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Oak Ridge National Laboratory review

State of the Laboratory—1986:

ORNL Engages in Collaborative Research

THE COVER: Collaborative research is the theme of ORNL Director Herman Postma's 1986 "State of the Laboratory" address, an updated, expanded version of which starts on page 1. Fusion energy research at ORNL offers many examples of collaboration. Here, researchers from Europe, Japan, and the United States confer in the control room of the International Fusion Superconducting Magnet Test Facility at ORNL. See page 11 for identifications.

Oak Ridge National Laboratory

review

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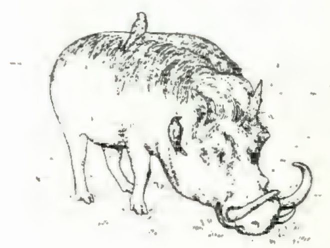

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State of the Laboratory—1986:

ORNL Engages in Collaborative Research

By HERMAN POSTMA

An increasing amount of research and development (R&D) at Oak Ridge National Laboratory is collaborative. The work we do jointly with technical groups in industry, universities, other national laboratories, and laboratories in foreign countries is the theme of this address. I will also describe theme-related R&D projects, technical highlights, and milestones for 1986 and present a summary and an outlook for the future. Finally, I will announce the name of the ORNL division chosen to receive the third annual Director's Award.

Collaborative research at ORNL takes many forms. For example, ORNL is engaged in

- Working with industry, universities, and other laboratories locally, nationally, and internationally in many ways
- Assembling teams within Energy Systems to accomplish tasks that individuals could not do alone
- Undertaking joint industry-university-laboratory projects across the country involving many participants
- Coordinating national and international programs such as the Integrated Forest Program
- Operating user facilities, unique laboratories that can be shared with many people, including outside researchers
- Participating in the Science Alliance with the University of Tennessee at Knoxville (nine Distinguished Scientists will be working at ORNL and UTK as part of this program).
- Forming industrial consortia such as the Ceramics Advanced Manufacturing Development and Engineering Center (CAMDEC).

CAMDEC is an example of one of President Reagan's goals set forth in a position paper released after the presentation of his 1987 State of the Union address. That goal is the formation of partnerships between national laboratories and industry to help make the United States more economically

During refreshments after the address, Jon Soderstrom (left) and Vic Tennery talked about technology transfer and the High Temperature Materials Laboratory.

The State of the Laboratory address attracts both employees and outside scientists and engineers interested in ORNL's many research activities. Here, Doan Phung (cup in hand), who owns his own private firm in Oak Ridge and who coauthored a book with Alvin Weinberg on the second era of nuclear power, keeps up with the latest ORNL news.

competitive with other countries, thus reducing its trade deficit.

Here are some indicators of increases in ORNL's external interactions:

- Guest assignments are up to 1406, a 36% increase over 1985
- Now that the High-Temperature Materials Laboratory and the Roof Research Center are completed, the number of ORNL user facilities is up to 13
- More experimenters are visiting ORNL each year (698 visitors for 13,157 days in 1986)
- ORNL's work with other federal agencies has about doubled since 1980
- The fraction of ORNL's budget allotted to subcontracts has increased, suggesting that ORNL's involvement in developing potentially marketable technologies has increased
- Eight commercial licenses were granted to private firms in FY 1986, expediting the transfer of marketable ORNL technology to the private sector.

ORNL is performing an increasing amount of work jointly with technical groups in industry, universities, other national laboratories, and laboratories in foreign countries. This collaborative research includes a physics experiment at an accelerator in Switzerland, applications of surface-modification techniques, studies of radon in the home, the Integrated Forest Study, breeder fuel-reprocessing tests in Japan, development and testing of SDI optical components, modeling of the Chernobyl reactor accident, and tests of superconducting magnets and pellet fueling for fusion energy.

What is the value of collaborative research? First, it permits a cost-effective use of funds and facilities—a better deal for taxpayers. Second, it helps us focus on national issues and scientific priorities. Third, it allows us to interact with some of the best minds in the country in certain fields; these people benefit us by offering fresh points of view, new insights, and provocative questions. Because our collaborators help make us preeminent in certain areas of expertise, it is easier for us to attract other high-quality researchers to help us stay on top. In turn, ORNL offers our collaborators—particularly college and university faculty members and students—unique research experiences.

Science highlights in collaborative research include the following.

ORNL Physicists Try Recreating First Moments of Big Bang

According to a well-accepted theory, the universe was created as the result of the Big Bang. Out of that vast amount of energy emerged a primordial soup, consisting largely of free quarks and gluons. After a few microseconds of cooling, this "quark-gluon plasma" condensed into the known particles that form atoms, the basic building blocks of matter. Quarks are the basic constituents of particles in atomic nuclei, and gluons are particles that bind quarks together.

Quarks have never been observed in a free, unconfined state. They seem to exist only in pairs or groups of three. However, if a quark-gluon plasma can be created in an accelerator, scientists may be able to observe quarks in their free form for the first time. Creating such a plasma is the goal of a series of large experiments at the European Laboratory for Particle Physics (CERN) in Geneva, Switzerland.

ORNL's role in this search has been to design and build massive detectors called calorimeters and to participate in conducting one of five experiments. The 5 experiments involve a total of 300 scientists and 62 institutions, representing 18 countries. WA80, one of the first two experiments proposed, involved 45 scientists, including 10 from ORNL. The other scientists were from the Lawrence Berkeley Laboratory, the University of Lund in Sweden, and the University of Munster and the GSI nuclear physics laboratory in the Federal Republic of Germany (FRG). ORNL participants in the experiment included Terry Awes, Cyrus Backtash, Dick Cumby, Bob Ferguson, Jim Johnson, I. Y. Lee, Felix Obenshain, Frank Plasil, Soren Sorensen, and Glenn Young.

ORNL technician Dick Cumby climbs the ladder to replace one of the 720 phototubes in the ORNL-designed, 60-ton Wall Calorimeter (seen from rear) at the CERN accelerator complex in Geneva, Switzerland.

In June 1986, ORNL's 8-ton Zero-Degree Calorimeter was shipped to CERN after being assembled at ORNL by stacking thin sheets of plastic scintillator interleaved with sheets of depleted uranium produced by Manufacturing Sciences Corporation of Oak Ridge. The Wall Calorimeter, a large array of 180 towers, was designed at ORNL and assembled in Geneva during the fall of 1985. Both detection devices performed well in the WA80 experiment in late November and early December.

In the two-week WA80 experiment, accelerated nuclei of oxygen were collided with target nuclei of carbon, copper, silver, and gold at energies of 3.2 trillion electron volts, or 200 GeV/nucleon. This ultrarelativistic energy, which is about 10,000 times higher than can be attained at ORNL's Holifield Heavy Ion Research Facility, is the highest energy ever reached by accelerated nuclei.

The conversion of energy into matter was shown dramatically during the WA80 experiment. The ORNL team observed a record 400 charged particles produced in a collision between nuclei of oxygen and gold in which the initial number of charged particles—protons—is only 87. It was also observed that high energy densities are achieved during the collisions, easing scientists' concerns that nuclei at such high velocities might pass through each other without significant interaction.

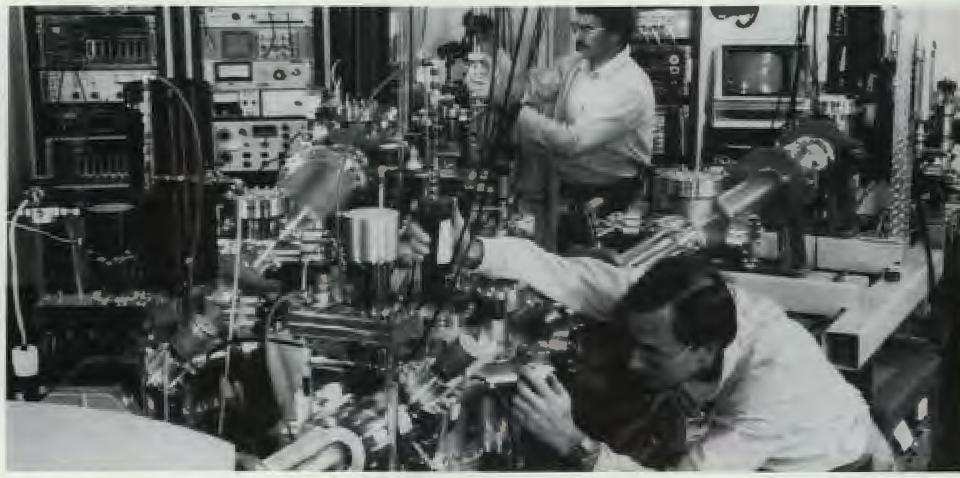
The results indicate that (1) high velocities will allow the creation of the region of high temperature and density needed to form the quark-gluon plasma and (2) the highest energy density achieved in the first experiment was about two-thirds that required to form the quark-gluon plasma. Scientists are hopeful that when heavier sulfur projectiles become available this fall, a quark-gluon plasma will be formed, recreating the first microseconds after the Big Bang.

Surface-Modification Techniques Aid Electronics Industry

Using beams of ions, laser light, and electrons alone and in combination, ORNL scientists have pioneered advanced processes for altering surfaces of materials; as a result, they have produced new materials having unique structures and desired properties. This work has been done at ORNL's Surface Modification and Characterization (SMAC) Collaborative Research Center in the Solid State Division. The user facility attracts scientists from universities, industry, government, and other laboratories who wish to work with ORNL personnel on fundamental and applied problems of materials research.

The nonequilibrium fabrication methods developed at the SMAC center include ion-implantation doping, ion-beam and laser mixing, and pulsed-laser processing, all in an ultrahigh-vacuum environment. A new method called ion-beam deposition—a means of directly depositing low-energy ions of virtually any species onto any substrate—can be used to construct artificial materials. In 1986 ORNL scientists demonstrated that ion-beam deposition can be used to deposit epitaxial films of a variety of materials on semiconductor and metal-crystal substrates at low temperatures.

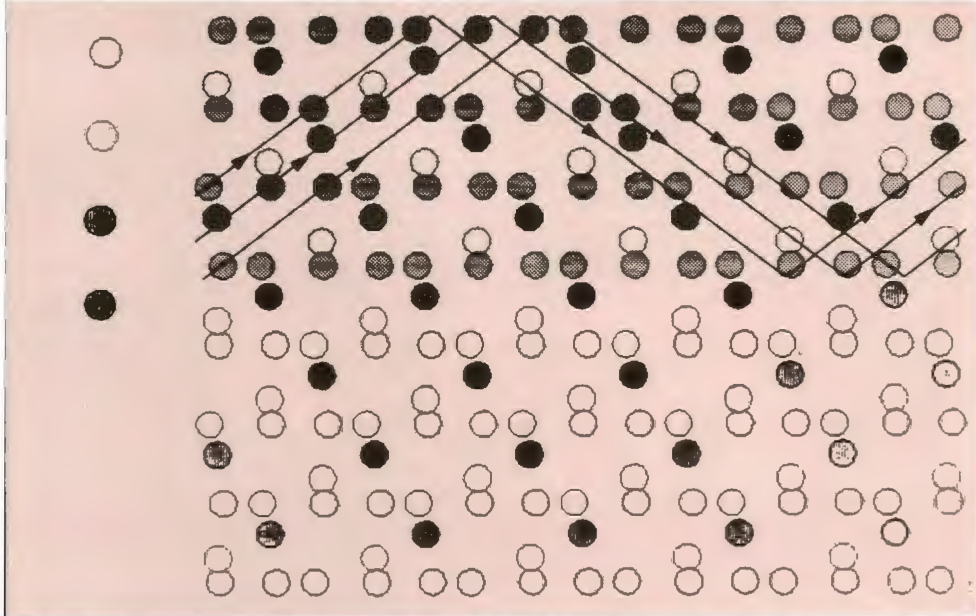
Construction of artificial materials atom by atom, layer by layer, to create desired structures and properties is the next frontier in solid-state materials research. Because ion-beam deposition and other nonequilibrium fabrication processes can occur at low temperatures, they may be the techniques of choice for making future three-dimensional integrated electronic circuits, which are envisioned to contain thousands of individual submicron devices integrated into the circuits, layers of which would be fabricated one on top of the other. Conventional processing steps normally require high temperatures, which could destroy adjacent circuits or cause unwanted interactions of materials. Thus, low-temperature processes using ion, electron, and laser beams will likely be used for future electronic devices.



Darryl Thomas (top) and Terrence Sjoreen of the Solid State Division make adjustments to the beam-transport system at the 1.7 MV tandem accelerator-implanter at the Surface Modification and Characterization Collaborative Research Center.

Jim Williams of the Solid State Division examines an artificial hip joint made from a titanium alloy. Ion implantation technology developed by Williams and collaborators from the University of Alabama at Birmingham is being used in industry to greatly increase the wear resistance of this alloy in artificial joints for humans.

A few years ago the SMAC center was the first facility in the United States to use laser annealing on semiconductors, a technique that has been integrated into the electronics industry. Rapid thermal annealing, a subsequently developed technique based on laser annealing, is now an accepted method for constructing integrated circuits from ion-implanted semiconductors. An important biomedical application of ion implantation also was discovered



The first optical waveguides made by implanting titanium ions in a material consisting of lithium, niobium, and oxygen ($LiNbO_3$) were fabricated at ORNL's Surface Modification and Characterization Collaborative Research Center.

at the SMAC center. ORNL researchers and collaborators found that implanting nitrogen ions in a titanium alloy used for artificial hip and knee joints reduced the corrosive wear of the material in the body. Ion implantation has been adopted by industry as a method to make surgical implants that perform better and last longer than those fabricated from conventional materials.

New uses for ion implantation continue to be found at the SMAC center. In 1986 it was demonstrated that ion implantation can be used to form optical waveguides in a complex material made of lithium, niobium, and oxygen ($LiNbO_3$). This material is important for electro-optic applications (e.g., transmitting information-bearing light signals through optical cables in the presence of electric fields).

In 1986 the SMAC center logged nearly 2000 experimenter days involving 60 projects and 100 users. ORNL scientists and technicians heavily involved in activities of the SMAC center include Bill Appleton, Robert Culbertson, Wayne Holland, Jim Moore, David Poker, O. E. Schow, Terrence Sjoreen, Darrell Thomas, Woody White, Jim Williams, Steve Withrow, and Ray Zuhr.

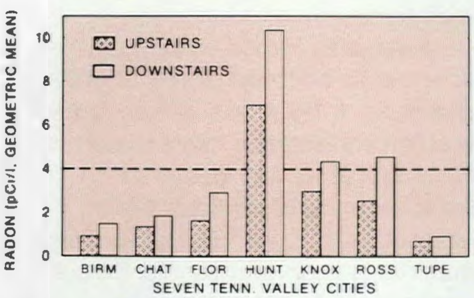
ORNL Helps Assess Home Radon Levels in Five States

For many years, Americans and people in other industrial countries have been concerned about outdoor air pollution, but recently the quality of indoor air has also become a concern. This growing concern is underscored by the increase in U.S. funding for research on the potential health effects of radioactive and chemical pollutants in the air inside buildings. Researchers are seeking answers to these questions: What potentially hazardous substances are in the indoor environment? How does indoor air become polluted? What levels are hazardous to health? What can be done about unsafe levels?

One major source of concern is radon, high concentrations of which have been linked to increased risk of lung cancer. The actual health risk of radon gas, which is a decay product of uranium, comes from its decay products lead-210, bismuth-214, and polonium-218, which attach themselves to microscopic airborne particles. These radioactive particles may lodge in the lung, where they may eventually cause cancer.

The three main sources of radon to homes are the soil (by far the most likely source of high levels), building materials, and well water. The indoor concentrations of radon may be somewhat higher in tightly sealed, energy-efficient homes. However, factors related to geology, soil permeability, and house construction are far more important determinants of elevated radon levels. Concerned homeowners can reduce indoor radon concentrations by a variety of methods, including removing source gas (e.g., by subslab depressurization), sealing basements, and increasing ventilation.

ORNL is collaborating with Harvard University and University of Tennessee (UT) personnel in two field studies of indoor air pollution. ORNL researchers are Alan Hawthorne, Charles Dudney, Tom Matthews, and Tuan Vo Dinh of the Health and Safety Research Division (HASRD) and Richard Tyndall of the Environmental Sciences Division



Average radon concentration in homes in seven Tennessee Valley cities (Birmingham, Chattanooga, Florence, Hunstville, Knoxville, Rossville, and Tupelo). Downstairs radon levels were consistently higher than upstairs levels. Only Huntsville has a high number of sampled homes having radon levels that exceeded EPA's action level.

Equipment in living room (right) samples for the by-products of the decay of radon, which are health hazards. The passive samplers on the table measure average concentrations of various indoor pollutants.

(ESD). Public and private sponsors for the research include the Department of Energy (DOE), the Tennessee Valley Authority, the Consumer Product Safety Commission, the Environmental Protection Agency (EPA), the Electric Power Research Institute, the Harvard University School of Public Health (under a National Institute of Environmental and Health Sciences grant), and Alabama Power Company.

Staff members and students from Harvard, the University of Alabama at Birmingham, and UT worked with ORNL staff members to gather data from all over the Tennessee Valley to monitor indoor exposures to radon and chemical pollutants, an important component of total human exposure. This information is most valuable in determining a baseline for indoor exposures. By correlating health effects of residents with indoor concentrations of certain pollutants, it may be possible to determine which levels are safe and which levels increase the probability of respiratory health problems.

ORNL coordinated research interests of several organizations in the design of studies to collect field data from 40 homes in the Oak Ridge–Knoxville area, 70 homes in the four Tennessee Valley states, and 300 homes in the Kingston-Harriman area. Other cities in the four-state Tennessee Valley study in which homes were sampled were Chattanooga; Florence, Birmingham, and Huntsville, Alabama; Rossville, Georgia; and Tupelo, Mississippi. The field technicians left passive-sampling devices to collect specific indoor pollutant levels in the homes over a week-long period and returned them for later analysis.

According to the EPA, the action level for indoor radon concentrations is 4 picocuries/liter of radon in air; in other words, at that level or above, action should be considered to reduce radon concentrations below 4 picocuries/liter. A number of houses monitored in Huntsville had radon levels that required action. The ORNL researchers are currently evaluating specific methods for reducing radon levels in seven New Jersey homes (in collaboration with researchers at Princeton University) and will be conducting a similar study in the Tennessee Valley next year.

Some findings that have come out of ORNL's indoor air studies follow:

- In winter, radon concentrations are generally higher than in the summer
- Radon concentrations are lower on the top floor than on the bottom floor of most houses
- Concentrations of formaldehyde, an indoor pollutant arising from materials containing urea formaldehyde, depend on temperature and humidity; on hot days, formaldehyde may be released into houses by being "baked out" of pressed wood products and urea formaldehyde foam insulation
- The presence of specific pollutant sources in a home is more likely to produce elevated indoor pollutant levels than is energy efficiency (reducing air leakage).

Besides radon and formaldehyde, the group is also measuring other indoor pollutants such as polynuclear aromatic hydrocarbons, combustion gases, particulates, volatile organics, bacteria, and fungi.

ORNL Manages International Integrated Forest Study

ORNL is coordinating one of the largest single international research efforts on the effects of atmospheric deposition on forests, including acid rain. The Integrated Forest Study on Effects of Atmospheric Deposition was originally proposed at ORNL in 1983. Dale Johnson and Steve Lindberg of ESD serve as the principal investigators, and Ernie Bondietti is project manager. ORNL researchers involved in the effort also include Paul Hanson, Rob Harrison, Doug Schaefer, and George Taylor.

The international program, whose goal is the assessment of forest ecosystems, involves the study of 18 forest types in the United States, Canada, and Norway. Among ORNL's collaborators are 14 universities, the U.S. Forest Service, and the National Park Service. The primary sponsor of the study is the Electric Power Research Institute. Other sponsors include the Empire State Electric Research Corporation, Southern Company Services, the Canadian Forestry Service, and the Norwegian Forest Research Institute. The program's U.S. research sites include forests in Georgia, Tennessee, North Carolina, New York, and Washington.

