Volume 21 Number One 1988

REVIEW

Oak Ridge National Laboratory

REVIEW

Volume 21 *Number One 1988*

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

ON THE COVER

An assortment of parts, including tubing and ceramic heat-engine components as well as cutting tools, can be made from ORNL's fracture-resistant, whisker-reinforced ceramics, which have been licensed to industry. A special section on "Transferring ORNL Technology" starts on page 2.

With this issue, the ORNL *Review* has a new staff and a new look. Luci Bell has joined the editorial staff as associate editor. Our new designer is Vickie Conner of the Graphics Arts Department at ORNL. She succeeds Bill Clark, the *Review*'s designer for 20 years, who retired at the end of 1987. With our new designer comes a new open design, logo, and format that we hope will appeal to our readers.

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Toward a Technological Commons

Editorial by Alex Zucker

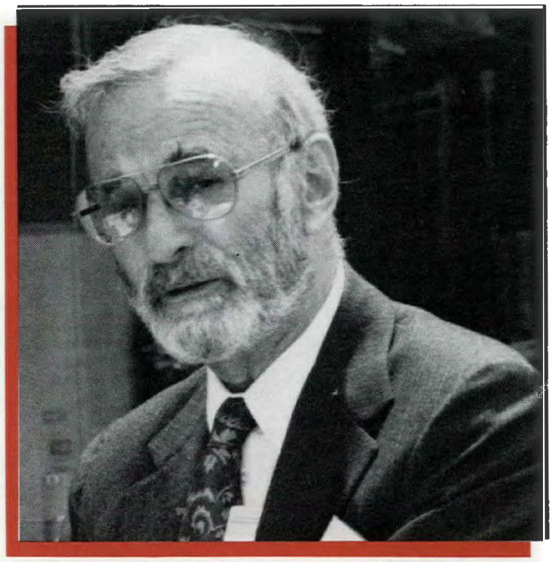
"The role of the national laboratories as a techno-logical commons is beautifully simple."

In colonial times, villages and towns in New England set aside land for pasture on which townspeople could graze their cattle. The land, which was considered to be held in common by all, was called the common or commons. The animals that grazed were individually owned, and the cows were driven home each evening to be milked. It was a good arrangement: the townsfolk had easy and assured access to pasture, the cattle thrived, the towns prospered.

We draw a modern-day parallel with this bucolic situation. Today the U.S. Department of Energy supports eight large multidisciplinary national laboratories. Five are multiprogram energy research laboratories: Oak Ridge National Laboratory, Argonne National Laboratory, Brookhaven National Laboratory, Lawrence Berkeley Laboratory, and Pacific Northwest Laboratories; three are defense program laboratories: Los Alamos National Laboratory, Lawrence Livermore National Laboratory, and Sandia National Laboratories.

Collectively, they spend about $3 billion for DOE work and they employ highly trained people, including superb scientists and engineers. The laboratories are provided with the most modern equipment, and many have built and operate large user-oriented facilities such as accelerators, reactors, light sources, lasers, or other large devices that are unique in this country and the world. They are very productive facilities and attract thousands of users every year. Here then is the germ of a modern "technological commons." All U.S. taxpayers support the national laboratories; they belong to the nation and are indeed engaged in important national work.

However, because there is elasticity in the system, the laboratories could do more to further an emerging national purpose. One such purpose is receiving increased attention under the fashionable name of global competitiveness. The role of the national laboratories as a technological commons is beautifully simple: industry, especially its high-technology component, can use the national laboratories as a super R&D resource to conduct research, develop products, or render special services—activities it cannot carry out



with its own facilities. This flexible system can accommodate ventures by a single corporation or a consortium of several companies in the same field.

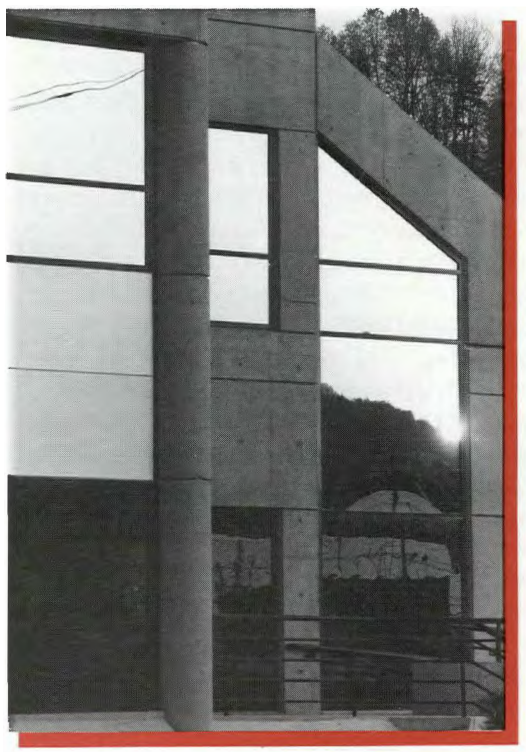
The federal government has taken several important steps in the last five years to facilitate industrial use of the laboratories. First, access is provided where there are no security restrictions. Second, industry can obtain patent rights and licensing agreements under these arrangements. Third, the laboratories protect proprietary information. Fourth, in many cases the government is prepared to fund part of the work. Finally, much of the antitrust legislation that impacts such activity has been changed to encourage technology transfer.

Who pays? The current arrangement requires that any private company wishing to retain patent rights pay at least a fraction of the cost; the minimum is generally set at 20%. If the company does not want the patents, and if the research is of interest to DOE, the company's access to the laboratories, their equipment, and, to some extent, the staff is free. However, the industrial user is expected to supply scientific and technical personnel to carry out the work. If an industrial firm wants to carry out a research project at a national laboratory and cannot find government support, it can go it alone. The company pays for the full operating cost of research, but it need not pay for amortization of the equipment or its maintenance, nor for the general infrastructure. In this case also, the industrial firm retains the patent rights and supplies the scientific and technical personnel.

What are the limitations? The obvious ones are available time, space, and access to the facilities. The time is limited by user pressure and by the need to carry out DOE programs that receive priority. Other limitations are the classified nature of the defense program laboratories and the limited technical support staff for user research at the laboratories. A less obvious, but currently much more serious, limitation is the seemingly endless contractual wrangling required to satisfy the multilayered legal arrangements among three parties: the industrial firm, DOE, and the contractor operating the national laboratory. Such negotiations can take up to two years, and even renewals take many months to complete. All three parties agree that this time delay must be drastically shortened, but in spite of all efforts we do not have our act together on this.

Perhaps the most important obstacle to effective industrial use of U.S. national laboratories is cultural. In this country, the federal government is not expected to support industry for which it is not a customer and, for its part, industry looks upon government as the regulator or–very often–the enemy. National laboratories have not been motivated to work with industry, with the notable exception of the development of nuclear reactors. Finally, an industrial scientist sees only disadvantages in spending a year or two at a government laboratory; the reward for such an effort is nonexistent.

If indeed we should begin to regard the national laboratories as a technological commons, much good could come of it. The nation would at once possess an unmatched R&D resource in the quest to reassert its dominant role in global commerce. The laboratories at this time are ready to assume such a role, but it would be most helpful if DOE and the Congress were to add the global competitiveness aspect explicitly to the mission of the national laboratories. The final, and most important, change needed is an improvement in the attitudes of both government and industry toward each other. They must work together for the good of all. The technological commons is a good place to start. Let industry use what we all hold in common and take from it inventions and new processes, so that our nation will thrive and all of us are enriched.



The High Temperature Materials Laboratory, shown here at dusk, is the first ORNL-DOE user facility in which industrial firms are expected to be the primary users.

Alexander Zucker is acting director of Oak Ridge National Laboratory. On March 23, 1988, he presented his "technological commons" concept to members of the U.S. Congress in testimony before the Subcommittee on Energy Research and Development, Committee on Science, Space, and Technology ornl

A New Licensing Approach

By Jon Soderstrom

"We must make sure that our ability to innovate is followed up by our ability to actually produce and market innovative products."
Senator Sasser, February 12, 1988, at ORNL.

Although the United States is enjoying a period of relative economic stability, our preeminence in world commerce has eroded over the past decade. We are being challenged by both our European trading partners and the emerging industrial nations in Asia and Latin America. In 1987, the United States had a trade deficit of more than $171 billion. To maintain our standard of living, advance our foreign policy aims, and ensure our national security, we must reverse this trend and regain our competitive edge in global trade.

Technological innovation, stimulated by research and development (R&D), is vital to our future because it is the key to advancing our productivity and increasing foreign demand for U.S. products. Over the past 50 years, technology has been the most important generator of productivity growth, far surpassing the contributions of capital, labor, or economies of scale. The United States must support, advance, and apply new technologies to enhance the nation's economic vitality and well-being. Nothing less can ensure U.S. industrial leadership in our increasingly competitive world.

An analysis by the President's Commission on Industrial Competitiveness (1985) revealed that our total national investment in R&D, as a percentage of the gross national product (GNP), is commensurate with that of other nations and that the U.S. government funds nearly 50% of this R&D. However, more than 50% of this federal funding is for defense-related purposes. The Federal Republic of Germany and Japan, in contrast, devote the vast majority of their government-supported R&D to civilian purposes. To restore global market competitiveness and reverse the international trade imbalance, our country must increase its efforts to develop technologies of commercial value. Oak Ridge National Laboratory and other Department of Energy laboratories can contribute to this venture.

Armada Corporation, of Detroit, provides an example of the impact technology development can have on American businesses and our trade balance. Armada uses nickel-chrome alloys to manufacture heating elements for dishwashers and clothes dryers. The two major world suppliers of chromium are South Africa and the Soviet Union. Although the Soviet Union sells chromium at less than the market price, domestic companies are prohibited by U.S. policy from buying it, leaving us at a price disadvantage. Currently Armada is testing some ORNL-developed nickel aluminide alloys in their heating elements. These intermetallic materials share the characteristics of both metals and ceramics and actually grow stronger at higher temperatures. At 600° C (1100° F), they are six times as strong as stainless steel! If Armada succeeds in developing heating elements from these alloys, the resulting products will be longer lasting, more reliable, and less expensive to produce than conventional elements. The company will also be freed from its dependence on expensive or unreliable foreign supplies.

Value of National Labs

To reach effective R&D parity with our global trading partners we must improve our ability to derive commercial benefits from federally funded R&D. More than one-third of this R&D is conducted in more than 100 federal laboratories, which employ about one-sixth of the nation's scientists and engineers. The importance of our national laboratories in achieving global competitiveness has been recognized at ORNL, where a year-long series of seminars on the subject has been established. The first seminar of the series, presented by Senator James Sasser in February of this year, underlined the seriousness of the situation. As Senator Sasser pointed out, U.S. industry must learn how to quickly move new technologies from the laboratory to the marketplace. The federal government can help accomplish this by (1) using incentives to motivate private-sector firms to invest in the commercial development of federally developed technologies, (2) making

based on Oak Ridge-developed technologies.

Before 1985, DOE had traditionally applied for and retained patents on all potentially marketable ORNL innovations. Responding to Energy Systems' proposals and to a national push toward increasing technology transfer, in 1985 DOE agreed to transfer ownership of selected ORNL patents to Energy Systems to permit licensing of these patents to commercial firms.

Senator Sasser (left) and Clyde Hopkins, Energy Systems president, observe a magnet suspended over high-temperature superconducting materials produced at ORNL.

government-developed technologies readily available to the commercial sector under attractive licensing terms, and (3) increasing R&D cooperation between federal laboratories and industries.

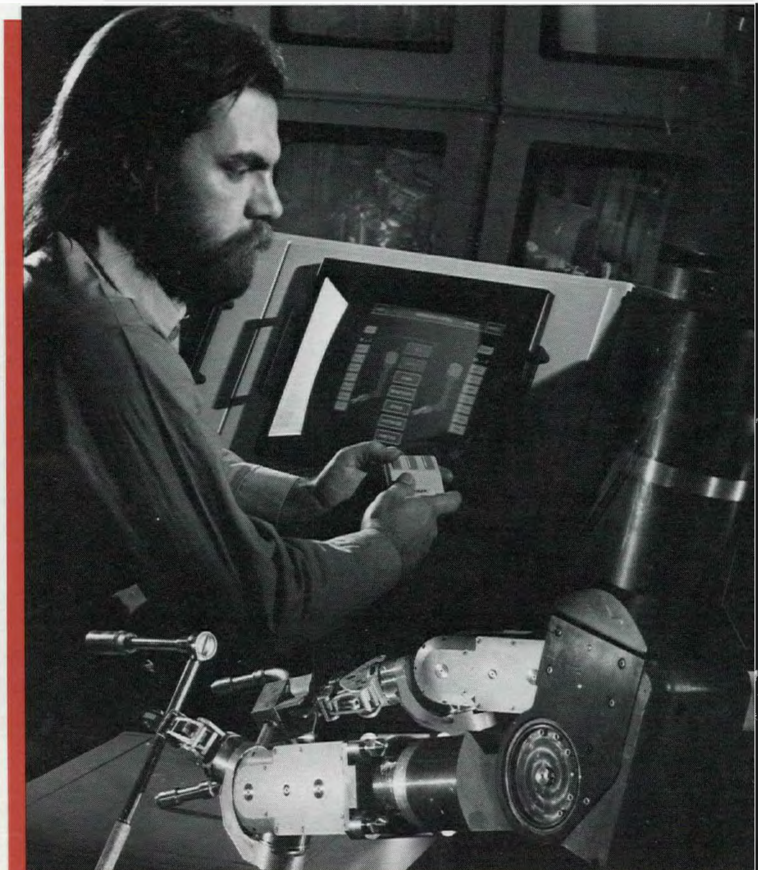
In 1984, Martin Marietta Energy Systems, Inc., as ORNL's new operating contractor for DOE, proposed four measures designed to boost the flow of technologies from ORNL to the private sector:

- broaden and centralize the scope of technology transfer functions at ORNL to include all operating facilities under the management contract;
- title all intellectual property of commercial value (e.g., patents and copyrights) in the contractor's name under the terms of an advanced blanket waiver;
- develop and provide financial rewards and recognition for inventors;
- create mechanisms to encourage the formation of new businesses, especially locally,

Licensing Policies

Since 1985, patent waivers on several ORNL innovations have been granted, and Energy Systems has used them to aggressively pursue commercial licensing. We are now able to offer these ORNL technologies to U.S. companies under conditions that make investment in their commercial development attractive and potentially profitable. For example, an ORNL-developed ceramic composite that is toughened with ceramic "whiskers" has been licensed to seven industrial firms (see table on p. 11), principally for applications in industrial cutting tools and wear parts. This technology is already being marketed commercially by these firms and is expected to have a significant impact on the billion-dollar-a-year cutting-tool industry. Bill Carpenter, Energy Systems' vice-president for technology applications, believes the vigorous pursuit of technology licensing agreements such as these will help rejuvenate U.S. industry and its competitiveness in the world market.

Using a flexible negotiation approach, Energy Systems offers licensing arrangements to



Walt Glover does a computer checkout of the Advanced Servomanipulator (foreground), an ORNL development that has been licensed to industry.

commercial firms that may include various types of protection, up to and including an exclusive agreement, giving the licensee the sole right to manufacture and market the transferred technology. Exclusive licenses are usually issued for the technologies that require significant additional development before commercial production can begin. This protection from competition provides the incentive necessary for a firm to invest in commercializing the innovation.

The licensing agreement may also be extended to include any Oak Ridge-developed improvements to the technology waived to Energy Systems by the DOE during the life of the contract. Such agreements ensure licensees the greatest possible benefit from using a federally developed invention. Exclusive licensing arrangements usually include a reciprocal agreement that the licensee will share with ORNL information about improvements and modifications made by the licensee to the basic technology. This arrangement allows Energy Systems to provide other licensees the right to use such modifications in noncompeting fields of use and may stimulate additional technological developments.

Our flexible licensing approach both preserves and expands some important national objectives. Under these agreements, the government is allowed to retain a royalty-free, paid-up, nonexclusive license to any federal technology, and any firm has the contractual freedom to use the technology for government-directed purposes (e.g., make ORNL-developed widgets to sell to other government laboratories without acquiring a license from Energy Systems). Licensees are not required to pay royalties on sales of the technology for government use; in fact, the Energy Systems licensing agreements require proof that the firm reduced the price charged for government sales by at least the amount of the royalty due on a commercial sale. In other words, our licensing approach grants exclusive commercial sales rights to the technology, rather than an exclusive production license.

In many cases, a technology may be licensed to several companies for its applications in various fields of use. This approach was used with the series of modified nickel aluminide alloys recently developed at ORNL. A license was granted to Cummins Engine Company for use of the alloys in large-displacement diesel engines. Armada Corporation has a license to use the alloys in electrical-resistance heating elements, and Metallamics, Inc.,

milestones for producing a commercial product, planned levels of investment for further developing the technology, and a schedule for introducing the product onto the market. If the licensee does not actively pursue commercialization of the technology, the license may be terminated by Energy Systems, allowing other clients to pursue development.

Our policy also requires that products from these licenses, if sold on the U.S. market, must be substantially produced in the United States. This ensures that all firms pursuing domestic markets will have similar capital and labor costs. U.S. taxpayers gain in two ways: jobs are generated for American workers, and higher tax revenues are received from the increased economic activity.

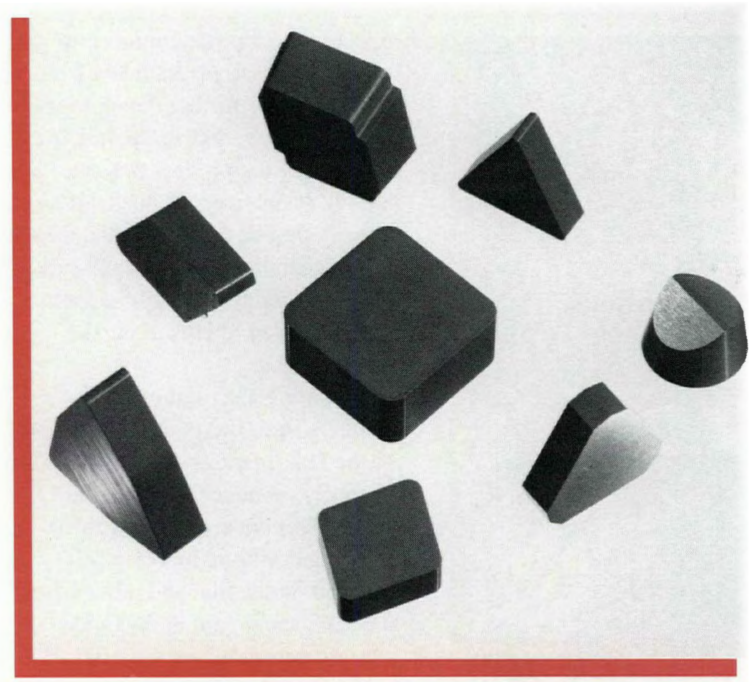
Our experience shows that the government policy changes instituted in the past few years can accelerate the rate of technology transfer from government facilities to industry. Granting substantial patent rights to a government contractor such as Energy Systems provides the incentive to work aggressively toward commercialization of the research. The royalty proceeds received provide the means to reward inventors, produce sample materials or prototype instruments to demonstrate the technology to industries, and take other actions (such as organizing workshops or seminars) that will speed the technology's commercialization.

The originating organization is best able to facilitate this rapid technology transfer and to provide the opportunities for interaction between laboratory inventors and their commercial counterparts in a particular area of technology development. Energy Systems' licensing policies provide incentives for increasing inventor contacts and interactions with companies interested in commercializing their innovations and may, in some

Charlie Dunn checks rolls of sheets of ORNL's modified nickel aluminide alloy produced by a strip casting technique. Energy Systems has licensed five companies to manufacture and market the alloy for different uses.

received a license for various tool-and-die and wear applications. Our promotion of this material has been so successful in generating interest among manufacturers that we have recently granted a nonexclusive license to Armco, Inc., to supply various product forms. Our licensing of other Oak Ridge-developed innovations has also had good results, as indicated by the fact that the Armco license was the 18th such agreement granted by Energy Systems since 1985 (see table). Negotiations are under way for the licensing of other innovations developed here.

Energy Systems' licensing policy does not allow a licensee to merely place our technology "on the shelf." An action plan for commercial exploitation of the technology must be prepared and implemented before the license is granted. The plan typically includes technical goals and



These cutting tools produced by the Greenleaf Corporation are made of ceramic composites reinforced with silicon carbide whiskers, based on materials developed at ORNL.

cases, encourage private funding for continued development of the technology by the inventor at a government facility.

Incentives

Many new incentive programs have been established at ORNL to encourage employee participation in the technology transfer program. For example, more than $53,000 has been distributed to inventors for their assistance during the patent application process. Another new practice is sharing 10% of the royalties received (up to a limit of $100,000 per invention) with the inventors. The first royalty distribution, made to seven employee inventors in December 1987, totaled more than $24,000. A second distribution was made in March 1988, and future distributions will be made as the royalty checks are received from licensees.

Employees who are not named inventors on licensed patents, but who have contributed significantly to our technology transfer program, will receive monetary rewards totaling 4% of the gross royalty receipts. An additional 4% has been set aside to share with inventors of technologies that are considered to be unlicenseable but of significant value to the government's missions. A technology may be deemed unlicenseable because it is classified, the market is limited to government uses, or the application is too far in the future.

Other incentive measures we have adopted include:

- establishing an "Inventor of the Year" award to recognize the inventor of the most significant new technology each year,
- holding an annual patent award luncheon to recognize inventors receiving patents during the year, and
- forming an internal Inventor's Forum to allow patent-holding employees an opportunity to meet on a regular basis to discuss issues of common concern.

The results of these initiatives are worth noting. First, invention disclosures have increased, reversing a five-year decline. Second, technical publications have also increased, again reversing a five-year decline. These indicators are even more important because they come at a time when little or no growth has occurred in our R&D budgets.

More than $350,000 in license fees and royalties have been received, and nearly $7 million of commercial product sales have resulted from Energy Systems' technology licensing efforts of the past two years. This encouraging start indicates good prospects for future increases in U.S.-based commercial production from federally funded technologies developed at Oak Ridge.

