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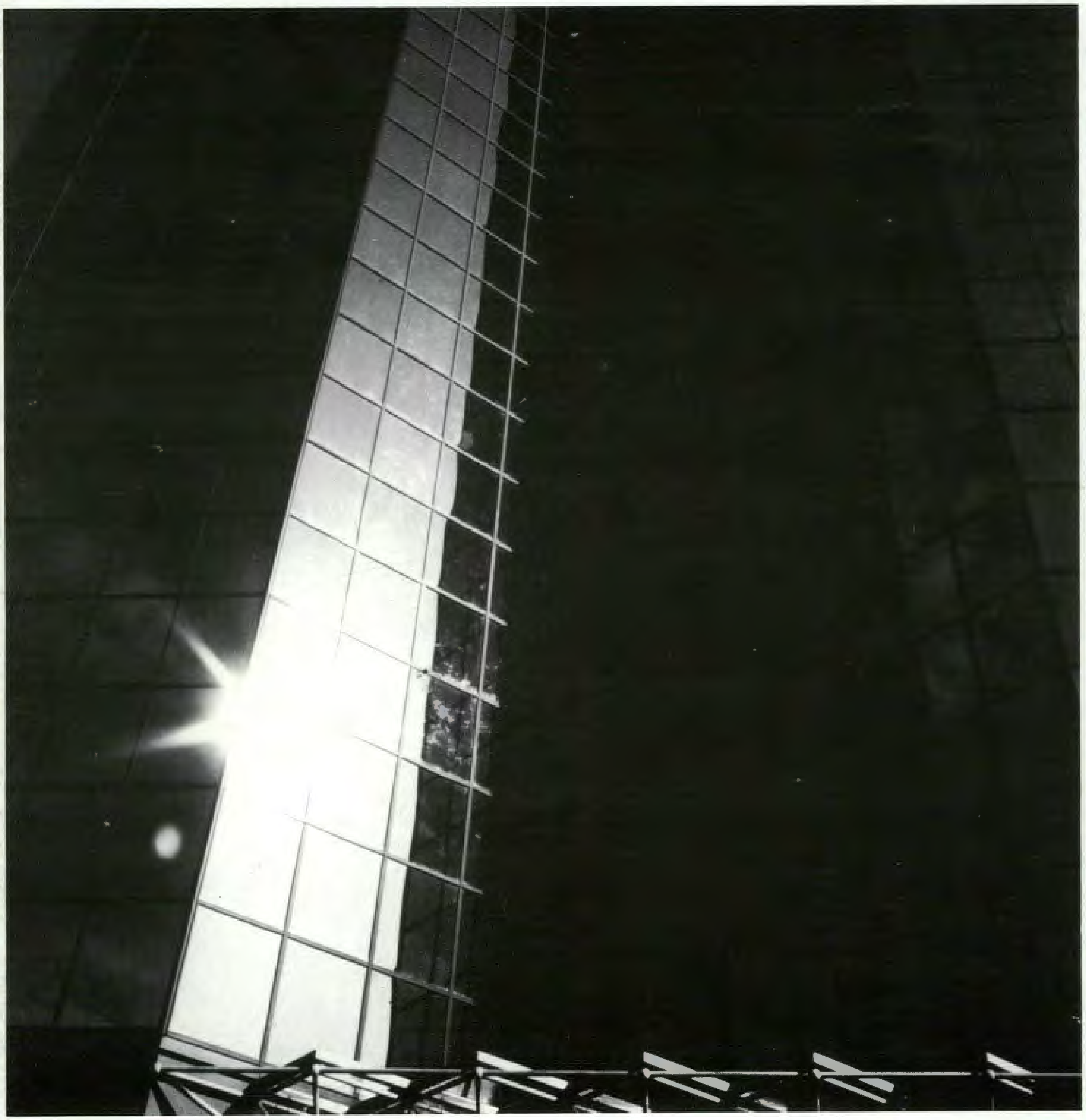

PHOTOGRAPH/BILL CLARK

Energy-Efficient Buildings

THE COVER: ORNL is DOE's lead laboratory for energy conservation retrofit research for commercial buildings. This and many other ORNL projects related to improving building energy efficiency are covered in a special section in this issue. See page 10.

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EDITORIAL: The *Review* Is 20 Years Old

By ALEX ZUCKER

Most of the . . . ideas of science are essentially simple, and may, as a rule, be expressed in a language comprehensible to everyone.

Albert Einstein

With this issue the Oak Ridge National Laboratory *Review* is 20 years old: an occasion to look back, to see what has been accomplished, what changes have occurred, and what purpose it has served then and now.

Most of all the *Review* mirrors the profound changes that have taken place at the Laboratory and in science and technology in the last 20 years. Volume 1, Number 1, carried an article by Phil Hammond on "Desalted Water for Agriculture." Can you remember those days when everything seemed possible and we were still on our way to the moon? By contrast, some recent articles deal with fractals, protein engineering, parallel computers, artificial intelligence, or technology transfer—the very words had no meaning 20 years ago! We used to read about nuclear power for cheap and abundant energy; we are more likely to read now about technologies for the conservation of energy. We used to read about the Breit-Wigner formula; we now read about the quark-gluon plasma. The AEC was replaced by ERDA, soon turned into DOE. The energy crisis came and went; its impact and passage are recorded in the pages of the *Review*. There were special issues on coal, materials, power systems, technology transfer, and the basic physical sciences, and there was even a special Bicentennial issue in 1976, which contains a 25-year history of ORNL (1943–1968). In short, the *Review* reflects the times, it reflects the state of science, and it really reflects what we at ORNL think and what we do. That is still the best definition of its purpose.

The early articles in the *Review* tended to be global and often dealt with the broad context within which the work at ORNL would be viewed. In Alvin Weinberg's words, the purpose of the *Review* was "to give . . . a better understanding of what ORNL was all about . . . as a coherent, purposeful, and interacting institution." In that sense the early issues reflected the spirit of the place, but left out much of the detail.

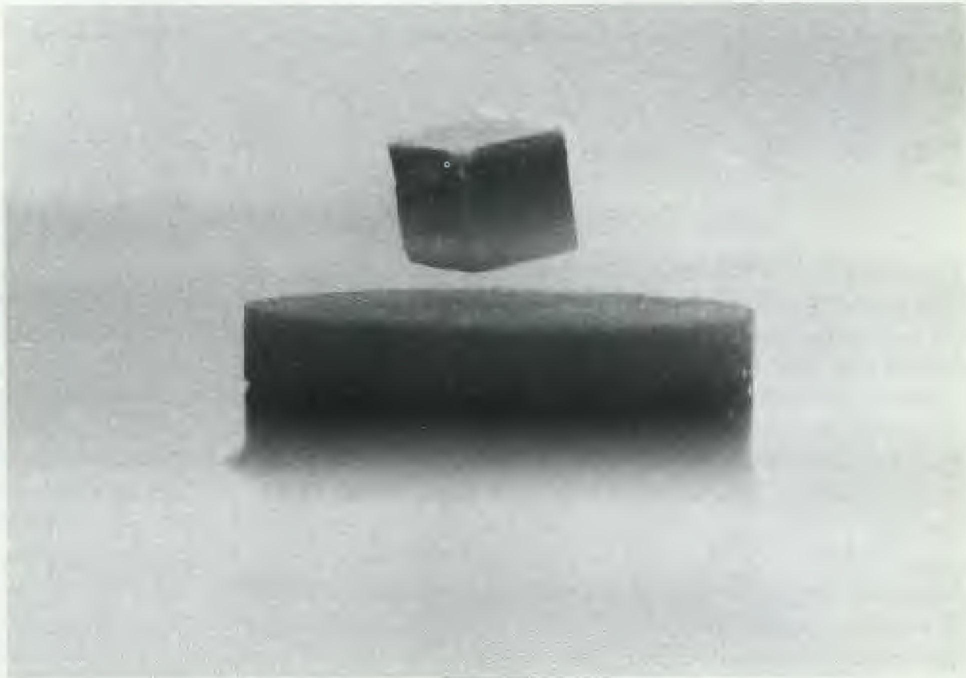
Under the guidance of Barbara Lyon and later Carolyn Krause, the *Review* became more reportorial, more descriptive—less about the whole and more about its parts. It also became fatter. The early issues typically ran to 28 pages. Now a normal issue is 52 pages, and special issues have gone to 250 pages. Still, we continue one tradition: each year the *Review* publishes the ORNL Director's "State of the Laboratory" address, which presents the broad picture of ORNL—its integrated purpose, its successes, and the issues facing it.

The audience has changed as well. In the beginning, the Laboratory staff was the only readership considered; now we use the *Review* to tell the ORNL story to the prospective employee here for an interview, to the administrators in DOE and other agencies in Washington, to the Congress, to the scientific establishment, and lately to industry—a diverse audience.

With few exceptions the articles are written by the people who do the work, and their personalities shine through as does their enthusiasm. No two articles are alike: some are written to be accessible to a high school graduate; others can be useful to professional colleagues. They all enrich our understanding of the Laboratory, the topic under study, and the standards and quality that prevail at ORNL.

And what about the next 20 years? One thing is certain: the *Review* in the next two decades will follow the changing scene in science and at the Laboratory. Will work for industry loom large for the Laboratory? Are high-temperature superconductors going to revolutionize electricity-based technologies? What technological innovations will be stimulated by the next oil shortage? Will fusion power be economically competitive with other sources of electricity in the next century? When will biotechnology come of age? What will be the verdict on artificial intelligence in 20 years? We may well have the answers to all these questions on the *Review*'s 40th anniversary. We can't predict the future, but we are certain that in unpredictable ways ORNL will make some of the future happen.

In less than a year, teams of scientists from all over the world achieved a goal sought for 75 years: high-temperature superconductivity. The rush to reach this goal has also involved ORNL scientists. They and many others are working frantically to find ways to fabricate wires and films from high-temperature superconducting materials, increase the current-carrying capacities of these materials, develop new superconducting devices, and arrive at a theory to explain high-temperature superconductivity.



A magnet suspended in midair at ORNL by a high-temperature superconducting material. This magnet-levitation experiment demonstrates the Meissner effect, in which superconducting materials repel, or exclude, magnetic fields.

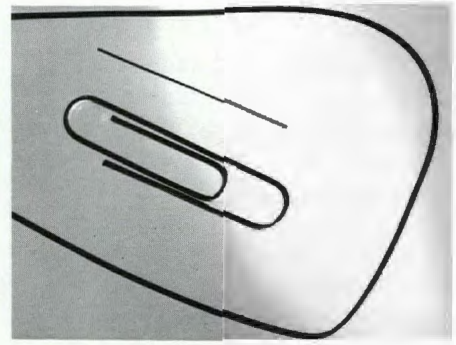
High-Temperature Superconductivity: *ORNL Joins the Scientific Stampede*

By CAROLYN KRAUSE

In less than a year, teams of scientists from all over the world achieved a goal sought for 75 years: high-temperature superconductivity. The rush to reach this Holy Grail of the electrical world has involved scientists from Switzerland, Japan, China, the Federal Republic of Germany, the Soviet Union, and the United States, including researchers at Oak Ridge National Laboratory. Worldwide, scientists are working frantically to find ways to (1) fabricate flexible wires and films from high-temperature superconducting materials, (2) increase the current-carrying capacities of these materials by a factor of 100, (3) develop new superconducting devices, and (4) develop a theory to explain why these materials are superconductive at temperatures above 90° Kelvin (90 K).

Recently, the U.S. Department of Energy formed two national laboratory consortiums to redirect and better coordinate government-sponsored superconductivity research. Members of one consortium are the Ames Laboratory, Argonne National Laboratory, and Brookhaven National Laboratory. One mission of this consortium is to develop a practical conducting wire from the new superconducting ceramics. The other consortium consists of Lawrence Berkeley Laboratory, Los Alamos National Laboratory, and ORNL. Besides DOE's additional commitment of funds, the National Science Foundation (NSF) announced $1.6 million in grants to help the United States stay competitive with other countries in superconductivity research.

Superconductivity is the loss of a material's resistance to the flow of electricity. Once an electrical current is started in superconducting wires, it courses through the material without resistive heat losses. Superconductivity was discovered in



Joanne Ramey and Homer Harmon extrude a wire made from oxides of yttrium, barium, and copper. First, they suspend the powdered oxide of yttrium, barium, and copper in a binder of ceresin wax and polyethylene. Then they place it in an extrusion dye, subject it to pressure, and extrude it through an orifice. Each wire is several inches long. At right are the extruded wire, which is flexible like a thin rubber cord, and the wire after firing, which is brittle like pencil lead. The paper clip provides perspective. Efforts are under way to make fired wire more flexible and able to carry larger currents.

1911 by Heike Kamerlingh Onnes of the University of Leiden in the Netherlands. Three years before, Onnes was the first to liquefy helium by reducing it to a temperature of 4.2 K (0 K is absolute zero, the temperature at which, classically, all molecular motion stops). He then chilled mercury with liquefied helium and discovered that the metal's resistance to the flow of electricity disappeared.

Today, liquid helium is still used as a coolant for superconductors, which are usually made of alloys of gallium and vanadium; niobium and titanium; niobium and tin; or niobium, aluminum, and germanium. Liquid helium, however, is rare and expensive to produce. A goal of particular fields of science, therefore, has been to discover materials that remain superconductive at or above the temperature of liquid nitrogen (77 K). Liquid nitrogen is preferable to liquid helium as a superconductor coolant because it is abundant (it's basically liquid air) and economical. At 12¢/L (compared with $3/L for liquid helium), the cost of liquid nitrogen is 4% that of liquid helium.

In the period 1986–1987, scientists discovered a new class of superconducting rare-earth compounds that exhibit superconductivity at temperatures ranging from 30 to 125 K. In the past few months, materials that are superconductive at temperatures above 90 K have been synthesized at dozens of laboratories around the world, including ORNL. These materials remain superconductive at temperatures above that of liquid nitrogen—a revolutionary discovery that could have practical uses in electronics, energy storage, long-distance power transmission, fusion energy, medicine, and transportation.

Breakthroughs

The series of breakthroughs in superconductivity began in January 1986, when J. Georg Bednorz and K. Alex Müller of the IBM Zürich Research Laboratory in Switzerland observed that oxides of lanthanum, barium, and copper (a ternary compound) might be superconducting at temperatures up to 35 K. They reported their findings about this rare-earth ceramic in the summer of 1986. In the fall, a University of Tokyo group led by Koichi Kitazawa fabricated superior samples of this ceramic and discovered that they exhibited the Meissner effect. This phenomenon, discovered by German physicist Walther Meissner in 1933, occurs when a superconducting material completely repels, or excludes, a magnetic field. The effect can be demonstrated by placing a magnet over a disk of superconductive material; the magnet will stay suspended in midair, or levitate.

By December 1986 the University of Tokyo, AT&T Bell Labs, and the Institute of Physics in Beijing reported independently that substituting strontium for barium in this class of oxides resulted in a material that was superconductive at 37 K. In late 1986, Paul Chu of the University of Houston placed oxides of lanthanum, barium, and copper (La-Ba-Cu-O) and of lanthanum, strontium, and copper (La-Sr-Cu-O) under 12 kbar of pressure and observed the onset of superconductivity at temperatures up to 52 K. Scientists at AT&T Bell Labs saw the same effect in similar materials placed under pressure. The Chinese group in Beijing then claimed to have observed the onset of superconductivity in rare-earth ceramics at 70 K. Some of these superconductivity findings were reported at a U.S. conference in early December 1986.

In January 1987 a group collaborating with Chu, led by Maw-Kuen Wu at the University of Alabama in Huntsville, substituted yttrium for lanthanum. They measured superconductivity in one yttrium-barium-copper-oxygen (Y-Ba-Cu-O) compound at a temperature of 92 K. NSF formally announced these results on February 16. The results were first published in the March 2, 1987, issue of *Physical Review Letters*.

After the publication of their paper, Chu and Wu and groups at Bell Labs, Argonne, and IBM independently discovered a single-phase composition that exhibits superconductivity at slightly higher temperatures than the one reported in the paper. That composition is $YBa_2Cu_3O_{9-y}$, where Y stands for any rare earth and y represents a number close to 2 (giving O_7).

The scientific euphoria over the rapid progress in superconductivity research made the headlines toward the end of the American Physical Society (APS) meeting March 16–20, 1987, in New York City. The APS session on superconductivity started at 7:30 p.m. Wednesday, March 18, and did not end until 3:15 a.m. on March 19. Some reporters referred to the "boisterous enthusiasm" or the "stampede" of more than 1000 physicists attending the standing-room-only meeting. Other reporters quoted scientists who compared the session to a "quiet rock concert" or described it as the "Woodstock of physics." One ORNL scientist joked that an appropriate name for a rock group of scientists in this field would be the "High Tc's"—T_c is the critical temperature at which a material abruptly loses its resistance to the flow of electricity.

At the APS meeting Constantin Politis of the Karlsruhe Nuclear Research Center in the Federal Republic of Germany reported the highest T_c yet obtained in a Y-Ba-Cu-O material, 125 K. At a Solid State Division seminar at ORNL on March 24, 1987, he talked about the progress of his work with the new class of superconductors in December 1986.

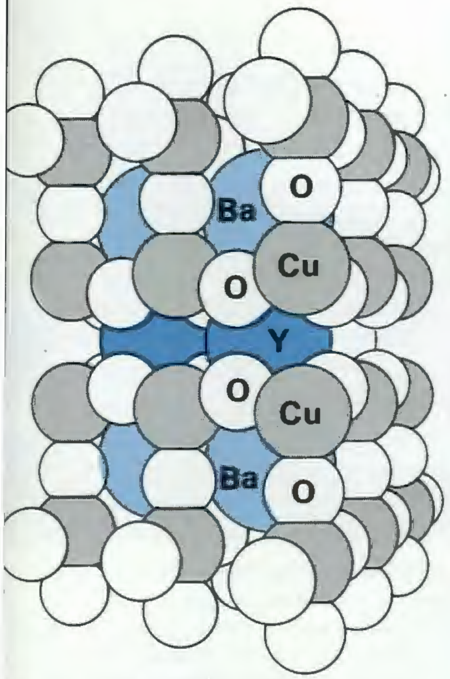
Politis said he prepared superconducting samples by making fine, ultrapure powders of copper oxide and combining them with yttrium oxide and barium carbonate by mixing, grinding, cold pressing, heating, and hot pressing. His group discovered, as did a group at ORNL and many other places, that annealing in a vacuum does not work but annealing in air does (he found that the best annealing temperature is 740°C). Unfortunately, for reasons not yet understood, samples having T_c's higher than about 95 K revert to 95 K in a short time (two weeks or less).

Practical Applications

Barriers to the practical use of superconducting materials have been (1) the high cost of refrigeration required to make materials superconducting, and (2) the difficulty of fabricating superconducting materials into usable forms. The discovery of the new class of high-temperature superconductors could overcome the first barrier because inexpensive liquid nitrogen can replace liquid helium as the coolant. Fabricating usable forms from superconducting materials has long been a challenge. For example, in 1954 it was discovered that a tin-niobium alloy has a high transition temperature of 18 K (high at that time) and can support a magnetic field of 250,000 gauss without losing its superconductivity. However, six years elapsed before a technique was developed to form wires of this normally brittle alloy. Fabricating wires, films, tapes, and rings from the new class of superconducting materials appears to be possible but not easy.

In addition to the fabrication problem, high-temperature superconducting materials are plagued by another difficulty: extremely low critical current density. Current density is a measure of the material's ability to carry an electrical current. By May 1, 1987, the highest current density achieved in a wire made of the new material was just under 200 amps/cm^2.

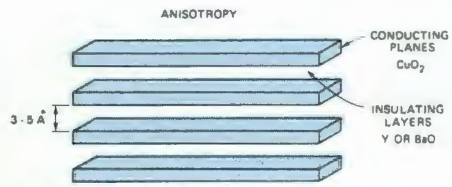
Once these hurdles are cleared, many applications for the high-temperature superconductors seem likely. Superconductors are used commercially in magnetic separation of ores and in magnetic resonance imaging, which is a medical diagnostic tool superior to computerized tomography or X rays. Another application could be magnetically levitated trains—trains that travel hundreds of kilometers an hour while suspended above rails by electromagnets—now being operated in the Federal Republic of Germany, Japan, and the United Kingdom. Superconducting wires could also be used to provide super-efficient, no-loss transmission lines that carry power hundreds or



The spheres in this computer drawing show the positions of atoms in the high-temperature superconducting material—yttrium, barium, and copper oxide.

thousands of kilometers from power plants to homes and businesses. (Recently, DOE's Office of Energy Storage and Distribution in its Superconducting Power Transmission project at Brookhaven confirmed the technical feasibility of transmitting large blocks of power over long distances using a niobium-tin conductor in flexible cables cooled by supercritical helium.)

Many scientists think the first applications of high-T_c materials may be in electronics—particularly interconnections between microcircuits and possibly in memory elements in tiny devices. To make computers faster, the circuits must be packed more tightly to shorten the distance that electrical signals travel. Compact electronic devices require superconducting films because they emit no heat, which can damage circuits. Thin films for interconnects will be needed for ultrafast supercomputers.



Computer drawing of the proposed structure for the yttrium-barium-copper-oxygen superconductor.

Structure of New Superconductors

The structure of the superconducting La-Ba-Cu-O compounds is thought to be the same as that of a crystal in the tetragonal system, which is characterized by three axes at right angles of which only the two lateral axes are equal. This structure, which is related to the perovskite structure typical of the potassium-nickel-fluoride compound K_2NiF_4, is believed to be layered. That is, the copper atoms surrounded by oxygen atoms lie in planes. Apparently, the small amount of strontium or barium helps to line up the copper-oxygen axis to allow the flow of conducting electrons.

During two weeks in March, many laboratories mapped out the structures of more than 200 compounds and took X-ray diffraction pictures of the powder samples. They determined the positions of the metal atoms, but they could not determine the positions of the oxygen atoms.

According to the March 28, 1987, issue of *Science News*, most researchers think the Y-Ba-Cu-O structure is a "triple-layer or oxygen-defect perovskite in contrast to the layered perovskite of the first family of 40-K superconducting oxides. The unit cell consists of three perovskite cubes stacked atop one another with barium atoms at the center of the top and bottom cubes and a rare earth in the middle cube, while copper atoms are on the cube corners. Some oxygen sites on cube edges are vacant, hence the term oxygen-defect, but which ones and how many are disputed." Since then, the positions of the oxygen vacancies have been determined by neutron scattering performed by researchers from the Naval Research Laboratory and the National Bureau of Standards.

Superconductor Theory

To explain superconductivity in materials chilled by liquid helium, theorists have relied on the 30-year-old Bardeen-Cooper-Schrieffer (BCS) theory, which was formulated in 1957 by John Bardeen, Leon Cooper, and Robert Schrieffer. According to this theory, the conductivity of the crystal is believed to increase because the conduction electrons are attracted to each other. As a result, instead of colliding and losing energy through heat as in a normal conductor, the electrons form pairs, which move in step with each other. In essence, the bound electrons condense into a new state of matter, the superconductor.

How can electrons form pairs? The BCS theory holds that the electrons interact through crystal vibrations called phonons. In this "electron-phonon interaction," positive ions in the material "sag together" in response to moving electrons, creating extra-positive charges that attract more electrons. As a result, electrons are indirectly and weakly attracted to each other despite their natural repulsion. If the material is cold enough, the electrons will allow the weak attraction to overcome the random thermal motion, resulting in electron pairing.

Many theorists think the electron-phonon interaction is still a viable explanation of superconductivity in low-temperature superconductors, including those containing lanthanum. However, most agree that a new theory is needed to explain the mechanism of high-T_c superconductivity. An intermediary other than the phonon is believed necessary to explain high-T_c electron pairing.

Much work needs to be done to refine the theory of superconductivity now that new materials show promise of working at temperatures around 95 K. The theorists and experimenters will be working together to understand the nature of superconductivity as well as to find the best ways of making and using these exciting new materials.

New ORNL Effort

ORNL joined the superconductivity stampede in early 1987, roughly a month after the first report confirming a new class of high-temperature superconducting materials. By mid-March, several ORNL groups had made the new materials and measured many superconductive properties. This year so far, ORNL scientists have demonstrated the two-dimensional nature of the new superconducting materials and found a way to double the critical current density of the low-temperature superconducting material.

ORNL's increased effort on superconductivity studies, which now involves 20 staff members, began in January 1987. Brian Sales and Lynn Boatner of the Solid State Division used a controlled urea precipitation technique to form ceramic powders of rare-earth compounds of the new class of oxides, now called low-T_c materials. The unique preparation technique used by the ORNL scientists resulted in extremely homogeneous and high-quality superconducting compounds made of La-Ba-Cu-O and La-Sr-Cu-O. After forming the new material by pressing and heating it at 1100°C, the ORNL scientists found that it became superconducting at over 37°K.

Other measurements were carried out by Dave Christen, Stan Sekula, and Jim Thompson of ORNL's Solid State Division. They found that the material's superconductivity survives in strong magnetic fields (much greater than 80,000 Gauss), an important property for electrical materials that are to be used in superconducting magnets.

At the APS session on superconductivity in March, Christen presented a paper on ORNL studies of the effects on different materials' conductivity of changes induced artificially in atomic lattices (e.g., through thermal processing or neutron bombardment). He reported that neutron bombardment doubles the critical current density in the 35-K material (oxides of lanthanum, strontium, and copper). Critical current density is the current density at which energy loss occurs even though the material is in the superconducting state.

Meanwhile, others at ORNL that week kept up a feverish pace tackling the problems of making the new materials, studying their structure, and determining which compositions work best. Using a technique different from that of Boatner and Sales, Bob Lauf and Claudia Walls of the Metals and Ceramics (M&C) Division also made homogeneous powders of the lanthanum compound. They used thermal denitration to make a mixture of oxides from nitrates of lanthanum, barium, and copper. After dissolving the nitrate salts in water and drying them, they heated them at 900°C in air and later at 1100°C in air to drive off the nitrate as nitrogen dioxide gas. The product of the thermal decomposition is a prealloyed oxide.

Don Kroeger of the Metals and Ceramics Division checks the sample holder containing the new material that becomes superconducting when chilled by liquid nitrogen at temperatures above 90 K. As the sample is chilled, he monitors its change in temperature (using a thermocouple) and resistivity (using an ohmmeter) and determines the transition temperature (when the resistance sinks to zero and the material becomes superconducting).

For this material, the T_c value was about 40 K.

Using samples about 1 cm long and 0.6 cm in diameter, several ORNL scientists confirmed others' findings that the normal resistivity of these special materials can be reduced greatly by annealing them in air or oxygen at certain temperatures and pressures. In other words, superconductivity in these materials depends strongly on their oxygen content, heat treatment, and rate of cooling after sintering.

Bob Williams of the M&C Division studied samples of the La-Sr-Cu-O material that had been densified by hot isostatic pressing at 1000°C. This material precipitates La_2O_3 when heated to 1200°C in air and becomes a semiconductor in the normal state and a superconductor at about 35 K. Annealing the samples at lower temperatures increases their electrical conductivity and produces a much sharper transition to the superconducting state. Williams later produced dense samples of the Y-Ba-Cu-O compound.

After reading about the discovery of the high-T_c (92 K) material in the March 2 issue of *Physical Review Letters*, Lauf and Walls and Boatner and Sales tried to make the Y-Ba-Cu-O superconductor, but their techniques failed at first. Joe Brynestad of the Chemistry Division successfully made the material using a method similar to the one used by the University of Houston group. He mixed barium carbonate, yttrium oxide, and copper oxide in a dry-atmosphere box (free of water), pressed the mixture into pellets, and heated it to drive off carbon dioxide from the barium carbonate in dry air at 900°C. Then he pressed the ceramic powder into pellets, sintered it at 950°C, and annealed it at 700°C in pure oxygen.

Brynestad has made superconducting material from oxides of yttrium, barium, and copper having several compositions. At first he obtained T_c values of only 55–65 K, so he made other compositions using the same elements and came up with a single-phase material having the composition of $YBa_2Cu_3O_x$. This material registered a T_c of 94 K. Once the $YBa_2Cu_3O_x$ composition was identified in Brynestad's sample through microprobe work by Tom Henson, samples were also fabricated by thermal denitration.

A fourth technique for fabricating high-T_c materials will be tested by ORNL's Chemical Technology Division. It is the sol-gel method of precipitating oxides that has been used to make nuclear fuel particles and biocatalyst beads for bioreactors.

ORNL studies of the structure of the 94-K material confirm that it is related to the perovskite structure and has an orthorhombic structure—a crystal system having three unequal axes at right angles to each other. As for the number of oxygen atoms essential to superconductivity at high temperatures for $YBa_2Cu_3O_{9-y}$, Brynestad's studies confirm that the magic number is 7 (i.e., $y = 1.9$ to 2.1).

Researchers in ORNL's M&C Division are currently trying to understand the properties of the high-T_c material. Their goals are to improve methods of processing the ceramic powders to make a uniform bulk material and to increase the material's critical current density. To achieve these goals ORNL researchers are (1) determining the conditions for transforming the material from the tetragonal crystal structure to the orthorhombic structure, which is superconducting, and (2) determining the composition of the grain boundaries of the high-T_c material. Grain boundaries are areas where two grains having different orientations impinge.

At ORNL's new High Temperature Materials Laboratory, E. D. Specht, Cullie Sparks, Ashok Dhere, Burl Cavin, Brynestad, and Don Kroeger studied the effect of oxygen pressure on the orthorhombic-tetragonal transition in $YBa_2Cu_3O_x$. They made high-resolution X-ray diffraction measurements of the lattice constants of the material as its crystal structure changed from orthorhombic to tetragonal during heating and cooling at a series of oxygen pressures. They observed the coexistence of orthorhombic and tetragonal phases over about 30°C at each pressure; at reduced oxygen pressures, the orthorhombic-tetragonal transition occurs at both lower temperature and lower oxygen content in the superconducting material. The

Joe Brynestad of the Chemistry Division mixes dry oxide powders in a glove box. He was the first at ORNL to make an yttrium-barium-copper-oxygen sample that was superconductive at 94 K.

transition is reversible in oxygen but irreversible under helium when the material is heated to 425°C.

A likely cause of the poor current-carrying ability of the oxide superconductors is resistance to current flow at grain boundaries. In recent studies of sintered rods of $YBa_2Cu_3O_7$, Kroeger, Ray Padgett, and Jim Scarbrough of the M&C Division and Brynestad found evidence for a thin layer of material at grain boundaries that differs in chemical composition from the interior of the grains. When rods are broken by bending, the fracture is primarily transgranular in character—that is, the interiors of grains are exposed at the fracture surface. However, in a few places, grain boundary surfaces are exposed.

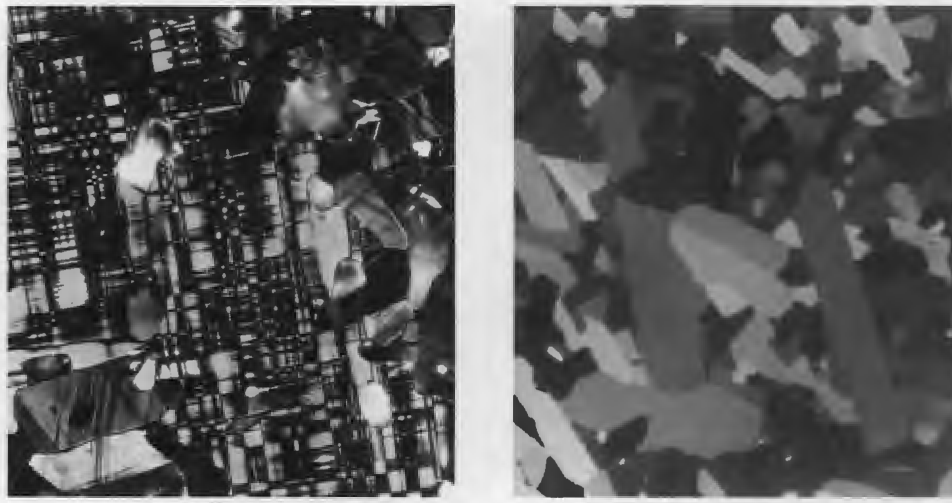
Using Auger electron spectroscopy, the ORNL researchers found that the composition of the exposed grain boundaries differed significantly from that of the grain interiors. The grain boundary layer is thin—about 10 to 30 Å thick—and is probably an electrical insulator. Thus, it may limit current flow without dissipation but not prevent it altogether.

The researchers also found that the grain boundary composition can be varied by making small changes in sample composition relative to the stoichiometric composition. A goal of this work is to determine if a correlation exists between the critical current density and the grain boundary composition. If a correlation is found, it may be possible to increase the critical current density by altering the composition of the grain boundaries.

Two-Dimensional Nature

Boatner and Sales are now using their urea precipitation technique to make Y-Ba-Cu-O material. They have substituted magnetic elements in the rare-earth series (e.g., europium, gadolinium, holmium) for the yttrium. These new compounds, studied by Jim Thompson, Dave Christen, and group leader Stan Sekula, were found to retain both their magnetism and superconductivity, properties that do not normally coexist in most materials. The T_c's of the yttrium-substituted materials were measured at around 92 K, comparable to the transition temperature for the yttrium compound. The holmium experiment demonstrated the two-dimensional nature of the material—that is, electrons move easily along the copper-oxygen plane but avoid visiting the holmium (rare-earth) sites perpendicular to this plane, possibly explaining the low current-carrying capacity (about 200 amps/cm^2) of this class of oxides.

