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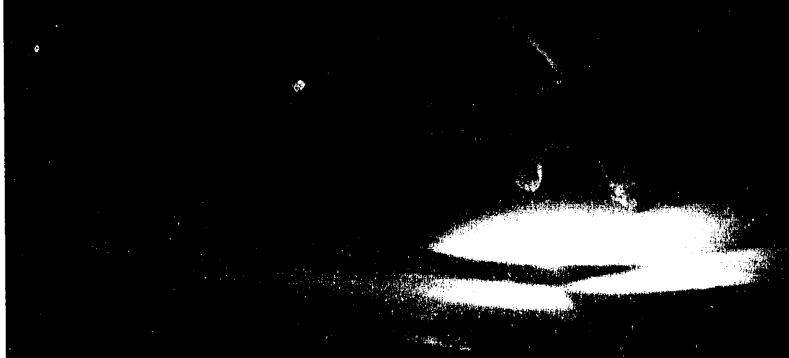
Technology Transfer



1994

U.S. Department of Energy

The Secretary of Energy
Washington, DC 20585

Welcome!

Let me introduce you to the Department of Energy, perhaps in ways you haven't thought about.

Technology transfer is one of the primary missions of the Department of Energy. We seek to provide added benefits to the American people, and to promote economic enhancement and industrial competitiveness, through partnerships that build on our key research areas (energy supply and efficiency, environmental technology, national security, and science) and the technologies, facilities, and core competencies that we have developed to accomplish the tasks assigned by the nation.

Technology transfer is not new, but this Administration has recognized its value to America and given it a new, vigorous commitment. President Clinton and Vice President Gore, in their policy paper, *Technology for America's Economic Growth: A New Direction to Build Economic Strength*, state,

> We are moving in a new direction that recognizes the critical role technology must play in stimulating and sustaining the long-term economic growth that creates high-quality jobs and protects the environment.

As part of our strategic planning process, the Department has established a technology transfer vision for itself — to become a *recognized leader and partner with industry in developing and transferring science and technology to enhance economic performance and serve public needs.*

To be an effective partner, we must do many things, including change our culture, improve our integrated planning, improve our processes, provide better access to our laboratories and facilities, and maintain the trust and confidence of the American public.

This open letter to our potential partners and our interested friends is first and foremost an invitation — an invitation to explore with us the opportunities available to create jobs, expand the use of energy-saving technologies, develop pollution prevention as well as cleanup technologies, and help build the scientific and technological foundation for global competitiveness throughout the next century. I hope you will use this document as one way to look into the Department and to identify areas you want to learn more about. Moreover, I hope you will join us in exploring ways to build a tomorrow that will be a source of enjoyment, satisfaction, and pride.

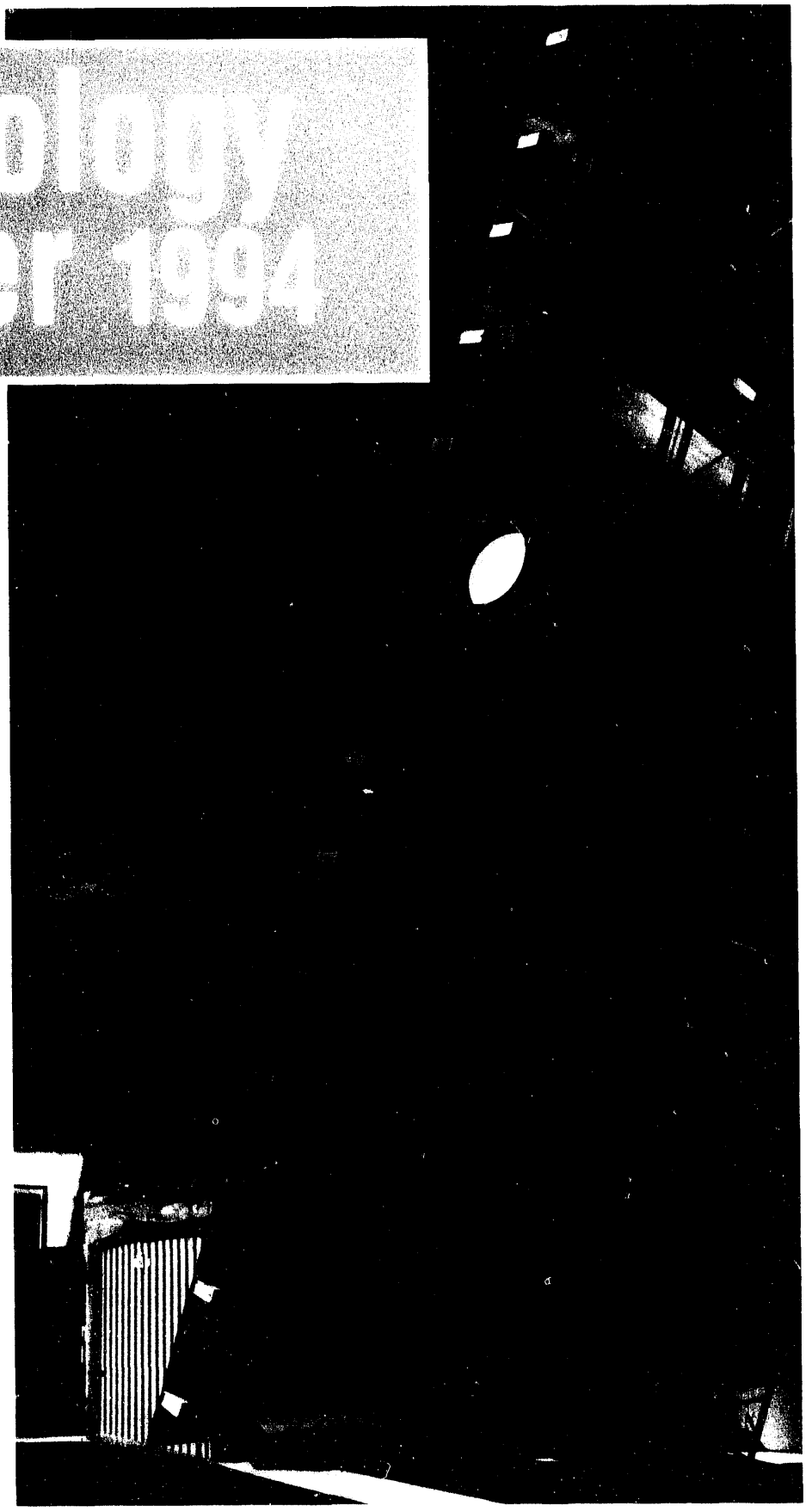
Sincerely,

Hazel R. O'Leary
Secretary of Energy

Front cover:

Silica aerogel insulates a delicate flower from the direct flame of a gas burner. This unusual material combines transparency with the best thermal insulating properties of any solid. New production methods developed at Lawrence Berkeley Laboratory unlocked the key to its commercial production. It is available for licensing and collaborative research.

Technology Transfer 1994



U.S. Department of Energy

Washington, DC 20585

January 1994

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The High Flux Solar Furnace at the National Renewable Energy Laboratory uses a unique configuration to concentrate sunlight up to 50,000 times. This recently designated national user facility can be employed for a variety of industrial tasks, including detoxifying contaminated soil, cladding steel, fabricating diamond-like carbon films, processing electronic materials, and making advanced ceramic coatings.

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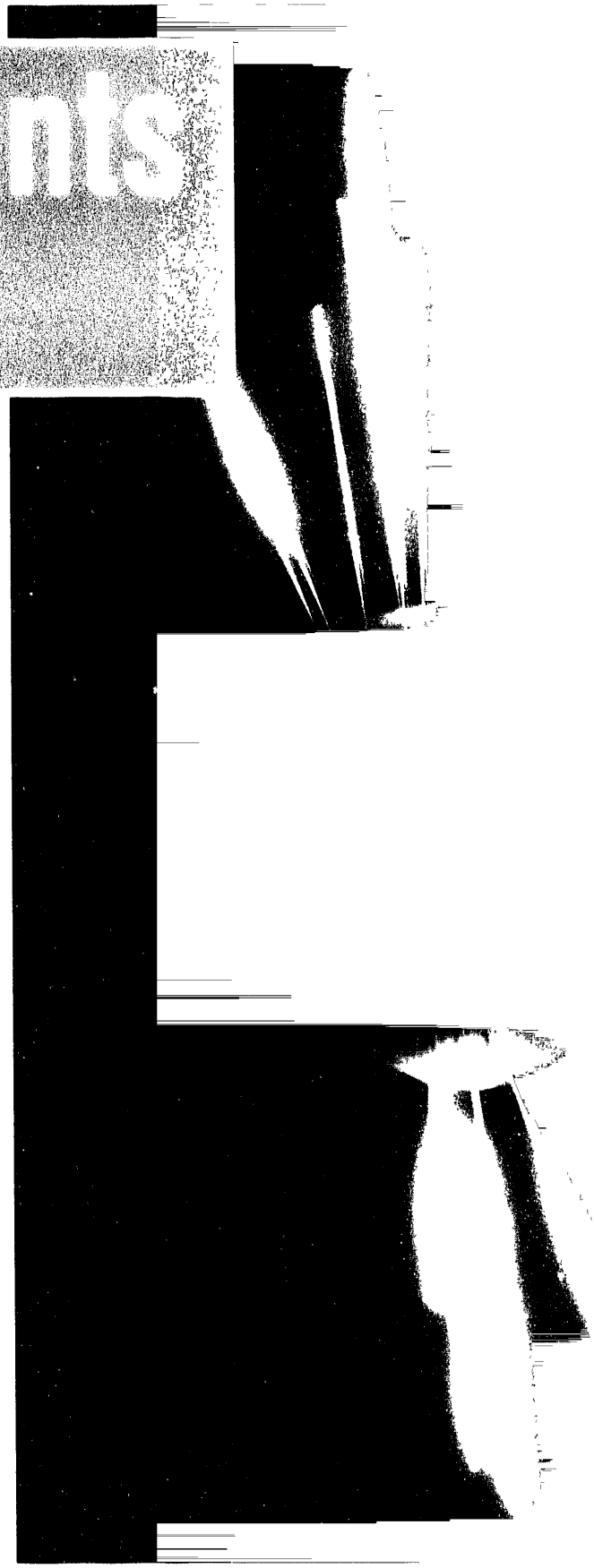

Fiber optics, used for more than a decade in such diverse applications as medicine, aerospace, and communications, may soon be used to help characterize radioactive waste in underground storage tanks at the Hanford Site in southeastern Washington State.

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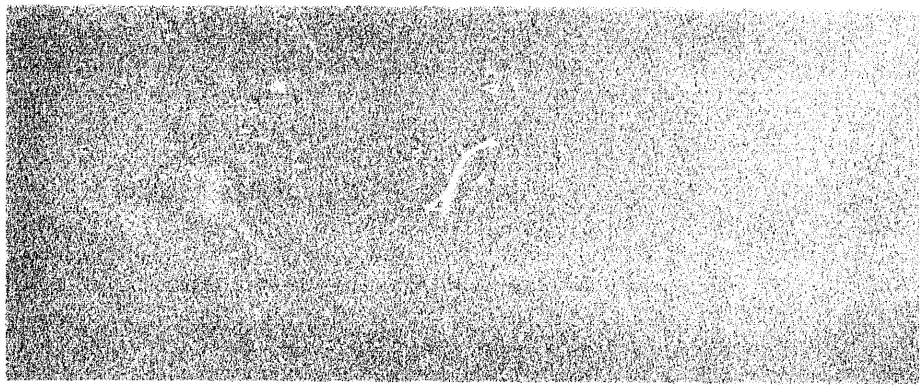


The U.S. Department of Energy (DOE) was established in 1977. With funding amounting to about $20 billion, it has five major mission areas: energy resources, national security, science and technology, environmental cleanup, and industrial competitiveness. The DOE laboratories and facilities needed to carry out the Department's mission are home to approximately 59,000 scientists, engineers, and technicians, who performed about $6.6 billion worth of research and development in fiscal year 1993.

