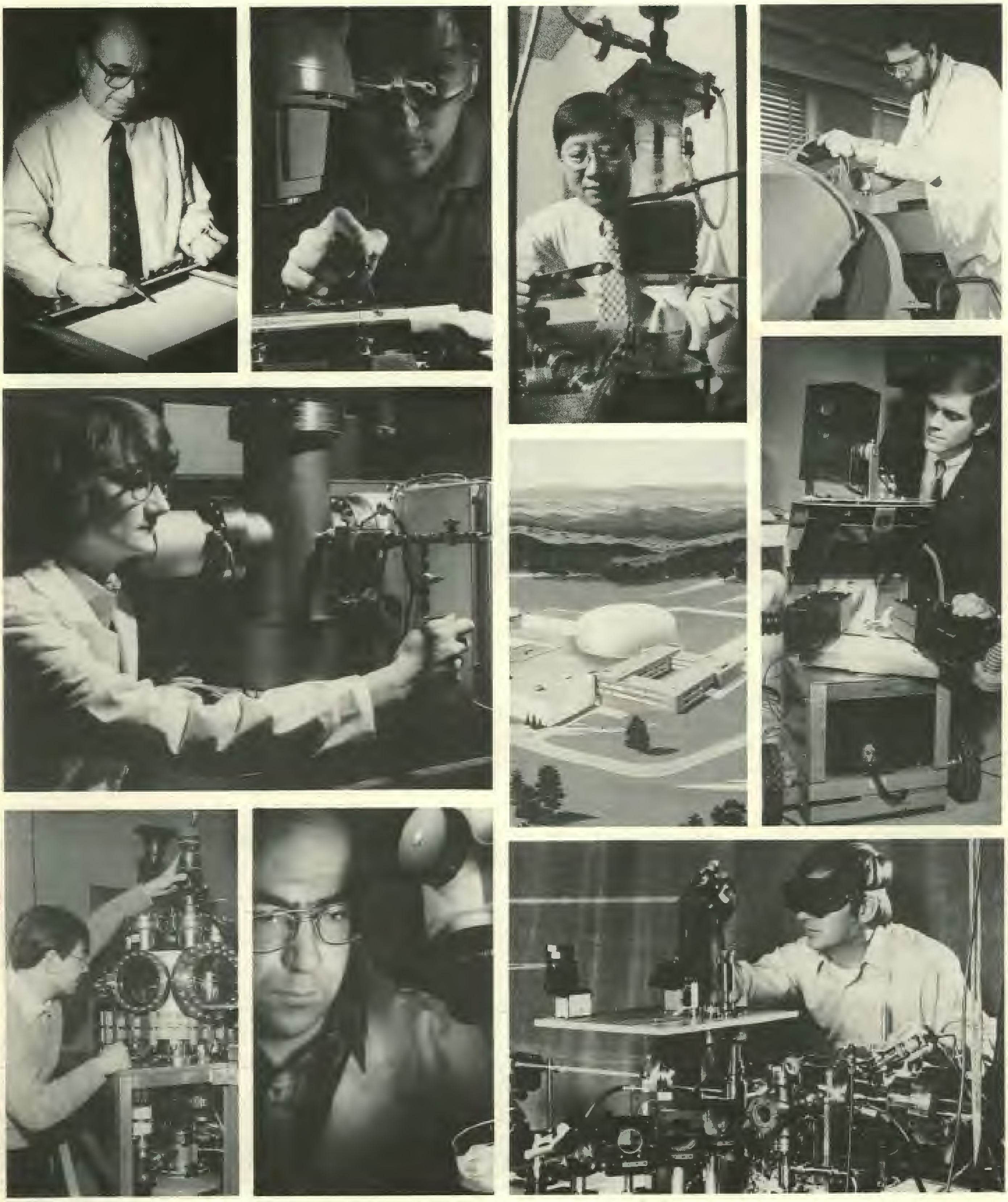
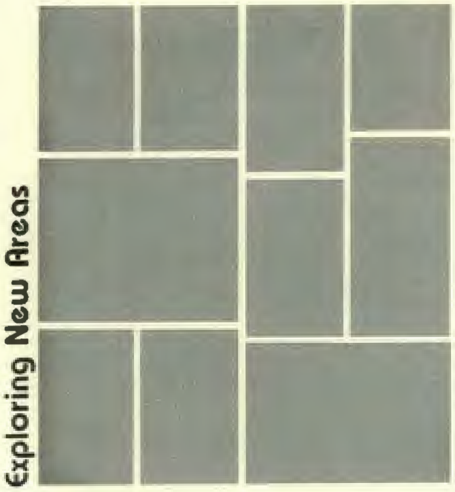
Number Two 1985

Oak Ridge National Laboratory review

Exploring New Areas



State of the Laboratory—1984



THE COVER: ORNL researchers here are "exploring new areas," the theme of ORNL Director Herman Postma's 1984 "State of the Laboratory" address. These research areas, many of which were initiated by internal funding, include the development of new alloys, the design of a new research reactor, and applications of robotics and artificial intelligence. See Postma's address, beginning on page 1.

Oak Ridge National Laboratory

review

VOLUME 18 **NUMBER TWO 1985**

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By HERMAN POSTMA

In this updated report based on his February 5, 1985, address to the staff, Postma notes that the Laboratory's return on some investments has been remarkable. Seed money projects have brought about $4 in research funds to ORNL for every $1 invested by the internal Exploratory Studies Program. ORNL research also has helped others save money. For example, Laboratory recommendations on energy options have helped Liberia save up to $20 million annually. ORNL studies of the potential thermal shock problem of commercial nuclear reactors saved electric utilities millions of dollars.

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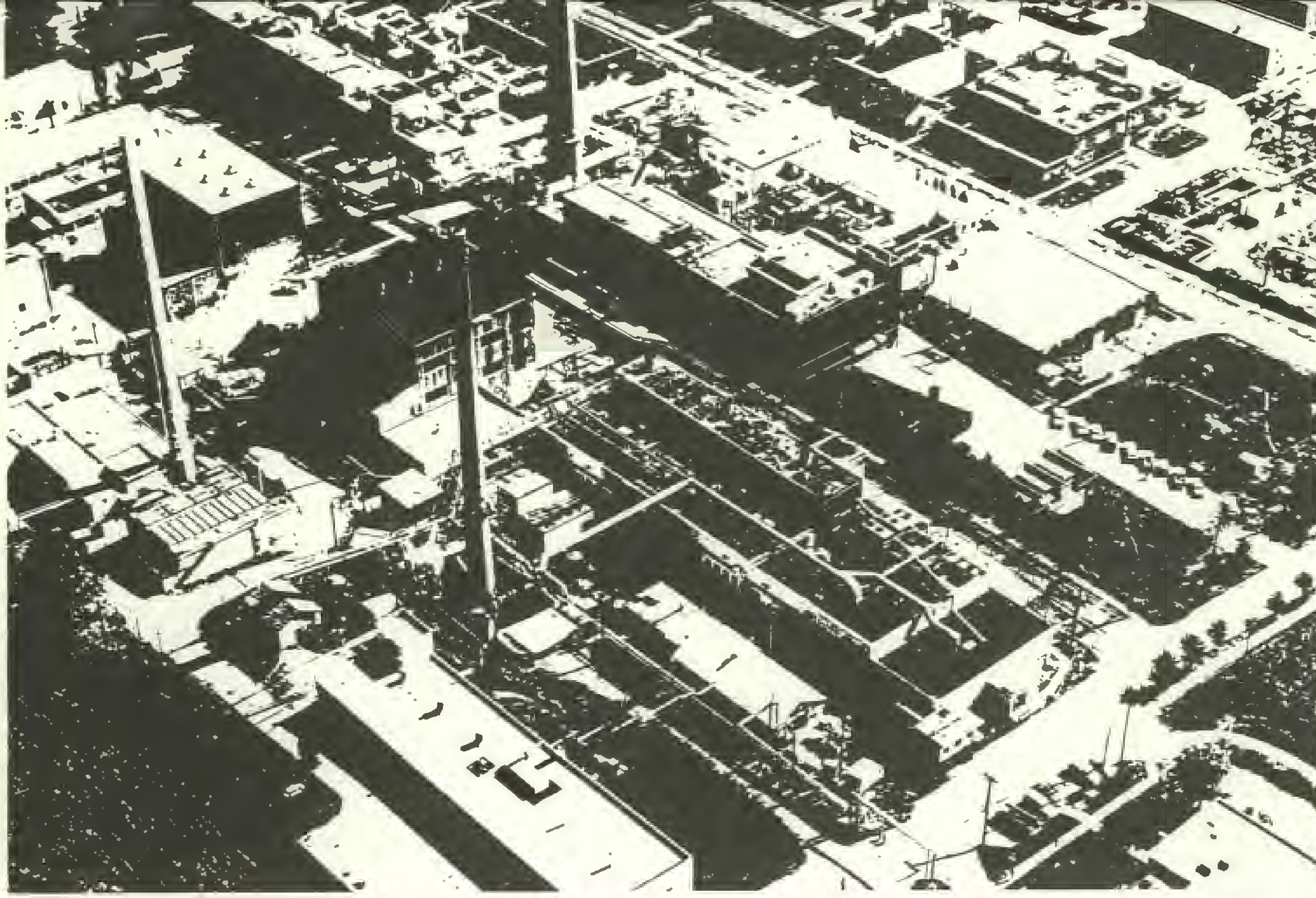


State of the Laboratory—1984:

Exploring New Areas

By HERMAN POSTMA

The areas of research and development in which Oak Ridge National Laboratory becomes involved are determined by anticipating the interplay between external and internal forces. Our research directions are often influenced by public opinion and the will of Congress. For example, by the 1970s when energy shortages and antinuclear sentiments surfaced, the Laboratory had already begun the shift from conducting nuclear research almost exclusively to taking a diversified approach to the energy question; we began large programs on energy conservation and multiple energy sources—coal, biomass, breeder reactors, fusion, solar and geothermal energy—and expanded our studies of the health and environmental effects of energy consumption. In the early 1980s after detente had ended and new tensions developed between the superpowers, we began doing defense-related work and are now beginning to contribute to the new "Star Wars" antimissile defense program initiated by the President.

At the same time, we are receiving support for many "science-driven" programs that are outgrowths of "Seed Money" projects initiated by ORNL researchers and funded by the Laboratory's Exploratory Studies Program. These projects include the development of new alloys for energy-efficient, high-temperature engines; ion-implanted materials for artificial hip joints; and special glasses for possible storage of nuclear wastes. In this year's annual report to the staff, I will focus on the theme "Exploring New Areas" as I discuss our new research missions (resulting from external and internal influences) and the contributions that have influenced science and technology.

Perspective on 1984

As always, each year at the Laboratory is marked by considerable change. In the 11 years that I have been Director of the Laboratory, ORNL has responded to the will of four Presidents, three energy agencies, a half dozen energy agency heads, and two contractors. Last year was dominated by one very fundamental change—the transition from one operating contractor, Union Carbide Corporation's Nuclear Division, to our current contractor, Martin Marietta Energy Systems, Inc. Perhaps more significant for ORNL, however, was what did not change: the Laboratory's steady improvements in creativity and in the quality of our publications and research and development (R&D). These improvements will be measured by the U.S. Department of Energy, which is now paying closer attention to the details of its contractors' performances.

April 1, 1984, brought a smooth transfer of operating responsibility, a new managerial outlook to stimulate progress toward key long-term objectives, and active interchanges within our new Martin Marietta "family." The new award-fee system under which Martin Marietta is paid is based on the company's success in meeting DOE performance criteria for ORNL and other DOE facilities. This new performance-based management structure puts a premium on innovative, well-focused, and timely technical and managerial accomplishments—a good fit with ORNL's traditional strengths.

The new Waste Operations Control Center, located near ORNL's cafeteria, monitors tank levels and flow rates of radioactive materials from vents and hot cells in in-plant buildings. The center collects data from 250 sensors scattered around ORNL's grounds. Because the new information collection system records data automatically (previously they had been manually recorded and logged), the new center will greatly increase the speed of detecting trends or sudden changes in conditions.

We can expect that Energy Systems will influence the plans and activities of ORNL, the other facilities, and the region itself. Our past emphasis on institutional planning to chart long-range directions for ORNL and a strategic approach to defining and developing appropriate energy R&D missions will carry over into Energy Systems as a whole. The company is now doing strategic planning for all its plants. In addition, Energy Systems President Ken Jarmolow has established a new ORNL Advisory Board to review the Laboratory's multiple roles and to help us define the most important missions within each program area.

Already, Energy Systems has provided the Laboratory with new accesses to different agencies of the federal government, such as the National Aeronautics and Space Administration (NASA) and the U.S. Department of Defense (DOD), and to parts of the Martin Marietta Corporation with similar interests, such as the Orlando and Denver aerospace divisions and the corporate laboratories in Baltimore.

In this updated report based on his February 5, 1985, address to the staff, Postma notes that the Laboratory's return on some investments has been remarkable. Seed money projects have brought about $4 in research funds to ORNL for every $1 invested by the internal Exploratory Studies Program. ORNL research also has helped others save money. For example, Laboratory recommendations on energy options have helped Liberia save up to $20 million annually. ORNL studies of the potential thermal shock problem of commercial nuclear reactors saved electric utilities millions of dollars.

In the midst of a natural-gas shortage several years ago, ORNL switched from gas to coal to produce steam for heat and other purposes. But coal poses more environmental problems than gas, including acidic runoff water from the coal pile. A system to treat the discharges is now being installed.

The company has influenced our attitudes toward customers, staff, and organizational strategies. We are now more oriented toward pleasing the customer through timely accomplishment. We are giving more recognition to individual achievement, particularly through an annual awards night every spring that will honor many ORNL and Energy Systems staff members for their achievements in invention, science, technology, management, operations, and community service. To improve the efficiency of operations at the three Oak Ridge plants, Energy Systems has consolidated information, computing and telecommunications, technology applications, and other services.

To promote regional economic growth and to provide incentives for effective transfer of home-grown technology to American industry, Martin Marietta has taken several steps to strengthen the Oak Ridge anchor for the Tennessee Technology Corridor. The company has established the Oak Ridge Technology Park to attract industries to the area and thus broaden the Oak Ridge tax base. Martin Marietta has set up a Tennessee Innovation Center to encourage the growth of new firms selling products and services based on technologies spun off from ORNL and the other Energy Systems plants. (At the beginning of 1985, two start-up businesses using ORNL technologies—Redox Sciences, Inc., and Technology Corridor Instrumentation, Inc.—took root in the Innovation Center, which will be the first structure built in the new Oak Ridge Technology Park.)

To further stimulate technology transfer, Energy Systems proposed a plan for owning and licensing patent rights to ORNL-developed technologies to keep them from languishing on the shelf. Under this blanket waiver of patent rights (which DOE approved in February 1985 for profit-oriented contractors such as Energy Systems), the company is seeking the right to patent all inventions made under the operating contract (except for those involving nuclear weapons, enrichment, fusion, and nuclear fuel reprocessing). By owning these rights, Energy Systems would be able to license to different companies the exclusive right to "practice the art" of manufacturing specific products or of providing specific services based on these techologies. In return for the technology and the protection against competition, the licensed companies will pay Energy Systems royalties or license fees, which will all be reinvested in product refinement, prototype production, royalty shares for inventors, university programs, and other technology-transfer activities—all locally.

Broadened Thrusts

In 1984 the Laboratory greatly increased its efforts in several areas. We emphasized identifying and solving our environmental problems. Our environmental actions included hydrofracturing of the last gunite-tank sludges, thus eliminating a 40-year problem; upgrading the gaseous waste-handling system; completing the Waste Operations Control Center; operating the new White Oak Creek, Melton Branch, and White Oak Lake monitoring stations; suppressing groundwater in burial grounds for radioactive wastes; starting construction on a new sewage treatment plant; reducing the inflow and infiltration of contaminated water into underground piping; signing a contract for a new system to treat the steam plant's coal-pile runoff water; expanding the monitoring of our discharges to local streams under National Pollutant Discharge Elimination System permits; obtaining authorization to proceed with construction of a new Hazardous Waste Storage Facility; and meeting the environmental criteria on which the state of Tennessee and the U.S. Environmental Protection Agency concur. Other programs to solve our environmental problems will begin in 1985 under our five-year environmental plan.

We have broadened our collaboration with the University of Tennessee (UT) through the Science Alliance, which extends the resources of both UT and ORNL. Under the Science Alliance umbrella, we have established the Distinguished Scientist Program, which calls for hiring 30 leading experts in a variety of technical fields. In 1984 two distinguished scientists were hired. As a member of the recently established Research Institutions Consortium, the Laboratory is also collaborating with UT and the Tennessee Valley Authority (TVA) in planning joint research projects. Out of this joint planning came UT's "Center of Excellence" in waste management and the construction of the second building of the UT-administered Joint Institute for Heavy Ion Research, which provides working and living space for visiting scientists working at the Holifield Heavy Ion Research Facility. Finally, after recognizing that no U.S. university has a program for teaching measurement and control engineering, we collaborated with UT in setting up a university-industry cooperative research center for training graduate students in this area. Richard Anderson of ORNL's Instrumentation and Controls (I&C) Division has spearheaded the ORNL part of this effort to establish the nation's only graduate program in a dynamic specialty where the number of skilled workers is low and on-the-job training is the rule. So far 28 students have signed up for courses at the new Measurement and Control Engineering Research Center. At least eight companies have agreed to contribute $50,000 a year to help support students and purchase equipment in exchange for the right to use any new technologies developed in the graduate program.

Conferring on solutions to managing ORNL's environmental problems are, from left, Tom Oakes, head of ORNL's Department of Environmental Management; Raymond Wiltshire, ORNL's Executive Director; and Dennis Parzych, director of the Environmental and Occupational Safety Division.

This new program is only one of many examples of ways in which we have broadened our interactions with industry. This past year in the materials area, for example, Cabot Corporation invested $400,000 in a collaborative ORNL-Cabot study of the ductility of long-range–ordered nickel alloys. Babcock and Wilcox (B&W) is collaborating with ORNL on fabricating ceramic composite tubes, using their expertise in making preforms and our expertise in using chemical vapor deposition to toughen ceramics. Like Cabot, B&W will acquire patent and data rights; unlike the Cabot agreement, no funds will be exchanged between the two parties.

We are also becoming increasingly involved in projects involving international cooperation. Such projects, including the International Fusion Superconducting Magnet Test Facility at ORNL (formerly the Large Coil Test Facility) for testing large superconducting coils, will grow in number and will become more important to DOE with the realization that the U.S. government alone cannot pay for increasingly expensive demonstration projects.

In short, an increasing amount of our work is joint in nature, and a greater portion of our funding comes from other sponsors, including other agencies of the federal government, private industry, universities, and foreign governments.

Exploratory R&D Funds: Seed Money

As I mentioned at the beginning, an internal force that has stimulated research at the Laboratory has been our Exploratory Studies Program, which is designed to explore promising staff-originated technical opportunities. This investment in ORNL ideas began with the Seed Money Program pioneered at ORNL ten years ago. In 1984 we created two new discretionary funds in the exploratory R&D program—the Director's R&D Fund, for larger projects, and the Technology Transfer Fund, for commercially promising developments.

The expansion of the Exploratory Studies Program is well justified. We have found that our exploratory R&D initiatives have enlarged both the volume and the scope of Laboratory R&D. Our seed money projects have allowed us to demonstrate new technical capabilities that have attracted new federal funding from agencies such as DOD and the U.S. Nuclear Regulatory Commission (NRC) and induced DOE to give us new lead roles. In addition, several 1982-83 governmental reviews of the national laboratories (by the Packard Committee and the Energy Research Advisory Board, for example) recommended that they be given more flexibility to pursue independent R&D within their established budgets and program guidelines because of evidence that such flexibility has paid off in stronger laboratory capabilities and greater responsiveness to national needs. In principle and philosophy, this direction toward internal selection of good R&D ideas for support is consistent with DOE's move to decentralize R&D decision making and with our own strong view that the best judges of technical opportunities (and risks) are those doing the work and their peers.

Although the source of exploratory R&D funds is not new money but a tax on research program support (overhead), the crucial difference is that these overhead funds go directly back into R&D rather than into services. The money supports priority projects proposed by research staff and divisions. This "overhead with a difference," which amounts to about $3 million, or 1% of the Laboratory's total annual operating and capital funds, turns out to be a good investment—a fact increasingly recognized by DOE.

Since 1974 ORNL's Seed Money Program has supported about 50 projects. The return on this investment has been remarkable: Within the first three years after project completion, more than $4 in new program support has been obtained for every $1 spent. In addition, seed money has funded 25% of ORNL's innovations that received I•R 100 awards (given to 100 potentially marketable inventions each year by *Research & Development* magazine) and has spawned new programs and areas of research that now account for a significant fraction of the Laboratory budget. For example, our high-voltage research program, initiated by Loucas Christophorou using seed money, received $34 for every $1 we invested, and ORNL's coal chemistry research, initiated by Clair Collins under a seed money grant, pulled in 71 times the initial investment.

How does the Seed Money Program work? Each year we select about 20 projects to receive a small amount of funding, ranging from $5000 to $100,000. The seed money is used for one year, just long enough for a project to produce results that can attract attention—and funds—from some sponsor. Because the projects are peer judged, because the money is

Here are the top ten returns on the investment (ROI) of ORNL seed money in projects (through FY 1981).

SEED MONEY TOP TEN RETURNS (PROJECTS THROUGH FY 1981)

		ROI (R/I)	Four-Year Returns
High Voltage	L. Christophorou	34.2	$1.853 M
Ceramic Waste Forms	P. Angelini	39.3	$1.650 M
Nuclear Doping	J. W. Cleland	34.3	$ 971 K
Ion Implantation	B. R. Appleton	18.7	$ 907 K
Coal Chemistry	C. J. Collins	71.1	$ 875 K
Actinide Waste	L. A. Boatner	13.9	$ 865 K
Structural Ceramics	C. J. McHargue	10.6	$ 770 K
Waste Treatment	W. J. Boegly	18.6	$ 765 K
Toughened Ceramics	V. J. Tennery	7.8	$ 750 K
Resource Recovery	R. M. Canon	12.4	$ 741 K

turned over to the investigators in a short time, and because management plays no role in guiding and evaluating the projects, the Seed Money Program has been incredibly successful.

In addition to attracting sponsors and funds, seed money projects have had other benefits. For example, our 12 bioprocessing projects have established ORNL as a center of expertise in developing advanced bioreactors to produce fuel from biomass and remove pollutants from wastewater. Thus we have created the Oak Ridge Bioprocessing Research Facility User Resource, which is attracting outside researchers to the Laboratory to participate in collaborative research.

A seed money project to evaluate low-energy positrons for surface analysis resulted in worldwide use of a development by Lester Hulett and John Dale of ORNL's Analytical Chemistry Division. They found that tungsten is the most efficient material for the moderation (slowing down) of fast positrons. High intensities of fast positrons can be obtained from various radioisotopes and electron linear accelerators (such as the Oak Ridge Electron Linear Accelerator, or ORELA), but their energies are undefined and range over several hundred thousand electron volts. Hulett and Dale prepared the tungsten moderator in a special way to slow down positrons and reemit them at low kinetic energies that could be defined with very small uncertainties (down to 0.3 eV). Such monoenergetic positrons are useful for surface analysis. For example, low-energy positron diffraction (LEPD) has been made possible with the ORNL moderator. LEPD has features that complement and, in some cases, are superior to those of its electron counterpart, low-energy electron diffraction. By injecting slow positrons into solid surfaces, scientists can study lattice vacancies and other defects. Some institutions in the United States and abroad will be using tungsten moderators for the high brightness positron beams that they are designing for microscopy and other studies.

Another product that has received seed money—our inexpensive cement-based grouts used at ORNL's Hydrofracture Facility to dispose of radioactive wastes in layers of underground shale—may have a wider application in the disposal of nonradioactive hazardous chemical wastes. Grouting technologies, pioneered at ORNL and now being tested under the leadership of Les Dole of the Chemical Technology Division, can tailor grouts to the chemical characteristics of particular wastes to prevent them from entering the environment. For example, clays, coal fly ash, and other additives can be mixed with the grouts to immobilize the hazardous wastes and increase their resistance to leaching by water. The grouts show promise for the fixation of hazardous wastes such as fly ashes containing toxic metals, pickling liquor sludges, spent limestone-scrubber solids, oils contaminated with polychlorinated biphenyls (known as PCBs), and polynuclear aromatic compounds. Clean grouts can be used in other ways to solve potential environmental problems: They can be injected into the ground to form an

John Dale (left) and Les Hulett adjust a target for positron spectroscopy. In the center, through the viewport is the shield for the positron source and its tungsten moderator. Tungsten moderators like the one first developed at ORNL are used for positron studies throughout the world.

impermeable curtain against groundwater flow or to fill the voids in a collapsing waste-burial trench, thus stabilizing it and preventing subsidence.

The Biology Division has used seed money to develop a new method for determining whether single chemicals or complex mixtures of agents in industrial discharges and indoor air pollutants cause lung cancer. In this method, a trachea (a component of the respiratory system) is implanted on the back of a rat and is kept open at both ends so that test agents can be piped through it. In the original tracheal implant system, test agents could be delivered only as solutions or from solid pellets and could be introduced into the implant only a limited number of times. In the new model developed by Ann Marchok, the trachea can be exposed an unlimited number of times to noxious chemicals in any form, including gases used in animal inhalation studies. In experiments in which implanted tracheas were exposed to gases for the first time, Marchok and her colleagues found preliminary evidence that formaldehyde can act as a promoter of cancer in the lung. This open-ended exposure system helps bridge the gap between intact animal studies and short-term in vitro tests by quantifying the direct effects of toxic and carcinogenic agents singly and in mixtures on lung tissue. Many laboratories have expressed interest in using the new tracheal implant method.

John Kessler uses a V-blender for mixing dry solids to test grouts on an engineering scale. ORNL is now adapting grouting technologies used to immobilize radioactive wastes at the Hydrofracture Facility to the fixation of hazardous chemical wastes such as fly ashes containing toxic metals and oils contaminated with polychlorinated biphenyls, or PCBs.

Open-ended tracheal models have been implanted on the backs of these rats to determine whether test chemicals, including gases like formaldehyde, cause lung cancer. The ORNL implant permits multiple exposures by agents in any form.