By studying soils and vegetation, program scientists examine the effects of acid rain and dry deposition on forest nutrient cycles and try to determine long-term impacts. The question of leaching is of particular interest: Do acids deposited on foliage and soils carry away certain nutrients, robbing trees of their food supply?

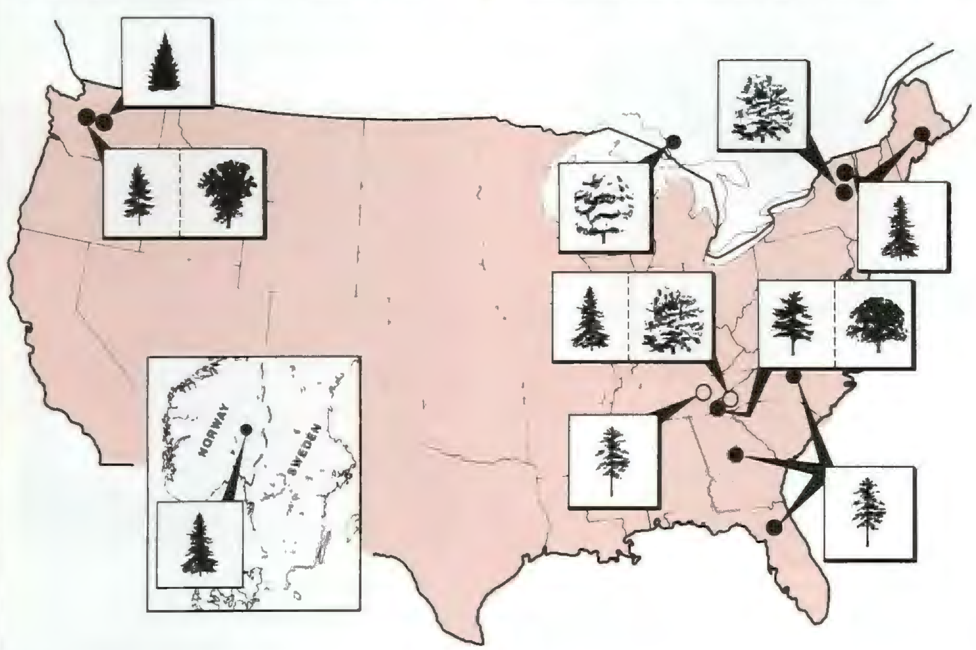
ORNL scientists led by Johnson and Lindberg have studied leaching at sites in the Great Smoky Mountains. Their studies show that the chief promoters of leaching are excessive amounts of nitrogen and sulfur from acid rain, other forms of atomospheric deposition such as cloud water and acidic gases, and other natural sources. The nitric acid produced in the soil is largely responsible for the leaching of toxic aluminum and nutrients needed to support the growth of beech and spruce trees in the Smokies.

In soil solutions from three sites near Clingman's Dome, Johnson found that nitrate is frequently the dominant ion. The high nitrate levels suggest that the trees and other vegetation have more nitrogen than they can use. The excess nitrogen reacts with hydrogen to create large supplies of ammonium, which nitrifying bacteria convert to nitric acid. Early estimates of atmospheric deposition by Lindberg suggest that more acidity may be associated with deposited nitrogen than with sulfur.

The source of the high levels of nitrogen is unknown. However, scientists speculate that possible sources include nitrogen oxide emissions from vehicle exhaust, high rates of decomposition of nitrogen-rich soil organic matter, or a disturbance such as an insect attack.

The ORNL scientists also found that sulfate plays a significant role in leaching; however, its importance is secondary to nitrate in causing nutrient losses. It is not known whether the aluminum leaching caused by nitrate and sulfate is high enough to be toxic to vegetation.

The results suggest that sulfur oxides from fossil-fuel combustion may not be a major contributor to soil acidity and that installation of expensive emission controls on coal power plants would not necessarily reduce soil acidification in the Smokies.



General forest types and locations of Integrated Forest Study sites in the United States, Canada, and Norway (inset).

The following are technology highlights of collaborative efforts at the Laboratory.

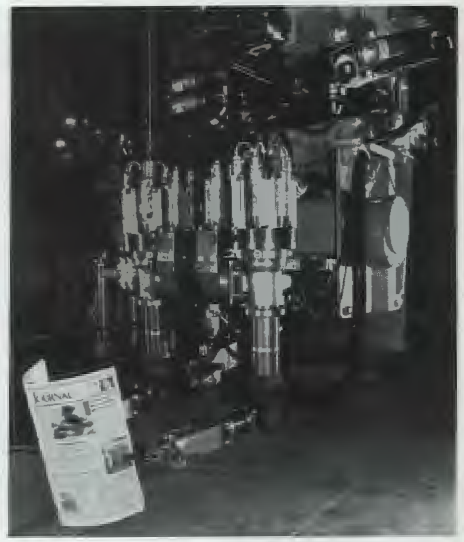
U.S.–Japan Pact Revives Breeder Reprocessing R&D

In March 1986 an agreement was reached on a proposed collaboration between the United States and Japan. In January 1987 a formal agreement was signed, affirming that the two countries would form a major joint breeder reprocessing R&D program for five years. Japan agreed to invest $5 million a year in the program, and DOE agreed to match that amount.

William D. Burch, Melvin J. Feldman, J. Grant Stradley, and Sterling A. Meacham of ORNL's Fuel Recycle Division were involved in the negotiations.

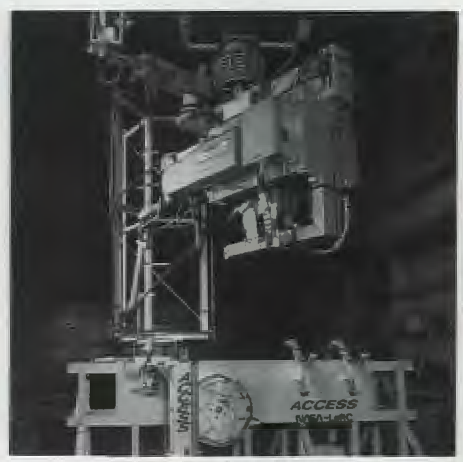
ORNL will play a major role in supporting the design, construction, and operation of Japan's planned fuel-recycle pilot plant. It will demonstrate the technology for breeder reprocessing—isolating radioactive fission products and recovering uranium and plutonium from breeder reactor spent fuel for use in a breeder. The plant will recycle fuel from Japan's MONJU breeder reactor, now under construction.

The Japanese pilot plant will serve as a testbed for ORNL-developed technology such as remote laser cutting of fuel assemblies, centrifugal contactors to carry out key chemical reprocessing steps, and remote maintenance systems required to operate and repair equipment in a radioactive environment. ORNL reprocessing experts assigned to the pilot plant will benefit from the experience and information obtained from actual operation. ORNL will follow developments in the Japanese breeder reprocessing program so that we will know the best way to proceed if the U.S. breeder reactor industry is revived. In addition to using U.S. technology, Japan will buy hardware from U.S. manufacturers. Thus, the U.S.–Japan agreement represents an ideal technological cooperation involving commercial interests.



The two slave arms of the Advanced Servomanipulator hold a copy of the **Knoxville Journal** *issue that carried an article about this development.*

Steve Zimmerman (left) and Mark Noakes operate the Advanced Servomanipulator from the control station.



In work done for NASA, ORNL tests the M-2 servomanipulator's ability to assemble a truss for the space station.

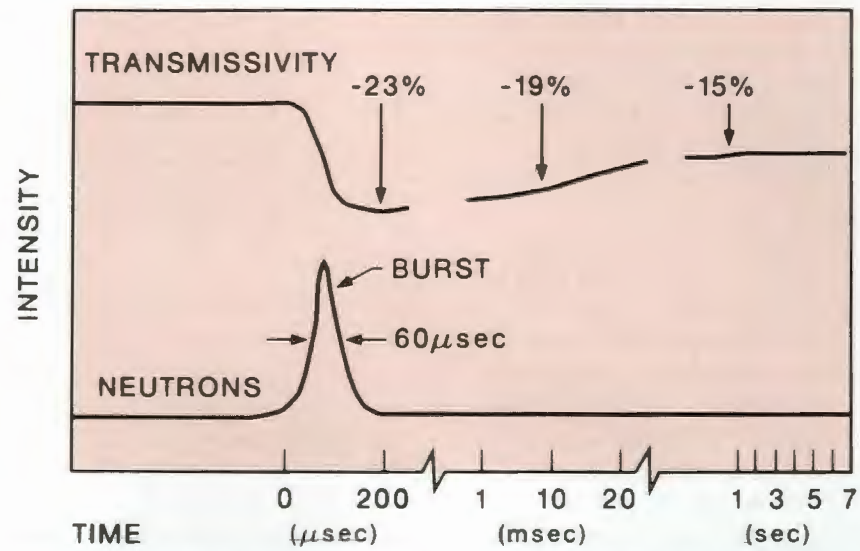
Energy Systems Develops Optical Components for SDI

Energy Systems teams from ORNL, the Oak Ridge Y-12 Plant, and Oak Ridge Gaseous Diffusion Plant (ORGDP) and several industrial partners have been working together to develop beryllium mirrors and advanced window materials for infrared surveillance (heat-sensing) applications. Funding for this work comes from the Strategic Defense Initiative (SDI) Program. The work, which involves fabricating, characterizing, and testing optical components, has advanced mirror and window fabrication technologies.

ORNL researchers involved in the project are Steve McNeany and Ken Thoms of the Engineering Technology Division (ETD); Carl McHargue of the Metals and Ceramics (M&C) Division; Jim Williams of the Solid State Division; Steve Sims of the Health and Safety Research Division (HASRD); and Don Hutchinson of the Physics Division. Their Energy Systems collaborators include Phil Steger, Tom Morris, Dave Gray, and Jones Arnold of the Y-12 Plant and Joe McNeely, Ted Nolan, Mary Alice MacIntyre, and Ulys Fulmer of ORGDP. Groups from Rockwell International; Honeywell, Inc.; Perkin-Elmer; and Brush Wellman Company also have been involved.

The SDI Program is interested in beryllium mirrors because they (1) are lightweight and therefore easier to loft into space, (2) have good structural properties, and (3) resist degradation by X rays. However, it is difficult to fabricate large, contoured beryllium mirrors to the high quality specifications that are required.

Mary Alice MacIntyre (left) and Ulys Fulmer operate optics inspection instruments in the SDI Optical Component Characterization Facility at Oak Ridge Gaseous Diffusion Plant.



SDI infrared window materials show time-dependent radiation effects. The material loses much of its ability to transmit light during exposure to a burst of neutrons and then partially recovers it.

Using high-precision, single-point turning techniques developed at the Y-12 Plant on various kinds of beryllium mirror blanks produced by Rockwell, Perkin-Elmer, and Brush Wellman, the Y-12 Plant group has been able to produce machined surfaces that permit major reductions in polishing times required to produce the final surfaces. Up to 90% reduction in polishing times has been achieved for some specimens—a significant advance for this time-consuming process. The Solid State Division is examining the potential of using ion bombardment to smooth the mirrors.

ETD, HASRD, and Physics Division personnel and a Honeywell, Inc., group have been studying the effects of radiation on the optical properties of infrared window materials. Tests were conducted at

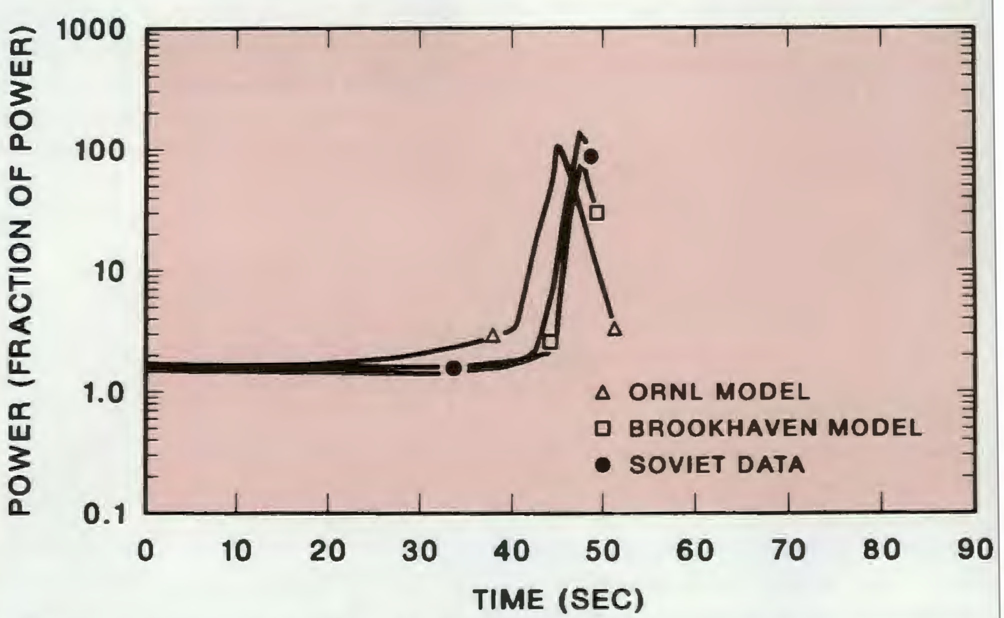
ORNL's Health Physics Research Reactor to determine the reduction in transmittance of light when a window is subjected to pulses of neutrons and gamma rays. Measurements were made using helium-neon lasers. In some materials, transmittance is greatly reduced after a short burst of neutrons and then is partially recovered. These data will aid in the selection of window materials for heat sensors in nose cones of ground-based missiles designed to intercept attacking ones.

The M&C and Solid State divisions are exploring the use of ion implantation for hardening the surfaces of these windows to make them more resistant to the abrasive effects of the atmosphere during high-speed travel.

In 1986 the Optical Component Characterization Facility was established at ORGDP. Its mission is to use state-of-the-art techniques to characterize optical materials being developed for SDI infrared surveillance applications. It will also evaluate effects of radiation on the optical properties of materials used in underground nuclear tests.

ORNL Helps Evaluate the Chernobyl Nuclear-Reactor Accident

After the April 26, 1986, accident at one of four reactors operating at the Chernobyl complex in the Soviet Union, ORNL teams evaluated the causes and consequences of the world's worst nuclear-power accident. Shortly after news of the accident reached the West, Allen Croff of the Chemical Technology Division (CTD) used the ORNL-developed computer code called ORIGEN to estimate the radionuclide inventory in the Chernobyl core. Ed Beahm, Dick Lorenz, Morris Osborne, and George Parker of CTD called European colleagues to obtain estimates of airborne concentrations and fallout measurements for various countries. Combining this information with Croff's inventory calculations and radionuclide decay times, the scientists calculated the time of the accident within 30 min of the time announced by the Soviets days later. CTD also used this information to estimate the concentrations and composition of the first and second releases of radioactivity from the Chernobyl plant, to determine possible release mechanisms, and to evaluate the chemical environment of the reactor during each release. Owen Hoffman of ESD calculated the approximate time of the accident using fallout information obtained from Sweden and the known speed and direction of the winds between that country and Chernobyl.



Dynamic analysis models developed by ORNL and collaborators reproduce the damaging power increase during the Chernobyl reactor accident.

ORNL researchers helped prepare the DOE *Resource Document* to guide U.S. representatives to the August 1986 meeting of the International Atomic Energy Agency (IAEA) in Vienna, Austria, in understanding and responding to the Soviet report on the accident. ORNL personnel involved in this effort were Steve Hodge and Tom Kress of ETD; Tony Malinauskas, head of NRC programs at ORNL; Les Oakes of the Instrumentation and Controls (I&C) Division; and Hoffman. Kress was a member of the IAEA team that participated in the Vienna meeting; he remained in Vienna a week following the meeting to help the IAEA prepare a report on the accident for member countries.

One assessment activity to help prepare the DOE team was the dynamic-analysis project led by Oakes. In this joint effort with Argonne, Brookhaven, and Pacific Northwest national laboratories, ORNL helped model the dynamics of

The ruined reactor at the Chernobyl nuclear-power plant complex has stimulated international cooperation on improving reactor safety.

the accident based on available data and surmises. The model of a severe power excursion suggested that a possible cause of the Chernobyl accident was a steam-line break, resulting in severe loss of cooling. This analysis, along with a later one in which the actual cause was used, provided the Vienna team with an understanding of what was known about the accident and what questions needed to be asked and answered.

Information presented in the Soviet report confirmed the validity of the U.S. dynamic-analysis model. Had the Soviet operators used the model to predict reactor behavior during their planned turbogenerator experiment, they might have proceeded more carefully or altered their plan of action.

Magnets and Pellet Fueling Highlight Fusion Energy Research

Fusion energy research is probably the most collaborative of ORNL's programs. It involves members of the Fusion Energy Division (FED), other ORNL research divisions, Energy Systems' Engineering and Computing and Telecommunications divisions, and the Y-12 Plant support staff, as well as domestic and international groups. The countries involved in our fusion projects include, among others, Australia, Spain, the European Community, Switzerland, Japan, and the Soviet Union.

The $180 million Large Superconducting Coil Task is an example of a joint effort involving ORNL, U.S. industry, the European Community, Switzerland, and Japan. In 1986 the project reached its fruition with completion of a 420-ton test array of six superconducting magnets. These magnets have been tested at cryogenic temperatures (4.2 K) since February 1986. The six coils each operated at design currents and fields of 8 tesla (150,000 times the earth's magnetic field). The experiments demonstrated that the coils can individually withstand stresses induced by background fields from the other magnets. They also showed that the coils operate stably under simulated nuclear heating loads.

Researchers confer in the control room of the International Fusion Superconducting Magnet Test Facility. From left in front are T. Kato of Japan, B. Jakob of Switzerland, and J. A. Zichy of Switzerland; from left in the middle are K. Okuno of Japan, A. Ulbricht of the European Community, and Martin S. Lubell of ORNL; from left in back are F. Wuechner of the European Community and S. Kamiya of Japan.

The project, led by Paul Haubenreich and Martin Lubell of

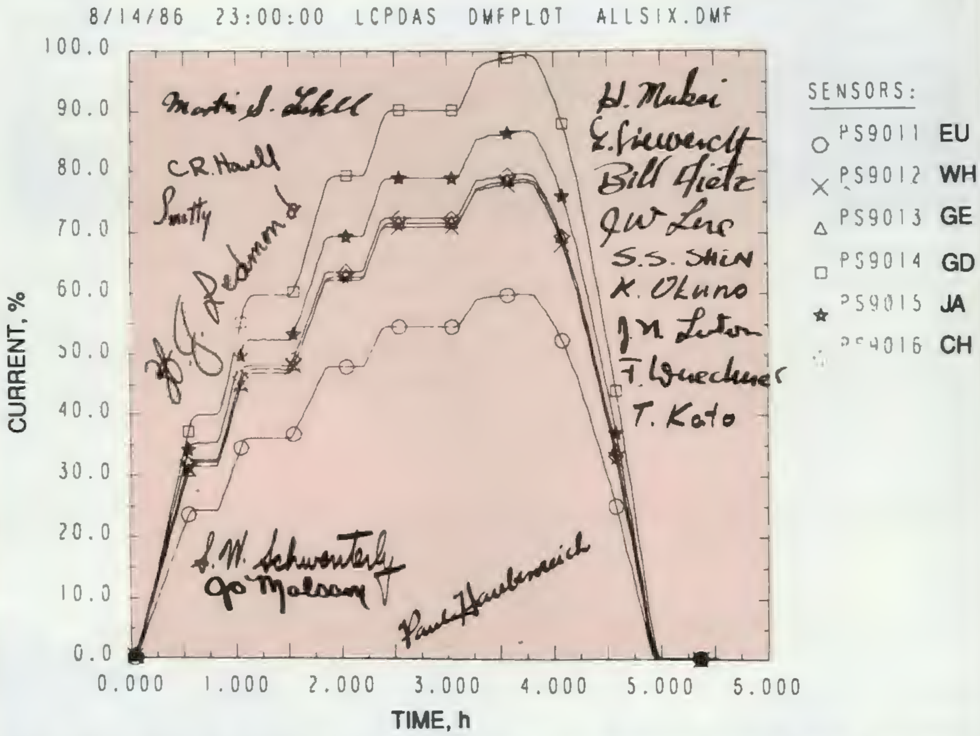
FED, is producing valuable data that will help participants develop larger magnets for big fusion machines. Superconducting magnets are needed to make fusion energy economical because they consume little electricity to produce the fields needed to confine fusion plasmas for power production.