These institutions have a long history of excellence in a number of areas, including the basic sciences, applied energy research, and weapons-related technologies. Research at DOE laboratories and facilities has resulted in important scientific discoveries and the development of more efficient energy sources, new materials, and related technologies; at the same time, DOE education, training, and outreach programs have served to increase the science and engineering capabilities of the nation as a whole. In addition, in carrying out its mission, the Department has developed world-class core competencies in a number of important technologies, including energy, pollution control and remediation, advanced materials, advanced instrumentation, biotechnology, advanced manufacturing, information and communication software, and aerospace and transportation technologies.

If the full benefits of these laboratories, facilities, and core competencies are to be realized, results of the research and development programs must be used by the nation. In recent years, DOE has laid the policy foundation and built the programmatic infrastructure to share its knowledge with industry through partnerships. Many mechanisms for developing and sharing new technology have been established. (These are discussed in

Introduction

This geodesic sphere for the Sudbury Neutrino Observatory (SNO) represents the first major component that Lawrence Berkeley Laboratory (LBL) is providing for an experiment to detect neutrinos from the sun and supernovae. The SNO site is in Canada, 6,800 feet below the ground in the INCO nickel mine. As part of a dust control program, LBL scientists are using x-ray fluoresence to measure low-level surface contamination, which must be eliminated to conduct the experiment.

the section on *Access to Laboratories and Facilities.*) Although technology transfer has always been an element of the activities of DOE and its laboratories, it has received increasing emphasis from U.S. policymakers in recent years as an avenue for enhancing the nation's competitiveness. As a consequence, a number of laws enacted throughout the 1980s and early 1990s, culminating in the National Competitiveness Technology Transfer Act of 1989 and the Energy Policy Act of 1992, have firmly established technology transfer as a mission of all federal laboratories and facilities.

To increase the priority of technology transfer within DOE, the Secretary of Energy initiated a strategic planning process that involves the entire Department: headquarters, the field offices, and the laboratories and facilities. As a result, the Department developed a strategic plan entitled *Partnerships for Global Competitiveness* and a vision statement for its technology partnership activities. This vision is for DOE to be a "recognized leader and partner with industry in developing and transferring science and technology to enhance economic performance and to serve public needs."

The Department has adopted five critical strategies to help realize this vision. It must:

1. Change its culture.

2. Optimize its technology partnership processes.

3. Make it easier for industry to have access to its technologies, resources, and facilities.

4. Ensure that its technology transfer process and technology development programs are guided by market pull.

5. Develop, with industry and others, integrated program plans.

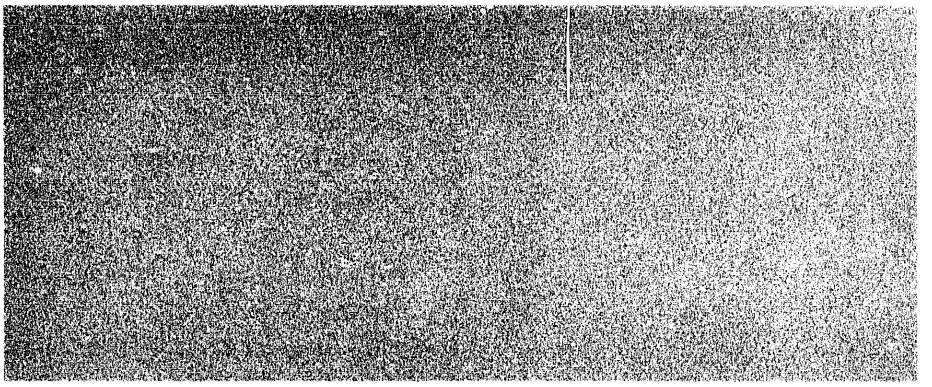
This document, *Technology Transfer 94*, is intended to communicate that there are many opportunities available to U.S. industry and academic institutions to work with DOE and its laboratories and facilities in the vital activity of improving technology transfer to meet national needs. It has seven major sections: *Introduction*, *Technology Transfer Activities*, *Access to Laboratories and Facilities*, *Laboratories and Facilities*, *DOE Offices*, *Technologies*, and an *Index*. *Technology Transfer Activities* highlights DOE's recent

developments in technology transfer and describes plans for the future. *Access to Laboratories and Facilities* describes the many avenues for cooperative interaction between DOE laboratories or facilities and industry, academia, and other government agencies. *Laboratories and Facilities* profiles the DOE laboratories and facilities involved in technology transfer and presents information on their missions, programs, expertise, facilities, and equipment, along with data on whom to contact for additional information on technology transfer. *DOE Offices* summarizes the major research and development programs within DOE. It also contains information on how to access DOE scientific and technical information. *Technologies* provides descriptions of some of the new technologies developed at DOE laboratories and facilities.

We hope you find this document a useful starting point. We are very interested in hearing from you. Did this document prove helpful in making a contact? How could it be improved? Are there other types of information you need or other formats in which you would like information provided? We are committed to a continuous improvement process. Please send your comments to:

Roger A. Lewis, Director
Office of Technology Utilization
U.S. Department of Energy
Washington, DC 20545

Thanks. We hope to highlight one of your "success stories" in a future edition!

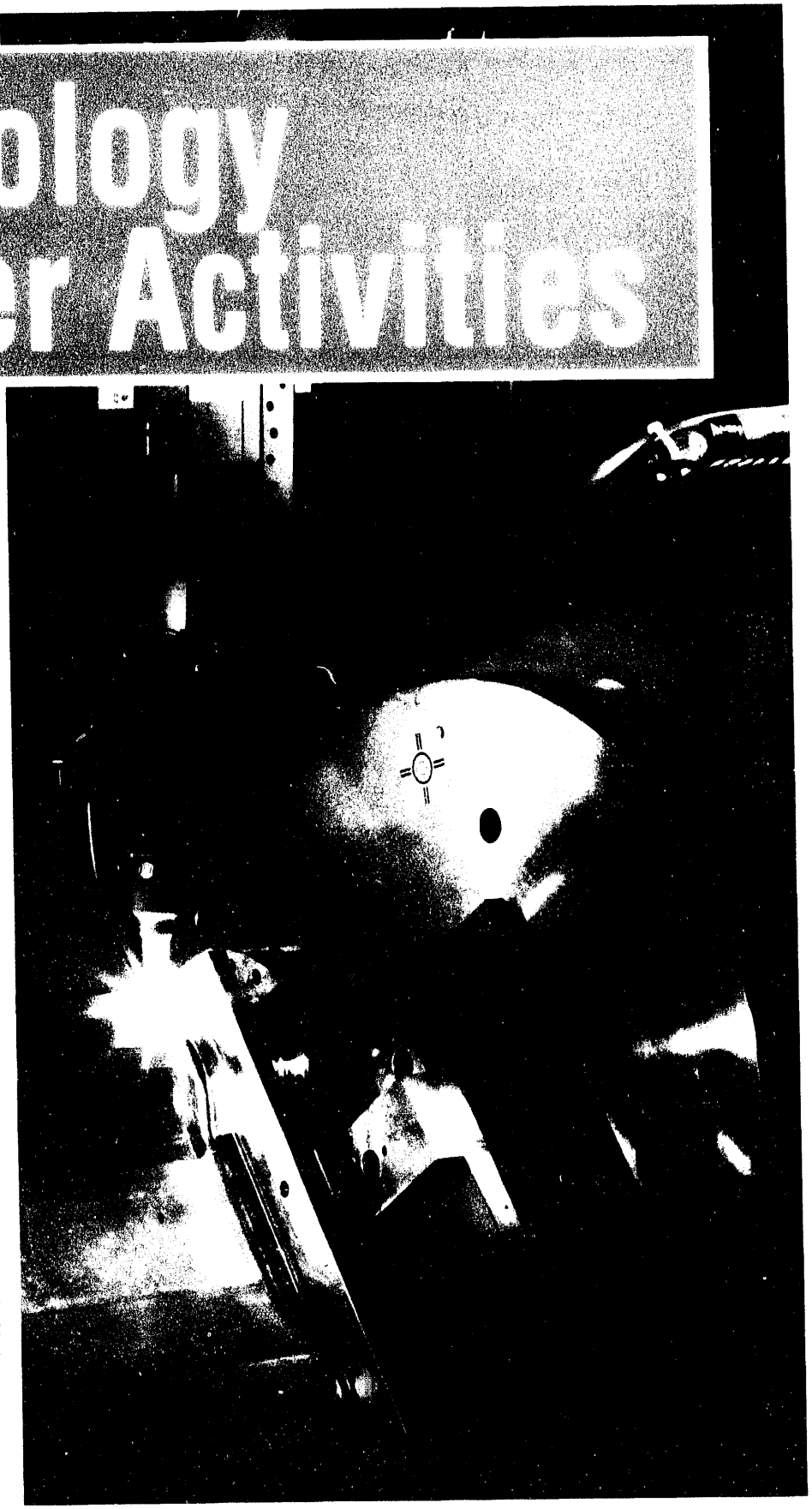


In 1993, national policy focused on science and technology. A new emphasis on public/private partnerships was enunciated by the Administration on February 22 of that year, when a paper, *Technology for America's Economic Growth: A New Direction to Build Economic Strength,* was released. (The Secretary of Energy refers to this paper in her letter on the inside cover of this document.) Technology became recognized as one of the key driving engines for long-term economic growth. Moreover, the old adversarial relationship between government and business began to be replaced by a relationship that acknowledges these sectors' commonality of interests and need for cooperation, both for their mutual benefit and for the economic security of the nation.

To respond to this new national imperative, the Department of Energy is substantially expanding its partnership activities, which tie its research and development programs and world-class laboratories and facilities with the academic, private research, and business communities in the United States. A wide range of mechanisms are already available to facilitate these partnerships; these are highlighted below and fully described in the section on *Access to Laboratories and Facilities.* Moreover, in cases where existing mechanisms do not meet "customer" needs, the Department is committed to developing, with customer participation, new methods.

The Department's goal is to concurrently meet both DOE's program needs and the needs of its partners through the integrated planning of research and development, careful attention to feedback from its partners, and the development and implementation of faster and better technology transfer processes. This section of *Technology Transfer 1994* describes some of the activities DOE has undertaken, as well as some of the improvements it intends to make, to achieve that goal.

Technology Transfer Activities



After precision machining, part of the vacuum chamber for the Advanced Photon Source, a generator of high-energy x-rays under construction at Argonne National Laboratory, is being welded. Each weld must be almost perfect to prevent any interference with the beam traveling inside.

Major Accomplishments

This was a productive year with respect to DOE's technology transfer efforts. Progress was made in many important areas: leveraging of funding, process improvements, outreach, interagency coordination, and small business relationships. An indication of the success of its efforts was the dramatic increase in the number of times DOE's technology transfer mechanisms were used. For example, visits by industry representatives to DOE facilities significantly increased, licensing of DOE inventions grew by 75%, and the number of cooperative research and development agreements (CRADAs) that were approved continued to climb substantially. More than 600 CRADAs with 492 partners are now in place throughout the United States. These represent an estimated investment, at completion, of more than $1.4 billion, and the DOE partners are contributing more than 55% of the funding for these efforts. This rapid growth across all mechanisms reflects DOE's commitment to establishing partnerships as well as the business community's recognition of the value they receive from the partnerships.