Bill Carpenter has recently stated that Energy Systems' five-year goals for technology transfer include developing 50 additional active licenses, achieving $100 million per year in U.S.-based commercial production from technologies licensed at Oak Ridge, and the start-up of at least 25 new local business spin-offs. Every possible effort will be made to accelerate the transfer of Oak Ridge-developed innovations into the commercial sector and to help restore our country's competitive edge in the global marketplace. ornl

ROYALTY-BEARING LICENSES

TECHNOLOGY	LICENSEES	LICENSE SCOPE	COMMERCIAL IMPACT
Nickel aluminides (high-temperature super alloys)	Cummins Engine	*Exclusive*: Large nonautomotive diesel engines	Potential markets large
	Armada	*Exclusive*: Heating elements	Eliminates need for strategic material
	Armco	*Nonexclusive*: Materials supplier	
	Metallamics	*Nonexclusive*: Wear parts	
Whisker-toughened ceramic composites	Advanced Composite Materials	*Nonexclusive*: Cutting tools	U.S. recaptures cutting tool market ($200M/year) from Japan
	Advanced Composite Materials	*Nonexclusive*: Wear parts	
	High Velocity Corp (Oak Ridge)	*Nonexclusive*: Cutting tools	If these advanced materials used for engine components, markets large and significant to U.S. economy
	Iscar	*Nonexclusive*: Cutting tools	
	Dow Chemical	*Nonexclusive*: Cutting tools and wear tools	
	American Matrix (Knoxville)	*Nonexclusive*: Cutting tools and wear parts	
	Cercom, Inc.	*Nonexclusive*: Wear parts	
Ceramic gripper	Instron	*Exclusive*	Small market, important for ceramic testing
Anaerobic waste treatment system	ANFLOW, Inc. (Oak Ridge)	*Exclusive*	Tens of millions per year
Fiberoptics luminoscope	ESC, Inc. (Knoxville)	*Exclusive*	Small market, important new product line
Container design for tritium transport	Ontario Hydro	*Nonexclusive*	Small specialized market copyright
ANALIS (Software to manage volume chemical analyses)	Future Tech (Oak Ridge)	*Nonexclusive*: Copyright	Licensee sublicenses and services users
Advanced servo-manipulator	REMOTEC (Oak Ridge)	*Exclusive*: Patent	Preserve competitive edge against Japan
	REMOTEC (Oak Ridge)	*Exclusive*: Copyright	

Biographical Sketches

E. Jonathan Soderstrom (right) has been director of licensing in the Office of Technology Applications for Martin Marietta Energy Systems, Inc., since 1984. In this capacity he is responsible for marketing and licensing patents that are based on technologies developed at Department of Energy facilities in Oak Ridge. He received his Ph.D. degree in psychology from Northwestern University in 1980. That same year he began work at ORNL as a member of the Social Impacts Analysis Group in the Energy Division. In 1983, he founded and became leader of the Technology Transfer Research Group in the Energy Division. A primary focus of his research has been the evaluation of the effectiveness of various programs designed to stimulate technological innovation and transfer. He is the author of a number of publications on the technological innovation process and the impact of new technology on society and co-author of two books: *Social Impact Assessment: Experimental Methods* and *Approaches and Impacts of Hazardous Technology: The Psycho-Social Effects of Restarting TMI-1*. Soderstrom is a founder and president of Aid to Distressed Families of Anderson County.

Warren D. Siemens is director of Technology Applications in the Office of Technology Applications at Energy Systems. A native of Buhler, Kansas, Siemens began in 1959 as a research assistant at the Argonne Cancer Research Hospital in Chicago, developing radioactive isotopes for medical use. He left there to attend the Massachusetts Institute of Technology (MIT), from which he received a B.S. degree in physics in 1963. From 1963 to 1965, he was employed by Raytheon Company in Bedford, Massachusetts, as a systems analyst in the Space and Information Systems Division. Siemens joined Abt Associates, Inc., in Cambridge, Massachusetts in 1965 and worked as manager of the Technology Management Group. During this time, he began working toward a Ph.D. degree in the philosophy of science at MIT (which he received in 1983). From 1971 to 1976, Siemens served as vice-president of Public Technology, Inc., in Washington, D.C. He also directed a Technology Applications Program sponsored by the National Aeronautics and Space Administration to apply aerospace technologies to local government needs. In 1976, Siemens joined Informatics, Inc., in Rockville, Maryland, as director of the Information Programs Division. He was responsible for information and technology transfer programs, R&D policy, planning, and evaluation, new product planning, and commercialization. Siemens was hired by Martin Marietta Corporation in 1977, serving as manager of their Market and Program Development until 1982, when he became associate director for Biotechnology and later associate director for Technology Applications at Martin Marietta Laboratories in Baltimore. In 1985, Siemens transferred to Energy Systems to assume his current position. He has been instrumental in implementing many of the new policy changes designed to speed the transfer of government-developed technologies to the private sector. Under his leadership, industrial consortia, private investment funding, and collaborations between government, academic, and industrial institutions are being established to expedite technology transfer. ornl

Industrial R&D Consortia

By Warren Siemens

The recently issued *ORNL Institutional Plan for FY 1988-1993* emphasizes that one of the most significant challenges in our future will be learning how to help American industry turn the results of government-sponsored R&D into commercially important products. Interactions on an unprecedented scale will be required between industry and national laboratories such as ORNL. To help the United States regain a competitive edge in the world marketplace, we must strive to remove all administrative, legal, and contractual barriers to industry-laboratory cooperation.

"The primary goal for ORNL is scientific advancement, but the goal for industry is profit."

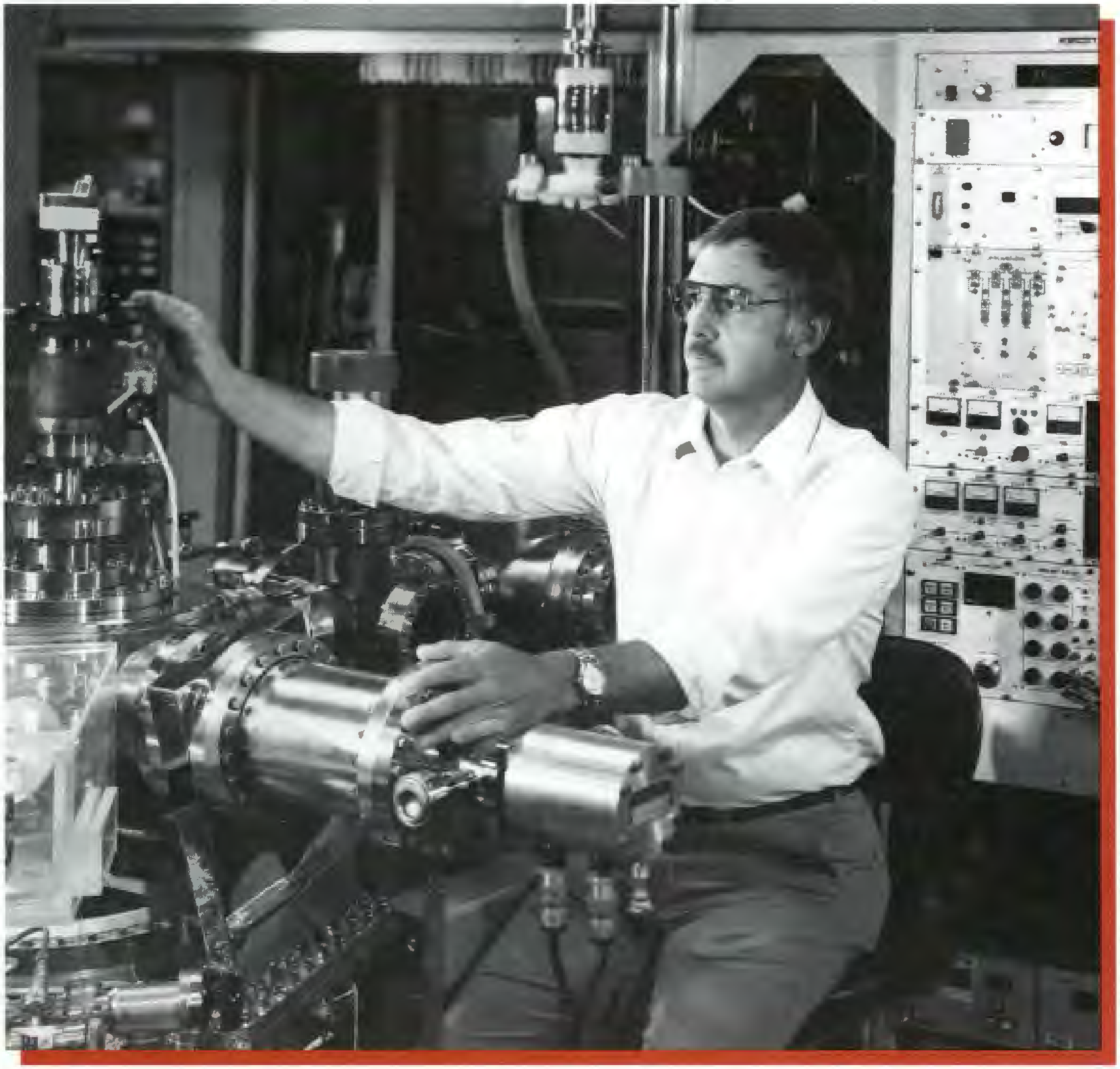
A report entitled *Competitiveness, Technology, and ORNL*, prepared by Don Kash of the University of Oklahoma for ORNL's Program Planning and Analysis Office, points out that "Legally there are a whole series of constraints that revolve around who should enjoy any economic benefits that flow from work paid for with public monies. Organizationally there are powerful turf concerns reinforced by the lack of a body of experience and procedure for working with industry outside the nuclear arena." Kash points out that ORNL has hesitated to develop close links with industry in the past for fear of allegations of corruption and because of the ever-present threat that some congressman will use industrial cooperation as an excuse for attacking the Laboratory or cutting funds. There has also been concern that the Laboratory might be accused of becoming an unfair competitor to industry or that cooperation with a particular company might give that company an unfair advantage over its competitors.

Industries have hesitated to form alliances with ORNL for some of the same reasons and because they often perceive the Laboratory as moving slowly and being unconcerned about development costs. ORNL too often views industry as being concerned only with short-term, intellectually uninteresting work. Both ORNL and industry worry about possible conflicts of interest. Historical and cultural barriers to industry-laboratory cooperation include the perception by industry that ORNL is, in Kash's words, "predisposed to scientific and technological elegance and not simplicity and efficiency" and the perception by ORNL that industry is "focused on the mundane and applied, not the more intellectually challenging efforts that significantly advance the state of the art." The primary goal for ORNL is scientific advancement, but the goal for industry is profit.

Overcoming the Barriers

It will not be easy to overcome these barriers, but ORNL has made a beginning by establishing several cooperative arrangements with industry. Industrial firms have been attracted to federal laboratories such as ORNL because they generate inventions the companies want to develop into marketable products. Since the expertise needed to produce a new technology is located at ORNL, it is often viewed by a commercial company as the best place to conduct additional development. For example, Babcock and Wilcox (B&W) Corporation became interested in applying ORNL's forced chemical vapor infiltration (CVI) technology for producing ceramic composites to the manufacture of heat exchanger tubes. ORNL and B&W entered into a two-year joint development effort in applying CVI technology to ceramic fiber preforms, which were woven together using B&W's proprietary weaving capabilities. Increased U.S. emphasis on the development of technologies to restore global competitiveness and redress the trade imbalance has led ORNL to encourage the formation of additional partnerships between national laboratories and industry.

ORNL management believes collaborative R&D with industry is valuable for three reasons. First, it permits cost-effective use of funds and facilities in the development of new technology for both industry and government. It also helps ORNL focus on national issues and scientific priorities. Finally, it allows ORNL scientists to interact with some of the best minds of our country's industrial sector. We benefit from exposure to fresh points of view, new insights, and provocative questions. Such collaborations



Bill Appleton surveys the lasers and accelerators in ORNL's Surface Modification and Characterization facility, which is available to researchers in the semiconductor industry.

can also help keep ORNL preeminent in some areas, enabling the Laboratory to attract other high-quality researchers.

New Mechanisms for Cooperation

In addition to promoting one-on-one interactions with industry at ORNL, Martin Marietta Energy Systems, Inc., has created mechanisms for consortia of several companies to work together on a technology application in collaboration with ORNL. These mechanisms are most appropriate for cases in which

- the companies can identify generic technology developments critical to their international competitiveness,
- the risks and capital requirements are too great for a single company to undertake, and
- the national laboratory has strong capabilities that supplement or complement those of industry.

Energy Systems has initiated industrial consortia to expedite the commercialization of R&D results in several areas of national importance, such as electronic controls, software development, ceramics, and semiconductors. This type of industry-government cooperation will, in time, contribute significantly to improving our nation's economy and international competitiveness.

Tennessee Center for Research and Development

In 1985, the Tennessee Center for Research and Development (TCRD), a not-for-profit corporation, was established on the Technology Corridor between Oak Ridge and Knoxville to derive economic value from the strong science and

"ORNL is currently involved in the planning stages of two additional industrial R&D consortia efforts."

technology bases of the region (e.g., ORNL, the University of Tennessee, and the Tennessee Valley Authority). The TCRD bridges the gap between R&D and commercialization by supporting the development of market-driven applications for new technologies and allowing the consortium sponsors to develop these technologies beyond the capacity of their respective institutions. The TCRD's activities are funded by a variety of sources, including federal and state agencies, industry associations, individual companies, and private investors. The TCRD draws on the R&D resources and capabilities of the sponsoring organizations to accomplish its objectives through various consulting and contractual agreements. Two organizations that have developed through the TCRD are the Power Electronics Applications Center and the Thermomechanical Model Software Development Center.

PEAC. One of the first major achievements of TCRD was the establishment of the Power Electronics Applications Center (PEAC). This organization will help regain the competitive position of the U.S. power electronics industry through the development, demonstration, and transfer of new power electronics technologies for U.S. companies, including electric utilities. Development areas include new devices and components, circuits and controls, industrial electrotechnology systems, power conversion and conditioning systems, and power quality. Initial funding of $6 million was provided to the PEAC by the Electric Power Research Institute.

Currently, R&D partnerships at the PEAC are also being formed and funded by interested U.S. companies to conduct power electronics developments for specific applications such as adjustable speed drives, power line conditioners, and uninterruptable power supplies. The primary objective is to develop high-voltage and high-current electronic devices and systems that provide more efficient electricity end-use management. When industries use electricity more efficiently, it has a moderating effect on electrical rates, and industrial product costs become more competitive. Thus, all economic sectors ultimately benefit from advances in power electronics.

TMSDC. The Thermomechanical Model Software Development Center (TMSDC), funded by 13 sponsoring companies, was initiated by the TCRD to develop a user-friendly, intelligent software system for accessing a highly complex set of finite-element thermomechanical stress analysis models. These models, primarily designed for stress analysis in refractory systems such as furnace linings, were developed by the Massachusetts Institute of Technology for ORNL over an eight-year period. However, their current configuration is too complex for practical use by industrial design engineers.

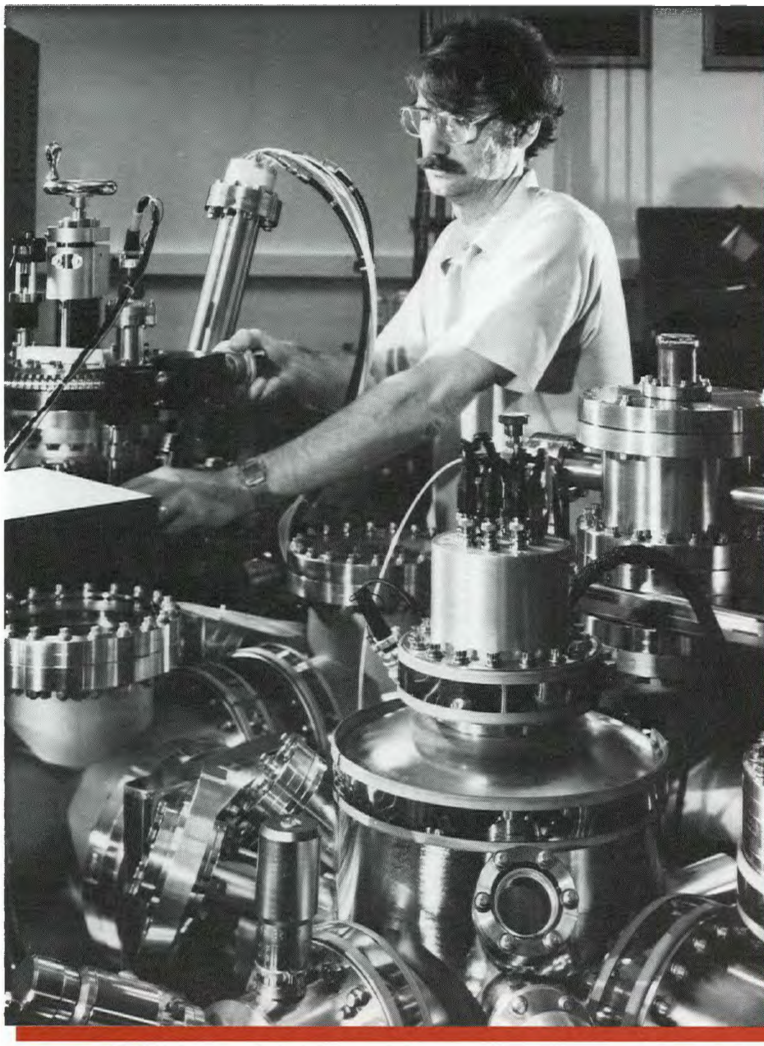
In addition, preparation of the input files for the models is too time-consuming, and interpretation of the results requires considerable background experience with the model. The TMSDC consortium seeks to develop software that will allow engineers to input the necessary design parameters and interpret the analysis results without being experts on the analysis models. Such software will be valuable to those concerned with refractory behavior in coal gasification plants and other high-temperature refractory applications, such as blast furnaces in the steel industry.

In addition to participating in the PEAC and TMSDC consortia, ORNL is currently involved in the planning stages of two additional industrial R&D consortia efforts.

CAMDEC

The Ceramics Advanced Manufacturing Development and Engineering Center (CAMDEC) is sponsored and managed by several U.S. companies interested in developing advanced ceramic processing and manufacturing technologies. Its aim is to develop technologies to characterize and control each step of the manufacturing process to ensure the reliable production of advanced ceramic components.

Our foreign competitors, particularly in Japan, are already adept at systematically investigating process technologies to refine and improve their products. Unless U.S. companies can initiate such



Fred Walker uses ORNL's molecular beam epitaxy apparatus to grow ceramic materials having layers of different compositions.

- cost-effective, highly reliable, mass-production processes;
- new composite materials;
- a better understanding of ceramic characteristics by designers and users;
- improved forming technologies; and
- the development of in-line sensors and in-process nondestructive evaluation techniques.

practices and quickly learn how to use our excellent R&D base to improve commercial ceramic processing, they will lose the emerging and potentially large markets for advanced ceramic components to foreign competitors.

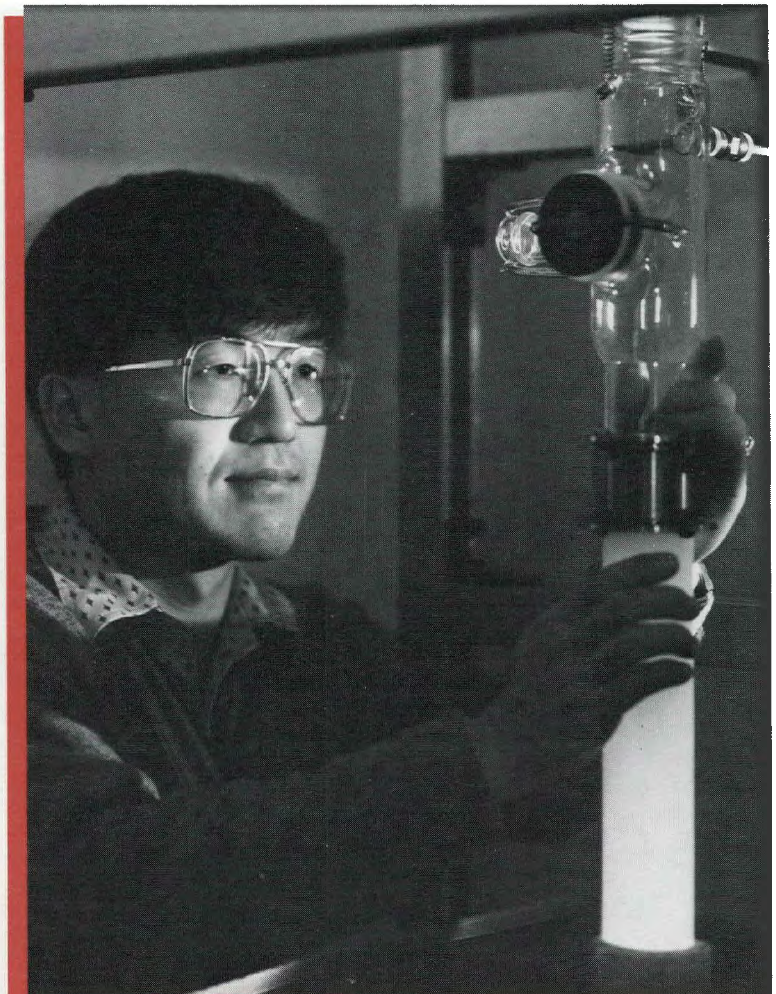
To identify specific industrial needs in this area, CAMDEC conducted a comprehensive survey in the fall of 1986. According to the respondents, the most critical requirements for U.S. industry's commercialization of advanced ceramics are:

- means to control defect size, concentration, and distribution in finished ceramic products;

CAMDEC and its technology plan were developed with assistance from an advisory board of key executives from six companies: Allied Signal, Boeing, Dow Chemical, GTE Products, Norton, and Standard Oil. The advisors met in September 1986 for an intensive review of the initial consortium plan and concluded that a bolder, more aggressive program was needed to accomplish their objectives. They recommended that CAMDEC staff members visit each company to gain input to the technology plan and a better understanding of each industry's processing needs. A revised technology plan was presented to the board and approved in February 1987. The advisory board also initiated a membership campaign to broaden participation in the CAMDEC consortium.

All the necessary policies and procedures are in place for CAMDEC members to access the excellent user facilities at ORNL, such as the High Temperature Materials Laboratory (HTML), which contains some of the most advanced willing to publish the results in the open literature. If the work conducted is proprietary, the users must pay full costs. In either event, CAMDEC may retain the patent rights to any intellectual property developed under the user agreement. In some cases, CAMDEC members may contract with ORNL to conduct R&D or, alternatively, may employ ORNL scientists and engineers as consultants (on their own time), subject to certain restrictions.