The Large Coil Task is a landmark in international cooperation—in multinational sharing of information and technology. It is a small miracle that so many people from different countries have been brought together and have agreed on tasks and priorities for testing large superconducting magnets.

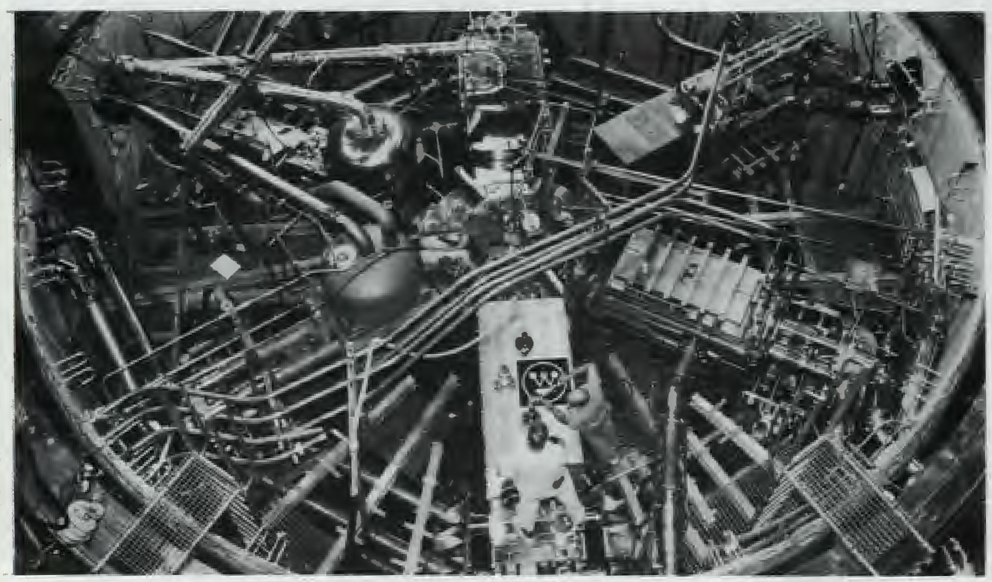
ORNL's Plasma Fueling Program led by Stan Milora also achieved some landmarks in 1986. ORNL's repeating pneumatic injector (RPI) contributed to a record plasma density in the Tokamak Fusion Test Reactor (TFTR) at Princeton University. The frozen hydrogen pellets from the RPI helped TFTR attain a record density-confinement product, or Lawson parameter, of 1.5×10^{14} $cm^{-3}s$. This result is twice the criterion needed to achieve breakeven (energy input equals energy output).

An improved device developed at ORNL and installed at the TFTR is an eight-shot deuterium pellet injector (DPI) built under the direction of Steve Combs. The guns can be individually programmed to produce frozen fuel pellets of three different sizes at different speeds and intervals. The DPI will be used at the TFTR in experimental runs combining pellet fueling, edge plasma control, and intense neutral-particle-beam and radiofrequency heating. These runs will be used to test scenarios for achieving fusion energy breakeven.

Currently, the ORNL group is building the first tritium pellet injection (TPI) system for tests planned at the Tritium Systems Test Assembly of Los Alamos National Laboratory. A TPI will be built to



Charging cycle for the first full-array test of the General Dynamics coil to 100% design current at a field of 8.1 tesla on August 14, 1986. The signatures of members of the international team attest to the achievement of a milestone for the Large Coil Program.

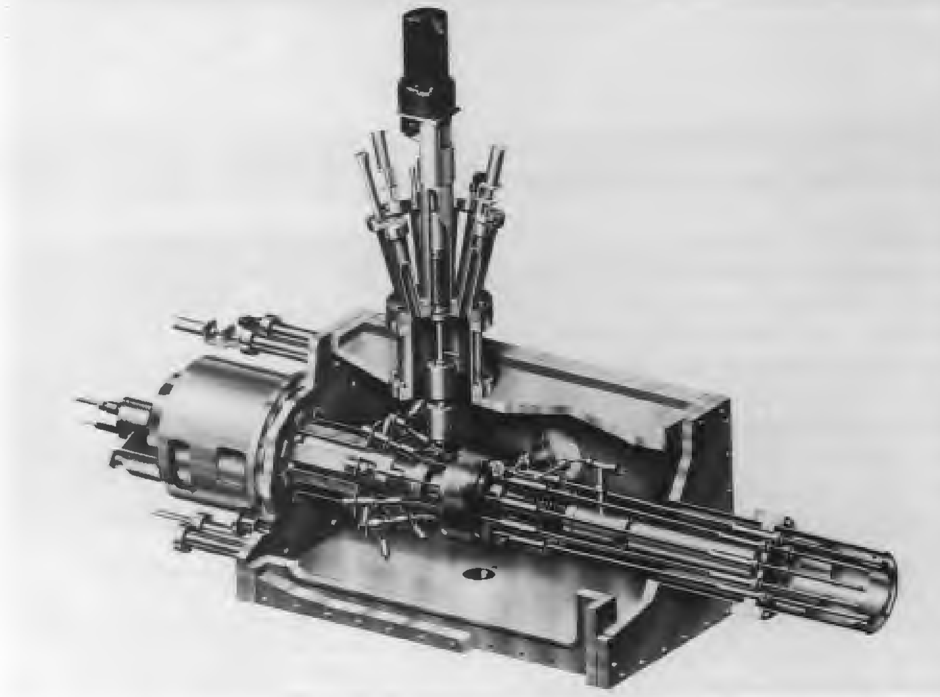


Final preparations are made in the vacuum tank of the International Fusion Superconducting Magnet Test Facility. Shortly after the sixth coil was installed in October 1985, the lid was lowered onto the tank and pumpdown was started.

replace the DPI at the TFTR in 1990. The TPI will be featured in the first deuterium-tritium experiments.

ORNL is leading the development of a new three-barrel RPI system for the Joint European Torus (JET), the European Community tokamak located in Abingdon, England. The system was to be installed this past spring. Of all fusion machines, JET is the most likely to attain record plasma parameters in the next several years. The European Community has asked for ORNL's help because ORNL-developed pellet-fueling technology has become the standard procedure for fueling advanced fusion devices.

Next: Technical Highlights



This schematic of ORNL's eight-shot pneumatic deuterium pellet injector received an award of achievement in the International Art Competition sponsored by the Society for Technical Communication. The injector has been installed on the Tokamak Fusion Test Reactor at Princeton University for refueling fusion plasmas.

ORNL's Scanning Tunneling Microscope Images Single Atoms

Major achievements at ORNL in 1986 were the operation of the scanning tunneling microscope (STM) by HASRD and its success in imaging single atoms on a silicon surface. Financial support for the instrument came from the Director's R&D Fund in October 1985. In June 1986 it was operating, and in one year, it was imaging individual atoms. Only a handful of STMs exist in the United States; the Oak Ridge unit is the only one of its kind in the Southeast.

Applications for STMs are surface physics, chemistry, and biology. In addition to physical surfaces, ORNL will use the unit to image biological specimens to better understand structures of DNA macromolecules and complex proteins such as enzymes.

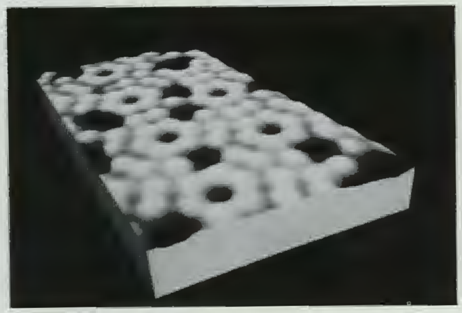
In October 1986 the ORNL instrument imaged single atoms of silicon and achieved resolution of atomic structure on a semiconductor surface. The STM could discern between height differences as small as a tenth of an angstrom (10^{-1} Å).

The chief features of the current microscope are a sealed vacuum chamber, a tungsten needle, piezoelectric crystals, and a

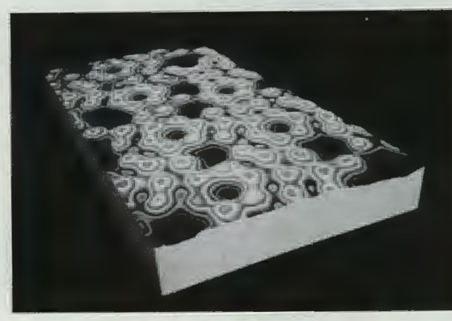
Bruce Warmack operates the scannning tunneling microscope (STM) in the Health and Safety Research Division. The STM is housed in an ultrahigh vacuum chamber (at left). Good vibration isolation is necessary to keep the tip-positioning precision to a tenth of an angstrom. Scanning of the tip is controlled by a personal computer. The electronics and vacuum controls are at right.

computer. The electronic components take up about twice as much space as the vacuum chamber. The barely visible needle scans the surface of the sample (e.g., a stamp-size slice of silicon) without touching it, and under a small applied voltage, electrons flow from the tungsten atoms at the needle tip to the surface atoms, a phenomenon called tunneling. This tunneling current is regulated by the distance from the tip to the sample and is controlled by a piezoelectric crystal, which is made to expand or contract in proportion to the current. If the surface atom being scanned is larger than adjacent features, it will be closer to the needle and, thus, will increase the current. As a result, the crystal contracts, raising the tungsten tip so it can pass over the atom. A drop in current, on the other hand, causes the crystal to expand and lower the tip.

The computer receives and stores information on the varying tip heights with respect to the surface being scanned. These indications of small differences in elevation on a surface reveal relative positions of different types of atoms. This contour map of a material's surface is displayed on a screen, and its images can be enhanced by computer graphics to provide more detail.



Perspective view of a silicon surface imaged by the STM at ORNL. The higher points are lightened so that individual atoms appear as fuzzy balls arranged in definite patterns. Defects, such as atoms missing from the perfect pattern, are clearly visible.



The same data as the preceding micrograph are presented here with height contours separated by only one-sixth of an angstrom. This image shows that very precise and low-noise data can be obtained at room temperature with the STM.

The STM was developed at the IBM Zurich Research Laboratory in Switzerland, and the developers received the 1986 Nobel Prize for Physics. The STM at ORNL is operated under the direction of Bruce Warmack and Tom Ferrell of HASRD.

ORNL Develops High-Efficiency, Laser-Processed Solar Cells

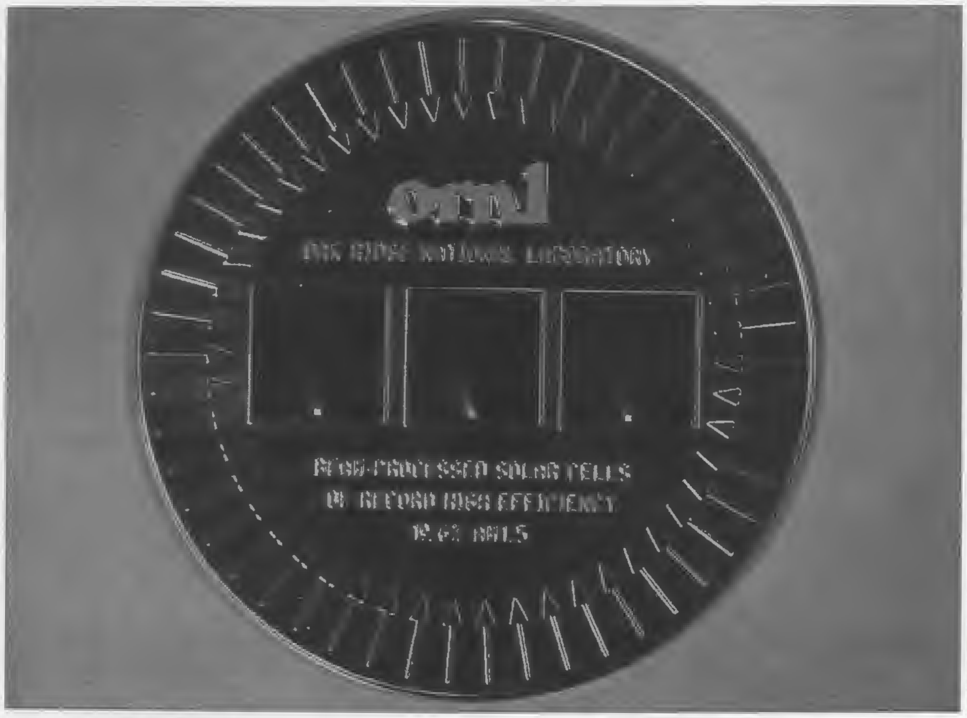
Using laser processing, ORNL's Solid State Division developed solar electric cells that in 1986 achieved several record conversion efficiencies for silicon cells. These cells convert nearly 20% of light energy from the sun into electrical energy. The best conversion efficiency achieved in solar electric cells so far is 20.5%, but the processing used to achieve this high efficiency—complex microelectronic fabrication on specially prepared silicon surfaces—is not likely to be as economical as laser processing. Commercially available solar cells have efficiencies of 12 to 14%.

The ORNL achievement is an outgrowth of an early Solid State investigation to find methods for fabricating solar electric cells to improve their conversion efficiency and cost effectiveness. DOE's Solar Energy Research Institute measured the ORNL cells and confirmed that they achieved a number of efficiency records.

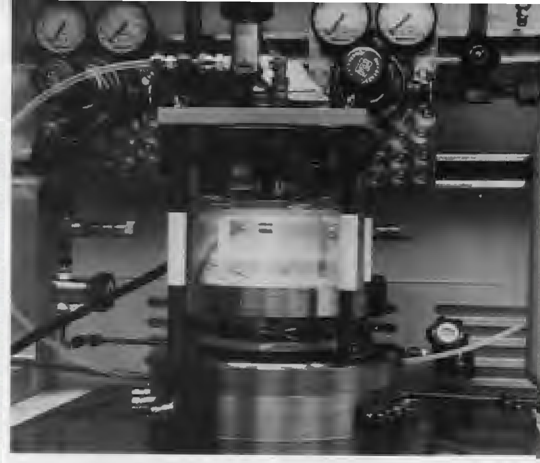
ORNL made two types of cells using two different processing methods. The first type of cell was made by pulsed laser annealing in which the front surfaces were "passivated" by high internal electric fields formed in the silicon by laser processing. This pulsed-laser-annealed, or PLA, cell type achieved an efficiency of >18.5%, higher than any cell ever fabricated without the growth of a thin oxide layer.

The second type of cell is made by a two-step process, glow-discharge implantation and laser annealing. In this process, an electric discharge in a gas implants donor atoms into the silicon semiconductor and a high-powered, rapidly pulsed, xenon-chloride laser anneals the implanted surface, tailoring its electrical properties and restoring the crystalline lattice. To passivate the surface of these cells, ORNL scientists grow a thin oxide layer on the surface, creating "hybrid" cells. They attained an efficiency of 19.7%.

The ORNL researchers responsible for achieving this landmark in laser processing and solar cell fabrication are Dick Wood, Russ Westbrook, and



This plaque was made to commemorate the attainment of the record high efficiencies of solar electric cells (nearly 20%) made at ORNL. The cells were fabricated by advanced beam processing. The antireflection coatings on the cells cut the amount of reflected light to 2–3%, making the cells very nearly black.



The gaseous discharge implantation system for making solar electric cells is shown in operation. The silicon wafer to be implanted is mounted on the pedestal serving as the cathode. The system is pumped down to a low vacuum, the flow of dopant and carrier gas is started, and then an electric field of about 1 kV is established across the electrodes. The molecules are ionized and accelerated, giving them enough kinetic energy to be implanted in a very thin surface layer of the silicon wafer. The glow is characteristic of hydrogen, the carrier gas.

Jay Jellison of the Solid State Division.

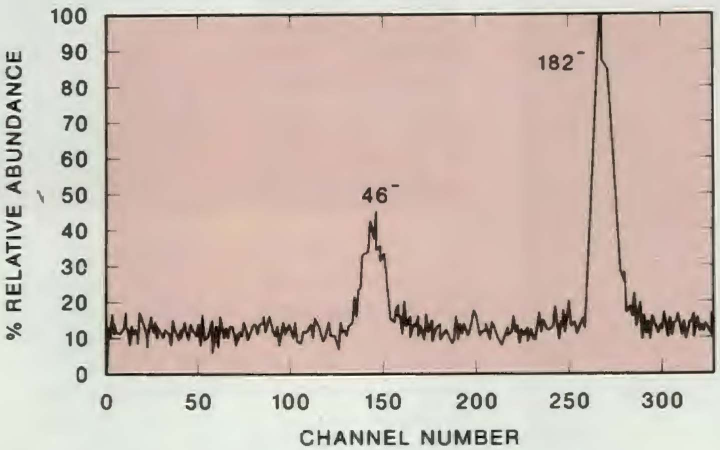
ORNL's goal is to demonstrate that solar electric cells can be manufactured at low temperatures and at high rates of production using special laser processing techniques. Currently, silicon solar cells are fabricated by costly high-temperature processes. Because they require little thermal energy and pose no risk of thermal damage, ORNL-developed processes should be more economical than current methods for making large volumes of high-efficiency, solar electric cells.

Trace Detector of Explosives May Be Anti-Terrorist Device

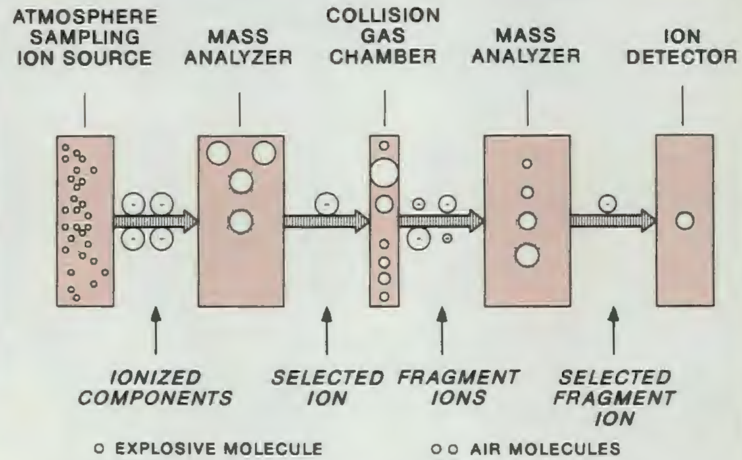
Researchers in ORNL's Analytical Chemistry Division have developed a compact device that can instantly detect vapors of concealed explosives at parts-per-billion concentrations. Far more efficient than the trained dogs that are sometimes used, the new "explosives sniffer" can detect and chemically identify organic nitrogen-oxygen compounds in air in less than a second. These compounds are the basic ingredients of explosives such as TNT, plastiques, and nitroglycerine.

The highly automated explosives detector is a miniaturized version of

ORNL's highly automated explosives detector is a compact version of a research mass spectrometer that can identify and quantify trace constituents of chemical substances. Developers of the "explosives sniffer" are, from left, Gary Glish, Scott McLuckey, and Henry McKown of the Analytical Chemistry Division.



The explosives sniffer achieves parts per billion sensitivity in one second.



The two-step spectrometric process of the explosives sniffer can select and identify traces of explosives almost instantly.

mass spectrometers used in research. These devices are usually large and expensive, and specialists are needed to operate them. In the ORNL detector, computer programs control the analysis, eliminating the need for special training for operators of the sniffer (e.g., security personnel).

The ultrasensitive ORNL instrument could be used to scan persons entering airport terminals, nuclear power plants, defense installations, or other sensitive locations, providing greater security against potential terrorism. The device may also be used to sniff vapors emanating from concealed drugs and flammable liquids.

The device consists of an ultrasensitive atmospheric sampling ion source coupled with a compact two-stage mass spectrometer. It is linked to a booth in which the person being screened is asked to stand for a few seconds. The air in the booth is pumped to the ion source, a chamber in which high-energy electrons bombard and ionize airborne compounds from the person, producing negatively charged particles. These are measured by mass in a quadrupole mass spectrometer before being passed through a gas and forced to decompose into simpler fragments. The second-stage time-of-flight mass spectrometer sorts the charged fragments by their weight. Information on molecular weight of charged particles and known decomposition patterns of their fragments allows a determination of whether compounds typical of explosives are present. The two-stage spectrometric analysis takes less than a second.