Some major accomplishments from the last year are briefly described here:

- The most significant accomplishment has been the development of a DOE-complex-wide strategic plan for technology transfer entitled *Partnerships for Global Competitiveness.*
- Congress authorized the Department to enable the DOE weapons facilities to enter into CRADAs.
- An exhibit on DOE technology transfer was displayed at 15 events (trade shows, conferences, etc.), where total attendance exceeded 300,000 people.
- Six regional meetings were held throughout the United States to obtain feedback from technology transfer partners; these were

Secretary of Energy Hazel O'Leary signs the AMTEX™ cooperative research and development agreement (CRADA). AMTEX — the American Textile Partnership — involves 5 U.S. textile research and development organizations, 10 DOE laboratories, and several U.S. universities. Its focus is to enhance the competitiveness of the U.S. textile industry. For more information on this partnership, see the writeup on page 189.

followed by a DOE-complex-wide conference in Washington, D.C., to obtain even more partner feedback.

- Guidelines were published to help small businesses learn about the technology transfer process and establish partnerships with DOE.
- A model CRADA specially tailored to meet the needs of small businesses was developed.
- A modular CRADA that provides maximum flexibility for achieving agreements was developed.

Technology Transfer Tools

DOE has laid the policy foundation and built the programmatic infrastructure to meet the needs of any partner. CRADAs, a popular technology transfer mechanism, are not the only means available for partners to work with the DOE system. Many other mechanisms for developing and sharing new technology are equally effective and may be more appropriate, depending on a particular partner's requirements. Some of these mechanisms are listed here:

- Personnel exchanges.
- Data exchange agreements.
- Use of specialized facilities.
- Cost-shared procurement.
- Cooperative agreements.
- Patent and software licensing.
- Reimbursable work for others.
- Technical assistance.

These and other mechanisms for interacting with the Department are described in detail in the section on *Access to Laboratories and Facilities.*

An essential part of technology transfer is outreach, that is, making the capabilities and facilities available in the Department of Energy known to potential partners. The major outreach mechanism employed by DOE is participation at trade shows, expositions, conferences, professional society meetings, and similar events. During 1993, DOE's Office of Technology Utilization had exhibits at 15 such events, and individual DOE laboratories had exhibits at many more. In addition, several publications — including this document, *Technology Transfer 1994*, and *DOE New Technology* — list innovative technologies that are available for commercialization. These outreach activities are supported by staffs at the DOE regional operations offices located throughout the United States and at each laboratory's Office of Research and Technology Applications (ORTA), as well as by the Federal Laboratory Consortium for Technology Transfer, a network of federal laboratory representatives.

To ensure that its partners' needs are being met, DOE has instituted an information feedback loop by which the partners can directly and candidly tell the Department how it is doing with regard to technology transfer and cooperative research and development, where it can improve, and where it has succeeded. Six Regional Partners Feedback Meetings held around the country in the fall of 1993 and hosted by DOE regional operations offices gave Department personnel an excellent opportunity to meet with partners and listen to them describe their experiences working with DOE. These meetings were followed in November 1993 by a large, DOE-complex-wide Partners Feedback

Conference in Washington, D.C., that brought together about 300 partners. Input from the meetings and conference gave DOE a great deal of information on how to improve with regard to technology transfer. This type of information is incorporated as changes in the Department's technology transfer process and administrative actions, and it plays an important part in the continuous improvement policy established by DOE.

Future Priorities

As a result of its new strategic plan, the Department will be pursuing technology transfer with three major goals in mind: streamlining technology transfer processes, planning for success, and reaching small businesses.

Streamlining Technology Transfer Processes

Optimizing the Department's technology transfer processes is one of the most critical steps for improving technology transfer. This step can be achieved by streamlining existing processes (particularly with regard to CRADAs) and establishing new processes that will make it easier for interested partners to get access to Departmental resources. To streamline, DOE is working on reducing the CRADA processing time. The Secretary of Energy has established a CRADA Working Group, composed of personnel from across the Department and its laboratories, to identify and remove unnecessary obstacles in the CRADA path. The Department is also working to delegate authority to the directors of its contractor-operated laboratories to execute certain CRADAs directly.

Planning for Success

One of the Department's highest priorities is to develop integrated program plans with other government agencies and industry. The Department has undertaken several initiatives to contribute to the success of this effort:

- The Department is developing an integrated technology partnership plan, which is being coordinated with other federal agencies and the Office of Science and Technology Policy, to provide a multiyear agenda for partnership activities.
- Senior representatives from the private sector have been appointed to serve on the Secretary of Energy Advisory Board. This panel will provide, on a regular basis, independent assessments of the Department's technology partnership activities.
- The Department, with input from its customers, is developing a system for measuring success in its partnership programs. This effort will build on the extensive work already done by the Department independently and through the Interagency Committee on Federal Technology Transfer to define appropriate short-, medium-, and long-term performance measures for both process improvements and partnership results.

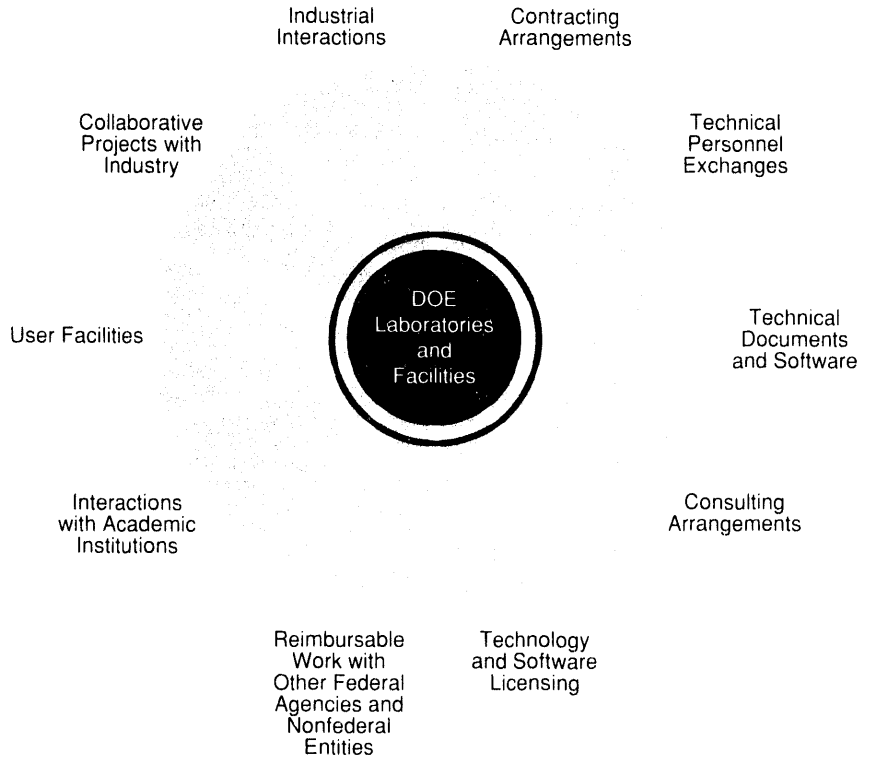
Reaching Small Businesses

Another high-priority goal is for the Department to reach small businesses, particularly by working with existing public and private business networks. In 1993, DOE released guidelines for transferring technology to small businesses. The guidelines were developed to facilitate the transfer of technology to small businesses and to provide an

information, access, and referral process for guiding the small business partner through the technology transfer process at DOE headquarters, regional operations offices, program offices, and laboratories. In addition, DOE offers a simplified CRADA for small businesses. The Department has also issued policy guidance, which states that the provision of technical assistance to small businesses by scientific and technical employees of the Department, its laboratories, and its facilities is a recognized and vital component of the technology transfer mission of the laboratories. Moreover, DOE has identified small business technology transfer coordinators, both at regional operations offices and at headquarters, to improve these businesses' access to the Department and its laboratories and facilities.

Various programs targeted at small businesses have been piloted within the Department and proven to be highly successful. These initiatives are being expanded and integrated with those of other agencies, principally those of the Department of Commerce. For example, DOE has taken steps to make its laboratories and facilities available as a technical resource for, and integral component of, the manufacturing outreach and extension system being developed by the Department of Commerce. DOE's goal is to implement a plan that builds on the unique but complementary strengths of the two departments. DOE is also undertaking a phased expansion of technical assistance across the Department, with an emphasis on forming teams with state governments and other entities to reach small businesses. Many DOE laboratories and facilities are already involved with state and local government agencies and organizations. These relationships, established through a range of mechanisms from formal CRADAs to less formal technical assistance and training partnerships, often include universities.

In summary, the Department of Energy's aim is to establish a balanced portfolio of partnerships with academic and research institutions and private companies that are based on each partner's unique interests and requirements. Included in this portfolio could be industrywide collaborations among a number of companies and laboratories, one-on-one partnerships between a company and a laboratory, and the provision of technical assistance for a small business. DOE believes that, along with the other federal research and development agencies, it offers its partners an unprecedented opportunity to benefit from the public investment in research and development. Opportunities abound to achieve more than one benefit from specific programs and facilities. This document, by reporting on the mechanisms that have worked and the technologies that have been developed, invites institutions to participate in the technology transfer process. ■



Opportunities to work with DOE laboratories and facilities are many and varied. Each "petal" in this design represents a means of access available to U.S. companies, academic institutions, and agencies of state and local governments.

Access to laboratories and facilities

The U.S. Department of Energy has a long history of successful partnerships with the private sector and academia, particularly through its applied research programs. These partnerships take many forms; for example, they can be relatively simple technical assistance arrangements with small businesses, or they can be agreements involving collaborative technology development, with the private-sector partner playing a central role in defining the research agenda. Discussed in this section are the mechanisms through which representatives from companies of all sizes and researchers from academic institutions can interact and collaborate with DOE laboratories and facilities.

President Clinton peers into the plasma-source ion implantation chamber in a facility at Los Alamos National Laboratory. For more information, see the writeup on *Plasma-Source Ion Implantation* on page 140.

Collaborative Projects with Industry

One of DOE's most important goals in the area of technology transfer is to increase the number and scope of collaborative research and development projects with U.S. industry. Successful technology transfer cannot occur if organizations work in isolation: the technology transfer process requires a team effort from DOE facilities and industry. The benefits from these partnerships are truly mutual; they can help the Department fulfill its missions and sustain its scientific and technological base more effectively, and they can help the private-sector partners meet their goals.

A cooperative research and development agreement (CRADA) is an extremely valuable collaborative tool used by a company or university to gain access to government-owned/government-operated (GOGO) and government-owned/contractor-operated (GOCO) DOE laboratories, technologies, and expertise. In this contractual agreement, a DOE laboratory and one or more partners outside the federal government (usually from industry or academia) agree to collaborate, share costs, and pool the results from a particular research and development program.

Each partner contributes to the research effort. The DOE laboratory may provide its partners with personnel, facilities, equipment, or other resources (but not funds). Nonfederal participants may provide funds, personnel, equipment, or other resources to conduct specific research and development efforts that are consistent with the mission of a laboratory or facility.