The CAMDEC consortium arrangement provides industry with a financially leveraged investment, not only through membership cost sharing, but through the cost avoidance achieved from using the existing facilities, equipment, and expertise at ORNL.



Hyounn-Ee Kim prepares to load a sample in an apparatus he built for measuring corrosion rates of ceramics at high temperatures. Ceramics is one area where ORNL seeks to cooperate with industry through an R&D consortium.

APSC

A major initiative at ORNL is the establishment of an Advanced Processing Science Center (APSC) in collaboration with several of the major semiconductor industries. This is considered an urgent need because the United States has already lost much of its market in semiconductor device processing, which underlies many major sectors of the world economy, including energy, communications, computers, consumer electronics, and military weapons systems. The nation that develops the most advanced and efficient techniques for fabricating the submicron electronic devices and integrated circuits needed in these fields will become the leader in semiconductor commerce.

The Japanese are devoting increased R&D efforts to developing the advanced processing techniques needed to fabricate these delicate structures. The techniques are based on the use of ion, photon, plasma, and electron beams to alter materials and induce the necessary precision-controlled, atomic-scale interactions. The resulting submicron semiconductors can be used to make compact, complex control systems for future supercomputers, communications equipment, and home electronic appliances.

ORNL has been a world leader in developing ion beam, laser, and plasma processing techniques for altering materials and improving their properties. Our leadership position was established by the development of the calutron electromagnetic isotope separations techniques here in the early 1940s. Subsequently, the first U.S. laser-annealing experiments were performed here in the early 1970s. Another ORNL user facility, the Surface Modification and Characterization Collaborative Research Center, established in 1980, is a focal point for current research in this field. If linked to industry in a cooperative development partnership, ORNL's expertise has the potential for helping the United States surpass Japan in developing processing techniques to produce advanced semiconductor devices.

The APSC consortium of major U.S. semiconductor industries will have access to ORNL's materials processing and analysis facilities and expertise. The basic idea of the APSC is to create a forum in which competing industries can share technologies and ideas, while still competing in device and systems manufacture. ORNL's industrial partnership will ensure the relevance of the R&D and facilitate commercialization of the technology. The Laboratory's estimated involvement in APSC consortium R&D could reach $12 million per year and and involve about 25 in-house staff members and 25 U.S. industrial and academic personnel.

National Mandates

Numerous acts of Congress and Presidential directives in recent years have underscored the urgency of improving technology transfer from the public to the private sector. In spite of these mandates, the effectiveness of such programs has been uneven. Industry has not been assured of a reasonable return on investments in new, government-developed technologies. Recent changes in federal patent policies (described in the previous article) should provide such assurance. In addition, the rewards and incentives provided by the new policies should encourage researchers and government contractors to become more aggressive in promoting the commercialization of new innovations. These incentives have already begun to foster closer linkages between federal research institutions and industry. Government laboratories in other countries, particularly Harwell in England and Karlsruhe in the Federal Republic of Germany, have demonstrated that such cooperation can be mutually beneficial. Commercial exploitation of government research developments is needed to provide U.S. taxpayers the maximum return on their investment in federal laboratories.

Industry and laboratory interactions and increased collaborations between researchers in industrial firms and those in government laboratories will generate new ideas and technologies of value to both types of organizations. Most importantly, these cooperative ventures with industry will help integrate the vast technical resources of the federal laboratories into the nation's economy and increase U.S. productivity and competitiveness in today's global economy. ornl

"ORNL's expertise has the potential for helping the United States surpass Japan in developing processing techniques to produce advanced semiconductor devices."

Local ORNL Spin-off Companies

by Louise Dunlap

More than 50 technology-related companies in the Oak Ridge area can trace their roots to Oak Ridge National Laboratory. Until 1984, these local spin-off firms were a primary means for transferring ORNL technology into the private sector. The regional economy has greatly benefited from the more than 1000 jobs created and from the millions of dollars of capital investment in the start-up and growth of these industries.

EG&G ORTEC's products include a complete line of computer-controlled nuclear instrument modules and the PopTop™ Transplantable High-Purity Germanium Detector Capsule for gamma-ray spectroscopy.

ORNL's Entrepreneurs

One of Oak Ridge's first major spin-offs, ORTEC, was founded in 1960 by a small group of ORNL scientists. Originally a manufacturer of nuclear radiation detectors invented at ORNL, ORTEC is now a wholly owned subsidiary of EG&G and an international supplier of radiation detectors and related electronic processing instruments. Radiation measurement systems manufactured by ORTEC in Oak Ridge are being used in European and Middle Eastern countries to inspect food products for hazardous levels of radioactive contamination from the Chernobyl reactor accident. EG&G has recently announced the relocation of another of its manufacturing operations—Princeton Applied Research of New Jersey—to Oak Ridge, increasing the number of local employees from 260 to 480.

Also in 1960, ORNL scientist Edward Fairstein launched Tennelec, which manufactures nuclear radiation monitoring and measurement instrumentation. In 1977, Tennelec was purchased by David Coffey, a former ORNL scientist who had previously incorporated a start-up company called The Nucleus. The product line of The Nucleus today includes a variety of multichannel analyzers, computer-based gamma spectroscopy systems, nuclear medicine and clinical diagnostic instruments, and X-ray fluorescence analyzers. Coffey's two companies, which employ a total of 150 people, merged in 1987 to pool their technical and marketing strengths.

Harold Schmitt represents a few former ORNL scientists who have been instrumental in numerous start-ups of small local companies. One of the original founders of ORTEC, he was also

One of Tennelec's more recent products is the LB 5100 Series III Low-Level Alpha-Beta Planchet Counter.

involved in the founding of Environmental Sciences Corporation (a Knoxville firm that is a licensee of ORNL technology) and Pic-Air, an Oak Ridge die casting firm. Currently, he is president of Atom Sciences, which he co-founded with ORNL scientist Sam Hurst in 1980 to commercialize the Laboratory's developments in resonance ionization spectroscopy (RIS). Atom Sciences developed an ultrasensitive trace-element analysis technique using RIS called Sputter Initiated Resonance Ionization Spectroscopy (SIRIS).

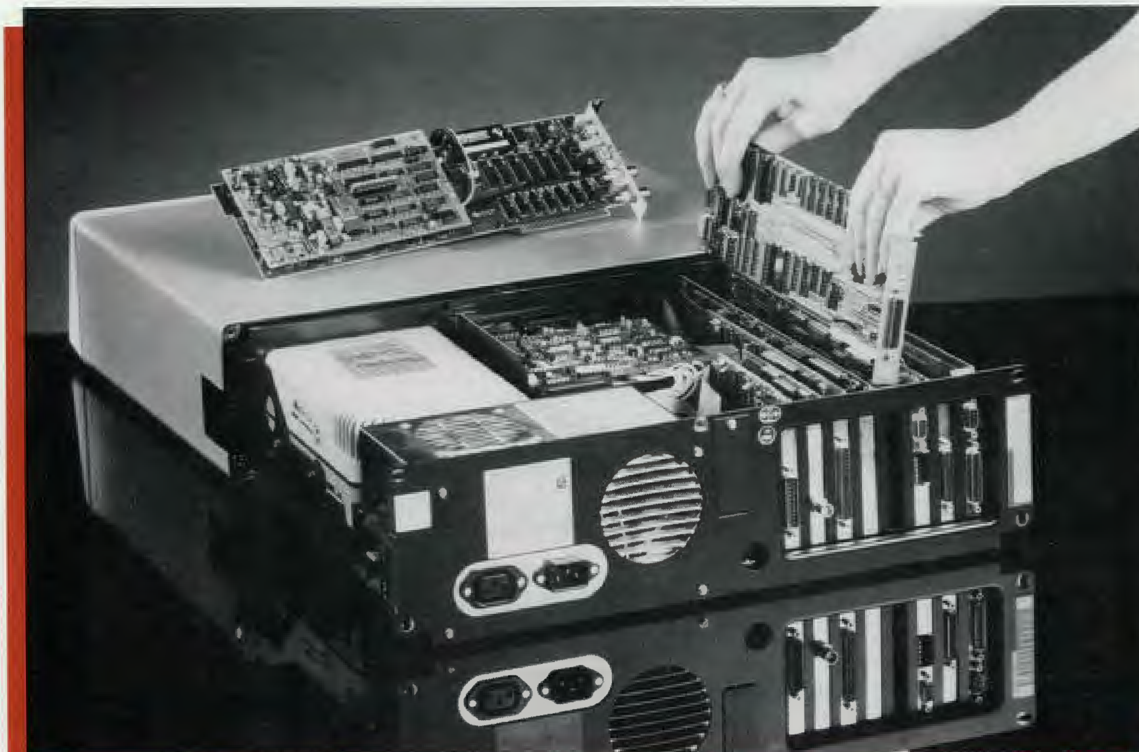
Scientist-entrepreneur Hurst has demonstrated that a "team effort" is essential to making business ventures succeed and that scientists can play a significant role in steering the development of products for the private sector without giving up their scientific careers. While at ORNL, he founded Elographics, an Oak Ridge company that manufactures computer peripheral devices, including the "touch screen" invented by Hurst for computer terminals. In 1985 this company was sold to Raychem, and Hurst retired from ORNL. He and former Elographics president Bill Gibson co-founded another small company, called Pellissippi International (PI), to turn basic science results into products using Small Business Innovation Research (SBIR) funding. During its first year of operation, PI received four SBIR grants, two of which supported further development of ORNL technologies. Under a contract to the Tennessee Center for Research and Development (TCRD), PI wrote a successful proposal to the Appalachian Regional Commission for a grant to establish the Laser Technology Center. In addition to conducting applied research using lasers, the Center will establish a two-year curriculum in laser technology at the State Technical Institute of Knoxville and will serve as a "user center" for regional small companies. Jim Parks is the new director of the Laser Technology Center, which is the first of its kind in the state.

Other local companies started by ORNL employees offer a range of products and services that include environmental monitoring, biomedical research, superconducting magnets, software, and precision machining.

Second-generation spin-off companies are also contributing to this local growth cycle. Computer Technology & Imaging, Inc. (CTI), which manufactures positron-emission-tomography (PET) scanners and cyclotrons for medical diagnosis, is a spin-off of EG&G-ORTEC. (A PET scanner and cyclotron system assembled by CTI is now operating at the University of Tennessee Memorial Research Center and Hospital in Knoxville.) Integrated Systems, Inc., one of more than a dozen spin-offs of Technology for Energy Corporation (a 1975 ORNL spin-off firm), specializes in integrated computer-based systems for electric utilities, the nuclear power industry, waste management, and government.

Local Licensees

The technology transfer process was accelerated in 1984, when Energy Systems and DOE implemented new national legislative policy that encourages technology transfer, allows the contractor to obtain waivers to patent rights and license those rights to private companies, and encourages employees to consult and initiate collaborative agreements with outside organizations. The Office of Technology Applications, which manages Energy Systems' technology transfer program, aims also to increase the number of start-up businesses and expand the product lines of existing firms by giving preferred



EG&G ORTEC's products include the ACE™ multichannel analyzer and multichannel scaler plug-in cards for IBM and IBM-compatible computers for spectroscopy applications and computer flexibility.

and favorable terms to regional companies in licensing new developments. By early 1988, 18 licensing agreements had been signed; 6 of these are with area firms and 2 with small out-of-state companies that have relocated in Oak Ridge to implement the new technology.

One of the local licensees is a 1980 ORNL spin-off firm, Remote Technology Corporation (REMOTEC), which signed an exclusive agreement with Energy Systems to commercialize a robot-like ("telerobotic") device called the Advanced Servomanipulator. This latest acquisition enhances the firm's main product line, which provides specialized robotic equipment to replace human workers in hazardous environments.

Technology transfer is also accomplished by forming a new company to develop and market a licensed technology. In 1985 Richard Genung, now director of ORNL's Chemical Technology Division, helped found ANFLOW to manufacture and market an ORNL-developed fixed-film, anaerobic, bioreactor wastewater treatment system. The local company sells these systems throughout the country to municipalities, small industries, and residential developments.

Other local ORNL spin-off firms include

- American Magnetics, Inc. (1968), which custom designs and fabricates superconducting magnets and cryogenic accessories;
- Technology for Energy Corporation (1975), which supplies high-tech engineering products and services for the energy production industry;
- Ridge Metals, Inc. (1980), a precision machine shop that fabricates components for special applications;
- Oak Ridge Research Institute (1981), which conducts biomedical research and develops environmental monitoring and biological waste treatment systems;

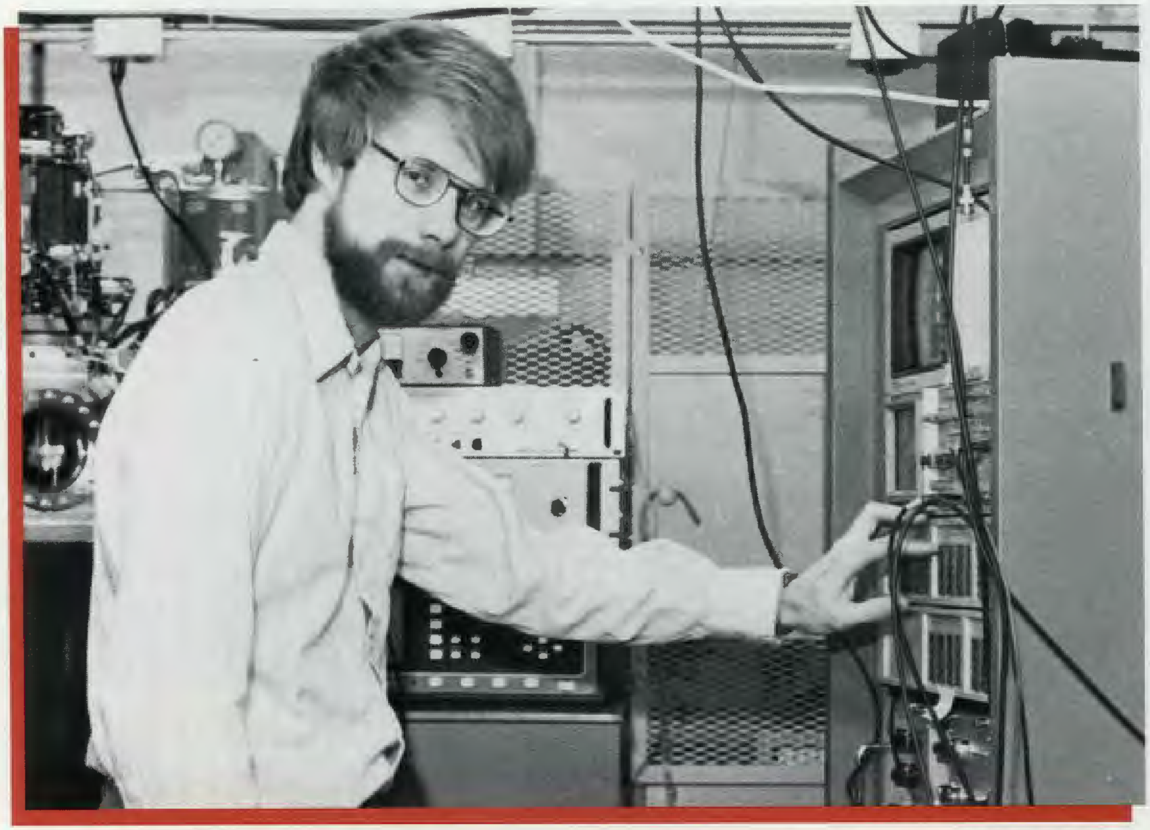
Hal Schmitt and Sam Hurst are well-known local scientist-entrepreneurs.

- Delta M, Inc. (1983), which manufactures small-diameter, high-quality thermocouples and instruments for measuring level, flow, and heat flux;
- Computational Systems, Inc. (1984), which develops and manufactures software and hardware systems for stress analysis and preventivemaintenance;
- Telerobotics International (1986), which designs and develops hardware and software for robotic systems;
- Oxyrase (1986), which produces an oxygen-reducing enzyme system;
- Electro-Optics Laboratory, Inc. (1987), which makes advanced laser equipment for medical uses.

Incubator Facilities

In 1985, Martin Marietta Corporation established the Tennessee Innovation Center (TIC) to assist entrepreneurs in the formation and growth of technology-related companies. Operating from a new headquarters building in Oak Ridge, TIC provides a positive, supportive environment and direct assistance through management, accounting, legal and technical advice, and seed capital. This "incubator" facility becomes a minority partner in each new venture and is committed to making each company productive and successful. ANFLOW, Computational Systems, Inc., and Delta M are examples of companies that have been nurtured by TIC. Assistance for new technology-transfer companies is also available through the University of Tennessee and the Tennessee Technology Foundation.

Recognizing the value of start-up businesses to the economy, the City of Oak Ridge developed its own incubator facility, becoming one of the first cities in the United States to provide this type of support. This facility, which is located in Valley



Don Beelsman, Atom Sciences researcher, adjusts the company's first Sputtering Initiated Resonance Ionization Spectroscopy (SIRIS) instrument for ultratrace element analysis of surfaces. The instrument incorporates lasers, a mass spectrometer, and a computer system.

Industrial Park, offers entrepreneurs low-cost space for up to five years and allows the fledgling business to minimize operating costs while establishing a market for its product. ORNL spin-off companies located in this facility include Comstock, ORDELA, and Syn Crys. Chemrad, a Texas-based company that recently licensed an ORNL technology to be developed in Oak Ridge, is scheduled to become the newest tenant.

To bolster the existing entrepreneurial system and spawn additional start-up and spin-off businesses, Energy Systems is supporting two new initiatives through TCRD. The Entrepreneurial Development Center will provide a forum through which would-be entrepreneurs can seek advice, exchange ideas, and acquire business skills. The other program, the Senior Professionals Center, will organize retired professionals in the region to provide temporary services in scientific research, engineering, law, finance, and management.

The creation of new jobs by spin-off and start-up companies is not a dramatic form of economic development. Growth tends to occur slowly, often with many setbacks. Some new companies do not survive. The winners, however, have collectively created more new jobs than any other single source in the area, and the unique resources for continuing and expanding this type of growth have only been tapped. Besides bolstering and diversifying the regional economy, these successful businesses conceived at ORNL and "born and reared" in the Oak Ridge area are playing a significant role in attracting other companies here and giving the region its new image as "The Resource Valley."

Biographical Sketch

Louise B. Dunlap is director of technology applications in the Energy Systems' Office of Technology Applications, where she is responsible for economic development activities. Before joining Energy Systems in 1984, she was executive director of the Oak Ridge Chamber of Commerce, managing programs in community and economic development. She has a B.S. degree in chemistry from the University of Tennessee (UT) at Knoxville and has taken courses at the UT Graduate School of Business. She has been active in numerous community organizations. She served as chairman of the Oak Ridge Charter Commission, president of the Anderson County United Way, member of the Oak Ridge Regional Planning Commission, and member of the Board of Directors of the Methodist Medical Center of Oak Ridge. While at the Chamber, she was appointed to the first Governor's Advisory Committee for Women in Business in Tennessee and also served as president of the East Tennessee Industrial Council and member of the Board of Directors of the Tennessee Chamber of Commerce Executives.

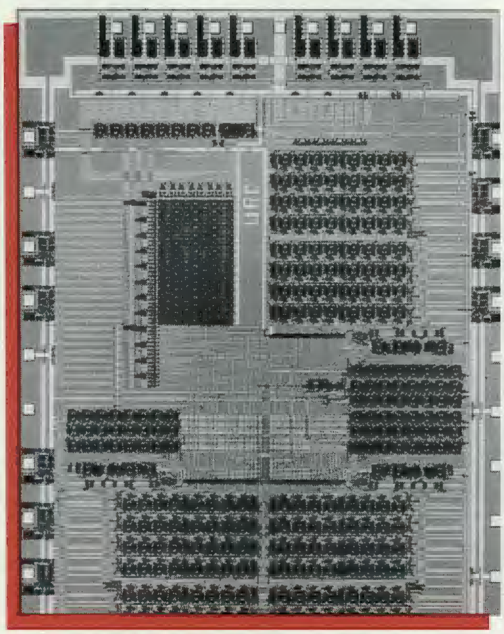
Designing Chips by Computer

Tiny silicon chips that can track the migration of Africanized "killer bees" or alert workers when they enter a high-radiation zone are being custom-designed at ORNL.

Gary Alley, Bill Bryan, and other members of the Research Instruments Section of the Instrumentation and Controls (I&C) Division are designing semiconductor chips using the latest computer and software technology. They are using advanced circuit synthesis tools developed as a result of government-sponsored research at universities across the country. Working at the new I&C Engineering Analysis and Design Synthesis (EADS) Center in Building 3500, they custom-design very-large-scale integrated (VLSI) circuits for the "bug-a-bee" and other projects.

This new ORNL capability is now available to other Laboratory researchers needing customized, application-specific integrated circuits (ASICs). Smaller size, higher performance, lower power consumption, and greater functionality are some of the benefits of these chip designs.

Although the EADS Center is primarily being used for ASIC design, software tools will be made available here for many other engineering tasks. "The heart of the new facility," says Bryan, "is a network of 32-bit engineering workstations, including those from Sun Microsystems, Apollo Computer, and Apple Computer. The I&C engineers use this system to develop, simulate, and test new custom chip designs as well as perform research on device structures."



This very-large-scale integrated circuit on a silicon chip designed by I&C Division personnel was fabricated under the auspices of MOSIS.

Several chips have already been fabricated and tested, and others are in different stages of design or fabrication. According to Alley, there are three main reasons to consider designing a customized VLSI chip:

- to develop an application-specific architecture that can't be feasibly implemented any other way;
- to produce a more cost-effective solution to a problem; and
- to miniaturize a circuit to meet a limited-space requirement.

Efficient Design Process

Creating a new customized integrated circuit has been a complicated process. However, by using the latest in VLSI circuit-synthesis tools, the I&C group can develop complex VLSI systems more efficiently than before. Each chip is composed of many layers of semiconductor materials and interconnects between layers. The lowest-level building blocks (leaf cells) are laid out at the transistor level. These cells are then "tiled" together (fitted together like blocks of a tile floor) to form higher-level building blocks or cells, and the process is repeated until the complete chip has been designed.

Before fabrication, engineers simulate the new design to verify operational functionality and timing. It is critically important that new designs are thoroughly simulated to reduce the risk of fabricating a chip having hidden design errors. Unlike errors on printed circuit boards, errors on VLSI chips are almost impossible to correct after fabrication.