Trained dogs are much less efficient than the ORNL sniffer because they tire after 20 min and can learn to detect only one or two types of explosives at part-per-billion concentrations. The rugged, reliable ORNL device can detect a range of explosive vapors over a long time.

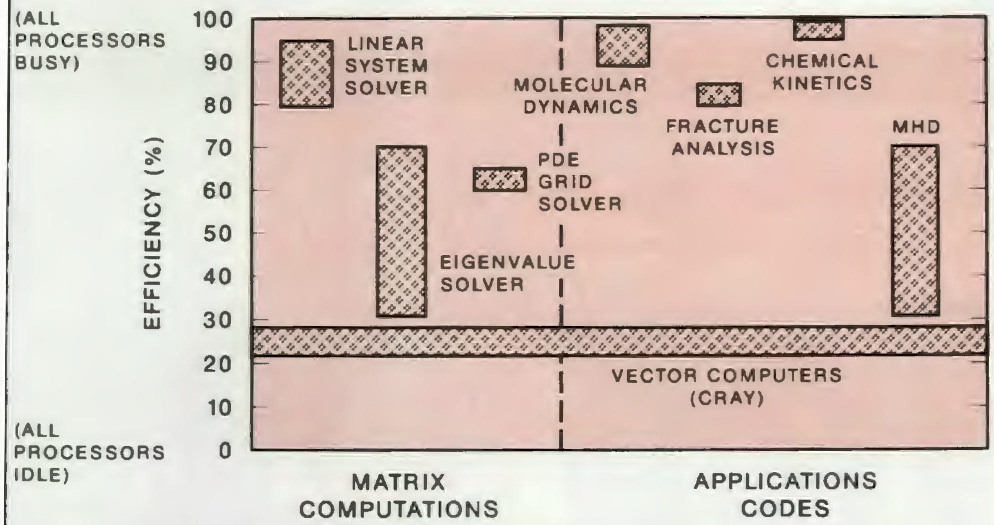
The ORNL detector, which will be tested at the Y-12 Plant this year, was developed by Gary Glish, Scott McLuckey, and Henry McKown of the Spectroscopic Research and Development Programs Group of the Analytical Chemistry Division. These researchers are members of one of the best groups of mass spectroscopists in the world.

Efficient Parallel Algorithms Developed at ORNL

ORNL is rapidly developing its capabilities in parallel processing—using computers connected in parallel to process information the way the human mind does instead of serially the way our traditional von Neumann computers do.

ORNL's Engineering Physics and Mathematics Division (EPMD) has acquired several parallel computers, or hypercubes, in the past two years. These computers connected in parallel can share memories or each can have its own memory (distributed memory) for making calculations and then transmit results along the network to share with the other computers.

ORNL mathematicians John Drake, Al Geist, Mike Heath, Esmond Ng, Skip Thompson, and



The hypercube (parallel computers) yields high efficiencies for a range of difficult problems.

Mike Heath (left) and Tom Dunigan at the hypercube.

Janice Trent works at an IBM PC as John Drake looks on. Drake, Dunigan, and Heath have been involved in development of algorithms for parallel processing.

Bob Ward of EPMD have been identifying types of problems most amenable to parallel processing. Questions of concern to them include: How efficient can you make parallel processors? Are ten processors ten times as fast as one processor? Does the kind of problem dictate the number of processors needed? Which problems are solved faster by parallel processing, and which are solved faster by serial processing?

The ORNL mathematicians have developed highly efficient algorithms for parallel computers using (1) the hypercube architecture that can solve many of the basic matrix problems and (2) a selection of computational problems from diverse scientific fields. Parallel efficiency of the algorithms ranged from about 30 to 99%; most were over 75%. The efficiency of an algorithm running on a parallel computer indicates the amount of the available computing power being used; if nine out of ten processors are doing useful work (leaving only one processor idle), the efficiency of the algorithm is 90%, which is considered very good. For typical large-scale matrix problems, efficiencies of the algorithms ranged from about 85% for the solution of dense systems of linear equations, probably the most basic of all computational problems, to about 60% for computing all the eigenvalues of a dense matrix.

The ORNL mathematicians have worked with Laboratory researchers to solve specific scientific problems. Algorithms for two of the problems—molecular dynamics calculations and the chemical kinetics portion of contaminant transport—performed at almost 100% efficiency by recognizing and exploiting the parallelism of the underlying physical problems. Even algorithms for difficult computational problems in magnetohydrodynamics and finite-element fracture analysis performed in the 60 to 85% efficiency range. By comparison, efficiency with respect to peak performance on vector computers is typically 20 to 30%.

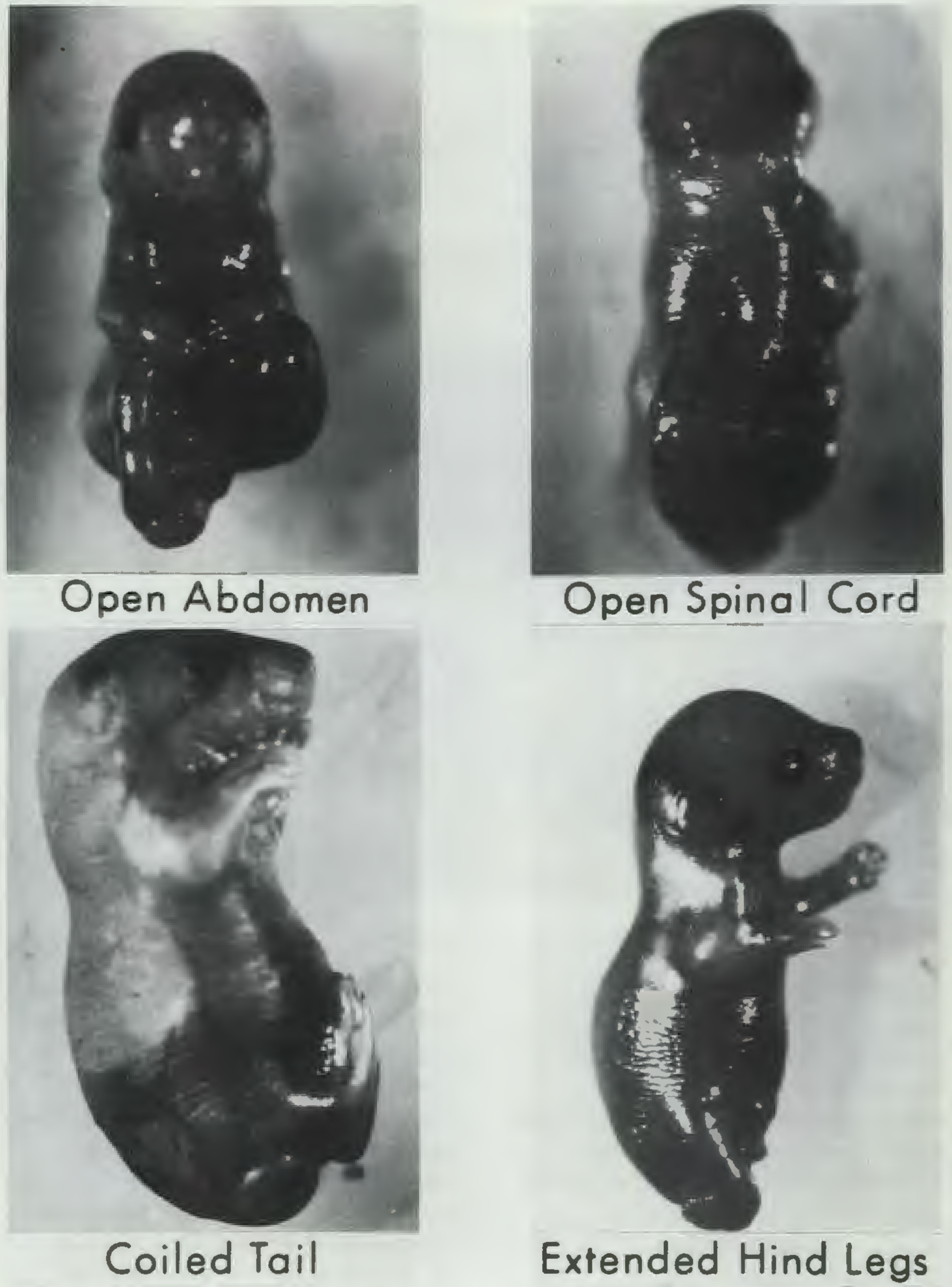
The scientific problems solved this way were presented by Elijah Johnson of the Chemistry Division, Vijay Tripathi of ESD, and John Clinard of ETD. The researchers were surprised at the excellent performance of the algorithms. The work offers the first evidence that high efficiencies can be obtained for general-purpose scientific computational tasks using modern numerical methods on parallel computers having distributed memory.

New Discovery Suggests Fertilized Egg May Be at Risk

The causes of developmental anomalies in human fetuses and birth defects in babies are usually unknown. In some cases, however, these abnormalities are known to be due to specific agents called teratogens. Until recently, in experiments on animals, defects had been produced only if various organs were developing during exposure to teratogens.

However, recent mouse experiments by Walderico Generoso of the Biology Division have revealed an earlier period of vulnerability to mutagenic chemicals. The period starts at the time the egg is fertilized and ends several hours later. Generoso exposed just-mated female mice to two commercially important chemicals, ethylene oxide and acrylamide, and produced a high incidence of developmental defects in the fetuses.

The new finding is expected to affect evaluation of chemical safety, particularly in the workplace. It raises questions regarding the vulnerability of humans in the first stage of life if the mother is exposed to environmental chemicals. The finding suggests that, under certain conditions, exposure of women to mutagenic chemicals soon after fertilization may induce birth defects in just-conceived progeny. Clearly, risk assessment studies should be broadened to include exposures to environmental or occupational substances near the time of fertilization.



These malformations of fetal mice occurred when the mothers were exposed to ethylene oxide at the time the egg was fertilized. ORNL biologists recently discovered that this early stage of development is more vulnerable to damage by teratogen chemicals than previously thought.

ORNL Manages Work To Improve Trees for Biomass Energy

In 1986 ORNL became project manager for the *Populus* Research Consortium, the largest U.S. effort to exploit a single genus for biomass energy production. The work is being performed by eight groups from universities and industry. The aim of the consortium is to identify techniques to speed the growth of poplar trees and to develop new hybrid poplars having both fast growth and desirable energy characteristics. Such trees will be raised as energy crops for conversion to liquid or gaseous fuels. Fuels will be produced from wood by four possible pathways: hydrolysis-fermentation to ethanol, anaerobic digestion to biogas (methane, carbon monoxide, and hydrogen), pyrolysis to thermgas (medium- and high-BTU gas), and modified pyrolysis to biocrude for conversion to gasoline.

The focus of the research has been to study the physiological and genetic characteristics of three species of poplar trees and several hybrid trees as a basis for determining ways to make them more hardy and increase their growth rate. By selecting the fastest growing trees and propagating them, consortium researchers doubled the growth rate of one poplar hybrid. The selectivity technique for increasing growth rate will be used in other species of deciduous trees. Desirable energy characteristics are being defined as a result of formal interactions between consortium members and wood-energy-conversion specialists.

A root or radicle develops during somatic embryogenesis of a hybrid poplar. The production of clonal "seeds" in the laboratory using such methods may lead to ways to lower costs of energy plantations.

Potential herbicide resistance has been identified in clones of hybrid poplar trees by somaclonally screening tissue cultured explants. Herbicide resistance greatly eases **Populus** *field culture. (Photograph from U.S. Forest Service.)*

Research projects are located in the Pacific Northwest, the Great Lakes states, the Northeast, and the Central Plains. A forest company and a power company are planting large-scale plantations of poplars for biological and economic studies. The consortium is actively involved in international projects such as the hybridization of European and Asian poplars with North American species.

ORNL researchers involved in project management and research are Jack Ranney, Patricia Layton, and Lynn Wright of ESD. In addition to its leadership role for the consortium, ORNL is also responsible for environmental studies, overall data synthesis, modeling the growth of tree stands, and linking various growth models.

Besides doubling the growth rate of a hybrid poplar, consortium achievements in 1986 include development of methods for establishing and growing poplars, a physiological model of the growth of individual trees, and an analysis of the costs and benefits to energy production of growing poplars for biomass energy.

ORNL Toxic-Waste Leaching Test May Be Adopted by EPA

C.J.C. Gouch and O.M. Sealand of ORNL's Environmental Sciences Division check the results of a field test in which industrial wastes are leached with municipal waste leachate. The test helped to validate ORNL's new Toxicity Characteristic Leaching Procedure for identifying potentially hazardous wastes. EPA has proposed using the ORNL test for classifying wastes at municipal landfills and Superfund sites.

In response to the Resource Conservation and Recovery Act, EPA has published regulations defining hazardous wastes that must be identified and managed in specific ways to protect health and the environment. Wastes classified as hazardous or toxic under these rules include those that could potentially release toxic constituents if disposed of in municipal landfills.

EPA has been using the extraction procedure toxicity (EP-TOX) test to determine toxicity characteristics of wastes. The technique has been used to identify wastes that contain leachable toxic metals, herbicides, and pesticides. The EPA test uses acetic acid to simulate the leaching of wastes by carboxylic acids in municipal waste leachates (products of leaching). This test, however, is limited by its inability to simulate a real-world disposal environment and its omission of toxic organic compounds, including volatile organics, from the criteria for toxicity.

In 1986 ORNL researchers Chet Francis of ESD and Mike Maskarinec of the Analytical Chemistry Division developed a real-world test for classifying landfill wastes that pose a toxic hazard. Because of the accuracy and reliability of the ORNL test, EPA has proposed using it in place of the EP-TOX test. It has also been proposed for use at Superfund sites (abandoned waste sites selected for cleanup) to determine which of the removed wastes must be managed as hazardous wastes.

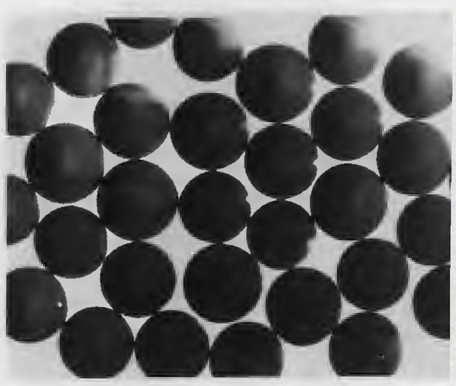
The ORNL test is superior to the EP-TOX test in that it better simulates the actual leaching behavior of industrial wastes under municipal landfill conditions. In contrast to the EP-TOX test, the ORNL test—called the Toxicity Characteristic Leaching Procedure (TCLP)—includes regulatory levels for 38 additional compounds, principally toxic organics.

The TCLP is unique because it is the first waste extraction test to be validated using field leaching conditions. In this validation, 11 potentially hazardous industrial wastes were leached with municipal waste leachate over periods as long as 100 days; the leachates from the 11 wastes were collected and analyzed for hazardous chemicals. Maskarinec identified 95 target constituents (57 organic and 38 inorganic) in the leachates. By comparing concentrations of these target constituents measured in the field leachates with laboratory extraction concentrations, the ORNL researchers verified that the TCLP more accurately and reliably simulated disposal leaching conditions than the EP-TOX test.

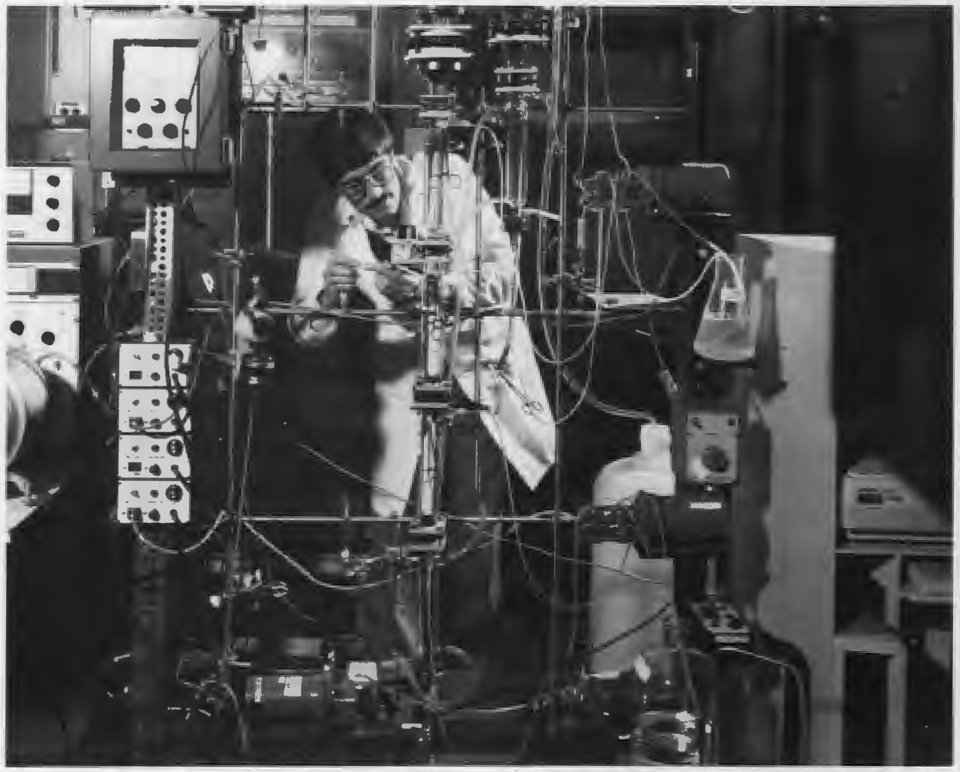
Fermentation Technology for Corn Gives High Fuel Yield

ORNL has developed an innovative method for fermenting corn sugars that yields ten times as much fuel alcohol as other methods. The ORNL method uses an advanced bioreactor system containing highly efficient immobilized bacteria. Brian Davison and Chuck Scott of the Chemical Technology Division have been working with A. E. Staley Company, the corn products firm, to turn this innovative method of producing ethanol into an industrial process.

The process involves entrapping large numbers of the active microorganisms *Zymomonas mobilis* within small gel beads contained in a fluidized-bed bioreactor. These biocatalyst beads, which are about 1-mm in diameter, are formed by an ORNL-developed process based on the sol-gel process (originated at ORNL for the creation of nuclear fuel particles). The protected cocoon-like environment of the small beads is more favorable for *Zymomonas mobilis* than is the usual bioreactor environment; as a result, the microorganisms metabolize more efficiently, converting almost all the sugar in corn to ethanol.



These biocatalyst beads—each about 1 mm diam containing about 10^{10} cells of **Zymomonas mobilis*****—were used in the highly efficient fluidized-bed conversion of industrial sugar to ethanol. These gel beads were made by an ORNL-developed process.***



Brian Davison operates a bench-scale fluidized-bed bioreactor for the continuous production of ethanol from industrial corn sugar.

In the process, dissolved corn sugar diffuses into the beads, where it is fermented into ethanol and carbon dioxide by the bacteria. The small size of the beads (and consequent larger surface area) increases the exchange of sugar and fermentation products, thus raising the overall production rate. Using a continuous fluidized-bed system increases mass transfer, improves disengagement of carbon dioxide, reduces the effect of "ethanol inhibition" in slowing down biological conversion, and will allow easier scale-up.

ORNL researchers and Staley employees have operated a small engineering-scale bioreactor for extended periods. The tests demonstrated that (1) 99% of the sugar was converted to ethanol, (2) the ethanol yield was ten times as large as the ethanol production by conventional batch-brewing technology, (3) the ethanol yield was 98% of the amount theoretically expected, and (4) the bacteria-bead biocatalysts have an active life of more than two months.

Staley sees this process as potentially useful for decreasing its operating and capital costs for corn fermentation. Preliminary cost estimates by an independent DOE consultant indicate the economic feasibility of the ORNL processing scheme. ORNL is planning additional laboratory-scale experiments to help determine the feasibility of using this technology in an industrial pilot plant.