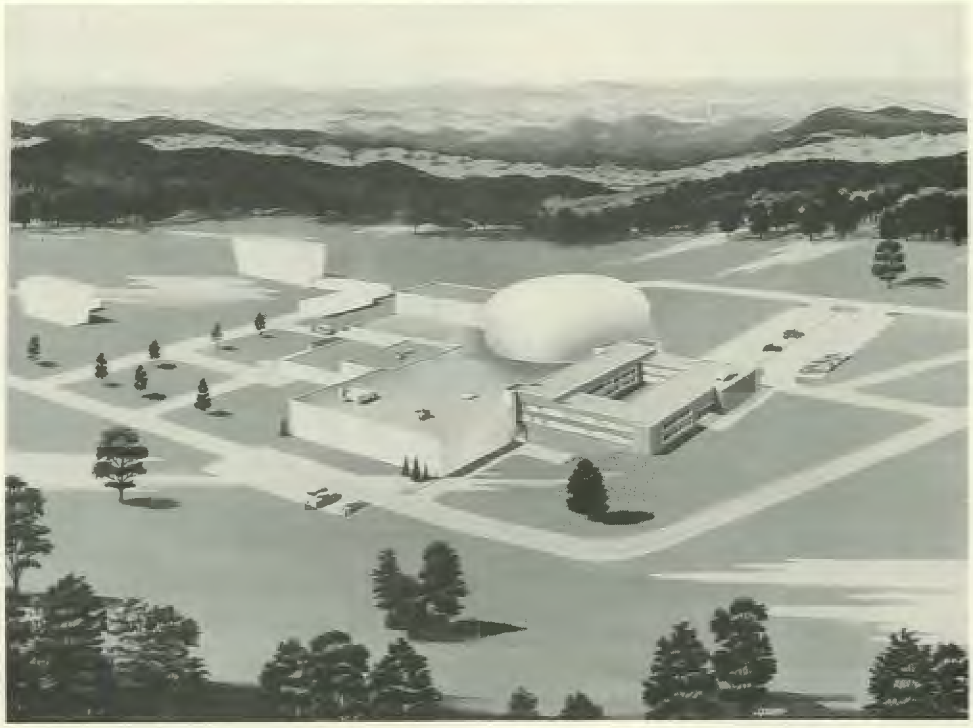
Exploratory Funds: Director's R&D Fund

In early 1984 the Director's R&D Fund was established. This fund has been used to support FY 1984 and 1985 projects involving about 20 person-years at an annual level of $1.5 million. Unlike seed money, this fund supports larger projects (at a level of $100,000 to $600,000) over a period of several years. The projects were selected from proposals solicited from divisions in target areas defined by the Laboratory's senior management. The program is just beginning, but some success is already apparent.

Projects being supported by the Director's R&D Fund are

• ***A preconceptual design of a research reactor***. The goal is to design an improved version of ORNL's High Flux Isotope Reactor (HFIR), which would be the world's best reactor. The new "HFIR-II" would be called the Center for Neutron Research. With such a reactor, the United States can regain its leadership in neutron scattering research, understanding of radiation damage to materials for fission and fusion reactors, and production of heavy elements for research or isotopes for commercial use. Our preliminary design aims at a threefold to tenfold improvement

The High Flux Isotope Reactor (HFIR) at ORNL has been used for many years for isotope production, materials testing, and neutron scattering studies. ORNL is now designing an improved version of HFIR, which would be the world's best research reactor.



Artist's rendering of ORNL's Center for Neutron Research (CNR), the proposed replacement for HFIR. This user facility would employ heavy water to cool the nuclear fuel core and to reflect neutrons back into the core. By contrast, HFIR uses ordinary water as the coolant and beryllium as the neutron reflector. If approved, CNR would be operating by 1995.

in neutron flux. The project designers are Ralph Moon of the Solid State Division, David Bartine of the Engineering Technology Division, and Wallace Gambill of the Chemical Technology Division.

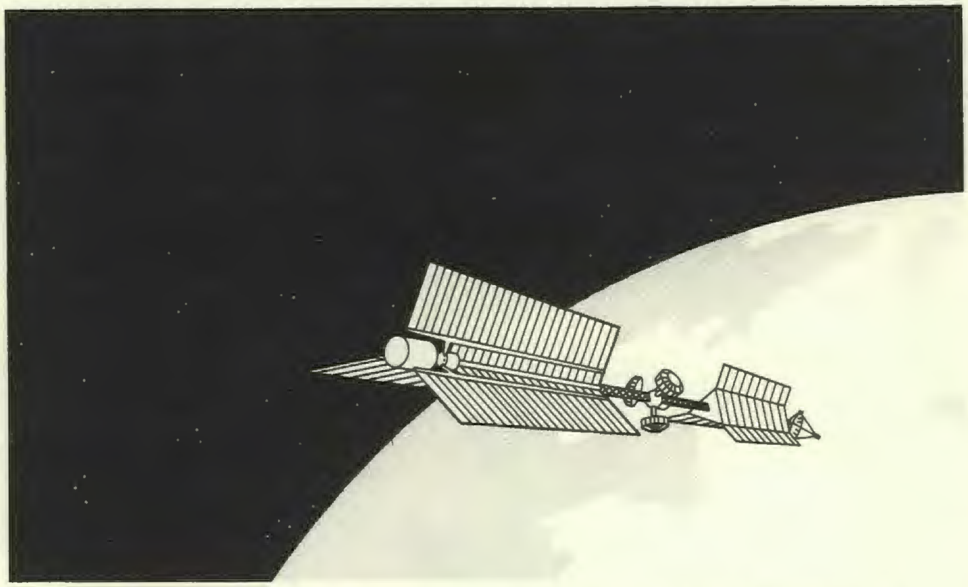
• ***Nuclear power options viability study***. In a joint undertaking with UT and TVA, Jim White of the I&C Division and Don Trauger of Central Management are leading a team of ORNL researchers in studying smaller reactors that are designed to be safer, less costly, more efficient, and easier to license than the present generation of commercial reactors used to produce electricity. One goal of the study is to determine what research is needed to improve advanced reactor concepts so that they will attract investors and gain public acceptance. Examples of reactor concepts under study are the modular high-temperature gas-cooled reactor (pebble-bed reactor) under development at ORNL, liquid-metal-cooled reactors, and the Swedish process-inherent ultimately safe (PIUS) reactor. The researchers are investigating whether such reactors could be ready for commercial orders by 2000–2010 (the anticipated "Second Coming" of nuclear energy), whether they could be competitive with coal-fired generators, and whether they could meet a range of investment, siting, operational, and regulatory criteria in the United States. Preliminary findings in the new study include the following: (1) electricity demand will increase, making the demand for new reactors more likely; (2) current light-water reactors more than meet safety standards and are not considered a threat to public safety; (3) the risk of investing in new reactors seems to stem from public concern about the possibility of accidents and construction delays that raise total cost; (4) reactor regulation (which may be influenced by ORNL study results) will improve slowly; (5) reactor operation and maintenance costs have risen sharply, particularly for safeguards and security; and (6) introducing new reactor concepts requires a long time and a great deal of money.

• ***Intelligent control and concurrent computation***. With the help of Laboratory management support, the Center for Engineering Systems Advanced Research (CESAR) was proposed to DOE and later established by DOE's Division of Engineering and Geosciences. CESAR is a national center for multidisciplinary, long-range R&D in machine intelligence (computer architectures for problem solving, perception, etc.), artificial intelligence (AI, which simulates human reasoning), and advanced control theory for energy-related applications. The CESAR director is Chuck Weisbin, and the two principal investigators are Jacob Barhen of the Engineering Physics and Mathematics Division and William Hamel of the I&C Division.

CESAR's initial research emphasis is on autonomous remote operations with specific applications in unstructured, dangerous environments where radioactivity, toxic chemicals, or explosives may be present. Examples of environments with significant risk are fuel reprocessing and waste handling facilities, coal mines, and the ocean. Research objectives include (1) modeling the dynamics of flexible structures (e.g., robot manipulators handling heavy loads), (2) developing software for real-time planning with sensor feedback (e.g., obstacle recognition and avoidance by a robot), and (3) formulating concurrent algorithms for implementation on advanced parallel computers (e.g., for a robot to understand and respond to the images it "sees" requires many simultaneous high-speed calculations, and the computation of forces and torques to appropriately guide a manipulator requires the solution of complex dynamics equations many times per second). In the summer of 1985, CESAR will be installing a high-performance 64-node concurrent processor machine based on the hypercube developed by the California Institute of Technology.

Tom Swift, a University of Tennessee student in electrical engineering, experiments with the HERMIES-I robot, which is currently being used to test artificial intelligence (AI) methods for making the robot work in and respond to changes in a hazardous environment. The mobile device has two HERO arms, sonar sensors, and a broad resolution camera. In the background is an LMI LISP machine dedicated for AI research by a group in ORNL's Center for Engineering Systems Advanced Research. The HERMIES robot incorporates mobility, manipulation, and sensory feedback into a low-cost operable system.

Additional support from the Director's R&D Fund will go to ORNL's Mathematical Sciences Section for research on the development of basic algorithms necessary for concurrent computation of large-scale scientific problems. The research is initially focused on the design of algorithms for solving matrix equations resulting from partial differential equations. These algorithms may be used to build parallel codes for the solution of applied computational problems in many disciplines. The project will include mathematical experiments on a hypercube



ORNL work for the Strategic Defense Initiative—the so-called Star Wars antimissile defense research effort—focuses on three technologies: multimegawatt nuclear reactors in space to power surveillance satellites and sources of particle and laser beams, flywheels for energy storage and pulsed power, and neutral particle beams for shooting down enemy missiles and warheads from space.

parallel computer with 64 processors. Bob Ward directs the project, and the principal investigators are Bob Funderlic, Al Geist, and Mike Heath.

The application of AI to reactor controls is being studied by another ORNL group, separately from CESAR. With support from the Director's R&D Fund, Ned Clapp, Frank Clark, Jim Mullens, Pedro Otaduy, and David Wehe of the I&C Division are trying to use AI methodologies to understand and better control the operation of nuclear reactors. Drawing on the expertise of ORNL's reactor operators, who rate among the best in the world by keeping our reactors operating 98% of the time, the I&C group will develop an AI "expert advisor" for operators at HFIR. The expert system is intended to monitor the reactor's status and identify incipient transients and failures using pattern recognition techniques. It will perform diagnostics, and if it spots anomalies or potential dangers, it will issue warnings, recommend procedures and corrective actions, and explain the logic behind its decisions—all in simple English.

• ***Protein engineering***. This effort in the Biology Division involves changing the structure of the product of a gene—an enzyme or other protein—by genetic engineering techniques. One goal is to alter an important plant enzyme so that it no longer uses atmospheric oxygen to break down carbohydrates (which it simultaneously helps to synthesize from atmospheric carbon dioxide, or CO_2). In the hope of preventing this CO_2 fixation enzyme from wasting energy and decreasing plant growth and yield, a group of ORNL researchers (Fred Hartman, Frank Larimer, Richard Machanoff, Bob Foote, Sankar Mitra, Bob Fujimura, and Salil Niyogi) is preparing mutant forms of the enzyme that might be less prone to catalyzing the oxygenation reaction.

• ***Strategic Defense Initiative (SDI)***. ORNL has received some funding and is seeking additional support from the SDI (popularly known as "Star Wars") program to assess the feasibility of developing an effective missile defense, space-based or otherwise, in a five-year, $26-billion national program. Under the direction of Dave Bartine, we expect to make contributions in three areas: (1) development of refractory materials, alkali metal cooling systems, shielding, and instrumentation for multimegawatt space nuclear reactors, which are needed to operate surveillance satellites and to power directed-beam energy weapons such as lasers and particle accelerators and kinetic energy weapons devised to shoot down enemy ballistic missiles and warheads; (2) development of flywheel technology to store energy for these weapon systems (which combines our mechanical energy storage program for conservation with centrifuge technology developed at the Oak Ridge Gaseous Diffusion Plant); and (3) adaptation of neutral particle beam technology from our fusion program to the needs for strategic defense in space. We expect to apply the experience that we have gained over a number of years to the new problems of SDI. We will be working with Martin Marietta Aerospace at Denver on these challenges.

Already a negative-ion source developed in the Fusion Energy Division (FED) has demonstrated the world's highest simultaneous current density output and pulse length. The Surface Ionization Transverse Extraction (SITEX) ion source, developed by Will Stirling, is derived from the Laboratory's development of neutral beams for heating fusion plasmas. The source issues a beam that does not diverge, or spread out, appreciably over thousands of kilometers.

How well the Director's R&D Fund will do in stimulating external support of large new research programs remains unclear. We are still in a "we'll see" period, but we do claim partial success after just one year. We are beginning to receive SDI funds from DOD, and DOE has funded our studies of future nuclear power options. Clearly the projects being funded are high risk—that is, they have a higher probability of failing to attract large amounts of funding than seed money projects. Even so, the greater size of the fund puts more pressure on the Director to identify research areas with a reasonable probability for success.

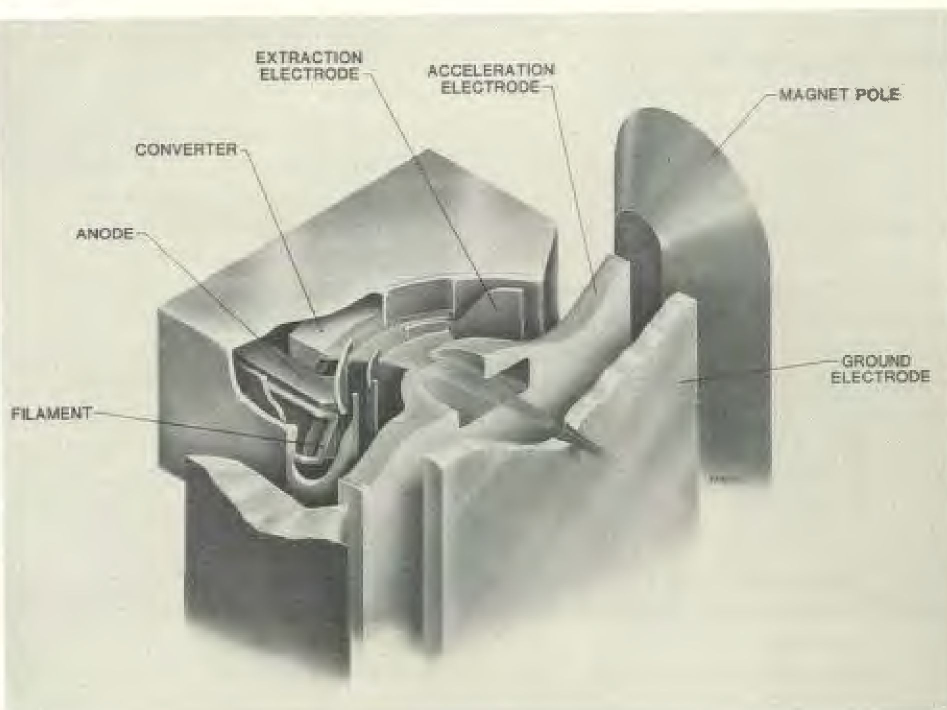
Exploratory R&D Funds: Technology Transfer Fund

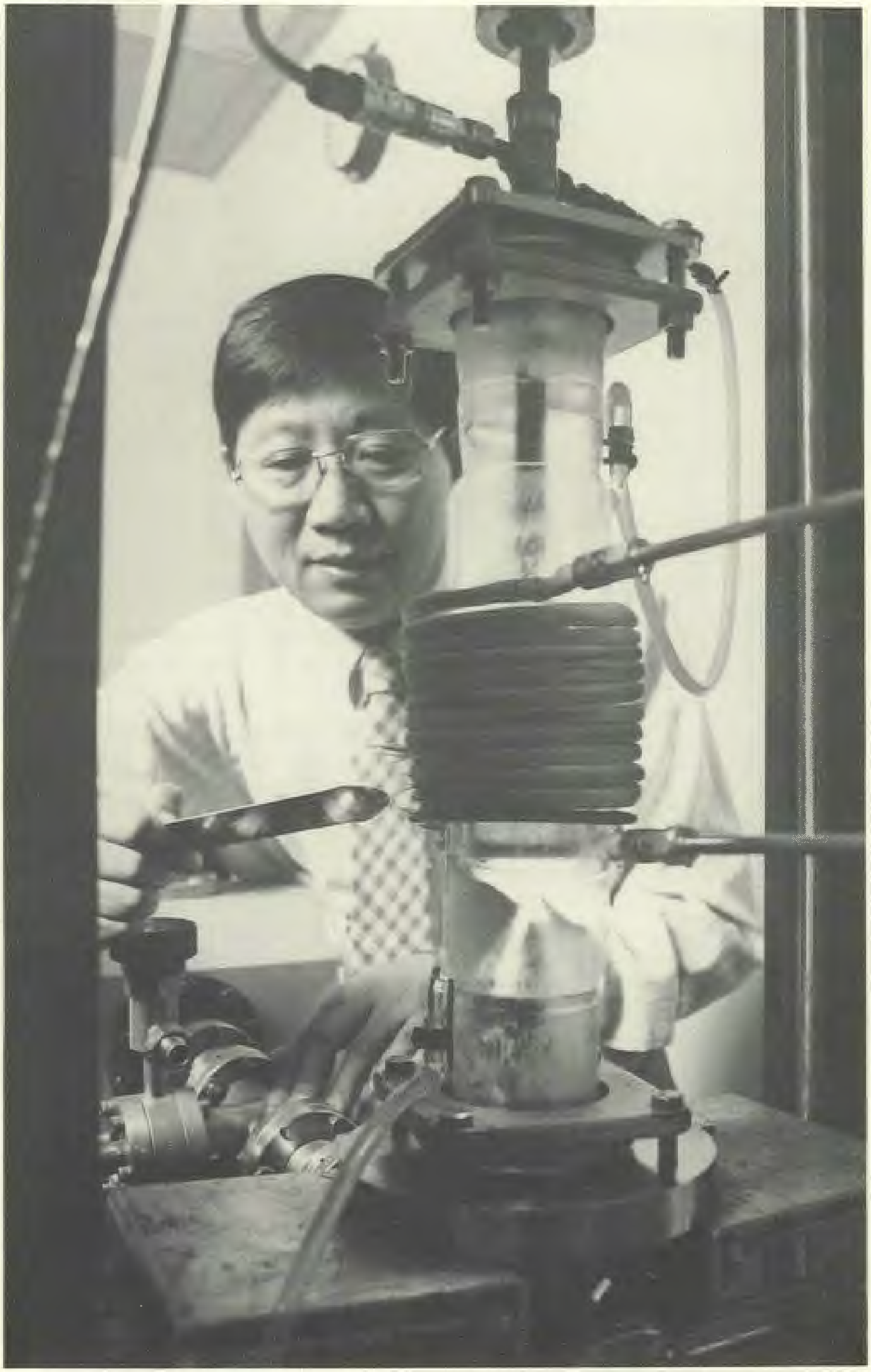
In 1984 we concentrated on a new industrial technology initiative. Our goal was to increase both the rate of innovation at ORNL and the frequency of effective commercialization. Our approach was to select a few commercially promising technologies developed at ORNL and bring them to the stage where industry can judge their commercial potential. We contributed $100,000 to the new Technology Transfer Fund, and DOE headquarters agreed to match our investment. Then we selected 5 of 24 ideas submitted by the staff for support by the $200,000 fund.

The projects that we have tried to make commercially attractive are modified nickel aluminide alloys, a pulsed-helium ionization detector for gas chromatography, multicomponent separations by continuous chromatography, electronic autofluorography, and remote analytical instrumentation. The most successful of these projects has been the nickel aluminide alloys developed under the leadership of C. T. Liu of the Metals and Ceramics (M&C) Division using 1982 seed money. These alloys modified at ORNL are of particular interest to the commercial world because of their light weight, their resistance to corrosion, and their peculiar property of becoming stronger and yet remaining ductile—able to be deformed or shaped without breaking—as they become hotter. The long-range ordering of nickel aluminide increases the alloy's strength with rising temperatures; the aluminum in the alloy contributes to the light weight and to corrosion resistance because aluminum forms protective oxide scales; and small additions of boron make the alloy ductile. Such modified alloys are in demand for components of energy-efficient engines operated at high temperatures as well as heat exchangers, turbines, valves, and vessels for coal gasification and liquefaction systems.

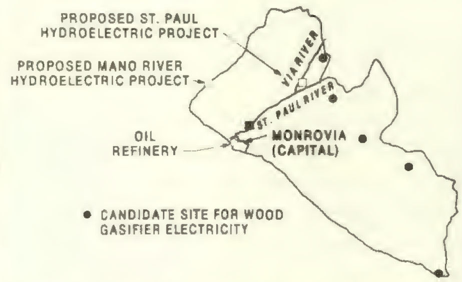
Efforts are now focused on the commercialization of nickel aluminides containing iron and small additions of cerium. Nickel-iron aluminides are more easily shaped into components at high temperatures than are nickel aluminides devoid of iron. Peter Patriarca of the M&C Division has initiated cost-sharing arrangements with five materials suppliers, resulting in industry commitments of up to $1 million over three years to scale up aluminide production to ingot size by commercial casting and powder metallurgy processes. ORNL's industrial collaborators and contributors include Cabot Corporation, Garrett Turbine Engine Company, Combustion Engineering, Homogeneous Metals, Universal-Cyclops, Special Metals,

The SITEX negative ion source developed at ORNL has the highest current output and pulse length in the world. Its ions can be converted into neutral beams that could be used for defense.





C. T. Liu measures the mechanical properties of a newly developed, high-strength nickel aluminide alloy at elevated temperatures. A number of industries have shown interest in fabricating components from this alloy for high-temperature energy uses.



ORNL's study in Liberia found significant energy options, such as abundant forests for wood energy, and problems, like an inefficient oil refinery.

and Pratt and Whitney. Each company has different interests in and uses for these materials.

In addition to support from industrial partners, the U.S. government is interested in the energy and defense applications of aluminide alloys. ORNL's aluminide development work has received funding from DOE's Basic Energy Sciences, Fossil, and Conservation programs. For these programs ORNL researchers are now trying to optimize nickel aluminide alloys—that is, to improve their high-temperature strength, ductility, fabricability, weldability, and corrosion-oxidation resistance. DOD is also showing interest in nickel aluminides, which have potential applications in military aircraft and armaments, and NASA is considering them for space systems.

International Cooperation

As I mentioned earlier, DOE has determined that the U.S. government cannot afford to sponsor all research projects that need to be done, so the agency is pushing multinational funding of large demonstration projects through international cooperation. For ORNL, working with other laboratories and outside researchers is nothing new: We have done this for years through formal agreements, joint projects, and information and personnel exchanges between research facilities in the United States and abroad. We have collaborated with many foreign researchers (400 per year) through exchanges and at our user facilities. International cooperation is, however, increasing; in 1984, for example, ORNL received more support from foreign governments ($15 million) than ever before. Most of this support has been in the areas of fusion and energy assessment.

In the Large Coil Program for testing superconducting magnets for fusion, we have been cooperating with and receiving support from Japan, the Federal Republic of Germany, and Switzerland. We are also collaborating with Japan on neutron scattering, nuclear fuel recycle development, and testing the effects of radiation on materials that are candidates for structural components of fusion reactors. With the countries involved in the Joint European Torus (JET) Project, we have performed tests on a beryllium limiter for a fusion device. And FED researchers Jim Lyon, Benjamin Carreras, Jeffrey Harris, and Tim Hender have collaborated with Spain on designing a flexible heliac stellarator; when this advanced toroidal device is built by the Spanish Junta de Energía Nuclear a new stellarator will be added to the world fusion program. (See "Technical Capsules" on pages 50–51.)

In another facet of international cooperation, ORNL has taken a new role in international energy policy development and planning. In 1984 the Agency for International Development (AID) asked ORNL to serve as its principal technical advisor in exchange for a multiyear commitment of about $1 million annually. AID was impressed with the previous work that ORNL carried out for the agency under the direction of Tom Wilbanks of the Energy Division. This work was done in Liberia, Tunisia, Costa Rica, Somalia, and Pakistan.

Celebrating the successful performance of the beryllium limiter in the last experiment performed on ORNL's ISX-B fusion machine are, from left, Joe Lenhard of DOE's Oak Ridge Operations, Jurgen Dietz of the Joint European Torus program, Peter Mioduszewski of ORNL, ORNL Director Herman Postma, and Phil Edmonds of ORNL.

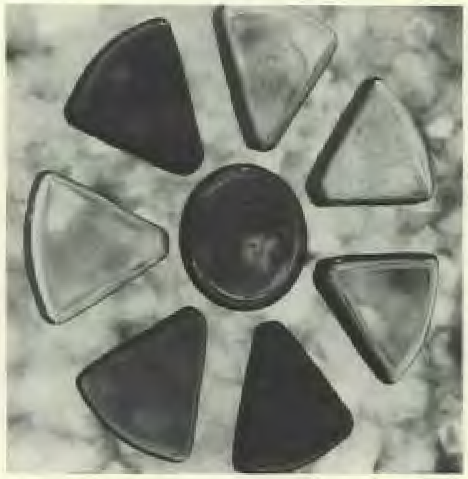
ORNL's 1982–83 assessment for AID of Liberia's energy use shows how the Laboratory can contribute to solving international problems. Because of the rising cost of imported oil, Liberia had been planning to build a large hydroelectric dam to provide its electricity. ORNL energy experts persuaded the government that a smaller dam would meet the country's needs for electricity for a long time. ORNL also pointed out that an attractive alternative was to replace some imported oil with wood energy from Liberia's abundant forests. For example, wood gasification could reduce the need for diesel oil to run electric generators in rural areas. A third ORNL recommendation was to shut down Liberia's inefficient oil refinery because refined petroleum products can be obtained more cheaply on the international market. As a result, the refinery has since been closed, and Liberia is now saving $15 million to $20 million per year, or 2% of its gross national product—a substantial payoff from a $200,000 research project.

(The following technical highlights cover some of ORNL's outstanding achievements in science and technology for the year. My remarks on program milestones and the outlook for the year ahead begin on page 25.)

Lead-Iron Phosphate Glass for Nuclear Waste Developed

The currently preferred method for isolating nuclear waste from the environment is to incorporate it in borosilicate glass for ultimate storage in metal canisters placed underground. An even better waste form for permanently storing radioactive materials, however, appears to be lead-iron phosphate glass, developed by Brian Sales and Lynn Boatner of ORNL's Solid State Division. This promising high-level waste host, formed by melting granules of lead-iron phosphate glass together with oxides of radioactive wastes, chemically binds the waste ions into a dense glass monolith. This development is an outgrowth of the work on monazite nuclear waste forms, originally supported in 1979 by seed money.

One advantage that the ORNL glass has over borosilicate glass is increased resistance to corrosive leaching of waste materials from the host by water. Corrosion tests have shown that the net release of all elements from the ORNL glasses containing simulated nuclear waste is at least 100 to 1000 times lower than that from comparable borosilicate glasses containing nuclear wastes. The key to increased corrosion resistance in the final waste form is its iron content. Sales and Boatner found that iron-rich defense wastes require little or no iron oxide additive but that iron should be added to waste forms for reprocessed commercial nuclear fuel.



These samples of lead-iron glass phosphate appeared on the cover of **Science** *magazine.*

Another advantage of the ORNL development is that lead-iron phosphate glasses can be prepared at lower temperatures than borosilicate glasses, even though similar technologies are used. Because of the lower temperature, less energy is consumed, and the volatilization, or boiling off, of radioactive materials is reduced, thus minimizing releases of hazardous gases to the environment.

Although borosilicate glasses have already been selected by DOE as the waste form for some military high-level wastes, DOE continues to fund development efforts devoted to alternative waste forms, including lead-iron phosphate glasses. The potential importance of the glasses of Sales and Boatner has not gone unnoticed. The glass samples were featured on the cover of the October 5, 1984, issue of *Science*, which carried their article describing the development. The ORNL development was also featured in *Science News*, and in its 1984 Materials Science Research Competition, DOE recognized the ORNL work for its significant implications for energy technology.