When the chip designs are completed, they are sent electronically via the ARPANET to the MOS Implementation System (MOSIS) facility in Marina del Rey, California. This facility was set up by the National Science Foundation and the federal Defense Advanced Research Projects Agency to produce prototype semiconductor devices as a service to universities and research facilities across the nation. "MOSIS," Alley explains, "has the chips fabricated through contracts with silicon foundries such as National Semiconductor and Hewlett Packard. The cost for prototyping through MOSIS is very reasonable. For example, four packaged 2.3 × 3.4 mm chips in a 28-pin package can be fabricated for about $400."

"MOSIS processes our chips in much the same way as a store develops film for a customer," says Alley. "It fabricates and returns chips to the customer based on transmitted designs. MOSIS performs minimal electrical testing and no functional testing. It's the customer's responsibility to simulate the design before fabrication and to test the chips after fabrication." Chips are usually shipped to the customer eight to ten weeks after the design has been transmitted to MOSIS."

Bug-a-Bee Chip

The bug-a-bee chip is an example of what can be done when this capability is made available to researchers. Ken Valentine and Diedre Falter of the I&C Division have developed a method to track the migration of killer bees. A microchip having its own power source (tiny solar cells) and an infrared transmitter has been attached to the thorax of a dormant bee, which later made a successful "test flight." The infrared transmissions may be detectable for distances of up to ~ 2 km (0.8 mi.) by ground-based receivers.

In addition to the bug-a-bee project, several other customized chips are under development in the I&C Division. One of these designs, developed in support of a U.S. Navy health physics instrumentation program, is a programmable audio annunciator chip. This chip, when incorporated into a hand-carried health physics instrument, will generate several different alarm tones to provide an audible indication of the presence of radiation. Using such a flexible system, health physics workers able to recognize the audible cues could gauge radiation levels in areas of poor visibility or even in total darkness where the instrument's radiation-level display cannot be read.

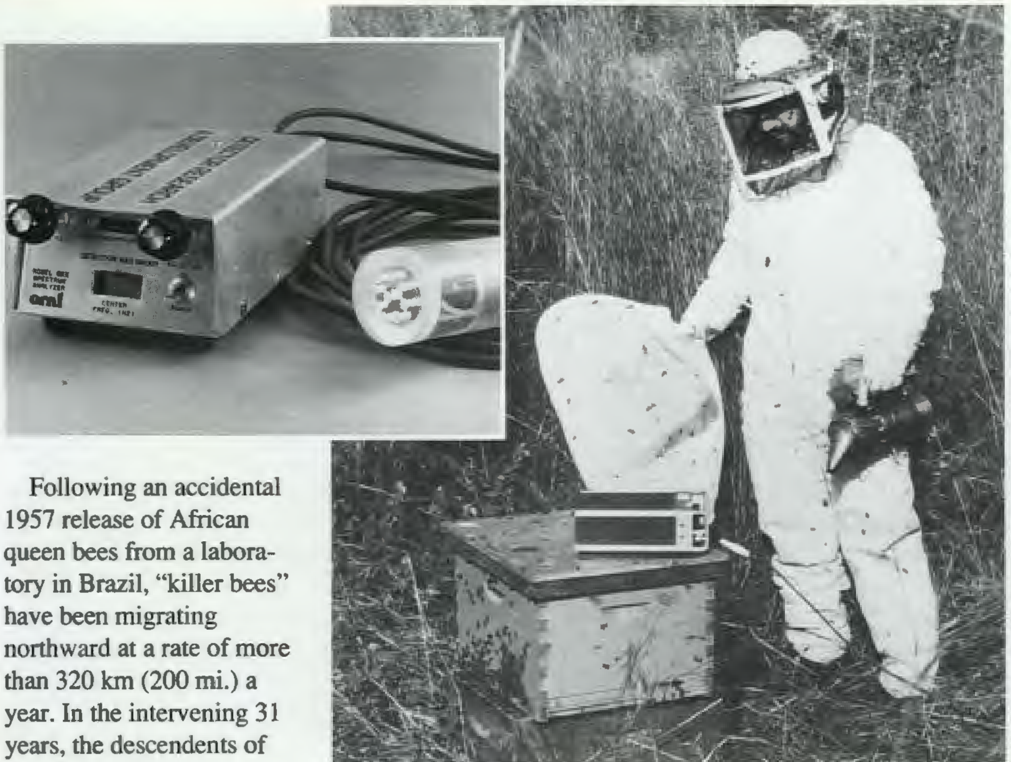
Other developments include a chip that digitally controls a high-voltage radiation detector and a generalized display-driver chip for a broad class of instruments. Most of the circuit designs thus far have been digital, but work is under way to develop analog circuit designs using the same process. Eventually, digital and analog circuits can be combined on the same substrate, increasing the versatility of the chip.

"With the new EADS Center resources," Alley says, "we now have the means to solve problems in unique ways. Custom VLSI design allows much more flexibility and creativity than design using off-the-shelf components. The availability of these computer design resources and prototyping services to the research community will enhance the competitive position of the United States in the world microchip market." ornl

"The availability of these computer design resources and prototyping services to the research community will enhance the competitive position of the United States in the world microchip market."

Bee Alert: The Killers Are Coming

A solar-powered, infrared-emitting microchip designed by the I&C Division is attached to the thorax of a European honeybee. Microchips like this one will be used to track the migration of Africanized killer bees, which are expected to invade the United States next year.



Howard Kerr calms residents of a Venezuelan beehive with a smoker, while recording wing vibration frequencies to determine whether Africanized bees are present. Inset: ORNL's Bee Spectrum Analyzer, which can detect the presence of Africanized killer bees in the hives of European honeybees.

Following an accidental 1957 release of African queen bees from a laboratory in Brazil, "killer bees" have been migrating northward at a rate of more than 320 km (200 mi.) a year. In the intervening 31 years, the descendents of the escaped bees have mated actively with new queen bees of domestic European varieties to form undesirable Africanized hybrids. These killer bees have nearly destroyed commercial beekeeping operations throughout the territories they have occupied. They are expected to cross the border between Mexico and the United States by 1989.

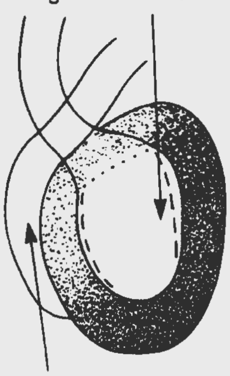
Although almost identical in appearance to domestic honeybees, the Africanized bees produce far less honey and are much more nest-defensive than the European species. Because these unpredictable bees have stung both animals and people to death, greater handling precautions and expensive protective gear are required for beekeeping operations. If our domestic bee population is overwhelmed by the Africanized species, as in other areas where they have migrated, the $20 billion annual production of U.S. agricultural crops requiring bee pollination could be threatened. Charting the migration of the Africanized species using the I&C Division's tracking device (see main article) will be essential to any attempt to control it.

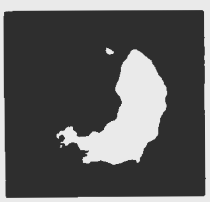
The killer bee problem is not new to the I&C Division. Engineers Mike Buchanan and Ken Valentine, together with Howard Kerr of ORNL's Engineering Technology Division, recently developed an instrument that improves the ability of scientists and beekeepers to distinguish between the European and Africanized bees. The I&C detector uses the same noise analysis technique pioneered at ORNL for identifying abnormalities in nuclear reactor operations. The Africanized bees move their wings with a slightly greater frequency than domestic species, and this difference can be detected electronically.

Kerr and Buchanan field-tested the instrument on hives of Africanized bees in Venezuela. A beekeeper and former president of the Tennessee Beekeepers Association, Kerr believes ORNL's new hand-held detector can help beekeepers quickly identify any hives that become infested with Africanized bees so they can be destroyed to prevent the spread of the killer species.

Images of the Heart

By RUSS KNAPP





Imaging agents help physicians diagnose and evaluate heart conditions.

After six years of effort, a group of Oak Ridge and Belgian researchers have developed and patented a prototype radionuclide generator system that will improve the diagnosis of heart diseases. The Nuclear Medicine Group of Oak Ridge National Laboratory, collaborating with scientists from the Cyclotron Research Center, University of Liege, Belgium, conducted most of the development work for the system at Oak Ridge. Clinical studies are being performed with the model system in several Belgian hospitals. U.S. patient studies are scheduled for 1988 at the University of Tennessee Memorial Research Center and Hospital (UTMRCH) and at Harbor Medical Center, Torrance, California. Several radiopharmaceutical companies have expressed interest in licensing the improved radionuclide generator system.

For many years, nuclear medicine practitioners have used radioisotopes such as technetium-99*m* (^{99m}Tc, half life = 6 h) by incorporating them into tissue-specific imaging agents for clinical diagnostic applications. Doctors then use radiation-sensitive imaging devices to evaluate kidney function or blood flow in the brain, tumors, or the heart chambers, depending upon which imaging agent is selected.

Radionuclide imaging techniques are particularly useful in cardiac care, where circulation changes may rapidly affect the patient's condition and where detailed information on blood flow is needed to guide physicians in prescribing and evaluating treatments. Nuclear medicine specialists use imaging techniques to determine blood volumes and flow patterns within the heart, to locate congenital heart defects, and to detect narrowing of coronary arteries. Plaque buildup in these arteries can deprive the heart of needed nutrients and oxygen; this and other factors can lead to muscle damage and possible myocardial infarction (heart attack).

In recent years, scientists have developed small bedside generator systems to produce ultra short-lived radionuclides (with half-lives of seconds, rather than hours) for such clinical applications. With these generators, the tissue-specific imaging compounds can be quickly produced and injected into the patient, minimizing exposure for both patient and health personnel. Like other such radionuclide generator systems, the ORNL model uses an ion-exchange column to separate the desired decay daughter from its parent radionuclide. The parent is retained at the top of the column, while the desired daughter nuclide is flushed by an eluting solution through the column for immediate injection into a patient's vein.

The few parent nuclides suitable for such medical use must be produced in cyclotrons or nuclear reactors. For example, cyclotrons produce radionuclides of krypton, gold, and tantalum that have clinical applications for producing imaging agents. One of the few reactor-produced isotopes used in radionuclide generators is osmium-191 (^{191}Os), which has been produced at ORNL.

An ideal radionuclide generator system for imaging should provide an ultra-short-lived nuclide (half-life <2 min), be portable (for bedside use), simple to operate, and reliable–that is, give reproducible results. In addition, it should minimize the radiation exposure for both patient and health-care personnel so that imaging studies can be safely repeated.

The half-life of the generated radionuclides should be long enough (usually at least 7 to 10 s) to allow adequate evaluation of blood flow through the heart's chambers after the imaging agent is injected (usually in an arm vein), yet short enough to preclude recirculation of the radioactive material through the patient's body. Finally, the daughter nuclide obtained from the generator should radiate photons of sufficient energy to be easily detected by the commonly used gamma-sensitive imaging devices.

The improved radionuclide generator developed by the Nuclear Medicine Group and researchers in Belgium satisfies these criteria and has been tested successfully in more than 600 patient studies. In the ORNL generator, the ^{191}Os parent, with a 15-d half-life, decays to produce an ^{191m}Ir daughter. If the iridium daughter is not contaminated by "breakthrough" of the osmium parent and if the performance and sterility of the generator are

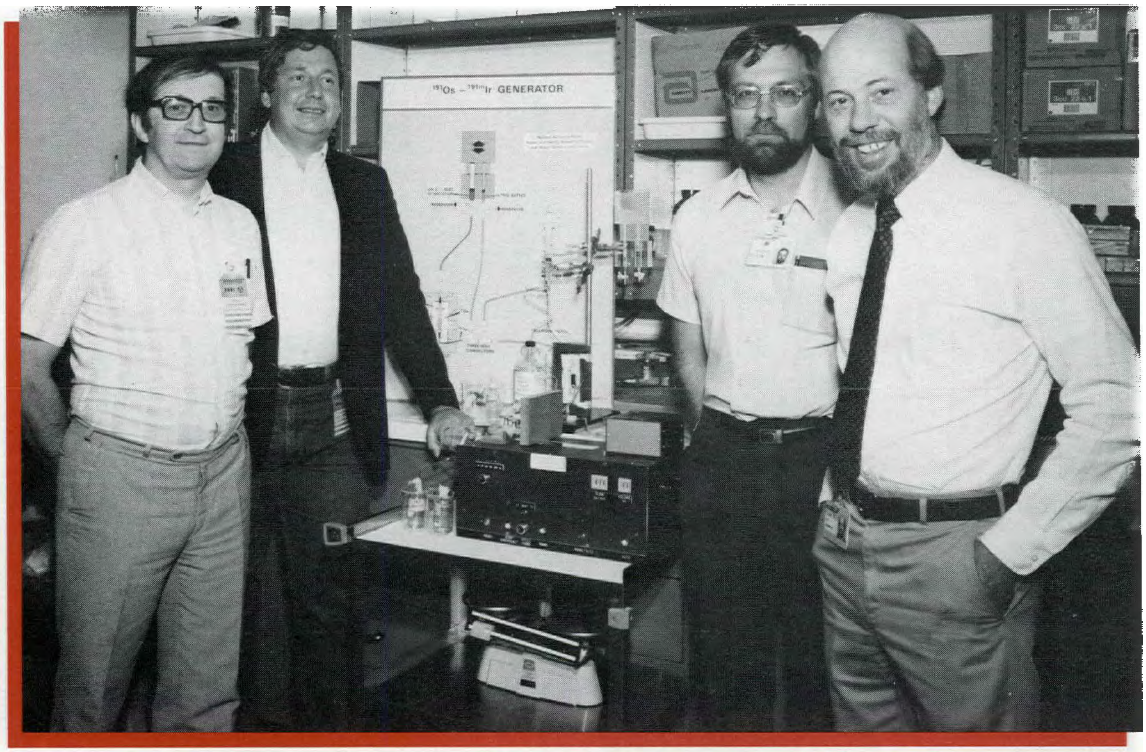
maintained, the generator system has a useful shelf life of at least two weeks. Because its iridium decay daughter has a half-life of only 4.96 s and emits gamma photons of a suitable energy (129 keV), it is a useful and safe agent that produces high-quality images.

In April 1983, Claude Brihaye, while on sabbatical leave from the University of Liege, Belgium, worked with me in the Health and Safety Research Division. We initiated an intensive screening program to evaluate the binding properties of three chemical forms of ^{191}Os, using 39 different ion-exchange adsorbents. Our objective was to determine which combination produced the best ^{191m}Ir yield in the shortest time. We found that Os(IV), as potassium hexachloroosmate, binds particularly well with heat-treated carbon. We used this information to develop a radionuclide generator that uses heat-treated carbon as the column adsorbent and a saline solution containing potassium chloride as the eluting solution. The generator has a high elution yield of 12 to 18%–that is, 12 to 18% of the ^{191m}Ir produced by the generator gets through the column and into the patient.

Our generator's high yield, coupled with the other favorable characteristics of our system–good shelf-life of the parent nuclide, limited radiolysis (damage) to the adsorbent during use, and production of a stable daughter radionuclide having adequate half-life and gamma energy for use in patient studies–makes it a superior system for clinical applications. An important additional advantage of this improved generator is its very low breakthrough of the parent ^{191}Os isotope into the eluting solution ($2 \times 10^{-4}\%$). Use of the ORNL generator system therefore minimizes the risk of patient exposure to the longer-lived parent radioisotope.

Since late 1984, more than 600 patient studies using the ORNL ^{191m}Ir generator have been completed at medical institutions in Liege, Antwerp, and Brussels, Belgium. Toxicity studies are scheduled to begin soon at the

Researchers screen new radiopharmaceuticals by injecting the agent in animal tissue, such as this rat heart, to check for any damaging effects.



Belgian collaborators, shown with the ORNL generator system they helped to test, are (left to right) Marcel Guillaume (Liege), Phillipe Franken (Antwerp), and Claude Brihaye (Liege). Russ Knapp (far right) invited them to present their test results at ORNL's radiopharmaceutical workshop.

UTMRCH in Knoxville. Physicians Karl Hubner, head of UTMRCH'S Nuclear Medicine Department, and Joe Fuhr, director of Academic Resources, will be coordinating these tests. We also anticipate that patient studies at the Harbor Medical Center will begin sometime in 1988.

Although the basic development work has been completed, potential commercial producers and users of the model generator system must address several important considerations: (1) determining the minimum neutron flux required for reactor production of ^{191}Os; (2) finding the most efficient and economical method for ^{191}Os purification; (3) developing procedures for generator fabrication and use; and (4) dosimetry considerations–ensuring that the radiation exposure of the technician administering the ^{191m}Ir is within permissible limits.

These issues were discussed in a July 1987 "Workshop on the Development of the Osmium-191/Iridium-191*m* Radionuclide Generator System and Other New Radiopharmaceuticals at Oak Ridge National Laboratory." Representatives from 12 private companies attended the workshop, and several of these companies have since indicated interest in manufacturing and marketing the ORNL device, if an exclusive license can be granted.

Belgian Patient Studies

The first clinical studies using ORNL's ^{191m}Ir generator system evolved from an effective international collaboration between our ORNL team and Brihaye with his colleagues at the Cyclotron Research Center, University of Liege, Belgium. Since the Belgian studies began in 1984 at the clinical section of the Cyclotron Research Center, interest in, and applications for, the technology have steadily increased.

Until it was idled in November 1986 for possible embrittlement problems, ORNL's High Flux Isotope Reactor (HFIR) was the principal source of the ^{191}Os parent isotope used in the Belgian clinical studies. When the HFIR was in operation, targets were irradiated there and then transferred to hot cell facilities in the ORNL

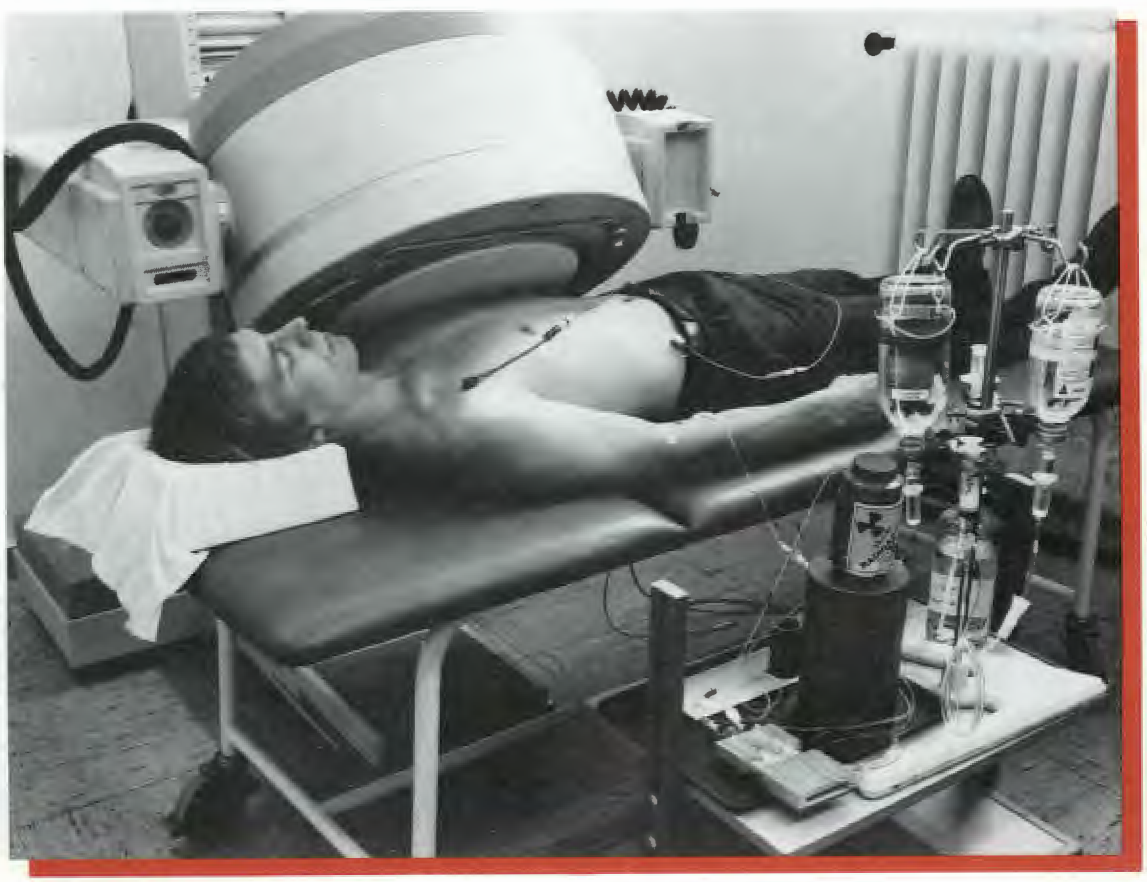
Isotopes Separations Area for chemical processing of the ^{191}Os. Careful coordination of the processing at ORNL with the clinical studies in Belgium was needed to minimize isotope loss through decay. After processing, the parent material was shipped by air to Brussels and then transferred to the University of Liege facilities for the additional processing and fabrication steps needed to convert the ^{191}Os to the desired Os(IV) species for use in the radionuclide generator.

At the Belgian Center, the parent radionuclide was loaded into the generator under sterile conditions. The entire system was then tested for performance and sterility to ensure its safety and effectiveness prior to clinical use. Because the time between the ^{191}Os isotope's discharge from the HFIR and its actual clinical use in Belgium consumed 8 to 10 d of its 15-d half-life, it was vital that delivery, processing, and testing occur on schedule.