The ORNL-Managed Athens Automation and Control Experiment Balances Electrical Loads, Is Model for Nation's Utilities

ORNL is managing the most highly automated electricity distribution system in the nation. The system, located in Athens, Tennessee, is supported by DOE and the Athens Utilities Board (AUB). The Athens Automation and Control Experiment has been operating since September 1985.

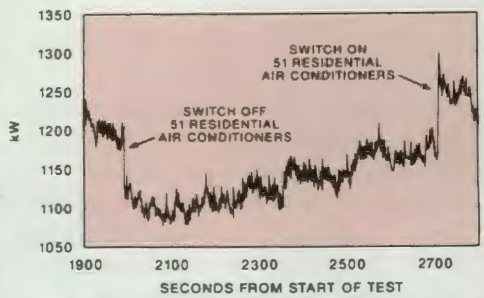
Using computers and two-way communications devices, the system monitors and controls electricity distribution. To flatten AUB's peak loads, the system reduces electricity use by water heaters, space heaters, and air conditioners in 2000 homes without inconveniencing customers. The system can also control voltage levels and switch loads automatically to increase the efficiency and reliability of distribution equipment.

ORNL researchers involved in managing the Athens experiments are Paul Gnadt, Pat Hu, John Stovall, William Nelson, John Reed, Tom Rizy, and Robert Stevens of the Energy Division and Randall Wetherington and Eva Broadway of the I&C Division.

Two major experiments were started in 1985. One was the "volt/var control" experiment, which controls capacitors and regulators to control voltage and reduce energy losses. The other was the "system reconfiguration" experiment, which involves automatically transferring electric loads between substations and quickly restoring power after an outage caused by a fault (e.g., a tree across a power line).

In 1986 high-speed monitoring (10,000 readings per second) of power consumption was employed for the system—distribution, circuit breakers, and regulators and space heating and cooling and water heating units in homes. The monitoring allows the system to selectively switch home heating and cooling on and off without causing any discomfort to customers. As a result, the AUB can determine quickly how to redistribute power use to balance out its loads effectively. This ability to control loads allows an electric utility to defer construction of expensive power-generating facilities.

Electric utilities are now beginning to accept the potential of automation for minimizing the cost of electricity. Calculations show that increasing the efficiency of U.S. utility transmission and distribution systems by 1% would save the utility industry $140 million a year and that decreasing U.S. utility peak loads by 1% (through automated load management) would save $3.6 billion and increase available capacity by 4500 MW. Not surprisingly, the ORNL-managed Athens system, which has demonstrated that new technologies can increase a power system's efficiency, has become a model for the nation's utilities.



In the Athens Automation and Control Experiment, changes in end-use demand are monitored at the feeder level.

G. R. Wetherington, Jr., of ORNL's Instrumentation and Controls Division checks the operation of the Fast Data Acquisition System. The system is used in the Athens Distribution Automation and Control Experiment to determine the effects of control actions on distribution feeders.

Milestones for 1986

In 1986 two ORNL researchers became members of exclusive U.S. groups in science and engineering. Liane B. Russell was elected to the National Academy of Sciences, and Charles D. Scott was elected to the National Academy of Engineering.

In 1986 Liane B. (Lee) Russell was elected to the National Academy of Sciences. She is the first woman from Tennessee to be so honored.

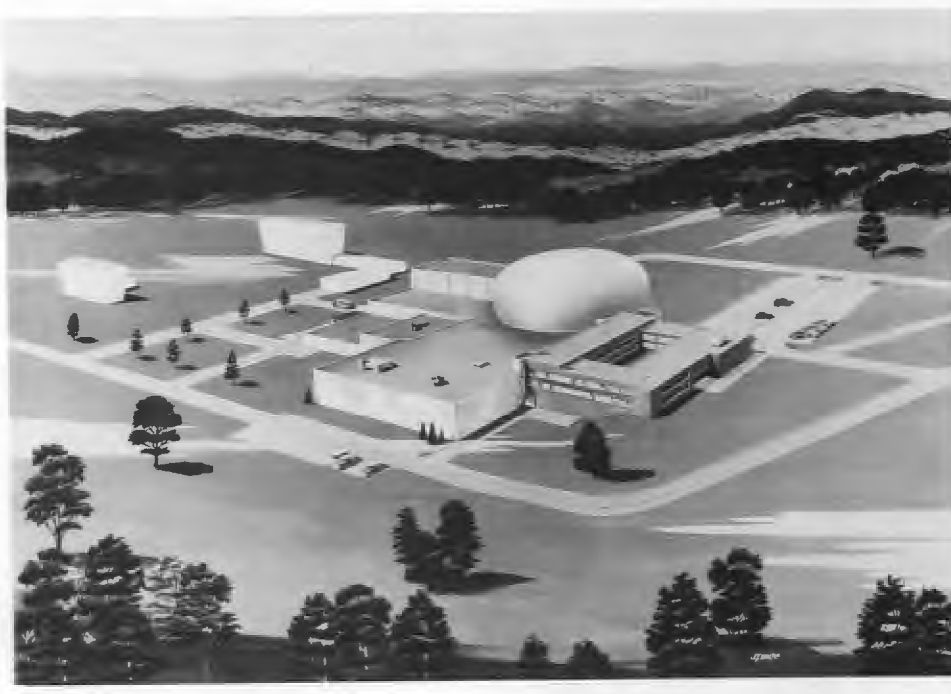
This year ORNL researchers received three I•R 100 awards. Since 1975, when we started keeping track, ORNL has received 49 I•R 100 awards, putting it second—after the National Aeronautics and Space Administration (NASA) laboratory in Cleveland—among federal laboratories. On the corporate level, Martin Marietta Energy Systems, which has received 55 awards, trails only General Electric Company, Varian Corporation, and Westinghouse Electric Corporation in the number of I•R 100 awards.

Winners of the three 1986 awards were Robert Lauf (M&C Division), Barbara Hoffheins and Michael Emery (I&C Division), and Melvin Siegel (Carnegie Mellon University) for an integrated gas

In 1986 Charles D. (Chuck) Scott was elected to the National Academy of Engineering.

analysis and sensing chip; Michelle Buchanan and Marcus Wise (Analytical Chemistry Division) for the multimode ionization detector; and Tom Callcott and Edward Arakawa (HASRD), Ken Tsang (UTK), and David L. Ederer (National Bureau of Standards) for the soft X-ray emission spectrometer.

In other milestones, the **Advanced Neutron Source** (ANS), which was previously called the Center for Neutron Research, received initial funding of $2.5 million in 1986. The goal of this project, which began three years ago with support from the Director's R&D Fund, is to construct the world's most powerful research reactor. Under current plans, it will have a power level of 270 MW and a neutron flux 5 to 10 times higher than ORNL's High Flux Isotope Reactor in some regions and higher than the best regions of the Institut Laue Langevin reactor in Grenoble. The plan is to build the ANS by the mid-1990s. In 1986 the congressional language in the budget designated Oak Ridge as the site for the ANS and ORNL as the lead laboratory. The ANS studies have been the result of an interdisciplinary effort within six ORNL divisions and Energy Systems Engineering.

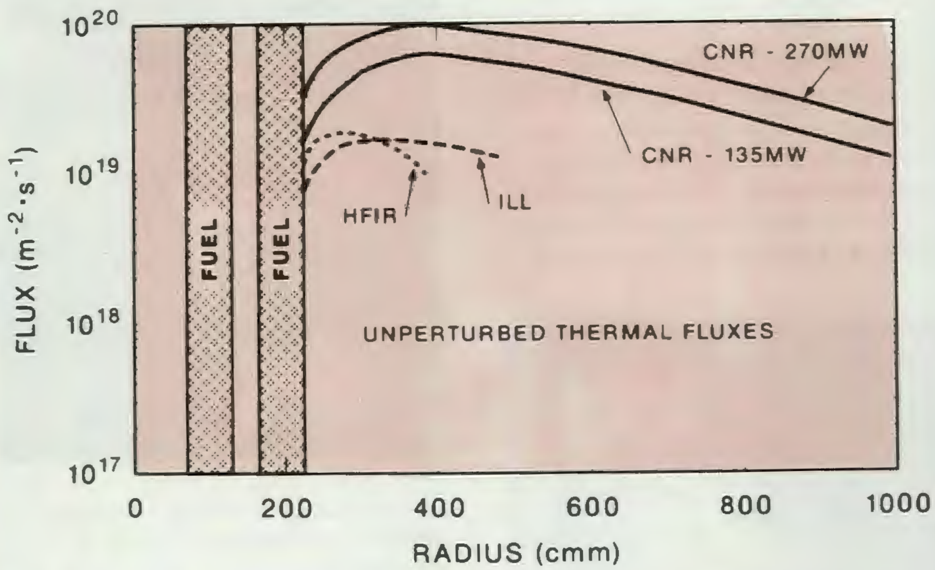


Artist's conception of the Advanced Neutron Source, which would include the world's most powerful research reactor. It would have a power level of 270 MW and a neutron flux 5 to 10 times higher than that in the best regions of ORNL's High Flux Isotope Reactor.

The **High-Temperature Materials Laboratory** (HTML) is complete, and most of its offices are occupied by M&C staff members. Because of its elegant and unique architecture, I expect it to be one of the most photographed places at ORNL. HTML user centers are becoming available for outside researchers. This collaborative center will be one of the best research facilities in the world.

The **Advanced Toroidal Facility** (ATF), an extremely complex stellarator-type fusion device, was essentially complete in 1986, except for a vacuum chamber, which was scheduled to be shipped and installed in early 1987. The ATF is elegant because all components of the helical coil system had to be designed, fabricated, and assembled with high precision to achieve certain plasma parameters. The helical coil system produces the twisting, toroidal, or doughnut-shaped, magnetic field for the stellarator. To speed overall assembly of the ATF, the helical coils were built in 24 segments with a precision approaching 0.25 mm over distances of about 3 m. Mechanical engineers recognize the difficulty of achieving such tolerances. We recently were notified that the national award in the energy category from the American Society of Mechanical Engineers went to the ATF. It is a beautiful job resulting from a considerable amount of cooperation.

ORNL's new **Robotics and Intelligent Systems Program** (RISP) was created in 1986. It unites groups in the Engineering Physics and Mathematics, Fuel Recycle, and Instrumentation and Controls divisions. This $10 million program focuses on intelligent machines, including robots, teleoperators, and parallel processors. One source of funding is NASA, which has asked ORNL to build a new generation telerobot for possible use in assembling the space station. Our work will include designing controls for the robot now being developed for use in space. RISP's overall goal is development of advanced technology; recent examples of ORNL developments are featured on the covers of two magazines—*NASA* and *Robotics World.*



The objective of the Advanced Neutron Source project at ORNL is to design and construct the world's best research reactor.

In 1986 ORNL completed the decade-long **Consolidated Edison Uranium Solidification Program** (CEUSP). Some 1050 kg (2300 lb) of reprocessed uranium fuel in liquid solution was converted into an inert, solid oxide form for safer long-term storage. The highly radioactive liquid nitrate solution from a Consolidated Edison fuel reprocessing plant had been shipped to ORNL in the late 1960s and was stored here for 16 years. The CEUSP facility was created to concentrate the liquid waste, convert it to a dry oxide form, and double-seal it in steel cans, using ORNL-designed complex remote-processing equipment. Thanks to a tremendous effort, the project was completed two months ahead of schedule.

DOE's **inspection and evaluation of ORNL's safeguards and security** took place in 1986. We were tested to determine whether we have adequately protected and safeguarded materials that terrorists might want to steal for making weapons. We were subjected to a rigorous examination by DOE headquarters, their outside consultants, and composite adversary teams. This examination is one we did not want to fail; one national laboratory failed it and had to pay $4 million to hire guards and install safeguard devices to meet DOE criteria. Fortunately, we passed this test with flying colors—a great tribute to our people who performed so well. Then, ORNL earned a superior rating from DOE on our safeguards and security accomplishments for the latest award fee period, an outstanding achievement.

Another 1986 milestone was the success of the **waste reduction program**. ORNL met its goal of reducing generation of radioactive waste so that less waste would have

Vic Tennery, director of the High Temperature Materials Laboratory, enjoys the unique design of the new HTML facility.

A. D. Cofer of Y-12 Maintenance works inside the ATF structural shell. The lower segments of the ATF helical coils are visible. The upper segments will be reassembled after installation of the ATF vacuum vessel.

to be processed and buried. Generation of liquid low-level waste has been reduced by a factor of 2.5, from 25,000 to 10,000 gal/week since 1984. The concentrated volume of these wastes is down from 12,000 to 2000 gal/month, a factor of 6 reduction. This success may be attributed to process changes, a newly instituted "tax" on Laboratory waste generators, and drier weather.

We plan to reduce the amount of solid waste requiring disposal by a factor of 3. ORNL currently generates 90,000 ft^3/year of solid waste; however, by using a supercompactor, we can cut the amount of waste to 30,000 ft^3/year. I pay tribute to all employees who have realized the seriousness of the problem and have taken steps to minimize generation of waste. Producing less waste saves money because large volumes of waste are expensive to handle and dispose of properly to protect worker health and the environment.

In another milestone for management of radioactive waste, ORNL received approval for its program for certifying newly generated, contact-handled transuranic (TRU) waste. The program, approved by DOE's Waste Acceptance Criteria Certification Committee, allows ORNL to develop procedures for training personnel in packaging TRU waste and operating ORNL's Waste Examination Assay Facility. At this facility, we have nondestructively assayed and examined some 2000 drums containing contaminated rags, gloves, and other materials that had been used in the handling of radioactive substances, including transuranium elements and TRU compounds. By assaying the radioactive contents of each drum, we determined which drums should be disposed of as low-level waste and which ones should be held for later disposal at the Waste Isolation Pilot Plant, a federal facility under construction in New Mexico for TRU wastes. Because of our ability to identify and quantify TRU wastes (with the help of an assay system developed by Los Alamos National Laboratory), ORNL has been licensed to certify TRU wastes for shipment to and disposal in the national repository.

The HFIR Situation

In May 1986, several weeks after the Chernobyl reactor accident, I appointed a committee to probe the safety of operating the High Flux Isotope Reactor. The committee, headed by Don Trauger of the Central Management Offices Division, sought evidence of possible neutron-induced embrittlement of the HFIR pressure vessel. Committee members asked for information and found that some data were not in a recognizable form; in some cases, data were not available because the specimens removed three years earlier from the reactor had not been analyzed. By insisting upon seeing the data, the committee learned in early November that the vessel had been embrittled much faster than had been anticipated at its installation 20 years ago. Of course, the people who designed the reactor were not absolutely certain that the vessel would last 20 years. Thus, they wisely placed removable specimens inside the vessel to monitor the embrittlement rate.

When the reactor was shut down for refueling and maintenance November 14, we decided to keep it idle for a prolonged period, report what we had found to DOE, and begin determining what actions must be taken to resume its safe operation. We formed another ORNL committee, headed by Dick Cheverton of ETD and Randy Nanstad of the M&C Division, to determine how much life remained in the reactor vessel and whether that life could be extended by lowering reactor power or pressure or by warming the vessel to anneal out the damage. According to this committee's assessment, in the most conservative estimate, 3.7 years of life are left in the HFIR vessel. If we take advantage of all allowances in NRC codes, the vessel has 8 years left.

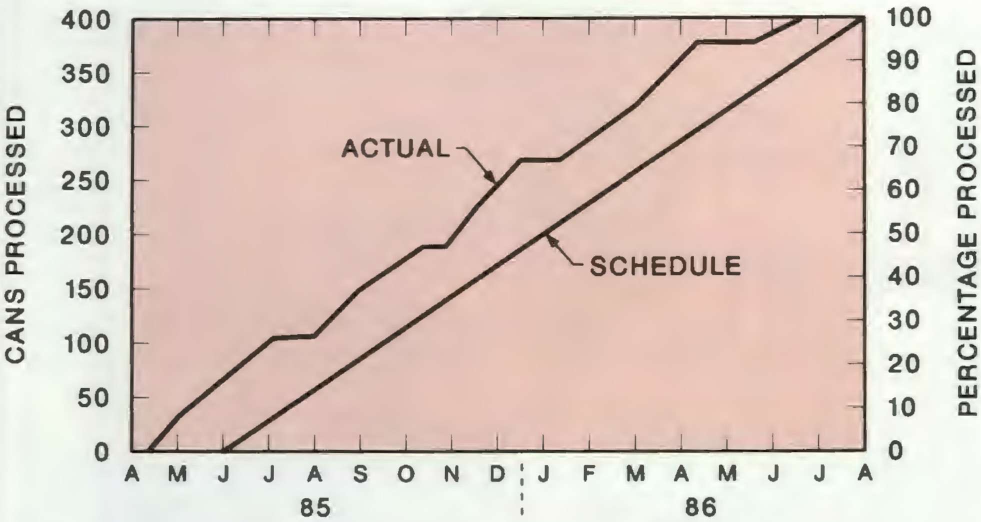
DOE has formed eight teams from local and national headquarters to investigate the embrittlement problem, operational safety, and management of the HFIR. ORNL must be responsive to these teams by providing requested information and complying with new requirements. Because we have been less than excellent in our surveillance and testing, DOE committees may raise other questions such as "What other jobs did you not do correctly?" Trauger's committee has already identified 11 requirements that should be satisfied and made 18 recommendations for remedial action. I'm sure outside teams will find other items that we need to address. The HFIR will also be reviewed by the National Academy of Sciences.

***ORNL's new Robotics and Intelligent Systems Program has a growing number of collaborators and customers. Already its technology developments have graced the covers of two magazines—*NASA *and* Robotics World.**

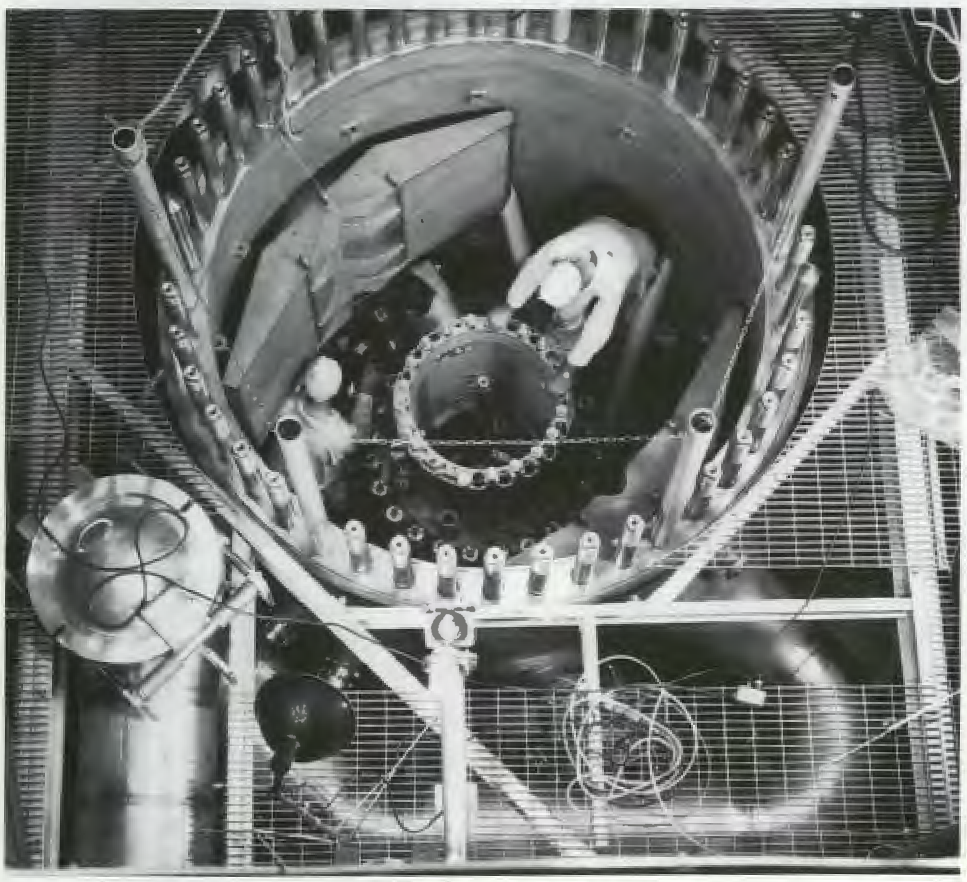
We still do not know exactly when the HFIR will be operating again. The 3.7- to 8-year span gives us adequate time to replace the embrittled vessel with a new one, which we intend to do. In the meantime, we are looking at options for minimizing the impact of the neutron-induced damage and reversing the embrittlement. We hope to come up with a technically sound basis for the option selected and the plan for restart.