In late March 1987 Herb Mook of the Solid State Division began to study the magnetic structure of these yttrium-substituted superconductors using neutron scattering while Sekula, Richard Kerchner, Thompson, and Christen made plans to study the effects on these materials of radiation damage. Because ORNL reactors were shut down at the time, Mook collaborated with a University of Maryland group at the National Bureau of Standards reactor on neutron-scattering studies; they confirmed the coexistence of magnetism and superconductivity in the holmium sample.

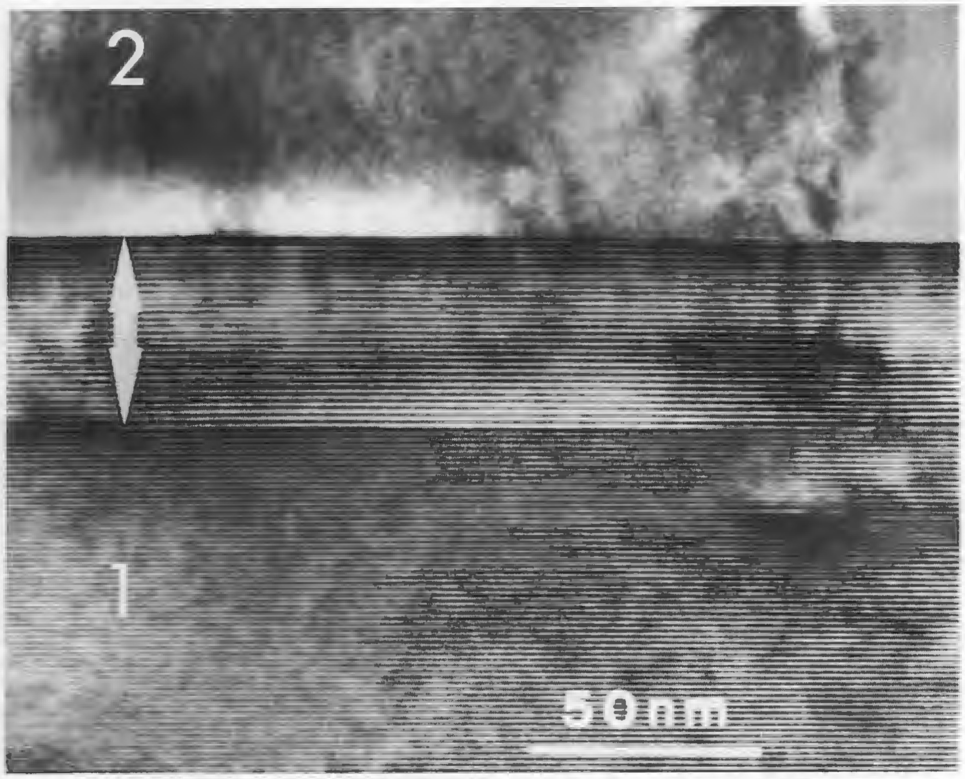


These micrographs (400x magnification) show the structure under polarized light of the high-temperature superconducting material, YBa_2CuO_7. This sample was made 85% dense by Bob Williams. It was sintered at 950°C in oxygen and heated at 700°C in oxygen for 44 h. The bonding and serrations appear to be associated with transformation (phase change) from the tetragonal to the orthorhombic structure. The resultant internal strain may be responsible for the extremely poor mechanical properties of the material and the low critical current density.

Joanne Ramey and Homer Harmon, working with Boatner and Sales, have fabricated ceramic fibers from the high-T_c material by suspending the powdered ceramic oxides of yttrium, barium, and copper in a binder of ceresin wax and polyethylene. The material is then placed in an extrusion dye, placed under pressure, and extruded through an orifice. Each fiber, which can be any length, is then fired to burn out the binder and form the superconducting compound. The fibers produced so far are flexible until they are fired. After firing, they are brittle ceramics, and a remaining challenge is to learn to fabricate these materials into useful forms. The T_c of the fibers made from the Y-Ba-Cu-O material is 72 K.

Recently at ORNL, the crystal structure of a new, but unstable, phase was discovered during high-resolution electron microscope studies of a Y-Ba-Cu-O related ceramic that showed large decreases in electrical resistance near room temperature as well as zero resistance near 90 K. The discovery was made by Jagdish Narayan, a former ORNL solid-state physicist and now professor of materials science at North Carolina State University, and electron microscopist Steve Pennycook of ORNL's Solid State Division. Although the new phase is a small part of the entire sample, it is possible that it is responsible for the resistance anomaly near room temperature. If so, understanding the structure of the new phase could lead to methods for producing a room-temperature superconductor.

Djula Eres, Dave Geohegan, Doug Mashburn, and Boatner of the Solid State Division have fabricated thin superconducting films on strontium-titanium-oxygen substrates using $YBa_2Cu_3O_x$ polycrystals grown by Boatner and Sales. Doug Lowndes and his colleagues in the Solid State Division are applying a laser



Electron micrograph taken by Steve Pennycook and Jagdish Narayan at ORNL showing a thin region (arrow) of a new crystalline phase of the Y-Ba-Cu-O compound. The unstable phase is located between two grains of a 90-K superconducting sample showing a large reduction in electrical resistance near room temperature. The horizontal lines are the lattice planes of the material; clearly, the spacing between the planes of the new phase and grain 1 are different. Grain 2, which is also 90-K material, has a different orientation and invisible lattice planes.

deposition technique (originally developed at Bellcore) to the evaporation of films on silicon and silicon dioxide substrates. Dave Poker and Bob Culbertson are using these superconducting films for ion implantation doping and damage studies at the Solid State Division's Surface Modification and Characterization facility.

In further studies to understand the anisotropic nature of the new Y-Ba-Cu-O superconductor, Dave Christen and his collaborators have used the interaction of a strong magnetic field (70 kilogauss) to orient fine powder of the new superconductor in a fast-setting epoxy. Magnetization measurements by Christen and X-ray measurements by John Budai have shown that this technique results in a composite having highly oriented crystallites of the new superconductor.

Mike Chang in the Solid State Division has succeeded in growing single crystals of the $YBa_2Cu_3O_7$ superconducting compound using a copper oxide–rich flux growth technique. Single crystals are essential for fundamental property studies. Jon Tischler is using X-ray diffraction to determine the detailed structure and perfection of these crystals.

In addition, theorists Bill Butler, Sam Liu, Gayle Painter, Mark Rasolt, and Malcolm Stocks are busily trying to understand whether a new theory is required to explain the mechanism of superconductivity in high-T_c materials. They are looking at whether an attractive interaction between electrons (electron coupling) is possible without phonons and whether a higher-frequency form of matter, such as excitons or plasmons (electron gas), might contribute to electron coupling.

Butler thinks that the light masses of the oxygen and the strong electron-ion interaction in the copper oxide conduction planes lead to a strong electron-electron interaction through the phonon mechanism. However, he believes that this interaction is not strong enough to explain the extraordinarily high T_c's. Butler, together with Rufus Ritchie and Tom Ferrell of ORNL's Health and Safety Research Division, are searching for another mechanism to account for this phenomenon. They are investigating whether the attraction between the electrons may arise from the electronic polarization (distortion of electron clouds around the atoms) of the insulating layers that separate the conducting copper oxide planes.

ORNL theorists also used a first-principle, local-density approximation to calculate the electronic structures of La_2CuO_4 and $YBa_2Cu_3O_7$ and the bonding properties of CuO_6.

During the bimonthly colloquium given at ORNL on April 28, 1987, Liu said that the challenges for ORNL scientists are to explain the reason for high T_c so that researchers can understand how to raise the critical current density, to improve the mechanical strength and physical properties of these superconducting ceramics, and to form them into flexible wire and films. He hopes ORNL will use a variety of experimental techniques to better understand the properties of high-T_c materials and to help determine the mechanism making them superconductive.

The results of work at ORNL and elsewhere may someday lead to economical ways to make large quantities of superconducting material, to enable it to carry large amounts of current, and to form the material into useful components for electrical systems. ornl

PHOTOGRAPH/BILL CLARK

These houses on Alcoa Highway near McGhee-Tyson Airport in Knoxville have been used to test energy-conservation technologies, such as passive solar gain, insulation, and ORNL's Annual Cycle Energy System, or ACES, for space heating and cooling.

Introduction to Special Section
Building Energy Conservation and ORNL

By CAROLYN KRAUSE

Improving building energy efficiency seems unnecessary when petroleum supplies are plentiful and inexpensive and when many gas and electric utilities have excess capacity. However, because of finite supplies of nonrenewable energy resources and projected economic growth worldwide, this favorable situation is not expected to last beyond the early 1990s. In addition, energy efficiency is, in itself, a valuable resource and, therefore, efforts to improve it using emerging technologies and new policies and programs should be encouraged.

These points are made in a 1986 book *Energy Efficiency in Buildings: Progress and Promise* by Eric Hirst of Oak Ridge National Laboratory's Energy Division and coauthors Jeanne Clinton of Barakat Associates; Howard Geller, associate director of the American Council for an Energy-Efficient Economy; and Walter Kroner, director of the Center for Architectural Research at Rensselaer Polytechnic Institute. (The book, which received a 1987 Publication Award from Martin Marietta Energy Systems, Inc., was edited by Fred O'Hara, Jr., of Oak Ridge.) According to the authors' Afterword:

"In our view, the 10 to 15 years after the 1973 oil embargo showed the tremendous contribution that improved energy efficiency can make to the resolution of our nation's energy problems. U.S. energy use today is roughly one-third lower than it would have been had pre-embargo trends continued. Improved energy efficiency can be considered the largest source of "new" energy production since 1973, having provided more energy services than new oil and gas wells, new coal mines, or new electric power plants. Indeed, greater energy efficiency throughout the world is a principal reason why we are now enjoying stable energy prices."

So, in the era of the oil glut, will persistence in further improving energy efficiency still pay off? Yes,

This geodesic energy-efficient home on Watts Bar Lake was built by Jim and Judy Weir. Jim Weir works for ORNL's Metals and Ceramics Division and Judy Weir is an editor with the Information Resources Organization of Martin Marietta Energy Systems, Inc. The energy-saving features of the Weirs' house, known as Domus Isle, include airtight construction, extra-thick insulation, and use of well water as a source of heat.

according to Hirst et al.:

"Further increases in energy efficiency will stretch supplies of nonrenewable resources, cushion our economy against future fuel shortages or price hikes, and provide more time to develop alternative fuels. In addition to these long-term global objectives, there are strong pocketbook reasons to increase energy efficiency levels. Improved energy efficiency can drastically reduce the operating costs of residential and commercial buildings; can reduce the investment requirements of electric utilities, thereby making capital available to strengthen the U.S. economy; can increase local and regional employment; can reduce the adverse environmental impacts of fuel extraction, transportation, and conversion; can reduce U.S. dependence on foreign fuel supplies; and can improve our nation's balance of payments."

Hirst and his colleagues document the considerable progress of the past 10 to 15 years that has significantly improved energy efficiency in U.S. residential and commercial buildings. This progress has been brought about largely by:

- government and utility conservation programs in which buildings are given "energy audits," building owners are advised to consider certain retrofit measures to improve building energy efficiency (e.g., storm windows, weatherstripping, insulation jackets for water heaters, and low-flow showerheads), and, in many cases, the owners are offered loans or payments to cover the costs of taking recommended actions or buying more efficient appliances
- private companies that manufacture, sell, and install a variety of energy conservation devices and systems, including energy efficient air conditioners, furnaces, refrigerators, water heaters, and other appliances that use much less energy than conventional models; and
- government actions such as the promulgation of appliance efficiency standards; the

Weatherization Assistance Program, which provides funds to states to weatherize low-income-household dwellings at no charge to residents; the residential energy conservation tax credit; and state loan programs and seed money for conservation activities.

ORNL Achievements

In the past ten years the national laboratories of the Department of Energy have also helped through research and development (R&D) to determine ways to upgrade residential and commercial buildings to efficiency levels warranted by fuel prices. At ORNL researchers have studied insulations and thermal storage, developed and tested the Annual Cycle Energy System for heating and cooling buildings; established a Roof Research Center as a national user facility; examined the relationship between home conservation measures and indoor air quality; monitored government and utility conservation programs; and worked with industry to develop more efficient appliances such as the heat pump water heater and advanced absorption heat pumps. Most of this work has been done by the Energy Division with major contributions by the Metals and Ceramics Division. A number of other ORNL divisions have been involved, including the Engineering Technology, Health and Safety Research, and Instrumentation and Controls divisions, and the Information Resources Organization. An important contribution to the planning and organization of effective research strategies has come from John Millhone and the staff of the Office of Buildings and Community Systems at DOE Headquarters.

Some recent ORNL achievements in building energy conservation R&D have resulted from work to develop gas-fired heat pumps. In the United States today, natural gas and oil are major fuel sources for building heating, but almost all air-conditioning consumes electricity. Electric heat pumps are increasingly popular for heating and cooling buildings. However, advanced gas-fired heat pumps are receiving increasing attention at ORNL and elsewhere. These devices promise to reduce consumer energy costs, cut the consumption of primary energy, and balance demands for electricity and natural gas in the summer when power usage is highest and the demand for abundant reserves of gas is lowest. Recent results from ORNL heat pump R&D and program management include:

- development of advanced absorption heat pump concepts that have coefficients of performance (ratio of energy output to input) substantially higher than those of advanced gas-fired cycles being tested by subcontractors,
- design of a gas-fired, free-piston, Stirling-engine heat pump by industry under DOE and ORNL guidance, and
- independent verification of the good performance for the heat pump driven by the Braun linear internal combustion engine, using natural gas as the fuel.

ORNL has been developing a strategy for increasing energy efficiency in the 86 million single-family buildings in the United States. The strategy involves selecting the most cost-effective retrofit measures. Early results of the research indicate that radiant barriers (sheets of reflective aluminum foil) installed horizontally in the attic reduce electricity consumption for heating and cooling by 8 to 17%.

ORNL research on commercial buildings shows the possible value of substituting efficient gas-powered air-cooling systems for conventional electric-powered compressors for air-conditioning of buildings. A massive conversion to gas-fired cooling systems might reduce electric utilities' need to increase generating capacity, lower building energy costs, and provide a new market for natural gas.

Another way to improve building energy efficiency is to reduce heat losses from buildings by upgrading roofs. ORNL's Roof Research Center was conceived out of a need to increase the thermal efficiency, durability, and service life of low-slope roofs. DOE is particularly interested in thermal efficiency, and the roofing industry is interested in durability and longevity. Thus, the costs of operating the Center and conducting research there will be shared by DOE and industry. Recent achievements of ORNL's roofing research group have been:

- development of a new method for field determination of the thermal resistance of roofs and
- validation of a surface-reflectance model by studies of white and black membranes on roofing sections showing the extent to which black membranes reduce building heating costs in winter and white membranes reduce cooling costs in summer.

The ORNL evaluations and technology transfer group has played an important role in measuring the effectiveness of government and utility conservation programs. Experiences of these programs suggest that financial incentives (e.g., loans, direct payments, and rebates) and proper presentation of information (e.g., showing residents how to caulk and providing specific, relevant, and understandable tips) are the keys to persuading homeowners to take conservation measures.

Many people believe that conservation measures to reduce home heat losses are responsible

PHOTOGRAPH/BILL CLARK

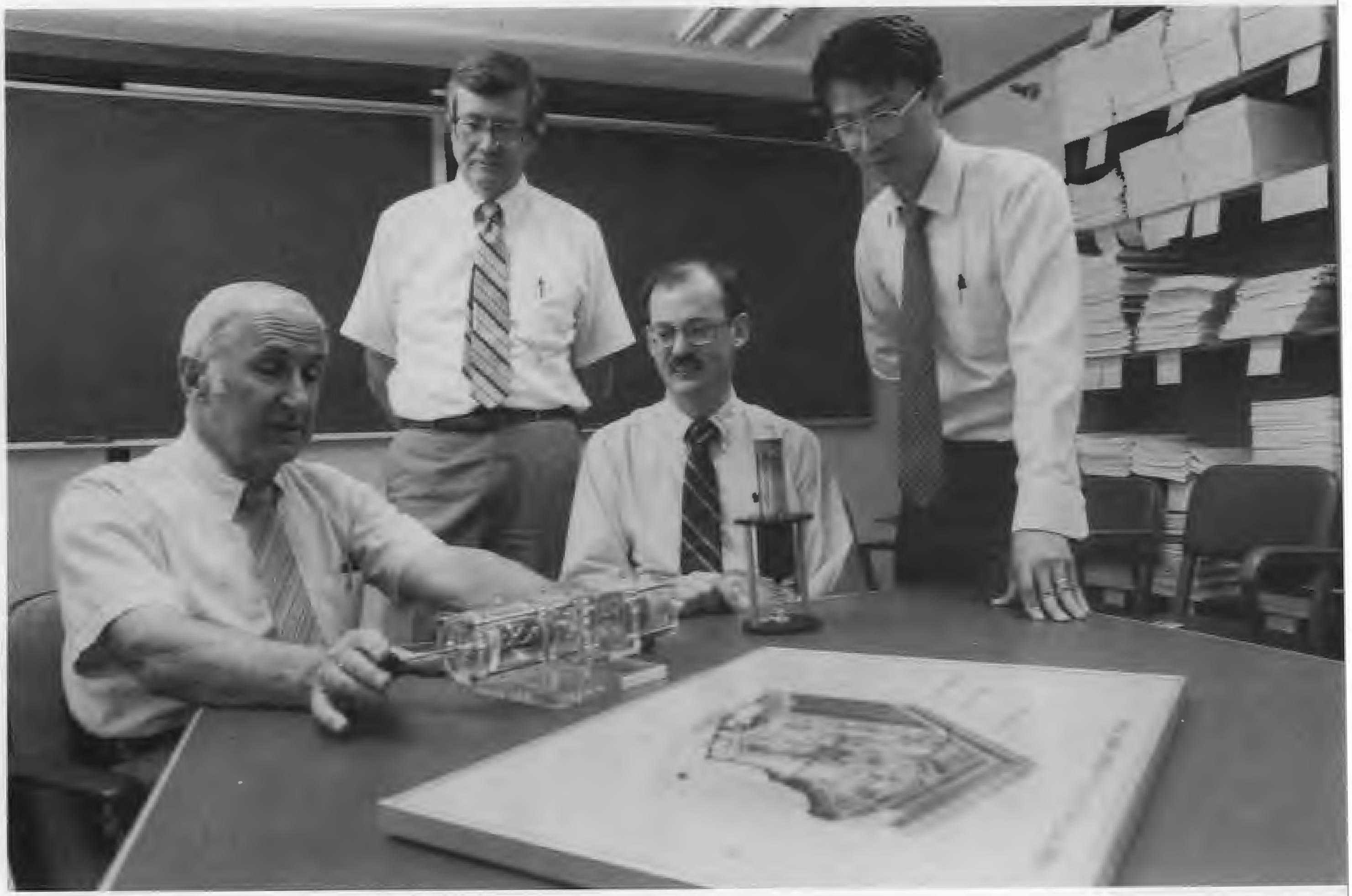
for high levels of radon in homes because "tightening" reduces the rate of outdoor-indoor air exchange. Knowing that radon is a radioactive gas that can induce lung cancer, many people defer tightening their homes. Studies by ORNL's Health and Safety Research Division and other laboratories suggest that, when conservation measures are a factor, the air-exchange rate of a house is usually much less important than other factors in producing elevated radon levels. In fact, the studies suggest, home conservation measures such as sealing between floors may even reduce radon levels.

Ozone Problem and Conservation

A national issue of increasing urgency is the environmental effect of chlorofluorocarbons (CFCs). These compounds, often referred to by the trade name Freon, are used in automobile air conditioners, building heat pumps, and foam insulations. However, accumulating evidence indicates that the release of CFCs is reducing the concentration of ozone in the upper atmosphere, thus allowing more ultraviolet light to reach the earth and increasing the number of cases of skin cancer. To prepare for the possibility that CFCs may be restricted or banned, ORNL has proposed research on substitute materials and systems. Phil Fairchild of ORNL's Energy Division recently presented testimony on this subject to the U.S. Senate Committee on Environment and Public Works.

Our efforts in building energy conservation R&D also include monitoring energy consumption in ORNL's earth-sheltered building, the Joint Institute for Heavy Ion Research; studies of ground-coupled electric heat pumps; analysis of different types of insulation for foundations, floors, walls, ceilings, attics, and roofs; studies of thermal mass in building envelopes and diagnostic techniques for measuring heat losses and pinpointing their sources; and helping revise the National Electrical Code to set the stage for developing and implementating the Smart House project for designing "electronic" homes that can be programmed to use energy intelligently.

Much of the work is covered in the articles in this special section. The energy conservation R&D at ORNL is expected to affect the direction of technology development and policy changes for improving building energy efficiency in the 1990s. ornl



The Promise of Gas-Fired Heat Pumps for

By FREDERICK CRESWICK, ROBERT DEVAULT, FANG CHEN, and GEORGE PRIVON

The potential economic and energy-efficiency benefits of gas-fired heat pumps (GFHPs) for heating and cooling buildings are enormous. The experimental heat pump systems that have been developed under the Building Equipment Research Program at Oak Ridge National Laboratory can operate in the heating mode with a coefficient of performance (COP) approaching 2.0. That is, the heat delivered to the living space is twice the heating value of the natural gas. This COP is double the maximum possible efficiency of the most advanced gas furnace.

GFHPs developed for use in the United States also deliver cooling efficiently. In the cooling mode, they will probably use no more primary energy than the best electric air conditioners likely to be developed in the next decade. Primary energy is the fuel energy consumed—at coal-fired power plants and nuclear power stations, for example—to produce electricity.

At full penetration, we estimate that GFHPs could annually save 0.5 quad per year of primary energy now used in the United States for space conditioning in residential and commercial buildings. The corresponding economic benefit at current energy prices is over $6 billion per year. In addition, during the cooling season, GFHPs would benefit gas utilities, which have excess capacity in the summer, and electrical utilities, some of which have problems meeting peak demand for summer air conditioning.

In spite of these major potential benefits, very little internally

Frederick A. Creswick has 35 years' experience in research and development (R&D) work on a variety of thermal-mechanical systems. He has a B.S. degree from Wayne State University in Detroit and an M.S. degree in mechanical engineering from Ohio State University. He worked on developing automotive gas-turbine engines for seven years at General Motors Research Laboratories. During his 18 years at Battelle Memorial Institute–Columbus Laboratories, he was involved in research on gas and refrigerant compressors, including a free-piston engine-compressor for air-conditioning systems, Stirling engines, automotive engine fuel systems, and exhaust catalyst performance. Since coming to work at ORNL in 1977, Creswick has worked in various capacities on heat pump R&D. He is a registered professional engineer in Ohio. Since 1979 he has been alternate U.S. delegate to the International Energy Agency Executive Committee on Advanced Heat Pump Systems.

Robert C. DeVault is technical program manager for the Absorption Heat Pump Program at ORNL. He has a master's degree in engineering science from the University of Tennessee. He came to ORNL as a full-time consultant to the Energy Division in 1975 and became an ORNL employee in 1977 when he joined the Regional and Urban Studies Section of ORNL's Energy Division. In 1980 he transferred to the heat pump program of the Efficiency and Renewables Research Section of the Energy Division. In 1987 he received an Inventor Award from Martin Marietta Energy Systems, Inc., which cited him for "exceptional innovation and creativity that led to several inventions in advanced absorption heat pump technology with large potential benefits."

Fang Chen is a group leader in the Energy Division. He is responsible for heat pump projects involving Stirling-engine-driven and novel cycles for the Building Equipment Research Program. He has a B.S. degree in mechanical engineering from National Taiwan University and a Ph.D. degree in applied physics from Harvard University. Before joining the Laboratory staff, he worked for NUS Corporation in Rockville, Maryland, where he conducted studies in thermal environmental engineering. He also worked for the TRW Energy Systems Group in McLean, Virginia, in energy conversion and conservation.

George T. Privon is group leader in the Efficiency and Renewables Research Section of ORNL's Energy Division. A native of Chicago, he has an M.S. degree in mechanical engineering from the University of Kentucky. He began work at ORNL in May 1980 as a member of the heat pump group of the Energy Conservation Program. He holds a number of patents dealing with refrigerant compressor designs. Before coming to ORNL he held various positions of responsibility in research, design, and product development with the Carrier Corporation, Sundstrand Corporation, and Bristol Compressors.

Here, Privon, Creswick, DeVault, and Chen (from left) examine a plastic model showing the operation of a free-piston engine-compressor.

Buildings

ORNL has developed advanced absorption heat pump concepts that could outperform advanced gas-fired cycles being tested by subcontractors and has guided the design of industrially developed heat pumps driven by gas-fired Braun and Stirling engines. A goal of the work has been to develop economical gas-fired air-conditioning equipment for buildings to even out demand for electricity during the cooling season and increase the market for new reserves of natural gas.

'unded research and development (R&D) on GFHPs had been conducted by U.S. equipment manufacturers when we began this program in 1978. Even today, almost all R&D on these devices is institutionally supported either by ORNL through the U.S. Department of Energy or by the Gas Research Institute. The reason: R&D on GFHPs is technically challenging, high risk, long term, and expensive. Because no demonstrated market exists, such R&D simply has not been an attractive investment for U.S. industry.

Fortunately, several different equipment concepts exist for GFHPs, although they fit into two basic categories: engine-driven and absorption systems. Early in the program, we decided after considering all the technical risks to undertake parallel approaches to achieving our goal: to advance the technology enough to demonstrate its performance potential and to understand and quantify the remaining technical risks. Once our goal is achieved, private-sector organizations will have enough information to analyze the market potential of technologies developed in this program. We chose to pursue development of three existing technologies: the free-piston internal-combustion (Braun) engine compressor, the advanced absorption heat pump, and the Stirling engine compressor. Our work is sponsored by the Building Equipment Division of DOE's Office of Buildings and Community Systems.

Free-Piston IC Engine Compressor

One of the more obvious GFHP concepts uses a gas-fueled internal combustion (IC) engine to drive a heat pump. In this concept, the engine simply replaces the electric motor in a conventional electric heat pump. An important difference is that the energy in the engine exhaust and cooling water can be partly recovered, greatly increasing the heating efficiency of the engine-driven system.

The problem with the IC approach is that few, if any, small engines have the required durability for heat pump service. A heat pump can accumulate more than 3000 hours of operation in a year of service and ideally would have only one maintenance period in that time. By contrast, an automobile engine typically accumulates 2500 hours of operation in its entire lifetime and has many maintenance intervals. Besides durability, high efficiency and low manufacturing cost are important requirements for the IC concept.

Our approach to this challenge was to support the development of a free-piston engine-compressor unit at Tectonics Research, Inc., of Minneapolis. This device, known as a Braun engine (after its inventor, Anton Braun) had already been developed as an air compressor and had proven its durability in that application. Because of its simplicity, it has few components to wear out or to maintain. The question was, Can it operate satisfactorily as a heat pump compressor, which has a far greater range of operating conditions? To prevent leakage of the refrigerant

What Is a Heat Pump?

A heat pump is a conventional refrigeration system that takes up heat at a certain temperature and releases this heat at a higher temperature. It can use energy efficiently because the total energy output can exceed the energy used to drive the heat pump. Its life-cycle cost—the initial cost plus the cost of operating it over time—can be lower than that of a traditional furnace. It can be even more economical if it can cool a building by reversing its operation, taking up heat from the conditioned space and releasing it at a higher temperature to the outdoors.

Many different types of heat pumps exist, but they can generally be divided into those which are driven by electricity and those which are run by thermal energy. Electric heat pumps are commercially available today and have proven to be effective and popular in milder climates. Thermally activated heat pumps (TAHPs) are being developed and tested; none are in the U.S. market today. TAHPs fall into two generic classifications—those driven by an engine and those using chemical processes and heat to "pump" up the temperature of the heat-transfer medium. Both types are being studied at ORNL.

Both electric heat pumps and engine-driven TAHPs operate on the conventional vapor-compression refrigeration cycle, as do air conditioners and domestic refrigerator-freezers. These devices use a volatile refrigerant fluid such as Freon (Du Pont trade name). The cycle takes in heat from the environment or the cooled space by boiling the refrigerant at low pressure and temperature in a heat exchanger called the evaporator. The resulting refrigerant vapor is compressed to a high temperature and higher pressure and then releases its energy by condensing back to the liquid state in another heat exchanger called the condenser.

The compressor can be driven either by an electric motor or by a gas-fueled engine. The energy delivered is the sum of the purchased energy used to drive the compressor and the "free" energy taken in from the environment by the evaporator. Thus, in the heating mode, the beneficial output is greater than the purchased energy input, but no magic is performed because the total energy input and output balance.

The coefficient of performance (COP) is defined as the ratio of the heating or cooling energy delivered to the purchased energy input. Currently available efficient electric heat pumps operate with COPs of 2 to 3, depending upon weather conditions. Comparison of gas and electric heat pump COP is complicated because the gas system operates with primary energy on-site, whereas the electric system uses high-grade electric power that in the heat pump, another requirement to make the IC concept work was to develop an effective reciprocating-shaft refrigerant seal.

The Braun engine-compressor-seal assembly has few major components (see Fig. 1). The piston motion is linear—back and forth in a straight line; here no rotating

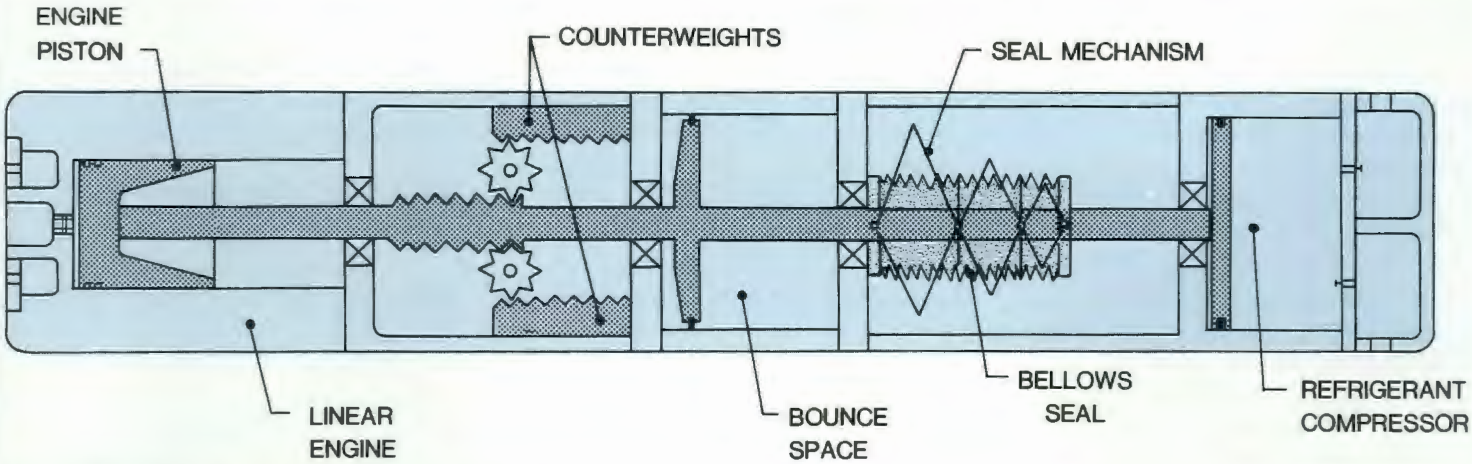
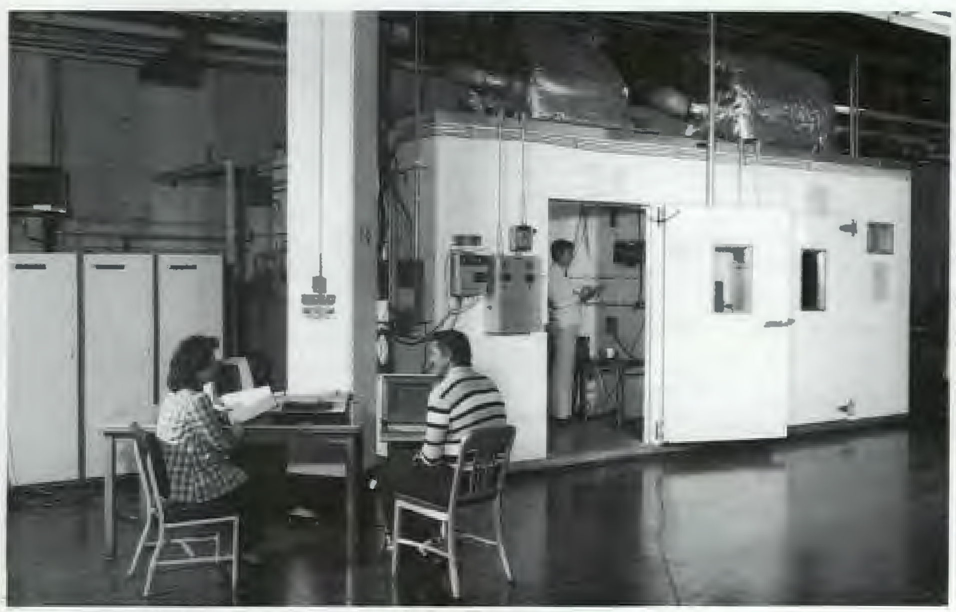


Fig. 1. This schematic shows a free-piston-engine-compressor-seal assembly for heat pump applications.

has been obtained by converting primary energy at the power plant at a representative efficiency of 30%. Also, both gas furnaces and gas heat pumps consume both fuel energy and electric power. No completely satisfactory means to compare the efficiency of devices using two kinds of power has been devised.



This environmental chamber has been used by ORNL for heat pump experiments. The temperature and humidity of the two chambers on the right are used to simulate indoor and outdoor air conditions. The racks on the left house the computer used to set and control test conditions, acquire data, and compute results.

