in the world marketplace.

A CRADA allows Energy Systems to enter into cost-sharing partnerships with industry. The agreements for intellectual property rights would include protection of technical data for up to five years.

The arrangements will be structured to leverage R&D funds both for DOE and the CRADA partner, which should permit more efficient use of scarce R&D funds. The new legislation, which provides the congressional authority for CRADAs, is applicable to ORNL and the other four facilities managed and operated by Energy Systems.

CRADAs also provide the means for working together with industry to transfer technology effectively through person-to-person "know-how" and expertise. Energy Systems' licensing program, which has obtained 46 licenses so far, has demonstrated that a technology from a national laboratory can be effectively commercialized.

CRADAs will allow licensees to continue the relationship developed with Energy Systems by using our expertise and facilities to further develop the technology. The use of CRADAs is expected to generate new licensing agreements and provide a means of bridging the gap between R&D and commercialization.

According to the Energy Systems Office of Technology Applications, the CRADA mechanism is especially important to two new technology transfer initiatives—the Precision Manufacturing Technology Center to be established by the Oak Ridge Y-12 Plant and the Inorganic Membrane Technology Transfer Program at the Oak Ridge K-25 site.

The Precision Manufacturing Technology Center works with manufacturing companies on technology development and demonstration, problem solving, and training in best practice technologies. The Inorganic Membrane Program involves the declassification of aspects of the gaseous diffusion technology used for uranium enrichment. The inorganic membranes used for this technology, developed in the 1950s and 1960s, are believed to have commercial potential.

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Next Issue

Three ORNL researchers surprised an elephant seal as they evaluated the environmental impacts of scientific activities in Antarctica.