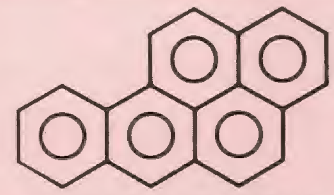
ORNL Method Can Identify Environmental Carcinogens

One of the largest classes of cancer-causing agents discharged to the environment by industry comprises polycyclic aromatic hydrocarbons (PAHs), which are present in coal conversion by-products and wastes. Not all PAHs are carcinogenic, however. Many PAHs that cause cancer have an isomer—a compound composed of the same atoms but in a different arrangement—that is noncarcinogenic. Unfortunately analytical chemists using combined gas chromatography and mass spectrometry (GC/MS) have found it difficult to distinguish between the mass spectra of various PAH isomers despite their distinct structural differences and vastly different biological activities.

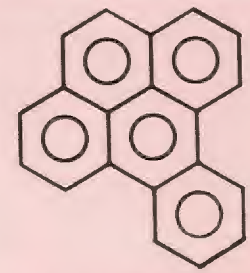
Recently, Michelle Buchanan of ORNL's Analytical Chemistry Division has overcome this limitation of mass spectrometry by substituting a negative chemical ionization technique for the conventional electron-impact ionization technique. The conventional technique uses a beam of electrons to eject electrons from target molecules, thus producing positively charged ions. Buchanan found that low-energy electrons ejected from methane by electron impact are captured by some PAHs; as a result, negatively charged ions are formed. However, other PAH isomers do not capture electrons. In the mass spectrometer the negatively charged PAH molecules of one isomer are sorted by their relative mass-to-charge ratio and then are detected. The uncharged molecules of another isomer are not detected and cause no interference.

Buchanan has used this technique to differentiate between a number of PAH isomers, including fluoranthene and its isomer, pyrene. More significantly, she has distinguished between benzo[*a*]pyrene, a highly carcinogenic chemical present in cigarette smoke and certain processed coal products, and its

Michelle Buchanan adjusts the methane pressure in the mass spectrometer used for negative chemical ionization studies.



BENZO(A)PYRENE
CARCINOGENIC



BENZO(E)PYRENE
NONCARCINOGENIC

The isomeric structure of polycyclic aromatic hydrocarbon compounds profoundly affects their biological activity. An isomer of one compound (such as the one at the top) can be carcinogenic while another isomer of the same compound (bottom) can be noncarcinogenic.

relatively noncarcinogenic isomer, benzo[*e*]pyrene. Benzo[*a*]pyrene is often used as a benchmark in the assessment of the biological activity of a complex mixture. This technique allows the benzo[*a*]pyrene to be selectively detected in the presence of its isomer without interference.

The technique's ability to distinguish between various PAH isomers is based upon differences in electron affinity—the characteristic ability of certain molecules to capture extra electrons. This phenomenon permits faster, unambiguous identification of PAHs without the need for difficult-to-obtain compounds for comparison (standards).

Dating Ancient Water by Counting Krypton-81 Atoms

The age of ancient groundwater and polar ice cannot be determined by conventional dating techniques, such as those using radioactive carbon-14. A technique recently developed at ORNL has extended the dating time scale for water to 50,000 to 1,000,000 years, thus allowing analysis of samples of ancient water. The technique involves counting atoms of krypton-81, a slightly radioactive rare gas which has a 200,000-year half-life—that is, half of its radioactivity decays away in that time. This highly sensitive and selective dating method uses ORNL's rare gas atom counter, which received an I•R 100 award in 1984 as one of 100 innovations recognized by *Research & Development* magazine. The counting technique is an extension of resonance ionization spectroscopy, the initial development of which was supported in part by seed money.

Sam Hurst, Steve Kramer, C. H. Chen, and Steve Allman of ORNL's Health and Safety Research Division and B. T. Lehmann of the University of Bern in Switzerland recently used the rare gas counter to measure the minute concentrations of krypton-81 in a sample of groundwater from Switzerland. They counted 1000 krypton-81 atoms among the billions of atoms present in 1 L of groundwater extracted from a sandstone aquifer near Zürich—an achievement equivalent to finding a specific grain of sand on a large resort beach.

Radioactive krypton-81 atoms are formed when krypton-80 gas in the atmosphere is bombarded by cosmic rays; the rare gas atoms are carried by precipitation to the ocean, polar ice packs, and groundwater, where they decay into nonradioactive atoms. By counting the number of krypton-81 atoms (which declines with age) and comparing that number to the total concentration of all krypton isotopes in the water sample, the scientists can calculate the age of ancient water in underground reservoirs or polar ice packs. In the case of the 1 L of water from Switzerland, the ORNL scientists determined that the water is "modern," not ancient. However, the technique could be used to date water up to a million years old.

The ORNL method allows a better

understanding of groundwater chemistry. One energy-related application of this technique is the ability to determine whether groundwater is isolated or whether groundwater from different sources has migrated and mixed. If dating information suggests that the water is isolated and stationary, adjacent areas might be suitable sites for disposal of radioactive wastes because migration of water, which can leach out and transport nuclear wastes to the environment, is not a threat.

The ORNL technique involves tuning a laser to ionize target atoms—in this case, atoms of krypton-81. The ejected electrons are then counted to give the number of krypton-81 atoms. The technique can also be used to study the interior of the sun by detecting solar neutrinos passing through the earth (which signal their brief encounter with our planet by converting a few atoms of bromine to krypton-81 atoms), to measure minute levels of plutonium in the soil, and to chart ocean circulation (which affects the ocean's absorption of atmospheric carbon dioxide from fossil fuel combustion and other sources) by measuring variable concentrations of the rare gas argon.

Steve Allman operates a laser in a system (known as Maxwell's Demon) to count krypton-81 atoms recovered from a sample of groundwater. This new method of counting atoms, based on resonance ionization spectroscopy rather than radioactivity, makes it possible to use long-lived isotopes like krypton-81 (half-life of 200,000 years) to determine whether groundwater is isolated or has been circulating.

Trace Elements in Tree Rings Can Signal Air Pollution

Variations in the width of annual growth rings from hardwood and coniferous trees in the Great Smoky Mountains National Park may be caused by environmental changes. Variations in climate (temperature, humidity, and rainfall levels) and recent changes in the levels of air pollution, including heavy metal deposition and acid rain, may be affecting the forest.

Fred Baes (right) and a technician measure concentrations of heavy metals in tree rings by inductively coupled plasma optical emission spectroscopy. Increased iron concentrations in tree rings were correlated with suppressed tree growth. The high iron levels can indicate an increase in levels of air pollution associated with escalated fossil fuel combustion.

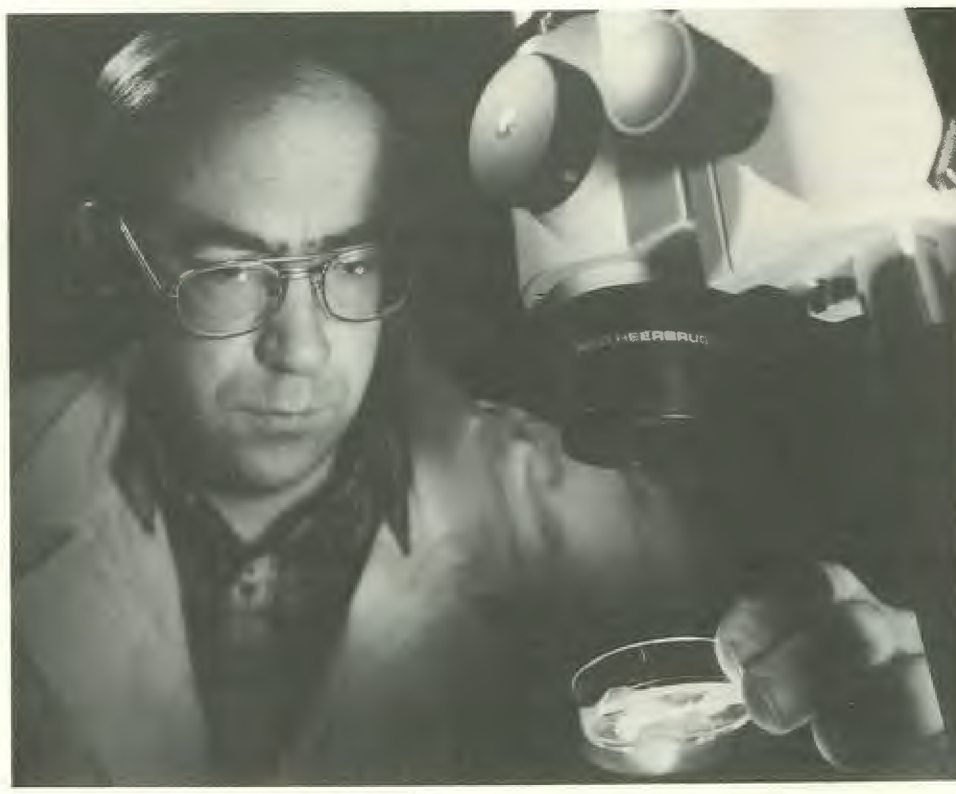
To examine the possible impact of pollutants on tree growth, Fred Baes and Sandy McLaughlin of ORNL's Environmental Sciences Division have measured the concentrations of metals in ring tissue from trees in Oak Ridge and the Great Smoky Mountains. Intrigued by the hypothesis that acid precipitation increases the availability to plants of aluminum and iron in soils, they sought to find out if increased metal concentrations were reflected in the chemical composition of trees and if these changes were related to annual tree growth. They proposed that a pattern of changing metal concentrations in tree rings could indicate the timing of past changes in rain acidity and metal deposition, both of which can be increased by escalated fossil fuel combustion.

Baes and McLaughlin sampled numerous trees in East Tennessee and North Carolina and performed multielement analysis of tree ring tissues by inductively coupled plasma optical emission spectroscopy. They found that annual growth rings from shortleaf pine trees in the southeastern portions of the Smokies showed both suppressed growth and increased iron content between 1863 and 1912, a period when copper smelting and large sulfur dioxide releases 90 km (56 miles) upwind at Copperhill, Tennessee, caused extensive mortality of trees within about an 18-km (11-mile) radius of the smelter. Similar growth suppression and increases of iron and other metals were found in rings formed in the past 20 to 25 years, when regional fossil fuel combustion emissions from industry increased about 200%. This finding on the historical parallel between tree growth suppression and increased iron content in tree tissues appeared in the May 4, 1984, issue of *Science*.

ORNL Devises Method for Genetic Monitoring in Human Males

Environmental chemicals can damage chromosomes in somatic (body) cells and in germ cells, which pass traits from one generation to the next. Methods have been proposed to detect chromosomal damage in somatic cells, but no validated procedures have existed for detecting chemically induced chromosomal damage in postmeiotic germ cells, damage that could lead to defects in offspring.

Last year Gary Sega of the Biology Division found a way to detect chromosomal damage in postmeiotic germ cells, including those found in human sperm. He adapted alkaline elution, a technique originally used to measure breaks in single strands of DNA in cultured somatic cells, to measure DNA strand breaks induced in mammalian sperm cells after exposure of the mammal to chemical agents. Sega used sperm recovered from mice that had been exposed to selected chemical agents, such as methyl methanesulfonate and ethylene oxide. His results indicate that sperm in which the frequency of DNA strand breakage is highest are derived from treated germ-cell stages that also yield increased dominant-lethal and translocation frequencies. Thus increased DNA strand breakage appears to correspond with a rise in other measurable forms of genetic damage.



Gary Sega is working on procedures that may prove useful in monitoring for potential genetic damage in human sperm cells.

To test the applicability of this procedure to human subjects, Sega assayed DNA single-strand breaks in human sperm, using samples obtained as part of a collaborative study with A. J. Wyrobek, a Lawrence Livermore Laboratory researcher who is studying morphological abnormalities in sperm. Sega's DNA single-strand breakage measurements may prove useful in monitoring human males for signs of genetic damage—that is, potentially heritable defects—resulting from exposures to environmental contamination.

Next: Technologies

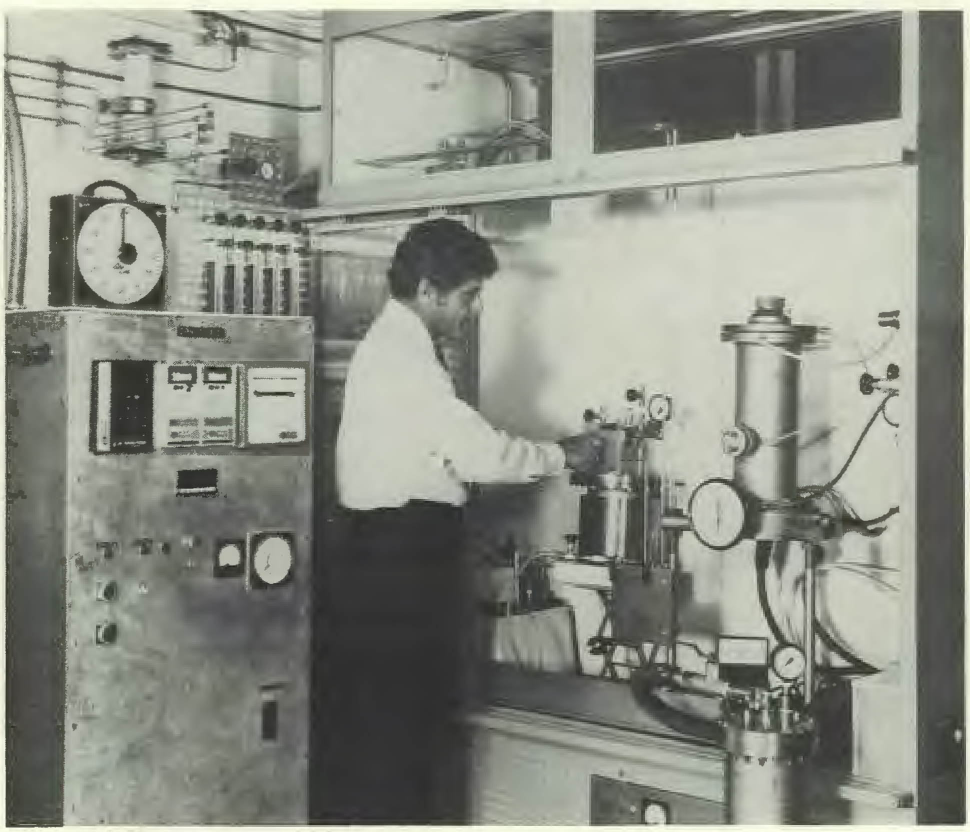
ORNL Produces Toughened Ceramic Composites

Because their properties at high temperature are superior in many ways to those of conventional metals, ceramics are desirable materials for energy-efficient, high-temperature engines now being developed. However, ceramics have a drawback that must be overcome: They are inherently brittle. To increase the fracture toughness, or resistance of ceramics to cracking under stresses (loads), ORNL researchers Terry Tiegs, Paul Becher, Dave Stinton, and Tony Caputo of the M&C Division have taken three approaches to developing toughened ceramic composites for use as high-temperature materials. All three processes are considered commercially attractive.

The first approach is to incorporate silicon carbide (SiC) "whiskers" (produced from rice hulls) into alumina and other ceramic matrices. These whisker-reinforced composites are much stronger and tougher than the unreinforced materials. For example, the strength and toughness of alumina are essentially doubled by the incorporation of 20 vol % of SiC whiskers. These composites are fabricated by conventional ceramic processing techniques, which can mass-produce at low cost ceramic materials needed for automotive-engine and industrial applications. Three industrial firms are working under cost-sharing contracts to further develop this ceramic composite approach.

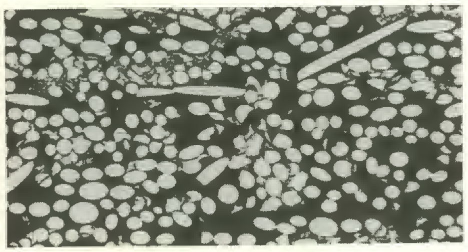
In the second approach, ceramic composites are fabricated at ORNL by infiltrating low-density fibrous structures with vapors, which deposit as solid phases—SiC or silicon nitride (Si_3N_4)—on and between the fibers to form the matrix of the composite. This approach uses the chemical vapor deposition (CVD) infiltration technology developed at ORNL; in this technique, solid products are formed by the dissociation or reaction of gases at high temperatures. High strengths result because loads can be transferred from the chemically vapor-deposited matrix to the high-strength fibers. ORNL's tests of the mechanical properties of the composites have shown maximum fracture stresses above 350 MPa (50,000 psi) and the ability to carry a significant load after the maximum stress has been reached, thereby avoiding brittle fracture. Tests also show that the flexibility of the fibers permits the material to be preformed into desirable shapes.

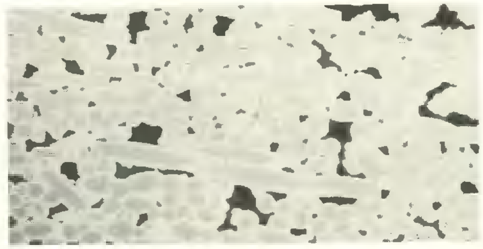
The third approach produces ceramic composite coatings by using CVD technology. Toughened ceramic composite coatings were produced by the simultaneous chemical vapor deposition of a SiC matrix and a dispersed phase of titanium disilicide ($TiSi_2$). Like conventional ceramics, these composite coatings exhibit high-temperature strengths. However, the coatings are superior to conventional



Tony Caputo adjusts the flow of vapors to the low-pressure chemical vapor deposition furnace at right for the infiltration of a fibrous preform to make a ceramic composite.

Scanning electron micrograph of fibers coated with silicon nitride by chemical vapor deposition. Note that the fibers have been interlocked by the coating, thus increasing the strength and toughness of the composite.





The silicon carbide fiber preform before and after infiltration. The white phase at right is the chemically vapor deposited silicon carbide matrix. The density of the fibrous preform is typically increased from 30 to 80%, thus increasing the strength and toughness of the composite.

ceramics because they also possess greater fracture toughness. Toughened SiC composite coatings can also be used to increase the oxidation resistance of carbon-carbon composites. In addition, for certain structural ceramics and metals, these new coatings can reduce friction and increase resistance to wear and corrosion.

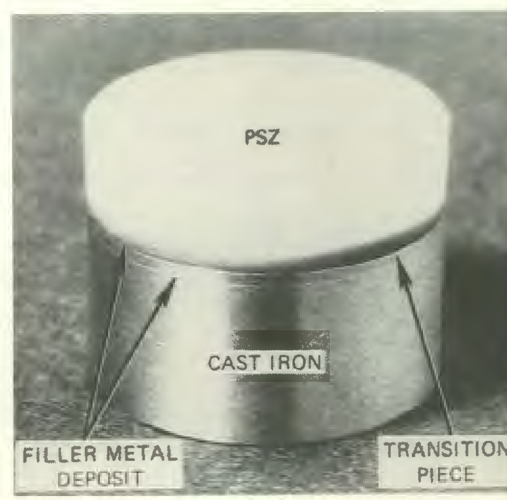
The three processes developed at ORNL show promise in creating ceramic composites that should attract broad interest, because the new ceramics combine new properties of high strength and toughness with the traditional properties of resistance to high temperature, abrasion, and corrosion. In an example of technology transfer, we are transferring the CVD infiltration technology developed at ORNL to Babcock and Wilcox (B&W), which is working jointly with ORNL in developing and characterizing ceramic composite tubes made by CVD infiltration of ceramic fiber preforms. A B&W scientist is spending one week per month at ORNL learning how to use the ORNL infiltration process to toughen preform specimens made at B&W in Lynchburg, Virginia. We expect that additional technology transfer will occur for our other ceramic materials.

Ceramic-to-Metal Joining Process Developed at ORNL

Ceramic materials are receiving increasing interest from designers of reciprocating engines (such as piston-driven gasoline and diesel engines) because advanced engines incorporating these materials promise greatly improved performance. Ceramic engine components can operate at much higher temperatures than current alloy components. In addition, because certain structural ceramics have relatively low thermal conductivity, they can reduce waste heat losses by holding in the heat. Further, exhaust heat from the fuel can be used to drive turbine blades to produce additional automotive energy. Thus properly designed diesel engines with ceramic components can make efficient use of fuel by extracting useful work from the nearly 60% of the fuel's heat that is normally lost from current designs.

In the United States, Cummins Engine Company and others are developing advanced high-temperature diesel engines in which the combustion chambers and other critical areas are thermally insulated with ceramic materials. The goal is to improve fuel economy by 40 to 50% over current engine designs. One major technological problem with this engine concept has

Joe Hammond (left) and Jim Woodhouse survey the results of the ORNL process of joining a ceramic (partially stabilized zirconia) to metal (nodular cast iron) in a piston cap. Ceramics are candidate materials for insulators in highly efficient diesel engines.



An important technological advance was made at ORNL when processes were demonstrated for brazing partially stabilized zirconia to ductile iron (2.5-cm cap) at 735°C.

been the difficulty of reliably joining insulating ceramics, such as partially stabilized zirconium oxide (PSZ) to metal engine components. ORNL, however, has found a solution to this problem, starting with laboratory-size specimens.

In the M&C Division Joseph Hammond and Stan David have developed surface preparation and brazing processes that can be used to join a PSZ piston cap to nodular cast iron, the alloy of choice for the pistons in advanced high-temperature diesel engines. The ORNL process involves surface modification treatments—ion etching and sputtering of a thin, active titanium layer on the substrate of the zirconium oxide cap and copper plating of the ductile iron—to promote "wetting" by the braze alloy. The metal and ceramic have been successfully brazed at temperatures below 750°C without degrading the properties of the ductile iron. ORNL tests on brazed samples have shown that the shear strength of the braze meets the design requirements and that the PSZ–ductile iron joint resists thermal and mechanical shock.

To help transfer the technology to industry, ORNL researchers are working closely with Cummins Engine, which is developing an adiabatic diesel engine for DOE and a diesel military engine for DOD. Cummins has supplied ORNL with samples of engine components as well as the design requirements. The company is interested in testing the ORNL process for joining full-size engine components.

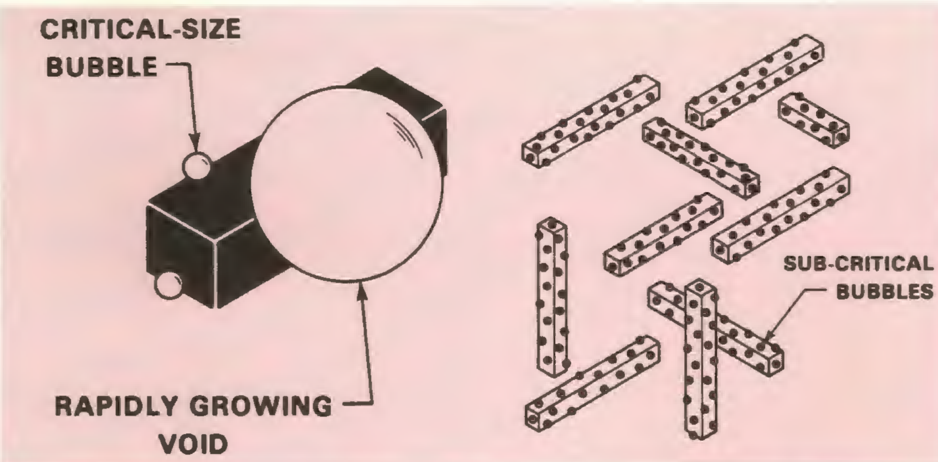
Improved Stainless Steels Developed for Fusion Reactors

Irradiation of metals and alloys by energetic neutrons results in the displacement of atoms and the creation of both vacancies and interstitial defects in the metal structure. In addition, helium is created through nuclear transmutations. Under certain conditions the helium atoms and vacancy defects may combine, giving rise to tiny helium bubbles that form from the nuclei for the eventual growth of internal voids, which cause the material to swell. Helium bubbles are also one source of high-temperature grain boundary embrittlement. Radiation-induced swelling and loss of ductility create serious design problems in breeder reactors, and these phenomena are expected to create significant problems for the designers of future fusion reactors.

While working in ORNL's basic Radiation Effects Program, Lou Mansur and Eal Lee have made major advances in understanding the behavior of helium in complex alloys and its role in swelling. They demonstrated by both theory and experiment that when bubbles achieve a critical size, they begin to grow rapidly as voids, leading to high swelling. However, if helium is dispersed on a sufficiently fine scale, bubbles can be maintained below the critical size. Working in parallel in the Fusion Materials Program, Phil Maziasz and Arthur Rowcliffe have radically improved the understanding of the relationships between alloy chemistry and the phases that develop during irradiation. As a consequence, it is now possible to control the nature, chemistry, and degree of dispersion of the phases that occur in stainless steels during irradiation.

During neutron irradiation, conventional stainless steels swell because of the formation of internal voids. The electron micrograph on the left (50,000x) shows voids growing in association with large intermetallic particles, which develop during irradiation. In the new swelling-resistant alloys, the microstructure (right) is characterized by a very fine dispersion of carbide or phosphide phases and the elimination of the coarse intermetallic phase.

The combined efforts of these scientists have led to ways of controlling the distribution of helium within the alloy so that resistance to swelling and embrittlement is improved. The strategy consists of two parts, based on two major effects that precipitates have on swelling. (Precipitates are particles of a different phase—that is, with a structure and composition different from that of the matrix, or bulk of the alloy.) First, the



This schematic of the internal structure of the alloys illustrates (on the left) the development of a rapidly growing void from a critical-size bubble situated on a coarse intermetallic particle in a conventional stainless steel. In the new swelling-resistant alloys (represented on the right), helium is dispersed in subcritical bubbles nucleated on the surfaces of a large number of fine particles.

precipitate-matrix interface collects vacancies, which assist the growth of a void attached to the precipitate. A large precipitate enables the void to collect more vacancies than it would if the void were isolated in the matrix. This effect increases swelling. Thus large precipitates must be eliminated. However, a bubble cannot begin growing as a void until it collects the critical number of gas atoms (or equivalently, achieves critical size). If the precipitate can be dispersed on a very fine scale—the second part of the strategy—then the increased area of the precipitate-matrix interface dilutes the helium produced by neutron-induced transmutation reactions in which alpha particles (helium nuclei) are generated. As a result, the number of helium atoms in each bubble is decreased. Because the amount of helium is constant, the production of a larger number of bubbles decreases the average bubble size. Sufficient dilution ensures that the critical number of gas atoms is not exceeded, and swelling is inhibited.

To promote helium dilution, ORNL metallurgists have altered the microstructure of austenitic stainless steel by tailoring the alloy composition so that the material will form numerous, very small particles of metal carbides or phosphides during irradiation. In addition, they carefully balanced the alloy chemistry to ensure the long-term stability of the finely dispersed particles and the elimination of potentially harmful large and coarsely dispersed precipitate particles.