The Federal Technology Transfer Act of 1986 created the CRADA concept, but this Act applied only to GOGO laboratories and facilities. The National Competitiveness Technology Transfer Act of 1989 permitted GOCO laboratories to enter into CRADAs and was designed to encourage and facilitate collaboration between U.S. industry and the DOE laboratories.

A CRADA's terms are flexible; each CRADA with a laboratory can be tailored to the needs and resources of the participating parties. As part of the CRADA process, the partners draw up a joint work statement that outlines the scope of work, responsibilities of each organization, allotted time, schedule, and other terms and conditions. This statement is then submitted to a designated DOE operations office for approval. All participants sign the CRADA.

A CRADA is designed to protect intellectual property developed by all participants as part of the agreement. Commercially valuable data generated in a CRADA can be withheld from public release for up to 5 years.

The DOE laboratories and program offices give high priority to CRADAs that can mutually benefit the missions and objectives of DOE and its partners to strengthen the nation's competitiveness in the global marketplace. Funding for DOE laboratories to enter into CRADAs is available through the DOE program offices and other government agencies. Parties wanting more information are encouraged to contact a representative of either the DOE program office or DOE laboratory of interest. ■

Technology and Software Licensing

The DOE laboratory and facility contractors can often retain title to inventions they develop at the laboratory or facility and can license technology to industry. Each laboratory or facility contractor licenses its own patents; DOE headquarters licenses government-owned patents in accordance with governmentwide licensing regulations. The Office of Scientific and Technical Information (OSTI) in Oak Ridge, Tennessee, maintains and periodically publishes a list of DOE-funded technologies entitled *DOE New Technology*.

The number of patents awarded for DOE-developed technology has increased steadily. Within broad guidelines governing, for example, conflict-of-interest and fairness-of-opportunity activities, DOE laboratory and facility contractors are free to negotiate a variety of terms and conditions for their technology licenses. Among the purposes of these terms and conditions are these three: to protect the federal government's and/or the contractor's investment in the technology; to encourage the licensee to make additional investments; and, most important, to ensure the commercialization of the technology and the attendant benefits to the U.S. economy.

A 1988 DOE policy allows laboratory contractors to copyright and license computer software expressly for commercialization purposes. To ensure public availability of basic information, citations of source codes are provided to the Energy Science and Technology Software Center operated for OSTI. Licensing of DOE-developed computer software by laboratory contractors also continues to increase steadily. Technologies may be licensed from the laboratories and facilities on three bases: fully exclusive, exclusive for a particular application or field of use, or nonexclusive.

The laboratories and facilities advertise licensing opportunities widely through press releases, attendance at trade and technical conferences, and informational mailings. Additional details on DOE laboratory and facility licensing programs and opportunities can be obtained by getting in touch with the technology transfer contacts identified in the profiles that appear in the *Laboratories and Facilities* section of this publication. ■

User Facilities

The DOE laboratories and facilities provide valuable and often unique expertise and equipment that can be used for experiments by university and industrial scientists in many fields. Potential users must submit research proposals, which are peer-reviewed for appropriateness and quality; access to a DOE laboratory or facility is provided on the basis of the scientific merit of the proposal. Traditionally, users who publish the results of their work incur no charges for their use of the laboratory or facility; however, if their work is proprietary to these users, they must pay the full costs for use of the laboratory or facility. Patent rights to any resulting inventions are generally given in advance to users who are doing proprietary work and paying full costs and also to users of certain dedicated user facilities, even when there is not full cost recovery. ■

Industrial Interactions

The Department and its laboratories and facilities interact with private industry in a variety of ways. Some of these interactions occur on a program-specific basis through advisory committees that provide guidance in specific research and development areas. Others occur through workshops and conferences sponsored by the laboratories and facilities.

The Department and its laboratories and facilities are major participants and supporters of the Federal Laboratory Consortium, which focuses on facilitating more interactions between U.S. industry and federal laboratories. The DOE laboratories and facilities also frequently participate in events sponsored by the Industrial Research Institute. They conduct various activities with state and local governmental organizations and formulate methods to strengthen interactions with such organizations, particularly to improve outreach to small businesses. Increasing the number of industrial interactions — at all levels of DOE laboratory and facility activity, and throughout all phases of research and development programs — is a major goal of current technology transfer efforts. ■

Contracting Arrangements

Contracts, subcontracts, grants, cooperative agreements, user facility agreements, and other arrangements (e.g., CRADAs) are used by DOE and its laboratories and facilities to work with industry and universities. These contracting arrangements are often overlooked as technology transfer mechanisms. However, they offer an opportunity for the private sector to play an integral part in developing new technology. They also provide the laboratories and facilities with access to needed capabilities available from private industry and universities and serve as an automatic vehicle for communication among the various participants. Total acquisition and assistance agreements from DOE and its laboratories and facilities exceed $1 billion a year, and a significant number of these arrangements facilitate technology transfer. ■

Secretary of Energy Hazel O'Leary watches Alvin Trivelpiece, director of Oak Ridge National Laboratory (ORNL), and Mark Elliott, president of Ogden Environmental and Energy Services Company, Inc., Fairfax, Virginia (at right), sign an agreement to transfer environmental remediation technology developed by ORNL to Ogden. Ogden is testing the technology on water from a pond in eastern Germany contaminated by uranium mill tailings. For more information, see the writeup on *Bacteria-Based Adsorption of Heavy Metals* on page 110.

Reimbursable Work with Other Federal Agencies and Nonfederal Entities

The U.S. Department of Energy laboratories and facilities are available to conduct work for other federal agencies and nonfederal entities (including state and local governments and academia) on a reimbursable basis. The work must pertain to the mission of the laboratory or facility, may not conflict or interfere with the achievement of Departmental program requirements, and cannot directly compete with capabilities that are available in the private sector. Since all reimbursable work with nonfederal partners is considered technology transfer, a newly developed, user-friendly mechanism has been made available to all nonfederal entities interested in gaining access to Departmental resources on a reimbursable basis. ■

Consulting Arrangements

Scientists and engineers at the DOE laboratories and facilities are available to consult in their areas of technical expertise, and their involvement in consulting activities is increasing. Each laboratory and facility contractor has its own consulting practices that comply with DOE consulting guidelines. Laboratory and facility staff are generally free to consult for a fee. Many laboratories and facilities also have programs that allow their employees to provide free technical assistance to outside organizations on a limited and selected basis. Laboratory and facility employees involved in consulting activities are allowed to sign nondisclosure arrangements. ■

Interactions with Academic Institutions

All DOE laboratories and research programs have an education mission. As part of this mission, DOE and its laboratories support the training of the next generation of U.S. scientific and technical leaders in several ways. DOE funds thousands of graduate students and hundreds of postdoctoral research fellows at academic institutions, laboratories, and research facilities. Ongoing research and education programs at the laboratories involve academic faculty, undergraduate students, and precollege science students and teachers. Increasing emphasis is being placed on reaching minority and female students through educational outreach and training programs.

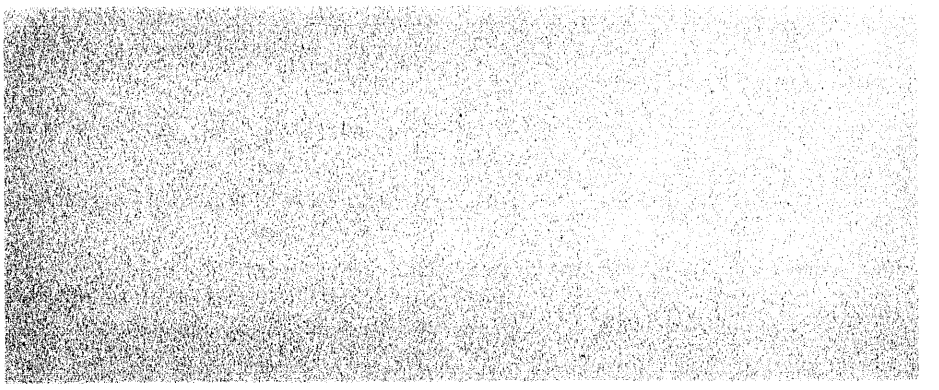
Collaboration among university, private-sector, and federal scientists is ongoing in various research and development programs and at scientific user facilities located at the DOE laboratories. Most of the laboratories have formal collaborative agreements with universities that cover staff and faculty exchanges, joint instructional programs, university agreements for joint research, admin-istrative procedures for large-scale scientific computing systems, and joint appointments of affiliate scientists. In addition to promoting interactions with colleges and universities, the laboratories play a pivotal role in implementing DOE initiatives to promote and improve science and mathematics education at the precollege level. ■

Technical Personnel Exchanges

The exchange of personnel with U.S. industries and academic institutions is an important component of DOE's technology transfer efforts. Exchanges are conducted through specific research and development programs or arranged on an informal basis with the laboratories or facilities. In addition, a separate technical personnel exchange program focuses on technology transfer between private-sector companies and the DOE laboratories and facilities. This program supports travel, living, and other costs for personnel participating in these exchanges. To encourage participation, the rights to any resulting patents go to the participant's employer. These exchanges, which typically last about 6 months, provide opportunities for the laboratories and facilities and industry to enhance their interactions and are ideal for updating the technical skills of the participants. ■

Technical Documents and Software

Technical documents and computer software are traditional means of disseminating information on research results and technologies available at DOE laboratories and facilities. Copies of reports containing scientific or technical information originating at DOE facilities are submitted to the Office of Scientific and Technical Information (OSTI) in Oak Ridge, Tennessee, for dissemination to DOE and its contractors. OSTI ensures public access to DOE scientific and technical information by providing information and announcement products to the National Technical Information Service (NTIS) and Government Printing Office (GPO). Scientific and technical software is submitted to the Energy Science and Technology Software Center (ESTSC) (which is operated for OSTI) for dissemination to the public or, as copyright provisions allow, to DOE or the government and its contractors. To further support Departmental activities and ensure public availability of technical documents and software, OSTI develops announcement publications and databases. Additional information on OSTI and its services is provided in the *DOE Offices* section of this document. ■



The U.S. Department of Energy manages the nation's largest system of federal laboratories, with a combined annual budget of more than $6 billion and more than 56,000 employees. The DOE network of 9 multiprogram laboratories, 12 major single-program laboratories, and other laboratories and facilities is a significant national resource. Research activities at the laboratories and facilities span a broad range of scientific and technical areas: materials science, chemistry, environmental science, biotechnology, life sciences, physics, nuclear energy, fusion energy, defense-related research, waste management, conservation, renewable energy, and fossil energy.