Creswick, DeVault, Privon, and Chen (from left) review a printout from a data-acquisition system used for heat pump experiments. The output includes a tabulation of raw data and a complete set of computed performance parameters.

cranks or rocking connecting rods are present. The one-cylinder engine operates in a two-cycle mode (like some of the more durable lawn mowers) rather than in the conventional four-cycle automotive mode. Thus, the engine has no valves, valve-train gear, or distributor. However, like a conventional IC engine, it has a spark plug, battery, and generator. The lubricant to the engine piston is metered by drops, as in the rotary automotive engine, to ensure long piston-ring life and low exhaust emissions. Thus, no oil changes are necessary.

The engine assembly consists of two moving subassemblies, a piston and rod, and a balancing counterweight. The balance mechanism, between the engine and compressor, results in smooth vibration-free operation. This mechanism consists of a gear-driven rack that moves in an opposite direction to the pistons but at the same speed.

A bounce space and piston are in an adjacent position on the assembly and assist in operation and control of the engine. The bounce space acts as a gas spring that helps to control the motion of the piston assembly.

Once started, the engine operates at a natural resonant speed determined by the combined effects of the compressor load and the bounce-space pressures. The piston stroke length varies with load conditions. Thus, by controlling the bounce space pressures and fuel quantity, the stroke can be varied to respond to load change.

To prevent refrigerant leakage from the sliding rod that connects the engine and compressor pistons, a unique patented hermetic-seal assembly was developed at Tectonics. The assembly consists of metal bellows, a mechanism to limit bellows travel, and a means of controlling the pressure across the bellows. The seal is designed for low-cost manufacture and longevity. As of March 1987, a bellows subassembly on an accelerated life test had accumulated 2.5 billion cycles. At the nominal engine speed of 1000 cycles per minute and 4000 hours of system operation per year, this result is the equivalent of 10 years of operation.

Early tests of the engine equipped with a carburetor running on propane fuel confirmed that the system could operate over a broad range of heat pump operating conditions despite a moderate mismatch in engine-compressor size. The tests were conducted using a calorimeter, a standard device for compressor refrigerant testing. The carbureted fuel system, never viewed as a permanent feature, was discarded because of its poor efficiency.

A second engine incorporating a redesigned compressor section and a cylinder-injection natural-gas fuel system produced stable operation over the complete range of expected operating temperatures and engine efficiencies 15 to 25% higher than those of today's automotive engines.

Recently, a prototype unit was installed in a complete 15-ton packaged system and subjected to standard performance tests by a manufacturer of heating, ventilation, and air-conditioning equipment. The results verified the system's high performance. The unit produced 180,000 Btu/h (53 kW) of cooling at 95°F (35°C) ambient temperature at a COP of 1.1 to 1.2 and a heating capability of 300,000 Btu/h (88 kW) at 47°F (8°C) ambient temperature and a COP of 1.9 to 2.0. Note the COP values are in terms of primary energy; any comparison to electric system values must take into account the inefficiency of the power generation source and distribution system.

In the near future, two packaged units will be prepared for field performance evaluation in cooperation with two gas utility companies. ORNL is planning this project with Minnegasco Company of Minnesota and Northern Natural Gas Company of Nebraska.

Absorption Heat Pump Technology

An absorption heat pump (AHP) differs from a conventional electric heat pump or an engine-driven heat pump in the way the refrigerant is compressed. Instead of the usual piston or rotary compressor, the AHP absorbs the refrigerant vapor from the evaporator in a solution, pumps the solution to a higher pressure, and releases high-pressure refrigerant vapor by boiling the solution. Because the pump requires only a small amount of power, most of the energy input to an AHP is in the form of heat provided by a gas-fired burner.

Early in the program, ORNL supported the development of two experimental AHPs, one by Arkla Industries and the other by Allied Signal Corporation (the latter jointly with the Gas Research Institute). Both systems were based on a simple conventional thermodynamic cycle referred to in the industry as "single-effect." Both prototypes operated successfully and achieved their performance goals. However, the single-effect performance levels were too low to be economical—that is, the energy savings would not compensate users for the increased equipment cost for many years. Because of such a long payback, neither machine was further developed or manufactured.

In late 1981, ORNL reevaluated its absorption heat pump program goals and decided to focus on advanced absorption cycles that can produce higher efficiency while still using existing combinations of absorption fluids. Studies conducted with the help of experts in this technology convinced us that substantially higher AHP efficiencies could be achieved through the use of advanced cycles that featured higher operating temperatures, greater solution concentration differences, and regenerative heat exchanges internal to the cycle.

Accordingly, ORNL issued a request for proposals in 1982 for the development of one or more advanced machines. Three organizations were awarded subcontracts: Carrier Corporation, a division of United Technologies Corp.; the Trane Company, a division of American Standard, Inc.; and Phillips Engineering Company.

The current work in the advanced absorption cycles program is divided into three phases: (1) the analytical evaluation of advanced cycles and selection of a preferred advanced cycle for further development (Phase I); (2) the development and testing of laboratory breadboard prototypes of the selected advanced cycles (Phase II); and (3) the development and testing of packaged proof-of-concept prototypes after successful completion of Phase II (Phase III).

The goal of the Phase I selection of a preferred advanced cycle was not necessarily to pick the highest-efficiency cycle, but to select cycles with a combination of features, such as high efficiency, low manufacturing cost, and high inherent reliability. Combining desirable features appeared to offer the most likely path to a manufactured product by the 1990s.

In Phase I analysis work, Phillips Engineering examined a variety of cycles. They evaluated each cycle's potential efficiency, heat-exchanger surface requirements, and ability to operate over a broad range of temperatures. Phillips selected the generator-absorber heat-exchange (GAX) cycle for residential uses because it has the best combination of high potential efficiency and low manufacturing cost. In the GAX cycle, the amount of external heat input required is reduced by an internal regenerative exchange of heat from the absorber to the vapor generator. Both ammonia-water and ammonia–lithium bromide–water were selected as candidate absorption fluid systems for this cycle.

The Trane Company and Carrier Corporation each evaluated advanced cycles for commercial applications. The Trane Company, which conducted a Phase I analysis similar to that of Phillips Engineering, also selected a GAX cycle but added other features and an additional internal heat exchange for higher efficiency. Economic analysis of the improved GAX cycle indicated that it will offer a payback of less than three years in commercial buildings and help gas and electric utilities balance their loads.

Carrier's study of advanced cycles resulted in selection of a dual-loop cycle based on the use of methylamine–lithium bromide–water in the lower (temperature) loop and lithium bromide–water in the upper loop. DOE has been granted six patents based on Carrier's Phase I work.

Each of these advanced cycles selected by Trane, Carrier, and Phillips offers potential for a rated heating COP in the range of 1.8 to 2.0 and cooling COP in the range of 0.8 to 1.2, significantly exceeding the original program goals.

In 1985, as part of Phase II, Phillips Engineering demonstrated their GAX-cycle laboratory breadboard (see Fig. 2) and achieved COPs of over 1.8 in heating at 47°F (8.3°C) and 0.8 in cooling at 95°F (35°C). An independent cost analysis of the Phillips Engineering prototype concept has projected a customer-installed cost equal to existing midline gas furnace–electric air-conditioner combinations or to electric heat pumps.

Trane expects to demonstrate proof of principle with a laboratory breadboard prototype model of a commercial-size unit in 1987. Carrier is scheduled to build and test two separate laboratory breadboard prototypes. The first prototype, a single-stage commercial-size AHP that can operate at below-freezing temperatures, is scheduled for operation in 1987. The second prototype using the dual-loop concept is scheduled for testing in 1988.

To support the system-development efforts in the ORNL AHP program, research is being performed on a variety of subjects including fluid properties, advanced instrumentation, heat and mass transfer, computer simulation models, and solution pump development.

In one supporting research project, ORNL's Analytical Chemistry Division developed a unique fiber-optic instrument to measure the concentration of absorption-fluid solutions such as ammonia-water. In 1986 DOE filed a patent on the device, which was developed by Horacio Perez-Blanco of the Energy Division and Leon Klatt, Debra Bostick, and J. E. Strain of the Analytical Chemistry Division. The fiber-optic instrument monitors the dynamic concentration of the refrigerant in the absorption fluid solution during operation of the heat pump by continuous measurement of the refractive index of the solution. The refractive index, which changes as fluid concentrations change, is determined by measuring light loss from an unclad segment of fiber-optic cable immersed in the fluid (see Fig. 3). Information obtained by the ORNL fiber-optic instrument is being used to improve the design of new absorption systems and increase their operating efficiency.

Recently, in cooperation with Phillips Engineering Company, ORNL initiated experiments using a gear-type solution pump having gears fabricated of silicon carbide whisker-reinforced alumina composite ceramic, a material developed by ORNL's Metals and Ceramics Division. A simple, low-cost solution pump component that can operate in a corrosive nonlubricated environment is badly needed for residential-size absorption equipment.

Even though operating advanced-cycle-absorption prototypes have already exceeded the original program goals, work on more advanced cycles that will underpin the next generation of equipment has been continuing at ORNL. A triple-effect cycle conceived by Robert DeVault has a calculated performance potential 30 to 50% more efficient than the best existing double-effect absorption chillers.

Collectively, these developments promise to revolutionize AHP technology, and ORNL is pleased to have participated in fostering these important changes. Other U.S. developments supported by the Gas Research Institute promise substantial efficiency improvements, as do efforts under way in Europe and Japan. Although these developments could become technically and commercially successful, many challenges must be met before complete success can be claimed. Obstacles to be surmounted include solving potential corrosion problems brought about by new fluids or higher operating temperature and developing the thermal-design knowhow needed to fully exploit the efficiency potential of these advanced cycles.

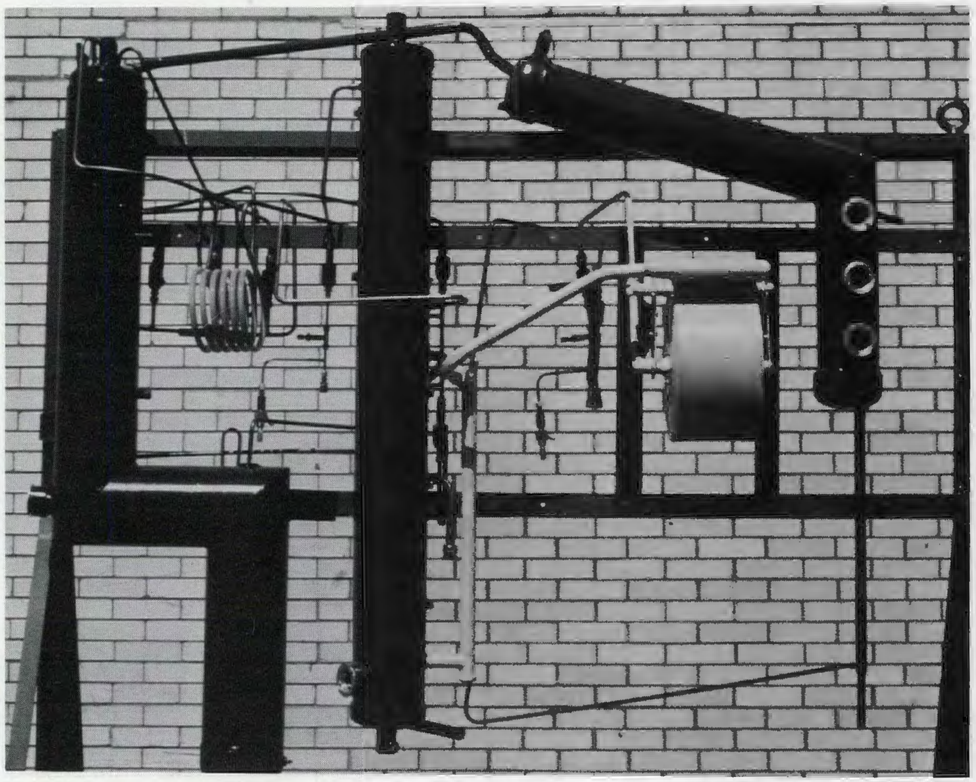


Fig. 2. This laboratory "breadboard" absorption heat pump system operates on a generator-absorber-heat-exchange (GAX) cycle.

Free-Piston Stirling-Engine-Driven Heat Pump

In principle, almost any kind of an engine can be used to drive a heat pump. In addition to the spark-ignited internal combustion engine already described, the Stirling engine is particularly well suited to this application. The basic Stirling engine concept was invented over 150 years ago; it was used commercially for small power plant applications in the 19th century before internal combustion engines were developed. In this century it has been used only experimentally for various applications, including automotive, rail, and marine propulsion and aerospace and military auxiliary power. In spite of its long history, its technology has to be considered immature in today's environment. Engine types such as gasoline, diesel, and gas turbines, which are widely used today, have been the subjects of considerably more R&D activity than the Stirling engine in the past 50 years.

The Stirling engine's principle of operation is not easily understood by most scientists and engineers. In its simplest embodiment, it consists of two pistons, one called a displacer and the other a power piston, working in a sealed system charged with a high-pressure gas such as hydrogen, helium, or air. The displacer shuttles the gas charge alternately through hot and cold heat exchangers, thus causing a cyclic pressure variation. The motion of the power piston is phased so that it moves outward when the gas pressure is high and inward when the gas pressure is low, resulting in work output. Heat is provided to the "hot" heat exchanger by an external

Fig. 3. This diagram shows the principle of operation of a fiber-optic instrument for measuring fluid concentration in an absorption heat pump. The ORNL instrument uses changes in light transmission to measure changes in fluid concentration. The index of refraction of the fluid influences the angle and therefore the amount of light leaking from the unclad section of the fiber.

combustor; a coolant is used for the "cold" heat exchanger. The engine has no valves and requires an ignition system only for starting.

Several types of Stirling engines exist, but the most common ones are kinematic and free-piston types (see Fig. 4). A kinematic Stirling engine uses a mechanical linkage to establish the motion of the displacer and power piston, maintaining a fixed phase angle between the two. The displacer and power piston in a free-piston engine, on the other hand, are not connected by a mechanical linkage. The motion of the displacer and power piston results from their masses and the pressure variations of the working gas. The output power is in the form of linear motion, which can be used directly to drive a vapor compressor. The engine and the compressor can be hermetically sealed to form a single Stirling-engine heat pump unit.

Although a Stirling engine heat pump (SEHP) might take many forms, the basic concept offers some important potential advantages in addition to high thermal efficiency. Perhaps most important is its exceptionally quiet and vibration-free operation. The continuous burning combustor can be designed to emit very clean exhaust. Ideally, no oil changes or tune-ups are required.

The free-piston configuration has these advantages over the kinematic type: fewer moving parts and bearing surfaces to wear out and the opportunity to hermetically seal both the engine and refrigerant sections of the device. The liability of the free-piston type is the requirement for close attention to "tuning" in the design of the system.

ORNL's involvement with the SEHP began early in our program when we assumed responsibility for a subcontract with the General Electric (GE) Company, which was already in progress with joint sponsorship by the Gas Research Institute. The GE configuration involved an inertial coupling between the engine and refrigerant compressor. Two generations of prototypes were developed; both ran convincingly but fell short of efficiency and capacity goals. After the second configuration, we concluded that it was uncertain whether the complicated dynamics of the inertia-coupled system could be dealt with in the time given. So we switched to an alternative configuration.

In cooperation with the Gas Research Institute, DOE and ORNL sponsored a free-piston, Stirling engine heat pump (FPSEHP) program at Mechanical Technology, Inc. (MTI), beginning in 1980. The system consists of an FPSE coupled to a resonant piston refrigerant compressor through a hydraulic transmission. Located above the engine diaphragm, the FPSE assembly consists of a recuperated natural gas combustor, a monolithic-finned heater head, a motor-driven displacer, and heat-exchanger components. The hydraulic transmission and compressor are located below the engine diaphragm.

The motor-driven displacer enables the displacer stroke to be controlled electrically, providing a convenient means for start-up and the primary control to match the engine output to the heat pump load. Separation between the engine working fluid and refrigerant (R-22) is achieved by using the flexible metal diaphragm between the FPSE and hydraulic transmission. Engine power is transferred to the compressor through the volumetric displacements of the diaphragms and corresponding displacement of the oil in the hydraulic transmission. The motion of the diaphragm is produced by the pressure wave developed in the engine.

The FPSEHP module has gone through two hardware design iterations and is in the proof-of-concept stage. It has met the proof-of-concept performance targets; for a module having a cooling capacity of three tons (10.5 kW) at the outside air temperature of 95°F (35°C), it has achieved a cooling COP = 0.9 and a heating COP = 1.6 at standard test conditions in laboratory tests. To further validate the laboratory results, the heat pump module is being evaluated at the product test laboratory of Lennox Industries, a major heat pump manufacturer.

We believe the success of this unit has demonstrated that this tuned system can operate with satisfactory dynamics over a wide range of operating conditions. Also, durability tests have produced encouraging results; after more than 1100 hours of operation, a durability-test engine was disassembled, and its mechanical components showed insignificant wear. The engine was reassembled and is now undergoing an additional 10,000-hour life test.

Although the current FPSEHP laboratory module has met the performance goals, it still can be improved. Like many new technology developments, it is a rather complex piece of hardware. Design refinements and hardware iterations are needed to reduce a laboratory prototype into practical equipment.

The next phase of FPSEHP development, now under way, focuses on converting the laboratory module into an engineering prototype. MTI is refining the engineering design of an advanced version of the FPSEHP module to simplify the mechanical arrangement of the module. Simplification should reduce the manufacturing cost and increase the reliability of the heat pump module without reducing the good performance achieved by the earlier version. Once the design refinement is completed, a new generation of hardware will be built and thoroughly tested both in controlled laboratory and real-world environments.

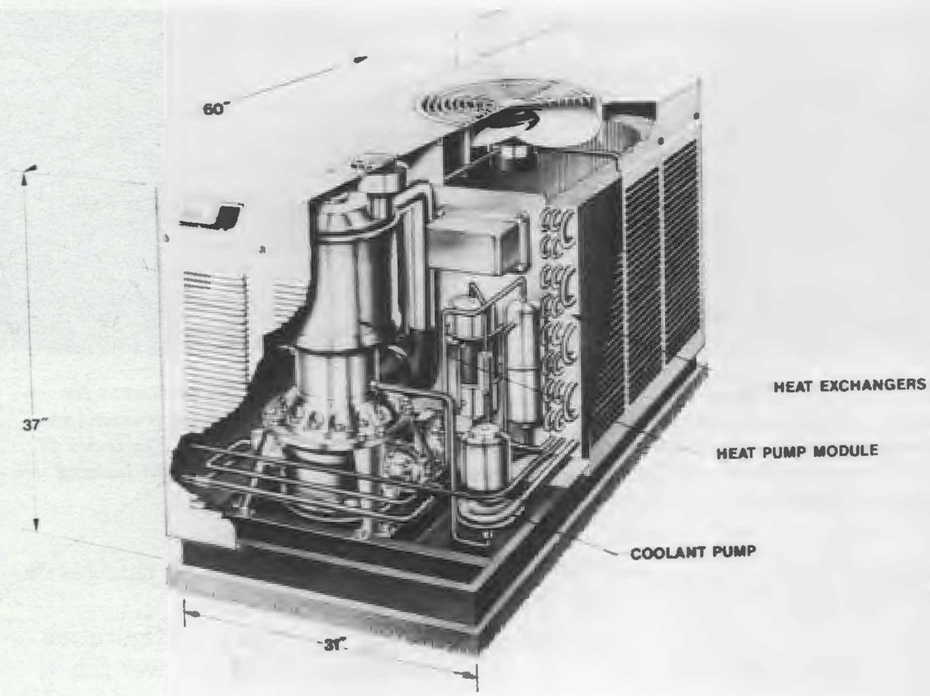


Fig. 4. Artist's rendition of a free-piston, Stirling engine heat pump.

The Promise

We think the prospects for eventual commercialization of gas-fired heat pumps are far brighter than they were in 1978 when we began our program. We have demonstrated in laboratory tests that our thermal performance goals can be met or exceeded with three different gas-fired heat pump concepts. In doing so, we have developed concepts and supporting technology to hurdle major technical obstacles and to make major advances in the technology. We cannot claim sole credit for these advances because we have had the advantage of significant cooperation from other organizations, especially the Gas Research Institute, and of general advances in related technologies external to heat pump development programs. However, we think we have made a significant difference.

The linear IC engine compressor development is now entering a transition phase in which ORNL will continue to fund work on improvement of seals, fuel systems, and controls while the developer negotiates an agreement with an organization interested in commercializing the device. Although the AHP developments are still in the early laboratory phase, product development could ensue quickly once thermal design and materials (corrosion) problems are solved. Because the SEHP concept needs to be simplified, it will probably take a little longer to reach the commercial stage.

The IC engine system is well suited to small- and medium-size commercial application. The AHP is potentially suited to both residential and commercial applications of all sizes and to industrial applications as well. The SEHP looks best in residential and light commercial applications. Quite possibly, one or more of these developments could be commercialized as early as the mid-1990s. ornl

ORNL has provided field data and models that have guided the development of ground-coil design guidelines for installers in the state of New York. These guidelines yield coil lengths 50% shorter than those recommended by theory, considerably reducing the cost of ground-coil heat exchangers.

Ground-Coupled Heat Pumps: *ORNL Research Aims at Lowering Costs*

Interest in heat pumps that extract heat energy from the ground instead of the air has grown in recent years because of their energy conservation potential. The ground is preferable to outdoor air as a heat source and sink for a heat pump because it is warmer than air in the winter and cooler than air in the summer. Thus, a ground-coupled heat pump (GCHP) should consume less electricity than the commonly used air-to-air heat pump (AAHP) for heating and cooling buildings.

Instead of the AAHP's outdoor air-heat exchanger and fan, the GCHP has either (1) a well from which groundwater is pumped directly to the heat pump (open-loop system) or (2) a vertically or horizontally oriented buried-pipe heat exchanger (closed-loop system) and a circulation pump. Although the open-loop type does not use an intermediate ground-coil heat exchanger, as does the closed-loop system, it requires a well having an adequate water capacity (usually 3 gpm per ton of heat pump capacity). Because wells are not needed for closed-loop systems, they can be used virtually anywhere. For this reason most researchers, including those at ORNL, have concentrated on the closed-loop GCHP.

Several GCHP systems tested in Knoxville by ORNL and the University of Tennessee have achieved higher efficiencies than a high-efficiency AAHP. Efficiency is measured in terms of seasonal performance factors (SPFs). The GCHPs had heating SPFs ranging from 2.6 to 2.9 compared with 2.0 for the AAHP. Cooling SPFs for the GCHPs were 1.5 to 2.6, compared with 2.4 for the AAHP. GCHP systems tested in New York by Niagara Mohawk Power Company (NMPC) achieved heating and cooling SPFs of 2.5 to 3.1.

Because of the high cost of a ground-coil heat exchanger, the GCHP is more expensive than the AAHP. Thus, even though GCHP heating is more efficient than the AAHP, it takes several years for the energy savings from the GCHP to compensate for its extra cost. The economic potential of alternative systems can be determined by computing the simple payback for a system in comparison with its less expensive alternative. The simple payback in years is calculated by dividing the additional cost of the more efficient system (compared to the base system) by the annual energy savings.

For current Knoxville electricity prices, the simple payback for the GCHP system is 15 years compared with the AAHP. However, for the NMPC service area in New York, the simple payback is only about 4.5 years compared with AAHPs and only about 5.5 years compared with oil furnace/central air-conditioner systems.

From these results it is evident that GCHPs have much better economic potential in northern climates where heating consumes most of the energy. Even so, the major obstacle to widespread penetration of GCHPs in these areas is the high cost of the ground-coil heat exchanger.

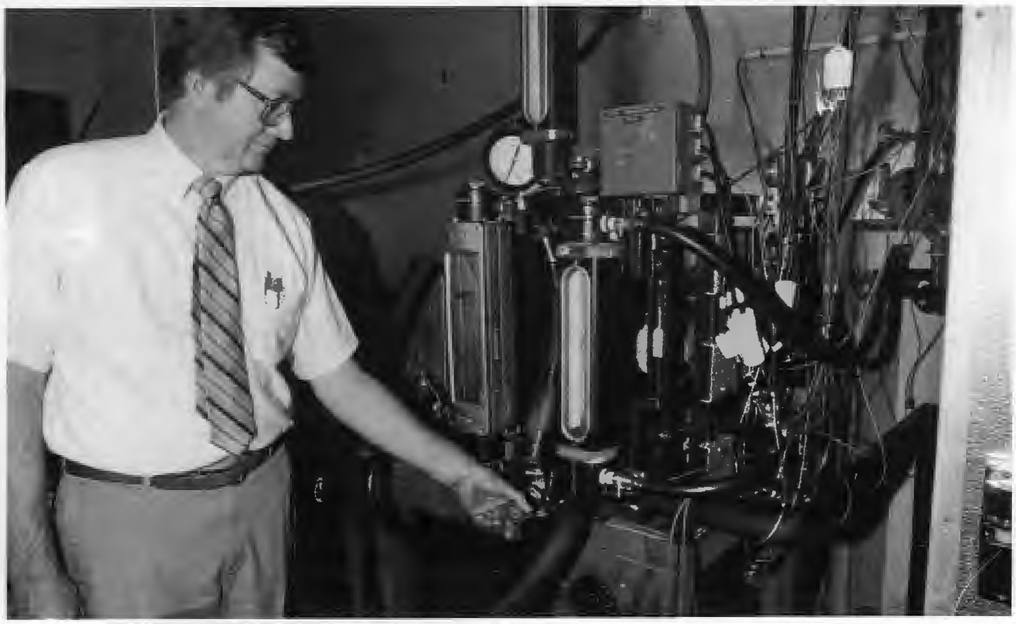
Goal is to reduce costs. Reducing the cost of the ground-coil heat exchanger has been the goal of ORNL research. Activities in DOE-sponsored GCHP research here have been the development of more realistic design models of the ground-coil heat exchanger and optimization of the GCHP system design.

Advanced design models for both vertical and horizontal closed-loop, ground-coil heat exchangers have been developed at ORNL. These models are based on an energy balance between the ground coil and surrounding soil, in contrast to the empirical line-source-theory-based models now used by most designers. The models can account for soil freezing, ground temperature variation with depth, thermal interference from an adjacent coil, circulating fluid properties, coil properties, and cyclic operation, all of which are difficult to handle with the traditional models (and are generally ignored). Field data from ORNL tests, Brookhaven National Laboratory (BNL), and NMPC have been used to validate the models. Using the ORNL models, monitored field data, and line-source theory models, W. S. Fleming and Associates, under sponsorship by NMPC and New York State, has developed ground-coil design guidelines for installers in the state. These guidelines yield coil lengths 50% shorter than those recommended by using line-source theory alone. The new guidelines are currently in use and have considerably reduced the cost of ground-coil heat exchangers.

The GCHP system design optimization project was a cooperative venture among ORNL, BNL, Climate Master, Inc. (a heat pump manufacturer), and NMPC. Reduction of both life-cycle cost and first cost of a GCHP system for northern climates was the project objective. For this project, the life-cycle cost was defined as the system first cost (or purchase and installation cost) plus the current value of seven years of energy costs.

Conventionally, GCHP systems have been designed around water-source heat pump (WSHP) packages that were not ideally suited for the low fluid operating temperatures typically encountered with closed-loop GCHPs. Results of the analytical phase of the optimization project showed that by increasing the efficiency of the WSHP by 20 to 30% (at a 15% cost premium) the ground coil length could be further reduced by 30 to 50%.

Prototypes built. Because these findings were encouraging, Climate Master agreed to build two prototype high-efficiency WSHPs based on the optimized design concept. NMPC field tested the prototypes near Syracuse, New York. Results of the field test showed that the advanced systems achieved the same heating SPFs (2.7) as previously monitored standard design systems, even though the ground coils of the advanced systems are 30% shorter than those of the standard ones. The reduced ground-coil length is projected to offset the increased WSHP cost enough to reduce the overall cost of the GCHP system by 10%. A cost decrease this large can reduce the GCHP simple payback to only 3.5 years compared with an AAHP for installations in New York State. Similarly, GCHP simple paybacks could be reduced from 5.5 years to about 4.5 years compared with oil furnace/central air-conditioner systems.—*Van D. Baxter and Vung C. Mei, Energy Division.*



Fred Creswick adjusts an experimental heat pump apparatus operating on a nonazeotropic refrigerant mixture. In this experiment, the possibility of modulating heat pump output by changing refrigerant composition is being investigated. This technology is potentially useful in both electric and gas-fired systems.

International Cooperation in Heat Pump R&D: *A Case History*

International cooperation in heat pump research and development (R&D) has long been a significant activity of the Building Equipment Research Program at ORNL. Our participation in the International Energy Agency (IEA) "Programme of Research and Development on Advanced Heat Pump Systems" has been the basis for this activity.

ORNL's involvement. The IEA is part of the Organisation for Economic Co-operation and Development (OECD). The agency was formed in the early 1970s to reduce member countries' dependence on increasingly costly foreign oil through international cooperation in R&D. DOE became involved in the IEA advanced heat pump program at the time of its formation in 1978—about the same time that ORNL had assumed the role as lead DOE laboratory in heat pump R&D. The manager of the DOE program on heat pumps was named the U.S. delegate and the author has served as the U.S. alternate.

Through ORNL, DOE has participated in several research projects called "annexes"—that is, annexes to the IEA "Implementing Agreement" that formed this cooperation. The research topics have included a general study of advanced heat pump systems, ground-coupled heat pumps, alternative refrigerant fluids, heat pumps driven by Stirling engines, and computer modeling techniques for simulation and design. We have also supported the IEA Heat Pump Center, which was formed to collect, process, and disseminate information on heat pump technology.

Through the IEA, we came in contact with researchers in Europe and Japan whose work and interests are similar to ours. On trips abroad to attend IEA committee meetings and working meetings, the DOE program manager and ORNL staff members made side visits to energy ministries, R&D organizations, and private-sector firms involved in developing heat pumps. These meetings resulted in mutually beneficial exchanges of nonsensitive information.

We quickly developed close contacts in Europe, but language barriers, cultural differences, and the Japanese practice of rotating delegates frequently inhibited communication with our Japanese colleagues. Then Etsuji Miura of the Heat Pump Technology Center of Japan provided the key that permitted us to cultivate Japanese contacts. He started attending all of the executive committee meetings, often accompanied by a different Japanese representative each time. Although he speaks very little English, he provided the continuity that enabled us to become acquainted with the Japanese participants. We now view our new contacts as open and cooperative, and some of the individuals have become our friends.

Benefits of cooperation. Our participation in the IEA annexes has produced a high return of useful information. For example, we knew the Swedish had made some major advances in the development and commercialization of ground-coupled heat pumps. Through an annex on this topic, we learned that although their technology was applicable in Sweden, it did not provide a way to improve the cost effectiveness of these systems in the United States. We also knew that the Europeans had developed a considerable technology base on nonazeotropic refrigerant mixtures. Participating in an annex on this subject helped us come "up to speed" quickly in this area. We learned that substantial additional research will still be necessary to obtain the potential benefits of this technology. Perhaps the most beneficial information exchange came from the Technical University of Munich, where we learned about some analytical methods that have been useful to U.S. researchers in developing concepts for advanced absorption heat pump cycles (see lead article).

International cooperation also allows us to learn about the R&D activities of our colleagues throughout the world. Such information helps us to avoid duplicating the research in progress at other laboratories or developing already obsolete concepts. As a result of some information we acquired abroad, we elected not to get into some research areas that we believed were being adequately addressed elsewhere. Moreover, through our observations we have come to believe that our work is indeed in the mainstream.

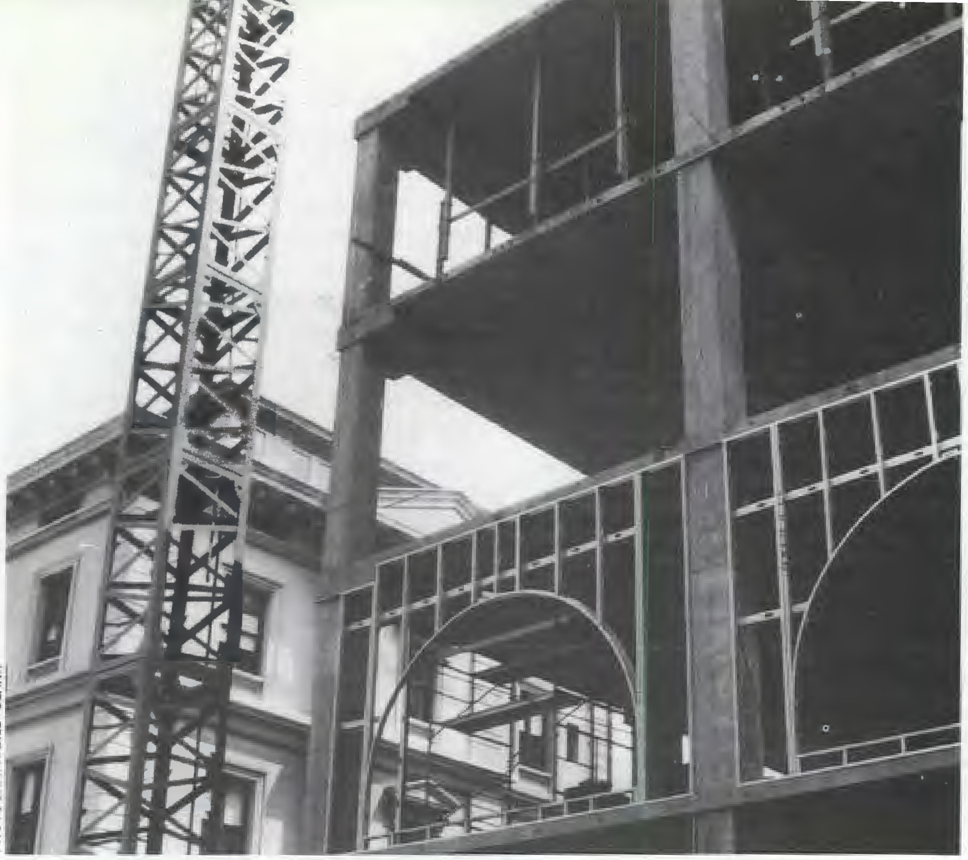
Other lessons learned. Through international cooperation, we have learned that no geographical area has a monopoly on heat pump technology. The expertise is well diffused throughout the industrial nations. In the past decade, the technology has advanced substantially in these countries, but no country is far ahead of the others.