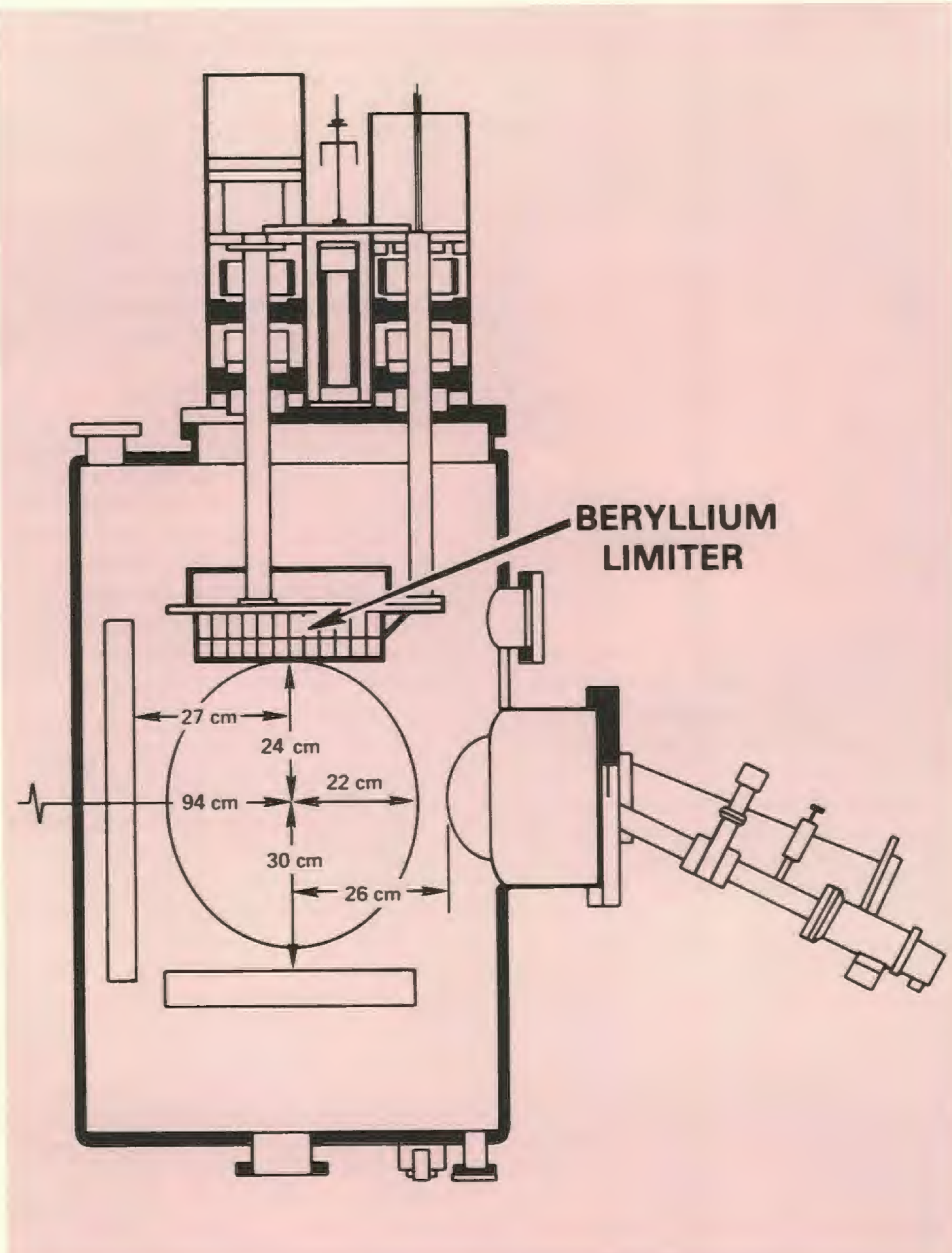
ORNL's initial tests of austenitic steels after three years of irradiation show that void swelling is reduced from a 25% increase in unmodified steels to virtually no increase (1%) in steels whose microstructure has been altered to put these principles into operation. Tests also showed that ductility is sustained in the modified steels even after helium bubbles were produced by neutron irradiation. In short, the modified stainless steels should tolerate the damage that could be inflicted on them by the energetic neutrons produced by fusion reactions. The ORNL researchers expect the theoretical and experimental framework developed for these materials to apply to other alloy systems currently under investigation.

Beryllium Limiter Performs Well in Fusion Experiment on ISX-B

To be efficient in producing power, a fusion reactor must have a low level of impurities in the reacting hydrogen (deuterium-tritium) plasma. Impurities degrade the heat-producing plasma by two means. High atomic number impurities are not fully ionized—that is, not all their electrons have been stripped off—before they enter the main confinement region. In collisions with other ions in the plasma, the remaining electrons on the ions are excited, resulting in the radiation of large amounts of energy from the plasma. This energy loss cools the plasma interior and reduces the reaction rate. In addition, because the plasma must have an equal number of positive charges (protons) and negative charges (electrons), the heavy impurity ions, whose positive charges are not balanced by their own electrons, displace many positive hydrogen ions. As a result, the amount of fuel available for the energy-producing reaction is reduced. These effects are much less significant for materials with low atomic numbers.

The primary source of these impurities is the reactor walls that face the plasma and any limiters introduced to define the plasma boundaries. Fusion researchers have proposed constructing these first surfaces and limiters out of materials such as carbon or beryllium, both of which have very low atomic numbers. A considerable amount of experimental evidence has shown that carbon (graphite) meets many of the requirements of a limiter; however, experimenters have been reluctant to use beryllium, which has the lowest atomic number of any suitable material, because of the considerable health hazard associated with the inhalation of beryllium dust.

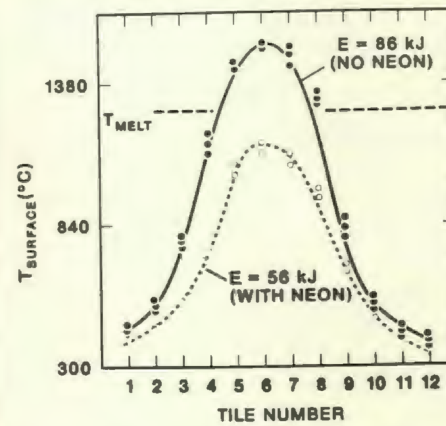
Researchers at the Joint European Torus (JET), a large tokamak experiment in Great Britain, are contemplating installing beryllium limiters. In order to establish some preliminary operating experience, JET funded a program with ORNL to test beryllium limiters in the experiment on



The beryllium limiter was located at the top of the ISX-B plasma cross section.

the Impurity Study Experiment (ISX-B). The objectives of the program were to identify and characterize the most suitable grade of beryllium, to experimentally compare the plasma and limiter performance with that of the graphite limiters coated with titanium carbide, and to establish the proper operating and safety procedures needed for plasma physics experiments using beryllium. This final experiment on ISX-B was successfully completed last fall under the leadership of Phillip Edmonds and Peter Mioduszewski of the Fusion Energy Division.

The beryllium limiter used in the experiment was designed and produced by ORNL in collaboration with Sandia



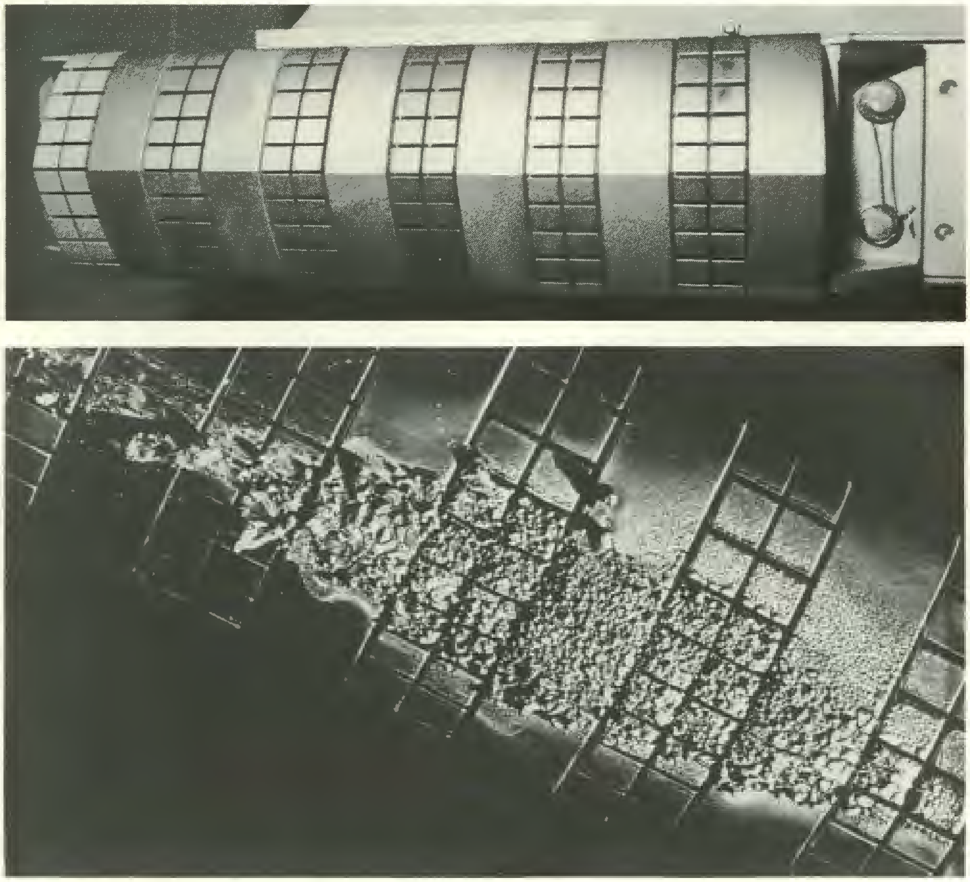
Neon puffing to cool the plasma edge keeps the surface temperature of the beryllium limiter below the melting point.

National Laboratories. The experimental program tested the limiter over a wide range of operating conditions, including limiter heat loads that caused extensive melting of the limiter surface. Under these conditions the plasma was not deleteriously affected by up to a 5% beryllium impurity level. The plasma performance under all operating conditions was comparable to or better than that obtained with the titanium carbide–coated limiters.

As well as functioning as an acceptable limiter material, the beryllium had an additional effect on the plasma. The material performed successfully as a "getter"—that is, some beryllium atoms evaporated from the limiter and migrated to the wall, combining with or burying harmful impurities such as iron, chromium, and oxygen. By gettering the impurities, the beryllium significantly reduced the general impurity level in the plasma. Previous experiments had investigated the effects of gettering with titanium for impurity control, and the "self-gettering" of the beryllium limiter produced similar plasma performance. An important experiment that was conducted with the beryllium-gettered discharges showed that the heat deposited on the limiter (and hence the surface temperature) could be reduced by injecting neon gas into the plasma, which cooled the plasma edge by increasing the radiation losses.

An essential requirement for any limiter is the ability to survive the long-term exposure to the thermal and ion fluxes that would occur in a reactor-like situation. The final phase of the experiment simulated the exposure expected in the JET experiment. The limiter was not significantly affected by the "fluence test," and significantly less deuterium was retained by the beryllium than would be expected to be retained by a carbon limiter. This result is important for the JET investigators because of the need to predict how much tritium—a hydrogen isotope and fusion fuel (like deuterium)—would be retained in the limiters. Because tritium is radioactive, its total inventory in an experimental device is a serious operations consideration.

On completion of the experimental program, the ISX-B device was decommissioned. Because precautions were taken to avoid health and safety problems, no such problems were experienced during the operating and the decommissioning cycles, although significant amounts of beryllium dust were produced inside the vacuum vessel during the experiment. The ORNL program showed that beryllium could be used successfully in a fusion experiment and, with proper handling procedures, need not pose a hazard to the workers or the environment.



The beryllium limiter before the ISX-B experiment (top) and the same limiter after the experiment (bottom). Considerable melting occurred in tiles in the initial tests, but this damage did not affect the plasma performance.

ORNL Evaluation of Pressurized Thermal Shock: Costly Reactor Fixes May Not Be Required

Before the late 1970s, NRC believed that the most severe loading conditions involving thermal shock that a pressurized water reactor (PWR) vessel would have to withstand would be those associated with a large-break loss-of-coolant accident (LOCA). As a result of a large-break LOCA, the primary-system pressure drops very low, and emergency core coolant, which may be at room temperature or lower, is pumped into the hot reactor vessel to cool the core. In the process, the low-temperature coolant contacts the inner surface of the vessel wall, and a momentary large difference in temperature between the coolant and vessel wall results in rapid cooling (thermal shock) of the vessel, thus creating thermal stresses and low temperatures in the wall.

Late in the life of the vessel, when considerable radiation damage may exist in the wall, the combination of this damage with thermal stress and low temperature introduces the possibility of propagation of flaws that may be present in the wall. However, in the late 1970s, thermal-shock studies conducted at ORNL as a part of the Heavy-Section Steel Technology (HSST) Program indicated that thermal shock in the absence of pressure could not drive flaws completely through the wall. Thus the large-break LOCA was no longer considered a safety issue—that is, a potential cause of vessel failure—so NRC's attention turned toward postulated PWR transients (sudden changes) that involved both thermal shock and substantial primary-system pressure. For these accidents the thermal shock is not as severe as that for the large-break LOCA, but nonetheless it appeared on the basis of ORNL studies that a potential for vessel failure exists. Furthermore, by this time the likelihood of such accidents seemed rather high because several mishaps, including those at the Rancho Seco nuclear power plant in 1978 and at the Three Mile Island reactor in 1979, had already occurred.

Concern over the possibility of vessel failure caused by combined thermal and pressure loadings [referred to as pressurized thermal shock (PTS)] prompted the NRC in December 1981 to declare PTS as an unresolved safety issue. Thus the HSST program at ORNL made an additional effort to help achieve a resolution.

In May 1981 NRC asked ORNL to undertake another PTS-related project, which was referred to as the Integrated Pressurized Thermal-Shock (IPTS) Program. This program would provide NRC with a technical basis for establishing a PTS rule, developing procedures with which licensees could perform plant-specific PTS analyses, and formulating acceptance criteria for proposed corrective measures. To attain these goals ORNL developed a methodology for performing a PTS evaluation and applied that methodology to 3 of 11 plants considered by NRC to have a potential PTS problem. The three plants represent each of the major PWR vendors—Oconee Unit 1, designed by Babcock and Wilcox; Calvert Cliffs Unit 1, designed by Combustion Engineering; and H. B. Robinson Unit 2, designed by Westinghouse Electric Corporation.

This IPTS program, which combined probabilistic risk assessment and deterministic methods, was performed with the cooperation of the vendors and the utilities. The program was led by an ORNL team consisting of Doug Selby, Tom Burns, and George Flanagan of the Engineering Physics and Mathematics Division; Jim White of the I&C Division; Dick Cheverton of the Engineering Technology Division; and Dave Ball of the Computing and Telecommunications Division. Supporting thermal-hydraulics analyses were performed by Science Applications International Corporation of Oak Ridge, by Purdue University, and by three other national laboratories—Idaho National Engineering Laboratory, Los Alamos National Laboratory, and Brookhaven National Laboratory. Through their combined studies, hundreds of thousands of potential overcooling transients were tracked, and fracture-mechanics calculations were performed for those transients considered to be the most serious.

The results of the IPTS study indicate to the NRC that PTS may not be a problem for the three plants examined. "Best estimates" of the probabilities of through-the-wall cracking at Oconee, Calvert Cliffs, and H. B. Robinson are 25, 500, and 1000 times lower, respectively, than the proposed NRC safety goal. Thus the possibility that the nuclear industry would be required to invest in vessel annealing or other expensive mitigating measures for these three plants may have been avoided. According to the nuclear utilities involved, this determination could save as much as $300 million per plant.

A thick-walled test vessel is installed at ORNL's Pressurized Thermal-Shock Test Facility (PTSTF) at Oak Ridge Gaseous Diffusion Plant. Measurements of brittle fracture initiations and arrests of running cracks that were deliberately generated in tests at the PTSTF agreed well with predictions of computer code calculations performed at ORNL. These results further confirm the validity of the fracture-mechanics methods of analysis that are being used to evaluate and help resolve the pressurized-thermal-shock issue.

The IPTS study has also shown that neutron flux–reduction schemes and changes in criteria identified in procedures which specify when reactor coolant pumps should be turned off are very effective means of reducing the potential for PTS-induced vessel failure. These relatively inexpensive fixes are being implemented by the industry as precautionary measures even at some plants considered to have a low PTS risk.

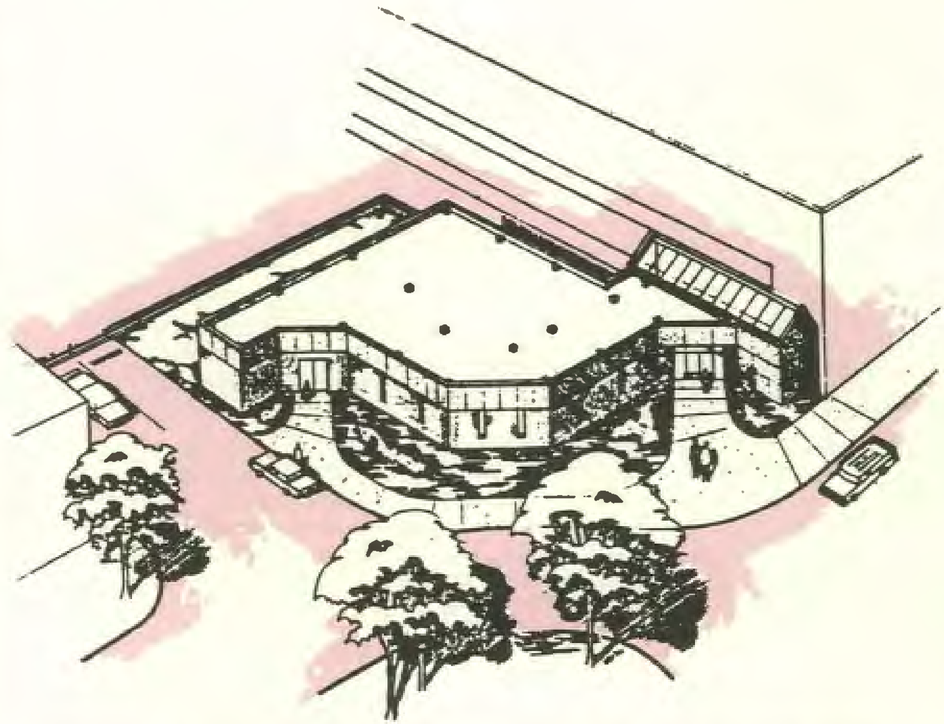
A major concern identified in the probabilistic study is the uncertainty in the number of flaws that might actually exist in a vessel wall. To reduce this uncertainty, recommendations have been made for developing improved capabilities for detecting and inspecting flaws.

Although PTS research is continuing, primarily within the HSST program, the NRC has already used the results of the IPTS project to develop a PTS screening-criteria rule for PWRs. On the basis of the three plants studied, it appears that the rule includes a substantial safety margin and yet does not produce an undue hardship on the nuclear industry. The application of these results to the eight other plants cited by NRC as having potential PTS problems may save the industry an additional $3 billion, which would have been passed on to consumers as energy costs. This saving represents an excellent return on the research investment.

Milestones and Outlook

Last year ORNL received four I•R 100 awards, bringing our award total to 41, including 23 over just the last 5 years. This was the third year in a row that we tied for the most wins of any organization in the United States. (See ORNL *Review*, Number Four 1984, pages 42–43, for a description of the award-winning research projects.)

Another 1984 milestone was the development of the Laboratory's five-year plan for environmental management, which projects the expenditure of $400 million in capital and operating funds to correct our environmental problems and prevent the occurrence of future ones. Our first-year funding commitments will be for priority projects on (1) upgrading process waste systems, (2) improving the sewage treatment plant and sanitary sewer system,



Artist's conception of the Laboratory Emergency Response Center, now being built between Buildings 5500 and 4500N at the X-10 site of ORNL. The building will be headquarters for the shift supervisors and guards.

A representative of an outside firm that disposes of ORNL's hazardous wastes inspects labels on barrels. ORNL's five-year plan for environmental management includes the construction of adequate facilities to store hazardous wastes before shipping them away for disposal.

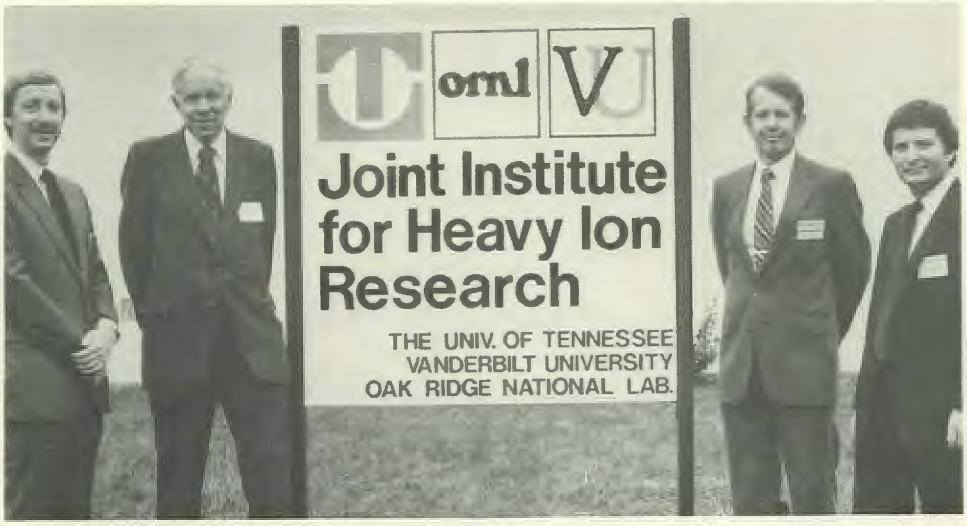
(3) upgrading the storm sewer system, (4) characterizing active ponds that receive radioactive effluents, (5) characterizing and cleaning up spill sites, (6) characterizing the White Oak Creek watershed and preventing the leaching of radioactive wastes from our burial grounds into the watershed, and (7) improving the management of hazardous and toxic materials.

Construction has also started on the Laboratory Emergency Response Center, which will be headquarters for the shift supervisors and guards. The center will be located between Buildings 4500-S and 5500.

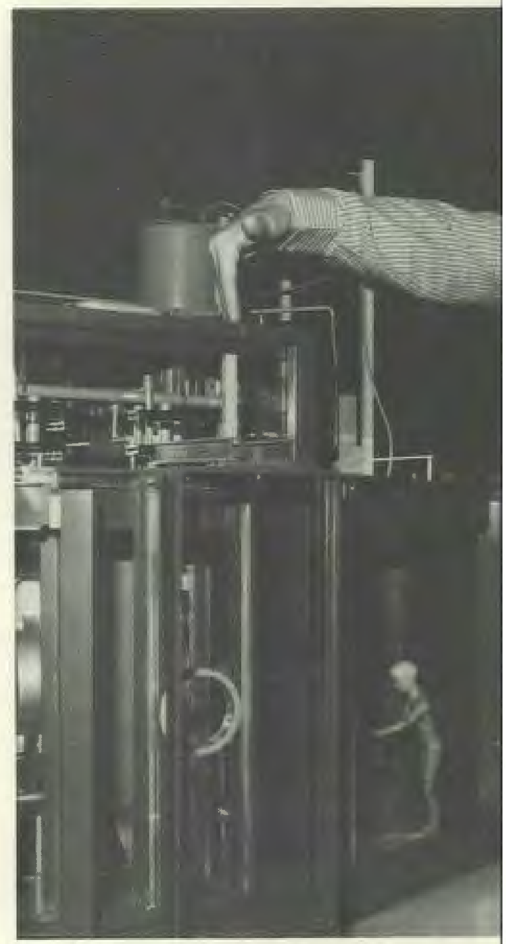
The second building of the Joint Institute for Heavy Ion Research, which provides office, laboratory, and living space for visiting scientists working at the Holifield Heavy Ion Research Facility, was completed last year. The Joint Institute is a collaborative effort of ORNL, UT, and Vanderbilt University. It was financed by the state of Tennessee and is administered by UT. The keynote speaker at the dedication of the Joint Institute last fall was Nobel Laureate Glenn Seaborg.

The Advanced Toroidal Facility (ATF), a fusion device designed to be an optimized version of the stellarator, is on schedule. The vacuum vessel, structural support shell, poloidal coils, and helical coil segments are being fabricated by outside contractors. The machine should be ready for operation in late 1986.

A Radio-Frequency Test Facility is being built by the Fusion Energy



At the dedication of the Joint Institute for Heavy Ion Research are, from left, Lee Riedinger, professor at the University of Tennessee; Glenn Seaborg, Nobel Laureate and professor at the University of California at Berkeley; Russell Robinson, scientific director of the Holifield Heavy Ion Research Facility; and Joe Hamilton, head of the department of physics at Vanderbilt University. Riedinger, Robinson, and Hamilton are members of the Policy Council, which manages the Joint Institute.



Walt Gardner (left) and Harold McCurdy discuss construction plans for the Radio-Frequency Test Facility, which is being built by the Fusion Energy Division to test advanced components for heating magnetically confined plasmas with radiofrequency energy.

Division to test advanced components under development for supplemental heating of magnetically confined fusion plasmas with radiofrequency (RF) energy. The facility is scheduled to go into operation in September 1985. It will allow full-scale testing of RF systems suitable for heating plasmas in the D-III device in San Diego, California, and the Tokamak Fusion Test Reactor in Princeton, New Jersey.

The Large Coil Test Facility at ORNL, which was renamed the International Fusion Superconducting Magnet Test Facility, successfully tested three magnetic coils in the superconducting mode. These magnets were supplied by Japan, Switzerland, and the U.S. firm General Dynamics–Convair Division. The last of the three superconducting magnets from abroad arrived in November from the European Atomic Energy Community (EURATOM), and the second U.S. magnet—begun by General Electric Company and completed by Martin Marietta Energy Systems, Inc.—is also on hand now. In June 1985 these five magnets were joined by one fabricated by Westinghouse Electric Corporation, and full-scale tests with all six magnets should begin in late summer or early fall.

The Electron Cyclotron Resonance (ECR) Multicharged Ion Source in the Physics Division is now fully operational at its design microwave frequency of 10.6 GHz. The device uses microwaves to heat magnetically confined electrons to temperatures approaching 100 million degrees; by colliding these electrons with neutral atoms, the ECR source strips the atoms of their outer electrons, producing highly charged ions characteristic of the atmospheres of suns and stars or man-made fusion plasmas. The ECR source will be used to study charge-changing collisions of multiply charged ions with both electrons and neutral atoms. Such collisions, which are studied by crossed- and merged-beam techniques, are of fundamental interest to theorists and have practical applications in fusion-energy research.

The Integrated Equipment Test (IET) facility in the Fuel Recycle Division has begun tests of the integrated process for performing chemical separations with nonradioactive fuel. This simulated head-end of a fuel reprocessing plant will test prototype hardware and remote maintenance schemes for repairing reprocessing equipment. With these tests ORNL will advance the development of concepts for reprocessing spent nuclear fuel.