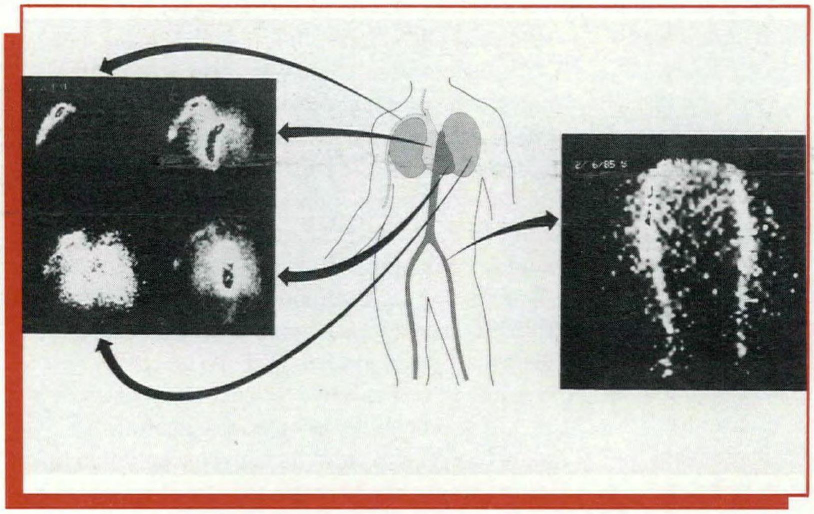
Effects of HFIR Shutdown

Our plans for continuing developmental studies at ORNL and clinical studies using the ^{191m}Ir generator in Liege were disrupted by the unforeseen prolonged 1986 shutdown of the HFIR, which produced the parent ^{191}Os isotope. For many years, the HFIR has been an important radioisotope production resource for ORNL's Nuclear Medicine Research Program. The high neutron flux of the HFIR is especially important in producing radioisotopes such as ^{191}Os, which is formed when a target enriched in ^{190}Os captures neutrons during irradiation in the reactor. Because ^{190}Os has a low production cross-section (i.e., low probability of capturing neutrons), a high-flux reactor, with its high concentration of neutrons, greatly increases the rate at which ^{190}Os atoms are transmuted to ^{191}Os atoms.

After the HFIR shutdown, we made arrangements with David Rorer of Brookhaven National



Patient positioned under gamma camera prior to intravenous injection of ^{191m}Ir from the newly developed ORNL generator system.



Selected gamma camera images illustrating passage of the radioactive ^{191m}Ir through the vascular system.

Laboratory (BNL) for use of the High-Flux Beam Reactor (HFBR) to supply ^{191}Os for patient studies. In the HFIR, a high ^{191}Os yield (~300 mCi/mg of enriched ^{190}Os target) can be produced over a 3-d irradiation period, using a flux of ~2.5 $\times 10^{15}$ neutrons/cm^2·s. In contrast, a 21-d irradiation period is required to produce ~225 mCi of ^{191}Os in the HFBR, at its lower operating flux of ~5 to 8 $\times 10^{14}$ neutrons/cm^2·s. Despite this lower production rate, enough of the parent isotope could be produced in the HFBR to continue our patient studies.

Unfortunately, the additional uncertainties and delays associated with shipping the ^{191}Os from BNL to Belgium often resulted in the material being delivered after a significant amount had been lost through decay. Our Belgian collaborators solved this problem by arranging for ^{191}Os production at a reactor located in Mole, Belgium. BNL has continued to supply the osmium isotope for our studies at ORNL.

German Patient Studies

During foreign assignment from July 1985 through August 1986 at the Institute for Clinical and Experimental Nuclear Medicine at the University Clinic in Bonn, Federal Republic of Germany (FRG), I coordinated the initial clinical studies there, using the ORNL model generator and patient volunteers. This work was performed as a cooperative effort with Hans J. Biersack, director of the Institute, and staff physicians Sven Reske and Joachim Kropp. Kropp will continue his collaboration on this and other projects during a guest assignment at ORNL during 1988.

In Bonn, I set up the generator system, developed detailed procedures for its use, and acted as a "catalyst" in initiation of the patient studies. These studies, and the extensive patient studies in Belgium, were essential for establishing the medical protocols that will allow us to meet the U.S. Food and Drug Administration's (FDA's) requirements for U.S. clinical use of the improved radionuclide generator.

Status of Clinical Studies

The Belgian clinical studies, performed by cardiologist Phillipe Franken and other medical investigators, focused primarily on the diagnosis of heart diseases. The short-lived ^{191m}Ir daughter produced by the improved ORNL generator model prepared in Liege enables physicians to make rapid, repeated heart studies without undue radiation exposure for patients and health-care personnel.

Iridium-191*m* is particularly helpful in evaluating differences in the blood volumes of the ventricles (pumping chambers) of the heart. An accurate determination of this parameter allows the cardiologist to evaluate ventricular performance both before and after therapy. Any difference in the volume of the completely filled ventricles (final diastolic volume) and completely contracted ventricles (final systolic volume) is an important indicator of cardiac function. This difference, referred to as the "ventricular ejection fraction," tells physicians how effectively the heart is pumping and whether the heart muscles surrounding the ventricular pumping chambers are contracting uniformly. Abnormalities in the pumping action may indicate previous muscle damage such as a "silent" heart attack or some congenital defect.

A typical clinical setup using the generator system is illustrated in the figure on page 35. The gamma camera is operated via computer and is capable of taking up to 40 frames per second, allowing continuous evaluation during passage of the radioactive injection (bolus), usually from an antecubital (arm) vein injection site. The venous blood carrying the injected radionuclide moves into the right atrium (upper pumping chamber) of the heart and passes through the tricuspid valve into the right ventricular pumping chamber. It is then pumped through the lungs, into the left atrium, through the mitral valve into the left ventricle, and through the aortic valve into the aorta for circulation throughout the body (see figure). The peaks and valleys of the simultaneous electrocardiographic (ECG) tracing correspond to the various phases of the pumping cycle in which the heart's chambers expand as they fill with blood and contract as they eject blood.

By feeding an electrocardiographic signal through the computer to activate the gamma camera at a rate of 25 to 40 frames per second, images of the final diastolic and final systolic volumes can be recorded during several successive cardiac cycles. Using these data and standard software, the computer calculates the ejection fraction, which may then be compared to a normal range of values for the left ventricle.

Iridium-191*m* is also useful for imaging heart morphology and for measuring blood flow in the brain and lower limbs. Its short half-life makes the iridium isotope superior to the traditionally used ^{99m}Tc-labeled blood-pool agents for first-pass tests. The much lower radiation dose to the patient allows repeated studies to evaluate the effects of exercise or pharmacological agents and (with repositioning of the gamma camera) better visualization of all muscle regions.

The Department of Energy has provided funds for toxicity testing of the new ORNL generator system to be conducted in conjunction with Hubner at the UTMRCH. The data from these tests are needed for filing an Investigational New Drug Application with the FDA, requesting permission for clinical testing of the system in the United States.

Technology Transfer

Patent approval for the ^{191}Os/^{191m}Ir radionuclide generator system was completed in 1987, and a patent waiver has been received by Martin Marietta Energy Systems, Inc., from DOE.

To encourage and expedite the technology transfer process, our group, in conjunction with Warren Siemens and Glen Prosser of the ORNL Office of Technology Applications, organized a workshop on technology developments in the ORNL Nuclear Medicine Program, which focused on the ORNL radionuclide generator. Speakers from ORNL's Nuclear Medicine Group, the University of Tennessee, and research collaborators from Liege and Brussels reviewed the patient studies and their own experiences using the new generator. A presentation by physician Ismael Mena, of Harbor Medical Center, outlined his plans to begin, in 1988, the first U.S.-based patient studies using the ORNL generator–probably for evaluating congenital heart defects in premature infants weighing as little as 1 to 1.5 kg (2 to 3 lb).

"Harbor Medical Center in Torrance, California, will use the ORNL generator to evaluate congenital heart defects in premature infants."

Most of the major radiopharmaceutical firms were represented at the ORNL workshop. The success of this gathering was partially the result of groundwork by Glen Prosser and Ernie Cadotte, associate professor of marketing at the University of Tennessee, who contacted opinion leaders in the field and in the commercial sector to determine their general preliminary response to ORNL's new radionuclide generator, predictions for its future use, and the best timing for the proposed workshop to ensure maximum participation.

Based on the favorable interest shown during and following the ORNL workshop and the potential commercial importance of the new radionuclide generator, Energy Systems is now pursuing the development of a licensing agreement with interested radiopharmaceutical companies. ornl

New Radiolabeling Technique May Aid Early Cancer Detection

In the early stages of cancer, the primary tumor often goes undetected until after it has metastasized–that is, spread the seeds of cancer to other parts of the body. Earlier detection could permit physicians to attack the cancer before it spreads and perhaps becomes untreatable. In almost all cases, this would greatly increase the patient's chances of survival and reduce the trauma of the cancer treatment.

Once a tumor begins to grow, it produces minute amounts of characteristic proteins called antigens. If these extremely small quantities of antigens could be detected, they would act as a "red flag" in the early diagnosis of cancer. Fortunately, special proteins called antibodies, which are produced by the immune system, seek out their specific antigens like guided missiles. If the antibodies to the tumor-associated antigens can be "tagged" with a radioisotope, the radiation-emitting antibodies can be used to locate, or perhaps even eradicate, new tumors.

My colleagues and I in the Nuclear Medicine Group of ORNL's Health and Safety Research Division form one of many research groups working in radioimmunodetection and radioimmunotherapy–designing the appropriate agents for radiolabeling antibodies that will aid in the detection or treatment of cancer. One of our major research goals is to find stable compounds to carry radionuclides of the appropriate energy. We are also working to make radiolabeled antibodies that will be safe for use in cancer diagnosis or therapy.

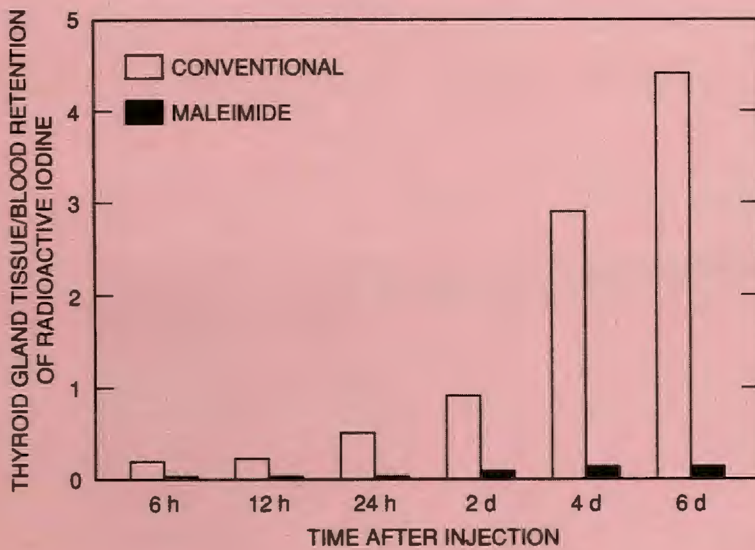
The traditional approach to the problem of radiolabeling antibodies has been to covalently bind the antibody of choice to a chelating agent to which a radioisotope has been attached. In the classical procedure, radioactive iodine (^{123}I or ^{131}I) is attached to the protein tyrosine, which is a part of the antibody. However, using conventionally radioiodinated antibodies for cancer diagnosis or treatment poses a problem: in vivo deiodination. That is, unwanted and potentially cancer-causing radioactive iodine could be released from the antibodies injected into the body, only to be trapped in the patient's thyroid or stomach.

The ORNL group has developed a labeling technique that avoids deiodination. The researchers designed and synthesized a new radiolabeled maleimide agent, an organic compound containing nitrogen, hydrogen, and oxygen, which can be covalently attached to a benzene ring (phenyl) that includes a stably bound ^{125}I atom. The new imaging agent, called iodophenylmaleimide, can be prepared using an iodine-reactive mercury acetate maleimide kit developed at ORNL. The agent has a strong affinity for the sulfhydryl (thiol) group that is naturally or artificially attached to the antibody which seeks out and locks onto proteins of the tumor antigens.

Although ^{125}I was selected for experimental reasons, the new agent could also be labeled with ^{123}I for diagnosis or with ^{131}I for therapy. Other radioisotopes that could be used with modifications of functional groups on the maleimide agent are indium-111, yttrium-90, gallium-67, and rhenium-188.

Our group at ORNL has prepared a chemistry kit in which the maleimide is ready for clinical use after radioiodination. Recently, ORNL supplied the maleimide agent to Donald J. Buchsbaum of the Department of Radiation Therapy, University of Michigan, for in vivo antibody studies.

Buchsbaum's preliminary studies, using mice implanted with melanoma and colon tumors, showed that the ORNL maleimide agent can label antibodies that seek out these types of cancer cells and that in vivo deiodination is insignificant (see figure). Buchsbaum's collaborative study used a cancer antibody labeled with the ORNL-developed maleimide agent in colon-cancer-implanted, "nude mice"–mice with impaired immune systems. An increase in thyroid uptake of radioactivity indicates in vivo loss of radioiodine from the antibody. As shown in the figure on the facing page, the maleimide-labeled antibody results in dramatically lower iodine retention in thyroid gland tissue, compared to iodine retention from use of the same amount of antibody labeled by a conventional technique.



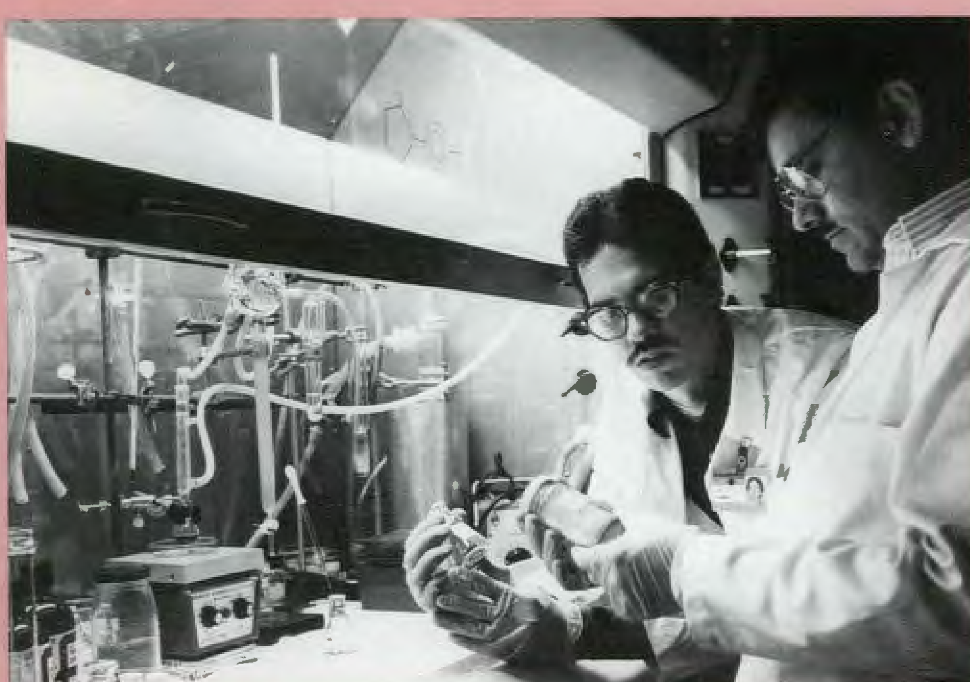
"Use of ORNL's maleimide-labeled antibody resulted in dramatically lower iodine retention in thyroid tissue than use of a conventionally labeled antibody."

The low thyroid uptake indicates a high relative in vivo stability of the ORNL-developed agent, which greatly decreases the patient's exposure to potentially cancer-causing radiation damage.

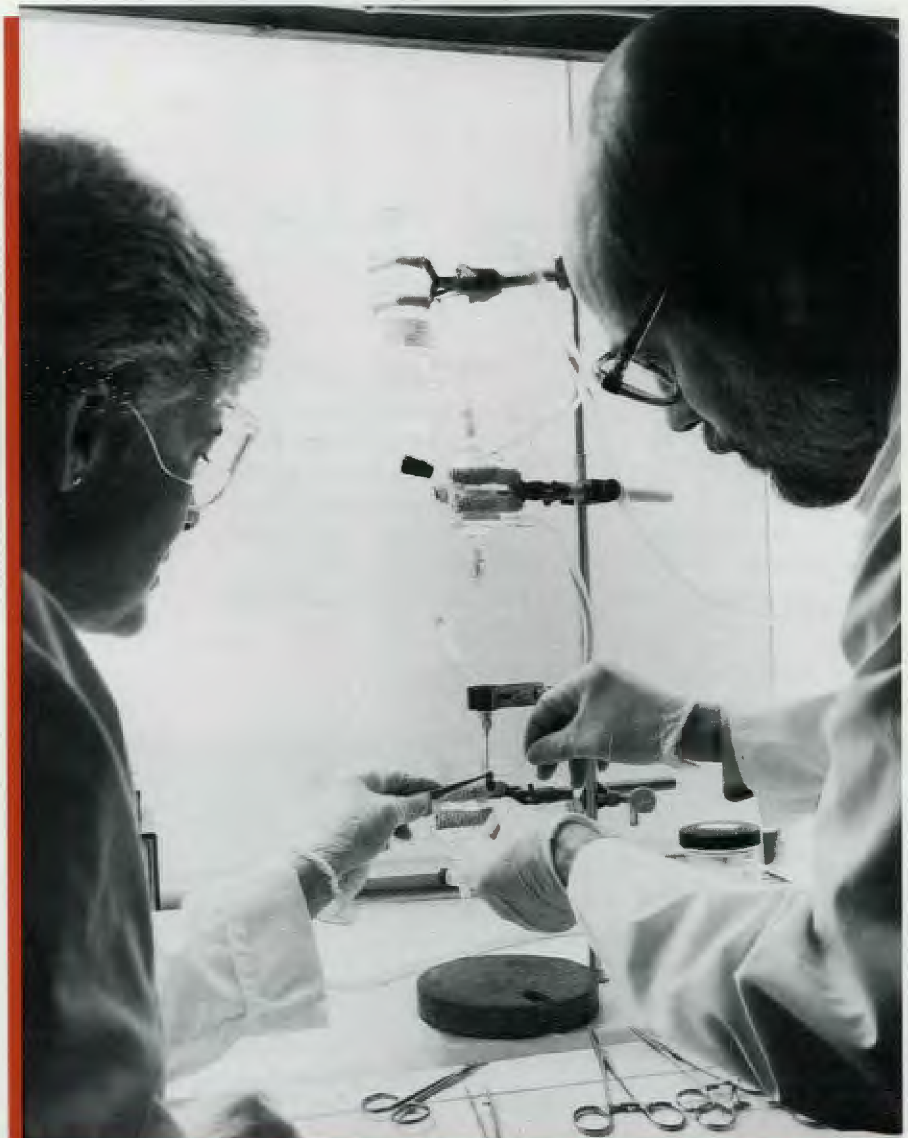
Studies done at ORNL to compare the performance of the ^{125}I maleimide agent and the ^{131}I tyrosine also confirmed that the ORNL agent results in less release and thyroid uptake of the radioactive iodine.

A U.S. patent application describing the ORNL technique for synthesizing the iodophenylmaleimide labeling agent has been approved. Radiopharmaceutical firms have expressed interest in using the technique for the commercial production of radiolabeled antibodies.

P.C. Srivastava, Health and Safety Research Division



P.C. Srivastava (right), assisted by John Allred, has developed a new technique for radiolabeling antibodies to detect cancer.



Nuclear medicine researchers Russ Knapp and Kathleen Ambrose evaluate the properties of a new radiopharmaceutical heart imaging agent, using the isolated perfused heart of a rat.

Biographical Sketch

Russ Knapp, leader of the Nuclear Medicine Group in ORNL's Health and Safety Research Division, is a native of St. Louis. He obtained his Ph.D. in biochemistry from the St. Louis University School of Medicine in 1970. After a two-year postdoctorate at the University of Liverpool, England, and a three-year appointment as research scientist with Rice University in Houston, Texas, Knapp joined ORNL in 1975 as a staff scientist in the Biomedical Radioisotopes Group of Operations Division. He has been in his current position since 1978, conducting research mainly in the development of new radioiodination techniques and new tissue-specific imaging radiopharmaceuticals.

Last Digits of Squares of Natural Numbers

By V.R.R. Uppuluri

By looking at the squares of the first few natural numbers $1^2 = 1$, $2^2 = 4$, $3^2 = 9$, $4^2 = 16$, $5^2 = 25$, $6^2 = 36$, . . . , you might conclude that the last digit of the square of any number must be either 1, 4, 5, 6, 9, or 0. This conclusion is correct. It can never end in 2, 3, 7, or 8.

The last two digits of the squares of two-digit integers 10, 11, 12, and 99 ($10^2 = 100$, $11^2 = 121$, $12^2 = 144$, . . . , $99^2 = 9801$) are 00, 21, 44, ... , 01. Only 22 different two-digit endings are possible for the squares of all natural numbers. They are 00, 01, 04, 09, 16, 21, 24, 25, 29, 36, 41, 44, 49, 56, 61, 64, 69, 76, 81, 84, 89, and 96.

Using a personal computer, you can find all possible three-digit endings for squares of natural numbers. These results should help you determine more quickly whether a natural number is a perfect square.

On a Bias in Voting

This is the second in a series of Take a Number *items on voting and elections from a mathematician's point of view.*

Suppose that three (s = 3) candidates must be selected from a slate of six (c = 6) in the election of a council of a professional society. Generally, no problem exists if all society members returning ballots choose exactly three of the six candidates, and the election results are unaffected by a block of voters who do not return their ballots because their potential votes can be assumed to be distributed equally among all candidates.

However, it is not unusual for some voters to select only one or two candidates. The election committee must decide whether to count these ballots or reject them because the voters ignored rules. Clearly, if a block of voters supports only one particular candidate and these ballots are included in the final tally, a bias exists in the election because other candidates are deprived of votes from this block. How can this bias be mathematically removed so that this block of votes may be included?

Based on the rationale that unreturned ballots do not affect the election's outcome, my colleague N. A. Fattu and I have proposed a correction to eliminate this bias. For example, if a block of 10 voters chooses only one candidate (d = 1), then, instead of giving this candidate these 10 votes, give him (or her) 6 votes based on the correction $\left(\frac{c - s}{c - d} \times 10 = \frac{6 - 3}{6 - 1} \times 10 = 6 \text{ votes}\right)$. Our formula is based on the interpretation that these 10 voters would like to see the specific candidate nominated but do not care which other two candidates are chosen from the remaining five on the slate. This procedure is equivalent to giving 10 votes to the specific candidate from the slate of six and 4 votes to each of the five candidates not chosen. The details of this bias correction procedure are discussed in our article in *The American Statistician*, Vol. 18 (1964), and a computer program using this formula is available.

"We have the best people around"

Interview with Associate Director Robert Merriman

Bob Merriman discusses his new job, nuclear power, ORNL's environmental problems, robotics, SDI research, and AVLIS for uranium enrichment.

Merriman at the High Temperature Materials Laboratory.

Bob Merriman has been Associate Director for Nuclear and Engineering Technologies at Oak Ridge National Laboratory since mid-1987. In that year, he also received the prestigious E. O. Lawrence Memorial Award for his work in uranium enrichment. A native of Maryville, Tennessee, he holds three degrees in chemical engineering—a B.E. degree from Vanderbilt University and M.S. and Ph.D. degrees from the University of Tennessee at Knoxville. He also participated in the executive management program of the University of Pittsburgh.