The excellence of the research and development work conducted by DOE laboratories and facilities is indicated by the high standing of their personnel within the scientific and technical communities and their success in receiving various awards within these communities. For example, 23 Nobel prizes in science have been awarded for work performed at these institutions. DOE laboratories and facilities have also received more than 340 R&D 100 Awards. Each year, these award winners are selected by *R&D Magazine* in an international competition; they represent the 100 most significant new products, processes, and materials developed in a given year. DOE laboratories and facilities have won more of these awards than has any other organization. In 1993, this tradition of excellence continued, when scientists and engineers at DOE institutions received 26 R&D 100 Awards; some of these award-winning technologies are described in this document. These DOE award winners have a commercial impact; according to a recent analysis covering a

Laboratories and Facilities

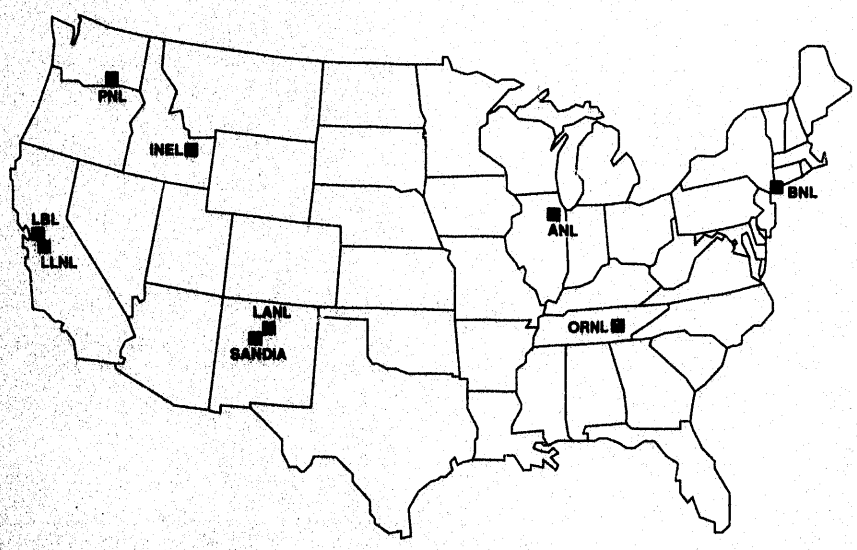
15-year period, about 45% of DOE-developed technologies that had won R&D 100 Awards have been commercialized.

This section of the document contains descriptions of the major DOE laboratories and facilities that have comprehensive technology transfer programs and provides information on the person to contact at each institution. In general, access to a new technology developed at a particular laboratory or facility can be obtained through that institution's Office of Research and Technology Applications (ORTA) or a comparable office. These offices are responsible for the transfer of DOE-developed technology to the private sector for commercialization.

Researchers at Argonne National Laboratory have developed molecular switches that use ultrashort laser pulses to "throw" the switch. For more information on this technology, see the writeup on *Donor-Acceptor-Donor Molecular Switch* on page 153.

Multiprogram Laboratories

Locations of Multiprogram Laboratories



Key to Laboratory Abbreviations

ANL Argonne National Laboratory
BNL Brookhaven National Laboratory
INEL Idaho National Engineering Laboratory
LANL Los Alamos National Laboratory
LBL Lawrence Berkeley Laboratory
LLNL Lawrence Livermore National Laboratory
ORNL Oak Ridge National Laboratory
PNL Pacific Northwest Laboratory
SANDIA Sandia National Laboratories

Argonne National Laboratory

Argonne, Illinois

Operated by The University of Chicago
FY 1993 Operating Budget $425,000,000
FY 1993 Staff 4,600

User Facilities

Argonne Tandem Linac Accelerator System (ATLAS)
High-Voltage Electron Microscope Tandem Facility
Intense Pulsed Neutron Source (IPNS)

Technology Transfer Contact

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Argonne National Laboratory
Industrial Technology Development Center
9700 South Cass Ave., Bldg. 900
Argonne, IL 60439
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FAX (708) 252-5230
zussman@smtplink.eid.anl.gov

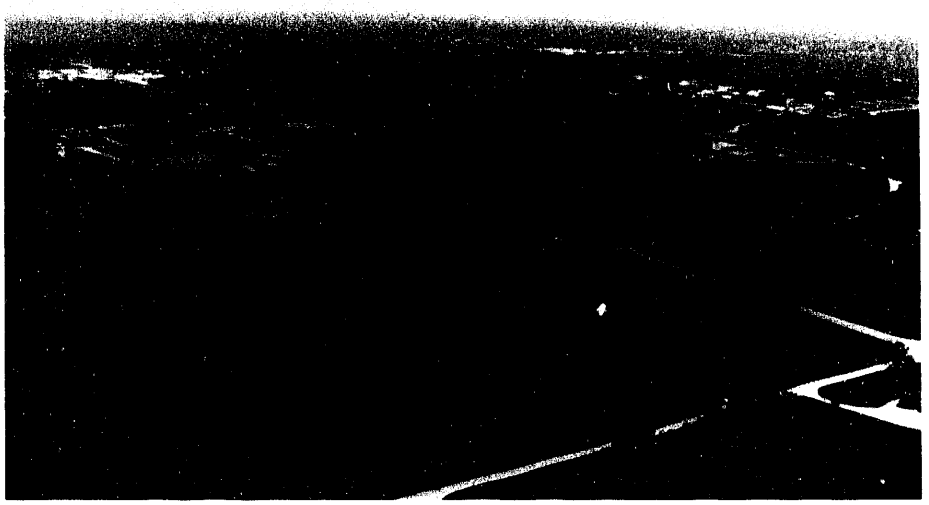
Argonne National Laboratory (ANL) is a research and development laboratory located 25 miles southwest of Chicago, Illinois. It has more than 200 programs in basic and applied sciences and an Industrial Technology Development Center to help move its technologies to the industrial sector.

At ANL, basic energy research is supported by applied research in diverse areas such as biology and biomedicine, energy conservation, fossil and nuclear fuels, environmental science, and parallel computing architectures. These capabilities translate into technological expertise in energy production and use, advanced materials and manufacturing processes, and waste minimization and environmental remediation, which can be shared with the industrial sector.

The Laboratory's technologies can be applied to help companies design products, substitute materials, devise innovative industrial processes, develop advanced quality control systems and instrumentation, and address environmental concerns. The latest techniques and facilities, including those involving modeling, simulation, and high-performance computing, are available to industry and academia. At ANL, there are opportunities for industry to carry out cooperative research, license inventions, exchange technical personnel, use unique research facilities, and attend conferences and workshops.

Technology transfer is one of the Laboratory's major missions. High priority is given to strengthening U.S. technological competitiveness through research and development partnerships with industry that capitalize on ANL's expertise and facilities.

The Laboratory is one of three DOE superconductivity technology centers, focusing on manufacturing technology for high-temperature superconducting wires, motors, bearings, and connecting leads. ■



Brookhaven National Laboratory

Upton, New York

Operated by Associated Universities, Inc.
FY 1993 Operating Budget $283,515,000
FY 1993 Staff 3,484

User Facilities

Alternating Gradient Synchrotron
Double MP-Type Tandem Accelerator Facility
High Flux Beam Reactor
JSW168 Small Cyclotron
National Synchrotron Light Source
Relativistic Heavy Ion Collider
(under construction)
Scanning Transmission Electron
Microscope Facility
60-Inch Cyclotron

Technology Transfer Contact

Ms. Margaret C. Bogosian
Brookhaven National Laboratory
Office of Technology Transfer
Building 902C
Upton, NY 11973
(516) 282-7338
FAX (516) 282-3729

The role of Brookhaven National Laboratory (BNL) is to conceive, design, build, and operate large, complex research facilities for fundamental scientific studies in a safe, environmentally sound manner and to carry out both basic and applied research in energy-related physical, life, and environmental sciences. By providing the use of its facilities to the scientific community, BNL closely interacts with scientific personnel in universities and industry and aids in educating scientists and engineers through cooperative research programs. Other educational programs reach students and faculty from the elementary school through the university level.

To fulfill its role as a multiprogram laboratory, BNL directs its scientific and technical efforts toward missions that include high-energy and nuclear physics; basic energy sciences that emphasize fundamental research on the biological, chemical, and physical phenomena underlying energy-related transfer, conversion, and storage systems; life science and nuclear medicine research and medical applications of nuclear techniques; and a broad range of applied programs in which the Laboratory has unique capabilities. An integral part of these programs is the parallel effort to ensure that useful results and knowledge obtained are made available to the nation's industrial and commercial sectors.

The Relativistic Heavy Ion Collider (RHIC), now under construction at BNL, will be a unique, world-class facility. It is designed to create matter at temperatures and densities so high that scientists hope to observe phenomena that have not occurred since the Big Bang. This capability will enable studies of the fundamental properties of matter in a state in which the primordial quarks and gluons are no longer confined as constituents of the nuclei of ordinary particles. ■

Idaho National Engineering Laboratory

Idaho Falls, Idaho

Operated by
- EG&G Idaho, Inc.
- Westinghouse Idaho Nuclear Company, Inc.
- Babcock & Wilcox Idaho, Inc.
- Protection Technology Idaho, Inc.
- MK-Ferguson of Idaho Company

FY 1993 Operating Budget $847,000,000
FY 1993 Staff 8,800

User Facility

INEL National Environmental Research Park

Technology Transfer Contact

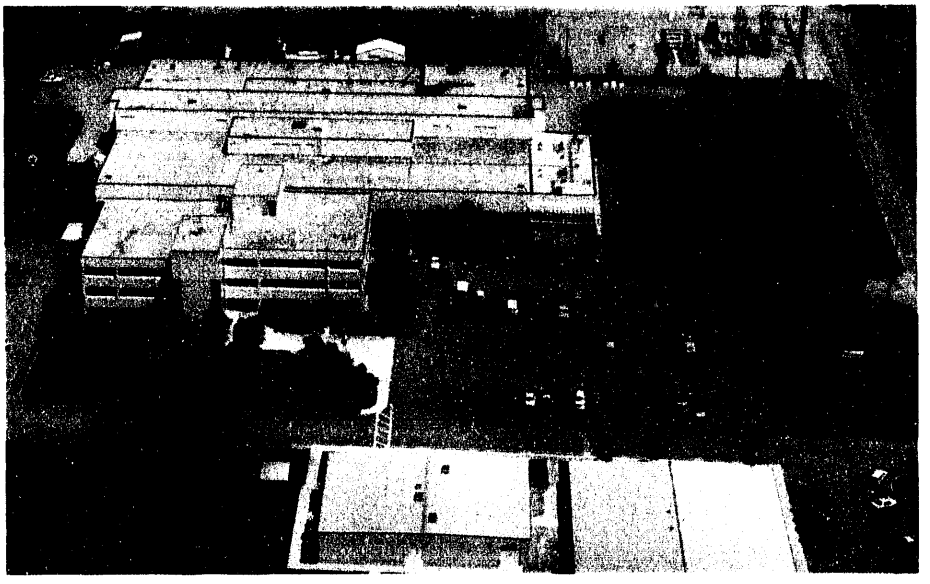
Dr. Donald E. Hagge
EG&G Idaho, Inc.
Idaho National Engineering Laboratory
Office of Research and Technology Applications
P.O. Box 1625
Idaho Falls, ID 83415
(208) 526-2883
FAX (208) 526-0876

Idaho National Engineering Laboratory (INEL) is a multiprogram laboratory. Historically a leader in DOE reactor technology programs and engineering projects, INEL conducts applied research and development to support the missions of DOE and other government agencies. It has expertise in biotechnology, chemical sciences, engineering sciences, instrumentation development, materials and materials processing, nuclear reactor research technology, information and communications technology, sensor development and measurement science, mechanical and electronic system development, robotics, computational intelligence, and environmental and waste treatment technology.

The Laboratory provides the federal government with independent scientific advice and technical verification and validation in areas of its expertise. It makes its unique facilities available to members of the technical community, cooperates with universities and industry in educating scientists and engineers, and provides technology transfer opportunities to the public and private sectors. Major INEL facilities are located in Idaho Falls, Idaho, and on an 890-square-mile tract west of Idaho Falls.