A new Roof Thermal Research Apparatus was constructed by the

Jerry Hale (left) and Fred Meyer prepare to conduct an experiment on the new Electron Cyclotron Resonance (ECR) Multicharged Ion Source in the Physics Division. Meyer was responsible for designing and implementing the device, which uses microwaves to heat magnetically confined electrons to temperatures approaching 100 million degrees. By colliding these high-energy electrons with neutral atoms, the ECR source strips the atoms of their electrons, producing highly charged ions characteristic of solar and stellar atmospheres or controlled fusion plasmas.

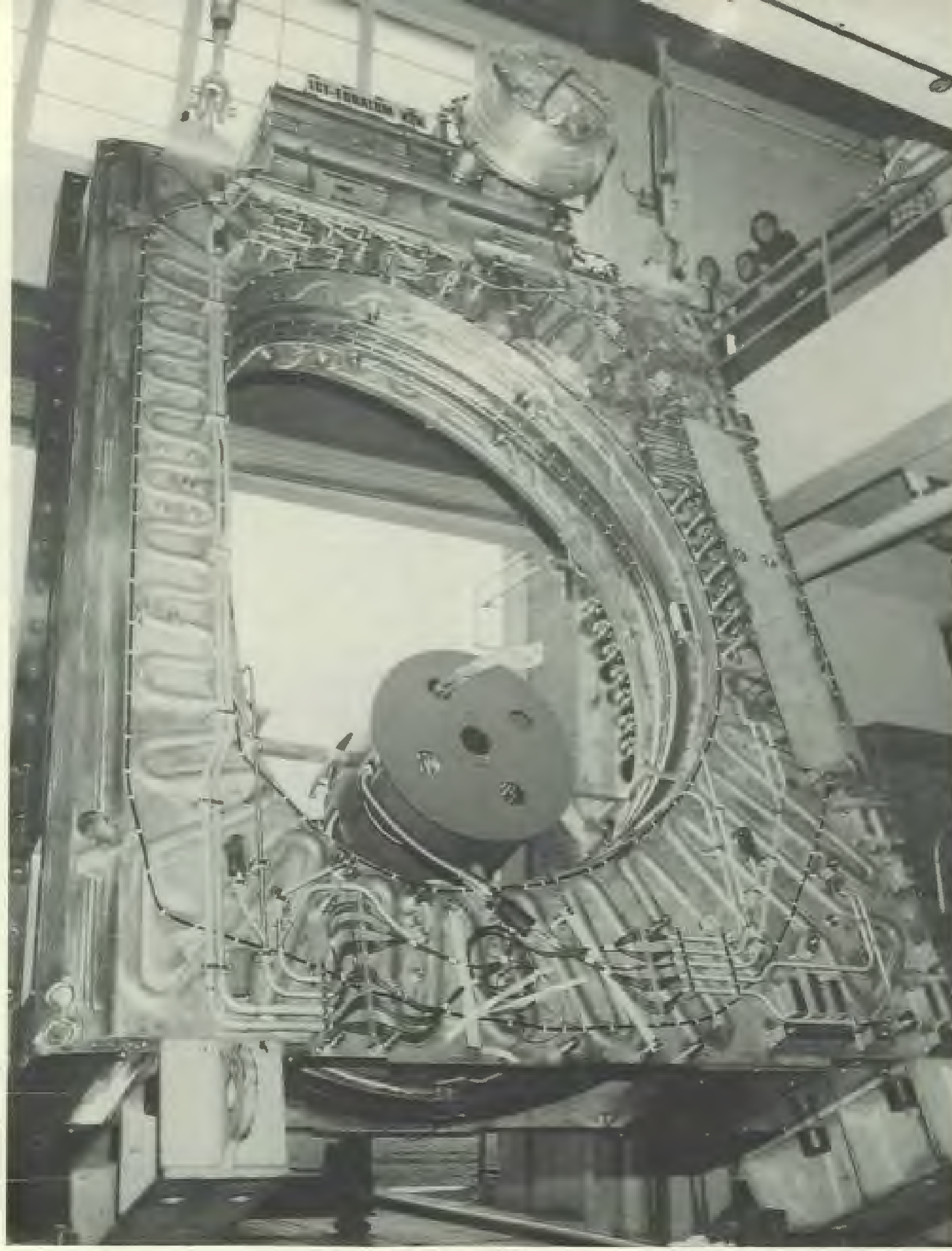
Energy Division to test how well roof segments handle the flow of heat energy and how that flow is influenced by moisture and other variables. This effort is part of ORNL's research on reducing energy use in buildings. The apparatus will be used to test the extent to which roof segments transfer heat into and out of buildings and also reflect and absorb incident fluxes of solar energy. The thermal transport data gathered by ORNL's instruments for various roof systems will be used to construct computer models. The models should be helpful in designing roofs to minimize loss of energy from buildings.

The contract to build the $19-million High Temperature Materials Laboratory has been signed. Following an inauguration in May 1985, the building will take shape over the next two years. The facility should be ready by the summer of 1987.

Looking Ahead

In 1985 we can expect new emphases and directions. The Laboratory will focus many resources on environmental cleanup. Demonstration projects will be scarce, except for those funded by international cooperation. Budgets will be tighter for technology than for science. Energy research will be placed on the back burner in Washington until we have a crisis such as a shortage of natural gas or gasoline. We will be taking more initiative to work with industry in a number of areas; for example, we are now offering our expertise in materials and instrumentation to aid the steel industry. We will be taking steps to rehabilitate and renovate our facilities as they grow older. In the next 15 years we will consolidate our life sciences work in a single complex, bringing the Biology Divison from the Y-12 area to the west end of X-10, where the Environmental Sciences Division is located. Finally, we will continue to change and refine our missions.

Murray Rosenthal, Associate Director for Advanced Energy Systems, holds the certificate of the Director's Award, whose creation was announced this year by Postma (center) during the State of the Laboratory address. The annual award was given to ORNL's Fusion Energy Division. Accepting the award plaque was O. B. Morgan (right), director of the Fusion Energy Division.



This superconducting magnet provided by the European Atomic Energy Community (EURATOM) arrived at ORNL in November 1984 and was installed at ORNL's International Fusion Superconducting Magnet Test Facility. It is one of six magnets to be tested at the facility later this year.

As for the President's FY 1986 budget request, it is tight. Except for a substantial increase in our programs for solving our own and the nation's problems with radioactive and hazardous chemical wastes, our levels of funding remain about the same as last year. We could have problems keeping everyone in their present positions. We expect that attrition of 150 people (up to 22 in the Biology Division) will take care of most of our problems, if the attrition is in the right places. We probably can move some people from places where there has been an adverse impact to places where none exists. However, to reduce the chances of forced layoffs, a voluntary reduction in force took place in April and May 1985.

In concluding this annual report, I have a surprise announcement. In the spirit of Martin Marietta Energy Systems' commitment to publicly recognize achievements, I have established an annual Director's Award to recognize a Laboratory division for its meritorious work. The first award goes to the Fusion Energy Division for its large-scale efforts in designing new fusion devices, testing internationally supplied superconducting magnets, developing centrifugal pellet injectors for steady-state fueling of plasmas, and cooperating with many international groups from Great Britain, the Federal Republic of Germany, Japan, Spain, and Switzerland. The outstanding work of the Fusion Energy Division, directed by O. B. Morgan, represents what a national laboratory should do well—get things done that are big, important, and difficult. The division has demonstrated that ORNL not only responds to national needs and political forces but also exerts its influence on the world.

awards and appointments

Herman Postma, ORNL Director, received the 1985 Public Awareness Leadership Award given at the WATTec Conference in Knoxville. He was cited for "his general effort and furtherance of invention, technology, and energy to the benefit of the general public."

During his State of the Laboratory address, ORNL Director Herman Postma announced that he had established an annual Director's Award for a Laboratory division whose performance was particularly outstanding. He gave the first award to the **Fusion Energy Division**.

Clarence F. Barnett has received the Distinguished Associate Award from the U.S. Department of Energy. This award is one of the highest honors that DOE can bestow on a nongovernment employee.

Rufus H. Ritchie has received the 1984 Jesse W. Beams Award, the highest honor for distinguished research in physics conferred by the Southeastern Section of the American Physical Society.

William E. Eldridge has been selected by the International Atomic Energy Agency to serve as a consultant to the Philippine Atomic Energy Commission. He is consulting with the nuclear regulatory operator licensing program for the first Philippine nuclear power plant, which will begin operation this year.

Phillip H. Edmonds and **Peter K. Mioduszewski** have been awarded certificates of appreciation from the U.S. Department of Energy for their contributions to an international fusion experiment. They were cited for "superior performance" as principal investigators in a recent study at ORNL of the possible use of beryllium as a material for limiters in fusion devices.

Lisa H. Stinton was named Young Engineer of the Year by the Oak Ridge Chapter, Tennessee Society of Professional Engineers, at the WATTec Conference.

Robert W. Swindeman has received the 1985 Award of Merit from the American Society for Testing and Materials (ASTM) for his work on the effect of temperature on the properties of metals. He also was elected a fellow of the ASTM.

Barbara T. Walton has been elected president of the Society of Environmental Toxicology and Chemistry.

Sam E. Hamblen has been named ORNL's energy coordinator.

Robert L. Childs of the Computing and Telecommunications Division and **Wayne A. Rhoades** of ORNL's Engineering Physics and Mathematics Division have received the best paper award of the Radiation Protection and Shielding Division of the American Nuclear Society. The paper, entitled "The Linear Nodal Method for Shielding Applications," was cited for significance of content and superior presentation.

Charles C. Coutant has received an Outstanding Service to Fisheries Award from the American Fisheries Society for his contributions to fisheries research.

George Wignall has been elected a fellow of the American Physical Society.

R. L. Livesay has been elected to the Executive Committee of the Fusion Technology Division of the American Vacuum Society.

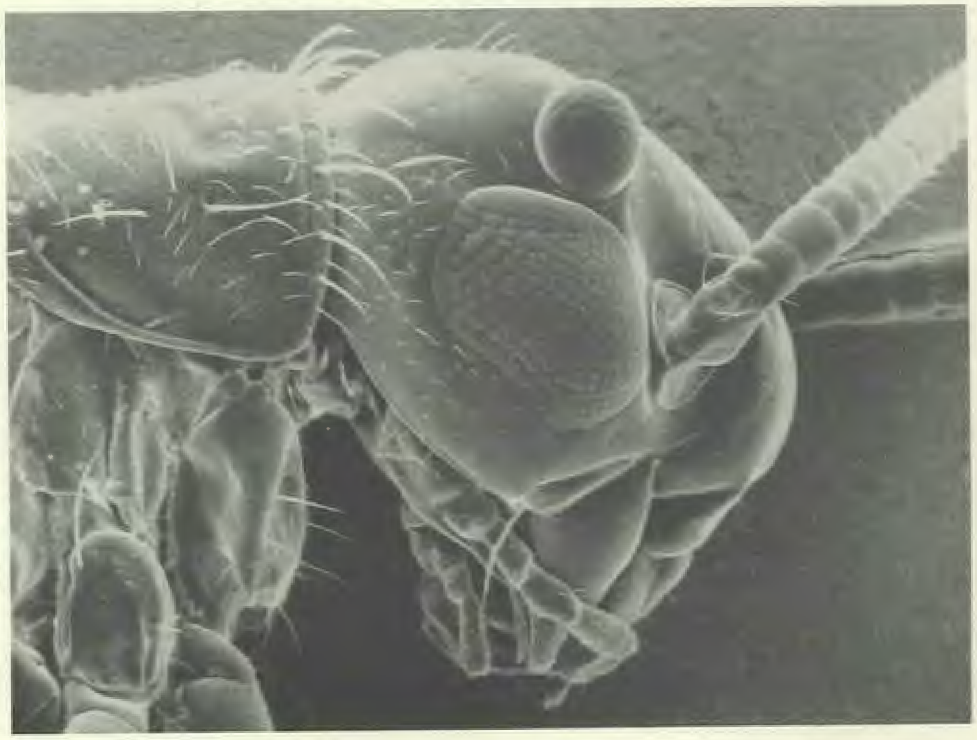
W. R. Corwin has received a certificate of appreciation from the Amercian Society for Testing and Materials (ASTM) for chairing a 1983 ASTM symposium.

J. T. Ensminger has been appointed ORNL Information Center coordinator.

In the "Battle of the Graphics Artists," a computer graphics competition sponsored by the ISSCO software company, **Morris Slabbekorn** won five awards and **LeJean M. Hardin** and **William Byrd** each received one. Slabbekorn received a silver medal in the diagrams category, a silver medal in business data representation, and three honorable mentions, one each in the categories of titles and text, diagrams, and scientific data representation. Hardin received an honorable mention in titles and text. Byrd's cartoon received an honorable mention in the open category.

David Fahey has been elected to a two-year term on the National Council of Professional Photographers of America, Inc.

Michael Osborne has been promoted to process supervisor of the Chemical Technology Division's Radiochemical Processing Plant.



Head of a 14-day-old cricket with a normal multifaceted compound eye and a smaller, extra compound eye above it. The cricket was treated during the egg stage with a coal liquid. This photograph appeared on the cover of the April 3, 1981, issue of Science.

Crickets and Coal Liquefaction Research

By BARBARA T. WALTON

***Editor's note**: In April 1981 a micrograph of a three-eyed cricket taken at Oak Ridge National Laboratory appeared on the cover of* Science *magazine. The* Science *report, based on ORNL experiments with coal-derived chemicals described below, sparked a flurry of publicity in* Science News, Discover, Chemical and Engineering News, *and many newspapers. The press and public seemed to be fascinated with the idea that exposure of insects to trace quantities of unknown chemicals could produce "monster crickets"—crickets with an extra eye, an extra antenna, even an extra head.*

Creating monster crickets was not the purpose of our research in ORNL's Advanced Fossil Energy Program. Nor was our goal to find a quick, inexpensive way to detect teratogens, which are chemicals that interfere with normal embryonic development. Rather, our purpose was to help identify those chemicals associated with the production, transport, and use of liquid fuel from coal that are mostly likely to be toxic. If technologists and engineers learned about chemical toxicity in advance, they could prescribe ways to alter the technology or operation procedures to minimize releases of toxic chemicals to the environment. Although our research was designed to fit this specific programmatic need for the U.S. Department of Energy, some experiments yielded results with implications for areas far removed from ensuring that the synthetic fuels industry in this country would be environmentally safe.

Synthetic Fuels Research Posed Special Problems

A unique aspect of DOE synthetic fuels research was the philosophy of preventive ecotoxicology—the prevention of toxic effects to animal and plant species in the environment. The historical approach had been to build commercial-scale facilities

Barbara T. Walton joined ORNL's Environmental Sciences Division (ESD) in 1977 shortly before receiving her Ph.D. degree in entomology and environmental toxicology from the University of Illinois (1978). In 1981 she received ESD's Scientific Achievement Award for her work on coal conversion effluents and insect development. In addition to this work, her research interests include the transfer of polycyclic aromatic hydrocarbons through food chains to mammals, the influence of soil organisms on technetium movement in terrestrial ecosystems, and the role of invertebrates in dispersion of radionuclides from contaminated bodies of water. She is an adjunct faculty associate in the Ecology Program at the University of Tennessee, where she teaches two courses, ecotoxicology and environmental toxicology. She is a diplomate of the American Board of Toxicology and in 1983 was elected chairman of the Biochemistry, Physiology, and Toxicology Section of the Entomological Society of America. In addition, Walton is vice-president of the Society of Environmental Toxicology and Chemistry (SETAC) and is editor of special publications for SETAC. She will become president of SETAC in November 1985.

Several years ago cricket eggs exposed to a chemical under study in the synthetic fuels program hatched crickets with assorted abnormalities such as an extra eye, antenna, or head. The author tells how ORNL toxicologists and analytical chemists determined that certain trace substances cause these teratogenic effects and how they eventually identified a teratogenic compound in these substances.

first and respond to environmental problems later. For example, the deleterious effects of sulfur dioxide and toxic metal emissions on vegetation were not considered until years after a copper smelter at Copperhill, Tennessee, began operations that led to widespread defoliation in the area. DOE's approach to coal liquefaction, however, was to undertake toxicological studies concurrently with technology development. The goal was to head off potential environmental problems of the technology by identifying problems at the outset and altering the technology to minimize or eliminate them. Thus crude products from demonstration and pilot plants were made available to researchers for these studies.

An immediate problem arose for researchers: The actual chemical composition of coal liquids was unknown. Describing samples used in experiments by batch numbers and dates would do little to advance understanding of coal liquid toxicology. Biological responses should be related to causative agents, that is, to specific chemicals. Yet coal liquids contain hundreds to thousands of compounds of unknown structures. Furthermore, chemical composition of the products might vary for different coal conversion processes; it might change for different coal types and operating conditions; it might even be altered during fuel storage because of volatilization or



Newly emerged from a chemically treated egg, the cricket at left has an extra eye on the right side of the head. In the center is a one-week-old, three-eyed cricket that was treated during the egg stage (arrow shows extra eye). At right is a cricket nymph with an extra antenna in the middle of the head. Treatment of the egg stage with certain chemicals causes nymphs to develop more than the two antennae normally found on crickets.

chemical interactions. Thus researchers faced a dilemma, because to wait for complete chemical characterization of the samples could delay toxicological studies for years.

Research began without delay, but certain assumptions had to be accepted without confirmation, albeit with an awareness of possible limitations. One approach was to view the crude coal liquids as collections of compounds belonging to a variety of chemical classes. Because chemicals within the same class share certain structural, physical, and reactive properties, they were assumed to have similar biological properties as well. Hence, by examining the biological activity of one or two chemicals within major groups, generalizations were formulated for structurally similar chemicals. By choosing compounds to represent, or model, the predominant chemical classes, the toxicity of a whole crude product was approximated.

An alternative approach to that of studying model chemicals shifted attention to the biological properties of the whole coal liquids. Certain biological or ecological endpoints were selected as significant targets of chemical action. Any coal liquid containing chemicals capable of disrupting such functions (at a low concentration) were then chemically fractionated to isolate and identify the active components. Biologically inert substances, on the other hand, were left uncharacterized to save time and resources. In addition to permitting experimentation with intact coal liquids, this approach provides for more realistic exposures of organisms to coal liquefaction products.

Like many researchers, Gerry O'Neill and I applied both approaches to learn how coal liquids might affect insect development. Among the samples we evaluated were model chemicals, crude coal liquids, mixtures of chemicals separated from coal liquids, and a synthetic crude product weathered on soil following an actual spill.

Insects Can Be Useful Experimental Animals

Insect development was included among the biological endpoints for both ecological and toxicological reasons. Insects are the most abundant animals on the earth; about three out of every four animal species are insects. Their roles in ecosystems are many and varied. As pollinators, decomposers, herbivores, predators, parasites, and prey for other animals, they make substantial contributions to energy flow and nutrient cycling in ecosystems. In addition, insects can be useful indicators of chemical action in other animals. Despite obvious differences between insects and higher animals, biochemical modes of action of toxicants are often identical in invertebrates and vertebrates. Many oxidative inhibitors, neurotoxins, and chemosterilants fall into this category. Thus insects can be useful in biomonitoring programs as sensitive indicators of chemical action before effects are seen on larger, longer-lived species such as humans.

Unlike human toxicology, individual well-being in insects and other animal species is of little importance when considering ecological effects of chemicals. From an ecological viewpoint, even

At left is a two-headed nymph six days after emerging from a teratogen-treated egg. An arrow shows the location of the eyes on the diminutive head. In the center is a cricket that vaguely resembles ET, the Extraterrestrial; it has two heads, each the same size. At right is an example of a cricket with missing legs. Normal crickets have six legs and one tarsus (foot) per leg. This deformed cricket of the species* Gryllus rubens *has only three legs. The leg on the right has two tarsi (feet). Inset: blowup of leg with two tarsi.

the death of large numbers of animals may be viewed with equanimity if the populations concerned produce large numbers of offspring within a short time and if death is an acute response to a single chemical release. In such instances, populations are quick to recover to preexposure numbers. However, when chemical releases occur over a prolonged time, even rapidly breeding animals can show population declines if reproduction, growth, or development is affected.

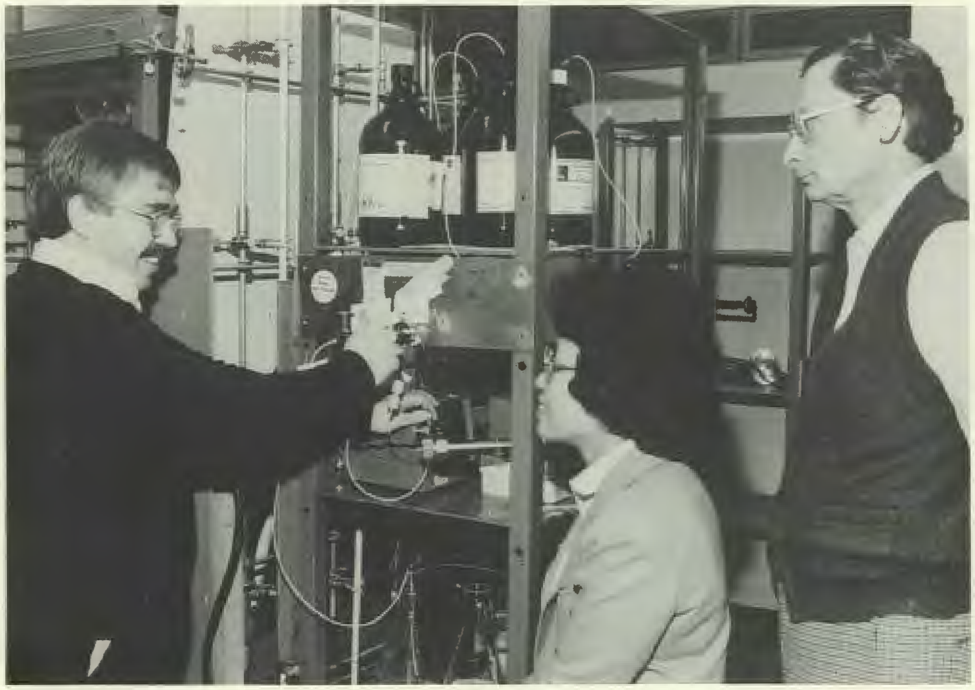
Sensitive Insect Needed To Evaluate Toxicity

Why did we choose crickets for studying whether coal-derived chemicals influenced insect development? To determine whether chemicals found in synthetic fuels could affect the development of insects, we required (1) a test insect common in leaf litter and soil that might actually be exposed to toxicants from synthetic fuels production, (2) a natural means of exposing eggs to chemical samples, (3) a quantitative rather than a subjective means of scoring treated animals, and (4) a simple test with few variables.

To meet these criteria, we elected to observe the development of cricket (*Acheta domesticus*) eggs in artificially contaminated sand. This method involved having female crickets lay eggs directly in sand to which measured quantities of chemicals had been added. Eggs were separated from the sand five days later and then incubated until emergence, which usually began on the tenth day. The eggs were observed under a light microscope during this latter incubation phase, and the percentage that failed to hatch served as an index of embryotoxicity.

Using the model chemical approach, I selected acridine, a nitrogen-containing three-ringed aromatic molecule found in coal liquids, as the first chemical to examine for toxicity in this system. The results were surprising: A small number of eggs in the first test showed extra eyes during development, and the emergent crickets had three compound eyes rather than two. One nymph had a perfectly formed extra antenna in the middle of the head. Subsequent experiments produced crickets with extra heads. This phenomenon, the induction of extra body structures *de novo* by chemical treatment of the embryo, had not been previously described. It was also noteworthy that these insects lived to the adult stage and were fertile.

To be certain that acridine was causing the effect and to achieve a maximum response, we used solvent partitioning to increase the chemical purity from 98% in the commercial sample to greater than 99%. When we reran the experiment, we could not get the same results. Thus we began a series of experiments to reproduce the results obtained in the first experiment and to establish which chemical was responsible for that effect. Eventually we found a trace impurity in the commercial sample that caused the extra eyes, heads, and antennae in the crickets. The findings were published April 3, 1981, in *Science*, with a cover photograph taken by O'Neill.



Analytical chemists who used high-performance liquid chromatography to separate the impurity biquidone from acridine are, from left, C. Ho and Russ Jones (photograph at right), and Mike Maskarinac, Jan Ma, and Del Manning (photograph above)

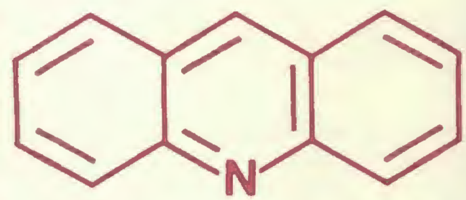
Next, we undertook research in several related areas simultaneously in an attempt to answer three questions: What, if anything, do developmental abnormalities in crickets have to do with the environmental safety of coal liquids? What is the identity of the trace impurity in acridine that caused the extra body structures in crickets? Could this substance interfere with the development of other animals? In addition to these queries, a number of questions were asked about chemical action on crickets alone. Would the offspring of abnormal crickets also be abnormal? Could body regions other than the head be affected? Could crickets see with their extra eyes? How does the chemical act within the developing embryonic cells to produce specific defects?

Questions dealing with synthetic fuels and chemical identification were addressed here at ORNL. Questions concerning more fundamental aspects of the study were pursued primarily through collaborations with university researchers.

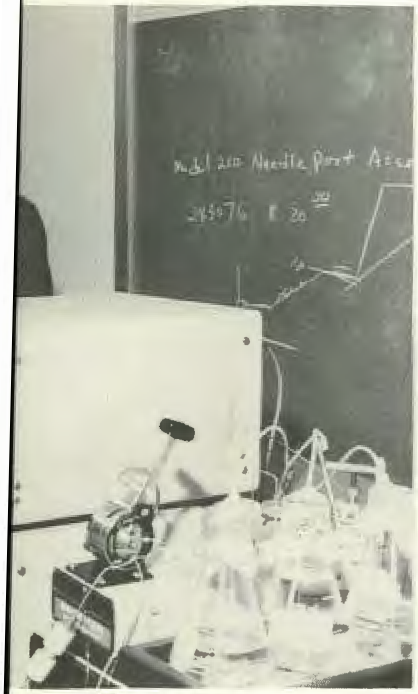
Some Coal Liquids, Not Petroleum, Teratogenic to Crickets

Our finding that gross developmental defects in crickets were caused by an impurity in acridine, rather than by acridine itself, did not automatically remove the problem from the realm of synthetic fuels research. We had selected acridine for study partly because of its presence in crude coal liquids; however, acridine is also obtained commercially by vacuum distillation of coal tars. Thus a contaminant associated with acridine might also be found in coal liquids.