Following work as a summer student at ORNL in 1962, Merriman began his career in 1963 at the Oak Ridge Gaseous Diffusion Plant. Since that time, he has held a variety of positions in the technical, engineering, operations, and business areas of the enrichment program at Oak Ridge and Paducah. In 1984 when Martin Marietta Energy Systems, Inc., replaced Union Carbide Corporation's Nuclear Division as operating contractor for the Department of Energy's Oak Ridge and Paducah facilities, Energy Systems appointed Merriman director of Enrichment Production and Technology. In 1985, he was named vice-president for Enrichment Business Services. In this capacity, he traveled extensively while marketing DOE enrichment services to nuclear utilities throughout the world.

Merriman's work in chemical process development focused on isotope separation, nuclear fuel reprocessing, nuclear waste disposal, and special materials production. Besides the Lawrence Award, he has received the University of Tennessee's Outstanding Engineering Alumnus Award and the Robert E. Wilson Award.

In the following interview conducted in January 1988 by Carolyn Krause, *Review* editor, Merriman speaks about the programs in his research area. He is responsible for the Chemical Technology Division, Engineering Technology Division, Fuel Recycle Division, and a new ORNL division, the Enrichment Technology Applications Center, as well as the Reactor Programs, Nuclear and Chemical Waste Programs, Nuclear Regulatory Commission Programs, the new Space and Defense Technology Program (which includes Strategic Defense Initiative and acoustic instrumentation research), the Robotics and Intelligent Systems Program, and the Atomic Vapor Laser Isotope Separation (AVLIS) Program.

* * *

You have been at the Laboratory over six months. What strengths do you see at ORNL? What major problems face the Laboratory?

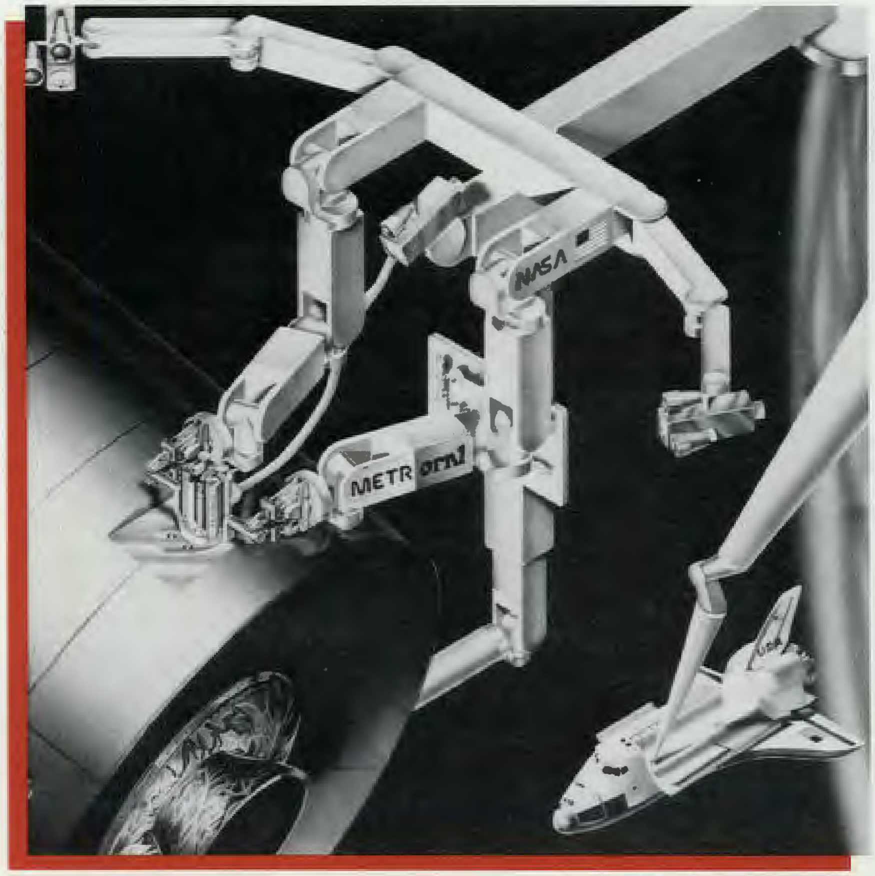
I'm most impressed by the technical capability and energy level of the Laboratory staff. Those are ORNL's strengths. In the past six months I've greatly enjoyed talking to people in my area and seeing what they do. I had forgotten how much I like technology-related work.

"I'm most impressed by the technical capability and energy level of the Laboratory staff."

Our problems include our environmental legacies, wastes left behind that must be cleaned up. Another challenge has been to restore our reactors and other critical facilities to top-flight operation, which is the key to maintaining our stature among research institutions. Beyond that, our problems are those of any national laboratory: highly debated national policies in our mission areas combined with funding constraints. Fortunately, we have the best people around to tackle these problems.

Now that energy problems are no longer pressing public issues and energy research has relatively low priority at DOE, compared with weapons research and development (R&D), what sort of future does ORNL have in energy research?

I think you have to take the long view of energy issues in this country. Energy policies are cyclical, a function of contemporary politics and international events. I think ORNL is probably the best place in the world for having a broad-gauged perspective on energy problems and opportunities. I think that is one of the strong points of this institution. As a service to the country, we need to find ways to preserve our energy research capability in the lean years, because energy will again be a problem that will demand attention. We have a lot to contribute, and our contribution will be badly needed. Energy is an area in which ORNL can provide true leadership to this country because we are very diversified and strong. So we must tough out the hard years.



The Man Equivalent Telerobot (METR) concept shown here was developed at ORNL to help NASA establish directions for future telerobotic efforts in space. ORNL has fabricated a ground-based research telerobotics system called the Laboratory Telerobotic Manipulator (LTM).

In your opinion, what is the outlook for the nuclear power and coal industries in the 1990s in the United States? What is the outlook for nuclear energy R&D and coal energy R&D at ORNL for the next few years?

I think both the nuclear and coal industries, in the next several years through the early 1990s, are in for continued hard times. Everybody can recite the litany of problems faced by both industries–financial, technical, and regulatory. The consequence of the years of problems, punctuated by events such as the reactor accidents at Three Milė Island and Chernobyl and concern over acid rain and the greenhouse effect, is the bottom line: no U.S. utilities will build any large central electrical generating station, nuclear or coal-fired, for the next decade because investors are not willing to take the financial risk.

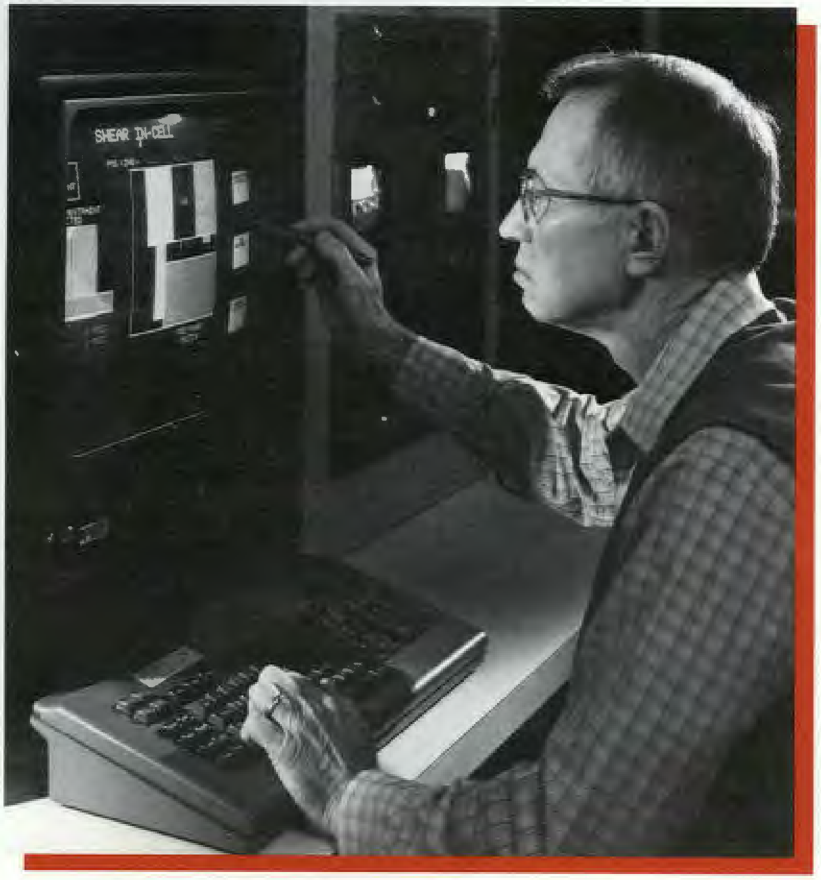
However, ORNL can help make nuclear power and coal technology more manageable by addressing safety, environmental control, and quality issues and developing technological improvements that put better products in the hands of manufacturers and utilities. For example, ORNL will try to fill critical niches through selected programs such as our Advanced Controls Test Operation (ACTO) initiative in the nuclear arena and through biotechnology developments in the coal area. Perhaps by the mid-1990s, we will see confidence restored in these technologies.

Do you think nuclear fuel reprocessing will be revived in the United States in the 1990s?

Commercial fuel reprocessing will not be revived in the United States in the next 10 to 20 years. There are many reasons for this predicament, including the lack of economic incentives. However, nuclear fuel reprocessing needs to be advanced in this country so that we can do a good job of producing materials for military programs, using whatever type of production reactor is selected. That initiative could be a shot in the arm for reprocessing R&D work.

ORNL's Fuel Recycle Division is devoting much of its work to NASA-funded space-station projects, robotics for space, and Japanese fuel recycle projects. Is the Division's mission shifting from reprocessing to robotics?

The Fuel Recycle Division is the country's flagship for maintaining reprocessing capability and advancing reprocessing technology around the



Wayne Johnson, an engineer in the Instrumentation and Controls Division, uses the control console to remotely operate equipment to disassemble and shear fuel elements. The fully operational system is part of ORNL's Consolidated Fuel Reprocessing Program.

world. Its main mission is the collaboration with Japan on their fuel reprocessing plant. Embedded in this division is a critical robotics program. I would not say that the division's mission has shifted to robotics, even though it has a very important robotics component. Because the Laboratory is getting more involved in robotics and teleoperator systems, one of the management issues for 1988 is how do we best organize the resources of the Laboratory to advance this technology?

Martin Marietta Corporation bids on many projects in space and defense. Some ORNL programs in your area have obtained funding for space and defense projects. Do these Energy Systems projects have any effect on Martin Marietta Corporation's efforts to win new government contracts in space and defense?

So far our work in these areas has not been a significant problem, primarily because ORNL and other Energy Systems facilities work on projects that are still in the developmental or prototype phase. The Department of Defense turns to industry for production work. That's where companies like Martin Marietta figure most heavily. We are very careful; we check with the Department of Energy, our sponsors, and the Martin Marietta Board of Directors to make sure we avoid conflicts of interest.

In a nutshell, what contributions has ORNL made to the Strategic Defense Initiative (SDI) Program designed to give the United States a ground- and space-based defense against enemy missiles? When President Reagan leaves office next year, the SDI program may be severely cut. Will some ORNL researchers lose their projects? Will ORNL's defense technology funding be affected by U.S. arms control agreements with the Soviet Union?

We have made a number of contributions to the SDI program. Perhaps the most prominent one currently is our development of shielding to protect our space assets from damage by kinetic energy and other types of weapons. In fact, President Reagan was shown a display of a point design shield developed by ORNL and the Oak Ridge Y-12 Plant at the recent SDI Science Fair in Denver. In that program, we've met objectives at a pace and with technical results that have pleasantly surprised all our sponsors. Right behind shielding is the optics work we are doing. We're very pleased that, as a result of what we've been doing in optics, we're in the running to be selected by SDI for a major role in the fabrication of some special optics hardware. That particular job would allow us to combine ORNL's technology capabilities with the computer-integrated manufacturing capabilities of the Oak Ridge Y-12

"Anything we can do to make the nuclear and coal industries healthier could reduce oil imports and, thus, the U.S. trade deficit."

Plant. I really like that idea. Energy Systems collectively has so much to offer the country. When we team up this way, we really put our best foot forward, and that's exciting.

I think generally the SDI as, a discrete program, will come on hard times. I don't know anyone in the country who can predict precisely how this program will shake out in the years to come. Much of the controversy seems to be over deployment issues, and that is a different arena from the development and demonstration projects in which Energy Systems is involved. One school of thought says that if Congress and the Administration back away from deployment, the result may be invigoration of the R&D. In all honesty, I have no feeling about the future of the SDI program except to acknowledge that it is a risky situation. I'd like to think that we are doing such a good job in optics and shielding and other areas that, even if the SDI program is radically restructured, the Defense Department will continue to fund this work here.

The recent arms control agreement concerns nuclear arms, and our defense technology programs are not involved in nuclear weapons areas, so the U.S.-U.S.S.R. pact probably will have little effect on ORNL. I think that ORNL and Energy Systems are building a good reputation within the Department of Defense in defense technology, a new area for us. As we do good work and turn out some first-class products, the Defense Department will realize that we have a lot of resources here that can be helpful. Although I anticipate that some individual projects in SDI or defense technology programs here will be cut, by and large the whole area of space and defense technologies will grow at ORNL and Energy Systems.

In terms of money and percentage of the ORNL budget, how high is the cost of cleaning up ORNL's hazardous chemical and radioactive wastes? What lessons might we learn from our costly cleanup efforts and waste R&D work?

I think we're going to spend over $1.5 billion over the next 25 to 30 years to clean up the wastes at this site. Today we're spending about 15% of the Laboratory's budget on waste-related

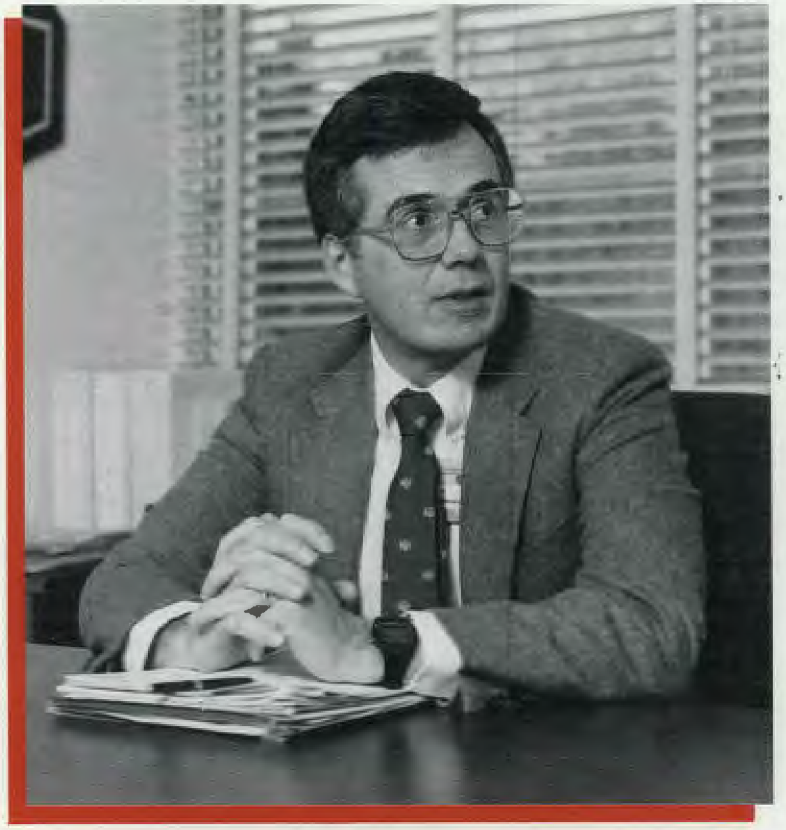
Kay Vandergriff, a mechanical engineer in the Fuel Recycle Division, checks a gear pump module used for the Advanced Servomanipulator, which has been developed for remote operations in fuel reprocessing and other hazardous environments. A schematic of this device shows on the screen.

activities. I don't see that proportion decreasing.

I hope the lessons we learn will include recognizing the importance of using our very best technologies to reduce these cleanup costs. I am concerned that the price tag of $1.5 billion will hurt the Laboratory's ability to compete with other laboratories for research programs. Our challenge is to figure out how to tackle the waste problems in a less expensive way. I'm satisfied that we have the best people working on these problems. We have internal resources to develop innovative technologies, and through the Waste Management Technology Center, we have an excellent channel for accessing the best technologies commercially available.

Our waste management program, which includes the R&D work, faces the agonizing dilemma of compliance, on the one hand, and taking the time to seek more cost-effective solutions, on the other hand. In some cases, we are already facing regulatory problems. Thus, we have a sense of urgency to solve these problems now; we don't have enough time to spend in the laboratory or to go out to industry to find a range of options to evaluate. So, we have to read the trajectory of our waste problems accurately and select those that allow us time to get funding and conduct research or canvass the commercial sector for innovative, cost-effective solutions. Because of the general Oak Ridge emphasis on environmental matters, I'd like to think that ORNL is ahead of many other laboratories in waste management. Therefore, I believe the country will benefit from our experiences. Hanford Engineering

"We have greatly reduced generation of waste in the past few years."



Development Laboratory, Idaho National Engineering Laboratory, and other DOE facilities have tremendous cleanup jobs ahead of them. We should view many of our projects as prototypes that can be used by other DOE facilities.

As for ongoing operations, our approach to waste management includes the reduction of waste volume. We have greatly reduced generation of waste in the past few years. The chargeback scheme that we are phasing in at the Laboratory will add an economic incentive to encourage waste generators to reduce the quantities of materials discharged from their operations.

What is your role and ORNL's role in the AVLIS program for increasing the efficiency of producing enriched uranium for fueling nuclear power plants? What problems remain to be solved? What are the chances that Oak Ridge will be the site of the AVLIS commercial production plant?

I wear two hats right now. In addition to working for the ORNL Director as an Associate Director, I also report to the Energy Systems Senior Vice-President as the Energy Systems AVLIS program manager. I think DOE takes the view, which I certainly share, that Energy Systems can bring the commercial and production perspective to the AVLIS program.

ORNL's role in the AVLIS program is quite extensive. The Laboratory has always been a vital member of the AVLIS team. The primary activity today resides in the Metals and Ceramics (M&C) Division, where work is conducted on advanced materials and systems for handling liquid uranium. In fiscal 1988 or 1989, ORNL will become involved in two other AVLIS activities. One is the demonstration of an advanced electrolytic reduction scheme for preparing uranium metal feed for the AVLIS process (M&C and Chemical Technology divisions). The other is the demonstration of advanced solvent extraction techniques for purifying the AVLIS product (Fuel Recycle Division).

When DOE selected the AVLIS process in 1985, it identified some technical issues and continued the charter of an independent technology review panel to oversee the program and report back to DOE periodically on the progress. Very recently this panel stated that the key scientific issues it had identified in 1985 had been satisfactorily resolved. Clearly, the process works. It will separate uranium isotopes. So, now the challenges are to solve numerous engineering issues to establish competitive process economics. We are making progress in this area. For example, in the AVLIS facility at Lawrence Livermore National Laboratory, the world's highest-average-power, visible-light-laser system has been running round-the-clock for over two years. Still, we have many difficult problems ahead in the engineering area. We have to scale up the lasers and separators, package them with a commercial orientation, and convince ourselves that we can enrich uranium at half the cost of gaseous diffusion—less than $50 per separative work unit.

The key to solving these problems is the demonstration pilot plant being built at Livermore. ORNL is playing a large role in this effort; the electrolytic reduction and product purification schemes that we will develop will be "long-distance" pieces of the Livermore pilot plant. We have the uranium-handling infrastructure, and Livermore has the laser infrastructure. That's why portions of the pilot plant will be built at both Livermore and Oak Ridge.

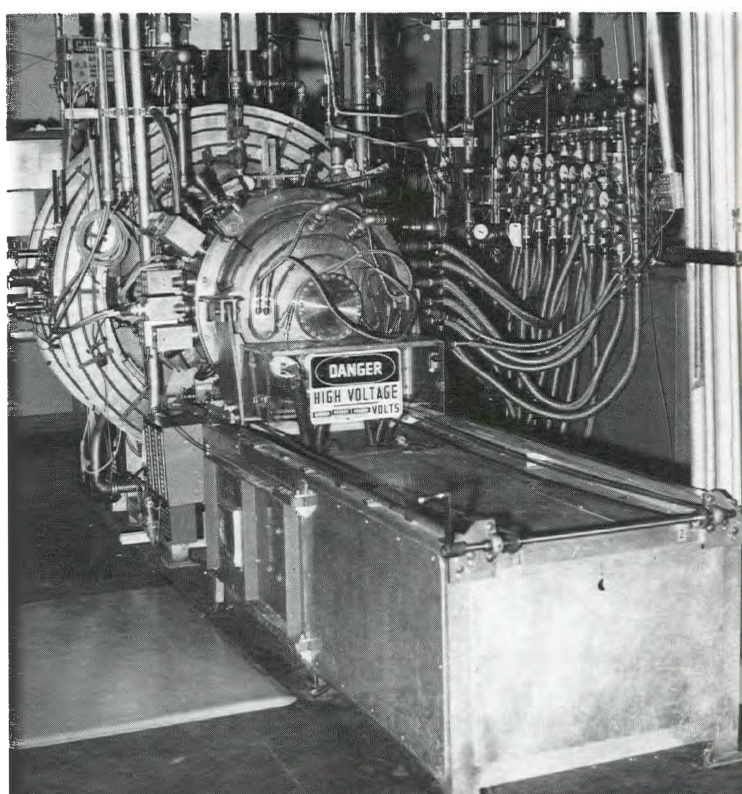
If the pilot plant is successfully operated in 1991, I think this country will move ahead with a commercial AVLIS facility, and I think Oak Ridge would be a very strong candidate for the site. I believe any of the three enrichment sites are preferable to other sites and that all three, including Oak Ridge, will be considered for the commercial facility. We have good people and much experience in enriched uranium technology and production.

Competitiveness is a dominant theme in Washington, D.C. What efforts in your area might contribute to making U.S. companies more competitive in the export market and reducing the U.S. trade deficit?