The Laboratory was the first of the government-owned/contractor-operated laboratories to sign a cooperative research and development agreement (CRADA). Twenty-four CRADAs are now in place, and more than 12 more are in various stages of completion and approval. The technologies and processes that have been transferred and the services that have been provided fall within the core competencies of the Laboratory: waste management and minimization, environmental engineering and restoration, energy efficiency and renewable energy, national security and defense, nuclear technologies, and advanced technologies and methods. Specific technologies include electric vehicle evaluation, improved materials production, environmental remediation through use of biotechnological and membrane separation methods, and computer software. Since 1986, INEL has received 13 R&D 100 Awards from *R&D Magazine* for scientific achievements, and over the past 6 years, it has transferred 31 technologies to the private sector.

In addition to the five primary contractors already identified, two other contractors are involved in INEL operations. Westinghouse Electric Corporation operates the Naval Reactor Facilities for DOE and the U.S. Navy, and Argonne National Laboratory operates the Experimental Breeder Reactor-II and associated research facilities. ■



Lawrence Berkeley Laboratory

Berkeley, California

Operated by the University of California
FY 1993 Operating Budget $212,500,000
FY 1993 Staff 3,580

User Facilities

National Center for Electron Microscopy
National Tritium Labeling Facility
88-Inch Cyclotron
Advanced Light Source

Technology Transfer Contact

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Lawrence Berkeley Laboratory
University of California
Technology Transfer Department
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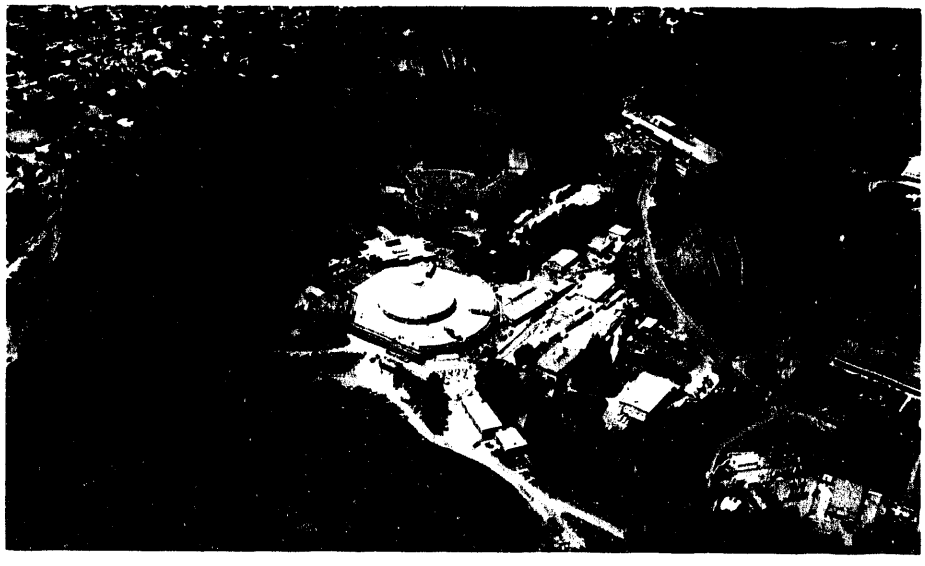
Berkeley, CA 94720
(510) 486-6461
FAX (510) 486-6457
sbdavies@lbl.gov

Lawrence Berkeley Laboratory (LBL) is a multiprogram energy research laboratory located in the foothills overlooking the University of California, Berkeley campus. LBL was founded in 1931 to advance physics and biomedical research through the development and application of the cyclotron invented by Ernest Lawrence. The Laboratory's major roles are as follows:

- Perform leading multidisciplinary research in the energy, general, and biological sciences in a manner that ensures employee and public safety and the protection of the environment.
- Develop and operate unique national experimental facilities.
- Educate and train the next generation of scientists and engineers.
- Transfer knowledge and technological innovations to industry, universities, and government.



The Laboratory integrates environmental, health, and safety goals within its research programs, and it strengthens DOE's national efforts in science, education, and technology transfer. By implementing its mission, LBL supports the fundamental and applied research and development needs of the nation.

Major energy research programs cover advanced materials development, chemical reaction dynamics, energy efficiency in buildings, electrochemical energy storage, heavy-ion fusion, accelerator development, environmental sciences, and earth sciences. LBL's general sciences research programs are in heavy-ion nuclear physics and high-energy physics, advanced detector instrumentation, and accelerator design. The biosciences programs cover molecular genetics, gene expression, carcinogenosis, structural biology, medical imaging, radiological cancer therapy, and biomedical research.

The Laboratory's Advanced Light Source — the brightest source of soft x-rays in the world — will promote scientific advancement in the materials and chemical sciences and biosciences. LBL's advanced electron microscopes and heavy-ion particle accelerators are available for use by industrial, academic, and other researchers. The Laboratory is one of three designated DOE centers for research on the human genome.

The Laboratory maintains a strong relationship with University of California faculty and students. Industrial collaboration and technology transfer are strengthened through LBL's Advanced Light Source, Center for Advanced Materials, Center for X-Ray Optics, and California Institute for Energy Efficiency. Its Center for Science and Engineering Education advances undergraduate and precollege student and teacher involvement in the Laboratory's scientific activities.

Lawrence Livermore National Laboratory

Livermore, California

Operated by the University of California
FY 1993 Operating Budget $1,088,700,000
FY 1993 Staff 7,923

Technology Transfer Contact

Mr. David C. Conrad
Lawrence Livermore National Laboratory
Technology Transfer Initiatives Program
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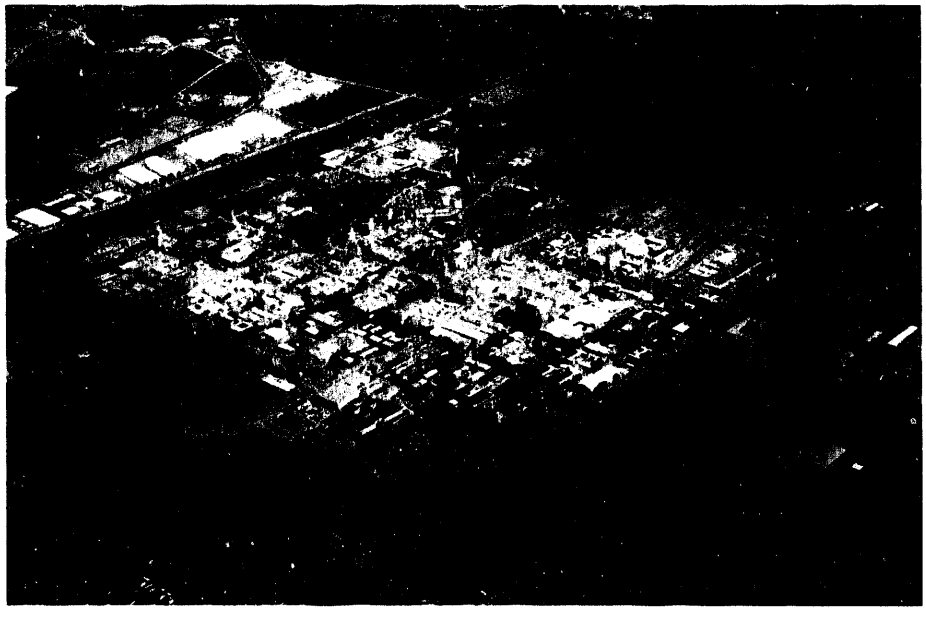
Livermore, CA 94550
(510) 422-6416
FAX (510) 423-8988
conrad1@llnl.gov

Situated on a 1.3-square-mile site in the Livermore Valley, Lawrence Livermore National Laboratory (LLNL) is in a unique position to collaborate with businesses in the Silicon Valley and Biotech Canyon and with world-class educational institutions, including Stanford University and four campuses of the University of California.

The Laboratory has been an essential element of the national security infrastructure since its inception in 1952. Its workforce has the physical and human resources needed to solve the most difficult scientific and engineering problems. LLNL's competencies in disciplines such as applied physics and chemistry; the atmospheric sciences, geosciences, and biosciences; computation; electronic and mechanical engineering; lasers; optics and electro-optics; manufacturing technologies; and measurement and diagnostics have helped keep the United States on the leading edge with respect to developments in science and technology.

In line with changing national priorities since the end of the Cold War, LLNL's defense-related work has been redirected to implement the Start I and II treaties and address the new nuclear danger. Nondefense work now accounts for almost one-third of the Laboratory's budget. In addition, a significant fraction of its defense expenditures could also benefit other areas such as energy use and environmental cleanup.

Livermore is strongly committed to promoting U.S. economic competitiveness. The success of its technology transfer efforts is proof of that dedication. The Laboratory has been creative in its approach to forming various types of partnerships with U.S. companies; the partnerships have included cooperative research and development agreements, an initiative directed toward small businesses, and an active licensing program. Companies have also joined LLNL in consortia, which have been formed to achieve the technological breakthroughs that will reinforce the position of the United States in the global marketplace. ■



University of California
Lawrence Livermore National Laboratory

Los Alamos National Laboratory

Los Alamos, New Mexico

Operated by the University of California
FY 1993 Operating Budget $1,118,000,000
FY 1993 Staff 7,670

User Facilities

Clinton P. Anderson Meson Physics Facility (LAMPF)
Manual Lujan, Jr. Neutron Scattering Center (LANSCE)
National Environmental Research Park at Los Alamos
National Flow Cytometry and Sorting Research Resource
National Genetic Sequence Data Bank (GenBank)
National Stable Isotopes Resource
Supercritical Fluids Cleaning Facility
Weapons Neutron Research Facility

Technology Transfer Contact

Dr. Peter B. Lyons
Los Alamos National Laboratory
Industrial Partnership Center
P.O. Box 1663, Mail Stop M899
Los Alamos, NM 87545
(505) 665-9090
FAX (505) 665-0154
plyons@lanl.gov

Covering more than 43 square miles of northern New Mexico, Los Alamos National Laboratory (LANL) is a multidisciplinary, multiprogram laboratory dedicated to developing world-class science and technology and applying them for the nation's security and well-being.

Fifty years ago, LANL was established to design, develop, and test nuclear weapons. The Laboratory's mission has broadened and evolved as technologies, the nation's priorities, and the global community have changed. Today, LANL uses the core technical competencies developed for defense programs to carry out both its national security responsibilities and its broad-based programs in energy, nuclear safeguards and security, advanced manufacturing, biomedical science, transportation, environmental protection and cleanup, high-performance computing, materials science, and advanced materials and advanced instrumentation.

Los Alamos is committed to promoting U.S. economic competitiveness and cooperative research and development through its technology transfer initiatives. Examples include an initiative that offers technical assistance and transfers innovative technologies to emerging U.S. companies; an initiative that focuses on high-risk, high-payoff ventures requiring long-term collaboration between industry and government; and an initiative that focuses on forming collaborative ventures to address well-defined industrial problems.