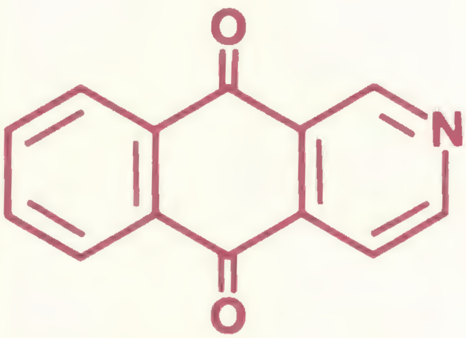
By testing an array of coal liquids for developmental effects on crickets, we found that crude products from three direct coal liquefaction processes produce multiple-eyed crickets. In addition, incubation of the eggs in soil collected at a coal liquid spill-site produced evidence that a coal liquid component can be teratogenic to cricket eggs. Neither shale oil nor crude or refined petroleum products caused these developmental abnormalities. More than 30 individual chemicals, including



Acridine, a chemical component of coal and of some synthetic fuels obtained from coal, was the first chemical tested in the cricket embryo assay at ORNL. At right is biquidone (benz[g]isoquinoline-5, 10-dione), a trace impurity isolated from commercial samples of acridine obtained by vacuum distillation of coal tar. Walton and Gerry O'Neill showed that treating cricket eggs with a small dose of biquidone causes morphological abnormalities in cricket embryos. This chemical is listed as a new biochemical tool in Aldrichimica Acta.



This nuclear magnetic resonance spectrometer was used in the identification of the acridine impurity biquidone, which was responsible for inducing teratogenic effects in crickets. Researchers involved in the separation and identification work are, from left, Mike Guerin (group leader), Michelle Buchanan, John Caton, and Ira Rubin.



several carcinogens and mutagens, had no effect on cricket eggs. Inspection of more than 52,000 eggs used in control experiments failed to show any spontaneous occurrence of the abnormalities produced by the coal-derived substances.

The picture emerging from these studies suggested that coal liquids are more effective in killing insect embryos than are petroleum products and that some coal liquids contain chemicals that cause insect embryos to develop in unusual ways.

Efforts to isolate and characterize the active chemical or chemicals were undertaken collaboratively with several researchers in Michael Guerin's Bio/Organic Analysis Section in ORNL's Analytical Chemistry Division. Using high-performance liquid chromatography, Michael Maskarinac, Del Manning, and A. Russell Jones performed some of the early separation work. Michelle Buchanan, Ira Rubin, and John Caton used nuclear magnetic resonance spectroscopy, mass spectrometry, and infrared spectroscopy to analyze those separated products. Later, in collaboration with C.-h Ho, C. Y. Ma, Jones, Guerin, and G. L. Kao, a series of structurally related compounds were laboriously synthesized and purified, guided by the results of the biological endpoint. Infrared spectroscopy was used for the final identification of benz[g]isoquinoline-5, 10-dione (or biquidone, for short) as the active teratogenic constituent. This compound represented less than 40 ppm of the original acridine. These results were published in the October 28, 1983, issue of *Science* and the May 1984 issue of *Environmental Science & Technology*.

During the isolation and identification studies, O'Neill and I modified the cricket embryo assay to maximize its sensitivity and to minimize the labor involved in checking the activity of samples. With these changes, we could easily detect teratogenic substances in picogram quantities, making the assay more sensitive than many of the analytical methods for identification.

Once we knew the identity and structure of the active teratogen, our next step was to evaluate its effects on other cricket species. We found that the activity of biquidone is not limited exclusively to the head region or to the cricket *Acheta domesticus*. Another cricket species, *Gryllus rubens*, tends to show

Gerry O'Neill at the scanning electron microscope used to take the three-eyed cricket that appeared on the cover of the April 3, 1981, issue of Science *(see photograph at the opening of this article).*

abnormalities of the legs after exposure to the chemical during the egg stage. Most common is an absence of from one to five of its six legs. Another abnormality is branching of the legs so that two or more feet (tarsi) are found on one leg.

My studies in collaboration with Lynn Riddiford of the University of Washington have shown that embryonic development of the tobacco hornworm, *Manduca sexta*, and of the linden bug, *Pyrrhocoris apterus*, is disrupted by treatment with biquidone. Microbiologists A. Clark and D. Huddleston of the University of Mississippi, working in collaboration with Ma and Ho, have recently reported that biquidone retards the growth of microbes and fungi. Whether biquidone is also teratogenic to mammals and whether it is the cause of the teratogenic activity in cricket eggs exposed to coal-derived liquid fuels is not known at this time.

DOE has currently shifted its emphasis away from synthetic fuels research, so the latter question will remain unanswered for some time. However, the Aldrich Chemical Company is now synthesizing and selling biquidone for experimental purposes, making examination of its developmental effects on other animal species easier. ORNL biologists have found that biquidone is not mutagenic in *Salmonella* bacteria. Recently, preliminary experiments by Abe Hsie's Biodosimetry Group in ORNL's Health and Safety Research Division found that biquidone has biological effects on Chinese hamster ovary (CHO) cells. Studies by Maria Rodrigues (a visiting scientist from Instituto Biologico, Sao Paulo, Brazil) and Leslie Recio (an Oak Ridge Associated Universities predoctoral fellow from the University of Kentucky Center for Toxicology) show that biquidone is moderately toxic to CHO cells and causes them to exhibit a weak mutagenic response.

Our studies of synthetic crudes and crickets contribute to a growing body of information indicating that coal liquids are generally more toxic than the petroleum products they would replace. This set of findings, however, should not prohibit the development of a synthetic fuels industry. Rather, it should alert developers to potential problems that may need to be addressed if coal liquids are to be safe for humans and the environment.

Our results also support the view that even trace organic contaminants in soils may have profound effects on organisms if exposure occurs during a vulnerable period in the animal's life cycle. We have demonstrated that a minor component of a complex mixture can assume major significance in producing a response.

More studies are needed before we will know whether the cricket embryo assay can provide a shortcut for recognizing chemicals capable of causing developmental abnormalities in humans. At present its most promising application is in ecotoxicology, where it could be used as a sensitive, inexpensive means of detecting trace levels of toxicants in soil, water, and waste samples. Our current efforts are directed toward the latter application. For us, producing monster crickets is not an end in itself but a means to finding whether something could go awry in our environment. ornl

take a number

BY V. R. R. UPPULURI

How Many Sons and How Many Daughters?

If you want to determine how many sons and how many daughters are in a given family, you could find out directly by asking someone who belongs to or otherwise knows the family. Or, if you enjoy playing games, you can figure out the number of sons and daughters by asking that person to use the following procedure.

Double the number of sons and add 5 to it. Multiply the result by 5 and add the number of daughters to it. Subtract 25 from this final result. When the person gives you the result, it will contain the needed information: The first digit represents the number of sons, and the second digit gives the number of daughters.

For example, suppose a family has 2 sons and 3 daughters. Doubling the number of sons and adding 5 gives $(2 \times 2) + 5 = 9$; multiplying this result by 5 and adding the number of daughters gives $(9 \times 5) + 3 = 48$; subtracting 25 gives $48 - 25 = 23$. In the result, 2 represents the number of sons and 3 represents the number of daughters in the family. This procedure works only if the number of sons or daughters does not exceed 10.

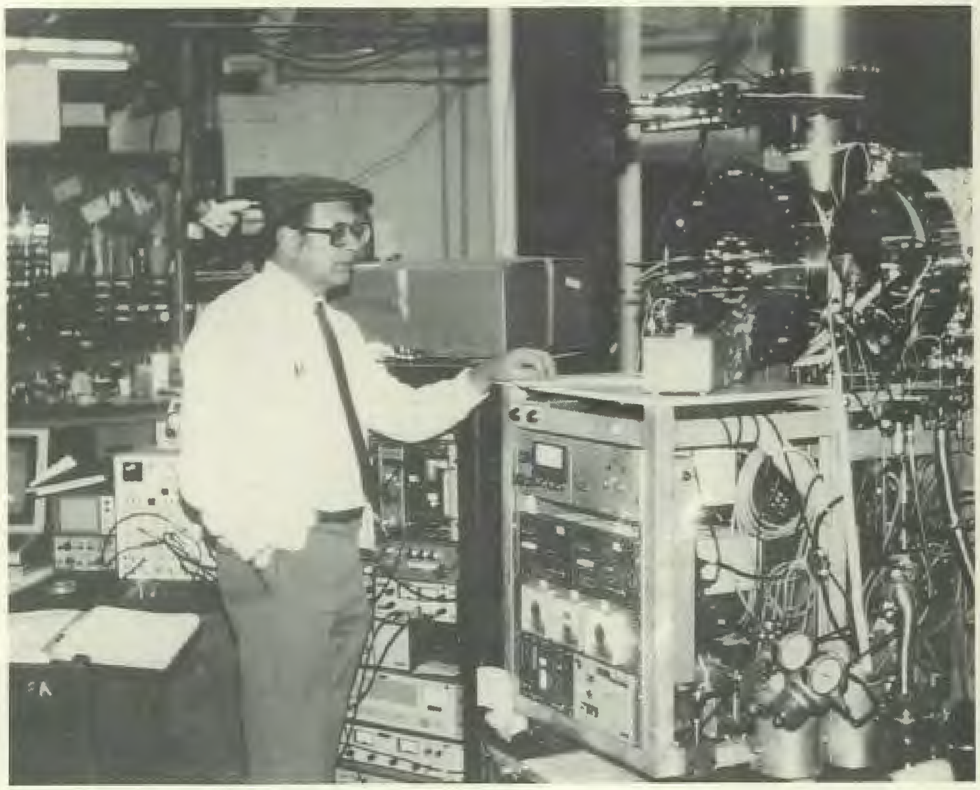
Convergence by Repetition: A Follow-Up

Ed Creutz, a physicist and former director of the Bishop Museum in Honolulu, Hawaii, suggests a generalization of the problem discussed by "Take a Number" on page 32 of the ORNL *Review*, Number Four, 1984. In one example of this problem, one could obtain the number 3 by starting with the number 6, taking its square root and adding 6 to the result, taking the square root of this answer and adding 6 to it, and repeating these calculations until they converge to 3. The same result can be obtained with 24 (take the cube root, add 24, and repeat) and with 78 (take the fourth root, add 78, and repeat).

To generalize the problem, take the number $\theta = (\alpha + 1)^p - (\alpha + 1)$ where α and p take the values 1, 2, 3, ... Take the p^{th} root of θ and add θ to it. Continue this process on the result obtained, and quickly you will converge to $(\alpha + 1)$.

More specifically, if $\alpha = 2$ and $p = 5$, we find that $\theta = 240$. Take the fifth root of 240 and add 240 to it. Continue this process on the result obtained and quickly you will converge to $\alpha + 1 = 3$.

Thomas A. Carlson (right) and Manfred O. Krause (left) are among the world's leading experts on electron spectroscopy and photoionization processes using various light sources, including the relatively new synchrotron radiation. Carlson is a senior staff member of ORNL's Chemistry Division, which he joined in 1954 after obtaining his Ph.D. degree in chemistry from Johns Hopkins University. From 1958 to 1979 he was a member of the Physics Division, and he spent two years on leave from ORNL (1966–67 and 1977–78) at the Research Institute of Physics in Stockholm, Sweden. In 1979 he rejoined the Chemistry Division. At ORNL Carlson was one of the first to introduce electron spectroscopy for chemical analysis in the United States. He also did some of the earliest work on electron shake-off in photoionization and angular distribution in photoelectron spectroscopy. He was chairman of the 1976 Gordon Conference on Electron Spectroscopy and cofounder and coeditor of the *Journal of Electron Spectroscopy* from 1972 to 1977. Carlson is author of two books on



electron spectroscopy, was a Guggenheim Fellow, and is a fellow of the American Physical Society. Krause, a native of Stuttgart, Federal Republic of Germany (FRG), received his doctoral degree from Technische Universität, Stuttgart, and Max-Planck Institut, Stuttgart. After working three years at the William H. Johnston Laboratory in Baltimore, Maryland, he came to ORNL in 1963 and collaborated with Carlson for two years in the Physics Division. Although no formal arrangement existed, they

Shedding Light on Molecules

Photoelectron Spectroscopy Using Synchrotron Radiation

By THOMAS CARLSON AND MANFRED KRAUSE

One of the most important means of studying atoms and molecules is through photoemission—the emission of negatively charged particles (electrons) from materials bombarded by photons of ultraviolet radiation, X rays, or synchrotron radiation. These studies provide some of the keys to the secrets of atomic and molecular physics. During the past two decades Oak Ridge National Laboratory researchers have contributed much to the field of photoemission studies and to the recent rapid growth in knowledge resulting from the use of synchrotron radiation. How we have used this new approach to a venerable methodology is told below.

In the 1960s two very important developments took place in the use of photoemission. Both dealt with photoelectron spectroscopy, or the measurement of the kinetic energies of ejected photoelectrons. In Sweden, Kai Siegbahn built an electron spectrometer of high

continued to collaborate on various research projects over the ensuing years. In 1980 they reunited their programs in the Chemistry Division and pursued research with synchrotron radiation. Krause is a fellow of the American Physical Society and is listed in the 1982 edition of Marquis' *Who's Who in the World*. In 1977 he received the Alexander von Humboldt Award from the Universität Freiburg, FRG. Here, Carlson and Krause work at the Synchrotron Radiation Center in Stoughton, Wisconsin.

and Atoms:

resolution to measure the energy of photoelectrons ejected by X rays. With X rays he could probe the more tightly bound atomic electrons. The binding energies he obtained for these electrons held in the deeper atomic shells were close to those anticipated from atomic theory. However, his high-resolution spectrometry also allowed him to note slight shifts in the binding energy that depend on the chemical environment. Thus was born electron spectroscopy for chemical analyses (ESCA). With ESCA one can measure not only the presence of a given element but also the nature of its chemical environment—for example, whether a given atom occurs in a metallic state or as part of a compound such as an oxide. If more than one kind of oxide exists, ESCA can even distinguish between them. ESCA is particularly useful as a tool for studying surfaces. In 1980 Siegbahn was awarded the Nobel Prize in Physics for his work on high-resolution electron spectroscopy, particularly ESCA. Today the technique is used in university and industrial laboratories throughout the world.

Meanwhile in England, David Turner sought to use electron spectroscopy to measure the binding energies of the least tightly bound electrons in a molecule. According to molecular orbital theory, each electron in a molecule moves in its own orbit about the molecule. The least tightly bound electrons are in the outermost shell, or valence shell, and they tend to move about the molecule as a whole rather than locally around the different atoms. What glues the molecule together is those electrons that move about and between the different atoms. Because electrons in the valence shell need only a small photon energy to eject them, Turner chose a monoenergetic source of 21 electron volts (eV) formed in a helium-discharge lamp; the source is intense and well defined in energy. The difference between the photon energy, 21 eV, and the energy of the ejected photoelectron measured by an electron spectrometer gives the binding energy of a particular valence electron. Robert Mulliken, another Nobel Prize winner, has said that although molecular orbital theory seemed a reasonable concept, not until the advent of photoelectron spectroscopy was a truly convincing experimental basis for molecular orbitals available.

While these exciting events were occurring in Sweden and England, we made our own contributions at

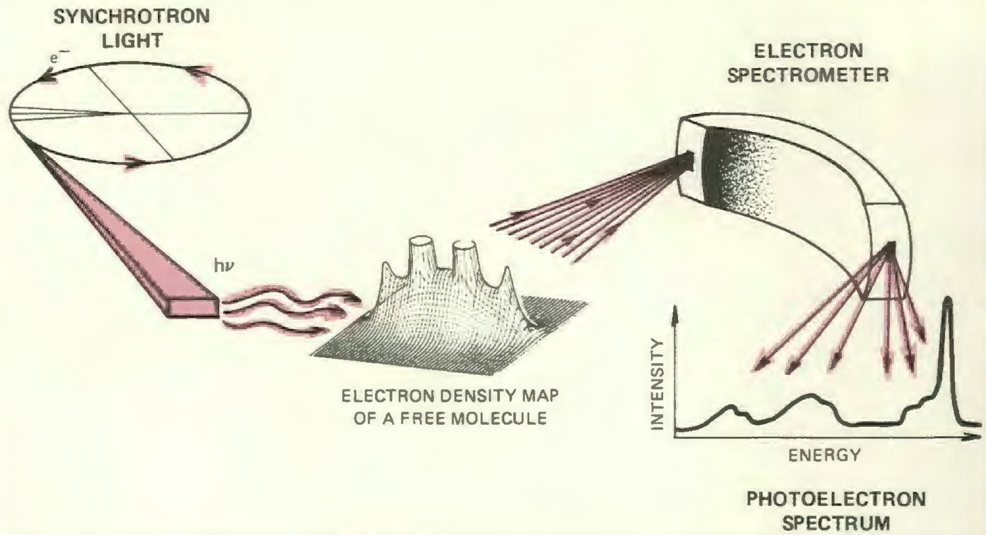
ORNL. Manfred Krause built the world's first photoelectron spectrometer for studying gases with photons of X-ray energy. Using Siegbahn's concepts, Tom Carlson built the first electrostatic ESCA machine in the United States. Carlson and Lester Hulett (Analytical Chemistry Division) were among the first to use ESCA to study environmental problems such as the analysis of fly ash. We carried out the first X-ray photoelectron studies with gases to examine the angular distribution of ejected electrons and later, with the helium-discharge lamp, helped to establish the field of angle-resolved photoelectron spectroscopy of molecules.

A New Era

In the early days of photoelectron spectroscopy the emphasis was on the binding energies. But a photoelectron spectrum does more than that. It separates, as a function of photoelectron energy, the various photoionization processes. As a result, one can study individually the cross section, or probability for ejecting an electron from a given atomic or molecular orbital. This change of emphasis from energies alone to cross-sectional measurements has ushered in a new era of photoelectron spectroscopy. The new approach is often called photoelectron dynamics, to emphasize the dynamics of the photoelectron process.

In addition to measuring the total cross sections for each photoionization event, one can also measure the cross section as a function of angle. The angle is defined as the difference between the direction of the ejected photoelectron and the direction of the photon beam (or more precisely, the polarization direction of the light). For a large number of randomly oriented free gas molecules, the angular distribution (the relative number of ejected electrons emerging in different directions in respect to the photon beam direction) can be reduced to a single parameter, beta. As with the cross section, beta can be measured separately for each photoionization event.

The reason these two measurements of cross sections and beta values are so very important is that they shed light on two of the most basic concepts in chemical physics. The first concept is the characterization of the wave functions for single electrons in a molecule. The wave function refers to the conception of an electron as a wave that curves all around the molecule rather than as a particle that circles a nucleus like a planet revolving around the sun. This wavelike behavior can be described by an equation called the wave function, which is deduced from the theory of wave mechanics. By knowing the wave function, or more precisely the square of the wave function, one can describe the electronic structure of a molecule—that is, the relative positions of different electrons in



Schematic view of how synchrotron radiation is combined with photoelectron spectroscopy for an experiment. Synchrotron radiation, which is produced by accelerating high-energy electrons in a storage ring, is emitted as polarized radiation. After passing through a monochromator to give a selected photon energy, the radiation strikes gaseous molecules, here represented by an electron density plot of a free molecule (in this example, acetylene). Electrons are photoejected from the molecule and separated according to their kinetic energies by an electron spectrometer. From the photoelectron spectrum the ORNL scientists obtain both the energy necessary to eject the electron from the different molecular orbitals of acetylene and the intensity or probability that these processes will occur.

ORNL researchers using the magic source of synchrotron radiation have helped to usher in a new era of photoelectron spectroscopy called photoelectron dynamics. Recently, use of this method has provided fresh answers to a number of fundamental questions on the electronic structure of small molecules and metal vapors.

Krause and Pam Woodruff take data with the new version of the ORNL electron spectrometer at the Wisconsin Synchrotron Radiation Center.

the molecule's outermost shells. The second concept relates to the dynamics of the photoionization process. By understanding the complex processes by which photons of different energies can knock electrons loose from the grip of the multiatomic molecule, one can begin to describe the first step of a chemical reaction.

Synchrotron Light Source

Measurements of angle-resolved photoelectron spectroscopy, described above, require a special light source. Measurements need to be made as a function of photon energy and as a function of angle. The ideal light source for studying cross sections and beta values must be intense, wide-ranging in photon energies, and polarized. Such a light source is synchrotron radiation. When electrons are accelerated, they emit a continuous radiation. To obtain photons in the range of 10 to 1000 eV, electrons must be accelerated in a synchrotron or similar high-energy machine at a billion electron volts.

Six synchrotron light sources have been built in the United States, and another dozen exist in the rest of the world. At a given synchrotron light facility, from 5 to 50 different research groups cluster around a storage ring of circulating high-energy electrons to make use of the ever-glowing light. A synchrotron radiation center is more like an institute for interdisciplinary science than a single one-shot experiment.

For four years we have been studying bound electrons in matter by using this special light produced by other, free electrons whirling around a circular track. Since 1981 we have been traveling to the Synchrotron Radiation Center at Stoughton, Wisconsin, carrying in a small van an electron spectrometer specially designed for studies with synchrotron radiation. In a collaborative program set up with Jim Taylor, professor of chemistry at the University of Wisconsin, we have conducted research on the 250-MeV storage ring called Tantalus.

With Taylor we are now planning to use a beam line ideally suited for gas molecules. It has been installed at the university's recently constructed 1-GeV synchrotron source (called Aladdin), which, when put into full operation, will be superior to Tantalus because it has both a greater light intensity and a wider range of photon energies. We also plan visits to other synchrotron light sources, such as the National Synchrotron Light Source at Brookhaven National Laboratory. (Our motto is, "Have electron spectrometer, will travel.") Another essential ingredient in our collaborative efforts is Fred Grimm, an ORNL consultant from the University of Tennessee, who has carried out the theoretical calculations that help interpret the experimental results.

Peaks and Valleys

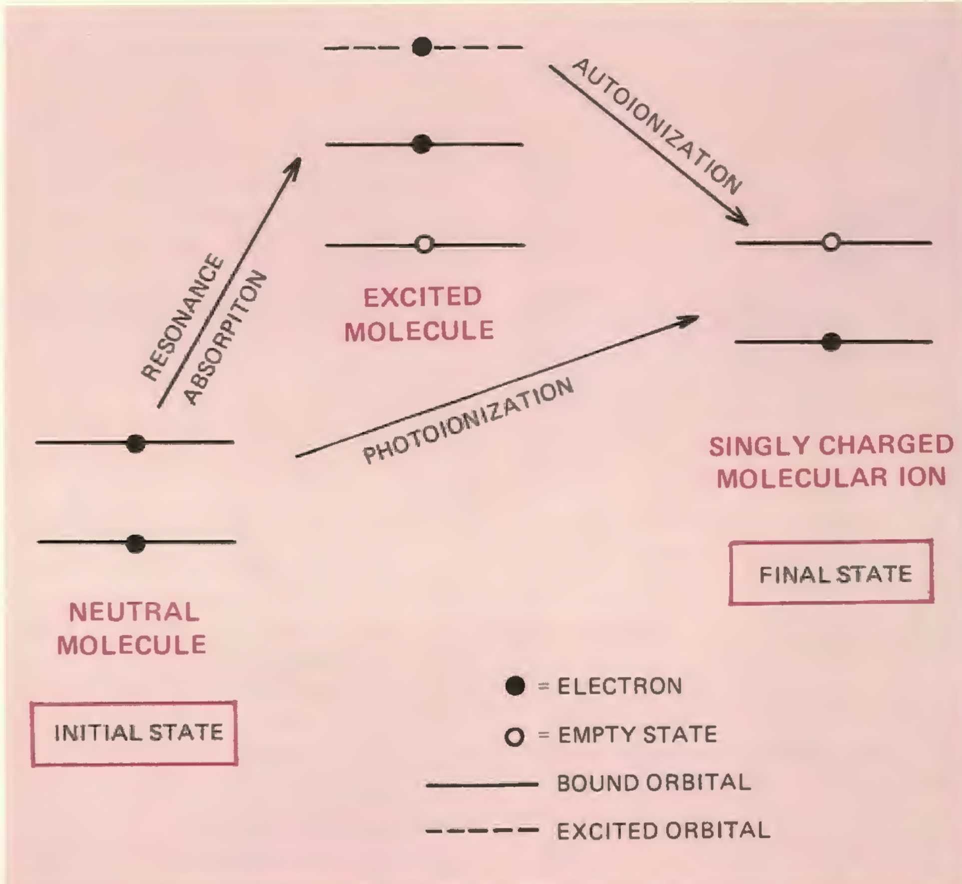
Using synchrotron radiation for angle-resolved photoelectron spectroscopy, our group has studied more than 60 atoms and molecules, ranging from hexafluorobenzene to silver vapor. We have actually studied more molecular systems by this method than have all other scientists combined.

Our study of a variety of molecules has been interlaced with the study of the rapid changes for cross sections and beta values found as one plots the measurements as a function of photon energy. For example, consider changes reflected in different kinds of resonances, or peaks in intensity. A resonance takes place when the energy between two electronic states is equal to the photon energy. Under these circumstances a transition occurs in which one electron is transferred from one state (energy level) to another. The cross section for photon absorption rises rapidly at the resonance energy.

One special resonance encountered in photoionization is a *shape* resonance. The term *shape* comes from the shape of the molecular potential, or potential energy plot of electrons bound to a molecule as a function of distance from the molecule. This potential energy plot can have a barrier above the energy needed for ionization, and thus a state can exist above the ionization potential. An electron resonantly absorbed into this state, however, quickly tunnels through the barrier to the continuum or outer world, and shape resonances are found to be unusually broad, even as wide as several volts.

We have demonstrated the occurrence of shape resonances in different molecules and have examined some special properties such as the effect of molecular vibration, or the relative movement of the different atoms, on the shape resonance. Recently, we have shown that one can examine the effects of a shape resonance by studying a series of related molecules, such as the tetrahalides of carbon, silicon, and germanium. Our goal is to relate the changes in molecular potential for a series of molecules by studying shape resonances.

Angle-resolved photoelectron spectroscopy also reveals resonances that are as narrow as a few millivolts. These *sharp* resonances involve autoionization. In contrast to direct photoionization (and shape resonances), which is a one-step process, a two-step process can occur. Following resonant absorption into an excited state, a second step, called autoionization, occurs. In this step two electrons in each atom or molecule rearrange themselves—that is, one falls to a lower energy state while at the same time a second leaps into the continuum, carrying away kinetic energy just like a photoelectron. Energy measurements alone cannot distinguish between direct, one-step photoionization and a two-step process involving autoionization. The rapid changes in cross sections and beta values as a function of photon energy are signals that a resonance has occurred. Using new computer-controlled techniques, we can now make comprehensive studies of autoionization. In dinitrogenoxide (laughing gas), for example, we have analyzed more than 100 such sharp resonances. Each has been characterized by the angular distribution of the ejected electrons. We hope that a clearer understanding of these excited states and their interaction with each other can be extracted from these data, because the

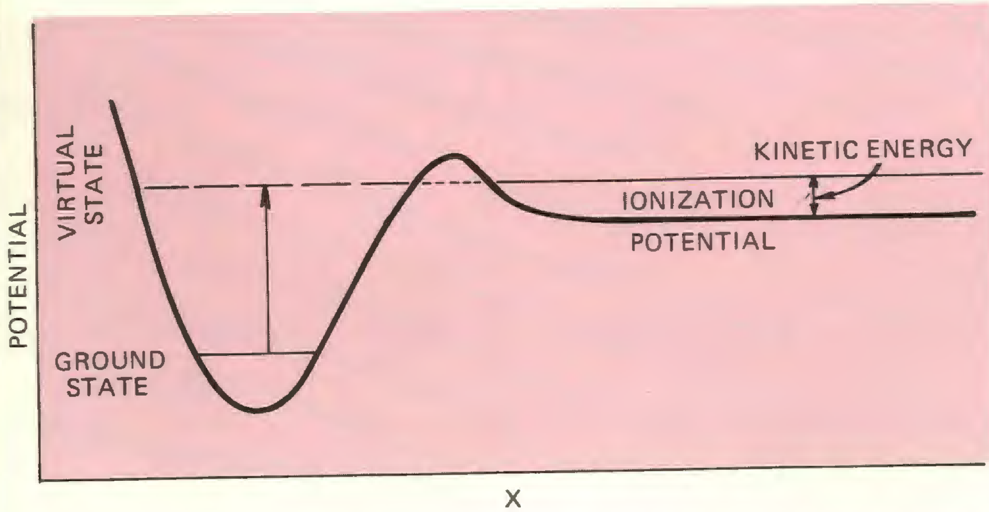


Schematic representation of autoionization. A neutral molecule can go to a given ionic state by two routes as the result of photon interactions: (1) direct ejection of a photoelectron or (2) a two-step process in which one electron is placed in an excited state followed by autoionization, which is the readjustment to a lower energy state by dropping an electron into an empty level while another is ejected from the molecule.

understanding of resonance and autoionization lies at the heart of the dynamics of photoionization.