I think the competitiveness theme, which is popular in Washington, is a bonafide theme for this Laboratory. For example, our robotics program has much potential for assisting American industry in improving both productivity and quality. Frankly, we don't have any major interactions with industry in this area yet, but it is one of our long-term objectives. Another area expected to contribute to U.S. competitiveness is our biotechnology work, which has potential for revitalizing research in the fuels, agricultural, and chemical industries. A third area is our nuclear technology program. The nuclear industry is still a big business in this country. U.S. firms sell nuclear fuel and reactor components. Our work in advanced controls (e.g., ACTO) could result in high-technology projects that could be used by nuclear firms.

We are doing work in carbon-carbon composites, primarily for defense purposes. As this project becomes successful, we can expect tremendous spinoffs to the aerospace industry.

"If the pilot plant is successfully operated in 1991, I think the country will move ahead with a commercial AVLIS facility, and I think Oak Ridge would be a very strong candidate for the site."



The EB-I separator facility tests the performance of advanced material systems in the specific environment of an AVLIS separator.

Barry Burks checks the operation of HERMIES-IIB, ORNL's robot that can navigate between obstacles, pick up and move small objects, and locate and read meters on a control panel.

The Chemical Technology Division is examining the potential of the sol-gel process for mass-producing high-temperature superconducting materials. This work could benefit the U.S. electronics industry.

What we do in the environmental area may assist U.S. industry because most industries must deal with environmental problems, that consume their resources. If we can come up with innovative waste-treatment and disposal methods that can save industry money, then U.S. industry can invest in increasing productivity and better our competitive position in world markets.

The last question concerns a major management issue for the future. How can ORNL overcome barriers to cooperation with industry to help produce innovative, marketable products and make the United States more competitive in world commerce?

Industry-laboratory cooperation is a broad issue that affects all federal laboratories, not just ORNL. Competitiveness is a pivotal problem facing the country. Basically, there are many barriers and disincentives to the kind of cooperation that would increase efficiency of innovation of marketable products. We'll do what we can to chip away at the problem, but it will be sticky for the next several years. This area requires rethinking by the Administration and Congress to determine how best to link the technical, scientific, and commercial resources to help the country put its best foot forward. Some new legislation and

Merriman converses with Metals and Ceramics Division researchers Larry Allard (left) and Ted Nolan.

policy changes will be required.

But, in the meantime, we're not letting the current barriers paralyze us and we're not "hand-wringing." Energy Systems is conducting an aggressive, successful, and widely acclaimed technology transfer program. Thus, ORNL can be a good voice for the technical community. We can provide other laboratories, the Administration, and Congress with information about our successes, as well as the problems we encounter, in laboratory-industry interactions. I hope the climate will permit these parties to consider our suggestions for improvements. I'm optimistic that the right changes will be made. This is a great country; it's really second to none in terms of resources, spirit, and attitude. Our country responds best when faced with a tough challenge. As our back gets to the wall in international competitiveness, I'm optimistic that our "can do" spirit will be contagious and turn things around. I think ORNL is well-positioned to articulate ways to link technical and commercial resources to help keep this country great in world trade. ornl

Microwave Processing of Ceramics: An Interdisciplinary Approach

By Carolyn Krause

Ceramics and microwaves—they suggest the familiar image of a covered dish in a microwave oven. To Hal Kimrey of ORNL's Fusion Energy Division, however, ceramics and microwaves offer an exciting technical challenge. He has seen ceramics fracture after exposure to microwaves. He has also seen the promise of high-frequency microwaves for uniformly heating, shrinking, and strengthening ceramic materials.

In collaboration with materials researchers Mark Janney and Paul Becher of ORNL's Metals and Ceramics (M&C) Division, Kimrey has found that stronger, denser ceramics can be produced at lower temperatures using high-frequency microwaves than using conventional radiant heating. This discovery could revolutionize ceramics processing and the quality of ceramic products.

In microwave heating, energy is absorbed throughout the material. As a result, the material heats uniformly without variations, or gradients, in temperature. In conventional radiant heating, energy is absorbed only at the material's surface, then moves slowly by conduction into the material's bulk. The resulting temperature gradients cause stresses because of thermal expansion and because some parts of the material shrink faster than others; such stresses can result in fracture.

"The more uniform temperature distribution provided by microwave processing," says Kimrey, "leads to rapid heating rates, more uniform shrinkage, and more uniform microstructures in ceramics. The resulting microstructure increases the material's strength."

Using conventional radiant heating, manufacturers can produce ceramic products of high density at temperatures approaching 1600°C. Using microwave heating, ORNL researchers have increased the densities of ceramic samples of aluminum oxide, or alumina, to 97% of the theoretical density at temperatures as low as 1100°C.

ORNL researchers believe that the microwave technique could be used to improve the properties of ceramic components having large complex shapes. It may also increase the production speed, yield, and quality of ceramic products.

"The idea of using microwaves for this purpose is not new," says Kimrey, "but we are the first group to heat-treat large ceramic components successfully using high-frequency microwaves. Through our experiments, we have found a furnace design that produces uniform microwave fields over a very large volume. As a result, the material is rapidly and uniformly heated."

"This project is ideal for an interdisciplinary laboratory," says Mark Janney, a collaborator from the M&C Division. "M&C offers ceramics expertise, and the Fusion Energy Division offers an unusual processing technology because it has the only microwave furnace of this type in the world. Now the challenge is to prove the potential of this new tool. It could revolutionize ceramic processing technology and produce ceramics that perform better than previously believed possible."

The new process could produce ceramics for advanced gas turbine engines, lightweight defense armor, and electronics, including improved high-temperature superconducting materials (i.e., materials that conduct electricity with virtually no resistance and heat loss). Other uses could be the production of specialty glasses and the joining of ceramic parts.

"We are now testing the technique to see whether it improves properties of new superconducting ceramics," says Bill Snyder of ORNL's Engineering Technology Division, who is coordinator for the Laboratory's new Microwave Processing Project.

How It Started

The project began in 1984 when Kimrey began looking for alternative uses for the gyrotrons in the Fusion Energy Division. A gyrotron is a device that generates high-frequency microwaves from a beam of electrons made to spin, or gyrate, in a magnetic field. ORNL had used these microwave tubes to heat plasmas in the Elmo Bumpy Torus (EBT), an experimental fusion device that was shut down in 1984. In his search for new gyrotron applications, Kimrey conferred with Paul Becher, Matt Ferber, and Vic Tennery of the M&C Division. He had previously worked with them on a gyrotron problem involving ceramics.

The gyrotron has windows, which hold a vacuum in the microwave tube but allow the microwaves to pass from the tube for transmission to the fusion vessel. During the development of the gyrotron, the manufacturer (Varian Associates, Inc.) experienced many window failures. Fusion Energy Division researchers asked the M&C Division for help in solving the problem. Through modeling, Ferber and Kimrey correlated microwave power level and frequency with the performance limits of ceramics. The ceramists extended these models to the study of failure behavior—that is, how stresses on the ceramic lead to cracking. Through their experiences in these studies, the researchers saw the potential for densifying ceramics using high-frequency microwaves.

Knowing that the EBT project was about to be terminated, ORNL personnel (in late 1984) wrote a proposal to study the use of microwaves for ceramic processing. Kimrey was not the first at Martin Marietta Energy Systems, Inc., to consider this approach to processing ceramics. Since 1982, Cressie Holcombe of the Oak Ridge

Jim Holder (top), R&D mechanic who built this apparatus, and Hal Kimrey (left) check the copper waveguide vessel that contains microwaves produced by a gyrotron at ORNL's Fusion Energy Division. A gyrotron is now being used to test microwave processing of ceramics.

Y-12 Plant (who holds more patents than any other Energy Systems researcher) had been testing the use of microwaves at 2.45 gigahertz (GHz) to process ceramics and metals. However, Kimrey's proposal was to use a gyrotron to process ceramics with microwaves at 28 GHz, more than 10 times the frequency used by Holcombe.

In March 1986, while working with the Y-12 Plant's Gordon Godfrey, Kimrey heated alumina samples at 28 GHz, increasing their density to nearly 98% of the theoretical density and becoming the first to scale up microwave processing to large samples (up to 320 cm^3). This scaleup was made possible by gyrotron technology, which provided for the first time significant average power (200 kW, continuous wave) in the upper-microwave-frequency regime (28 to 140 GHz). "By processing materials at 28 GHz instead of 2.45 GHz, we found that about 25 times more power can be delivered for heating high-purity alumina," says Kimrey. "Alumina is difficult to heat at 2.45 GHz, but it can be heated easily at 28 GHz."

In fiscal year 1986, Kimrey, Becher, and co-workers were awarded $350,000 from the ORNL Director's R&D Fund to test microwave processing of ceramics. The M&C Division asked ceramist Mark Janney to collaborate with Kimrey in this interdisciplinary project; Janney began work with Kimrey on Dec. 7, 1986.

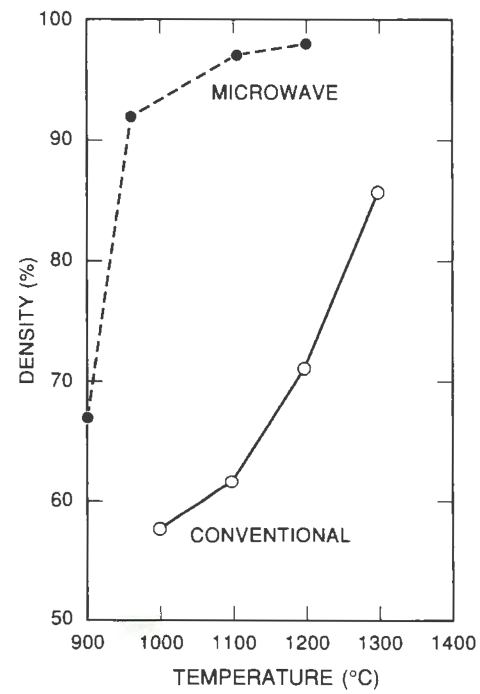
Microwave processing densifies alumina at lower temperatures than conventional ceramic heating.

Advantages and Applications

The new ceramic processing technique employs an ORNL gyrotron to power a cavity about 15 times the size of a typical microwave oven. Because the cavity is large and "untuned," the microwaves rebound from the walls in many directions, blanketing the sample and thus heating it uniformly. Gyrotron high-frequency microwaves also "weakly couple" with the microstructures, allowing for a depth of penetration rather than surface heating of the sample. As a result, energy is deposited throughout the sample, forming uniform microstructures and permitting full densification.

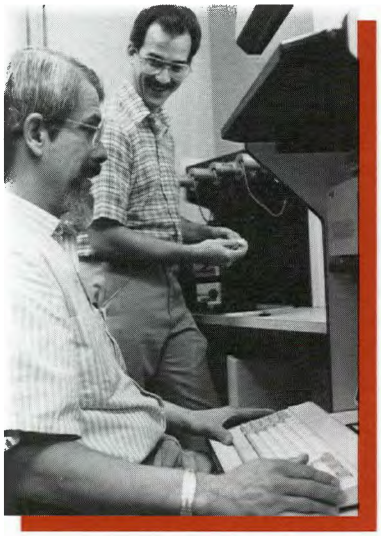
M&C researchers have discovered that the microstructures of alumina samples sintered by microwaves are more uniform than those of samples sintered by radiant heating.

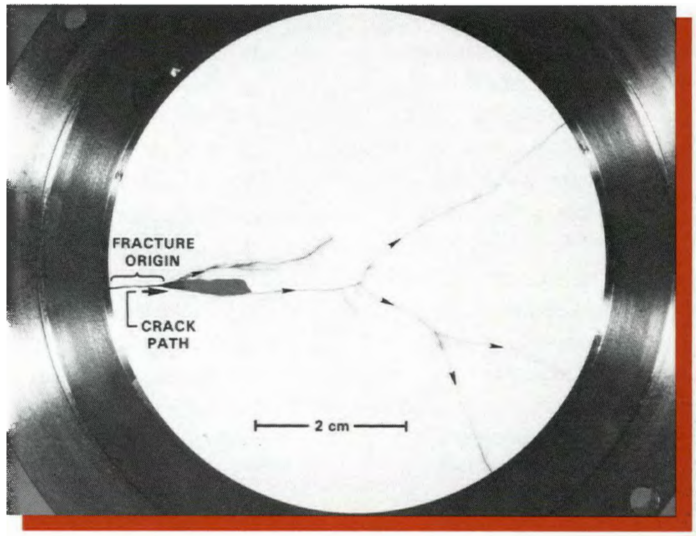
Microwave processing can be used to heat-treat large ceramic parts having complex shapes. Ceramic components processed this way easily reach the temperature at which they sinter (i.e., form a highly dense, coherent mass without melting) and avoid the formation and growth of "interparticle necks." These necks, which easily



form at the low heating rates typical of conventional radiant heating, limit densification.

The ORNL microwave process can produce difficult-to-make monolithic ceramics without adding the impurities required for conventional processing. Eliminating or reducing the impurities will increase the high-temperature strength of monolithic ceramics, such as alumina, silicon carbide, silicon nitride, titanium boride, and titanium nitride. Ceramic composites and whisker-





Mark Janney inserts a sample of microwave-sintered alumina in a mercury porosimeter as Paul Becher examines data on the microstructure pore size.

Cracks in gyrotron windows motivated ORNL researchers to study the effects of high-frequency microwaves on ceramics.

reinforced or particle-reinforced ceramics can also be made using the microwave process. All these materials have high fracture toughness, hardness, compressive strength, and tensile strength.

Very dense ceramic components having complex shapes are required for "heat engines," such as advanced gas turbines, which will be operated at extremely high temperatures to maximize fuel use. These energy-efficient devices will use heat-resistant ceramic components rather than metal parts, which would melt at such high temperatures.

Strong ceramics are also needed to build lightweight armored helicopter seats to protect pilots and for a new generation of armored personnel carriers and tanks that will be lighter and faster than their steel predecessors.

It is thought that microwave processing could have the same effect on high-temperature superconducting materials as on alumina. In addition, the use of microwave processing to increase the density of these materials might also permit them to carry more current.

From their development of hardware and procedures for routine processing of alumina at 28 GHz, Kimrey and Janney learned that microwave processing

- can sinter alumina to high density at remarkably low temperatures (e.g., 97.3% density after sintering at 1100°C for 1 h);
- can uniformly heat samples at up to 200C°/m in heating rates,
- does not eliminate the need for adequate processing of powder before sintering;
- does not remove agglomerates and other defects in starting materials, and
- offers the potential for improving the properties of already-formed ceramic components having complex shapes because of the uniformity of the microstructure.

The exact mechanisms by which microwave processing accelerates sintering and increases densification are not understood, but ORNL scientists are searching for the answers. Their chances of better understanding the mechanisms and applications of microwave ceramic processing are high because of ORNL's interdisciplinary approach. ornl

RE: Awards and Appointments


Clyde Hopkins


Herman Postma


Alex Zucker


Bill Appleton

Martin Marietta Energy Systems, Inc., has made several organizational changes recently. **Clyde Hopkins** has been appointed president of Energy Systems, replacing **Ken Jarmolow**, who has been named vice-president for technology planning for the Corporation.

Herman Postma, former ORNL director, has been named to succeed Clyde Hopkins as senior vice-president. **Alex Zucker**, ORNL associate director for the physical sciences, is serving as acting ORNL director during the search for a permanent director. **Bill Appleton**, director of the Solid State Division, is acting associate director for the physical sciences, and Fred Young is acting director of the Solid State Division.

Caleb B. Hurt has been elected president of the Board of Directors of Martin Marietta Energy Systems, Inc., and chief operating officer of Martin Marietta Corporation. **Norman R. Augustine** has been elected chief executive officer of the corporation.

R. Mack Wilson has been appointed vice-president for personnel for Martin Marietta Energy Systems, Inc. He replaces Bob McAllister, now director of compensation and benefit planning of Martin Marietta Corporation.

Liane B. Russell has received a DOE Distinguished Associate Award for her "research accomplishments of highest distinction in mammalian genetics, reproductive and developmental biology, and radiation biology." According to the citation, her "accomplishments at the leading edge of biological research have profoundly influenced scientific thought and made uniquely important contributions toward the development of sound national policies regarding radiological health protection."

L. Dean Eyman has been named director of the Hazardous Waste Remedial Action Program (HAZWRAP) for Energy Systems.

Timothy Myrick has been appointed head of the Waste Management Section in ORNL's Operations Division.

Sam Hamblen has received the Federal Energy Efficiency Award and the U.S. Department of Energy's In-house Energy Management Award. He was recognized for "outstanding individual effort" in his contributions to new energy-efficient building designs and a computerized utility allocation program. His effort resulted in energy savings of about 429 billion Btu's and an annual cost reduction of nearly $1.5 million.

Stan A. David, John M. Vitek, Paul Halton, and **Allison Barcomb-Baldwin** have received the 1987 International Metallographic Contest Best-in-Show Pierre Jacquet-Lucas Metal Award.

Sylvia S. Talmadge has received a second-place award in the category of outstanding student papers from the Society of Environmental Toxicology and Chemistry. Her paper is entitled "Small Mammals as Monitors of Environmental Contaminants."

Frank C. Kornegay has been named manager of the Risk Management Program of ORNL's Environmental Compliance and Health Protection Division.

John F. Cooke has been elected a Fellow of the American Physical Society.

Charles D. Scott has been elected director of the American Institute of Chemical Engineers.

Michael M. Miller and **Joseph A. Horton** received an Outstanding Paper Award from the journal *Scripta Metallurgica* for "An Atom Probe, Field-Ion Microscope Study of Boron-Decorated Boundaries in Nickel Aluminide (Ni_3Al)."

John Vitek received the annual Outstanding Paper Award from *Acta Metallurgica*, the premiere international journal of metallurgy, for "Diffraction Effects from Internal Interfaces."

Patrick P. Camus received the E. W. Muller Outstanding Young Scientist Award for his presentation and paper entitled "Atom Probe Analysis of Clustering Above a Miscibility Gap." The award was given at the 34th International Field Emission Symposium in Osaka, Japan.

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

O. Bill Morgan has received a Distinguished Service Citation from the College of Engineering at the University of Wisconsin. Morgan, who holds a doctorate from this university, was cited for 'his pioneering development of intense neutral beams and for his outstanding fusion program management."

The Environmental Sciences Division (ESD) has made several organizational changes. **R. I. Van Hook** has been named ESD associate director. **Webb Van Winkle** is manager of the new Ecosystem Studies Section. **Carl Gehrs** is manager of the new Environmental Toxicology Section. **Dale Huff** is manager of the new Environmental Engineering and Hydrology Section. **Steve Stow** has been named manager of the new Geosciences Section. **Judy L. Trimble** has been named manager of Technical and Administrative Services, **Frances E. Sharples** has been appointed group leader for environmental compliance in the Environmental Analyses Section, and **Robert B. Fitts** has been named program manager for the Department of Energy Environmental Survey at ORNL.

Each year the *Journal of the American Statistical Association* (JASA) selects one research paper as its JASA Theory and Methods Invited Paper for presentation at the annual Joint Statistical Meetings. The paper selected for 1988 is "Bayesian Variable Selection in Linear Regression", by **John J. Beauchamp** and **Toby J. Mitchell**. JASA has organized a whole session devoted to the paper, which will appear in its December 1988 issue.

Martin S. Lubell has been appointed to the new Superconductivity Technical Committee of the American Society of Mechanical Engineers.

Two publications of cryobiologist **Peter Mazur** have been designated "Citation Classics" by the Institute for Scientific Information. The papers are "Kinetics of water loss from cells at subzero temperatures and likelihood of intracellular freezing," *Journal of General Physiology* (47:347-369, 1963), and "Cryobiology: The freezing of biological systems," *Science* (168:939-949, 1970).

Tom Row, director of ORNL's Nuclear and Chemical Wastes Program, received the 1987 ORNL Director's Award, announced at the end of the State of the Laboratory—1987 address (the published version of which will appear in the next issue of the *Review*).

Barry Berven has been named head of the Dosimetry and Biophysical Transport Section of ORNL's Health and Safety Research Division, replacing **Rowena O. Chester**, who has joined Energy Systems' Data Systems Research and Development Organization.

Liane Russell

John Vitek

Peter Mazur

Tom Row

Controlling Technology: Ethics and the Responsible Engineer,

Stephen H. Unger, Holt, Rinehart, and Winston, New York (1982)

Reviewed by V. C. A. Vaughen, Chemical Technology Division

"Unger . . . challenges engineers to strive toward making the ethical aspects of their work as important as the technical aspects."

"This book is about the problem of democratically controlling technology for the benefit of mankind"–states Stephen Unger's preface. In the United States, we view the democratic process as the ideal way of governing, yet our businesses and bureaucracies are not democratic institutions. In full recognition of this potential for conflict between authoritarian institutions and a democratic society, Unger's book explores some of the ethical dilemmas faced by practicing engineers in our country.

Fundamental conflicts often exist among the interests of our society, of the institutions providing us with goods, services, and controls, and of the individuals who work for these institutions. Such conflicts can result in scandalous, and much-publicized, unethical activities. Many recent news items have focused attention on the *failure* of ethics in various segments of our society–for example, the ethical issues involved in the Challenger disaster, the outrageously inflated charges of some defense contractors for coffee pots, toilet seats, and minor parts, and the recent insider trading scandals on Wall Street.

Unger recognizes that the public is composed of individuals having multiple roles and responsibilities. The roles may include, for example, those of citizen, spouse, parent, child, and church member, or work-related roles such as employee, supervisor, employer, or independent business practitioner. It is not uncommon for some of these roles to be in conflict, resulting in some responsibilities remaining unfulfilled. Unger's interesting, highly readable book considers particularly the roles of engineers as employees in a high-technology society where most employees lack autonomy in decision-making.

After an introductory section and a chapter profiling some well-publicized cases of ethical failure, Unger delves into the bases for codes of engineering ethics. Much of this discussion is common sense and not particularly controversial. Occasionally however, he injects something the reader may not have considered. For example, one of the justifications he gives for having an ethics code is that it can be used as an "excuse" for ethical behavior, a sort of "fall-back position."

An ethics code is often viewed as a set of rules to be followed. But it has not been possible to compile a set of rules comprehensive enough to fit every situation, even in far simpler times. I suspect that even if such enormous computerized ethics data bases were established, it would not be possible (or affordable) to keep the rules up to date.

Fortunately, an ethics code can also be seen as a set of principles that can serve as guides to ethical behavior in any situation, leaving only the difficulties of interpretation and application. Unger's book lists five ethical principles. These are:

- truth, honesty, trustworthiness;
- respect for human life and welfare, including that of posterity;
- fair play;
- openness (i.e., not concealing actions from the public view); and
- competence.