The major impacts of the extended shutdown have been

• Loss of beam time for neutron-scattering users
• Delay in use of the new expanded Neutron Activation Analysis Facility at the HFIR.
• Change of plans for performing scheduled experiments in irradiating candidate materials for fusion reactors in collaboration with the Japanese Atomic Energy Research Institute
• Transfer of production of heavy elements for research and isotopes for medical and industrial uses to other reactors, including the Oak Ridge Research Reactor
• Availability of time for replacing two remaining heat exchangers in the HFIR—the only positive impact.



The Consolidated Edison Uranium Solidification Program converted a metric ton of fissile liquid to an inert solid for permanent disposal.



A look at HFIR fuel elements.

Summary and Outlook

As we plan ORNL's future role in national scientific research, we must assess our strengths, capabilities, relevance to national missions, and ability to innovate. We must also try to predict the future so we can determine where ORNL can fit into the long-term R&D picture. Thus, our Program Planning Office has developed a 15-year strategic view to guide our planning.

Between now and the beginning of the next century, we foresee the following:

- **A tightening of global energy supplies**. Currently, the United States is in the midst of an energy glut. Only about 20% of DOE's work is devoted to energy; the rest of its programs are related to weapons.
- **A renewed priority for energy R&D**. Because U.S. petroleum imports are increasing and low oil prices discourage exploration for new domestic reserves, concerns about a major interruption in oil supplies to the United States will mount. Thus, energy R&D will once again be emphasized. ORNL must try to perform appropriate research so that when that time comes, we are prepared to contribute the best way we can.
- **An increased U.S. effort to develop technologies to restore global market competitiveness and redress the international trade imbalance**. ORNL has been moving in this direction in recent years by increasing our emphasis on technology transfer through consulting and startups of spinoff businesses, collaboration with industry, and granting of exclusive licenses to private firms desiring to market ORNL-developed technologies. We are working with industrial consortia to expedite the transfer of R&D results to help create new jobs and products, thus helping the economy and the country's competitive position. Examples are CAMDEC and a group led by Bill Appleton to ensure that the nation's semiconductor industry receives the latest results of research on electronic materials at ORNL's Surface Modification and Characterization Collaborative Research Center.

• **Increased cooperation between national laboratories and industry.**
• **Re-emergence of liquid fuels as the central energy issue.**
• **A growing demand for improved waste technologies.** On February 3–5, 1987, the first DOE Oak Ridge Model Conference was held; about 400 people attended it. The purpose of the conference was to involve industry, universities, and other laboratories in collaborating with Oak Ridge researchers to develop innovative solutions to the management of radioactive and hazardous chemical wastes in Oak Ridge—solutions that could be applied or adapted to waste problems throughout the nation. The goal is to make Oak Ridge the model for the nation because innovative waste management techniques are being developed and demonstrated here.

In summary, energy, global competitiveness, and waste technology will be the long-term focus for national R&D.

For the near-term R&D focus, we must take into account some drastic changes that have occurred recently in energy R&D funding. DOE funding for nuclear power technology has declined from about $500 million in 1980 to about $75 million this year. ORNL's funds from DOE for civilian reactor technology have dropped from about $50 million in 1980 to $13 million this year. In short, DOE funding for nuclear power has declined by a factor of 10 and ORNL funding has declined by a factor of 5.

ORNL used to be thought of as a nuclear energy laboratory, a facility whose main mission was fission. That obviously is not the case now. The $13 million we get for reactor R&D is only 3% of ORNL's budget. By contrast, our budget for energy conservation this year is about $30 million, half of DOE's entire budget for nuclear fission technology. In other words, the emphasis in energy research has changed rather drastically in recent years.

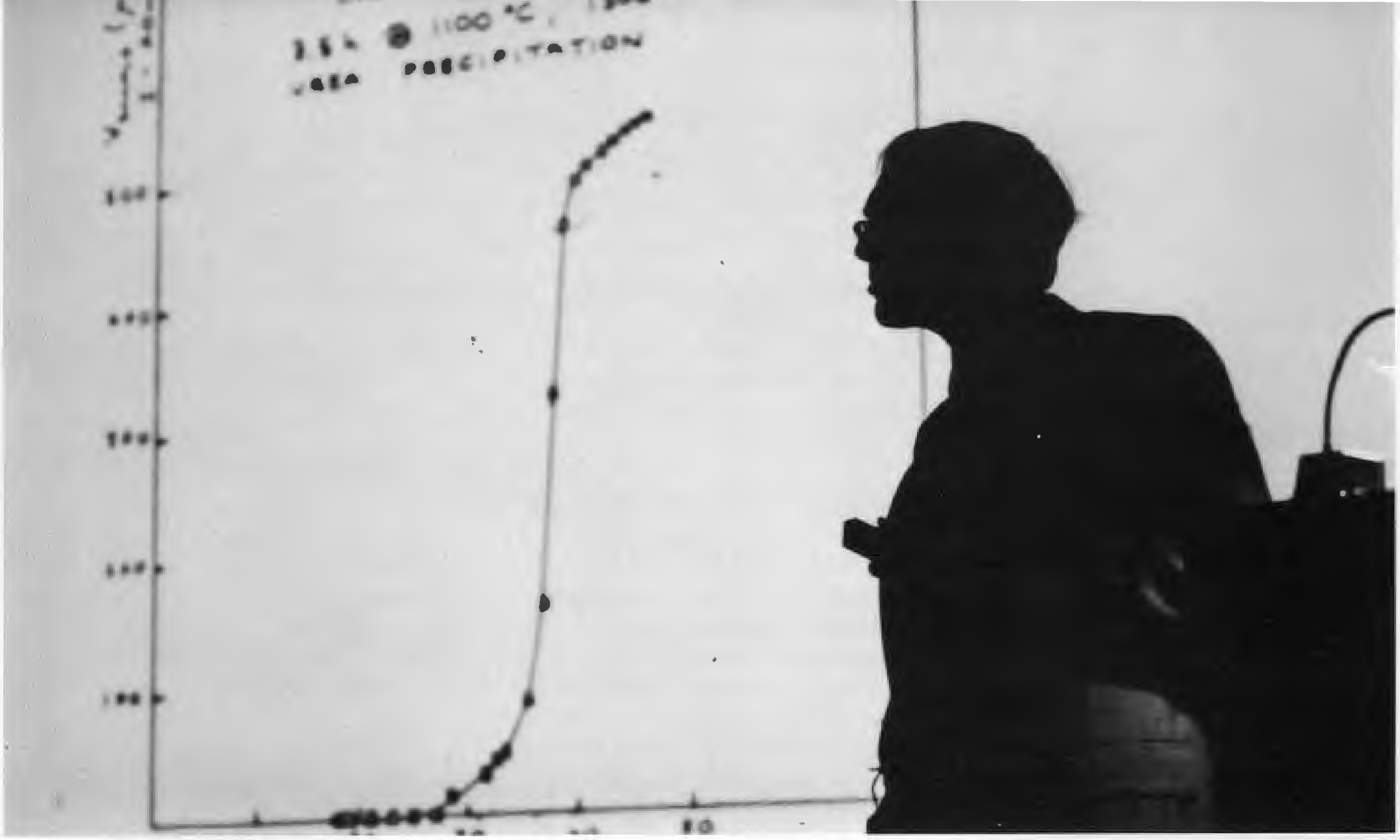
Babette Norris, technician at ORNL's Waste Examination Assay Facility, loads a waste drum onto the drum turntable of the segmented gamma scanner, which is used to help identify and quantify any transuranic wastes in waste drums.

The future direction for fusion research will be to build another large toroidal machine called the Compact Ignition Tokamak at Princeton University. Our Fusion Energy Division will be heavily involved with the technological aspects of that project. We have also been assigned responsibility for helping to develop several other major systems and are expected to receive about $60 million to do this work over the next few years. We also anticipate having a substantial role in the international Engineering Test Reactor (ETR) project; ORNL's work will amount to about one-third of the U.S. effort. The ETR is the focus of the next major international collaborative effort in fusion energy; besides the United States, the participants will be the European Community, the Soviet Union, and Japan.

In the area of advanced nonnuclear energy systems, ORNL will focus on energy conservation, environmental control methods, and materials R&D. Funding for the basic energy sciences, the "healthy" part of DOE's mission, should remain constant.

Environmental and health effects R&D will continue to grow at ORNL, not because DOE has increased funding in these areas, but because many other agencies have committed funds to ORNL's life sciences research. We should receive continuing support for basic nuclear physics, defensive weapons, the Waste Management Technology Center, and technology transfer.

In summary, ORNL's budget will be constant with slight growth because of diversification—that is, our ability to branch into other



research areas and attract other sponsors (work for others). The increased number of our customers helps us survive decreases in DOE funding and get a bigger share of the smaller R&D pie.

In our planning, we have identified **two new initiatives**—that is, projects using our expertise that are initially funded internally but show promise for receiving substantial support from DOE and other external sponsors because they meet national or other needs. The two new initiatives are the **Advanced Control Test Operation**, a major center for the development and testing of advanced digital control technology and artificial intelligence for commercial, research, and military reactors, and the **Waste Management Technology Center**, which will develop and test technologies for treating, storing, and disposing of TRU, low-level, hazardous, and mixed wastes in support of the Oak Ridge Model goal. Two continuing initiatives are the ANS (formerly the Center for Neutron Research) and the Heavy Ion Storage Ring for Atomic Physics, or HISTRAP, an advanced facility for the study of the atomic physics of multicharged ions.

The first two Director's Awards were given to the Fusion Energy Division and to the materials science divisions—M&C and Solid State. This year I am giving the Director's Third Annual Award to a division that should probably be called the Phoenix Division.

Last year when I gave the State of the Laboratory address, I predicted that this division's budget would decline greatly, possibly to zero. However, this division proved me wrong by negotiating a multiyear agreement with Japan in March 1986 for $25 million and persuading DOE to match this amount. In collaboration with other ORNL divisions and in conjunction with RISP, the Fuel Recycle Division diversified by attracting funds from NASA and the U.S. Army to adapt the Advanced Servomanipulator (ASM) developed here to these customers' needs. Because of ORNL's work in improving ASM to make an adroit remotely operated manipulator, NASA reached a 1989 milestone three years earlier. The division also made its mark in technology transfer by making ASM robotic arms available to industry on a cooperative basis. Finally, the division reached several important landmarks by developing centrifugal contactors for the key chemical steps required in separating usable nuclear fuel from waste fission products in spent fuel elements.

For making a great comeback, for rising from the ashes, for proving how wrong I was, and for making all these contributions in one year, I give the Director's Award to the Fuel Recycle Division, whose director is William D. Burch.

I congratulate the entire staff of ORNL for a job well done in 1986. ornl

awards and appointments

Fred R. Mynatt, former associate director for Nuclear and Engineering Technologies, has been named associate director for Reactor Systems. In this newly created position, he has primary responsibility for ensuring the safe restart and operation of all ORNL reactors, which were shut down by DOE order March 26, 1987. Mynatt also is responsible for timely and complete compliance with all of the recommendations of the several committees, both internal and external, that have recently reviewed ORNL's reactor operations. He also oversees reactor-related efforts (formerly in ORNL's Operations Division) that have been incorporated in a newly created Research Reactors Division and work associated with the Advanced Neutron Source (previously called the Center for Neutron Research).

J. Robert Merriman, formerly Energy Systems vice-president for Enrichment Business Services, has been named associate director for Nuclear and Engineering Technologies at ORNL, replacing Fred Mynatt.

A. L. (Pete) Lotts has been named director of the newly created Research Reactors Division.

T. L. (Tom) Dahl has been appointed head of the Reactor Operations Section of the Research Reactors Division. **Reuben McCord** has been named senior technical advisor to Dahl.

Henry B. Piper has been named manager of ORNL's new Office of Operational Safety.

Claud E. Pugh has been appointed the U.S. member of the International Atomic Energy Agency's Working Group on Reliability of Reactor Pressure Components.

The Federal Laboratory Consortium has presented Awards for Excellence in Technology Transfer to **Karl Haff, Andy Tompkins, Daniel Ramey**, and **Eugene Newman** for transferring radioluminescent light technology to government, state, and private users and to **Terry Tiegs** and **Paul Becher** for transferring silicon carbide whisker-aluminide technology to industrial manufacturers of cutting tools.

Charles D. Scott received the 1987 Nathan W. Dougherty Engineering Award from the University of Tennessee at Knoxville.

Jerry Swanks has been named the Outstanding Alumnus for 1987 of the University of Tennessee College of Engineering.

Steven V. Kaye is interim director of the Biology Division. He will resume his duties as director of the Health and Safety Research Division (HASRD) after a permanent director of the Biology Division is appointed. **Phil Walsh** is interim director of HASRD.

Steven V. Kaye, Richard M. Rush, and **Charles D. Scott** have been elected Fellows of the American Association for the Advancement of Science.

John S. Cook has been named coordinator for ORNL's Structural Biological Research activities.

David R. Rupert has been named coordinator for the Historically Black Colleges and Universities Program in ORNL's University Relations Office.

A 1968 paper "Evidence for excision of ultraviolet-induced pyrimidine dimers from DNA of human cells in vitro," coauthored by **J. D. Regan**, has been named a Citation Classic by the Institute for Scientific Information. The paper was published in the *Biophysical Journal*.

J. W. Hall is a co-recipient of the Frank R. Blood Best Paper Award of the Society of Toxicology. His co-authors are J. Y. Kao, formerly of ORNL's Biology Division, and F. K. Peterson of the University of Tennessee Memorial Hospital Research Center. The paper is entitled "Skin penetration and metabolism of topically applied chemicals in six mammalian species, including man: An in vitro study with benzo(*a*)pyrene and testosterone."

In the 1987 Computer Graphics Contest sponsored by the Integrated Software Systems Corporation Users Group, five artists in the Information Resources Organization of Energy Systems were winners. **Bruce Johnston** received the 1987 grand prize, a gold medal, a bronze medal, and two honorable medals. Other recipients were **Morris Slabbekorn**, a bronze medal and an honorable medal; **Thomas Henry**, a bronze and two honorable medals; **Peggy Brooks**, two bronze medals; and **LeJean Hardin**, a silver medal and a bronze medal.

L. C. Emerson has been elected secretary of the Plasma Science and Technology Division of the American Vacuum Society. ornl

BOOKS

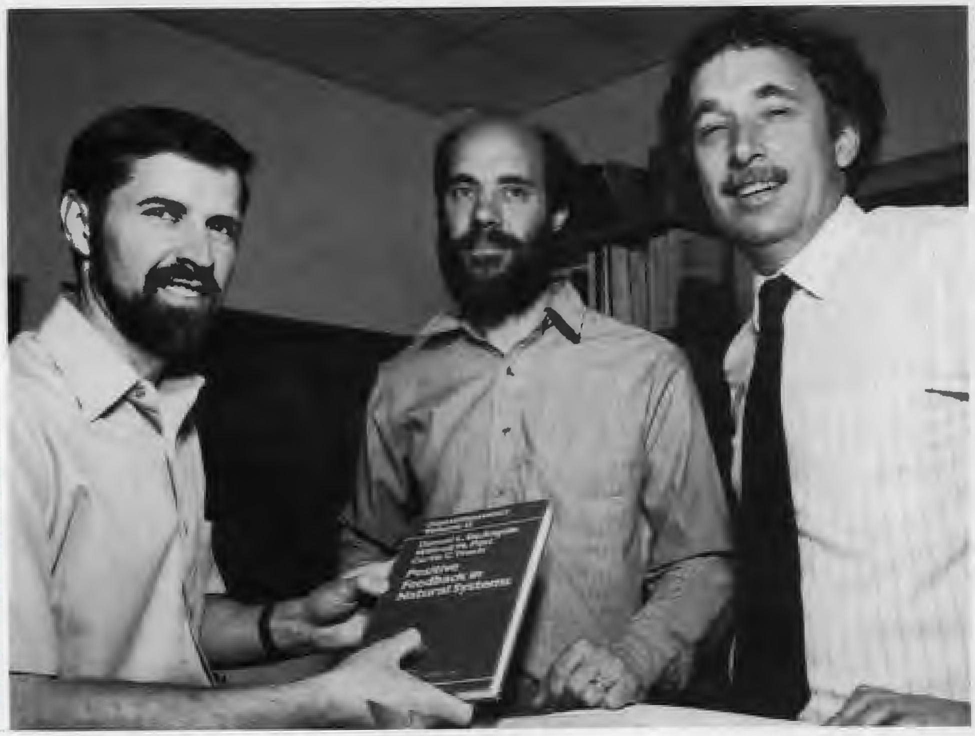
Biotechnology Risk Assessment, *ed. J. Fiksel and V. T. Covello, Pergamon Press, New York, 1986. Reviewed by Terry Donaldson, coordinator of the Oak Ridge Bioprocessing Research Facility User Resource and manager of Advanced Technology Programs in the Chemical Technology Division.*

For better or worse, the manufacture and marketing of the products of biotechnology are being restrained because of concern about the impacts of releasing genetically engineered microorganisms into the environment. This concern was voiced strongly this past spring when tests began on an engineered bacterium that promises to protect crops from frost damage. In 1984 the National Science Foundation (NSF) started a study to determine whether existing scientific methods are suitable for analyzing the risk to the environment of the release of genetically engineered microorganisms. A group of experts was asked to prepare review papers on biotechnology risk assessment—the basis for this book.

The eight chapters include a detailed presentation of the technical issues and the conclusions of the study (Chapter 1); description of the methods used to determine the important properties of microorganisms and to track their presence and behavior in test systems and in the natural environment (Chapters 2 and 8); and discussions of human exposure to the effects of bacteria and viruses (Chapters 3 and 4); ecological consequences, systems ecology concepts, and ecological modeling (Chapters 5 and 7); and the transport and fate of microorganisms in the environment (Chapter 6). For the most part, the chapters are readable and comprehensive and cite specific documented phenomena. Research needs are identified, as perceived by the individual authors. Readers unfamiliar with risk assessment or biotechnology may benefit most from reading the Preface and Chapter 1, which provide a good introduction to and overview of the issues.

One-third of the 12 expert authors are from Oak Ridge National Laboratory (Larry Barnthouse and Tony Palumbo of the Environmental Sciences Division) and the University of Tennessee, Knoxville (Gary Sayler and Gary Stacey). Such recognition of our local expertise in biotechnology risk assessment is both satisfying and appropriate. Researchers in environmental biotechnology at ORNL and UTK have been at the forefront of this important field and will continue to be among the leaders through new collaborative research programs now under way.

The two-page preface to this volume concisely presents the essence of the risk assessment problem and the conclusions of the NSF study. Microorganisms are capable of mutating, multiplying, and adapting to their environment and are thus significantly different from purely chemical contaminants in the environment. Current understanding of the behavior of microorganisms in open, natural environments is based on observations of a significant but limited number of special cases. General ecological models exist but lack sufficient validation to be useful for predicting the behavior of microbial ecosystems. A generic approach to risk assessment for release of genetically engineered microorganisms is desirable but not yet possible. In the meantime, empirical methods such as microcosm testing are indispensible in attempting to assess risk.