From our interactions with various governments in the participating countries, we saw wide variation in R&D funding. In European countries, the private sector defines the projects, government and industry share the costs about equally, and governmental oversight is minimal. The Japanese select a few major areas for R&D and form large cooperative research groups from government and industry. In the United States, the traditional reluctance of industry to get involved with the government and the fear of antitrust regulations have thus far inhibited strong industry-government cooperation. Consequently, the U.S. government has formulated the R&D programs and industry has maintained the role of contractor.

The future. ORNL and DOE are still participating in the IEA Advanced Heat Pump Systems program, and we expect substantial future benefits. For example, we decided a decade ago to pursue the development of free-piston Stirling engines for heat pumps instead of the competing technology of kinematic Stirling engines. This alternative route was taken by the Japanese and the Swedish. To help us determine whether our decision was justified, we are cooperating with Japan and Sweden to make a joint assessment of both technologies.

As evidence of our commitment to international cooperation, we worked for the past two years as lead organizers of the 1987 IEA Heat Pump Conference, which was held in April in Orlando, Florida. About 300 participants heard talks by internationally known experts. The event was sponsored by DOE, the Electric Power Research Institute, the Gas Research Institute, and five foreign organizations.

A possible development in the near future is the emergence of an international market for small and mid-size unitary heat pumps—the market for large commercial units is already international. So far, geographic differences in residential heating and small commercial unit heating and cooling practices have inhibited international marketing of unitary systems. The Japanese mainly use room units; the Europeans, central hydronic systems (which transfer heat by circulating fluid in a closed system of pipes); and the Americans, forced-air systems. If this international market does develop, advances in heat pump technology and the application of this technology will have increased significance. International cooperation may come to be viewed somewhat differently, but it will be no less important.—*Fred A. Creswick, Group Leader, Building Equipment Research Program, Energy Division.* ornl



PHOTOGRAPH/BILL CLARK

Technology Transfer and the Buildings Industry

In the United States, many cost-effective technologies have been developed to improve the energy efficiency of buildings. Yet, for a variety of reasons, most of these technologies have not fully penetrated the buildings industry. Examples are lighting controls, radiant barriers, the surface wave lamp, and energy-efficient refrigerators, freezers, and furnaces, as well as some of the other technologies discussed in this special section. The Department of Energy is committed to accelerating the use of energy-efficient technologies in buildings and has sought ORNL's help. Understanding the problem and implementing a program to stimulate commercial use of these technologies has been a major focus of the Evaluation and Technology Transfer (EATT) Group in ORNL's Energy Division.

ORNL, through the EATT Group, serves as the lead technology transfer laboratory for DOE's Office of Buildings and Community Systems (OBCS); the group is also involved in the technology transfer activities of other DOE programs. The technology transfer program that the EATT Group manages for OBCS is designed to overcome some of the major obstacles to the dissemination and commercialization of buildings technology.

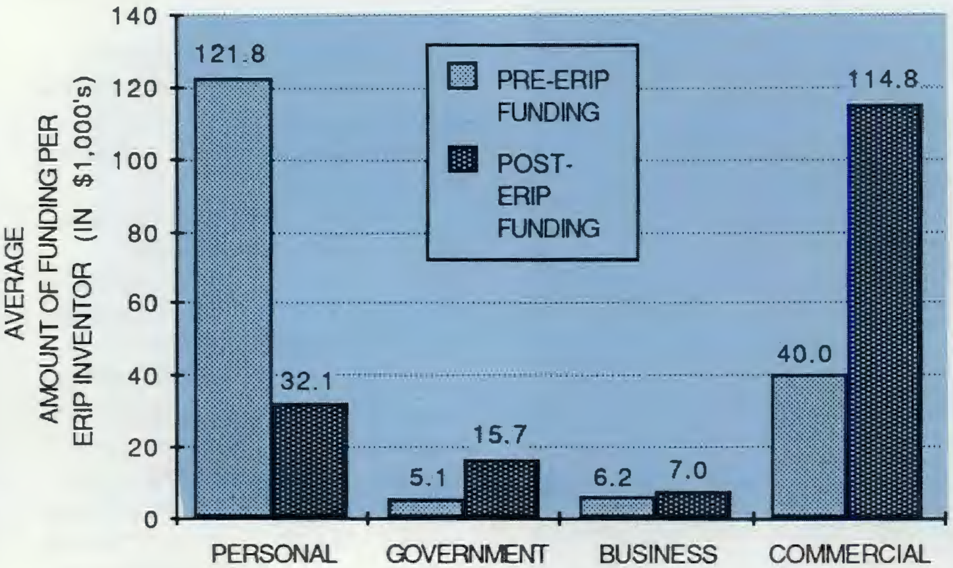
Technology transfer barriers. Transfer of the results of federal research and development (R&D) to the private sector has been hampered by the separation of R&D activities from the business and marketing expertise that is so essential for successful commercialization. Cooperative R&D involving federal laboratories and private industry is, therefore, emphasized in the OBCS technology transfer program.

Transfer of energy-conserving technologies to the buildings industry has been slowed partly by the public's indifference to energy conservation issues. Thus, the program's approach to technology transfer has been to emphasize the cost, comfort, aesthetic, and other benefits in addition to the energy savings from using energy-efficient technologies. Through a variety of subcontractors, the EATT Group has developed software and user-friendly decision tools that make it easier for the buildings industry and consumers to compare the energy costs of alternative building technologies.

Finally, transfer of building conservation technologies has been hindered by the fragmented nature of the buildings industry. The multiplicity of decision makers (e.g., manufacturers, designers, contractors, code officials, and occupants) creates numerous problems, including the misplaced incentives that arise because users of building technologies are often not the decision makers. Thus, our outreach activities are tailored closely to the particular needs of different market segments and decision makers.

Program results. In carrying out the OBCS technology transfer program, ORNL is assisted by many universities, trade associations, professional organizations, and other groups. Some of the more successful results of these cooperative efforts are:

• Two decision-making tools—SOLAR 5, a microcomputer-based design tool that received a 1986 *Progressive Architecture* citation for excellence, and ASEAM-2, a public



This figure illustrates the shift from personal to commercial support for innovation and documents the minimal role of other potential sources of funding for inventors. The data are based on a sample of 204 small business and independent inventors supported by the Energy-Related Inventions Program (ERIP).

domain microcomputer program that provides energy performance calculations for commercial and multifamily buildings

• Annual institutes for architecture and engineering school faculty that have been attended by faculty from more than 90% of U.S. schools of architecture and a majority of U.S. mechanical engineering programs

• An annual Design + Energy National Student Competition that has become the most widely subscribed student design competition in American history, attracting more than 12,500 student participants since its inception in 1981.

• Articles in numerous trade publications that highlight practical aspects of OBCS R&D results.

Energy-related inventions. Through research on the processes by which new technologies are commercialized, we have gained insights that help us design effective technology transfer activities for OBCS and other sponsors of the EATT Group. One particularly useful research project was recently completed by Jon Morell, Sherri Snell, Bill Friggle, Jon Soderstrom, and me. We updated and expanded on previous ORNL evaluations of the federal Energy-Related Inventions Program (ERIP)—a program established in 1976 to facilitate the development of nonnuclear, energy-related inventions, particularly by individuals and small businesses. ERIP is operated jointly by DOE's Office of Energy Utilization Research and the National Bureau of Standards. As part of the evaluation, data were collected from 204 inventors who had been supported by ERIP grants or other assistance.

Of these 204 inventions, 70 had entered the market by 1985. Some of the more commercially successful buildings technologies supported by ERIP are the multilayer insulating window shade; combination air-conditioning and fire-sprinkler system; strap insulation system; nonlight emitting fluorescent tube; low-energy icemaking apparatus; insulated garage door; and direct-contact, gas-fired hot-water heater. From 1980 through 1984, the 70 inventions generated sales exceeding $200 million, providing a return of $18 for every $1 from ERIP grants.

For those inventors who achieved sales, we found that the average time from project start to first sale is six years (three years before entry into ERIP and three years after). All inventors said the greatest difficulty was making the transition from prototype development to production and marketing. Our study also revealed that sales per invention are greater for licensed inventions than for inventions sold directly by the inventor's company. These findings suggest the need to educate inventors in effective marketing, development of business plans, and other ways to encourage commercialization and maximize profits.

Our data on fund-raising by inventors show a strong need for programs like ERIP. Although the average amount of money that inventors received from commercial sources was about $150,000, a majority of the inventors raised no more than $10,000 individually from such sources. Inventors dig deeply into their own pockets to finance the initial development of their technologies, but these personal funds diminish quickly. Only a small number of the inventors attract commercial funding—usually many years after prototype development (see figure).

The technology transfer efforts of the EATT Group and programs such as ERIP are examples of effective means of translating R&D results into commercial applications to improve the energy efficiency of buildings and other sectors of the economy. Efforts such as these help the nation better exploit the vast economic potential of its R&D results.—*Marilyn A. Brown, Energy Division.*

George E. Courville is program manager for the Building Thermal Envelope Systems and Materials Program in ORNL's Energy Division, where he has worked since joining the Laboratory staff in 1980. A native of Montana, he obtained his B.S. degree from Montana State College, M.S. degree from the University of Pittsburgh, and Ph.D. degree from Stevens Institute in New Jersey, all in physics. From 1964 to 1980, he worked at Fairleigh Dickinson University, initially in plasma physics and gaseous electronics and later in energy resources and energy policy. At the university, he served as chairman of the physics department for three years and spent a year as acting college dean and six months as acting campus provost. From 1977 to 1979 he had an Intergovernmental Policy Act appointment to the Department of Energy in the Office of Buildings and Community Systems. At ORNL, where he is a senior scientist, Courville manages a collection of programs dealing with walls, roofs, foundations, and building materials. His research has focused on thermal performance of roof systems and buildings applications of infrared thermography. Recently, he was appointed a member of the board of directors of the Building Thermal Envelope Coordinating Council of the National Institute of Building Sciences. Here, the author (left) and Phil Childs discuss a computer program for modeling the thermal performance of an insulated roof.

Raising Roofing to a Science: *ORNL's Roof Research Center*

By GEORGE E. COURVILLE

DOE's Roof Research Center, a national user facility at ORNL, permits studies of ways of upgrading roofs to reduce heat losses from buildings. Researchers are focusing on methods of increasing the thermal efficiency, durability, and service life of low-slope roofs. So far they have developed a new method for field determination of the thermal resistance of roofs and validated a surface-reflectance model by demonstrating that black roof membranes reduce building heating costs in winter and white membranes reduce cooling costs in the summer.

Through a new national user center established by the U.S. Department of Energy at Oak Ridge National Laboratory, roofing is being raised to a science. The new Roof Research Center (see Fig. 1) permits scientists and engineers to focus on serious problems in this engineering field that affect us all. In addition, this facility, the 12th of ORNL's 13 user facilities, brings to the Laboratory a new interpretation of the concept of national user centers.

The Roof Research Center was conceived out of a need to improve the thermal efficiency of low-slope roofs—that is, reduce heat losses from buildings to save energy and money—while maintaining durability and a long service life, all at competitive prices. DOE is particularly interested in thermal

Fig. 1. The Roof Research Center (three buildings in foreground) will be used for collaborative DOE-industry projects that are jointly funded. In this respect, the Roof Research Center differs from other user facilities at ORNL, which are available for use by non-DOE researchers as guests of DOE.

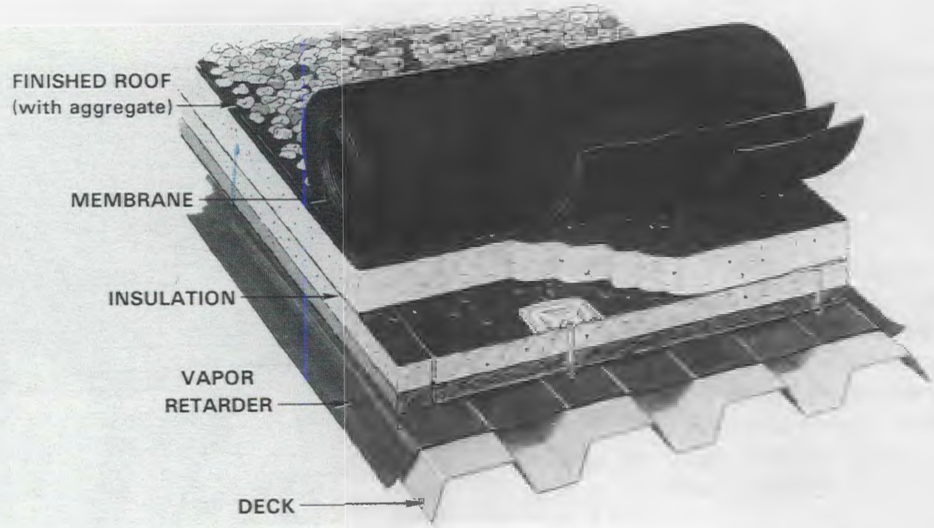


Fig. 2. This state-of-the-art, built-up roof is energy efficient. It has thick, rigid-board insulation that is mechanically fastened to a steel deck to prevent wind uplift.

efficiency, and the roofing industry is interested in durability and longevity.

Before the mid-1970s, roofing problems were rather narrowly focused. Nearly all low-slope roofs were built-up roofs. This roof type consists of a concrete, wood, or metal deck built over a superstructure with a single, thin layer of rigid-board fiberglass, perlite, or fiberboard insulation to provide a smooth surface for the roof's waterproofing membrane. The membrane is made of several layers of coal-tar-pitch or asphalt bitumen alternating with layers of felt material. The bitumen provides the waterproofing, and the felt provides the tensile strength to maintain the integrity of the system. Long experience had raised roofing to an art form that incorporated redundancies to strengthen weaknesses and included special procedures for handling each kind of weather condition, each kind of penetration (e.g., pipes and equipment mounts), and each kind of termination (e.g., parapets and penthouses). State-of-the-art, built-up roofs have energy-efficient, thick insulation boards mechanically fastened to a steel deck to prevent wind uplift (see Fig. 2).

Roofing and Energy Crisis

The roofing industry began to change rapidly in the 1970s. Because of the rising petroleum prices and dwindling oil supplies, asphalts (which are residues of petroleum refining) became expensive and their composition was less reliable. Also, the use of insulations soared because of the growing need to cut heating and cooling costs in buildings. Single-sheet rubber membranes, introduced by the chemical industry in the 1960s as new applications of its synthetic rubber products, became more cost effective than built-up roof membranes, and new, inexpensive, lightweight plastic foam insulations (polyurethanes and polystyrenes) began to take a share of the market from the more traditional fiberglasses, fiberboards, and perlites.

By 1982 it was estimated that more than 400 new products (see Fig. 3) were being used on roofs even though their performance had not been adequately tested. In 1986 it was reported that foams' share of the roof insulation market exceeded 60%, up from negligible amounts only 10 years earlier. This rapid growth has caused many problems in design and application: every seam in a rubber membrane must be perfect; every rubber membrane requires unique sealants; lightweight rubber and plastic roof systems require new and more complex fastening techniques in heavy winds; and durability tolerances need to be more exact because the margin of error is reduced in less-redundant plastic and foam systems. To compensate for problems, roofers altered their installation techniques and manufacturers changed their product formulations, producing even more configurations and further increasing confusion over which combinations of products give durable roof systems.

Against this background, in 1984 I introduced the concept of a Roof Research Center, and DOE agreed to support the idea. The principal objectives of the center are to develop a scientific basis for roofing; identify controlling performance parameters that describe the fundamental processes

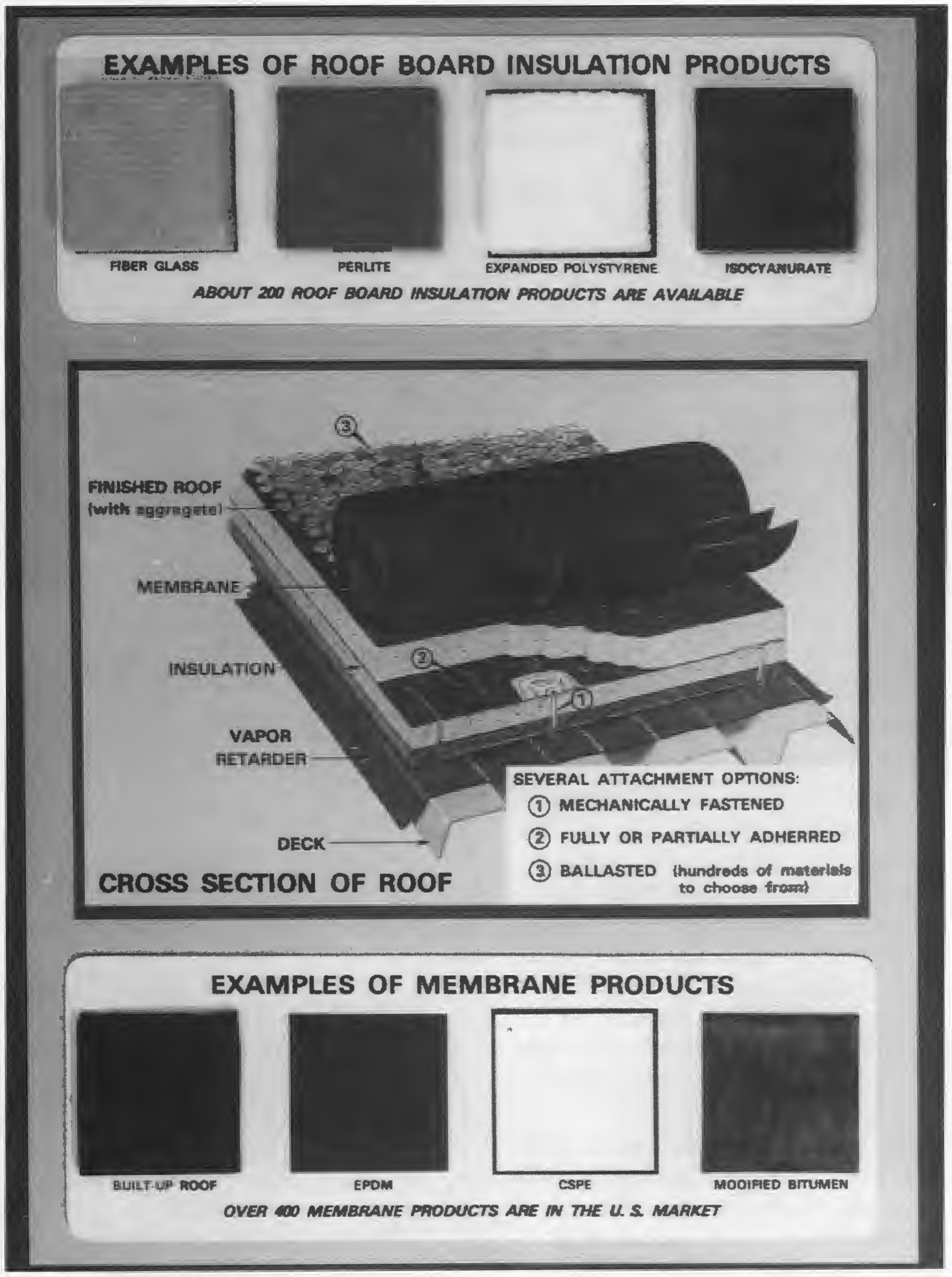


Fig. 3. Problems affecting U.S. roofs that will be explored at ORNL are the extreme range of weather conditions and incompatibility of some of the many materials available for roof components.

of roof waterproofing, insulation, and structural stability; describe the systems behavior that defines material compatibility; and identify and develop measurement procedures for properties that ultimately determine how materials should be formulated and installed to ensure that the roof is durable and energy efficient (Fig. 4).

More pragmatically, one goal of the center is to work toward doubling the average insulation in roofs, from an R-value of 8 to an R-value of 15. (The R-value describes the ability of a material to resist or retard the flow of heat, which tends to migrate from warmer to cooler areas; the higher the R-value, the greater the insulating value of the material.) A recent ORNL study for the U.S. Air Force has shown that doubling the roof R-value is cost effective.

Another goal is to increase the average lifetime of low-slope roofs from a range of 8 to 12 years to 14 to 18 years (by comparison, building lifetimes exceed 50 years). A third goal is to increase the average operational thermal efficiency of roofs from 80% of design value to 85%; because wet insulation lowers thermal efficiency, the key to raising efficiency is to prevent leaks, which currently affect a quarter to a third of all low-slope roofs. If these goals could be reached in a majority of new U.S. roofs by the year 2010, about 0.7 quadrillion Btu (quads) of building energy would be saved.

Climate Simulator

The principal pieces of equipment at the Roof Research Center are the Large-Scale Climate Simulator (see Fig. 5), which will be operational in early 1988, and the Roof Thermal Research Apparatus, which has been in use since December 1985. The design and construction of both facilities was carried out at ORNL under the leadership of W. R. Huntley of the Energy Division.

Staff members at the center include George Courville, Dick Huntley, Paul Shipp, and Phil Childs of ORNL's Energy Division; John Sanders of the Engineering Technology Division; Jim Hardy of the Instrumentation and Controls Division, who is responsible for instrument maintenance; and consultants Ed Griggs of Tennessee Technological University and Jim Beck of Michigan State University. The team gives the center expertise on heat and mass transfer, roofing and building performance, experimental design, and mathematical modeling.

The climate simulator (see Fig. 6) consists of two environmental chambers having a common side that has a 12-ft by 12-ft (3.6-m by

3.6-m) opening, which allows test specimens to be placed horizontally between them for systems performance tests. Each chamber can be independently controlled to hold constant temperature, pressure, and humidity across each roof specimen or to vary these parameters to simulate real weather conditions.

Large environmental chambers for conditioning roof sections exist at two laboratories in the United States: Tremeo Roof Products, Inc., and Manville Service Center. The ORNL facility, however, is the only one in which continuous performance measurements will be carried out as test conditions are varied. In the climate simulator, multiple experiments will be carried out except during brief down times for specimen change. The tests will require careful designing of experiments. Specimen transfer is achieved by the "diagnostics platform" concept in which test specimens are assembled, instrumented, and pretested before being brought to the climate simulator (see Figs. 7 and 8). In the example, four test specimens are mounted in one platform. All the diagnostics wiring is internal to the diagnostics platform and connects to a single terminal board that is connected to an umbilical cable. This cable first connects the specimen to a portable floor computer for pretesting. When the platform is installed in the climate simulator, it will be connected to the main system computer.

Experiments planned for the climate simulator will provide information of interest to both DOE and industry. Some of these interests will overlap, but some differences in their information needs are expected. For example, DOE will be interested in the effects on roof thermal performance of different types and

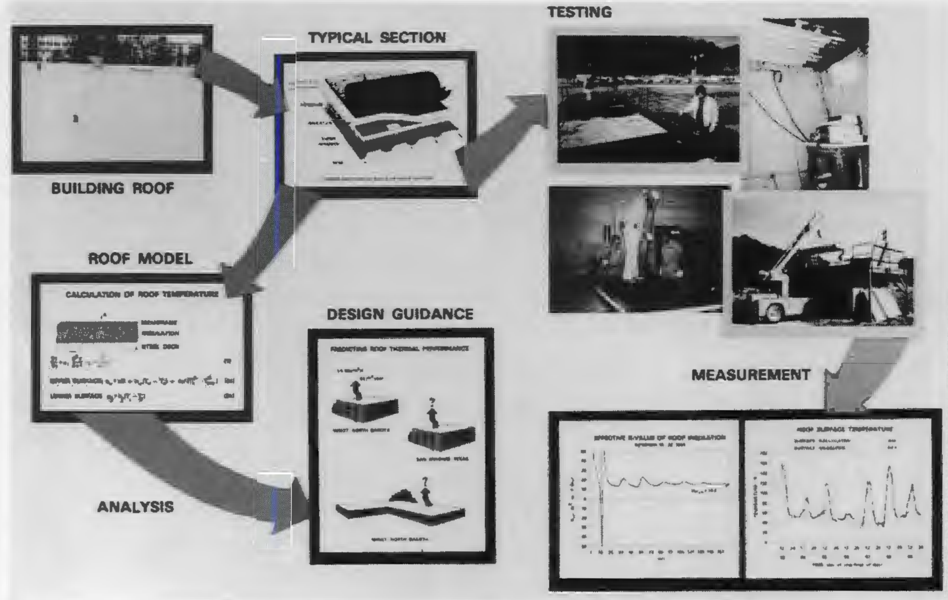


Fig. 4. Results from DOE-sponsored roofing research at ORNL should provide an improved scientific and technical basis for the design and construction of energy-efficient roofs.

amounts of insulation under different weather conditions. Industry, on the other hand, will be more eager to learn which roofing configurations reduce the number of roof failures and improve material compatibility.

One early experiment, for example, will deal with the issue of stress transfer from a roof membrane to the skeletal structure of a building. Membranes, both asphaltic and rubber, can have relatively large thermal expansion coefficients—that is, compared with most materials, they can expand considerably in response to only slight increases in temperature. Before the use of thick insulations, membranes were physically adjacent to the roof deck, and temperature variations and expansions and contractions resulting from environmental changes were respectively constrained by high heat transfer into the building and by relatively low expansion coefficients of high-density roof deck materials. In an energy-efficient roof, however, the membrane is both insulated and isolated from the deck by insulations that typically have a high thermal resistance and a low mechanical modulus—that is, they readily move when a force is exerted. Thus, in membranes over thick insulation, it is reasonable to expect greater movement and greater temperature variations.

Measurements at ORNL show that the surface temperature of a black membrane underlain by 5 cm (2 in.) of fiberglass insulation varies from about 10°F below the coldest air temperature to about 180°F on hot summer days and that the surface temperature changes by 30 to 40°F per hour on any sunny morning or afternoon.

The important issue in this case is whether using insulation accelerates deterioration of the membrane. If so, the impact on energy conservation strategies for roofs could be devastating. The lack of reliable material properties, the relative complexity of roof systems, and the unavailability of good models make it necessary to address this issue through experiments.

Roofing Insulation

Other aspects of thick insulations will also be studied at the Roof Research Center.

Fig. 5. Childs checks the progress of the construction of the Large-Scale Climate Simulator in the Roof Research Center.

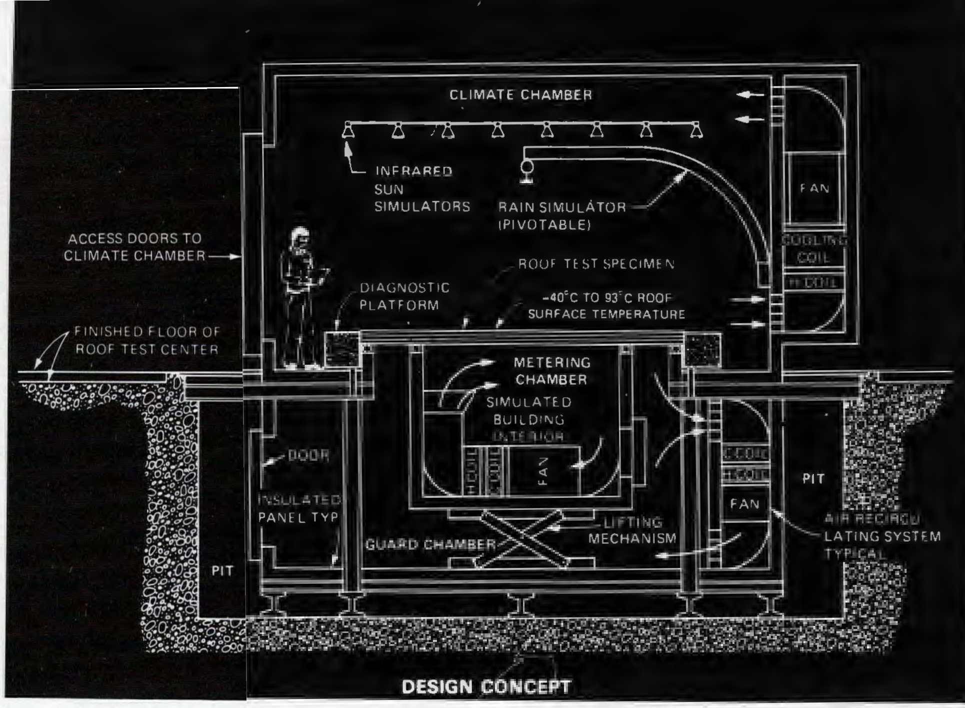


Fig. 6. Design concept of the Large-Scale Climate Simulator.

Researchers have measured the thicknesses of different roof insulations that are required to achieve a desired R-value. As mentioned earlier, a recent life-cycle cost study of roofs has shown that, at current prices, R-values of about 16 are probably cost effective. Thicknesses for commonly used roofing insulations required to achieve this R-value are: polyisocyanurate foam—2.7 in. (6.9 cm); fiberglass—4.0 in. (10.2 cm); expanded polystyrene foam—4.2 in. (10.7 cm); and perlite—5.8 in. (14.7 cm).

Currently, polyisocyanurate is the insulation of choice in the industry because it is lighter and less expensive than most other insulations and, because of its low thermal conductivity, less of this insulation is required to achieve a desired R-value. The very reason for this insulation's success, however, is also a source of considerable concern. Isocyanurate is a thin-wall, closed-cell foam insulation. The principal foaming agent (CFC-11) is a chlorofluorocarbon that remains trapped in the foam cells and, because of its low thermal conductivity, enhances the foam's thermal insulation properties. However, diffusion of air into the cells results in a lowering of the thermal resistance of the foam with time (aging), which reduces the insulation's competitive advantage over other insulations. CFC-11 is also high on the Environmental Protection Agency's "hit list" of chemicals that can reduce the concentration of ozone in the upper atmosphere, thus allowing more ultraviolet light from the sun to reach the earth, increasing the risk of human skin cancer. Hence, research is needed to find ways to slow aging in foam insulations, to lessen the releases of CFC-11, and to develop a foaming agent to replace CFC-11 in foams that has its advantages but not its defects.

Roof Thermal Research Results

The Roof Thermal Research Apparatus, the second major test facility (see Fig. 9) in the Roof Research Center, provides an in situ test bed for four 4-ft by 8-ft (1.2-m by 1.2-m) roof panels. One side of each panel is exposed to an inside environment, the other to local weather. Depending on the test, panels can be instrumented for temperature, moisture, and measurements of material movements under stress. All sensors are connected to an automatic data acquisition system for data processing, storage, and analysis.

The Roof Thermal Research Apparatus (see Fig. 10) is being used to develop thermal performance measurement packages for field use. We have already developed a new method for field determination of the thermal resistance of roofs. The apparatus is also used to conduct experiments to help validate two roof performance models. One model attempts to determine the effect of heat-reflecting surfaces on roof performance under different climate conditions to test the claim that surface reflectance is a significant energy saver. The other model predicts the thermal effects of adding high-mass materials to the exterior surface of roofs—a common practice for reducing damage from wind and foot traffic that may have thermal benefits. Validation work on the first model is discussed below.

Using the Roof Thermal Research Apparatus in the winter and summer of 1986, ORNL researchers conducted experiments to validate the effect of surface reflectance on thermal performance (see Figs. 12a, 12b, and 12c—specific numbers refer only to this building in this climate). The study focuses on the differences between white membranes, which are high-reflectance surfaces because white generally reflects more solar radiation than other colors, and black membranes, which are low-reflectance surfaces because black absorbs rather than reflects solar radiation.

In this study, it was found that during a week in July (at the height of the Southeast's record heat wave in 1986), the temperature of the black surface routinely reached 180°F for air temperatures around 100°F and that the white surface temperature peaked at about 130°F. During the night, both surfaces cooled to a temperature about 7°F below air temperature because of radiative heat loss to the cold atmosphere. Because the amount of cooling was the same for both systems, it was concluded that the chemical formulation altering the optical color of this membrane does not affect its infrared emittance.

Cumulative heat transfer across the white- and the black-surfaced roof systems was also measured. The results for a week in March 1986 and for a week in July 1986 are shown in Figs. 12b and 12c, respectively. Positive heat flow (Fig. 12b) represents heat loss when the building interior, on the average, is warmer than the outdoor air. Negative heat flow (Fig. 12c) represents heat gained by the building when the outdoor air is warmer than the air within. In the former case the heat loss is greater under the white roof, suggesting that it costs more to heat a building under a white roof in the heating season. On the other hand, Fig. 12c suggests that the summer heat gain is greater for a building under a black roof. Thus, the air conditioning costs for a building having a black roof are higher.