Minima, or valleys, in the cross sections and angular distribution parameters (beta) are also found when measurements are plotted as a function of photon energy. Such minima can arise when the probability for a transition into one of the main channels for photoionization becomes zero at a certain photon energy. (The word *channel* defines the total final system, including both the state of the ions and the kinetic energy and angular behavior of the ejected electrons.) A study of the cross section as a function of photon energy reveals a point where the positive and negative parts of the wave functions of the initial and final states can cancel in such a way that virtually no opportunity exists for a photoelectron to be ejected into a particular channel. We have found this phenomenon to be true for compounds containing chlorine, bromine, and iodine (but not for fluorine) as predicted by theory. We are using results on these minima (called Cooper minima) to determine the atomic makeup of the molecular orbitals. That is, the wave function character of a molecule can be expressed as a sum of partial atomic wave functions.

In most of our studies we have examined the outer, or valence,



Schematic representation of a shape resonance. In this highly idealized picture, the solid line represents the total molecular potential as a function of the position, x, of an orbital electron. If photoionization takes place, x goes to infinity. Because of the shape of the barrier above the ionization potential, a virtual level occurs. When the photon energy matches the energy difference between the ground state and the virtual state, an electron is resonantly absorbed into the virtual state, whereupon the excited electron travels through the barrier to freedom. The kinetic energy that the ejected electron carries is the difference between the virtual state and ionization potential.

shells of the molecule because valence electrons are involved in chemical reactions. However, the study of the photoelectrons ejected from the deeper core shells is also useful to measure the grip that the nucleus has on its closer electrons. These deeper core electrons can be identified with a given atom, and as the ejected electron emerges, it examines the molecular potential from a particular spot in the molecule. We have made a few limited studies, but with access to higher photon energies expected in the near future, we and others will be able to determine the molecular potential for core shells in nearly all the atoms in the periodic table.

Each of the phenomena discussed above gives its own special information. When melded together, the pieces form a whole that yields a rich understanding of the photoelectron dynamics of molecules. Such knowledge is the first step in discovering how electrons move and interact as atoms and molecules enter chemical reactions.

Atoms and the Many-Body Problem

Atoms are, of course, the building blocks of molecules. They also offer a closer look at some of the fundamental questions of photoionization. In particular, they constitute a sensitive test of the many-body problem. Most physical laws deal with forces between two bodies, such as the repulsions between two electrons: For many-body interactions, as in a multi-electron atom, approximations must be made. It has been said that most of physics is enmeshed in the many-body problem. If this is true of physics, it is even more applicable to the other branches of science.

Photoelectron spectroscopy of atoms offers many beautiful opportunities to test approaches to the many-body problem. The 5*s* orbital of the rare gas xenon is an example. When one plots the angular distribution parameter, beta, against photon energy, a dip, or sudden drop, in the value of beta is obtained at a photoelectron energy of about 8 eV. That any change in beta should occur for an *s* orbital is interesting because, nonrelativistically, an *s* electron can be photoionized into only one channel, which has a fixed beta value of +2, whereas changes in beta can result only from interaction of two or more channels. However, relativistic theory requires that the outgoing photoelectron have two different spins, thus allowing two different channels to interact and cause the dip.

For xenon, evaluation of many-body effects as well as of relativistic effects was needed to obtain agreement between theory and experiment. We discovered that even this agreement was only apparent. By carrying out careful, detailed measurements, Anders Fahlman (who took a year's leave from the University of Linköping in Sweden to work with us) found a large discrepancy between his measurements and the results predicted by theory. When his measurements were plotted, the dip was less than one-third of that predicted by the early theorists. These findings were confirmed elsewhere, leading to suggestions for improving the contributions from many-body theory. The photoelectron dynamics of atoms is a severe testing ground for many-body theory.

Recently, we completed the most comprehensive experimental study to date of the photoelectron dynamics of a transition metal atom—manganese. As constituents of metals, atoms have original properties that remain intact despite changes that take place in their electronic structure when they are squeezed together in close contact with their nearest neighbor. In metallic manganese, however, the outermost electrons and the next shell of inner electrons—in

Carlson and Fred Grimm ponder the results from an earlier version of the University of Wisconsin's electron spectrometer at the Synchrotron Radiation Center at Stoughton.

The vacuum ultraviolet (VUV) storage ring at the Brookhaven National Synchrotron Light Source is a typical synchrotron radiation facility. Experimenters are grouped around the VUV ring. ORNL scientists plan to use the facility there this year for their experiments.

this case the 3*d* electrons—form a conduction band, indicating that these electrons have lost their atomic character. The outer electrons no longer move locally around each atom but rather travel throughout the whole metal. The many-electron (many-body) effect of the closely associated electrons in the conduction band has been hypothesized as being responsible for the unusually large resonance, first noted 15 years ago in the photoionization cross section at a photon energy of about 50 eV.

However, our experiments with the free manganese atom present in the metal *vapor* showed that an alternative explanation was true. We found that although the many-electron effect exists in the metal, it also occurs in the atom and it is retained even when the electrons enter the sea of the metal conduction band. That is, unusual effects found in a metal may not necessarily be due to the nature of the metal; they may be the result of the atomic behavior. Studies of other metal vapor atoms—gallium, silver, lead, and ytterbium—help us to isolate and illuminate the atomic properties in their pure state (i.e., individual atoms in the gas phase) and at the same time provide an important key in the interplay between experiment and theory, which can be formulated at the simplest, most basic level for atoms.

The Future

Although our current research with synchrotron radiation has been most productive, we anticipate even more illuminating results as the expected improvements in the intensity of light sources occur. More efficient storage rings and new devices such as undulators and wigglers are expected to increase the light intensity several orders of magnitude, making possible a whole new realm of experiments. We should be able to study molecules in laser-induced excited states, to separate electrons according to their spin polarization, and to study metal clusters to bridge our knowledge of isolated atoms with that of atoms in metals. In fact, preliminary investigations are already under way in these new areas of study.

Most important, for molecules, we would like to make angular studies in which the molecular axis is oriented relative to the direction of the light. These studies would yield more direct information on how the electron density is spatially distributed in the molecule. We plan to do such studies in the near future by orienting molecules on surfaces of well-defined metal crystals such as copper or nickel.

The information gained on the behavior of the adsorbed molecules would also be highly beneficial to surface science and catalysis. Knowing the direction that a molecule is oriented on a particular surface and the changes in the molecular orbitals that occur when a molecule is adsorbed could help predict which chemical reaction might occur on a catalytic surface. Like the light sources that we now use for our research, the prospects for learning more about the nature of atoms and molecules by using synchrotron radiation and photoelectron spectroscopy seem very bright. ornl

news notes

ORNL-Japan microscope for fusion materials research

A new $500,000 electron microscope for studying radiation effects on materials is now operating at ORNL as part of a five-year, $10-million collaborative effort by ORNL and the Japan Atomic Energy Research Institute. A ribbon-cutting ceremony for the new microscope was held March 15.

The electron microscope, supplied by JAERI, is being used to investigate the microstructural effects of radiation bombardment on candidate alloys for 21st-century fusion power reactors. Alloys from both the United States and Japan are being irradiated in ORNL research reactors to determine their susceptibility to swelling and embrittlement, two principal forms of radiation damage. Fusion-reactor alloys must be specially designed to resist these forms of damage, because fusion produces neutron radiation so intense that it would cause ordinary alloys to fail.

Weinberg, former ORNL Director, honored

On April 19, a special symposium was held at ORNL in honor of the 70th birthday of former Laboratory Director Alvin M. Weinberg.

Weinberg, who came to ORNL in 1942, served as Director from 1955 to 1973. He received both of DOE's highest awards, the Lawrence and Fermi awards, and many more honors from other organizations. He founded the Institute for Energy Analysis at Oak Ridge Associated Universities in 1974 and directed it for the next ten years. IEA's work under Weinberg included studies of the climatic effect of the buildup of atmospheric carbon dioxide, the possibilities of revitalizing nuclear power in a "second nuclear era," and the potential role of defensive systems in reducing the nuclear arms race. Weinberg remains at IEA as its senior researcher.

At the April symposium, ORNL Director Herman Postma called Weinberg an "eloquent spokesman" for national laboratories; he also said that 20 years ago, Weinberg predicted the information explosion and set up information centers to deal with it at ORNL.

Ellison Taylor, former director of ORNL's Chemistry Division, noted that Weinberg was both a scientist and a philosopher of science and that he coined the phrases "big science," "trans-science," "technological fix," "priesthood of science," and "Faustian bargain" (as applied to nuclear energy).

According to Floyd Culler, president of the Electric Power Research Institute (and Weinberg's deputy director at ORNL for three years), Weinberg has been a "scientist, futurist, prophet, and, most of all, a teacher."

John Gibbons, director of the congressional Office of Technology Assessment (and head of ORNL's environmental program under Weinberg), said that Weinberg "prodded,

Alvin M. Weinberg.

nurtured, protected, and defended researchers and sometimes took abuse for standing up for principle and reason." Gibbons also noted that Weinberg introduced the idea of hiring social scientists at national laboratories because he saw the link between science and public policy.

Alex Zucker, ORNL associate director for the physical sciences, said he hopes that ORNL's proposed Center for Neutron Research (HFIR-II) will be built and operating by Weinberg's 80th birthday. The CNR would be the most powerful research reactor in the world.

For his part, Weinberg said his job as ORNL Director was "a piece of cake" compared with the job today, because "we were given goals to meet and money to do it with." Today, he said, ORNL's managers must first identify goals and then seek funding for them.

On a note of science and public policy, Weinberg expressed concern about the nuclear arms race and voiced his belief that defensive systems could lead to a negotiated reduction of offensive nuclear weapons.

Weinberg said he appreciated the fuss over his birthday but didn't really need it, because "living 70 years and still being able to hit an overhead smash on the tennis court is reward enough."

12,000th experiment at neutron facility

The National Center for Small Angle Scattering Research logged its 12,000th experiment this spring. The center was established in 1980 as a user facility, open to scientists from universities, industry, and other laboratories as well as to ORNL researchers.

Experimenters use the facility to study how beams of neutrons are scattered by materials such as metal alloys, plastics, and biological structures. The directions and patterns in which the radiation is scattered shed light on the materials' molecular structures and properties.

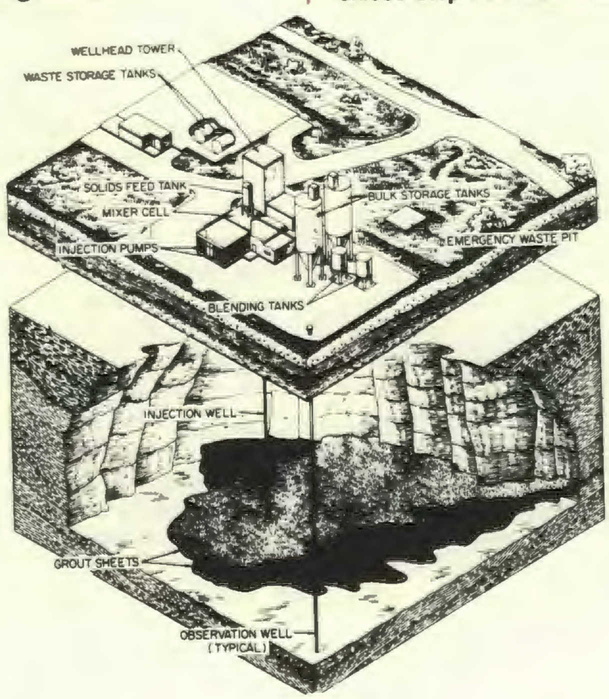
The 12,000th experiment was performed March 30 by Barbara Lewis, an ORNL biophysicist; she was using neutron scattering to make preliminary measurements of phospholipids, the molecular building blocks of cell membranes. Lewis is undertaking a series of neutron-scattering and nuclear-magnetic-resonance experiments aimed at learning how lipids and proteins organize themselves into membranes. She is particularly interested in one membrane that works as an energy "pump," converting solar energy into chemical energy. Eventually she hopes to synthesize a membrane whose properties closely mimic those of natural membranes.

Outside users of the neutron-scattering facility during the previous 11,999 experiments have included researchers from Exxon, DuPont, Union Carbide, 3M, Kodak, Firestone, Ford Motor Company, IBM, and Bell Laboratories, as well as scientists from a host of universities.

What future for hydrofracture?

ORNL's use of hydrofracture for radioactive waste disposal is at a crossroads. Hydrofracture injections have been used periodically at ORNL since the 1960s to cement low-level wastes within shale formations deep underground. Waste-bearing grout is forced under high pressure between layers of Conasauga shale about 300 m (1000 ft) below the ground. The grout hardens and traps the wastes within the impermeable shale.

In hydrofracture, low-level wastes are mixed with grout and pumped into horizontal fracture planes within layers of shale about 300 m (1000 ft) underground.



ORNL's 43rd hydrofracture injection had been planned for this fall, but last year the Tennessee Department of Health and Environment (TDHE) drafted regulations that would prohibit ORNL's use of the underground disposal technique. Also, contamination was discovered last summer in two deep monitoring wells near the hydrofracture site, raising environmental questions about the technique.

Frank Homan, head of the Waste Management Section in the Laboratory's Operations Division, says that without hydrofracture, ORNL would have to resort to disposal or storage options that would cost far more and pose greater risk than hydrofracture. Further, ORNL's storage space for low-level wastes could run out by the end of 1985 unless steps are taken to reduce the volume of wastes.

But TDHE is now apparently willing to consider an experimental injection this fall, to assess the technique's environmental performance in more detail than has been available in the past. If this injection proves successful, additional injections may be considered on a case-by-case basis.

Hot pursuit of frozen fauna

In the midst of subfreezing January temperatures in Tennessee, ORNL biologist Jim Selkirk headed south—to Antarctica, where the summertime temperatures were about the same as in wintry Tennessee and the wind was blowing constantly. Because of a temporary baggage mix-up, Selkirk says, he was "the first person ever to arrive in Antarctica wearing only jeans, a T-shirt, and running shoes."

A helicopter in Antarctica ferries scientists from the Federal Republic of Germany between a Polish base and a Chilean base. The snow and ice fields in the distance are hundreds of meters thick in places and contain many hidden crevasses.

Selkirk was there to determine the feasibility of making a detailed study of Antarctic fish and birds that have not been exposed to chemical pollutants. He's interested in learning how the animals' metabolic systems would respond to their first exposure.

Selkirk is studying a class of pollutants called polycyclic aromatic hydrocarbons (PAHs), which are found in auto exhausts, cigarette smoke, and other combustion products. Some PAHs cause cancer in animals and are thought to be carcinogenic to humans. When animals are exposed to the chemicals, he explains, an enzyme system in the liver switches on to metabolize, or break down, the chemicals into water-soluble forms that can be excreted. Evidence indicates, however, that cancer results not from the parent compounds but from a reactive intermediate formed briefly during the body's metabolism of them.

If the Antarctic creatures haven't previously been exposed to PAHs, their enzyme systems may respond at a different rate than those of organisms from more contaminated environments. Also, the fish may respond differently because they live in subfreezing waters, where—unless specially adapted—enzymes could not break down the pollutants as quickly as in warmer waters. A difference in the fishes' metabolic rate could affect their susceptibility to cancer caused by the reactive intermediate, says Selkirk, because it may be metabolized more slowly at such a low temperature.

"Wherever we look, we find pollution," he adds. "If there are species in Antarctica that have escaped exposure, we need to study them now. Then, if the pollution does reach this extreme end of the world, we'll be prepared to monitor the changes."

Selkirk is proposing a collaborative study that would compare the Antarctic animals to similar animals near Chilean cities such as Valparaiso. The study would involve collaboration with the medical school of the University of Chile at Santiago.

ORNL–steel industry program begins

The U.S. steel industry will benefit from a new cooperative program with DOE's Oak Ridge and Argonne national laboratories. The program, which began this year, is expected to expand into a multimillion-dollar effort next year. The program will include staff scientists at Oak Ridge and Argonne and steel-industry scientists working at the government labs.

Argonne is developing new techniques for making and casting sheet steel; ORNL is developing processing techniques that will improve the properties of the steel. Sheet steel is the most widely used type of steel; the biggest market for it is the auto industry.

Currently sheet steel is produced by first casting the molten metal into thick slabs (46 cm, or 18 in., thick), then rolling the slabs into sheets. An electromagnetic casting technique now under development would produce far thinner sheets—only 0.6 cm (0.25 in.) thick—that could easily be rolled to the thickness of, say, a fender panel. The new techniques could save up to 60% of the energy used by today's casting and rolling processes.

ORNL may also develop new "universal" grades of steel to replace the thousands of custom-made steels now in existence. Instead of varying the composition of steel to modify its properties, as is now done, ORNL favors using processing techniques to produce specific properties. This approach would reduce industry inventories of leftover steels and would minimize the chances of mistakes in filling orders.

ORNL's new steel program is headed by Vinod Sikka, chief developer of a modified chrome-molybdenum steel now being adopted for use in commercial power plants and boilers.

technology transfer briefs

Hitting the streets: Technologies in transfer

• **Fiber-optic luminoscope,** a sensitive, portable monitor developed at ORNL for detecting organic contaminants on skin and other surfaces. The instrument determines the presence of polynuclear aromatic compounds (PNAs) by exposing them to ultraviolet light and then detecting faint levels of fluorescence. The luminoscope has applications in the fossil-fuel, aerospace, and cosmetics industries and in medicine, agriculture, and cancer research. Environmental Systems Corporation of Knoxville, Tennessee, is acquiring exclusive rights to manufacture and distribute the instrument. The agreement will represent the first licensing agreement between Martin Marietta Energy Systems, Inc., and an East Tennessee company.

• **Fiber-reinforced ceramics.** Babcock and Wilcox is working at ORNL to learn more about the fabrication of ceramic composites by the deposition of a ceramic matrix with a fibrous preform. B&W is interested in making reinforced ceramic tubes for heat exchangers, heat-engine cylinder liners, and valve guides. The composites are produced by infiltrating a fibrous preform with vapors of silicon carbide or silicon nitride. The vapors deposit in crystalline form within the preform, producing the matrix of the dense composite. The preform, made of high-strength silicon carbide fibers, toughens the normally brittle ceramic. (For more detail on the process, see page 18.) Other companies, including Pratt and Whitney, United Technologies Research Center, and 3M, are interested in using the technique to make ceramic composites for other applications.

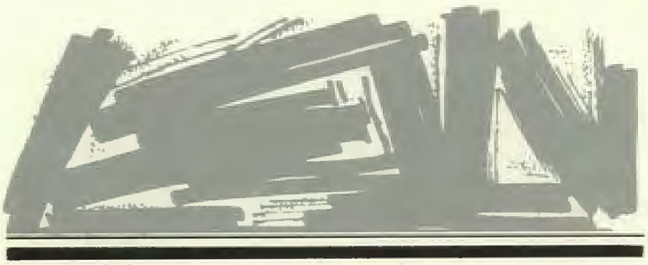
New invention incentives

Cash awards of up to $1000 are now available to inventors at ORNL and the other three DOE facilities operated by Martin Marietta Energy Systems, Inc. The new awards were instituted this spring, but they apply retroactively to all patent applications filed since the DOE–Energy Systems contract began (April 1,1984).

The specific amount awarded for an invention varies from $100 to $1000, depending on the invention's uniqueness, its manufacturability, and its potential impact on the U.S. economy. If the invention is a joint effort, the award will be shared by the inventors listed on the patent application.

In addition to the patent awards, Energy Systems is paying inventors a share of royalties it receives on their inventions. The inventors' shares can range up to $100,000 per invention. The remaining royalties received by Energy Systems are placed in a separate technology-transfer fund.

Other new incentives for inventors include the formation of an Inventors Forum, which is open to any Energy Systems employee listed as an inventor on a patent, and the establishment of invention awards, which will be presented at Energy Systems Awards Night each spring to up to 25 inventors, including one "Inventor of the Year." The Inventor of the Year becomes eligible for a similar competition that encompasses all Martin Marietta Corporation sites and employees. ornl



BOOKS

The Atom and the Fault, *Richard L. Meehan, The MIT Press, Cambridge, Massachusetts (1984), 161 pp. Reviewed by James E. Beavers, Engineering Division.*

The possible hazard to public health posed by damage to nuclear facilities from large earthquakes has been a subject of controversy for many years. Consider some recent examples:

• On March 13, 1979, the U.S. Nuclear Regulatory Commission (NRC) ordered five nuclear power plants in Maine, New York, Pennsylvania, and Virginia to shut down. The reason: NRC contended that the seismic code used to design nuclear piping systems contained an incorrect algebraic summation of earthquake forces (the developer of the code disagreed) and ordered that all systems be reanalyzed with acceptable codes.

• During a U.S. Geological Survey (USGS) workshop in May 1983, geologists speculated about the implications for the Southeast of the 1886 earthquake in Charleston, South Carolina, which measured 7.8 on the Richter scale. After the region's geological structure and the earthquake's probable cause were discussed, R. E. Jackson (then Chief of NRC's Geosciences Branch) commented, "I have counted a total of eight different hypotheses, one of which implies that a repeat of the 1886 earthquake could occur almost anywhere east of the Appalachian chain. If such a hypothesis were true, most of the reactors in the East might be shut down."

• On September, 7, 1984, the *Knoxville News-Sentinel* carried the front-page headline "Quake Fears May Save Ridge Plant" over an accompanying article entitled "Fault Casts Dire Shadow on Paducah." The article noted that then U.S. Representative Albert Gore, Jr., of Tennessee (now a U.S. senator) planned to hold a subcommittee hearing to determine whether the gaseous diffusion plant at Paducah, Kentucky, is a more likely candidate for shutdown than Oak Ridge's plant because Paducah lies along an active earthquake fault. (I was one of those requested to testify at this hearing.)

These recent events in the eastern United States are typical of those described by engineer Richard L. Meehan in his book *The Atom and the Fault.* In a chatty style, the book relates many anecdotes about Meehan's personal experiences after he was thrust into an adversarial role with other scientists, engineers, lawyers, and environmentalists over nuclear power plants and earthquake faults in California.

Meehan entered the adversarial arena as an idealist who believed that facts are facts and that only one truth exists. He begins his book with the question: "Aren't we scientists and engineers specially trained to perceive that one reality?" As a result of dealing with a scientific issue with emotional overtones, he concludes by asking, "In what ways can honesty and objectivity among scientific experts actually exist?"

Meehan focuses on the six-year debate about whether it would have been safe to continue operating America's first commercial power plant. The Vallecitos reactor, located at the test site of the General Electric Company (GE) in Vallecitos Valley, 56 km (35 miles) from downtown San Francisco, first came on-line in 1957. The plant was ordered shut down in 1977 because of a probable fault near the site. At the time of the shutdown, the reactor had a flawless safety record.

Meehan also touches on the events surrounding Pacific Gas and Electric Company's (PG&E's) cancellation of the Bogeda Head Nuclear Power Plant and the startup delay of the Diablo Canyon Nuclear Power Plant because of faults discovered at both places during project construction. At Bogeda Head the fault was found to be just under the reactor foundation. At Diablo Canyon the fault was discovered offshore, which required millions of dollars' worth of retrofits to make the reactor more resistant to much larger seismic forces.

That Diablo Canyon survived is amazing. As Meehan points out, PG&E, which collaborated with GE on Vallecitos, canceled the Bogeda Head plant, abandoned the Davenport and Point Arena reactor sites, and shut down the Humboldt Bay reactor (which operated only 13 years of its 40-year life), all because of newly discovered faults.

In his book Meehan, who represented GE during this time, criticized geologists for their indecision and their apparent enjoyment in disagreeing with one another. As he puts it, " In 1969, with passage of the Alquist-Priolo Act, armed with their newly found powers, the geologists did what they had been doing in their journals and meetings for more than a hundred and fifty years. They did it with all the lusty eagerness, nineteenth-century eloquence, and sly competitiveness that was a traditional hallmark of the geologic profession. They disagreed." As an engineer who has worked in the geologic arena and has engaged in such controversy, I understand what Meehan is saying. However, the engineer must recognize that a great distinction exists between engineering and geology: Engineering is largely "black and white"; geology is "gray," leaving much understanding of how and why things happen to hypothesis.

I found it a treat to review Meehan's book. I was amused that the discussions he had, the adversarial roles he played, and the confusion he encountered were similar to my experiences. I was interested in Meehan's portrayal of various personalities involved in his cases, how he quoted them, and what he said about them; several of these scientists and engineers are professional friends of mine. I am not sure they would agree with his interpretation of the events or his impression of them. They may strongly disagree in some cases. I doubt, however, that they can dispute his account of what can happen when scientists, engineers, lawyers, and environmentalists are thrust together in adversarial roles over such issues as whether a nuclear power plant can withstand damage from a hypothetical earthquake or whether such an earthquake potential exists.

Reading Meehan reminded me of a case much closer to home—a situation whose outcome will never be known. In a January 19, 1983, letter to NRC's Jackson, J. F. Devine, USGS Assistant Director for Engineering Geology, submitted the Geological Survey's final Seismology and Geologic Review of the site of the Clinch River Breeder Reactor Project (CRBRP). In this report the USGS states:

• J. B. Hadley and Devine show the Appalachian seismicity to have a "hot spot" (an area of historically small earthquakes) in the Maryville-Greenback area of eastern Tennessee. More recently J. W. Dewey and D. W. Gordon have determined new locations for the epicenters of a large number of instrumentally recorded earthquakes in the eastern U.S. Nine of these "relocated" earthquakes (on a map of the area) make up a zone 15 km (9 miles) wide and 180 km (112 miles) long.

• This alignment may represent a basement [bedrock 3 km (2 miles) to 16 km (10 miles) deep] seismic source or fault analogous to the proposed geologic structure believed responsible for the Giles County, Virginia, earthquake of 1897.