Donald DeAngelis (left), a native of the Washington, D.C., area, is a senior scientist in ORNL's Environmental Sciences Division (ESD). He came to ESD in 1972 after receiving a Ph.D. degree in plasma physics from Yale University. He spent a year as research associate in the Institute for Soil Science and Forest Fertilization of the University of Gottingen, Federal Republic of Germany, returning to ORNL in 1974. Since then, he has worked in many areas of population and ecosystem theory. In addition to the book *Positive Feedback in Natural Systems,* coauthored with Mac Post and Curtis Travis, DeAngelis has also coauthored (with R. V. O'Neill of ESD) the book *A Hierarchical Concept of Ecosystems.*

Wilfred "Mac" Post (center) is an ESD research staff member. A native of Allentown, Pennsylvania, he received a B.S. degree in mathematics and an M.S. degree in botany from the University of Wisconsin and a Ph.D. degree in ecology from the University of Tennessee. Since joining the ORNL staff in 1980, he has worked in several areas of population and ecosystem ecology. Currently his research involves the study of element cycling, particularly the global cycle of carbon.

Curtis Travis (right) is coordinator of the Office of Risk Analysis in ORNL's Health and Safety Research Division. He has a Ph.D. degree in mathematics from the University of California at Davis and has been involved in the field of risk analysis since coming to ORNL in 1976. He is editor of the journal *Risk Analysis* and is a member of the Science Advisory Board for the U.S. Food and Drug Administration. The three authors received 1987 Publication Awards from Martin Marietta Energy Systems, Inc., for their book.

Positive Feedback in Nature

By DONALD DEANGELIS, WILFRED POST, and CURTIS TRAVIS

"Positive feedback" and "negative feedback" are terms that, like "inertia," "entropy," and "the uncertainty principle," have passed from science and engineering into the common vocabulary—not always with complete faithfulness to their precise technical meanings. For the purpose of this article, we need to be rather precise in our definition of positive feedback to accurately convey its importance in ecology—the study of the interrelationships among plants, animals, and their environment.

Let us start, however, by defining negative feedback, an easy concept to grasp because most people are familiar with thermostats or similar devices. A thermostat regulates temperature to keep it close to some "set point," for example, 64°F (18°C) inside in the winter. When room temperature falls a few degrees below 64°F (18°C), the heat is automatically switched on, and when the temperature climbs a few degrees above 64°F (18°C), it is shut off again. The important concept here is that any deviation from the set point is counteracted. By definition, negative feedback occurs in a system when the deviation of a variable (room temperature, in our example) from a set point calls forth actions that counteract that deviation.

Amusing Examples

An often used example of positive feedback is a thermostat having crossed wires. A related example might be that of a

husband and wife who have individual thermostatic controls for their electric blanket. Suppose the husband prefers a cooler temperature than the wife and suppose also that the controls have been switched accidentally. If the husband feels too warm, he will turn down "his" thermostat, inadventently lowering the temperature of his wife's half of the blanket. She will react by turning up "her" thermostat, further raising the temperature of her husband's half of the blanket, and so on.

A more familiar example of positive feedback is the "cocktail party effect." Suppose you are at a cocktail party or some other indoor gathering where small groups of people are chatting. Early in the party, when the crowd density is low, people can converse normally. However, as more people arrive and the room becomes crowded and noisy, people eventually speak louder to be heard. As a result, the background noise increases, making it even harder for conversation to be heard. People speak even louder, further raising the general noise level. Soon everyone must shout to be heard. In this case, a noise threshold is passed, after which positive feedback between individual voices and the general level of noise in the room rapidly increases the decibel level. By definition, positive feedback occurs in a system when the initial deviation in one variable calls forth actions that amplify this deviation.

The above examples of positive feedback are amusing, but they may leave the impression that positive feedback is a destabilizing and undesirable phenomenon, harmful to our ears, our energy bills, and our marriages. This impression is strengthened by some of the contexts in which positive feedback is studied. Positive feedback occurs in many types of destructive events, from uncontrolled chemical and nuclear chain reactions to a variety of medical situations in which an injury to or disease in one part of the body indirectly causes damage in some other organ, which, in turn, aggravates the original disorder.

Ecologists have increasingly come to appreciate the positive feedback processes that occur in ecosystems. These processes are self-amplifying and promote ecological change as well as biological production and diversity. Positive feedback is involved in coevolution, ecological succession, insect and disease outbreaks, and many other natural phenomena.

Traditional View

Perhaps the association of positive feedback with such vicious cycles has influenced the traditional view of biologists and ecologists that negative feedback, or homeostasis, is more basic to natural systems. This view that a "balance of nature" exists and that deviations in the levels of natural populations, for example, are sooner or later corrected for by negative feedback, has permeated the writings of naturalists since the 1700s. (Before the 20th century the word feedback was not in use, but scientists and economists understood the concept.) Until recently, much ecological research was concerned with identifying the negative feedback mechanisms that tend to preserve ecosystems despite their continual buffeting by disturbances.

Given this heritage in ecology, it may seem odd that we have written the book *Positive Feedback in Natural Systems*. Actually, our ideas are not as revolutionary as they might first appear. Many ecologists have changed their thinking about feedback over the past 20 years. The idealized view of a balance of nature has given way to the idea that this balance is often only temporary and tenuous and that, even in the absence of human influence, both short- and long-term processes of change are

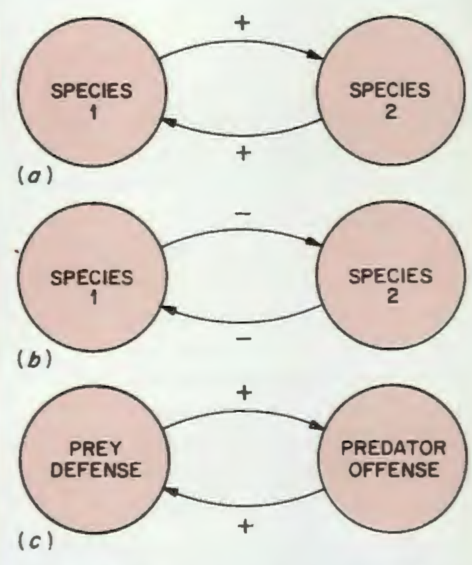
important features of the pattern of nature.

When the idea of writing the book occurred to us, we were each individually doing work in different areas of ecology in which positive feedbacks seemed to play a significant role. These areas are coevolutionary theory, mutualistic behavior, and disease and pest outbreaks. We were soon collaborating (a very productive form of positive feedback) and, as we broadened our research, we realized that positive feedback is a common thread that runs through many ecological phenomena. The similarities of our work became especially apparent when we discovered that many of the positive feedback phenomena could be analyzed using a special mathematical approach known as M-matrix theory. Our book systematically organizes many examples of positive feedback, starting from simple physical systems and culminating in phenomena at the complex, ecosystem level. The research described in the book was supported by the National Science Foundation's Ecosystem Study Program.

Coevolution

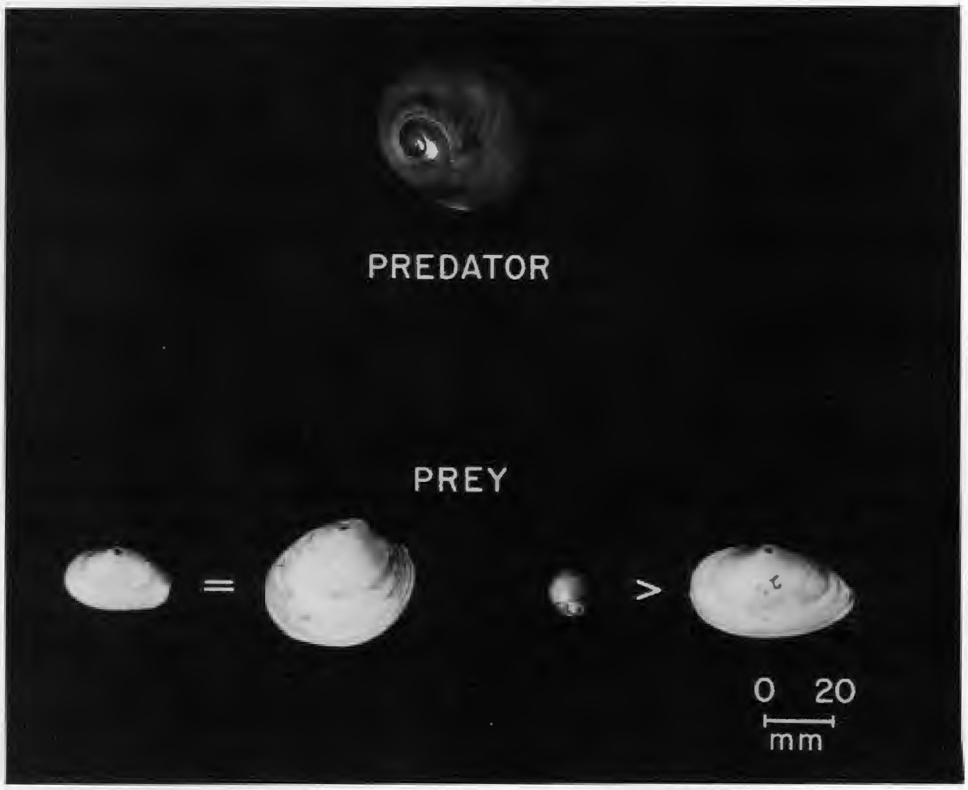
One important way in which positive feedback has shaped the biological world is through its role in evolutionary change. It is conspicuously present in cases of coevolution. Coevolution is an evolutionary change in a trait or traits (e.g., body size and visual acuity) of one species population that causes an evolutionary change in traits of another species population, followed by feedback that causes further changes in traits of the first species population, and so forth. Coevolution is generally assumed to be a very slow process, requiring thousands or tens of thousands of years for measurable changes to occur. A special class of this process is the coevolutionary "arms race" believed to have occurred between various species lineages through time.

One case that we have studied in detail mathematically (with Professor Jennifer Kitchell, a paleontologist at the University of Michigan) is the interaction between certain bivalves (two-valved shellfish such as clams and oysters) that live in sea sediments and predatory snails that feed on them by drilling through their shells. If thicknesses of shells vary slightly in a population of bivalves, those with thinner shells will be, on the average, more vulnerable to the snails. As a result, natural selection

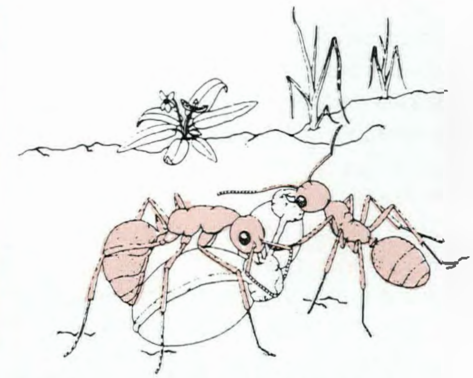


Three simple types of relationships in ecology that involve positive feedback: (a) mutualism, (b) competition, and (c) coevolutionary arms races. Note that the product of signs in the loop is always positive.

on bivalves by snail predation should favor the survival and reproduction of bivalves that have genes for producing slightly thicker shells. Because of this evolutionary tendency, thicker-shelled bivalves should eventually dominate the bivalve population. However, natural selection also acts on the snails. Snails having genes for above-average growth usually become large enough to drill into the thicker-shelled bivalves. These



In one example of coevolutionary arms races, the increasing thickness of bivalve shells stimulates an increase in the size of marine snails, the bivalve's predators. Positive feedback can shape the biological world through its role in evolutionary change.



*In this example of mutualism, ants (***Formica podzolica***) gather and disperse seeds of* **Viola nuttallii.** *If the seeds were not discovered and dispersed by the ants in a few hours, the seeds would be eaten by predators. The ants feed only on the elaiosomes that they remove from the seeds. In the background is a mature flowering plant grown from an ant-dispersed seed. Figure from Andrew J. Beattie's* **The Evolutionary Ecology of Ant-Plant Mutualisms.**

larger snails will survive longer than the small ones and will therefore leave more offspring, resulting in an increase in snail size in the population over time. This coevolutionary process is an example of positive feedback, because the increasing size of the bivalve acts to select for larger snails, which stimulates a further increase in bivalve shell thickness. Fossil evidence indicates that this form of positive feedback may have occurred for certain snail and bivalve lineages in the past.

Most examples of coevolution, however, are not as simple as outlined above. Coevolutionary arms races operate within certain constraints presented by the organisms' physiologies and by various environmental factors. Not every biological interaction will result in an arms race, and, when such a race occurs, it will slow down before it reaches ridiculous extremes that would make the organisms involved maladaptive in other ways.

Mutualism

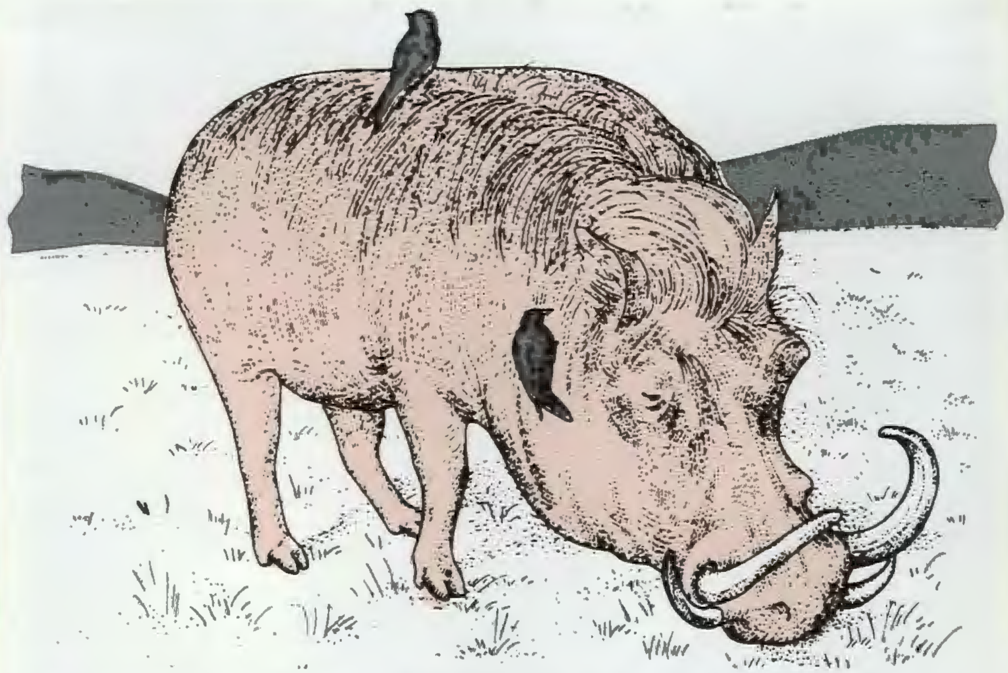
Another type of ecological interaction, in which two or more species benefit each other, is "mutualism." Mac Post has developed mathematical theory for large systems of mutualistic species. So many examples of mutualism exist in nature that it would be difficult to even list the general types here, let alone the specific cases. One of the most well known examples is that of flowering plants and the animals that pollinate them. The positive feedback inherent in this relationship is easy to see. Any increase in the number of flowering plants of a particular species will favor an increase in pollinators (e.g., bees) that derive nourishment from the flowers of that plant species. Conversely, an increase in bee density will increase the percentage of plants pollinated and seeds produced. The situation can be complicated if particular species of bees pollinate several plant species and some plant species support several species of bees, involving a whole web of interacting species. The extinction of one of these species could, under some circumstances, have little effect on other species; under other circumstances, it might have a ripple effect, influencing the numbers of many other species. By expressing these relationships mathematically, Post has developed a way to examine the effect of extinctions and other perturbations on mutualistic systems.

Disease and Pest Outbreaks

Positive feedback theory also allows for the mathematical treatment of reinforcing effects acting between spatial regions. An area of ecology where spatial heterogeneity is important is epidemiology, which is concerned with the outbreak and spread of diseases and pest organisms. Curtis Travis has contributed to developing mathematical models in this area.

The spread of an epidemic or pest is easily recognized as a phenomenon involving positive feedback. A local outbreak of bark beetles in a forest area, for example, may self-extinguish if the density of trees susceptible to beetle attack is low. However, the combination of a sufficiently large initial outbreak and a high enough density of susceptible trees will make the spread of the pest almost inevitable. The infestation will often proceed at an almost explosive level, because each increase in the size of the area infected by the pest results in an increased production of pest offspring that can disperse to new areas.

An historically interesting example of positive feedback in epidemics is smallpox. From 1958 to 1966 the World Health Organization implemented a program for worldwide eradication of smallpox through vaccination. It was thought that vaccination of 80% of the population would eliminate the disease; this assumption turned out to be erroneous. In spite of vaccination of 95% of the population of Java, smallpox was still not eradicated there. The disease persisted in a small percentage of villages because it was transmitted from village to village by traveling contacts. The disease continued to escape eradication both spatially, by continually being transported to unvaccinated pockets of the population, and temporally, by returning to a particular location through travelers every few years. Thus, positive feedback among residual pockets of smallpox kept the disease present longer than was initially expected. (Smallpox was successfully eradicated by 1979 by isolating patients and vaccinating actual and potential contacts.)

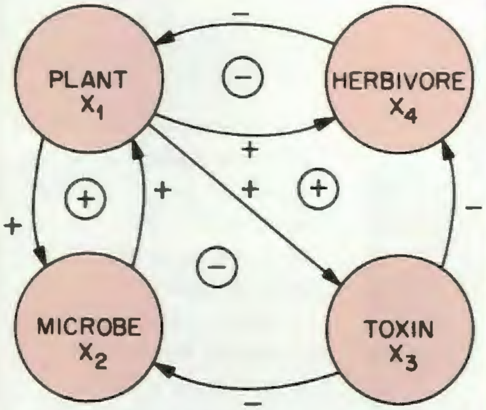


In this example of mutualism, tick-birds feed on the back of the wart-hog and alert the huge animal to approaching predators.

Mathematical models developed to study the thresholds of pest and disease outbreaks can also be used, with some modification, to help determine minimum areas of habitat required to maintain rare species threatened with extinction. Such species often occupy scattered patches of habitat. Random environmental disturbances may cause occasional extinctions on some patches. However, if enough patches exist and are close enough together to allow migration between patches, recolonization of vacant patches can occur rapidly enough to maintain a relatively stable total population level. Mathematical modeling of the resultant positive feedbacks between habitat patches can at least provide a preliminary idea of the viability of the population, which then should be examined by more detailed simulation models and field studies.

Ecosystem Studies

The importance of applying mathematical modeling to the phenomenon of positive feedback is even more evident in the study of whole ecosystems. Feedback interactions among species that make up an ecosystem can be extremely complex. Consider a very small part of an ecosystem, such as a plant that is fed on by an herbivorous insect or mammal. This example illustrates a negative feedback loop—the plant has a positive effect on the grazer, but the grazer has a negative effect on the plant. However, the plant might manufacture a toxin that inhibits the grazer, thus creating a positive loop favoring the plant. The loop works this way: over a long period, creation of the toxin decreases the number of grazers; decrease in grazer density increases plant productivity; the increase in plant productivity increases the amount of toxin the plant can produce; and so forth. However, the toxin produced by the plant may also



Feedback loops between a plant, an herbivore grazer, the toxin produced by the plant, and a soil microbe important to the plant.

damage a soil microbe that helps the plant by producing nitrogen compounds the plant can use. Thus, a negative feedback loop detrimental to the plant may result.

How do we compare the relative effects of the feedbacks in this case? The mathematics of positive feedback provides a framework for such comparisons. A framework alone, however, is insufficient. Quantification of the interactions mentioned, and any others that are to be considered, must be achieved before mathematical models can provide more than a heuristic understanding of ecological systems.

Constructive Role for Positive Feedbacks

Positive feedbacks should not be thought of as only disruptive of ecological systems. A broader view assigns positive feedback a constructive role as well. Our research has disclosed that many ecological systems have heterogeneous arrays of positive and negative feedbacks. Positive feedback can often be viewed as the engine of change and development.

The role of positive feedback in development and change can be seen at many levels of biological complexity, and morphogenesis in simple organisms is a good place to start. Researchers studying such phenomena as the regeneration of lost body parts (e.g., tentacles) in simple multicellular organisms have developed mathematical models of this process. An activator substance, experimentally determined to diffuse within body tissue and carry morphogenetic information, is a main component of such models, along with a positive feedback mechanism to accelerate formation of more activator substance; the models also simulate an inhibitor substance that suppresses the activator (negative feedback). Fascinating things occur in model simulations—an initially homogeneous mixture of activator and inhibitor substances can change into a spatial pattern of discrete stable regions of high activator concentration, representing, in the models, the analogous patterns of regeneration that occur in the organisms. The generality of this type of model is so great that variations of it have been used to describe such phenomena as the formation of regular spacing among termite nests in tropical savannas.