Are these differences in heat losses and gain significant? For a 200-ft by 200-ft (61-m by 61-m) roof

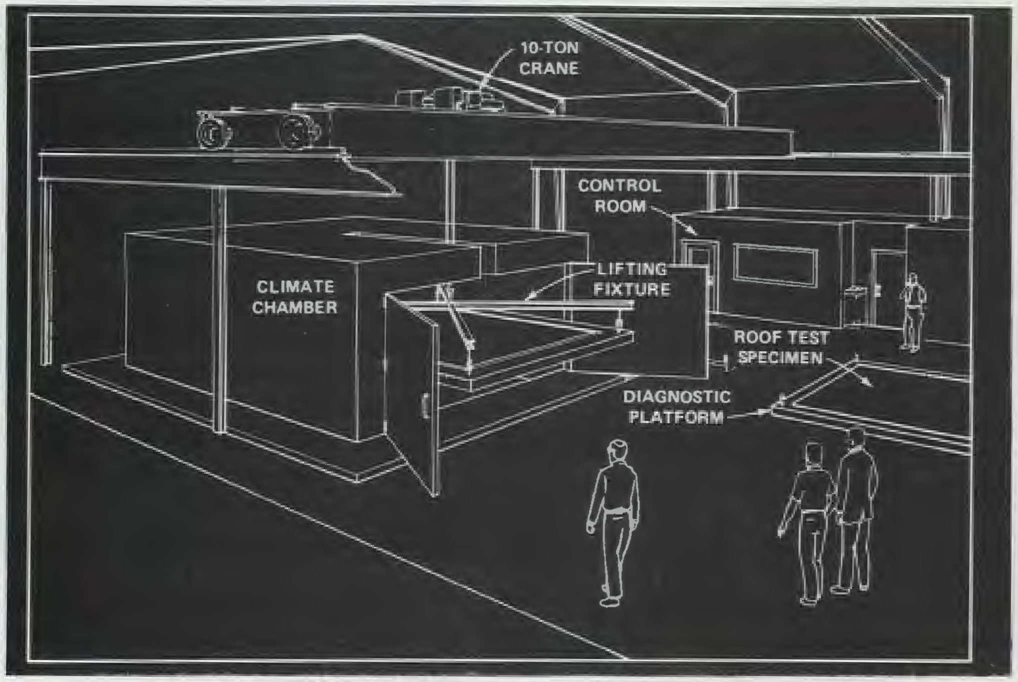


Fig. 7. The Large-Scale Climate Simulator at ORNL's Roof Research Center is designed to test the performance and durability of roof test sections. Each of the two chambers can be independently controlled to hold constant temperature, pressure, and humidity across each roof specimen or to vary these parameters to simulate real weather conditions. The ORNL facility, which will be operating in 1988, is the only one in which continuous performance measurements will be carried out as test conditions are varied.

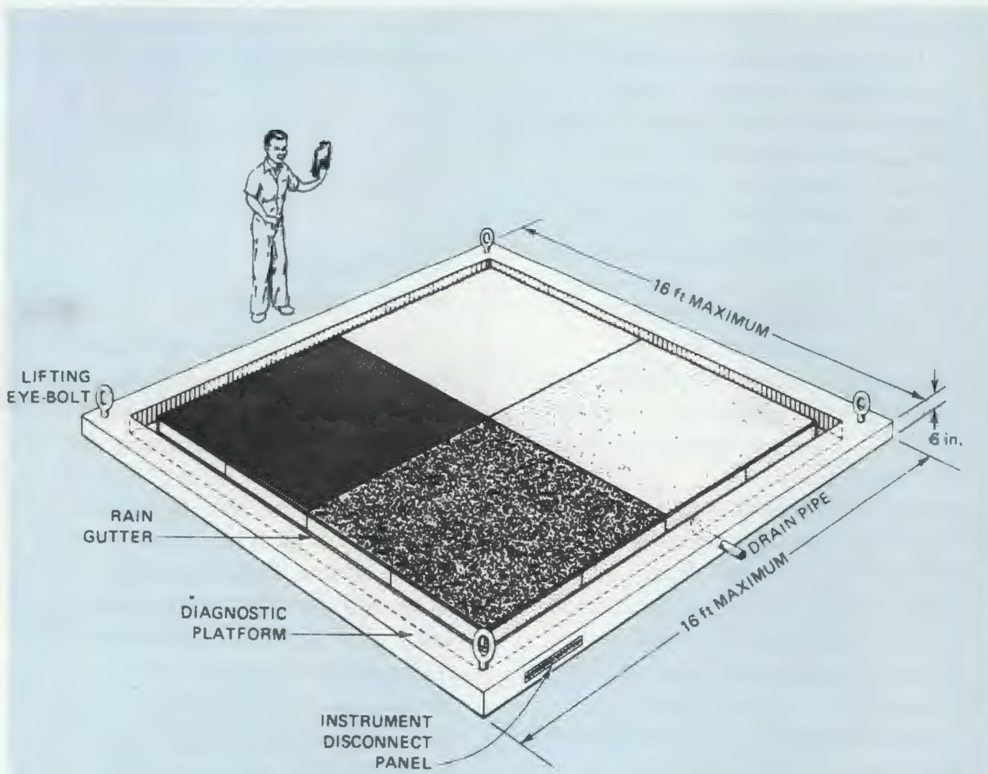


Fig. 8. Four different roof specimen surfaces can be installed on a diagnostic platform of the Large-Scale Climate Simulator at the Roof Research Center, as shown in this schematic.

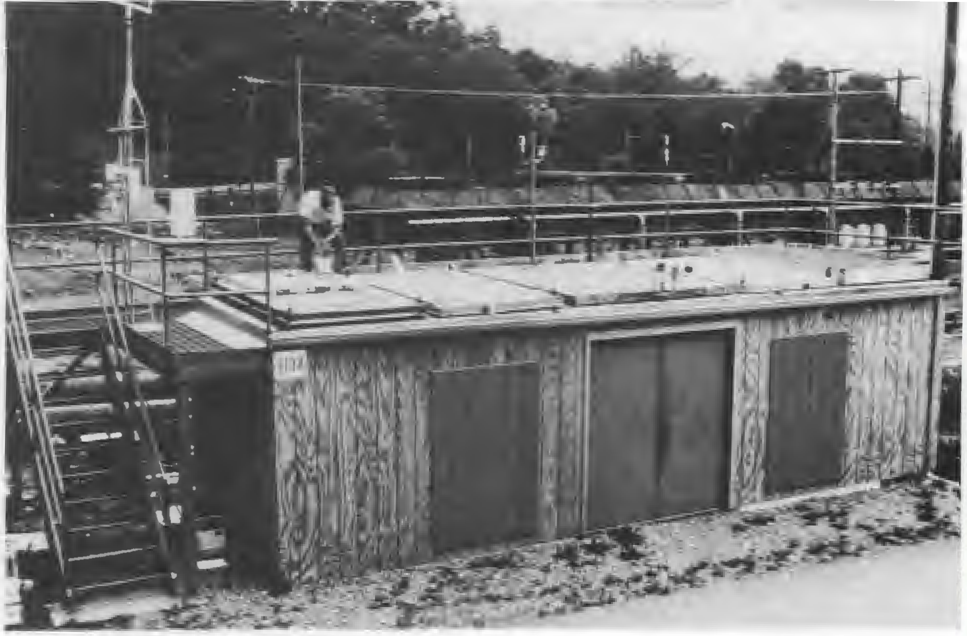


Fig. 9. Dick Huntley, who led the design and construction of the Roof Research Center and Large-Scale Climate Simulator, examines the different roof surfaces now being tested at the Roof Thermal Research Apparatus. The devices to the right indicate wind speed and direction.

Fig. 11. Dick Huntley (center), who led the design and construction of the Roof Research Center, shows the blueprints for the facility to, from left, Courville, Carlsmith, Shipp, and Childs.

over a building having electric resistance heating and summer air conditioning (coefficient of performance = 2) and using TVA industrial rates, ORNL researchers calculated that the March heating difference would save $120 in heating costs for the week if the roof were black and that the July difference would save $120 in cooling costs for the week if the roof were white. Which membrane saves more energy and money for the whole year? The answer in this case depends on a great many factors, especially the relative lengths of the heating and cooling seasons. We will have more results when other experiments are completed. The model that we are

Fig. 10. Roger Carlsmith (left), director of ORNL's Conservation and Renewable Energy Program, discusses plans for the Roof Thermal Research Apparatus with Paul Shipp and Childs.

validating will be able to extend the results obtained to other buildings at other sites.

User Facility

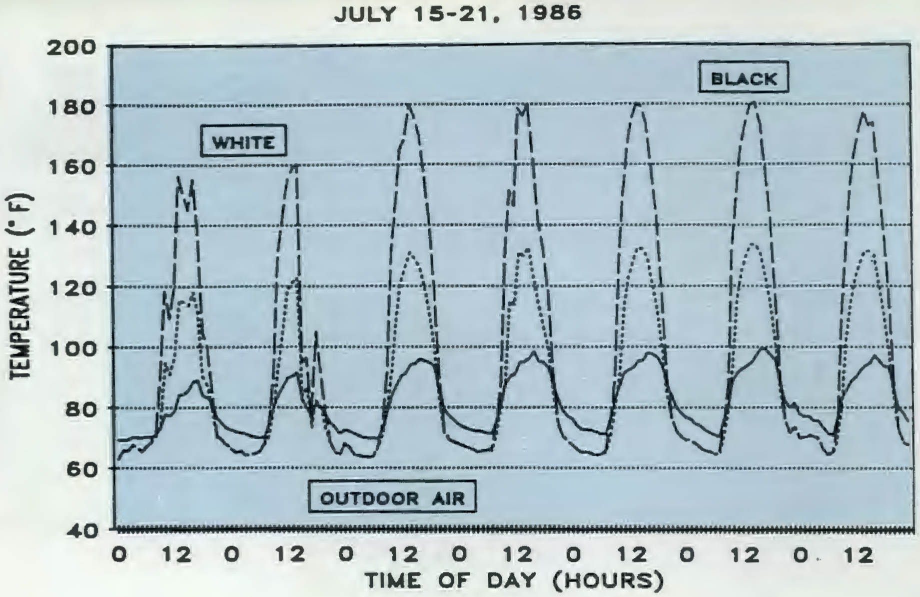
In January 1986 DOE designated the Roof Research Center as a national user facility and ORNL named me acting manager. To prepare for industrial use of the facility, an Industry Advisory Panel has been created and a users' manual for the Center has been drafted. In June 1986 Paul Shipp was appointed the first manager of the center.

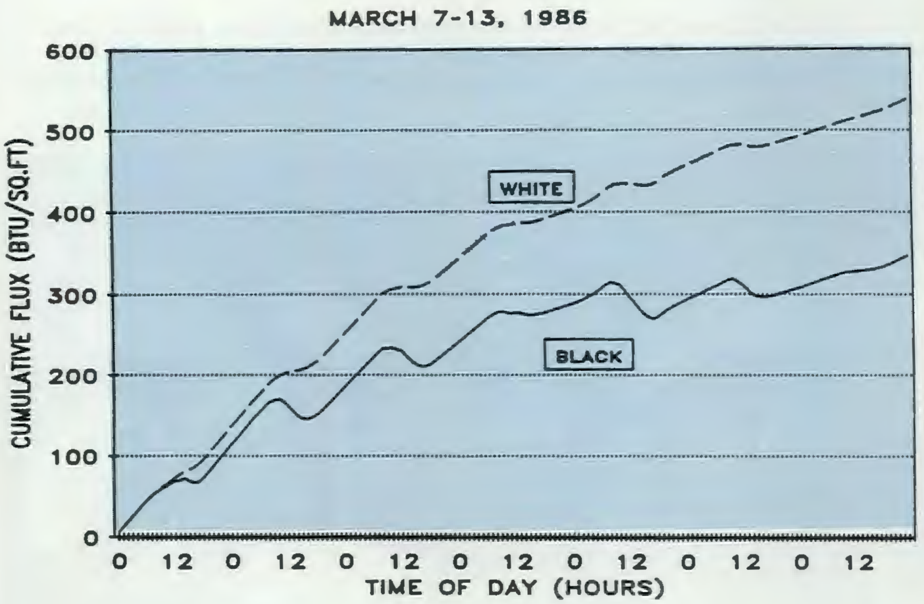
As is the case at other national user facilities at ORNL, the Roof Research Center (see Fig. 11) will be available for use by non-DOE researchers as guests of DOE. More frequently, however, the center will be used for collaborative DOE-industry projects that are jointly funded. In this respect, the Roof Research Center differs from other user facilities.

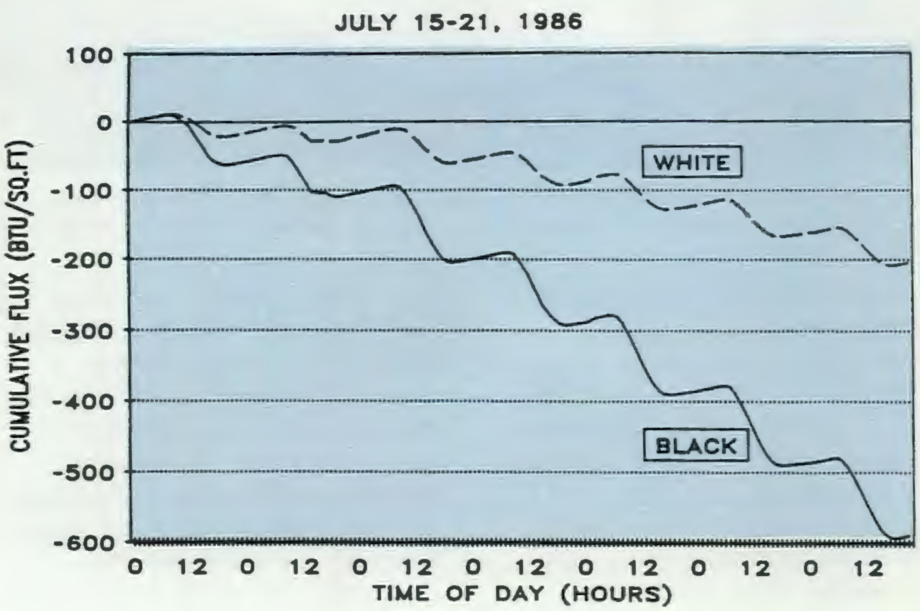
The reason for operating the center this way is that increased insulation, longer lifetimes, and improved performance of roofs are goals not only of DOE but also of industry. Like DOE, industry should benefit directly from work at the center and therefore should share in the costs.

The Industry Advisory Panel has been established to oversee the

Figs. 12a, 12b, and 12c. In this study comparing heat gains and losses for black and white roof surfaces, it was found that during a week in July (at the height of the Southeast's record heat wave), the temperature of the black surface routinely reached 180°F for air temperatures around 100°F and that the white surface temperature peaked at about 130°F. During the night, both surfaces cooled to a temperature about 7°F below air temperature because of radiative heat loss to the cold atmosphere. Cumulative heat transfer across the white- and the black-surfaced roof systems was also measured. The winter heat loss is greater under the white roof (Fig. 12b), suggesting that it costs more to heat a building under a white roof in the heating season. Fig. 12c suggests that the summer heat gain is greater for a building under a black roof. Thus, the air conditioning costs for a building having a black roof are higher.

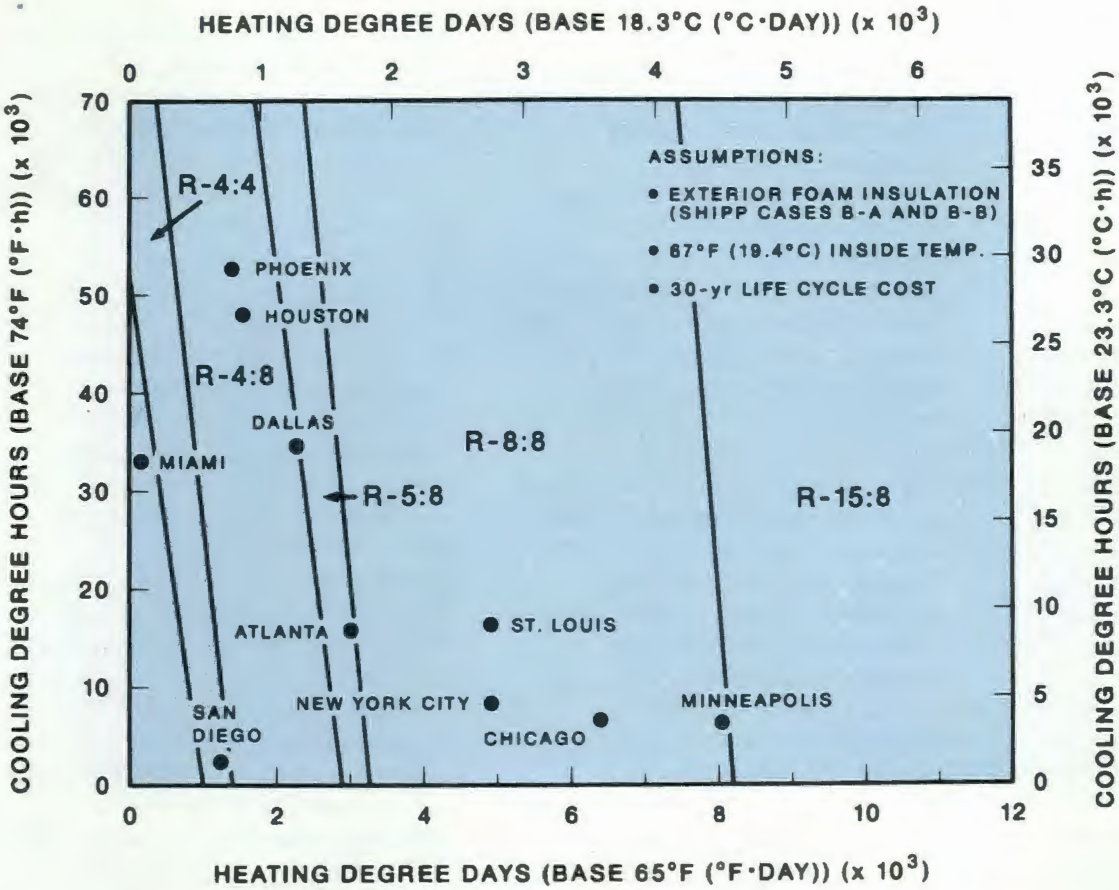






industry interest in the center. The Panel's role will be to evaluate industry proposals, to recommend priorities to the director of the center, and to review research results to ensure that high technical quality is maintained and that significant industry issues continue to be addressed.

At a recent meeting of the U.S. government Interagency Roofing Research Committee, Dennis Firman, manager for roofing maintenance programs in the U.S. Air Force, said: "The roofing industry is always telling us that roofing is an art and not a science. The Air Force is tired of buying artwork." The time seems to be right to bring science to roofing. Too many problems have accumulated and too many products are on the market to rely on trial-and-error experiences for answers. Generalizations are needed to categorize problems, solutions, and products, and mathematical models are needed to define optimum roof systems and to predict the behavior of new concepts. With the availability of the Roof Research Center, ORNL is in a position to provide the necessary leadership to raise roofing to a science. ornl



Optimum foam board insulation levels (R-values) for deep concrete and masonry basement walls.

Foundations for Building Energy Efficiency:

The Insulation Question

Building foundations are an important and integral part of the thermal envelopes of buildings. In most buildings the proportion of the surface of a building in contact with the ground vs the outside air is substantial, as much as 45% for a one-story residence having a full basement. The earth, for most of the year, presents a more benign thermal climate and undergoes smaller temperature fluctuations than the outside air over most of the continental United States. Thus, a properly constructed foundation should help maintain comfortable temperatures in buildings.

The ability of foundations to block heat flow has long been considered less important than other features in ensuring personal comfort and meeting building energy requirements. However, this picture has changed significantly. The aboveground envelopes of buildings have been insulated and tightened to the extent that uninsulated foundations no longer are responsible for only 10 to 15% of building heat loss. In fact, in some climates the measured heat loss through foundations has been as high as 60% of the total building heat loss.

Concerns about moisture, which can degrade structural integrity; about levels of radon, a cancer-causing radioactive gas that seeps into buildings from underlying soil; and about suprisingly high losses from ducts located in basements, slabs, and crawl spaces have also aroused interest in and highlighted the importance of properly built foundations. A recently completed study by Canada Mortgage and Housing Corporation in Ottawa, Ontario, reported a significant portion of the moisture in some buildings comes from the ground. ORNL researchers have found that for homes having concrete basement slabs and high indoor radon levels, a vent pipe through the slab and an exhaust fan can lower radon concentrations by depressurizing the space beneath the slab, thus preventing the radon-rich soil gas from flowing into the basement.

Of the millions of residential buildings in the United States, less than 5% have insulated foundations. Less than 30% of new homes under construction have foundation insulation. A recently completed study done for ORNL by a Martin Marietta Energy Systems, Inc., subcontractor assessed energy savings of foundation insulation. The University of Minnesota Underground Space Center concluded that an estimated 0.5 quads of primary energy could be saved per year by moderate levels of foundation insulation.

To help the Laboratory and the Department of Energy plan, review, and transfer foundation research results, ORNL has formed a joint private-public sector panel. This panel helps ensure the relevance of the research activities and helps transfer results to the building associations and foundation-material manufacturers who need answers. Panel members represent a diversity of public and private organizations in both the United States and Canada: insulation manufacturers such as Dow Chemical and Owens-Corning Fiberglas; foundation construction material and system suppliers such as Forest Products Industry; the National Association of Home Builders; architect-engineer firms; construction contractors; universities such as the University of Minnesota, University of Alaska, and University of Alberta; other national laboratories such as the National Bureau of Standards, Lawrence Berkeley Laboratory, and the National Research Council of Canada; and a number of federal agencies such as DOE, the Environmental Protection Agency, the Department of Housing and Urban Development, and the Department of Defense.

ORNL actions. The first task the panel suggested to ORNL's foundation program, which is sponsored by DOE's Buildings and Community Systems, is to raise the awareness of the importance of foundation construction features that provide thermal insulation. As a result of our studies, we recommended R-values specified for all climates in the United States for basement walls, crawl space walls, slab-on-grade edge, and floors above unconditioned spaces. When we submitted this foundation insulation recommendation to the national residential energy standards committee of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE 90.2), we noted that this insulation is as cost effective as recommended above-grade insulations (see figure, which is an example of the form of the foundation insulation recommendations).

Energy standards of the past either ignored the need for foundation insulation to completely seal the thermal envelope or were based on overly simplified assumptions of the three-dimensional heat flow around building foundations. ORNL staff members have prepared technical papers and general-interest articles to counter these misconceptions and to guide designers and builders in selecting cost-effective insulation thicknesses and combinations. The advantages of alternative insulation strategies are discussed and, in some cases, quantified in terms of energy savings.

A tool being developed for ORNL by the University of Minnesota Underground Space Center and Ken Labs of Undercurrent Design is a comprehensive *Building Foundation Design Handbook*. This book discusses not only thermal design aspects but also integration of structural features, waterproofing, radon mitigation measures, termite control, and subdrainage with foundations. The 400-page document covers about 200 foundation construction details and should be a useful reference for progressive-thinking builders.

Insulate inside or outside? Because of design considerations such as structural integrity, measures to reduce indoor radon levels, waterproofing, and subdrainage, we recommend that foundation insulation be placed outside masonry and concrete walls. Yet most of the few builders who insulate foundations install the insulation inside. Properly insulating outside is more difficult, yet the benefits to the overall building—reduced heat losses, lower influx of radon, and resistance to moisture—seem to outweigh the added cost. However, builders are unlikely to alter past practices unless convinced that the rewards for the added effort of change will be fewer callbacks and more building contracts.

Meanwhile, experimental measurements are needed to complement the information available from foundation thermal performance simulation models and the design handbook. ORNL plans to use the foundation of the Roof Thermal Research Apparatus at the Roof Research Center to measure the thermal performance of slab-edge insulation. The information will be used to check the accuracy of results calculated by ORNL's foundation thermal performance model. For the long term, we plan to have a dedicated facility equipped to test the energy efficiency of basements, crawl spaces, and slabs-on-grade having various degrees of foundation insulation. *—Jeff Christian, Energy Division.*

The Joint Institute for Heavy Ion Research, ORNL's earth-sheltered, energy-efficient building, provides living and working space for visiting nuclear physicists.

ORNL's Earth-Sheltered Building Results Guide Foundation Research

ORNL's Joint Institute for Heavy Ion Research, which was built in 1981, is a special building. An office building and dormitory for visiting nuclear physicists, it is an innovative earth-sheltered building having grass growing on the roof. The building is unique because it was designed at ORNL (by architect Hanna Shapira) and because its energy efficiency has been the subject of ORNL research (by Jeff Christian—see "Detailed Thermal Performance Measurements and Cost Effectiveness of Earth-Sheltered Construction: A Case Study," ORNL/CON-186). The experience gained from this research has influenced ORNL's current studies of building foundations.

Earth-sheltered buildings are an acceptable form of energy-efficient construction. The technique is particularly popular in tornado-belt areas. Because of their low profile and earth covering, these buildings blend more naturally into the environment. Our studies show that

Earth-sheltered buildings like ORNL's Joint Institute for Heavy Ion Research use about 70% as much energy as aboveground buildings of the same size and construction type. However, the construction expenses must be reduced to make this technique cost effective for energy-efficient homes.

earth-sheltered buildings use about 70% as much energy as aboveground buildings of the same size and construction type. However, the construction expenses will have to be reduced to make this technique cost effective for energy-efficient homes.

ORNL studies of building's energy efficiency. From 1983 to 1985, I studied the Joint Institute's energy efficiency and cost effectiveness using hourly measurements of temperature, heat flux, and soil moisture. The quantitative analysis of the results confirmed that earth-sheltered construction can indeed reduce energy use. To maintain the inside temperature year-round for 24 hours a day between 68°F and 79°F, the Joint Institute, which has about 4000 square feet of floor area, required only about $675 worth of electricity (at 5 ¢/kwh) in a year. By comparison, an aboveground building having the same size and masonry construction would use an estimated $900 worth.

Besides the overall thermal performance of the building, we also documented the effectiveness of the earth-covered roof and bermed north wall (covered by a grassy slope). The effective R-value—measure of resistance to flow of heat—of the bermed wall is about 60, even though the wall's insulation is only foam board having an actual R-value of 15.

Energy use in the ORNL building is also low because of passive solar gain and extensive amounts of interior thermal mass. The net energy savings from all the thermal mass in the exterior walls, partition walls, floor, and roof amount to about 14%. In other words, if the building were constructed of lighter-weight wood frame, it would have required 14% more energy to maintain the equivalent level of thermal comfort.

The Joint Institute is designed to make intensive use of all space for energy efficiency and the comfort of the occupants. For example, offices on the south side were designed both to collect solar energy for heating and to permit high-quality daylighting on visiting scientists' desktops.

ORNL blinds. ORNL-developed reflective insulating blinds were installed in this building to direct the bright light to the ceiling. The daylighting features work well. The nighttime insulating capabilities of the blinds are less impressive because of the relatively large cracks formed between the ribs when they are closed.

ORNL's contributions to the earth-sheltered building business have included monitoring and recording the performance of this potentially energy-efficient type of construction. Many useful measurements taken in the mid-1980s will help validate earth-contact heat-transfer simulation models for earth-sheltered buildings. Such models are also useful for simulating heat loss from more conventional aboveground buildings having standard full basements, slab-on-grade, and crawl spaces. In ORNL's foundation program, we are developing more detailed heat-transfer models for simulating heat loss from foundations. The Joint Institute data will be extremely useful in helping validate these models. In other words, the Joint Institute conservation research has provided a foundation for ORNL's foundation research.—*Jeff Christian, Energy Division.*

awards and appointments

J. Robert Merriman was one of six recipients of DOE's E. O. Lawrence Memorial Award for outstanding contributions to atomic energy. Merriman was recently named ORNL associate director for Nuclear and Engineering Technologies.

For the 12th consecutive year, ORNL has earned the National Safety Council's Award of Honor for its safety performance.

Ronald A. Phaneuf has been named a Fellow of the American Physical Society. He is also a member of the editorial board of the *Journal of Physical and Chemical Reference Data.*

Peter Mazur has been selected for inclusion in *Who's Who in the World.*

R. G. Wymer has received the Robert E. Wilson Award in Nuclear Chemical Engineering from the American Institute of Chemical Engineers.

Jonathan Woodward has been appointed advisory editor of the *Journal of the Biomass Energy Society of China.*

W. D. Manly has been appointed to the U.S. Army Science and Technology Board of the National Research Council.

William G. Craddick has been appointed head of the Reactor Technology Section of ORNL's new Research Reactors Division.

Robert L. Ullrich has received the 15th Research Award from the Radiation Research Society.

Carl J. McHargue has been elected to the Board of Directors of the Metallurgical Society.

Gary Glish has been elected vice-president of the American Society of Mass Spectrometry.

Mike Maskarinec has been appointed to a national task force for the U.S. Army and U.S. Environmental Protection Agency to improve quality assurance, quality control, data management, and methods development for U.S. Army environmental programs.

The Radiation Shielding Center in ORNL's Engineering Physics and Mathematics Division received a Technical Service Award from the American Nuclear Society (ANS) for 25 years of "dedicated support and service to the international radiation protection and shielding community." **Betty Maskewitz**, head and cofounder of the Center, accepted an engraved shield from the ANS.

Roy E. Fenstermaker has been named Quality Assurance Specialist for Reactor Systems at ORNL.

The name of ORNL's Environmental and Occupational Safety Division has been changed to the Environmental Compliance and Health Protection Division, headed by **Dennis Parzyck**. The Industrial Hygiene Department, headed by **Walter Porter**, has been moved from the Health Division to the Environmental Compliance and Health Protection Division.

Thirty-four ORNL employees who were granted 1986 U.S. patents were honored at the annual Inventors' Forum Luncheon. The patent recipients are **J. E. Mrochek**, **S. R. Dinsmore**, and **E. W. Chandler** for a disc valve for sampling erosive process streams; **W. K. Dagenhart** for a neutral-particle-beam-intensity controller; **G. R. Dyer** for a direct-current-switching regulated power supply for driving an inductive load; **J. H. Whealton** and **W. L. Stirling** for a negative-ion source having a low-temperature transverse divergence optical system; **I. Sauers** for a process for measuring degradation of sulfur hexafluoride in high-voltage systems; **W. B. Jatko**, **D. R. McNeilly**, and **L. H. Thacker** for a precision linear ramp function generator; **M. K. Kopp** for a wide-range radiation dose monitor; **H. L. Martin** and **S. L. Killough** for an electromechanical actuator for the tongs of a servomanipulator; **D. R. McNeilly** for a noise isolation system for high-speed circuits; **A. J. Caputo** for a process for preparing fiber-reinforced ceramic compositions by chemical vapor deposition; **J. P. Hammond**, **S. A. David**, and **J. J. Woodhouse** for a process for forming unusually strong joints between metals and ceramics; **M. A. Janney** for a process for preparing fine-grain titanium carbide powder; **D. M. Kroeger** for a metallic glass composition; **C. T. Liu** and **J. O. Stiegler** for ductile aluminide alloys for high-temperature applications; **A. J. Moorhead** for oxidation-resistant filler metals for direct brazing of structural ceramics; **V. K. Sikka** for a method for welding chromium-molybdenum steels; **D. P. Stinton** and **R. J. Lauf** for dispersion-toughened ceramic composites and a method for making them; **J. R. Beene** and **C. E. Bemis, Jr.**, for a device for frequency modulation of a laser output spectrum; **M. M. Abraham, J. L. Boldu, Y. Chen**, and **V. M. Orera** for a method for preparing photochromic insulating crystals; **Y. Chen** and **R. Gonzalez** for refractory oxide hosts for a high-power, broadly tunable laser.

Don Jared has been reelected Southeast regional coordinator for the Federal Laboratory Consortium for Technology Transfer.

The East Tennessee Chapter of the Association for Women in Science (AWIS) presented 1987 awards to **Barbara T. Walton** for distinguished and sustained contributions to science, **Linda L. Horton** for distinguished achievements in science, and **Carolyn T. Hunsaker** for contributions to the local and national AWIS organization.

Vivian Jacobs has been re-elected secretary of the Board of Directors of the international Society for Technical Communication (STC). The 1987 officers for the East Tennessee Chapter of STC include **Jeanne Dole**, president, and **Kathie McKeehan**, treasurer.

R. J. Olson was chairman of the Plenary Session for the Conference on Integrating Data for Decisionmaking held in May 1987.

George W. Suter has been appointed to the Editorial Board of *Environmental Toxicology and Chemistry*, the journal of the Society of Environmental Toxicology and Chemistry.

Carol A. Johnson has been appointed technical assistant to Chester R. Richmond, ORNL associate director for Biomedical and Environmental Sciences.

Martin Marietta Energy Systems, Inc., honored its employees May 8, 1987, at the third annual dinner and awards presentation program at the Hyatt Regency Hotel in Knoxville. More than 100 ORNL employees received awards. The scientist of the year was **Bill R. Appleton**, the inventor of the year was **Paul F. Becher**, and the author of the year was **Jose March-Leuba**. They are among the seven Energy Systems employees who received Jefferson Cups from Martin Marietta Corporation.