• The geological structure considered possible for the vicinity of Knoxville is significantly longer than that proposed for the Giles County structure. This hypothetical fault appears to be long enough to generate large earthquakes. (The proposed geological structure for the Giles County earthquake is considered capable of causing an earthquake that could measure as high as 7.0 on the Richter scale.)

The hypothetical fault, or seismic zone, that USGS refers to is within 15 km (9 miles) of the site where the CRBRP was to be built and within 5 km (3 miles) of my home. Of course, my reaction to this hypothesis was not merely the reaction of an engineer interested in objective information about geological phenomena; the first thing I did was to fetch a map and plot the line to see how close it was to my home. I also felt disturbed that such a hypothesis was put forward when no evidence of such a fault, other than the alignment of nine earthquakes, even exists. It appeared that in its final report USGS was trying to raise another issue—why the CRBRP should not be built.

In this case I could easily identify with Meehan's message: Engineers, scientists, lawyers, and environmentalists are people; and people react like people. They have different opinions, work environments, backgrounds, and lifestyles, all of which influence the way they approach scientific and engineering subjects. And, of course, any scientific subject that deals with possible risks to people's health and safety, or jobs, is bound to arouse emotion and provoke controversy. I know that from experience.

After presenting testimony for 15 min before the Gore subcommittee on earthquake risks and the nation's gaseous diffusion plants, I had to respond to questions for about an hour. I tried to give responses that were technically accurate and showed good judgment. However, because the session was somewhat adversarial, I found it difficult to remain objective. My answers were frequently misinterpreted. I found myself worrying more about how I might be trapped when I answered than about whether my answers were technically accurate.

Meehan states the problem in the last paragraph of his book in this way: "During this century science and engineering have gained an almost religious status, with all the accompanying trappings of power and authority. The current resurrection of the nineteenth-century struggle between science and religion may force us to reexamine our principles and justify our authority. Perhaps the controversies that I have described will have a similar salutary effect."

The earthquake controversy turned out to be a thorn in the side of the nuclear power industry; because of it, the cost of nuclear power plants soared and many plants died on the drawing board. *The Atom and the Fault* gives the reader a unique insight into that controversy. ornl

DOE To Use ORNL Earthquake Recommendations To Set Nuclear Plant Standards

Standards governing the construction of nuclear facilities to make them resistant to damage from earthquakes have been based largely on data from instrumented studies of earthquakes in the western United States. However, most nuclear power plants are located in the eastern United States, and the nature of the damage from earthquakes in the East appears to differ from that in the West.

According to Richard C. Gwaltney, an earthquake specialist in ORNL's Engineering Technology Division, "Only a few 'large' to 'great' earthquakes have occurred in the East—the New Madrid earthquakes near Memphis, Tennessee, in 1811–12, and the one at Charleston, South Carolina, in 1886. Unlike the situation in the West, no evidence exists in the East of surface ruptures related to earthquakes or of currently active tectonic plate boundaries.

"Eastern seismic characteristics are significantly different from those of the western United States. Major earthquakes in the East occur only every 50 to 100 years whereas earthquakes in the West occur every 5 to 10 years. However, because earthquakes in the East are larger in magnitude and the attenuation [weakening] of seismic waves is lower, the shaking and damage extend over a much larger area in the East than in the West. The damage area affected by the New Madrid earthquake, for example, was much more extensive than that from the 1906 San Francisco earthquake."

The problem that regulators face in setting standards for construction of nuclear facilities in the East is that the only instrument-derived information for eastern earthquakes is on small earthquakes. The large earthquakes that we know of occurred before nuclear power plants were built in the region, but little is known about them.

Because no design procedures existed specifically for designing nuclear facilities to be resistant to the damage that might be expected from a large earthquake in the eastern United States, the Department of Energy asked ORNL to develop procedures as part of the DOE Liquid-Metal Reactor Program. This program is developing the concept of a liquid-metal reactor that would be smaller and less expensive than current light-water reactors and would gain public acceptance because of its passive safety features.

ORNL assembled a team to assess seismic information and develop guidelines based on state-of-the-art knowledge. The team then recommended earthquake ground motion definition guidelines for liquid-metal reactors in the eastern United States. These guidelines were developed by both ORNL staff members and consultants for the former Clinch River Breeder Reactor Project.

Nuclear power plants are required to be designed to withstand seismic disturbances. Each plant owner must specify a "design basis earthquake"—that is, a hypothesized earthquake that the plant will be designed to withstand. The procedure used has been based on data obtained on earthquakes in the western United States. The "design basis earthquakes" include the "safe shutdown earthquake," which is based on the maximum earthquake potential, and the "operating basis earthquake," which is based on historically small earthquakes that could reasonably be expected to affect the plant during its lifetime.

The plant is then supposed to be designed to resist the "design basis earthquake." The plant floor structure and components, such as pressure vessels, steam generators, pumps, and piping, are built to be earthquake-resistant. Using the design basis earthquake, specialists perform complex dynamic analyses to ensure that no radiation is released to the public during a safe shutdown earthquake and that a plant shut down during an operating basis earthquake can be restarted after inspection.

The ORNL team recommended that, if sufficient data exist, the size of the operating basis earthquake should be determined by a probabilistic analysis instead of by assuming that it is one-half of the safe shutdown earthquake, as is usually done. Says Gwaltney, "The operating basis earthquake should be of such a magnitude that it would occur only once in 500 years at the site. This frequency is roughly equivalent to a 90% probability that such an earthquake will not occur more than once during the 40-year life of a plant."

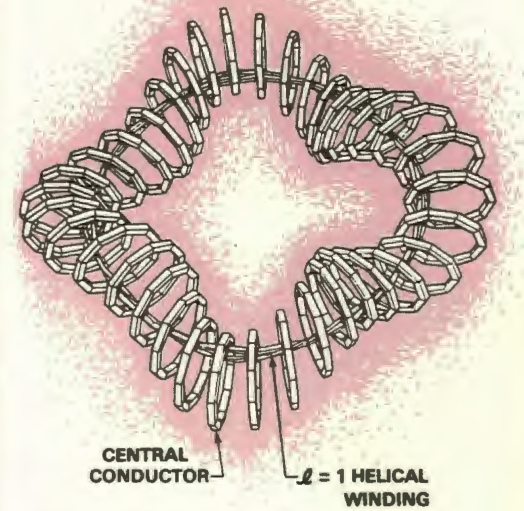
Currently most plant designers assume that 200 operating basis earthquakes will occur during the life of a plant. The Nuclear Regulatory Commission requires that five operating basis earthquakes be assumed during the life of each nuclear power plant.

In summary, the ORNL team has developed guidelines that allow nuclear plant owners to control the establishment of design basis earthquake guidelines in the eastern United States. ORNL also provided a new basis for developing the operating basis earthquake. These recommendations, which have been favorably reviewed by DOE and earthquake experts, will appear in standard seismic requirements for the design of DOE research reactors and other nuclear test facilities.

ORNL Collaborates with Spanish Team on Design of Fusion Stellarator

The collaboration between ORNL and the Spanish Junta de Energía Nuclear (JEN) in Madrid on the design of a new stellarator for fusion research is a story of international cooperation and of an unusual design involving a double helix, or a twist within a twist. Funding for this collaboration was available from the U.S.-Spain Committee for Cooperation in Science and Technology.

ORNL collaborators and the team from the Spanish Junta de Energía Nuclear take a break from making plans for building a stellarator based on ORNL's flexible heliac design. Members of the team are, standing from left, Tim Hender (ORNL), Jim Lyon (ORNL), Antonio Lopez, Jose Botija, and Ben Carreras (ORNL); sitting from left, Romualdo Martín, Jose Guasp, and Aluaro Pueblas.



Flexible heliac design adds helical winding to central circular conductor and helically encircling toroidal field coils to better control the magnetic field containing the fusion plasma.

Because of ORNL's successful Advanced Toroidal Facility (ATF) Program and JEN's past association with the Laboratory's Fusion Energy Division (FED), JEN turned to the ATF design team for assistance in designing an advanced toroidal device that will serve as the focal point of the Spanish fusion program. An interesting twist in this collaboration is that one member of the ATF design team—Ben Carreras, head of the Stellarator Theory effort—had been one of the early participants in JEN.

The collaborative design project itself involves some twists. A particular arrangement of magnetic field coils called a "heliac" had been proposed because it was considered theoretically capable of stably and efficiently confining fusion plasmas. This "twisting" arrangement had the potential of achieving high beta, the ratio of plasma pressure to the pressure of the confining magnetic field.

The heliac features a set of circular coils whose centers follow a helical path around a larger, linked central circular conductor. The magnetic geometry produced is sensitive to resonances in which a field line closes on itself after a relatively few transits around the torus. As a result, this particular geometry can produce islands in the confining magnetic surfaces, which can lead to breakup of these surfaces and lower the achievable value of beta.

An ORNL team consisting of Carreras, Jeff Harris, Tim Hender, and Jim Rome of FED proposed adding a helical (twisting) winding around the central circular heliac conductor in phase with the helical path followed by the centers of the encircling toroidal field coils—the twist within a twist. Although this idea sounds simple, many sophisticated calculations and an understanding of the heliac's limitations were necessary before it could be proposed. Besides introducing a critical degree of flexibility into controlling the magnetic configuration so that an experimental optimization could be achieved, addition of the helical winding reduced the total current required in the two central conductors, thus producing a more stable configuration.

A design team from JEN (Jose Botija, Antonio Lopez, Romualdo Martín, Alvaro Pueblas, and Emilia Solano) is working with an ORNL team led by Jim Lyon and Tom Jernigan to translate this concept into a practical device, the $15-million TJ-II being proposed by JEN. If approved, TJ-II would provide a definitive test of this potentially attractive confinement concept, give answers to questions not currently being addressed, and add a significant experiment to the world fusion program. ornl

O. Jay Krasner is professor of management at Pepperdine University in Los Angeles, California. He holds a doctoral degree in business administration from the University of Southern California. An expert in corporate strategic planning, Krasner is known for his work on the interaction between the corporation and government and for his computer-based simulation of alternative technological and market scenarios, domestic and worldwide. He has started several small firms, including Rensark Associates (a consulting firm specializing in corporate strategic planning) and Utah Computer Industries, Inc. Prior to 1970 he spent 25 years in industry, working for such large firms as General Electric Company and Rockwell International Corporation, particularly in planning and program management. Here, Krasner delivers his WATTec speech (photograph by Ruth Carey).

Innovation, Entrepreneurship, and Economic Development

By O. JAY KRASNER

Editor's note: *The following article is adapted from the keynote speech presented February 13, 1985, at the annual WATTec Conference in Knoxville. The conference is sponsored by more than 30 national engineering and technical societies. The author is an expert in management, corporate strategic planning, and entrepreneurship. During his WATTec talk, he ranked East Tennessee seventh in the nation among areas aiming for a Silicon Valley-style economic boom.*

More than 20 years ago, I attended a meeting at which participants were concerned about the obstacles that seemed to block the creativity so critically needed in the *Apollo* program, whose goal was to put a man on the moon. The meeting was chaired by my boss, Mac Blair, director of long-range planning at the Space Division of what was then North American Aviation, Inc. (now the Rockwell International Corporation). While we were agonizing over the technical, economic, and political obstacles, Mac suddenly beamed. With a conviction backed by uncanny technical soundness, he exclaimed, "We're going through *one big pert event*! We'll look back someday and see that this was a main event on the critical path to success!" Events later proved that he was right.

In an analogous way, I am convinced that we, the engineering talent of the United States, are now going through *one big event*. And with the complete conviction of a Mac Blair, I am certain that we shall look back someday and see that "this was a main event on the critical path to success."

What is this event? Simply put, it is the attainment of a "critical mass" by the integration of two processes: *innovation* and *entrepreneurship*. And the consequence of this propitious and pervasive event is a rich and enduring stream of favorable economic development and a higher quality of life.

Why now? What has led to this *one big event*? The answer will emerge as I trace a few of the highlights of the processes of innovation and entrepreneurship.

Innovation

James Brian Quinn of Dartmouth College has defined innovation as "creating and introducing original solutions for new or already identified needs." Because innovation embraces both the creating and the introducing of solutions, it is broader than invention, which is the "creating" phase of the total process. In fact, an invention, however creative in itself, fails to be an innovation if it is not introduced and used to serve the new or already identified needs of society.

Engineers understand this difference far more than most. Research scientists are creative in formulating new concepts, but they need engineers to solve the problems of making these concepts work. It is not surprising, then, that throughout the 20th century and increasingly in the past 40 years, the engineering mind has been the major source of society's innovations. When liberated from the concerns that inhibit innovation, the engineering mind will not only continue to produce society's innovations in the next 40 years but will also contribute to society's economic and political salvation.

Studies of Innovation

During the past 30 years—and with increasing intensity in the past 15 years—the process of technical innovation has been studied (with almost the same rigor imposed in technical research). Some of the key findings follow.

- The most significant *process* innovations have been, to a very high degree, achieved by engineering resources inside large organizations. The larger and older the organization, the more the "organization climate" motivates *incremental* (but not "leapfrog") process innovations. The higher the risk of the process innovation need and the greater the need for a technological "leap," the more likely that the successful innovation will be achieved by a new venture.
- With very few but highly visible exceptions, the most significant *product* innovations have been achieved by new ventures launched by teams comprising inventor-engineers, manufacturing engineers, marketing specialists, and general managers. Product innovations achieved by larger organizations are characteristically "incremental" improvements; the larger and older the organization, the more the "organization climate" rewards such incremental improvements and discourages, even penalizes, attempts at leapfrog innovations.
- An exhilarating symbiosis between new ventures and established organizations almost always exists. For example, after the new venture takes the risks of making leapfrog innovations at the component level, the established organization may integrate these innovations into incremental system or process improvement. For example, relatively new ventures like Texas Instruments, Inc., and what was called Fairchild Semiconductor, Inc., took the leap of devising and making the first silicon chips, which have been integrated into incremental systems (such as personal computers) and used to improve processes by many established organizations, including IBM Corporation and AT&T Company.

Other examples of this symbiosis abound. Consider my own activities involving new ventures:

- A venture begun in 1982 incorporated patented polystyrene microbead technology in instruments for real-time monitoring of industrial process fluids and blood viscosity. Both a patient-monitoring systems company and industrial users of petrochemicals are showing serious interest in the product, now that product development work is completed.
- A venture launched in 1983 combines microprocessor technology with plant genetics. The product is a greenhouse system for both seeds and clones of plants for commercial growth in arid regions. Already both U.S. and Middle East customers are placing orders.

Technical innovators and entrepreneurs are receiving new respectability as a result of a growing need for technical solutions to revitalize the economy. The time has come for East Tennessee to experience new economic development because both the need and capability for innovation and entrepreneurship are present.

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- A venture that I was involved with early in 1984 for remote electronic reading of "passive" tags (tags without a power source) has already received orders from such established organizations as a security systems company and a firm providing automation systems to the dairy industry.
- Just a few months ago, I helped begin a venture to carry into the international market a newly developed compact welding power source based on semiconductor technology. Already both public utilities and chemical processor organizations are expressing interest in using the new company's services for their own tube-welding applications.

Indeed, with this evolving symbiosis, we see other clues signaling the occurrence of the *big event*. For example, established organizations are investing in new ventures. Some big firms have even created venture capital funds or subsidiaries. In addition, joint ventures are forming between new companies and established organizations.

Perhaps the most significant research finding in technical innovation is that the potential *source* of the innovation—the scientist-engineer—is substantially motivated to innovate or not innovate, depending on certain factors in that person's environment. The most significant factors are the climate of the organization in which the person works and the economic climate of the area in which he or she lives.

If the organizational climate rewards such actions as "playing it safe" and "not making waves," the innovation urge is weakened and sometimes killed. If, on the other hand, the organizational climate encourages the practice of keeping at the new idea until one is convinced that it will—or will not—work and supports the belief that failure of a high-risk, high-payoff development effort is not necessarily a sin but can, in fact, be the best training for future success, then innovation will flourish.

Larry Udell, 1984 president of the National Congress of Inventor Organizations, has repeatedly pointed out that the potential for technical innovation is vastly greater now than the results suggest. He believes that the major inhibitors of this potential are psychological and organizational. Fortunately, the *big event* marks the beginning of a tremendous liberation of this potential for innovation.

As previously stated, innovation is also influenced by the environment in which scientists and engineers live. Albert Shapero, professor at Ohio State University, cites numerous examples illustrating that every community that creates and maintains the appropriate "seedbed" for new ventures gains a far better quality of life for all citizens than each community that seeks economic development by persuading a large company to relocate a big plant there. The key elements of this appropriate seedbed are

- Material resource suppliers who understand the problems of the innovator and provide the launching team with facilities, supplies, vendor trade credit, and services
- Financial resource suppliers who understand not only the risks of the venture but also the potential for high payoff if the venture is successful
- Educational institutions that can, in their own self-interest, serve the innovator's short-term needs while gearing up for the payoff from the the longer-term placement of its graduates.
- Government agencies, both taxing bodies and service providers, that recognize that short-term tax incentives and other stimulants of innovation can lead eventually to more private enterprise and thus a broadened tax base

I am convinced that in the United States the innovation process and, in particular, the new ventures, established organizations, and communities committed to innovation have reached the state where, in combination with advances in the entrepreneurial process, the *big event* is beginning to take place.

Entrepreneurship

The entrepreneurial process is the integration into a business of resources with the opportunity for an end product. Entrepreneurship has changed in the past 25 years, particularly in technical ventures. As a result of those changes and others over the past ten years, the image of entrepreneurship is also changing considerably.

Consider my personal situation as an example. I am the youngest of seven brothers. I grew up in

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St. Louis, Missouri, where my father was an entrepreneur, first in produce, then in newspaper delivery, and later in the laundry business. My brothers perceived his entrepreneurial life as insecure, frustrating, and characterized by hustling and struggling from day to day for survival. They saw his life as 180 degrees apart from the dignity (and security) of a profession. So did I, as I look back. It is not surprising, then, that four of us had careers in the technical professions and the other three have worked in the social science professions, typically in large organizations whose career systems reward professional achievement.

In my own case, I spent 20 years of my 25-year industrial career with the U.S. Navy, General Electric Company, North American Aviation, and Rockwell International Corporation before I had my first true entrepreneurial experience (which involved a futile attempt to market a patentable invention). Five more years passed before I found the trail of substantive research in entrepreneurship.

The point? Until fairly recently, entrepreneurship and technical professional careers were perceived as opposites. Entrepreneurship was perceived as Mom-and-Pop stores, the laundry truck, the sidewalk merchants, the garage mechanic, and the Ali Hakim of *Oklahoma!* Moving from a technical professional career to entrepreneurship was an admission of failure, a fall from grace.

However, in recent years the facts have been changing faster than the perception. Small technical entrepreneurships grew into big success stories (e.g., Polaroid Corporation and Xerox Corporation in the East and Varian Associates and Hewlett-Packard Company in the West). The technical entrepreneurships that followed increasingly demonstrated that the synergy of innovation and entrepreneurship was real and visible. It led the process of economic development, first at the community level, then at the regional level, and now at the national level.

Studies of Entrepreneurship

Similarly, 25 to 30 years ago research in entrepreneurship (using methods at least minimally acceptable to the technical world) was virtually nonexistent. Up until then, only a few profound conceptual contributions to economic theory had been made (e.g., by Joseph Schumpeter early in the 20th century). Folk-hero anecdotes, such as the rags-to-riches story of Horatio Alger, also abounded back then. But no specific, rigorous studies had been done on how entrepreneurship works, why it succeeds or fails, or how its productivity can be increased.

In the past 25 years, the launching of technical entrepreneurships has changed all that. It not only accelerated the growth of entrepreneurship but also stimulated increased research on entrepreneurs and the entrepreneurial process. For example:

- In the mid-1960s, Don Marquis and Ed Roberts of Massachusetts Institute of Technology studied in depth the successes and failures of new enterprises along Route 128 in the Boston area. They found a number of myth-shattering realities about what makes success.
- By the end of the 1960s, Arnie Cooper of Purdue University had studied similar phenomena in the Silicon Valley area of Palo Alto, California (still referred to by some Bostonians as Route 128 West).
- By 1967 Norman Smith at Michigan State University had found the "typical entrepreneur" stereotype to be a myth and constructed a "craftsman-to-opportunist" spectrum of archetypes that helped explain what makes for success.
- By the early 1970s, Al Shapero, Karl Vesper of the University of Washington in Seattle, and others were participating in symposiums on technical entrepreneurship, pooling research results, and initiating new studies.
- Since 1980 a national conference on research in entrepreneurship has been held annually. The ticket for admission is an acceptable piece of fresh research. This year's conference in Philadelphia featured 50 accepted research papers. The six sets of annual proceedings are a treasure trove of findings, with immediate practical applications.

These research efforts have occurred in parallel with the launching and growth of Digital Equipment Corporation, Data General Corporation, Intel Corporation, Apple Computer, Inc., Hybritech, Inc., Genentech, Inc., *"Martin Marietta Energy Systems, Inc., is committed to promoting innovation, technology transfer, and economic development. The technical competence, the perception of needs, and the potential for innovation and entrepreneurship are here."*

and—yes—Phyton Technologies, Inc., Computer Technology and Imaging, Inc., and Remote Technology Corporation in the Knoxville-Oak Ridge area. Furthermore, the communities that have enriched their economic and sociocultural quality of life with these entrepreneurial businesses have been those whose seedbeds are well tended.

Indeed, the advancement in the technical entrepreneurship process has stimulated a serious and increasing attempt by some established organizations to create "entrepreneurial subclimates" (or "intrapreneurships") based upon findings from this research. And, after some notable failures, the first signs of success are apparent.

How To Launch Successful Technical Entrepreneurships

What have researchers learned about launching successful technical entrepreneurships? Some results are presented briefly below.

Technical entrepreneurs experience trade-offs that, more often than not, are net positive. They enjoy the freedom to pursue technical development without the inhibiting factors of many large organizational climates. However, they also endure frustration as they encounter obstacles in marketing, finance, and human resources.

Technical innovators who openly and actively accept and engage other members of the launching team usually succeed; technical innovators who regard all other members of the launching team as "second-class citizens" often fail. (The "other" members of the team include experts in marketing, manufacturing and distribution, finance, and personnel management.)

Organizations with climates that promote innovation have members who see themselves as team players with a carefully thought-out game plan and a number of alternative strategies for adjusting to new opportunities or unexpected obstacles. They demonstrate persistence in attempts to overcome obstacles yet do not rigidly worship their initial plans. Their rewards are geared to the success of the total venture rather than to the personal attainment of specific position objectives (as in Management by Objective approaches).

Successful technical innovators are not gamblers. They do not perceive the venture as one with slim odds for success but rather as one with a high payoff if successful. They consider the risks tolerable and regard themselves as capable of reducing the risks of product development, market position attainment, and organization development. To them, failure is a learning experience out of which comes improved capability for future success. The more successful headhunters for technical entrepreneurial teams look for these attributes.

In reviewing the advancements in the entrepreneurial process, we find the following:

- The perception of the successful entrepreneur has shifted from that of the streetwise hustler to that of the creative technical professional.
- These technical professionals enhance their potential by creating not only a new product but also an effective team, which in turn creates an effective and exhilarating organization. Such organizations generate a stream of economic development that enriches community quality of life.
- Research on entrepreneurs and the entrepreneurial process is growing, and the valid, practical results of this research are being increasingly applied to further improve the process and enhance its contribution to economic development and the quality of life.

In my view, the two streams of innovation and entrepreneurship are approaching the interactive critical mass that will spark the *big event.* But what does my belief have to do with East Tennessee? Consider the capabilities represented here. This area has an extremely high concentration of Ph.D. scientists and engineers. It has organizations with outstanding technical expertise: Oak Ridge National Laboratory, Tennessee Valley Authority, and the University of Tennessee. Tennessee Governor Lamar Alexander is committed to the establishment and growth of the Tennessee Technology Corridor, and Martin Marietta Energy Systems, Inc., is committed to promoting innovation, technology transfer, and economic development. The technical competence, the perception of

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David Vandergriff, mechanical engineer, enjoys the company of Astronaut Fred at the Martin Marietta Corporation exhibit, which was one of the most popular at the WATTec Conference.

needs, and the potential for innovation are here.

Is innovation needed? After intensive study of needs on a large scale, Quinn concluded that "the only hope is to make room for the inventive approaches of both external and internal entrepreneurs." He cited the problems that the United States and the world must confront before the end of this century—only 15 years away:

- Feed a world population that will have doubled since the end of World War II, without relying heavily on chemical fertilizers and pesticides
- Develop and deliver between now and then as much energy as has been produced throughout all of history, with each increment harder to find and develop and with the constraint that adverse environmental effects such as acid rain should be minimized
- Meet demands 100% greater than today's needs for food, raw materials, and products, with land resources ever more marginal and safe waste disposal ever more difficult
- Generally improve the living, working, educational, urban, and environmental habitats of people in both industrialized and less developed countries
- Simultaneously increase each nation's health standards, shift from disease treatment to prevention, and restrain population growth within reasonable bounds
- Employ 30 to 50% more people, mostly in service industries, while increasing productivity enough to halt inflation
- Generate net capital at an annual rate at least twice as high as today's despite government's preemption of capital for defense and social needs
- Accomplish all the above without fatally disturbing the natural environment or creating resource crises that lead to war.

Clearly, the potential for massive capability exists to meet the massive need. Only two more elements are required: (1) increased awareness of the opportunity for liberating one's innovation potential and achieving innovation goals through technical entrepreneurship and (2) personal resolve to seize opportunity. I have attempted here to help with the first element by providing information on opportunities and how organizational climates and community environments can foster innovation. I hope this increased awareness will create the resolve in people to liberate their innovation potential and to seize those opportunities.

In closing, I want to share the moving challenge that Shapero presented in his remarks at a commencement at Ohio State University two years ago:

> At the Galleria dell' Accademia Museum in Florence, there is a passage leading to Michelangelo's magnificent statue of Young David. Along both sides of the passage are arrayed four blocks of marble, with a heavy, incompletely delineated figure emerging from each. They are Michelangelo's *I Prigione* ("The Prisoners").
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> Each individual comes into the world encased in a block of marble, and it is the efforts of parents and teachers, together with the events of life and what the individual does, that combine to release that individual from that block. Indeed, Michelangelo saw it in the same terms and usually worked from the front of a block to free the figure which he considered to be imprisoned within the marble.
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> Today we share a critical moment in the process [of uncovering in you what is the true potential]. This is a moment in which the working of the stone changes hands. You are at a potential decision [,] . . . a decision to take control of the process of freeing yourself from the enclosing stone. You have the wherewithal to complete the process of releasing yourself and finding full and free expression. Make that decision.

In making that decision, we become part of the *big event*, the joining of innovation and entrepreneurship into an era of richer economic development for ourselves, our loved ones, our community, and our nation. ornl

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These penguins in Antarctica, possibly among the last creatures on Earth to escape exposure to chemical pollutants, may be the object of an ORNL study. See "News Notes," pages 45–47.