The interpretation and application of these principles in formulating engineering ethics codes and in the relationships of engineers to their companies, to each other, and to society in general are Unger's subjects in the remainder of his book. Various chapters address the role of engineering societies in ethics, ethical engineers and the law, and means of averting conflict at the source. An interesting section discusses the Nuclear Regulatory Commission's procedure for handling differing professional opinions (DPOs), a formalized procedure developed for the resolution of dissenting views on technical (not personnel) matters. Although Unger doesn't mention it, the DPO process appears to be flawed, since it has an irresistible thrust towards the most conservative (most costly) solution.

The book also gives practical advice for engineers trapped in ethical dilemmas, citing numerous ethical case studies such as the Bay Area Rapid Transit (BART) scandals, the DC-10 disaster, and private consultant bribery cases. Other examples of real-life situations and supporting documentation are scattered throughout the main body of text and in the appendices.

Unger realistically acknowledges that some ethical problems have no reasonable solutions and that some ethical solutions may result in severe hardships to individuals. He suggests resolving ethical conflicts through a step-by-step process of communication and consultation, preferably through channels internal to the organization. He explores the alternatives (such as whistle-blowing) and possible consequences. Working relationships may become strained, and whistleblowers can be "sidelined," fired, or even blacklisted.

To counter or mitigate these penalties, Unger calls for engineering societies to increase their role in ethical support. He stresses the need for improved communication within the engineering field and between engineers and society at large, and he challenges engineers to strive toward making the ethical aspects of their work as important as the technical aspects.

Unger has chosen to limit the scope of his book to the role of the practicing engineer in society and the attendant responsibilities of that role. His book ignores the broader ethical issues concerning the social relevance of science and technology in the world today. Yet there is often a mismatch between what society-at-large views as a desirable future for the world and the real world that scientists and engineers are busily creating. This mismatch frequently generates ethical conflicts, causing us problems in the courts and other societal institutions (e.g., both the legal and ethical questions involved in genetic engineering and surrogate parenting). Engineers must learn to interact with the rest of society, dealing ethically and realistically with these broader issues to resolve the conflicts and achieve a desirable future.

Because of increased national interest in ethics and the renewed commitment to ethical responsibility by Martin Marietta Corporation and Energy Systems, Vic Vaughen was asked to select and review a recent book about ethics and the technical professions. Vaughen, a chemical engineer, is a section head in ORNL's Chemical Technology Division. He has devoted much attention to the ethical issues of engineering practices. In 1983 he served on a committee that established a code of ethics for staff members who consult outside ORNL. From 1983 through 1987, he was a member of the ad hoc committees on socio-technological (or ethical) issues of the American Nuclear Society. Since 1985 he has been a member of the State Ethical Practices Committee of the Tennessee Society of Professional Engineers, and since 1987 he has served on the Steering Committee of the National Society of Professional Engineers to establish a National Institute for Engineering Ethics. Vaughen also is a participating member of the Professional Society Ethics Group of the American Association for the Advancement of Science. In 1987 he served as a trainer in business ethics awareness for the Chemical Technology Division. He has given talks on ethics recently to the Oak Ridge Chapter of Sigma Xi, the Technical Society of Knoxville, Vanderbilt University, and WATTec 1987.

Athens Load-Management Tests Successful

"The Athens distribution system has demonstrated that new communications technologies and microelectronic devices can increase a utility system's control of power delivery."

On November 21, 1987, a ceremony was held in Athens, Tennessee, to celebrate the completion of the ORNL-managed, three-year, $15-million Athens Automation and Control Experiment.

The DOE-sponsored test showed that, compared to the conventional approach, remote computerized monitoring and operation of the Athens Utilities Board (AUB) distribution system reduced energy costs, restored interrupted power more quickly, and increased the reliability of providing electricity to more than 10,000 customers. The test was a demonstration of the nation's most highly automated electricity distribution system.

More than 40 regional utility and public power officials gathered for a briefing on project accomplishments. Attendees included U.S. Rep. John Duncan of Tennessee and Nancy Jeffery, staff member of the House Subcommittee on Energy Research and Development chaired by U.S. Rep. Marilyn Lloyd of Tennessee. ORNL Associate Director Murray Rosenthal and Bill Fulkerson, director of ORNL's Energy Division, joined with George Usry, AUB general manager, in presenting the results of the successful demonstration of distribution automation.

The results of the demonstration are expected to affect the design and operation of the next generation of U.S. electric power systems. AUB, one of 160 Tennessee Valley Authority (TVA) power distributors, was selected for the experiment because its pattern of peak demands for electricity was typical of the whole TVA system.

"The Athens distribution system has demonstrated that new communications technologies and microelectronic devices can increase a utility system's control of power delivery," says Paul Gnadt, now retired former manager of ORNL's Power Systems Technology Program. "It has become a model for the nation's utilities."

Since the energy shortages and rising energy costs of the 1970s, electric utilities have become interested in load management—changing the patterns of electricity use to lower the peak demand for power and thus reduce the need for expensive new generating capacity.

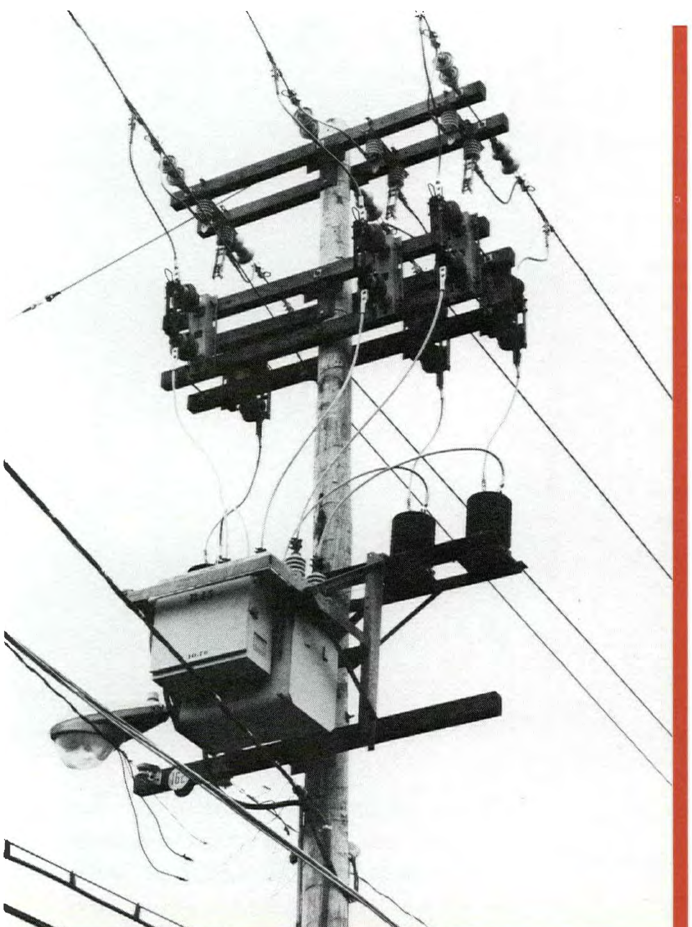
Using microcomputers, new computer programs, "smart" meters, and two-way communications devices, the Athens system operators can monitor and control electricity distribution and use. To flatten AUB's peak loads, the system shifts electricity use by water heaters, space heaters, heat pumps, and air conditioners in 1000 homes to a time of day when the demand for power is less, normally without inconveniencing customers. These computer-controlled actions were taken as part of the "load control" experiment, begun in 1986.

The system can also control voltage levels to reduce losses of saleable electricity. In addition, it can transfer loads from one part of the system to another automatically to reduce energy costs, shorten power outages, and increase power distribution reliability. These actions were taken as part of the "voltage/reactive power" experiment and the "system reconfiguration" experiment, begun in 1985.

"The Athens experiment," says Gnadt, "demonstrates that automation can minimize the cost of producing electricity. Calculations show that reducing transmission and distribution energy losses by 1% would save the U.S. utility industry about $160 million annually. Using automated load management to reduce U.S. utility peak loads by 1% would save $5 billion and increase available electrical capacity by 4800 MW."

ORNL researchers were responsible for integrating existing and evolving monitoring and communication technologies into an innovative integrated distribution control system. Automated methods for load control, voltage control, and load transfers have been tested separately by other utilities, but the Athens distribution system is the first to integrate all three methods into a flexible system. The idea for the experiment was proposed to DOE by ORNL in 1978.

ORNL developed a high-speed data acquisition



Technological University at Cookeville.

ORNL Conducts Weapons Disposal Analysis

Poles in Athens are outfitted with special units to increase control of electricity distribution.

In December 1987, ORNL completed the final programmatic environmental impact statement on the disposal of U.S. stockpiles of chemical weapons at eight facilities in eight states. The three-year effort for the U.S. Army was led by Sam Carnes of the Energy Division.

The 2200-page, three-volume document has been used by the Army for public hearings held throughout the country on disposal alternatives. Options include incinerating the hazardous chemicals on-site and transporting them by various means to regional depots for incineration. The Army's preference is on-site incineration.

Congress has ordered the final disposal of the stockpiles of chemical weapons by September 1994.

system that can rapidly measure power system changes caused by automated capacitor switching, load transfers, and load control. As a result of this monitoring capability, the AUB can determine quickly how to redistribute power use to reduce daily operating costs and peak demands for power.

Besides DOE, ORNL, AUB, and TVA, the Athens experiment participants included the Tennessee Valley Public Power Association, Electric Power Research Institute, a utility advisory group of ten utility experts from across the United States, and faculty and students from the University of Tennessee at Knoxville and the Tennessee

ATF Begins Experiments

ORNL's Advanced Toroidal Facility (ATF) has achieved its first plasma, and physics experiments are under way at this new toroidal (doughnut-shaped) magnetic fusion device. The ATF is the first large stellarator to be built in the United States in 20 years.

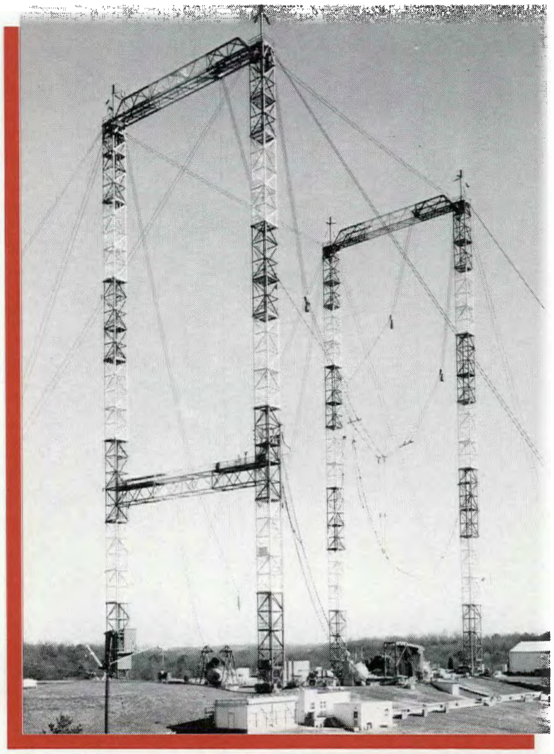
Achievement of the first plasma—a hot gas consisting of charged particles—follows four years of exacting design, component fabrication, and final assembly. Results from ATF experiments should guide improvements in a variety of toroidal devices, including stellarators and the more commonly studied tokamaks.

According to Mike Saltmarsh, head of the Confinement Projects Section in ORNL's Fusion Energy Division, "The ATF should help us understand the physics of this class of magnetic confinement devices. Our goal is to contribute to the development of toroidal fusion devices, based on tokamaks and stellarators, that will be reliable and economical sources of electrical power."

Unlike the more familiar tokamak, which operates in a pulsed mode, the ATF as a stellarator can operate continuously (at steady state) and uses only externally applied magnetic fields to confine a plasma.

In the fusion reactor of the future, the plasma will be fueled by the hydrogen isotopes, deuterium and tritium. Kept hot enough and dense enough, the plasma can sustain fusion reactions that result when the superheated ions overcome their natural repulsion and eventually fuse. Fusion reactions release large amounts of energy, which can be converted to electricity.

Another ORNL Reactor Permanently Shut Down



ORNL's Tower Shielding Facility was closed permanently in February 1988.

On February 4, 1988, DOE announced its decision not to restart ORNL's Tower Shielding Facility, one of four ORNL nuclear research reactors that were shut down in March 1987.

The DOE announcement said the decision to discontinue any further work leading to restart of the small reactor was made because of "diminishing program requirements, budget constraints, and the prolonged outage of the reactor."

ORNL officials were requested to develop a plan for the permanent shutdown of the reactor. Before its shutdown last March, the 1-MW reactor had been intermittently operated since 1954 for radiation-shielding studies. The Oak Ridge Research Reactor, another of the four reactors shut down in March 1987, has also been closed permanently.

Reactor Expert Oversees Last Phase of Restart Preparations

Robert W. Montross, a nuclear utility expert and ORNL consultant, has been named director of reactor operations for the final phases of the effort to restart three DOE research reactors at ORNL, including the High Flux Isotope Reactor (HFIR).

Montross brings to his new assignment a strong background in commercial nuclear reactor operation (he was general manager of two nuclear power plants in Michigan) and in the U.S. Navy's nuclear program.

Montross, working under a six-month contract that began April 4, reports to Clyde Hopkins, Energy Systems president. He has been given the temporary assignment of implementing safety and has line responsibility for the initial operation of ORNL's reactors.

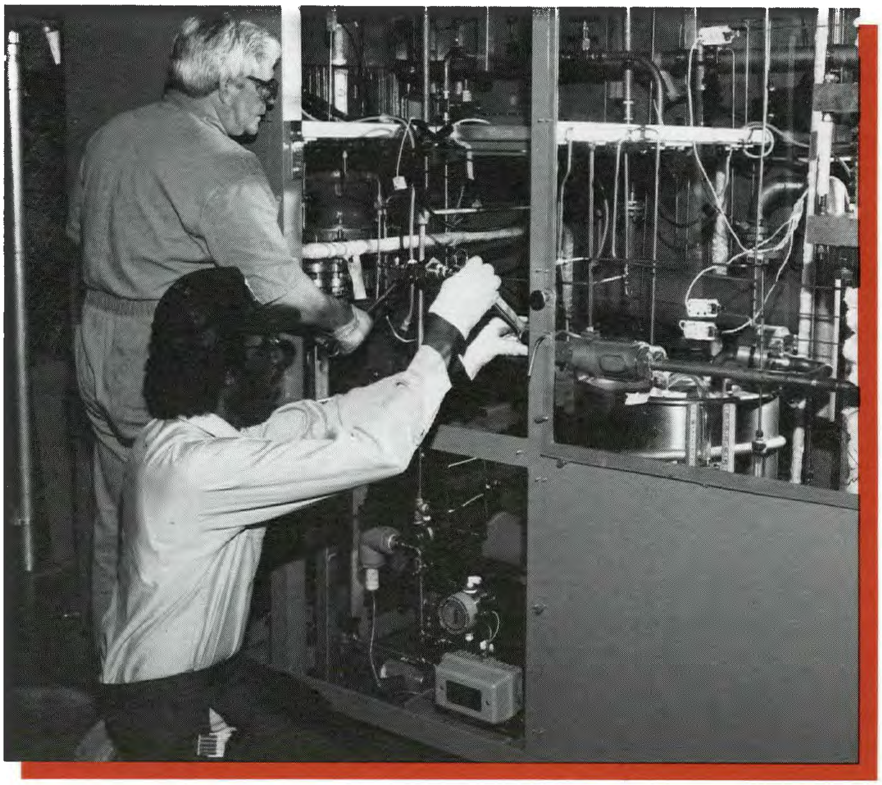
New Division, Program at ORNL

On April 8, 1988, the Enrichment Technology Applications Center (ETAC) at Oak Ridge Gaseous Diffusion Plant (ORGDP) became an ORNL division. Dean A. Waters, ETAC director, will report to Bob Merriman, associate director for Nuclear and Engineering Technologies.

In addition, Merriman has consolidated the Strategic Defense Initiative, Defense Technology, and Acoustic Instrumentation R&D programs into a new Space and Defense Technology Program, with offices located at ORGDP. David E. Bartine is the SDT program leader and Richard M. Davis, William H. Sides, Walter L. Roberts, and William R. Martin are associate program leaders.

ANS Loop Test

A new test facility to guide the selection of fuel cladding material for ORNL's proposed new reactor, the Advanced Neutron Source (ANS), has been completed. Data obtained at the facility will also be used in refining the reactor's design. The ANS Corrosion Loop Test Facility, operated by ORNL's Engineering Technology Division, permits studies of aluminum alloys under the heat-flux and water-velocity conditions expected in the ANS. An aluminum alloy will clad the ANS's uranium silicide fuel, which will be cooled by heavy water (D_2O).



Pipefitters C. R. Kelly (standing) and W. D. Clark from the Oak Ridge Y-12 Plant Maintenance Department prepare the Advanced Neutron Source Corrosion Loop Test Facility for operation.

The ANS will provide the world's highest flux of neutrons when it is completed in the mid-1990s. To achieve such a neutron flux, the ANS must have a much greater power density than the HFIR. The power density, however, could be limited by the tendency of the aluminum cladding to oxidize. Because this oxide layer insulates the cladding from the cooling water, too thick a layer would cause the fuel to overheat if the core has a high power density.

In the Corrosion Loop Test, aluminum sections are heated to 685°F (360°C) by a 30,000-amp, 20-volt, direct-current power supply (which simulates heating by the nuclear fuel). Cooling water at 140°F (60°C) is forced through the aluminum pipe sections at 89 ft/s (27 m/s); 0.02 s later, the water emerges at a temperature of 194°F (90°C).

Using the facility, ORNL researchers are obtaining oxide growth data and investigating whether and how much this harmful oxide buildup can be reduced by surface treatment, changes in coolant chemistry, or improvements in the coolant flow. If they can find a way to suppress oxide formation, the ANS could perform at an even higher power density.

Colin West is director of the ANS project. Bill Montgomery, manager of R&D facilities for the project, was responsible for the test loop construction. The corrosion (oxidation) studies are being led by Dick Pawel of the Metals and Ceramics Division, and operation of the test facility is directed by Grady Yoder of the Engineering Technology Division.

Endangered Whale Exposed to Carcinogen

An analytical technique developed and applied at ORNL has confirmed that an endangered whale species has been exposed to a cancer-causing chemical found in common pollutants.

At the request of Canadian scientists, Lee Shugart of ORNL's Environmental Sciences Division examined genetic material (DNA) from brain tissue of a beluga whale, an endangered marine mammal found in the polluted St. Lawrence River. He looked for evidence of chemical modifications of the DNA that result from exposure to benzo[*a*]pyrene (B*a*P), a potentially carcinogenic chemical.

Shugart analyzed the whale DNA using a fluorescence technique sensitive enough to detect even one DNA modification in ten million nucleotides (DNA building blocks). The technique revealed that the beluga whale had been exposed to B*a*P and that the St. Lawrence River whale's level of DNA modification was similar to that observed in experimental animals that had received a B*a*P dose high enough to produce tumors. Similar analyses on beluga whales from an uncontaminated environment in the Northwest Territories of Canada showed no evidence of exposure to B*a*P.

The analytical technique used for this study was developed with the support of the ORNL Director's R&D Fund. ORNL's contribution to documenting exposure of this endangered animal population to chemical pollutants has been widely reported in the popular press, including the *New York Times* (January 12, 1988), *The Gazette* (Montreal, November 14, 1987), and *Greenpeace* (Vol. 12, No. 2, 1987).

ORNL Modeling System Improves Emergency Response

ORNL has implemented a dispersion modeling system to predict concentrations and travel times of potential contaminant releases from White Oak Lake to the Clinch River. The system will be used for emergencies and emergency response planning.

The modeling system predicts hourly water velocities throughout the Clinch River as influenced by known reservoir releases. Contaminant travel times are calculated from the water velocities, and concentrations are estimated using dispersion coefficients.

To calibrate the system and evaluate the dispersion model, a dye tracer study was conducted in May 1987. The model was also tested by simulating the strontium-90 release that occurred in November and December of 1985. Test results showed that the model accurately predicts concentrations of nondecaying contaminants at the ORGDP intake and at the confluence of the Emory and Clinch rivers.

After documentation was completed, the modeling system was installed on ORNL computers by Michael J. Sale and Steven F. Railsback of the Environmental Sciences Division and Brady Holcomb of the Computing and Telecommunications Division to improve the Laboratory's emergency response capabilities.

Armco Gets Broad Rights to ORNL Alloy

Armco, Inc., the fifth-largest U.S. steelmaker, has received the rights for broad commercial use of modified nickel aluminide, a high-temperature alloy developed at ORNL. The company, which is headquartered in Parsippany, New Jersey, has acquired a nonexclusive license from Energy Systems to manufacture and market the alloy. Nickel aluminide has the unusual property of increasing in strength at high temperatures; it is six times as strong as stainless steel at 600°C (1100°F). Because the ORNL alloy is composed largely of raw materials available in North America, it is an attractive alternative to high-temperature alloys containing foreign-supplied cobalt or chromium.

The royalty-bearing agreement is the first that licenses an ORNL invention to a basic materials supplier. The rights acquired by Armco exclude applications of nickel aluminide licensed earlier on an exclusive field-of-use basis (e.g., large-displacement diesel engines and electric-resistance heating elements).

Energy Systems negotiated the agreement as ORNL's managing contractor under a waiver of patent rights from DOE and claims no interest in funds received under the license. Instead, under a DOE-approved formula, royalties are used to support other technology transfer activities.

Armco is in the process of selecting the best facility for producing the material and has not completed its marketing study to identify end-use applications. This license opens the potential for Armco to enter new markets.

Nickel aluminide, an intermetallic material, has characteristics of both metals and ceramics. Although intermetallics are inherently very brittle, this lightweight alloy is ductile (nonbrittle) and can readily withstand highly elevated temperatures as well as corrosive environments. Other potential applications include high-performance jet engines; gas turbines; advanced heat engines; heat exchangers in nuclear and coal-fired steam plants; and dies and molds for forging, forming, and casting at high temperatures.

Royalty Income Distributed to 57 Employees

On March 28, 1988, Energy Systems distributed royalty income totaling about $26,000 to 57 employees from all three Oak Ridge facilities. This marked the first time that checks were distributed to Energy Systems employees for royalties received from copyright licensing. Other checks were distributed for support of licensing activities and for the invention of significant technologies that cannot be licensed. These monetary awards were made from a special fund set aside from royalties earned by licensed technologies. ornl

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