Twenty-six ORNL employees received Technical Achievement Awards, which recognize excellence of employee contributions of a scientific or engineering nature to the activities of Energy Systems. The winners were **Oakland B. Adams, Jr.**, for project management contributions to both experimental and facility support activities associated with ORNL research programs; **Bill R. Appleton**, for innovative utilization of ion beam techniques for materials research, including the recent development of ion beam

At the 1987 presentation of awards by Martin Marietta Energy Systems, the winners of the special awards were, from left, L. Michael Cuddy, manager of the year; Paul Becher, inventor of the year; Jose March-Leuba, author of the year; and Bill Appleton, scientist of the year. All are from ORNL, except Cuddy, who received his award for outstanding leadership of the Oak Ridge Y-12 Plant's CIM Program, which was judged best in the United States by the Society of Manufacturing Engineers and is saving the Y-12 Plant $23 million per year.

deposition for fabricating artificially structured materials; **John B. Bates**, for research on the physical and chemical properties of solid electrolytes; **James Bentley**, for sustained outstanding contributions to the development of instruments and techniques of analytical electron microscopy and their application to materials science and engineering; **Joel A. Carter**, for exemplary technical leadership and many significant achievements that have placed ORNL among the nation's leaders in analytical mass spectrometry; **Stan A. David**, for outstanding leadership in the ORNL Welding Science Program, leading to his selection as coordinator of the national Basic Energy Sciences Welding Science Programs; **Thomas H. Dunigan, Jr.**, for development of a suite of computer simulators to aid in the development and analysis of parallel programs for hypercube multiprocessors; **Robert H. Gardner**, for outstanding research in the development of advanced statistical methods of error analysis that have led to improved predictions of responses of biota to their environment; **Joseph N. Herndon, W. R. Hamel, C. T. Kring, H. L. Martin, J. C. Rowe, D. P. Kuban**, and **M. J. Feldman**, for outstanding technical accomplishment by a multidivisional team of engineers in the development of the world's first Advanced Integrated Maintenance System; **James R. Keiser**, for design, development, and construction of a unique system for the fundamental study of the response of materials to the combined effects of corrosion and erosion at elevated temperatures; **Eugene J. Kelly**, for consistently outstanding contributions to electrochemistry of corrosion, magnetoelectrochemistry, and electrocatalysis by near-surface alloys; **Daniel P. Kuban**, for outstanding, innovative engineering contributions to the development of the Man-Equivalent TeleRobot concept that has been adopted as NASA's referenced system; **Robert J. Luxmoore**, for outstanding research contributions in the areas of plant physiology and soil physics; **Steven R. McNeany**, for excellence in the development of infrared optics in support of the national SDI program; **Robert V. O'Neill**, for outstanding contributions to the field of ecology—in particular, mathematical analysis of ecological systems; **Steven H. Overbury**, for significant developments in angle-resolved, low-energy ion scattering as a technique for determining the structure of clean and adsorbate-covered metal surfaces; **Gayle S. Painter**, for contributions to the understanding of the effects of impurities on the strength and fracture of alloys on a quantum theoretical basis; **Walter K. Sartory**, for development of an innovative simplified design chart adopted by the ASME Code for guarding against excessive inelastic deformations in high-temperature nuclear reactor components; **G. Elliott Whitesides**, for outstanding contributions and recognition as a preeminent authority in the technology of nuclear criticality analysis; **Richard F. Wood**, for pioneering contributions establishing ORNL as an international leader in laser processing of materials and for exemplary leadership in developing a new technology resulting in solar cells of record high efficiencies; and **Lee A. Zevenbergen**, for exemplary success in the development and preparation of large-area, ultrathin, neutralizer foils for use in SDI particle-beam systems.

Seventeen ORNL employees received the Inventor Award, which recognizes innovative employee contributions to the activities of Energy Systems. The winners were **F. Wallace Baity, Jr., Daniel J. Hoffman**, and **Thomas L. Owens**, for invention of the resonant double-loop antenna for fusion applications; **Paul F. Becher**, for application of scientific principles to the development of toughened ceramic composites; **Philip L. Butler** and **John D. Allen, Jr.**, for design and implementation of a unique parallel computer architecture combined with an inherently parallel operating system that executes artificial-intelligence codes several orders of magnitude faster than competitive machines; **Thomas A. Callcott** and **Edward T. Arakawa**, for design, construction, and testing of a new type of soft X-ray emission spectrometer that is the most efficient instrument of its type in the world; **Loucas G. Christophorou**, for continued innovative development of gaseous media for advanced technologies that led to 13 patents and, particularly, for the patents on repetitive pulsed-power switches; **Robert C. DeVault**, for exceptional innovation and creativity that led to several inventions in advanced absorption heat pump technology with large potential benefits; **Gary L. Glish**, for conceptualization and development of an advanced atmospheric-pressure ion source for mass spectrometry; **David O. Hobson,** for making four patent disclosures during the past year for advanced material processing methods and equipment that offer economic and quality advantages over existing techniques; **Leon N. Klatt, James E. Strain**, and **Deborah A. Bostick,** for the successful development of a method for measuring refrigerant/absorbent concentration in heat absorption machines; and **Prem C. Srivastava** and **Furn F. Knapp, Jr.**, for development of an innovative new approach for the brain-specific delivery of diagnostic radiopharmaceuticals.

Ten ORNL employees received an Operational Performance Award, which recognizes outstanding, exemplary performance in management, business, personnel, manufacturing, and other similar functions. The winners were **William D. Burch**, for outstanding performance in managing the U.S. DOE nuclear fuel reprocessing development program and for developing a long-term international collaboration to continue U.S. expertise toward future needs; **W. Charles Kuykendall**, for innovative leadership of ORNL's Safeguards and Security activities that led to successful passing of DOE's Inspection and Evaluation; **O. B. Morgan, Jr.**, for outstanding leadership of a team effort that has made Energy Systems one of the world's leading fusion organizations; **Sharon J. Ramos**, for organizing and leading a Performance Improvement Process Team that significantly reduced the probability of incorrect exclusion recommendations on property surveys at Grand Junction, Colorado; **Bonnie S. Reesor**, for consistently and successfully coordinating arrangements for major international and domestic technical conferences, workshops, and management meetings that were recognized as outstanding by ORNL and external contacts; **Anthony C. Schaffhauser**, for outstanding performance in the development and management of Materials Technology programs in support of energy conservation; **William H. Sides, Jr.**, for dedicated and outstanding leadership of the Energy Systems Acoustic Instrumentation Research and Development Program with the David Taylor Naval Ship R&D Center; **C. S. Sims**, for materially expanding the research and technology transfer applications of the Health Physics Research Reactor and for establishing international leadership in neutron dosimetry; **E. Jonathan Soderstrom**, for the extraordinary achievement in 1986 of instigating the contractual adoption of five Oak Ridge technologies by six industrial firms; and **Donald B. Trauger**, for his leadership as chairman of the Reactor Review and Audit Committee along with his insistence on verifiable and understandable data that led to the discovery of embrittlement in the pressure vessel of the High Flux Isotope Reactor and to detailed operational and management reviews of other ORNL reactors before problems could become serious.

Forty-five ORNL employees received Publication Awards, which recognize superior employee performance in the authorship of a paper, technical article, or book that represents a significant advance in the author's professional field. The winners were **A. C. Buchanan III, T. D. J. Dunstan, E. C. Douglas**, and **M. L. Poutsma** for "Enhancement of Free-Radical Chain Rearrangement, Cyclization, and Hydrogenolysis During Thermolysis of Surface-Immobilized Bibenzyl: Implications for Coal Chemistry"; **B. A. Carreras, L. Garcia** and **V. E. Lynch**, for "Toroidal Field Effects on the Stability of a Heliotron Configuration"; **D. R. Cole** and **H. Ohmoto**, for "Kinetics of Isotopic Exchange at Elevated Temperatures and Pressures"; **D. L. DeAngelis, W. M. Post**, and **C. C. Travis**, for *Positive Feedback in Natural Systems*; **K. Farrell, R. W. Chickering**, and **L. K. Mansur**, for "The Role of Helium in the Development of Damage Structure and Swelling in Neutron-Irradiated Aluminum"; **M. T. Heath** and **G. A. Geist**, for "Matrix Factorization on a Hypercube Multiprocessor"; **F. C. Hartman, C. D. Stringer, S. Milanez**, and **E. H. Lee**, for "The Active Site of Rubisco"; **E. Hirst, J. Clinton, H. Geller**, and **W. Kroner**, for *Energy Efficiency in Buildings: Progress & Promise*; **S. E. Lindberg, G. M. Lovett, D. D. Richter**, and **D. W. Johnson**, for "Atmospheric Deposition and Canopy Interactions of Major Ions in a Forest"; **S. H. Liu**, for "Fractals and Their Applications in Condensed Matter Physics"; **J. F. Lyon, B. A. Carreras, J. H. Harris, T. C. Jernigan, J. A. Rome**, and **J. Sheffield** (and K. K. Chipley, M.

J. Cole, R. L. Johnson, V. E. Lynch, B. E. Nelson, and P. B. Thompson of the Engineering and Computing & Telecommunications divisions), for "The Advanced Toroidal Facility"; **J. March-Leuba, D. G. Cacuci**, and **R. B. Perez**, for "Nonlinear Dynamics and Stability of Boiling Water Reactors: Part 1—Qualitative Analysis, and Part 2—Quantitative Analysis"; **A. J. Moorhead** and **H. Keating**, for "Direct Brazing of Ceramics for Advanced Heavy-Duty Diesels"; **J. R. Noonan** and **H. L. Davis**, "Atomic Arrangements at Metal Surfaces"; **C. D. Scott, G. W. Strandberg**, and **S. N. Lewis**, for "Microbial Solubilization of Coal"; **C.-Y. Wong** and **R. L. Becker**, for "Scalar Magnetic (e^+e) Resonance as Possible Source of Anomalous e^+ Peak in Heavy-Ion Collisions"; and **G. T. Yeh**, for "An Orthogonal-Upstream Finite Element Approach Peak in Heavy-Ion Collisions"; and **G. T. Yeh**, for "An Orthogonal-Upstream Finite Element Approach to Modeling Aquifer Contaminant Transport."

Four ORNL employees received Community Service Awards, which recognize outstanding and noteworthy performance by Energy Systems employees engaged in voluntary, uncompensated activities (social, civic, or governmental) that provide significant benefit to the community. The winners were **Frank E. Gethers,** for his quiet, effective, behind-the-scenes leadership and active stewardship, while serving as an outstanding role model for young men from 1968 to the present; **Herbert W. Hoffman,** for his significant service to the improvement of mental health and the easing of the anguish of mental illness through sustained volunteer involvement at local, state, and national levels; **Charles A. Mills**, for more than 34 years of outstanding contributions, devoted service, and distinguished leadership in numerous and varied civic and governmental organizations; and **David E. Reichle**, for outstanding contributions to the youth of Oak Ridge through active participation on the Oak Ridge Boys' Club Board of Directors.

Robert W. Swindeman has been named a Fellow of the American Society for Metals.

J. N. Dumont has been appointed quality assurance specialist for ORNL's Nuclear and Chemical Waste Programs.

A publication authored by **J. N. Dumont**, "Oogenesis in *Xenopus laevis* (Daudin). I. Stages of oocycte development in laboratory maintained animals," has been namd a Citation Classic by the Institute for Scientific Information.

W. L. Carrier is the coauthor of two publications recently named Citation Classics by the Institute for Scientific Information. The first paper, "The disappearance of thymine dimers from DNA: an error-correcting mechanism" (by R. B. Setlow and Carrier, 1964), was cited in the August 1979 issue of *Current Contents*. The most recent publication is "Evidence for excision of ultraviolet-induced pyrimidine dimers from DNA of human cells in vitro" co-authored with **J. D. Regan** and J. E. Trosko and published in *Biophysical Journal*.

Michelle V. Buchanan has been appointed a member of the Proposal Review Board for Major Instrumentation Grants for the National Science Foundation.

William A. Simpson, Jr., has been elected a Fellow of the American Society for Nondestructive Testing, Inc.

Dale D. Huff has been named the first president of the Tennessee Section of the American Institute of Hydrology.

The U.S. Environmental Protection Agency has awarded **Paul Kanciruk** the EPA Bronze Medal for his role in the agency's National Surface Water Survey.

Lynn Boatner has been elected to the Executive Committee of the American Association for Crystal Growth.

Chester R. Richmond and **R. J. M. Fry** have been reelected members of the National Council on Radiation Protection and Measurements. Both are also members of the International Commission on Radiological Protection (ICRP); Richmond is vice-chairman of ICRP's Committee 2 (Secondary Limits) and Fry is a member of Committee 1 (Radiation Effects).

ORNL has been developing a strategy for increasing energy efficiency in the 86 million single-family buildings and 4 million commercial buildings in the United States. The strategy involves selecting the most cost effective retrofit measures. Early results of the research have identified potential benefits from building retrofits, such as horizontal radiant barriers for houses and efficient gas-powered air-cooling systems for commercial buildings to reduce the demand for electricity.

Improving Energy Efficiency in Homes and

By WILLIAM MIXON, MICHAEL KARNITZ, and MICHAEL MACDONALD

Improving energy efficiency of existing buildings through retrofit measures offers the largest potential for energy savings in the next 10 to 15 years in the United States. Replacement of some 90 million existing buildings by more energy-efficient ones is slow; consequently, most of the existing stock will remain in use for the next 30 to 40 years. It is estimated that almost 90% of the 1985 stock of residential buildings will still exist in 2010.

Retrofits of existing structures include improving the building's thermal envelope—for example, installing insulation, storm windows, and weatherstripping to minimize heat losses—and improving or replacing mechanical equipment to reduce the use of energy for heating, air conditioning, and domestic water heating. Widespread use of retrofits for residential buildings could save 2.6 quadrillion Btu's (quads) per year and reduce annual energy costs by $17 billion. Full penetration of energy retrofits into the commercial building stock, for which initial costs are paid back by energy savings in three years or less, could save 2.5 to 3.5 Q per year and $15 to $20 billion per year.

However, to increase the rate of adoption of building energy conservation measures, a variety of barriers to retrofitting buildings must be overcome. Factors that limit achievable and cost-effective energy savings include:

- Financial incentives to retrofit rented buildings are lacking for both landlords and tenants.
- Retrofit investments are risky because energy savings are less than expected on the average and essentially unpredictable for individual buildings.
- Recent decreases in natural gas and fuel oil prices have reduced interest in conservation.
- Most conservation programs apply cold-climate retrofit measures only to the building envelope without realizing the potential of retrofit for mechanical systems, hot climates, and operation and maintenance.

At least two approaches could be taken to reduce the barriers to

William R. Mixon is manager of ORNL's Building Energy Retrofit Research Program in the Energy Division and assistant for X-10 site work under the division's Efficiency and Renewables Research Section. From 1978 through 1981 he was head of the Energy Division's Conservation and Use Analysis Section and from 1973 to 1978 he managed ORNL's Modular Integrated Utilities System Program sponsored by the U.S. Department of Housing and Urban Development. From 1968 to 1973 he conducted experiments in desalination by hyperfiltration using dynamically formed membranes. After he came to ORNL in 1957 he spent 11 years doing in-pile irradiation testing of advanced fuel elements and materials for nuclear reactors and conducting thermal and hydraulic studies of the Homogeneous Reactor Experiment core and replacement core. He holds an M.S. degree in engineering science from the University of Tennessee.

Michael Karnitz is leader of the Community Systems/Cogeneration Group in ORNL's Energy Division. Since joining the ORNL staff in 1976, he has developed and supervised a number of projects in cogeneration, district heating, and residential energy conservation. He holds a Ph.D. degree in mechanical engineering from Michigan State University. Before coming to ORNL, he worked as senior staff engineer at Consumers Power Company in Jackson, Michigan, and as vice-president of Stoner Associates, Inc., in Carlisle, Pennsylvania.

Michael MacDonald has worked at ORNL since 1984 in building energy conservation research. His interests include field surveys of industrial and commercial energy systems to determine ways to save energy, modeling of building energy use, development of analysis methods for understanding building energy use, practical aspects of selling energy services, and energy policy issues. Before coming to ORNL, he worked in Oak Ridge at TRW, Inc., and Lockheed, providing consulting services to ORNL's energy conservation programs. Before that he served as a field representative for energy management studies with the Office of Power of the Tennessee Valley Authority and as a designer of building heating, cooling, and piping systems at the 3M Company in St. Paul, Minnesota. MacDonald has a B.S. degree in mechanical engineering from the University of Tennessee.

Here, from left to right, MacDonald, Karnitz, and Mixon examine an instrument used to collect data from sensors for calculation of house energy performance.

Commercial Buildings

private investment in retrofit. First, retrofit proponents (e.g., states, utilities, shared-savings firms, and contractors) could share in the risks and savings of the investment to win significant participation of owners or occupants. Second, risk could be removed by providing the private sector with research results and predictive tools to help in the selection and installation of appropriate retrofits.

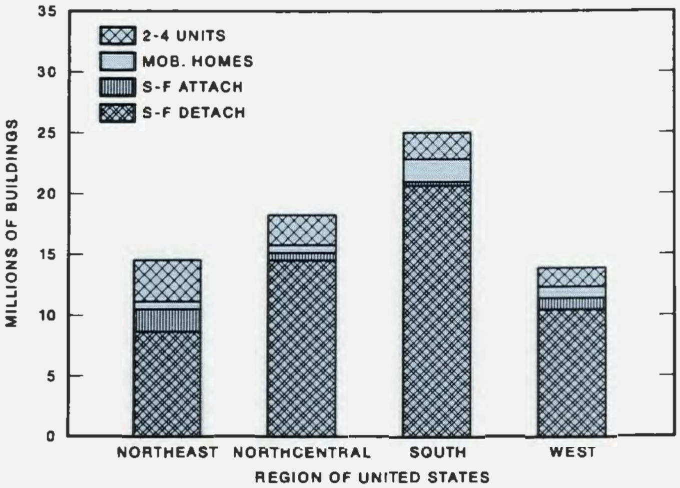
The Office of Buildings and Community Systems of the U.S. Department of Energy has selected the research approach as the long-term program goal. DOE is focusing on these technical objectives:

- provide reliable data on retrofit performance and the means of collecting such data,
- maintain the national capability for analyzing and updating retrofit performance data,
- measure and analyze the influence of human and other factors on the effectiveness of retrofits and postretrofit operations and maintenance, and
- make the results of retrofit research widely available to the building industry through technology transfer activities.

Through these positive measures, the Building Energy Retrofit Research Program within DOE's Building Services Division hopes to overcome the technical, financial, and behavioral barriers to the use of building energy retrofits. Research is being conducted on three building sectors: single-family and commercial buildings (Oak Ridge National Laboratory) and multifamily buildings (Lawrence Berkeley Laboratory). Other participants include Princeton University, the Solar Energy Research Institute, the Alliance to Save Energy, and Pacific Northwest Laboratory. The ORNL research is the subject of this article.

Single-Family Buildings

The U.S. public expects a return on its tax-dollar investment in energy conservation research. As DOE's lead laboratory for energy conservation research for single-family (S-F) buildings, ORNL has



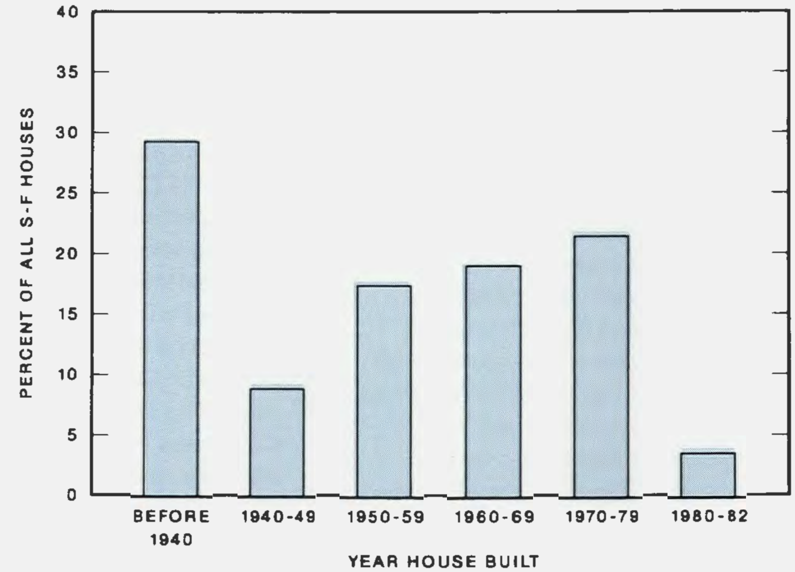


Fig. 1a. Numbers of single-family buildings, by census region, in 1982. Because of the large fraction of buildings in the South, ORNL suggested that research on improving building energy efficiency should focus more on cooling, not heating. Fig. 2a. Percentage of single-family buildings vs all buildings by year in which the house was built. The bar graph indicates that many houses were built in an era when energy was cheap. The energy efficiency of these buildings could be improved considerably by retrofit measures.

the opportunity and obligation to help reduce the utility bills of the 86 million S-F households in this country. ORNL has developed a strategy for increasing energy efficiency in homes and has obtained useful results.

To use limited funds most efficiently, members of ORNL's Energy Division drew up a research plan entitled *Single-Family Building Retrofit Research Multi-Year Plan* (ORNL/CON-207). This plan grew out of a careful review of studies describing the kinds of residential buildings in the United States and energy-use behaviors of their occupants. Findings from this review provided guidance for the S-F retrofit research program. Some important findings are:

• About three-fourths of the 86 million U.S. households live in S-F units (S-F detached homes, S-F attached homes, and mobile homes). More than one-third of these S-F households are in the South (see Fig. 1). Most early S-F retrofit programs concentrated on building modifications that would reduce heat loss. Cooling retrofits (e.g., air-conditioning systems and insulation to keep the heat out) were ignored. Because a large and growing number of the population lives in the South, the S-F retrofit research program should have a more balanced approach, seeking out retrofits that are economical for each geographic region of our country.

• Consumers are using less energy in their homes, but utility bills continue to climb. Energy conservation may be a mixed blessing for utility companies that have large fixed costs in generating plants or in long-term "take-or-pay" natural gas contracts that could result in the accumulation of excess gas reserves. If increasing utility prices continue to reduce the S-F householders' savings from conservation retrofits, other householders may hesitate to improve building efficiency. Such institutional barriers should be a subject of investigation by the S-F retrofit research program.

• Consumers are using a variety of fuel types in their homes, and some regional patterns are apparent. Electricity is important in all regions, but its use is particularly heavy in the South and West. Natural gas is also widely used, but the North Central region relies on it extensively. Fuel oil is used only to a large extent in the Northeast. Because of this regional variety in fuel types, the retrofit research program must broaden its scope to include electric retrofits (heat pumps and air conditioners) as well as liquid fuel retrofits.

• Almost three-fourths of S-F householders own their homes, but about two of every five have household incomes less than $15,000 per year, and one of four is 60 years old or more. There are incentives for homeowners to improve their homes, but low-income and elderly persons have limited investment capital. The retrofit research program must greatly improve the accuracy of predicting savings from retrofits on individual homes so that reliable advice may be given to homeowners having limited financial resources.

Fig. 2. Front view of the Karns houses, which are used by ORNL to test the cost effectiveness of retrofit measures such as radiant barriers in the attic for reducing home energy consumption.

Fig. 3. DOE conservation research staff visit the three Karns houses to learn about the research under way there.

S-F Building Achievements

The S-F Building Retrofit Research Group in ORNL's Energy Division, working with other public and private sector groups, carried out a number of projects that implement the research strategy described above. Achievements of four very diverse projects are:

• A low-income, S-F retrofit program in Wisconsin presented us with an opportunity to improve the cost effectiveness of such programs. During the winter heating season of 1985–86 in four southern Wisconsin counties, natural gas flow meters were connected to furnaces in 79 houses and read weekly both before and after the houses were retrofitted. ORNL researcher Lance McCold devised a new method to select appropriate energy-saving retrofits for each house to maximize total program benefits. Audit results are used to estimate the annual savings of various retrofits for each individual house. The benefit-to-cost ratios are then ranked for all possible retrofits to all candidate houses, and the top ranked benefit-to-cost ratio retrofits are selected for installation. This process, which is adaptable to varied housing types and different climates, maximized energy savings. Possible retrofits include infiltration control, insulation, storm windows, heating system tune-ups, heating system replacement, and installation of thermostat control systems. A member of the Wisconsin Energy Conservation Corporation worked out a method to use a blower door to spot infiltration leaks where caulking and weatherstripping are needed. The field test results showed that (1) the new ORNL procedure to select and tailor retrofits for each house doubled the overall efficiency of the program, causing the program "cost/therm saved" to drop from \$20 to \$10 annually and (2) the blower-door-guided procedure reduced the average cost of infiltration control from \$570/house to \$124/house. These procedures will be adopted by other state low-income retrofit programs.

• Under joint sponsorship by DOE and the Tennessee Valley Authority, the S-F Building Retrofit Research Group tested the energy-saving effectiveness of radiant barriers in three unoccupied research houses in Karns, near Knoxville, Tennessee (see Figs. 2 and 3). A radiant barrier is a sheet of reflective aluminum foil. Two variations in the installation of radiant barriers were studied. One house was used as the control house (no barrier was installed) and the other two were used to test the two installation methods. In one house, the radiant barrier was laid on top of the attic fiberglass batt insulation, and in the other house it was attached to the underside of the roof trusses. The attics of all three houses were insulated with a Kraft-paper-faced fiberglass batt insulation having an R-value (measure of the ability to retard heat flow) of 19.

Results from the houses using

the radiant barrier showed that in winter the horizontal barrier reduced consumption of space-heating electrical energy in both the resistance and heat-pump modes by 10.1% and 8.5%, respectively. The roof-truss radiant barrier, however, increased energy use by 2.6% in the resistance mode and 4.0% in the heat pump mode. In summer, the horizontal radiant barrier cut electrical energy use for air-conditioning by 17%, and the radiant barrier installed along the roof trusses saved 9%. These findings suggest that installing a horizontal radiant barrier is an inexpensive way for S-F homeowners to reduce both heating and air-conditioning costs.

- Most early retrofit programs emphasized space heating measures that were more appropriate for cold climates than warm ones. A recent study by the S-F Retrofit Research Group outlined a pilot program for retrofitting S-F houses of low-income families in the South. Findings of this study were presented at an Electric Retrofit Roundtable cosponsored by the Alliance to Save Energy and Edison Electric Institute. Participants at the meeting agreed that such a retrofit program is appropriate and that two pilot retrofit projects should be started—one for the humid South and one for the dry South. These pilot programs are now being planned. The field tests will occur in Austin, Texas, and Tulsa, Oklahoma. The retrofits to be tested include replacement air conditioners and radiant barriers in attics.
- The S-F Retrofit Research Group has worked with several potential user groups to produce an "S-F Monitoring Protocol." The purpose of the protocol is to improve and standardize field data-acquisition methods, instrumentation, and data handling to more efficiently monitor building energy performances that can be compared from project to project. The protocol document prompted the scheduling of American Society of

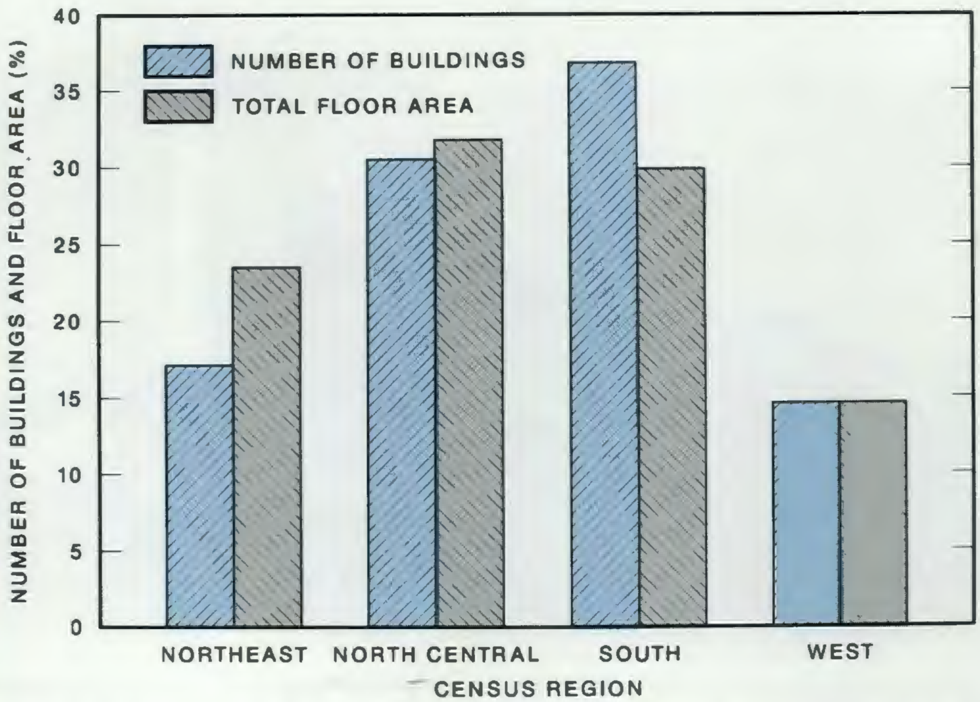


Fig. 4. Distribution of the number and total floor area of commercial buildings by census region (3,995,000 buildings, 47,685 million sq. ft.).

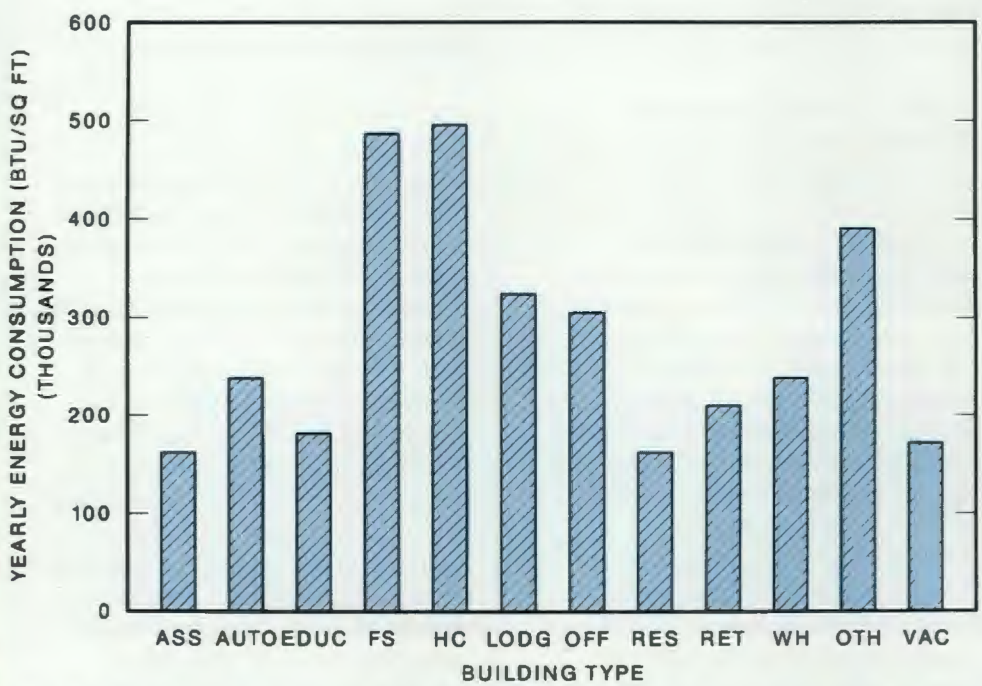


Fig. 5. Yearly energy consumption by Nonresidential Buildings Energy Consumption Survey (NBECS) classifications for commercial buildings. Building types are, from left, assembly (ASS), automotive sales and services (AUTO), education (EDUC), food sales (FS), health-care (HC), lodging (LODG), office (OFF), residential (RES), retail/services (RET), warehouse and storage (WH), other (OTH), and vacant (VAC).

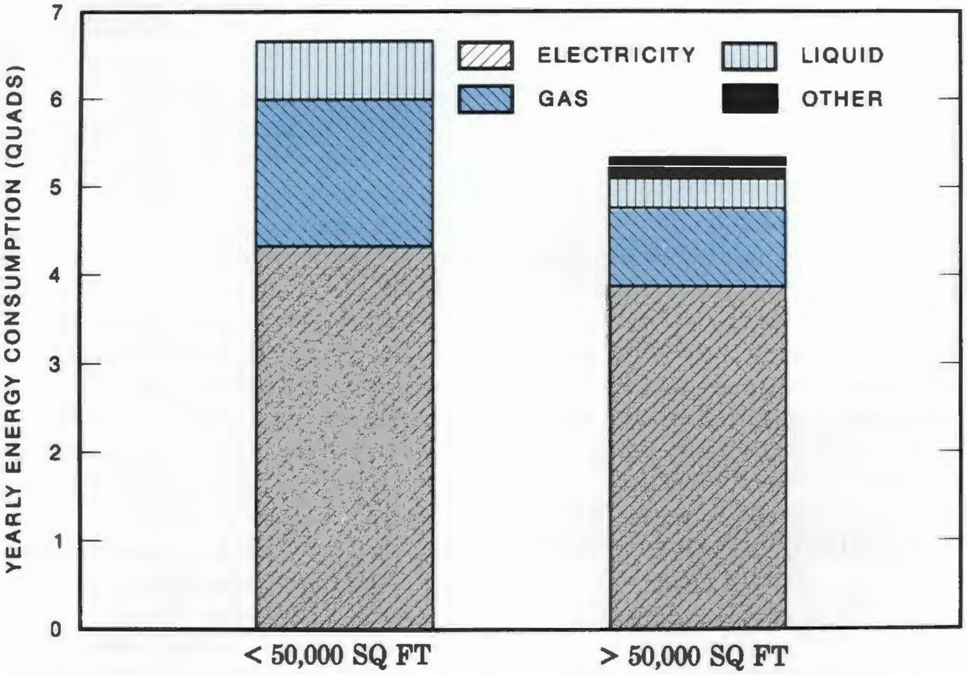


Fig. 6. Breakdown of primary energy consumption in commercial buildings by building size (less or greater than 50,000 sq ft) and fuel type.