Los Alamos maintains a wide range of research centers and resources available for use by U.S. industry. The Laboratory is one of three superconductivity technology centers, one of three DOE centers for human genome studies, and one of two DOE high-performance computing research centers. It has more than 30 user resources, including the Ion Beam Materials Laboratory, Advanced Waste Treatment Testbed, Atmospheric Light Detection and Ranging (LIDAR) Facility, Environmental Testing Facility, and Laser and Laser Spectroscopy Facilities. Private companies can gain access to these resources through a variety of arrangements. ■

Los Alamos
NATIONAL LABORATORY

Oak Ridge National Laboratory

Oak Ridge, Tennessee

Operated by Martin Marietta Energy Systems, Inc.
FY 1993 Operating Budget $533,000,000
FY 1993 Staff 5,031

User Facilities

Atomic Physics EN Tandem Accelerator
Bioprocessing Research Facility
Buildings Technology Center Facility
High Temperature Materials Laboratory
Holifield Radioactive Ion Beam Facility
Neutron Scattering Research Facilities
Oak Ridge Electron Linear Accelerator
Oak Ridge National Environmental Research Park
Shared Research Equipment (SHaRE) Program
Surface Modification and Characterization Research Center

Technology Transfer Contact

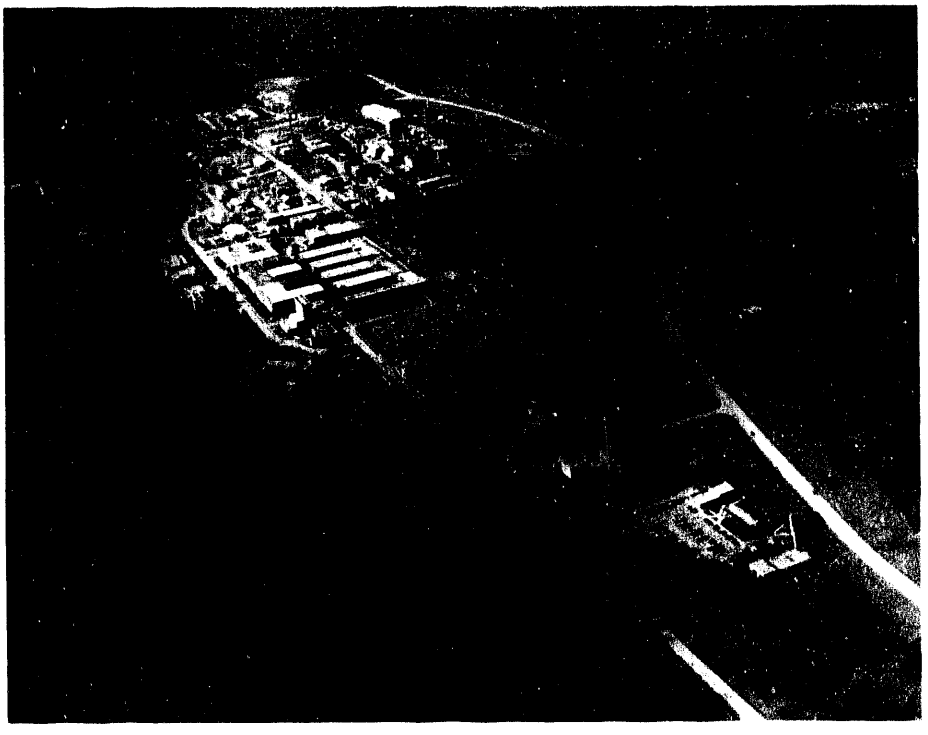
Mr. Joe W. Culver
Martin Marietta Energy Systems, Inc.
Oak Ridge National Laboratory
Office of Technology Transfer
P.O. Box 2009
Oak Ridge, TN 37831
(615) 576-6349
FAX (615) 574-1011

Oak Ridge National Laboratory (ORNL) is one of DOE's major multiprogram national laboratories. Originally called Clinton Laboratories, ORNL was built in 1943 as part of the World War II Manhattan Project. Its original mission was to produce and chemically separate the first plutonium as part of the national effort to produce the atomic bomb. The Laboratory is located on a 2,900-acre site 10 miles southwest of the city of Oak Ridge.

Activities at ORNL now focus on basic and applied research, technology development, and other technological challenges important to DOE and the nation. The Laboratory also performs research and development for non-DOE sponsors when such activities complement DOE's missions and address important national or international issues.

The Laboratory is committed to the pursuit of excellence in all its activities, including the commitment to carry out its missions in compliance with environmental, safety, and health laws and regulations. ORNL supports DOE through its activities in the following areas: energy production and conservation technologies, physical and life sciences, scientific and technological user facilities, environmental protection and waste management, science and technology transfer, and education.

The Laboratory welcomes approximately 4,400 guest researchers each year, about one-third of whom come from industry. ■



ornl

Pacific Northwest Laboratory

Richland, Washington

Operated by Battelle Memorial Institute
FY 1993 Operating Budget $481,400,000
FY 1993 Staff 4,158

User Facilities

Hanford National Environmental Research Park
Environmental and Molecular Sciences Laboratory

Technology Transfer Contact

Mr. Marv Clement
Pacific Northwest Laboratory
Office of Research and Technology Applications
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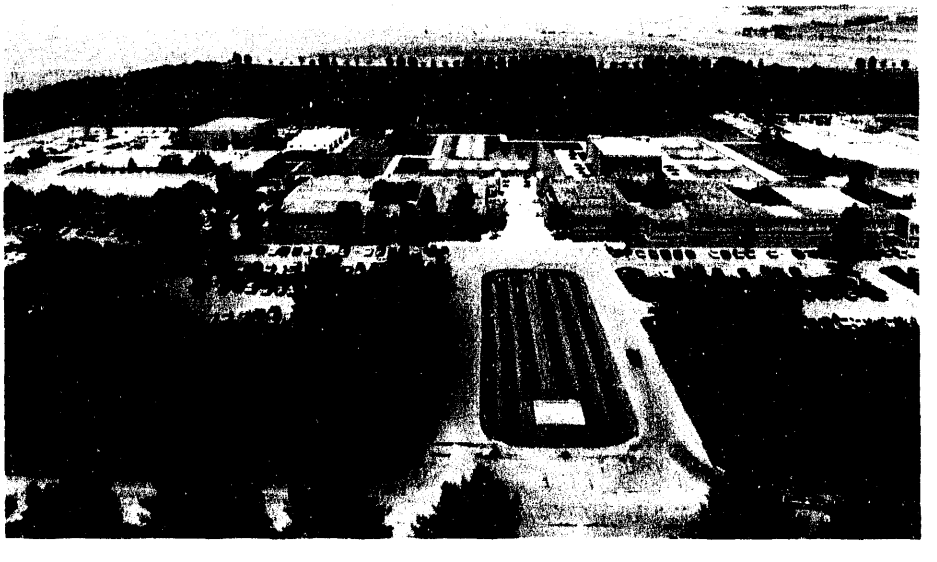
Richland, WA 99352
(509) 375-2789
FAX (509) 375-6731
mclement@ccmail.pnl.gov

The mission of Pacific Northwest Laboratory (PNL) is to conduct research and development to meet national needs related to energy, the environment, the economy, and the nation's security. Many of its activities focus on environmental issues, such as waste cleanup at the Hanford Site and global climate change. To accomplish its mission, PNL rapidly applies the latest scientific discoveries and engineering innovations. The Laboratory forms partnerships with universities, industry, and other federal laboratories to help it meet its programmatic responsibilities, enhance the nation's economic competitiveness, diversify the economy of the region, and help educate future generations of scientists and engineers. Included within the scope of these partnerships is the development and operation of major scientific user facilities.

The Laboratory acts as a steward of DOE's resources by anticipating future national needs and investing in the development of major new capabilities and programs to meet those needs. Current investments include molecular sciences research, advanced processing technology, biotechnology, global environmental change research, and energy technology development. As a result of these investments — and the expertise and reputation earned through programmatic efforts — PNL has the following core competencies: integrated environmental research, energy systems research, and process technology. Through these areas of competency, PNL makes use of its scientific and technical capabilities to support DOE's major missions. ■



PNL
Pacific Northwest Laboratory

Sandia National Laboratories

Albuquerque, New Mexico
Livermore, California
Tonopah, Nevada

Now Operated by Martin Marietta Corporation
Operated by AT&T Technologies, Inc., until October 1993
FY 1993 Operating Budget $1,400,000,000
FY 1993 Staff 8,500

User Facilities

Combustion Research Facility (CRF) at Livermore
Solar Thermal Test Center at Albuquerque, composed of:
- Central Receiver Test Facility (CRTF)
- Distributed Receiver Test Facility

Technology Transfer Contacts

Mr. Olen D. Thompson
Sandia National Laboratories
Technology Transfer Applications Department 4201
P.O. Box 5800
Albuquerque, NM 87185
(505) 271-7822
FAX (505) 271-7856

Dr. T. Michal Dyer
Sandia National Laboratories
California Technology Transfer 8800
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Livermore, CA 94551
(510) 294-2678
FAX (510) 294-3422

For more than four decades, Sandia National Laboratories has applied its talents, tools, and techniques to solving technological problems on a national scale. Established in the 1940s as the engineering arm of the nuclear weapon development system, Sandia has since grown into one of the country's largest technical resources, working in areas as diverse as environmental remediation, health care, transportation, and manufacturing. Today, Sandia has laboratories in New Mexico and northern California and test facilities in Nevada and Hawaii. Its assets include facilities for manufacturing process development, environmental testing, renewable energy research, radiation research, combustion research, computing, and microelectronics research and production.

During its more than 40 years of existence, Sandia has maintained a commitment to pursue technical and scientific excellence in meeting DOE's needs and those of the nation. Sandia's experience in industrial management, with its focus on developing theoretical concepts into useful solutions, is of great value. Its ability to bring knowledge obtained in the research laboratory to the factory floor — to move from vision to application — is a Sandia strength.

Sandia is committed to enhancing the security, prosperity, and well-being of the nation by responding to the challenges and opportunities of a dynamic and demanding world. Its broad-based research and development programs are designed to enhance the country's military and energy security, environmental integrity, and economic competitiveness. ■

Sandia National Laboratories

Major Single-Program Laboratories

Ames Laboratory

Ames, Iowa

Operated by Iowa State University
FY 1993 Operating Budget $38,000,000
FY 1993 Staff 500

User Facilities and Services

Materials Preparation Center (MPC) and Referral Service and Hotline (MRSH)

Technology Transfer Contact

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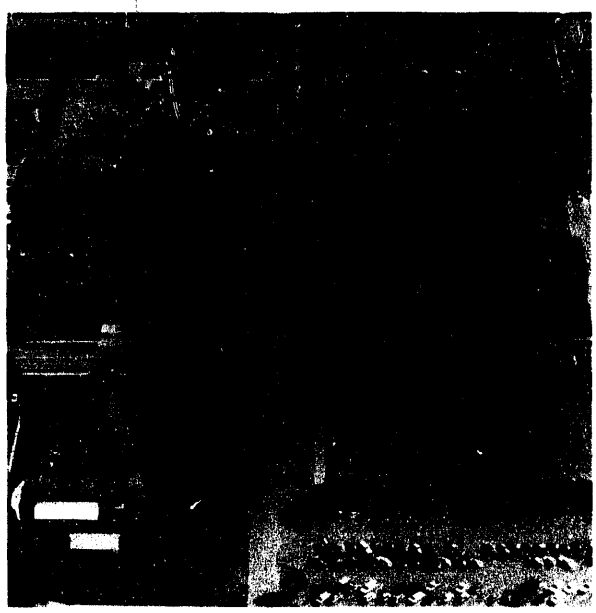
Ames Laboratory
Iowa State University
Office of Research and Technology Applications
119 O&L Building
Ames, IA 50011
(515) 294-2635
FAX (515) 294-3751
williams@ameslab.gov

AMES LABORATORY

Ames Laboratory's primary program areas include chemical, physical, material, and mathematical sciences; high-energy physics; environmental sciences, environmental restoration, and waste management; fossil energy; and energy efficiency.