On the level of ecosystems, we and other ecologists are exploring ways in which positive feedbacks influence the phenomenon of succession. Consider for example, the gradual biological colonization of a barren sand dune. Pioneer plants like marram grass first establish a tenuous foothold, both stabilizing the sand and concentrating nutrients. This action facilitates the invasion of more plants, which improve conditions enough to allow a still more diverse assemblage of plants and animals to flourish.

On a much larger scale, the evolution of the earth's biosphere exhibits a type of positive feedback in which each evolutionary step opens up possibilities for new and more complex changes. As is typical of positive feedback processes, biosphere evolution has been accelerating with respect to complexity. Whereas it took about 2500 million years after the appearance of the first simple procaryotic cell for more complex eucaryotic cells to evolve (about 1000 million years ago), the emergence of metazoans followed in only another 300 million years or so. Since that time, major evolutionary milestones (e.g., vertebrates, the amniotic egg, homeothermy, mammals, primates, humans) followed one another at shorter and shorter time intervals. Human cultural evolution has accelerated similarly. About two million years passed between the use of simple hand-held stone digging implements and the perfection of stone tools. From the end of the Stone Age (about 8000 years ago), however, it took only about 5000 years for bronze tools to be replaced by steel tools. We are all familiar with the accelerating pace of technological change since then.

These facts should lead us to ponder whether the positive feedbacks inherent in our technological culture that are powering its current dizzying rate of change will continue to operate and, if so, where they will take us. Understanding the feedback processes in our biological and cultural worlds is one way we can help steer them in the most beneficial directions. ornl

HTML dedicated April 22, 1987

Through the advanced ceramics research it makes possible, it may increase the competitiveness of the United States in the international marketplace. The state-of-the-art equipment it houses will help develop materials that could be used in highly efficient engines for vehicles and aircraft, parts for solar collectors, and toxic waste decomposers. Its presence at ORNL should help stimulate new capital investment, create new products, and open new jobs in the region.

These expectations were voiced during dedication ceremonies held April 22, 1987, for ORNL's new $19-million High-Temperature Materials Laboratory (HTML). The concrete-and-glass structure, which houses 49 laboratories and 72 offices for ORNL staff members and visitors, is a national user center. In the fall of 1987, the HTML will be open to university and industry scientists for independent research and development as well as collaborative projects with ORNL investigators.

The guest speaker at the dedication was Donna R. Fitzpatrick, DOE assistant secretary for Conservation and Renewable Energy, who also participated in the ribbon-cutting ceremony. Other speakers were ORNL Director Herman Postma; Eugene Helms, General Motors Corporation chief engineer for vehicular gas turbines; David L. Patterson, president of the Tennessee Technology Foundation; Jack Reese, chancellor of the University of Tennessee, Knoxville; and Robert Barlow, Oak Ridge assistant to U.S. Rep. Marilyn Lloyd of Tennessee. Alex Zucker, ORNL associate director for the Physical Sciences, served as master of ceremonies.

Donna R. Fitzpatrick, DOE assistant secretary for Conservation and Renewable Energy, cuts the ribbon at the April 22, 1987, dedication of ORNL's High-Temperature Materials Laboratory (HTML). Looking on are, from left, Ken Jarmolow, Martin Marietta Energy Systems, Inc., president; Vic Tennery, HTML director; Alex Zucker, ORNL associate director for the Physical Sciences, and Herman Postma, ORNL director.

The original proposal for the HTML, made by Tim Reilly in 1977, called for an Institute for the Studies of Materials at Elevated Temperatures. The proposal became a reality ten years later, largely as a result of the "hard work and dedication" at different times of Ted Lundy, Carl McHargue, John Cathcart, Vic Tennery (the HTML director), and Jim Weir and Jim Stiegler, who served as division directors of the Metals and Ceramics Division during this period.

The HTML was designed by the architect Dieter Ritchey Sippel of Pittsburgh (using input from ORNL architect Hanna Shapira, who insisted on an aesthetic appearance). It was built by Blaine-Hays Construction Company of Knoxville. Financial and management support for its design, construction, and operation has come from the Office of Transportation Systems in DOE's Heat Engine Propulsion Division.

DOE orders shutdown of all ORNL reactors

On March 26, 1987, the Department of Energy's Oak Ridge Operations ordered the shutdown of ORNL's four operating research reactors. The decision closed the Oak Ridge Research Reactor (ORR), the Bulk Shielding Reactor, the Health Physics Research Reactor, and the Tower Shielding Facility. The High Flux Isotope Reactor (HFIR) had been shut down since November 14 because of evidence that the 21-year-old pressure vessel had become brittle.

ORO ordered the "safe shutdown" because of concerns about ORNL reactor management and oversight. ORO Manager Joe La Grone said that management deficiencies requiring correction include poor training programs and poor recordkeeping. ORO asked Martin Marietta Energy Systems, Inc., to draw up a plan for improving reactor management and oversight. As soon as ORO-approved corrective actions are taken, the reactors can be restarted. During the first three months after the HFIR and ORR are back in operation, the "technical safety" of the two reactors will be appraised by DOE.

In response to the DOE order, ORNL announced a major reorganization that put a high-level manager specifically in charge of reactor operations. ORNL Director Herman Postma created a new position—associate director for Reactor Systems—and appointed Fred Mynatt, then associate director for Nuclear and Engineering Systems, to this position. J. Robert Merriman, formerly Energy Systems vice-president for Enrichment Business Services, was appointed to fill Mynatt's previous position. Mynatt created the Research Reactors Division and

J. Robert Merriman, ORNL's new associate director.

named A. L. (Pete) Lotts the director.

In his new position, Mynatt is responsible for timely and complete compliance with all of the recommendations of the several committees, both internal and external, that have recently reviewed ORNL's reactor operations. He also oversees the activities of the Research Reactors Division and work associated with the Advanced Neutron Source, a project to design and build a record-high-neutron-flux research reactor, previously called the Center for Neutron Research.

Lotts is responsible for improving the management and operation of all ORNL reactors, for making the improvements necessary for the safe restart of the HFIR, and for the safe operation of all ORNL reactors.

In April 1987 Mynatt expressed the hope that the four reactors shut down in March would be restarted in May and that the HFIR would resume operation at somewhat lower power in September.

DOE team issues report on HFIR

In February 1987, a DOE investigative team reported that oversight and independent review of the HFIR was less than adequate. The HFIR was shut down November 14, 1986, for a prolonged period after it was discovered that the 21-year-old pressure vessel was embrittled by exposure to neutrons from the reactor core.

The team, led by John Rothrock of DOE's Oak Ridge Operations, focused on the reasons for lengthy delays in gathering and analyzing evidence showing increasing brittleness in the reactor's pressure vessel. The team also determined that the monitoring delays caused no harm to ORNL employees, the public, or the environment.

The DOE team called for

- Improved recordkeeping by the HFIR embrittlement surveillance program
- Updated documentation on all aspects of the reactor and its operation
- Closer cooperation between the contractor operating the reactor and the DOE safety and quality assurance organizations
- A more consistent approach for safety reviews by the contractor
- More quality assurance oversight by DOE

Among the key findings of the DOE investigation were:

- Operating contractor personnel (Union Carbide Corporation, the former operating contractor, and Martin Marietta Energy Systems, Inc.) failed to properly monitor embrittlement of the HFIR pressure vessel
- Analyses of steel samples taken from the vessel wall were delayed or incomplete and the results were in an unusable form or were never reported
- Less than adequate oversight and independent review resulted because operating organizations were not required to prove that embrittlement had not occurred or posed no problem

Other investigations of the HFIR are under way or planned by DOE Headquarters, DOE's Oak Ridge Operations, Energy Systems, and the National Academy of Sciences.

Ninth Distinguished Scientist named

An internationally known researcher has accepted a joint appointment as Distinguished Scientist at the University of Tennessee and ORNL.

Georges Guiochon, a French-born scientist considered one of the top analytical-separations chemists in the world, became the ninth appointee in the UT-ORNL Distinguished Scientist Program.

Guiochon, currently professor of chemistry at Georgetown University, came to the United States in 1984. For the past 30 years at Ecole Polytechnique and the University of Paris, he had been a doctoral student, professor, and director of the Laboratorie de Chimie Analytique Physique. His tenure as a member of the UT Department of Chemistry and ORNL's Analytical Chemistry Division begins this summer.

The UT-ORNL Distinguished Scientist Program was established in 1984 to attract to the area a select additional number of scientists of national and international stature.

EPA scientist named to joint ORNL-UT post

Milton Russell, former policy chief of the U.S. Environmental Protection Agency, has accepted an appointment as a collaborating scientist with UT and ORNL.

Russell serves as an economics professor and senior fellow at UT's Energy, Environment, and Resources Center. At ORNL Russell is collaborating with Energy Division researchers in the areas of energy and environmental economics. He works directly with Bob Shelton, head of the division's Energy and Economic Analysis Section.

Previously, Russell had been involved with ORNL programs as a member of the Energy Division Advisory Committee. The appointment is not part of the UT/ORNL Distinguished Scientist Program.

Hollaender Auditorium dedicated

The Large Conference Room in ORNL's Biology Division (Building 9207) was recently dedicated as the Alexander Hollaender Auditorium. The auditorium was named after Alexander Hollaender, the first director of the Biology Division, shortly before his death in December 1986.

Hollaender was Biology Division director from 1946 until 1966. He left Oak Ridge to help found the Council for Research Planning in Washington, D.C.

A pioneer in radiation biology, he was a member of the National Academy of Sciences and was instrumental in founding both the Environmental Mutagen Society and the Radiation Research Society. He received DOE's Enrico Fermi Award in 1983.

ORNL Director Herman Postma (left) and Associate Director Chet Richmond unveil the portrait of Alexander Hollaender that hangs at the rear of the Alexander Hollaender Auditorium, formerly the Biology Division Large Conference Room.

Locally, he was known for organizing the annual Gatlinburg symposia sponsored by the Biology Division for many years and for helping to found the University of Tennessee–Oak Ridge Graduate School of Biomedical Sciences.

Alvin Weinberg, former ORNL director, attributed Hollaender's success as an administrator to "his total confidence that his people were the best in the world. He knew it, and he inculcated that notion into the minds and hearts of every member of the division."

Remedial action program contractor chosen for ORNL

Bechtel National, Inc., of Oak Ridge has been selected as the preferred bidder on a major subcontract to be awarded by Energy Systems for the Remedial Action Program under way as part of ORNL's Environmental Restoration and Facilities Upgrade. The subcontract will cover a remedial investigation and feasibility study of ORNL areas for storing hazardous and radioactive waste.

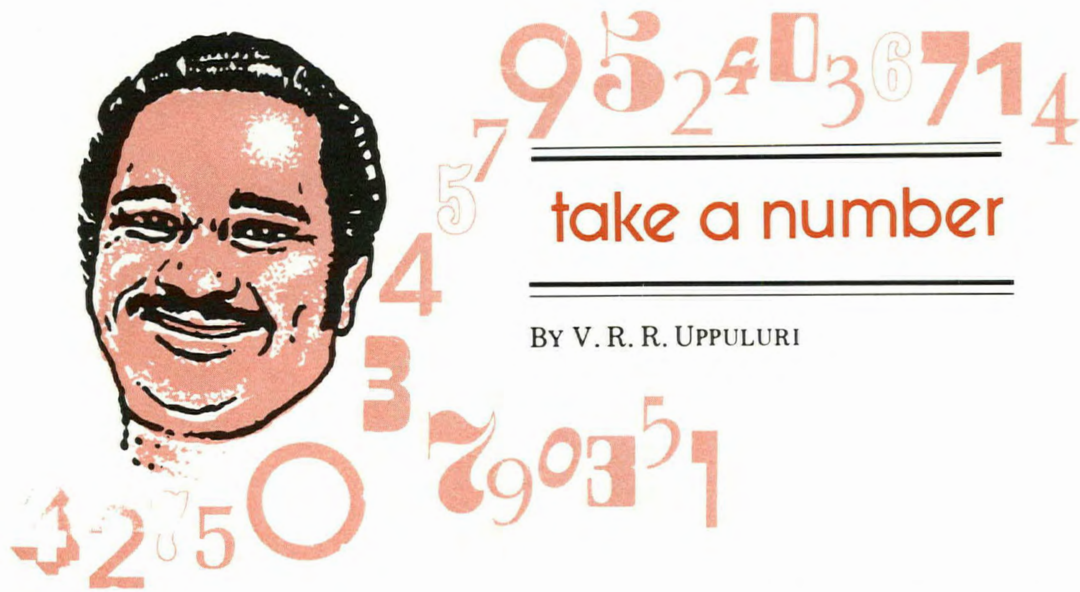
Bechtel will help determine the extent of continuing releases from contaminated areas at ORNL and the corrective actions needed to bring the sites into compliance with state and federal regulations. ORNL's Remedial Action Program, established in 1985, manages about 250 contaminated sites. The program examines the environmental impacts of proposed actions to stop releases, close certain sites, and decommission old facilities.

TECHNOLOGY TRANSFER BRIEFS

DOE waives rights to 20 ORNL inventions

DOE has waived the patent rights to 20 ORNL subject inventions. As a result, Martin Marietta Energy Systems can transfer these technologies for commercial use by negotiating licensing agreements with interested private firms. ORNL developments ready to be licensed are:

- Carbon-free zirconium oxide (ZrO)
- Modified nickel-aluminide alloys
- Servomanipulator
- Remote tong tool catch for the servomanipulator
- Silicon carbide whisker-reinforced ceramic composite
- Improved osmium-191/iridium-191*m* radionuclide generator system
- Rotor and disk system for automated processing and aliquoting of whole-blood samples for analysis in a centrifugal fast analyzer
- Tong actuator servomanipulator
- Master controller for the servomanipulator
- High-temperature modified nickel aluminides
- Method for producing biocatalyst beads
- Method for sintering whisker-reinforced alumina ceramics
- Silicon carbide whisker-ZrO-reinforced mullite ceramics
- Self-aligning hydraulic piston assembly for tensile-testing apparatus
- Multilayered composite of ZrO-bonded ZrO and metal oxide fibers
- Fiber optic coupling
- Biocatalyst beads incorporating an absorbent
- Production of anaerobic biocatalyst beads
- Rotor and disk system for processing whole blood
- Lead-phosphate glass compositions for optical components. ornl



take a number

By V. R. R. Uppuluri

Upside-Down Numbers

The number 2198 has a peculiar property: the sum of the digit farthest to the left (2) and the digit farthest to the right (8) is 10, and the middle digits, 1 and 9, also add to 10. The number 3467 has the same property: 3 + 7 = 10 and 4 + 6 = 10. Such numbers have been given a name by R. E. Kennedy and C. N. Cooper in the March 1987 issue of *Mathematics Magazine*. They call them upside-down numbers because they are analogous to music scores that sound the same when played right-side up or upside down. Thus, the number 34567 is also considered to be an upside-down number even though the middle number must be added to itself to get 10: 3 + 7 = 10 = 4 + 6 = 5 + 5.

Under the number 1000, 19 upside-down numbers exist, and there are 100 upside-down numbers less than 10,000. According to Kennedy and Cooper, no known formula for determining the *nth* number has been found, though specific numbers, such as the 59th upside-down number (5465), have been determined.

Approval Voting

In conventional elections, two or more candidates run for the same office and the voter is allowed to cast a ballot for only one of them. The candidate receiving the most votes is declared the winner.

An alternative form of voting is "approval voting." In this procedure, each voter votes for as many candidates as desired but casts no more than one vote per candidate. Again, the candidate receiving the most votes is declared the winner.

Approval voting has been used in several universities, including New York University, the University of Pennsylvania, and the University of New Hampshire. This method has also been used to select members of the National Academy of Sciences during final balloting and to choose Fellows of the Econometric Society. Recently, the Mathematical Association of America announced that its 1987 elections will be based on approval voting. The strengths and weaknesses of approval voting have been analyzed mathematically in several publications.

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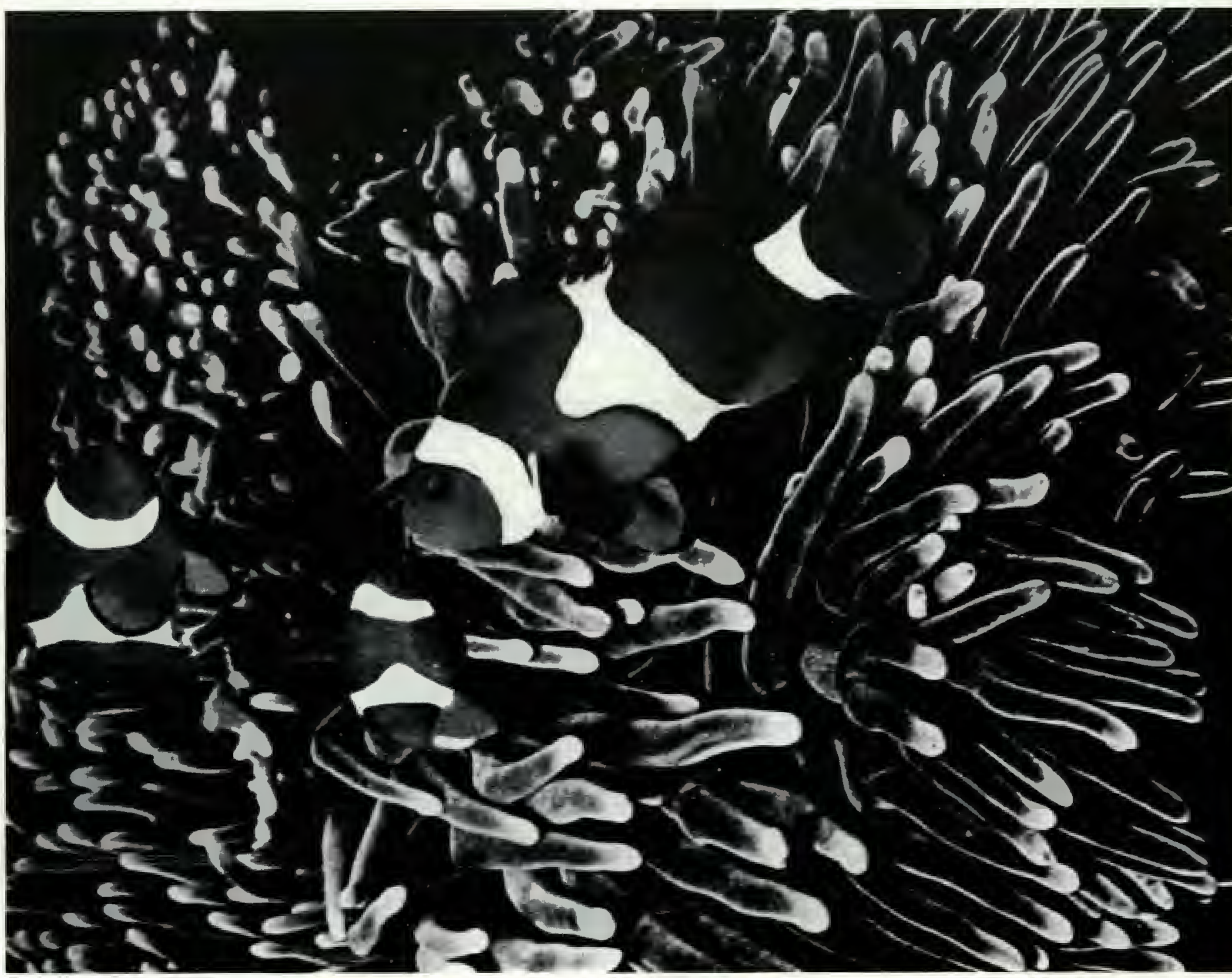

Clown fish living among stinging anemones are protected from predators. The anemones feed off the remains of food that the clown fish fetch and bring back to their habitat. Thus, both species flourish in this example of mutualism and positive feedback. *See article on "Positive Feedback in Nature" on page 32.*