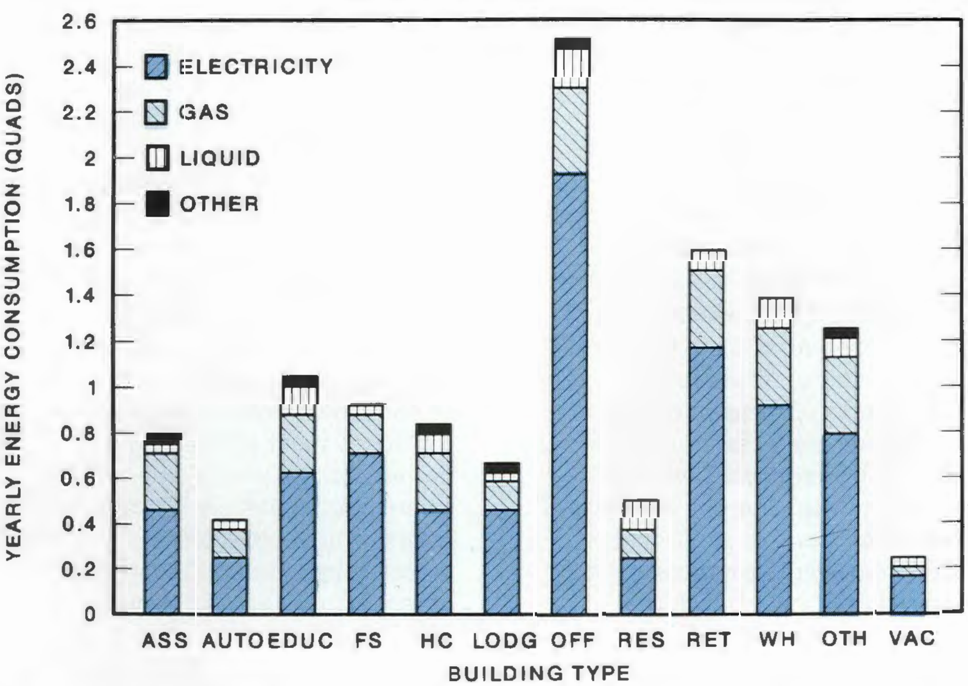


Fig. 7. Breakdown of primary energy consumption in commercial buildings by NBECS building type and fuel type.

Heating, Ventilation, Refrigeration, and Air Conditioning Engineers (ASHRAE) forums on the topic in January 1986 and January 1987.

Commercial Buildings and Energy Use

Commercial buildings are any buildings not classified as single-family, multifamily, or industrial buildings. They belong to the "all other" economic sector, including office buildings, schools, grocery stores, and a host of others (see Fig. 4). Acting as DOE's lead laboratory for energy conservation retrofit research for commercial buildings, ORNL has helped DOE devise a general research plan called the *Commercial Retrofit Research Multi-Year Plan* (ORNL/CON-218). Various groups in the public and private sectors are carrying out parts of this plan.

Commercial buildings have several characteristics of interest to retrofit research planners. They include space-conditioning equipment, fuel, energy use, and energy costs (see Figs. 5, 6, and 7).

About four million commercial buildings exist in the United States. Although the great majority of these buildings (96%) have less than 50,000 ft^2 of floor area, the total commercial building floor area of about 48 billion ft^2 is divided about evenly between those smaller than 50,000 ft^2 and those of larger floor area. Smaller buildings differ from larger buildings in the types of heating, ventilating, and air-conditioning equipment installed, access to professional system design support and operation and maintenance support, and access to retrofit capital. Retrofit research in this sector must take these differences into account.

Commercial buildings, large and small, are heavy users of electricity, which is chiefly for lighting and air-conditioning. Natural gas is the principal space heating fuel. The retrofit research program must consider ways to conserve electric energy and spread this large electric load over 24 h each day, thus reducing demand charges from electric utilities. (Utilities charge more for electricity used during periods of high demand than for other times of day.)

As with S-F units, commercial buildings have been accumulating in the South. This region, along with the north central region, contains two-thirds of all commercial floor space. Retrofits for both warm and cold climates had to be examined.

Commercial building occupants and owners have reduced their energy use per square meter of floor area, but their energy bills have doubled. From 1970–1985, the average use of site energy per square meter decreased by 16%, but, during the same period, the cost of energy per square meter increased by 96% in constant 1985 dollars.

Motivating building owners to improve the efficiency of energy use in their buildings is clearly a challenge. About one-third of U.S. commercial buildings are not occupied by the owners. The tenants of these buildings have little incentive or authority to upgrade their buildings. In addition, building owners often are skeptical about projected energy and cost savings. Also, potential energy cost savings often have low priority in relationship to other factors, such as (1) potential problems with comfort or attractiveness of the building that may occur during the installation of the retrofits, (2) the low cost of energy relative to overall costs, and (3) the uncertainty over how much money will actually be saved. Commercial building retrofit planning faces some knotty problems, but progress is being made.

Some Achievements

We have been conducting field monitoring experiments involving some small commercial buildings to document the savings that may be achieved from various common energy-conservation retrofits. One such field monitoring project is being conducted at a small bank building in Knoxville. Results will be used to understand how monitoring procedures can be simplified and to show how much energy can be saved through building operational changes such as nighttime lowering of thermostat settings for heating and raising of settings for cooling.

Howard McLain and Michael MacDonald have analyzed, in detail, the energy consumption of a prototypical large office building. A model (DOE-2.1B) was used to simulate the heat flow characteristics of a new ten-story office building having 100- by 200-ft dimensions for each floor. The DOE-2.1B program describes the flow of heat in the building and the loads on the space-conditioning equipment on an hourly basis. As expected, the summary of annual energy use, by fuel type, reveals heavy dependence on electricity, primarily for lighting and air-cooling.

The electricity use pattern shows that the peak demand corresponds with the 8:00 a.m.-to-4:00 p.m. occupancy period. This demand pattern can cause concern because of the peak power load placed on the electric utility and the potential costs to building occupants (e.g., those leasing space) in the form of demand charges.

These results have suggested an approach that could favorably affect both the electric and natural gas industries—conventional electric-powered compressors for air-conditioning replaced or supplemented with efficient gas-powered air-cooling systems. A large-scale switch to gas systems might reduce the electric utility companies' need to increase generating capacity, lower building energy costs, and provide a new market for natural gas.

To standardize procedures used in conducting field monitoring experiments, the Commercial Building Energy Retrofit Research Group at ORNL has worked with groups from other national laboratories to develop a proposed monitoring protocol. This proposed protocol will be reviewed by user groups and then presented to national standards groups such as ASHRAE and the American Society for Testing and Materials.

Once the field monitoring and modeling experiments produce potentially useful results, efforts will be made to encourage adoption of the new findings by commercial building operators, owners, and all others involved in making decisions to invest in retrofits. The Commercial Building Retrofit Research Plan includes strategies to encourage building owners to try new technologies, but work in this area is just beginning.

Over the past seven years, public funds have been spent at ORNL to support building energy retrofit research for S-F and commercial buildings. ORNL staff have worked with user groups to develop and test sound research strategies and to support efforts to better understand the amount of savings that should be expected. Recent results have identified potential benefits from building retrofits, such as the use of horizontal radiant barriers for S-F houses and efficient gas-powered air-cooling systems for commercial buildings. Future efforts will be directed at determining potential benefits from other retrofits and, in general, helping with national efforts to improve the energy efficiency of existing buildings. ornl

PHOTOGRAPH/BILL CLARK

A superinsulated house.

The Performance and Economics of Superinsulated Houses

A standard superinsulated house is comparable to a "reference" house, except that the "super" house has $5000 worth of features to minimize heat losses in the winter and heat gain in the summer and to maintain good indoor air quality. It has walls containing 10.5 in. of fiberglass, 16.5 in. of ceiling insulation, 9 in. of floor insulation, triple-glazed windows (80% surface facing south), and window overhangs. A well-sealed air-vapor barrier inhibits infiltration and an air-to-air heat exchanger controls ventilation.

The lack of drafts and temperature fluctuations in the super house makes for increased comfort. The reference house is the same size, is located on the same area, uses the same fuel type, and has only an average amount of insulation.

By how much will the super house reduce energy consumption, reflected in heating and cooling bills, and how soon will this energy savings compensate for the investment made in energy conservation features?

Floyd J. Zehr, physics professor at Westminster College, provides answers to these questions in a report (ORNL/CON-148) prepared by ORNL entitled *The Performance and Economics of Superinsulated Houses*. The subcontracted research was sponsored by Oak Ridge Associated Universities and DOE's Office of Buildings and Community Systems.

"The standard superinsulated house uses about one-third the energy for space heating as does the reference house," writes Zehr. The answer to the second question, however, is not as easy because it varies with climate and source of energy.

According to Zehr, the economic benefits are greatest for superinsulated houses in cold climates where space and water heating consumes the most energy. Thus, payback is generally more rapid in the more northern U.S. regions. The report indicates that, at best, the savings from using less energy in a standard superinsulated house for 25 years can be more than three times the amount invested in building energy conservation features.

Depending on location and fuel choice, the payback period can range from 6 to 25 years. For electric systems, according to Zehr, the paybacks take from 6 or 7 years in very northern cities to very long periods in the South. "If natural gas is available under the price and cost conditions used in this study," he states, "superinsulation appears to be economical only in areas with large heating loads."—*Carolyn Krause.*

take a number

By V. R. R. Uppuluri

Powers of Natural Numbers

The natural numbers 5 and 6 have a common property. The product of 5 multiplied by itself any number of times is a number whose last digit is 5. Similarly, any power of 6 ends with 6. Thus, $5^2 = 25$, $5^3 = 125$, $5^4 = 625$, $5^5 = 3125$, and so on. Also, $6^2 = 36$, $6^3 = 216$, $6^4 = 1296$, $6^5 = 7776$, and so on. No other number from 2 through 9 has an infinite series of powers whose last digit is the same as the number itself.

The fifth powers of natural numbers have a unique property—namely, the last digit of a natural number and the last digit of the fifth power of that number are the same. Note that 2^5 (32) ends with the digit 2, 3^5 (243) ends with the digit 3, 4^5 (1024) ends with 4, and so on.

Decimal Representations of 1/9 and 1/11

Recently, I received a letter from Sundaram S. S. Iyer, Instituto de Pesquisas Energeticas è Nuclèares, Sao Paulo, Brazil. He writes:

"I am one of the regular readers of your interesting column and am much fascinated by it. As I am not a specialist in mathematics, I am writing to you to seek an explanation for the interesting relationship between the numbers 9 and 11. Consider 11 as a denominator in fractions:

$1/11 = 0.09090909\ldots$
$2/11 = 0.18181818\ldots$
$3/11 = 0.27272727\ldots$
$4/11 = 0.36363636\ldots$
$5/11 = 0.45454545\ldots$
$6/11 = 0.54545454\ldots$

where the sum of each set of two neighboring numbers after the decimal point is always 9.

"When 9 is the denominator, we find that

$1/9 = 0.11111111\ldots$
$2/9 = 0.22222222\ldots$
$3/9 = 0.33333333\ldots$

where each set of two neighboring numbers after the decimal point is always a multiple of 11.

"What are the reasons for this? Is it because 9 and 11 are symmetrically situated with respect to 10 in the mathematics of base 10?"

I replied as follows: "Your guesses were quite correct. This is definitely because 9 and 11 are symmetric about base 10. Let us assume that an integer like 5 is equal in decimal representation to $5 = 4.999999\ldots$ Furthermore, if
$5 = 11 \times (.a_1a_2a_3\ldots)$
$= 10 \times (.a_1a_2a_3\ldots) + (.a_1a_2a_3\ldots)$
$= .a_1a_2a_3a_4) + .a_1a_2a_3\ldots$
and this implies $a_1 = 4$ and $a_2 + a_1$
$= 9 = a_2 + a_1 = 9 = a_3 + a_2$
$= a_4 + a_3 = \ldots$
Similarly, it can be seen that
$(1/9) = 0.bbbbbb\ldots$
Then $1 = (10 - 1) \times (0.bbbbbb\ldots)$
$= b.bbbbbb\ldots$
$-.bbbbbb\ldots = b.$
Therefore, any successive numbers of m/9 are divisible by 11 because they are of the type bb."

Alan Hawthorne is interim head of the Health Studies Section of ORNL's Health and Safety Research Division. The section's research focuses on the impact of physical and chemical pollutants on human health. He came to the Laboratory in 1976 and, in 1977, obtained his Ph.D. degree in nuclear engineering from North Carolina State University. His research interests include indoor air quality research, development of pollutant monitoring methods, and research management.

Radon Levels and Home Energy Conservation

By ALAN R. HAWTHORNE

Few current environmental issues have generated as much public concern as radon, the radioactive gas that seeps indoors and threatens human health. Nowadays radon is viewed as the premier indoor air pollutant. The U.S. Environmental Protection Agency (EPA) estimates that 5000 to 20,000 lung cancer deaths a year in the United States may be attributable to radon. These predictions are derived from the estimated distribution of human exposures to radon throughout the nation and the calculated health risks to the U.S. population based on the excess lung cancers incurred by uranium miners through exposure to high radon levels. In fact, the cancer risk to the U.S. population from radon is considered two to three orders of magnitude greater than the risk value at which the EPA typically sets a maximum permissible level for outdoor pollutants.

Experts disagree about the highest indoor concentration of radon that is acceptable for human health. The current EPA-recommended guideline for indoor radon levels, above which actions to reduce concentrations should be considered, is 4 picocuries per liter (pCi/L) of air for an annual average in the living space. The National Council on Radiation Protection has recommended a maximum level of 8 pCi/L. As with all carcinogens, the lowest exposure reasonably achievable is preferred.

Although it is widely believed that energy conservation measures that tighten houses can cause high radon levels in homes, research at ORNL and elsewhere indicates that house air exchange rates (which are affected by conservation measures) are usually much less important than other factors in producing elevated levels. In fact, some energy conservation measures may even reduce radon levels.

Certain locations, most notably the Reading Prong area of Pennsylvania and New Jersey, have exceptionally high radon levels; many houses there have concentrations above the 100-pCi/L level and some above the 1000-pCi/L level. Efforts are under way by the EPA and many states to perform surveys to identify other areas having elevated radon concentrations. This past spring the EPA conducted a survey of 3000 homes in Tennessee. EPA's survey was based on random sampling and covered the entire state in contrast to the earlier, more limited work conducted by Oak Ridge National Laboratory. From our ORNL studies we found that a sizeable percentage (>25%) of East Tennessee homes in our limited survey area have radon levels >4 pCi/L and that only a few have levels >20 pCi/L.

In addition to identifying areas having high radon concentrations, the federal government is testing the effectiveness of mitigation measures for reducing radon levels. Also, the Department of Energy (DOE) Office of Health and Environmental Research has recently begun a major radon research program to (1) develop models to predict radon availability, (2) determine radon dose to critical body cells, (3) assess the health risk of radon through epidemiological studies, and (4) quantitatively model lung cancer induction as a result of long-term exposure to radon. ORNL's Health and Safety Research Division (HASRD) hopes to have a role in carrying out some of the research of this DOE program. These efforts by the federal government indicate the magnitude of public concern about the possible hazards of radon in homes.

Exhaust vents (arrow) through the roof, which help reduce radon levels in homes, are aesthetically acceptable.

Air Quality in Tightened Homes

Poor indoor air quality has often been blamed erroneously on conservation measures, especially the "tightening" of houses to reduce heat losses (and thus ventilation). Unfortunately, many people unfamiliar with research in this area still have this misconception. Although much of the initial motivation for indoor air research was to evaluate the effect on indoor air quality of reduced air exchange rates resulting from conservation measures, we quickly learned that the impact of tightening of houses on levels of indoor air pollutants was small compared with other factors. We found that the variability of most indoor pollutant levels in houses is caused largely by several other factors, most notably the large range of emission rates from sources associated with individual homes. For example, the factor most responsible for elevated indoor levels of radon is its rate of entry into the home from the surrounding soil (source strength) rather than air exchange rates. However, because weatherization reduces air exchange rates, it can affect indoor radon levels. The effect, though, is generally not large. In fact, as I will discuss, various weatherization practices might actually reduce radon levels.

Why gain a better understanding of the relationship between weatherization and indoor radon levels? First, because elevated radon levels are a serious health threat, we should focus on the most important factors inducing elevated levels rather than factors of lesser importance such as air exchange rate. Second, if weatherization is incorrectly thought to be the chief cause of elevated radon levels, then health-conscious homeowners may defer taking conservation measures and thus forfeit potential energy savings. Perhaps an even greater concern is that homeowners having poorly weatherized houses will believe they cannot have elevated radon levels, giving them a false sense of security.

It is useful to look at the range of values encountered for indoor radon levels and for air exchange rates. The typical indoor radon level for many residences in the United States is 1-2 pCi/L, and a typical air exchange rate is about 0.5 h^{-1}. The ranges of values for these parameters are considerably different. Radon levels of up to 20 pCi/L are frequently found. Less frequently found are homes having levels between 20 and 200 pCi/L; only a few houses having levels up to 1000 pCi/L have been identified. The likely range of air exchange rates is 0.2 to 2 h^{-1}. The large variability in indoor radon levels (about three orders of magnitude) clearly cannot be explained by variations in average air exchange rates (about one order of magnitude).

Factors Affecting Indoor Radon Levels

Understanding the factors affecting high radon levels in homes will permit evaluation of the impact of specific energy conservation measures. The key factors that must be considered are location and concentration of the original source of the radon (uranium), transport into the houses (convection vs diffusion), distribution within houses (mixing), and removal (indoor-to-outdoor air exchange). In almost all homes having very high radon levels, the source of the radon is the soil surrounding the substructure of the home. In a few areas, a significant amount of the radon may enter with well water and be dispersed during showers or other uses of water. Building materials containing radium (radium is one of the intermediate decay products of uranium leading to radon) can be a source of radon in homes; however, the levels generally associated with release from building materials are low when compared with "problem" levels of radon entering from the soil. Most elevated radon levels in homes are linked to naturally occurring uranium in soils, although some are associated with "technologically" enhanced radioactivity such as that from uranium mill tailings used as fill material (see "Sizing Up Contaminated Properties: A Saga of ORNL's Western Pioneers," by Craig Little and Barry Berven, ORNL *Review*, Vol. 19, No. 4, 1986). Interestingly, some areas where homes have exceptionally high radon levels have uranium concentrations high enough to be considered suitable for mining.

Although uranium is present in most soils, it may not pose a health threat. Radon produced by decay of uranium must find its way into the house to create a problem. In fact, most radon produced either decays while in the soil (radon has a 3.8-day half-life) or diffuses into the atmosphere, where it is diluted to such low concentrations that it poses minimal risk to health. The problem arises when the radon entering a house builds up, creating high levels of radon progeny, which ultimately damage the lung and induce cancer.

At first it was thought that high indoor levels of radon resulted from diffusion of the gas through floors and basement walls. However, it was found that the rate at which radon diffuses through such material cannot generally account for high radon levels. Scientists now have a much better appreciation of the process by which radon enters homes. Most of the radon in homes accompanies soil gas, which is drawn into homes through sumps, wall and floor penetrations, cracks, and other openings. The driving force for this convective flow is a slight pressure difference (a few pascals) between the soil gas and the interior of the house. This pressure difference is associated with the "stack" effect, which leads to exchange of indoor and outdoor air. The stack effect is caused largely by temperature differences and wind speed. Another important environmental factor, soil permeability, affects the distance over which radon moving by soil gas flow is "pulled" into a house.

Once radon has entered a house it must be transported into the living area to become a major health problem. In some homes having unfinished (i.e., minimally occupied) basements, the basements are isolated enough from the upstairs living space that a much lower concentration of radon is measured in the living space than in the basement. Charles Dudney of HASRD's Measurement Applications Group and co-workers have found that the radon content in the upstairs level of many homes is frequently 50% lower than that in the basement. In other cases, especially when doors are open between house levels or when the low-pressure side of leaky heating, ventilation, and air conditioning (HVAC) duct work intersects with an area of high radon concentration, radon levels upstairs may be similar to those downstairs.

A final important factor affecting radon concentration in a house is the rate of removal from the air. Decay of the radon is a removal mechanism, but it is not a benign process because the radon daughters (lead-210, bismuth-214, and polonium-218) resulting from the decay are the real health culprits. Furthermore, removal by decay is slow compared with removal by diluting radon-bearing air with outside air infiltrating the house. This rate of dilution of indoor radon levels by outside air is the primary factor that is affected by tightening a house through caulking cracks, installing weatherstripping on doors and windows, sealing between floors, and other energy conservation measures.

Conservation Measures and Radon Levels

Although greater success in tightening houses can be achieved in new construction, retrofit weatherization generally will reduce the air exchange rate by less than 20%, unless the house was originally quite leaky. All other factors remaining constant, a 20% reduction in air exchange rate will lead to a 20% increase in radon concentration. Daily and seasonal variations in radon levels can be quite dramatic (as much as a factor of 10), making it difficult to reliably measure less than a 20% variation as a result of weatherization.

Can weatherization lower, rather than elevate, indoor radon levels? Yes, in some cases. Suppose that an HVAC system in a home has had leaky duct work or an improperly balanced air flow, pulling radon from a high radon area into the negative pressure side of the HVAC system and distributing the gas throughout the living area. If the homeowner chooses to weatherize and, as a result, the HVAC system is properly sealed or balanced, weatherization could reduce levels of radon (and perhaps other pollutants as well) in addition to saving energy.

In a recent study, Dudney and co-workers found that the mean level of radon in homes having crawl spaces and duct work in the crawl space was higher than the mean level of radon in homes having crawl spaces but no duct work. The ORNL data were obtained from a recently completed study of indoor air quality in 300 homes in Harriman and Kingston, Tennessee (see Fig. 1).

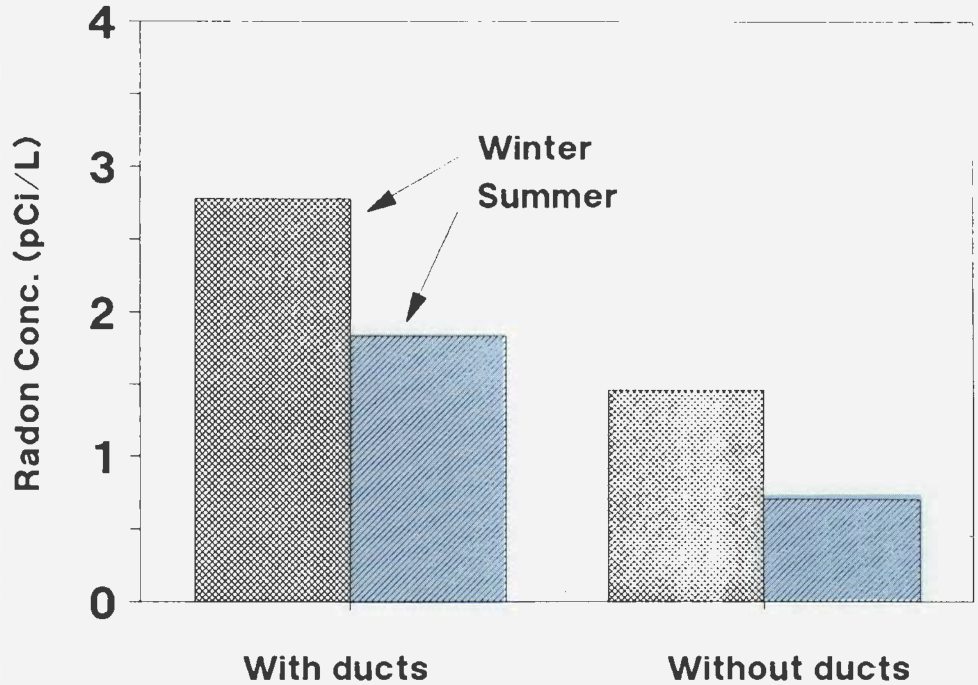


Fig. 1. In a recent study of indoor air quality in Kingston and Harriman homes, radon levels were found to be higher in houses having heating, ventilation, and air-conditioning duct work in the crawl space (n = 15 winter, n = 17 summer) than in houses having crawl space but no duct work there (n = 19 winter, n = 20 summer). [Standard error of mean is 0.67 pCi/L for mean winter radon level in houses having duct work in the crawl space and about 0.25 pCi/L for other mean levels.]

Another energy savings approach that is likely to reduce indoor radon levels is the external air supply installed for combustion appliances such as wood stoves, furnaces, and fireplaces. If these appliances were operated without this makeup air, the additional negative pressure created would probably increase radon levels.

Removal of "thermal bypasses," or paths for air to flow unimpeded from a lower floor to an upper floor or attic, is a final example of the potentially positive effects of weatherization. Thermal bypasses include openings within walls and around chimneys, plumbing fixtures, or other items extending vertically through a house. These easy paths for vertical air flow can enhance the stack effect, which pulls air from the lower area of the house and releases it near the upper portion. Proper sealing of these areas (not always easy to do) not only will reduce energy losses from rooms but also may lower radon levels, especially if the pressure difference between soil gas and the basement is reduced. Sealing between an unfinished basement and living level of the house could also reduce mixing of radon in the basement with the upstairs air.

Thus, home weatherization does not necessarily cause higher indoor radon levels, as is commonly believed. The relative importance of various factors must still be evaluated in greater detail in carefully studied homes before we can determine conclusively the

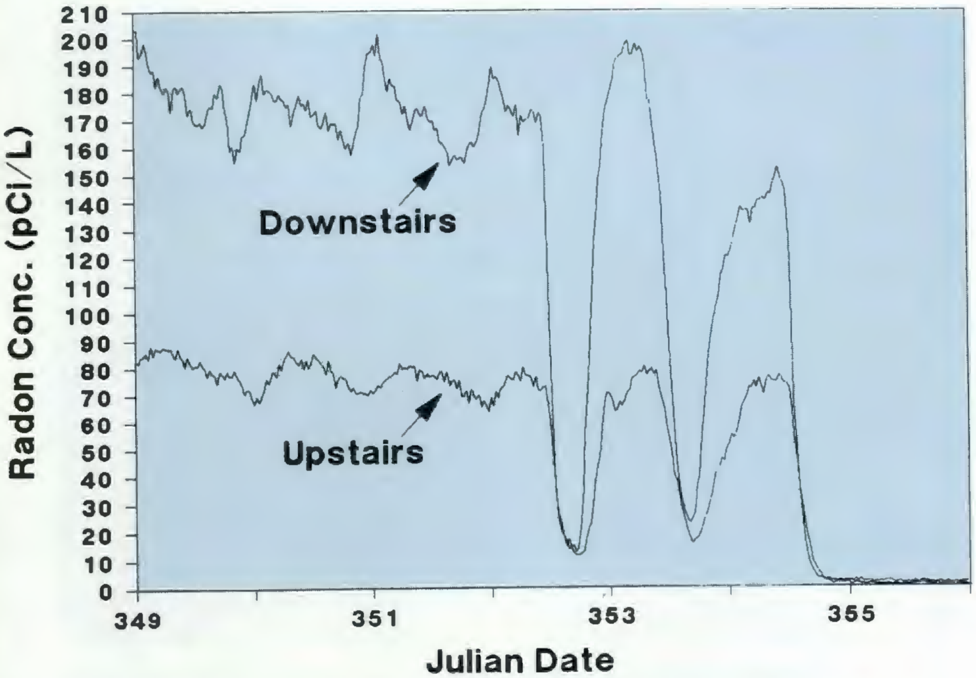


Fig. 2. Upstairs and basement radon levels in a New Jersey study house show the dramatic effectiveness of subslab depressurization as a mitigation measure. The two large daily decreases occurred while the basement was ventilated during installation of the measure.

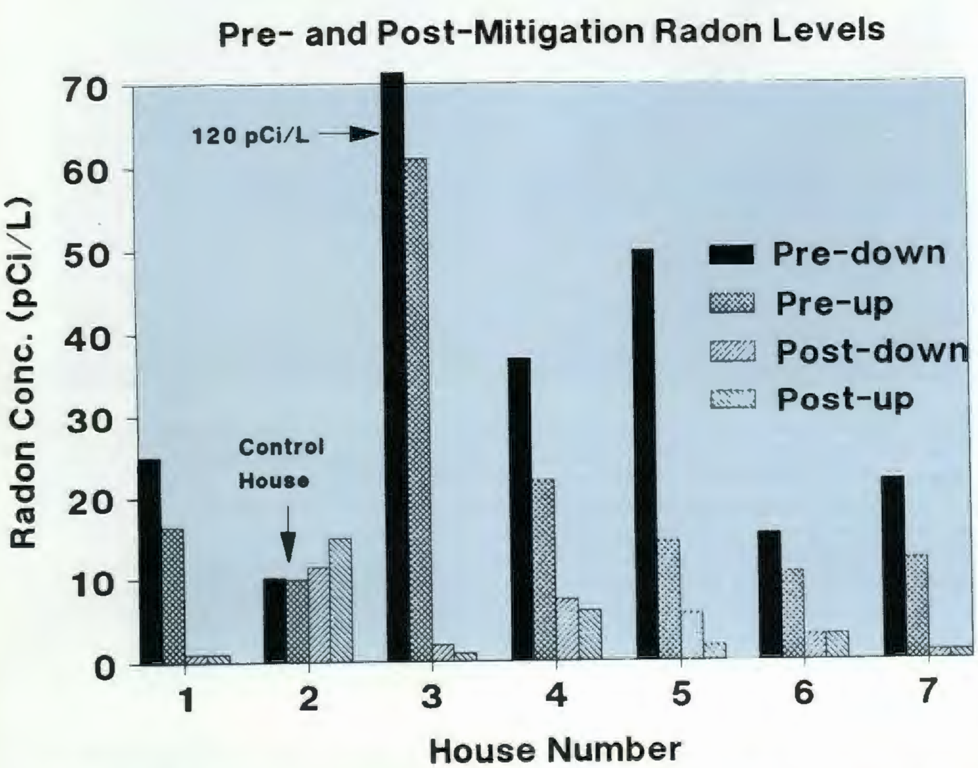


Fig. 3. Six houses (and a control house) in a detailed radon study in New Jersey show that high levels of radon can be reduced by several mitigation measures, including subslab depressurization.

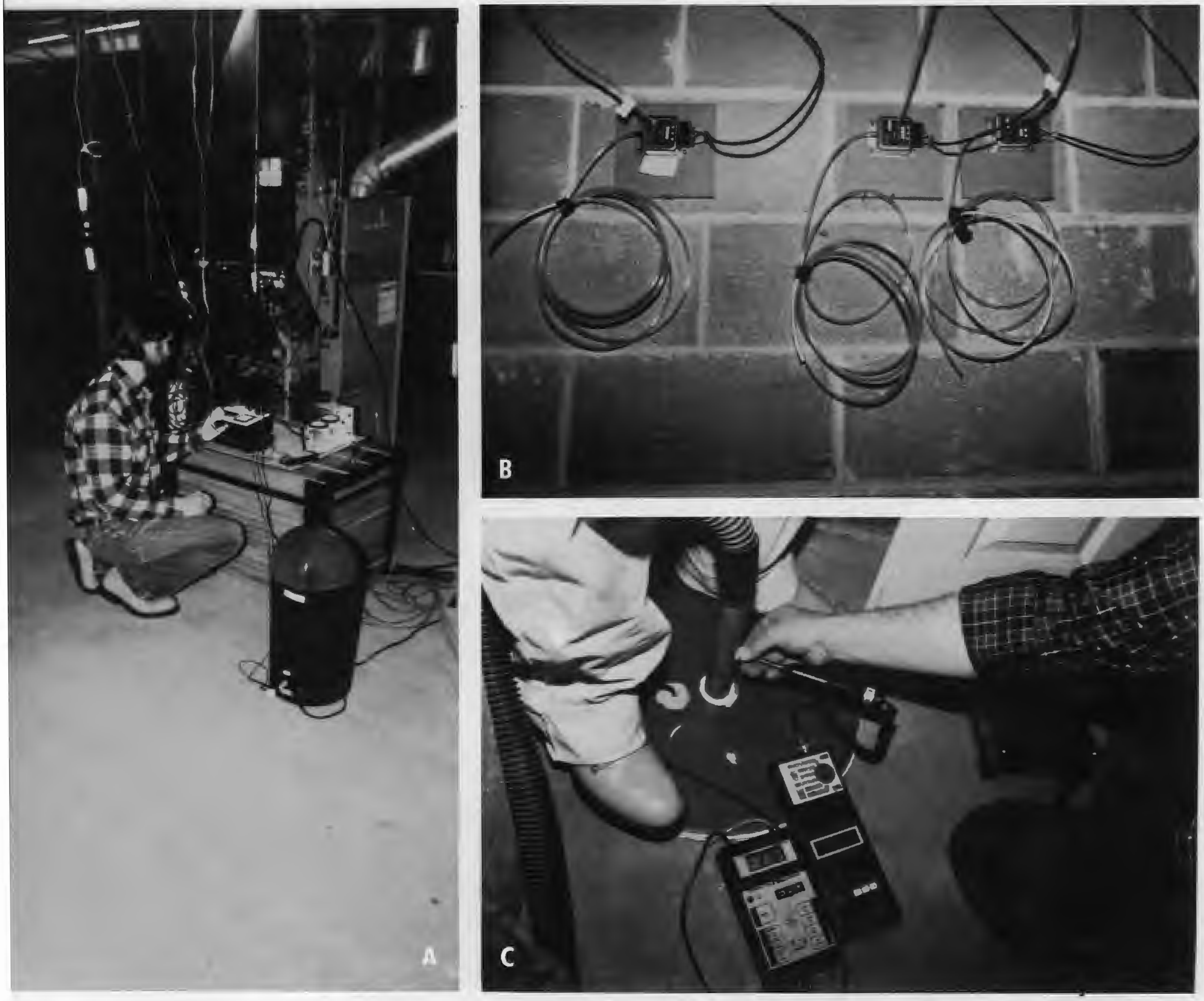
impact of weatherization measures on radon levels in homes. To better understand the details of radon entry and the factors that affect it, detailed investigations of a set of New Jersey homes having elevated radon levels are being conducted by HASRD's Tom Matthews and Dudney in collaboration with Lawrence Berkeley Laboratory and Princeton University this year, and another set will be studied in the Tennessee Valley next year.

Reducing Radon Levels

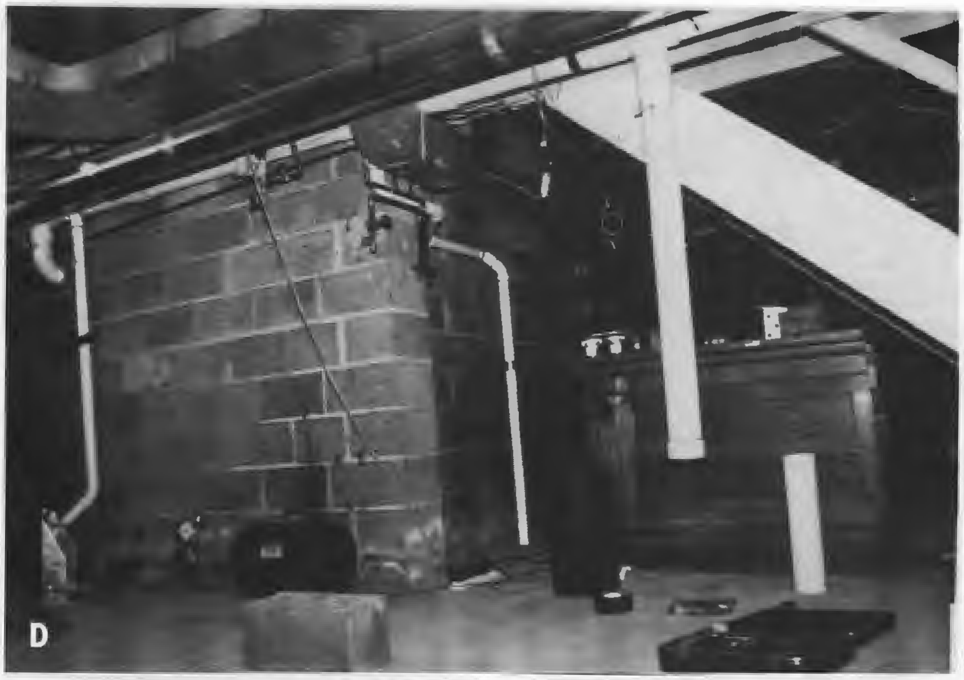
In addition to studying the entry of radon into these homes, ORNL and other researchers are evaluating the effectiveness of various mitigation measures in reducing radon levels. We found that an effective mitigation measure exists for homes having concrete basement slabs over a layer of aggregate, which allows air to flow easily from beneath the slab. For those homes in this category that have high radon levels, a relatively simple "fix" is a vent pipe through the slab and an exhaust fan. This system can depressurize the space beneath the slab, preventing the radon-rich soil gas from flowing into the basement.

EPA Booklets Available on Reducing Radon Levels in Homes

For those interested in additional information on radon in homes and ways to reduce elevated levels, EPA has prepared two booklets entitled "A Citizen's Guide to Radon: What It Is and What To Do about It" and "Radon Reduction Metods: A Homeowner's Guide," which can be obtained from the Tennessee Division of Air Pollution Control, the Knoxville Chapter of the American Lung Association, or EPA Region IV.



Reducing radon concentrations to acceptable levels in homes requires monitoring and mitigation measures, such as subslab depressurization to prevent radon-rich soil gas from flowing into the basement. (A) Radon and environmental parameters are continuously monitored by a portable data logger that can be accessed by telephone from ORNL. (B) Differential pressure sensors are used to measure small pressure differences among upstairs, outside, and subslab locations and the basement. (C) Subslab pressures and air flows are measured as part of the diagnostics made before installation of a mitigation measure. (D) Alternate configurations for subslab ventilation (single central location [disconnected in photo] vs smaller perimeter locations) are compared for effectiveness. (E) Some homes also require wall ventilation to reduce radon concentrations to desired levels.



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E

The fan is usually exhausted through the roof like a bathroom vent. In some cases, wall venting may also be needed. Using this depressurization method, we reduced the radon levels to surprisingly low levels in one study house in New Jersey (see Fig. 2). We measured the mean radon values in six homes in which this method or other measures were used and in one control home. The percentage reduction varies considerably between houses, but all houses using mitigation measures showed substantial radon reductions (see Fig. 3). The best mitigation measures for houses not in this category, however, await the results of further research.

New housing, it is thought, can be readily "radon proofed" for a few hundred dollars. The basic approach is to (1) put down a good layer of aggregate, (2) place a vapor barrier between the gravel and the concrete slab, and (3) install a venting pipe in the floor and cap it in case it is needed later for depressurization. Should high radon levels still be found in a newly completed house, the homeowner should be able to reduce the levels significantly simply by installing an exhaust fan. EPA is now evaluating several thousand homes in which this approach was tried.

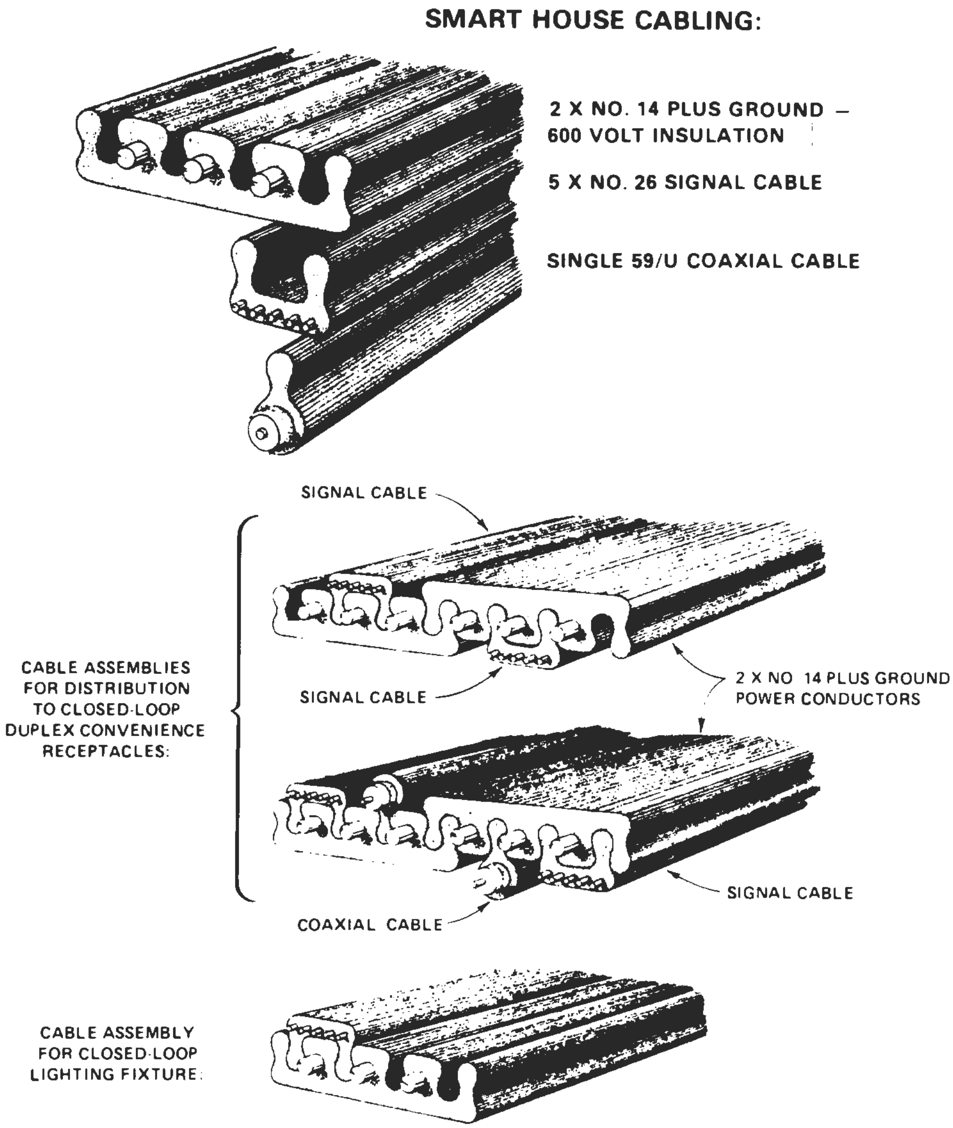
In summary, energy conservation measures that tighten houses do not usually constitute the primary cause of high radon levels in homes, as is commonly believed. When conservation measures are a factor, the outdoor-indoor air exchange rate of a house is usually much less important than other environmental factors in producing elevated levels. In fact, some energy conservation measures may even reduce radon levels. ornl

The Smart House of the future will detect a home fire, sound an alarm, and show the fire's location on a monitor.

The Smart House Project:
ORNL Plays a Role

Applying advanced technologies to use energy more intelligently in homes is a goal of the Smart House Project, a cooperative research and development (R&D) effort headed by the National Association of Home Builders Research Foundation. In the United States, 35% of the electricity used is consumed in homes, posing a potential burden on electric utilities during peak usage periods. Through the Smart House's sophisticated microcomputer controllers, heating, ventilating, and air-conditioning can be switched on and turned off at preset times to meet various needs. For example, the devices permit homeowners to help electric utilities manage loads—that is, shut off appliances to lower demand for electricity during periods when demand is normally highest. As a result, the homeowners can get special price breaks under innovative electric power pricing schemes and utilities may be able to defer construction of expensive peak-power plants. Utilities could also acquire data on home energy use more economically using Smart Houses.

150 microcontrollers per home. Most houses built in the United States in the 1990s are



The hybrid power–signal cable concept proposed for the Smart House has been approved in the revised National Electrical Code. This cabling uses a "zip-lock" design for tailoring the cable configuration to a specific purpose.

expected to use the Smart House concept. Instead of conventional electrical wiring, the design of these houses will integrate microelectronics and power semiconductors. A typical Smart House wiring diagram would show use of 150 microcontrollers, each the size of a cigarette package, which manage power and signalling in the home. As a result, the house appliances can electronically communicate with each other and can be programmed to turn on or off at preset times or in response to information picked up by sensors—presence of an occupant, light or smoke, or changes in temperature and humidity. These appliances include air-conditioning units, hot-water heaters, television sets, stereos, coffee makers, microwave ovens, garden sprinklers, electric lights, burglar alarms, telephone recording machines, and telephones programmed to call the police or fire department. Among these are gas-fired appliances.

A safer house. In addition to managing household energy use (data on which can be displayed on TV at will), the Smart House will be safer than houses of today. The possibility of fires and shock hazard, including electrocution, will be virtually eliminated because of the Smart House's closed-loop energy distribution in which branch circuits are not energized except when operating an appliance. Thus, when a child inserts a finger or toy into an outlet, no electrical shock will occur because the circuit is energized only if the inserted object indicates electronically that it is an appliance.

The Smart House concept also includes automated data links between appliances and maintenance providers. Thus, maintenance workers can automatically monitor appliance performance and, when they see indications of declining performance, they can arrange a service call with the homeowner before the appliance breaks down.

The Smart House Project involves 40 leading U.S. manufacturers of electrical, electronic, and gas-fired home products. These companies are contributing product R&D in exchange for license rights to market Smart House-approved appliances and components. Overseeing the project is an advisory council composed of representatives from

- Independent R&D institutes—the Electric Power Research Institute, Gas Research Institute, and Bell Communication Research,
- Industry trade organizations—American Gas Association, Edison Electric Institute, and Copper Development Association, and
- U.S. government agencies—Department of Commerce, National Bureau of Standards, and Office on Aging.

ORNL's role. ORNL has been involved in the Smart House

The Smart House will keep track of home energy consumption and help homeowners use energy efficiently.

Project since the fall of 1984. The chief participant from the Laboratory has been Robert Edwards of the Decision Systems Research Section in the Energy Division (formerly of the Computing and Telecommunications Division). Edwards served as technical director during the development of the overall system concept.

Edwards helped obtain approval of several changes to the National Electrical Code (NEC). These changes were reviewed and adopted by the NEC Technical Code-Making Subcommittees, which are responsible for examining the merits of proposed amendments to the code. The proposed changes permit use of innovative cabling concepts. One of these is a "zip-lock" type of attachment that allows various combinations of signal and power conductors to be assembled at the job site (see figure). Advantages of this arrangement are that (1) only a single pull is needed to install power and signal conductors and (2) the number of different types of cable required for wiring is minimized. Thus, the costs of wire installation are reduced under the Smart House concept because a single compact cable replaces the spaghetti-like wires that conventionally deliver current throughout the house.

Approval of the revised electrical code was difficult to obtain because no Smart House products are on the market and the code committees usually make changes only after hardware becomes available. However, approval was given because it was considered the incentive needed for Smart House participants to continue product design and development.

The Smart House will offer greater convenience, comfort, safety, security, and energy efficiency than today's houses, promoters say. Initially, the Smart House will add $5000 to $7000 to the cost of a $100,000 home, but that amount should drop to a few hundred dollars as the product matures.

news notes

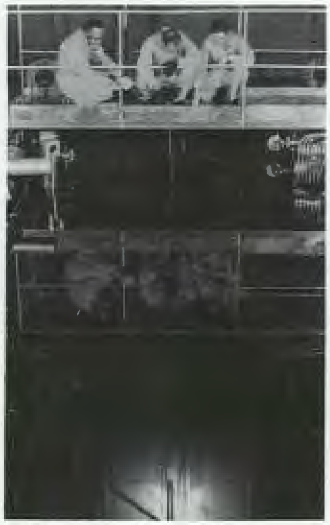
The ORR is shut down permanently

On July 20, 1987, the Department of Energy's Oak Ridge Operations (ORO) ordered the permanent shutdown of ORNL's Oak Ridge Research Reactor (ORR).

The 30-MW ORR and three other ORNL reactors have not been operating since March 26 because of concerns over deficiencies in reactor management. The order to shut down the ORR, however, was made because its mission was deemed complete; safety and management issues did not affect the decision.

Another ORNL reactor, the High Flux Isotope Reactor, has been idle since November 20, 1986, because of radiation embrittlement of the reactor's pressure vessel.

DOE's plan to shut down ORR was first announced in July 1986. However, ORR's operation was extended for another year to test the performance of recently developed low-enrichment uranium fuels designed for possible use in nuclear research reactors. Argonne National Laboratory conducted the tests using enriched uranium fuel containing about 20% uranium-235. Before this test, the ORR operated on high-enrichment fuel containing about 98% uranium-235. The low-enrichment fuel is preferable to the high-enrichment fuel in research reactors because it cannot be used to make weapons.



Technicians working from a bridge over the pool of the ORR adjust an experimental rig that extends through the top of the containment tank to the reactor core. The ORR, which first reached criticality in March 1958, was operated at ORNL for 29 years.

In 1959 King Hussein of Jordan tried his hand with remote manipulators at ORR.

After the March 26 shutdown, the adequacy of fuel test data was re-examined, and it was determined that the amount of data obtained by that time was sufficient to conclude the test.

The ORR, which began operation in 1958, had been used for radioisotope production, materials irradiation research, neutron-scattering studies, and development of nuclear fuels.

Permanent shutdown operations will involve the removal of spent fuel from the ORR's storage pool and decontamination of certain components. Surveillance of the ORR will continue during and after the shutdown effort.

ORO gets reactor restart concurrence

On June 22, 1987, ORO received concurrence from DOE headquarters to restart the Tower Shielding Reactor (TSR), one of the four reactors ordered shut down by DOE on March 26. However, ORO elected to delay restart of the TSR because of the labor strike that began on June 21.

Some 900 ORNL workers and 3200 Y-12 Plant workers in the Atomic Trades and Labor Council voted to reject the new contract proposed by Martin Marietta Energy Systems, Inc.

Fusion magnets at ORNL set records

A major milestone in the development of superconducting magnets for fusion power was achieved at ORNL on September 3, 1987, when the two-year test program of the International Large Coil Task was completed.

In the final test at the International Fusion Superconducting Magnet Test Facility, all six 45-ton, D-shaped coils showed they could operate well beyond design points by reaching peak magnetic fields of 9 teslas (T)—180,000 times the earth's background magnetic field—and a total stored energy of 950 megajoules (MJ).

On May 1, 1987, the European Atomic Energy Community (EURATOM) magnet operated at 140% of its rated current. The coil's current reached 15,950 amperes (A), and its peak magnetic field was 9.0 T (design values are 11,400 A and 8 T maximum field). The stored magnet energy was 201 MJ. The EURATOM coil is the largest magnet (by an order of magnitude in either size, weight, or stored energy) to ever attain such a high field.

The magnet, which uses a niobium-titanium conductor, was cooled by forced-flow helium at 15 times the earth's atmosphere. During this record-breaking run, the input helium temperature was 3.7 K and the output temperature was 4.2 K. The data show that the coil maintained its stability.

In August 1987, both the EURATOM and General Electric-ORNL coils in the six-coil array were energized to 9 T, reaching a maximum of 9.1 to 9.2 T in the corner region.

Analysis of all the tests and documentation comparing all the coils will occupy the Large Coil Program staff for many months. A technical report comparing the performance, reliability, and economics of operating magnets of different designs is due out in the spring of 1988.

European tokamak has ORNL gun for plasma refueling

A frozen-hydrogen pellet gun developed at ORNL for refueling fusion plasmas has been installed at the Joint European Torus (JET) in Abingdon, England. JET, a European Community tokamak, is believed to be the most likely of the world's fusion devices to attain records in energy and particle containment in the next several years.

Because of the success of ORNL's pellet fueling experiments on the Tokamak Fusion Test Reactor at Princeton Plasma Physics Laboratory, the European Community asked DOE and ORNL for help on JET. In response, ORNL developed a powerful three-gun repeating pneumatic injector (RPI) that can fire pellets of three different sizes (for experimental purposes) at speeds up to 1500 m/s (5000 ft/s) into JET's 100-million-degree plasma.

High velocities are required to propel pellets to the center of the plasma and increase its density. To produce significant power, the plasma of a fusion reactor must have a particle density of 100 trillion/cm^3. Pellet fueling is superior to traditional gas refueling techniques because it is better able to deposit the hydrogen fuel in the plasma center, where most fusion reactions occur. The use of pellet fueling on small experimental fusion devices has improved their performance by a factor of two.

Six Energy Systems researchers, headed by Stephen Combs of ORNL's Fusion Energy Division, accompanied the injector to England in late April 1987 and oversaw its reassembly and installation in May. The JET pellet injector task is part of a broad collaboration between the United States and Europe on the development of fusion energy.

Under the direction of Stan Milora of the Fusion Energy Division, ORNL pioneered pellet-fueling technology, which has become the standard procedure for fueling advanced fusion devices. Now that the JET injector has been installed, Milora's group is setting its sights on another European tokamak. Researchers led by Chris Foster are now building a centrifuge-type injector for the Tore Supra tokamak in Cadarache, France, for a 1988 collaborative study of plasma fueling and exhaust.

Biology Division consolidated

To cut utility costs and increase funds available for research, ORNL's Biology Division has undertaken a major consolidation of space. Building 9207 is expected to be vacated after October, and staff members from 9207 will be working in tighter quarters in three division buildings at the Oak Ridge Y-12 Plant: 9211, 9220, and 9224. No changes will occur at three remaining buildings: a maintenance building, Building 9208, and Building 9210, the "mouse house" that is home to an internationally known mouse genetics program.

The consolidation was undertaken by division management to reduce the high cost of building operation. According to ORNL figures, the cost of utilities (heating, cooling, water, and electricity for other building needs) had consumed 25% of the Biology Division's basic research budget.

Stephen V. Kaye, interim director of the Biology Division until a permanent director is found, estimates that the consolidation could reduce the division's electricity bill by $1.2 million to $1.6 million.

DOE has asked one of its contractors, Oak Ridge Associated Universities (ORAU), to consider providing a new home for the biologists. If ORAU agrees to take over the research and provides a workable plan, Energy Systems would have to give up the Biology Division, which in the 1960s was the jewel in ORNL's crown.

Three years ago, ORNL and DOE had proposed building a $35-million Life Sciences Complex near ORNL's Environmental Sciences Division to house the Biology Division. However, because of the commitment to reduce the federal deficit, approval by Congress was not obtained for the new complex. A recent proposal to build a $9.7-million molecular genetics laboratory at the same ORNL site may be more acceptable to Congress.

ATF vessel arrives in June

The circular vacuum vessel for the $20 million Advanced Toroidal Facility (ATF), ORNL's new fusion research device, arrived June 13, 1987, at the Fusion Energy Division. The facility is expected to be operating later this year.

The 9-ton stainless steel vessel was built by Pittsburgh Des Moines Steel Corporation in Pittsburgh, Pennsylvania. It will contain the fusion plasma—a hot, dense gas made of charged particles—that in a fusion reactor could react, or fuse, releasing

The new pressure vessel of the Advanced Toroidal Facility.

large amounts of energy. The plasma will be heated to 30 million degrees using neutral beams and will be confined magnetically by external water-cooled copper magnets.

The ATF, a type of stellarator, will be used to study ways to improve toroidal devices such as the stellarators and related tokamaks. Like the tokamak, the ATF is a doughnut-shaped fusion device that uses magnets to confine a plasma. Unlike the tokamak, the ATF and similar devices known as stellarators do not require a plasma current for plasma confinement. In addition, the vacuum vessels of the tokamak and the ATF are shaped differently; the tokamak vessel resembles a smooth doughnut, and the ATF vessel looks like a cruller.

Construction of the vessel involved meeting rigid dimensional specifications, allowing some magnetic coils to be closely fitted in the grooves spiraling around the twisted vessel. The manufacturer was required to limit deviations from the specified dimensions to 1 cm in 5 m.

The original plans called for the ATF to begin operation in late 1986, but the manufacturer encountered difficulties with fabricating the vessel. As a result, the ATF experimental program has been delayed about a year.

10th Distinguished Scientist selected

Bernard Wunderlich, a renowned chemist, has been named the tenth University of Tennessee-ORNL Distinguished Scientist. A professor of physical chemistry at Rensselaer Polytechnic Institute (RPI) since 1965, Wunderlich is known for his work in thermal analysis of polymers. From 1963 to 1965 he was an associate professor at RPI and before that an assistant professor at Cornell University and an instructor at Northwestern University.

The Distinguished Scientist Program, funded by the State of Tennessee and DOE, was created to attract researchers of national and international stature to the Knoxville-Oak Ridge community.

Superconductivity data base in Oak Ridge

A national superconductivity data base has been established by DOE in Oak Ridge. The computerized data base is accessible through DOE's Office of Scientific and Technical Information (OSTI). OSTI offers on-line access to data, information on research in progress, and bibliographic data bases. The information is also available through electronic mail.

In announcing plans for the data base, DOE Secretary John Herrington said, "If American scientists are going to stay in the forefront of this research, and American industry in the forefront of its application, we must provide a better way to facilitate the free flow of information."

Nickel aluminide alloy licensed

Energy Systems has granted exclusive rights to Armada Research Corporation of Detroit for use of a modified nickel aluminide alloy developed at ORNL. Armada Research will use the alloy in resistance heating elements, such as those employed in electrical appliances and furnaces.

The alloy has the potential of making the U.S. heating-element industry more competitive in world markets and less dependent on costly foreign supplies of strategic metals.

A key advantage of the alloy is the domestic abundance of its elements. It could replace heat-resistant alloys containing imported cobalt and chromium, easing concerns about fluctuating prices and politically motivated supply interruptions.

Lowell Robinson, president of Armada Research, said: "We are very encouraged by early test results and believe that the aluminides offer significant advantages as a heating element material. We hope to begin supplying production quantities through our subsidiary, Hoskins Manufacturing Company, within 24 months."

Energy Systems negotiated the agreement under a waiver of patent rights from DOE and claims no interest in the funds received under the licensing agreement. Instead, under a DOE-approved formula, royalties will be used by Energy Systems to create a technology fund to support development and transfer of other inventions having commercial potential.

The agreement marks the second licensing of the nickel aluminide alloy for a specific industrial application. In December 1985, Cummins Engine Company, Inc., acquired exclusive rights to its use for large diesel engines. Energy Systems retains rights for other applications.

Intermetallic alloys, such as nickel aluminides, become stronger at high temperatures but generally are brittle. However, ORNL has modified nickel aluminide alloys to make them ductile without sacrificing the important property of high-temperature strength. As a result, these special alloys can be shaped into useful components for energy-efficient systems operated at high temperatures.

Other potential applications for modified nickel aluminides include high performance jet engines, gas turbines, advanced heat engines, and heat exchangers in nuclear and coal-fired steam plants.

REMOTEC gets rights to servomanipulator

Energy Systems has signed an exclusive license agreement with the Remote Technology Corporation (REMOTEC) of Oak Ridge for commercialization of the ORNL-developed Advanced Servo-manipulator (ASM). This agreement is one of 15 licenses signed by Energy Systems and the fifth with a local firm.

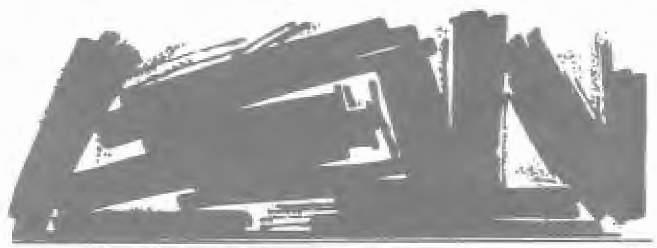
The ASM is a robotlike device that has been used at ORNL to demonstrate control of a nuclear fuel reprocessing "factory of the future" by a human operator from a remote location. The two-armed, gear-driven ASM allows the human operator to perform work in distant hazardous, radioactive, or otherwise inaccessible environments. It could be used for future assembly, exploration, or maintenance tasks in space, deep under ground, or in the ocean.

REMOTEC has acquired access to the government-sponsored technology under two separate licenses. One covers the ASM and three hardware components on which patents have been applied for—an electromechanical actuator, remote tong-tool catch, and master controller. The second covers copyrighted system control software and the dual-arm master controller design.

REMOTEC, Inc., has acquired the rights to develop a commercial version of ORNL's Advanced Servomanipulator.

REMOTEC, which plans to provide specialized robotic equipment to replace human workers in hazardous environments, will invest its own funds in ASM development as part of the technology-transfer agreement. It will join DOE, under a four-year cooperative agreement, in supporting continuing development of a commercial version of the ASM based on the ORNL prototype.

Energy Systems has also granted licenses to four companies to manufacture and market products using ORNL-developed whisker-reinforced ceramics. The companies are Dow Chemical Corporation, Iscar Ceramics, American Matrix, and High Velocity Tool Company. The latter two companies are based in Oak Ridge.



BOOKS

***Survival Strategies for New Scientists**, by Carl J. Sindermann, Plenum Publishing Corporation, New York (1987). Reviewed by W. S. Lyon, consultant, ORNL's Analytical Chemistry Division.*

Survival Strategies for New Scientists is the third book in Carl Sindermann's self-help-for-scientists trilogy. In this book the author returns once more to the themes and ideas that he developed in his first book, *Winning the Games Scientists Play*. The thesis of the new book is captured in his statement that "doing good science is a worthwhile career objective, but there are interpersonal strategies, some quite complex, which enhance the pleasures of doing it." These strategies he calls scientific games. The book is directed to junior members of the scientific community: graduate students, postdocs, and new hires in academia, government, or industry. One might say that this volume is for the sons and daughters of those for whom *Winning* and *The Joy of Science* were written (both were reviewed in the Books section of the ORNL *Review*—see Volume 17, Number Three, 1984, and Volume 19, Number 3, 1986).

Sindermann outlines procedures for beginning a scientific career using devices such as block diagrams and "follow the line panels." They remind me of the oversimplified personal evaluations in the Sunday supplements, *Readers Digest*, and pop psychology paperbacks.

Survival Strategies is a blend of near homespun philosophy and serious advice based on the author's observations and experiences as a distinguished biologist. He suggests that young scientists "Try it"—that is, follow in the footsteps of older ones by writing papers, giving talks, serving on committees, etc. However, he cautions young scientists to "never prepare an oral presentation that cannot be given without the slides should the projector break down" and advises them to "go regularly to the library and read both in your field and in general science news as well."

Many enlightening discussions of pathways to success are presented in this book. A particularly intriguing one concerns the many facets of professionalism. Sindermann elaborates on this subject in several chapters.

The book contains an illustration that could be used as a career planning tool (see the chapter, "Characteristics of Science Workplaces"). The figure, which strongly resembles many personal evaluation schemes for scientists, has five bar graphs, each subdivided into segments of increasing responsibility. The figure is titled "Major Positions in the Hierarchies of Science," and the five bar graphs are labeled Professional Society, Academic/Institute Rank, "In-group" Status, Research Grants, and Reviewing and Editing. Each bar graph represents the beginner state at the bottom and the exalted state at the top (e.g., in the Professional Society graph from member through committee member on up to society president). Presumably, a line drawn through each bar at the proper level will give a profile of the person. The beginning scientist would do well to study this figure carefully and use it for career planning, considering that this type of evaluation is often used for salary review and promotion.

Some readers may not feel comfortable with Sindermann's rather pragmatic and unromantic approach to a science career. Most, however, will probably agree with many aspects of his presentation. For practicing scientists, reading the book can be a consciousness-raising experience. For those contemplating or just beginning a career in science, the book offers a wealth of experience and wisdom. ornl

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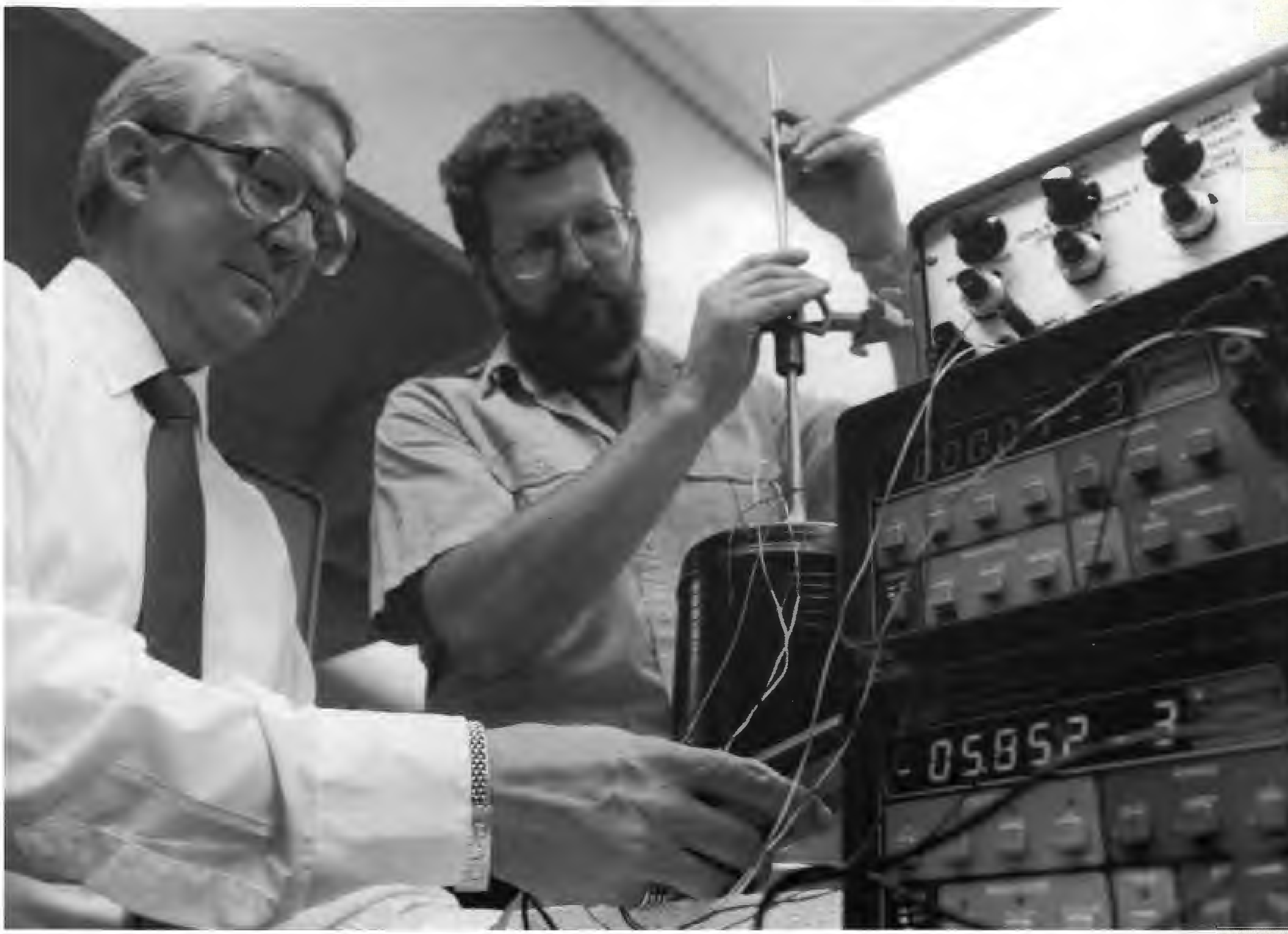

Lynn Boatner (left) and Brian Sales measure the drop in resistivity of an yttrium-barium-copper-oxygen material chilled by liquid nitrogen. They were the first at ORNL to form powders of rare-earth compounds of the new class of superconducting ceramics made of lanthanum, barium (or strontium), copper, and oxygen. For an overview of ORNL research on the new superconducting ceramics, see page 2.