Ames researchers seek solutions to complex medium- and long-term energy-related problems of national concern. For example, its studies of photosynthesis are directed toward understanding processes that may ultimately be used to design synthetic molecules for direct solar-energy conversion. Its integrated capabilities in metallurgy and ceramics, condensed matter physics, materials chemistry, and related computational and theoretical sciences give the Laboratory a major core competency in the synthesis, characterization, and processing of advanced materials. Its internationally recognized expertise in preparing ultra-high-purity and well-characterized metals, alloys, compounds, and single crystals benefits other DOE laboratories, federal agencies, and the U.S. industrial and educational sectors.



Ames Laboratory's Environmental Technology Integration Program finds commercial partners interested in helping meet DOE cleanup needs. Its Rare Earth Information Center maintains a database to provide companies and universities with the most current information on rare earth materials. The Laboratory's *High T_c Update* publication service offers the latest news about research and developments in high-temperature superconductivity.

Ames Laboratory capitalizes on its integration with Iowa State University by maintaining highly effective programs for training graduate students, science education, and technology transfer. ■

Continuous Electron Beam Accelerator Facility

Newport News, Virginia

Operated by Southeastern Universities Research Association (SURA)
FY 1993 Construction Budget $32,000,000
FY 1993 Operating and Equipment Budget $29,800,000
FY 1993 Staff 483

Technology Transfer Contact

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Continuous Electron Beam Accelerator Facility
Superconducting Radiofrequency Technology Department
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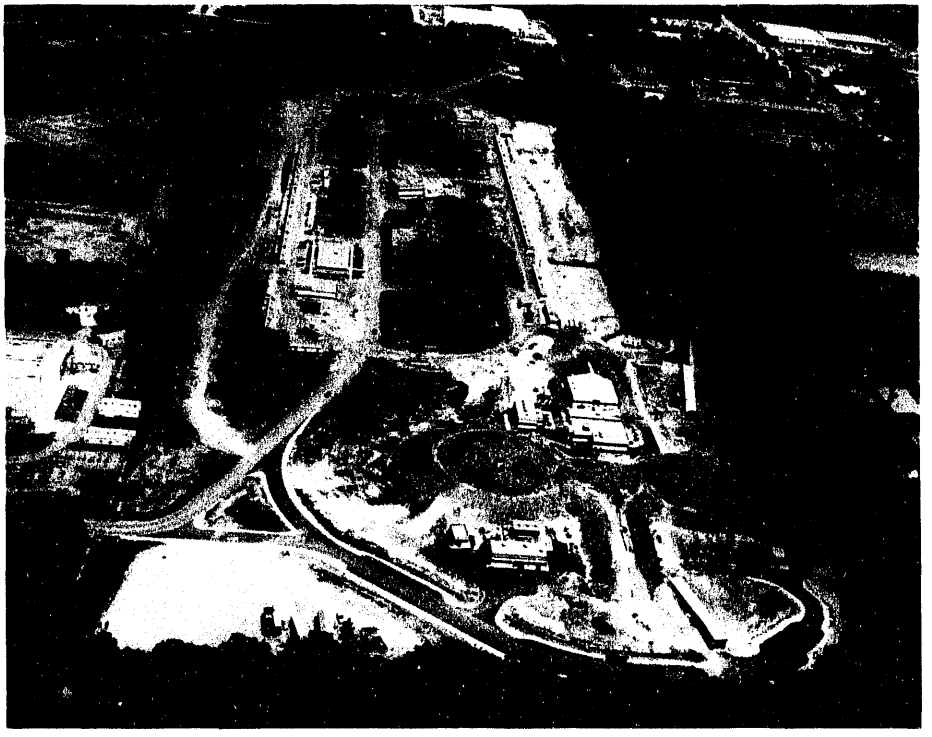
Newport News, VA 23606
(804) 249-7450
FAX (804) 249-7658

The Continuous Electron Beam Accelerator Facility (CEBAF) will begin operations as a national user facility for nuclear physics research in June 1994. At CEBAF, scientists will be able to study the structure of atomic nuclei with unprecedented precision. Its superconducting accelerator will probe the quark structure of nuclear matter by providing simultaneous, continuous beams of electrons at energies of up to 4 billion electron-volts for experiments in each of three experimental halls.

CEBAF researchers are now collaborating with users to prepare experiments, the earliest of which will begin in spring 1994. More than 118 proposals have been received, requesting 80,000 hours of beam time. Of those, 25,000 hours have been recommended for approval. More than 700 nuclear physicists from 199 institutions are participating in the CEBAF user program.

The technology for the superconducting radio-frequency accelerating cavities at the heart of the accelerator has been transferred to industry. Other technology transfer opportunities exist for the cavities as well. Their potential for use in high-power, free-electron lasers to provide tunable monochromatic laser light for scientific applications and industrial research and development has led to the formation of a Laser Processing Consortium. CEBAF's computer-based accelerator control system is also attracting the attention of industry. ■



CEBAF

Fermi National Accelerator Laboratory

Batavia, Illinois

Operated by Universities Research Association, Inc.
FY 1993 Operating Budget $171,100,000
FY 1993 Staff 2,342

User Facilities

The entire facility is designated as a scientific user facility. The following specific resources are included:

- Antiproton Source
- Colliding Beam Areas
- Meson Experimental Area
- National Environmental Research Park
- Neutrino Experimental Area
- Proton Experimental Area
- 1,000-GeV Superconducting Accelerator System (Tevatron)

Technology Transfer Contact

Mr. John T. Venard
Fermilab
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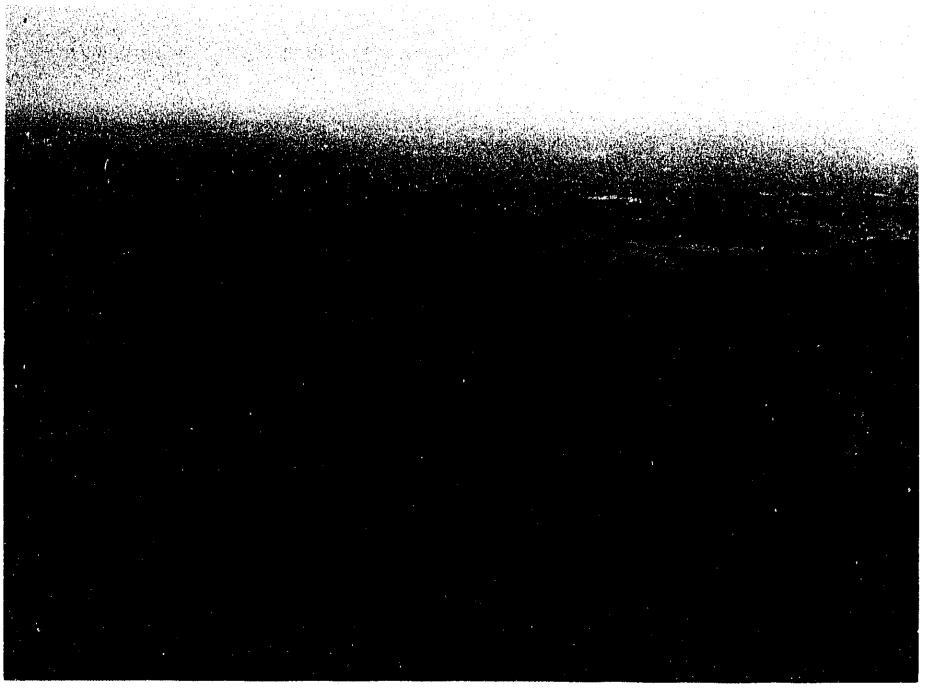
(708) 840-3333
FAX (708) 840-8752
jnet%"venard@fnal"

Fermi National Accelerator Laboratory has applied its expertise and experience in five areas: the development of superconducting magnets, design and operation of particle accelerators, development of detectors, high-performance computing, and experimental and theoretical physics. Its mission is to provide resources in these core areas to researchers in high-energy physics and related disciplines. Fermilab fosters and stimulates science education, transfers technologies developed at the Laboratory to industry, and conducts operations while promoting excellence in health and safety and protecting the environment. ■



Hanford Site

Richland, Washington

Operated by Westinghouse Hanford Company
FY 1993 Operating Budget $1,200,000,000
FY 1992 Staff 11,100

Technology Transfer Contact

Mr. Alva L. Ward
Westinghouse Hanford Company
International Environmental Institute
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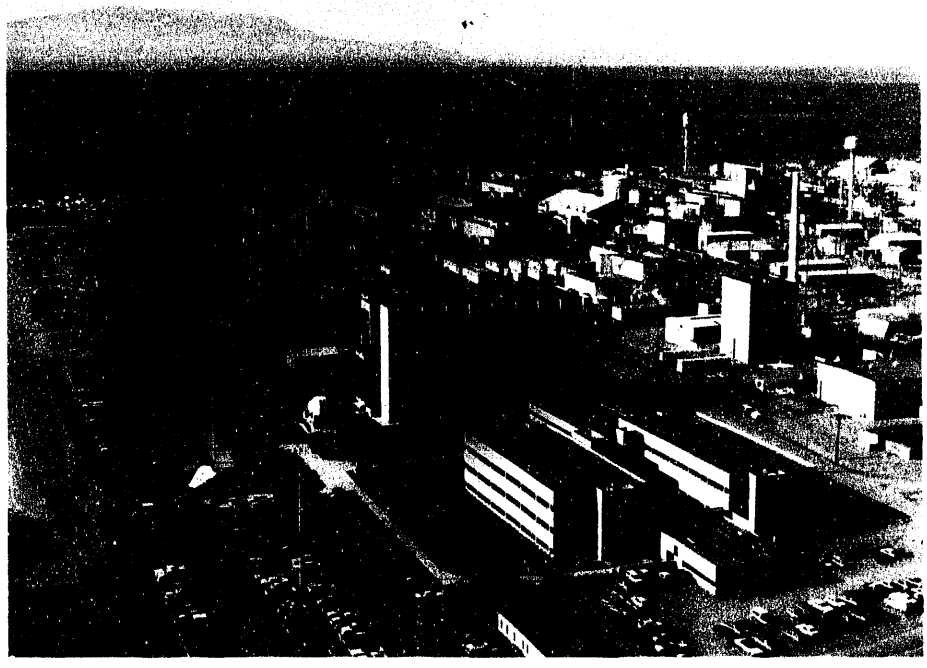
Richland, WA 99352
(509) 376-8656
FAX (509) 372-2454

Westinghouse Hanford Company is the management and operations contractor for the DOE Hanford Site. Its primary mission is Site restoration and management of the radioactive and hazardous wastes generated at the Site over a period of nearly 50 years. Its broad scope of work also includes management of the Fast Flux Test Facility and other engineering development and chemical processing facilities, as well as responsibility for reactor decommissioning, site security, and other support services.

Westinghouse Hanford Company manages the underground storage tank integrated demonstration project. The project focuses on the radioactive waste materials stored in the tanks, which account for a large portion of the overall Hanford cleanup effort. Integrated demonstration projects are designed to provide pilot-scale tests of the technologies and processes required to handle a variety of waste forms through the use of optimized remediation methods. Technologies developed to support Hanford cleanup activities are being made available to other U.S. government agencies and the private sector. ■



Westinghouse Hanford Company

Morgantown Energy Technology Center

Morgantown, West Virginia

Government Owned and Government Operated
FY 1993 Operating Budget $400,000,000
FY 1993 Staff 307

Technology Transfer Contact

Dr. William F. Lawson
Morgantown Energy Technology Center
Technology Transfer Program Division
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Morgantown, WV 26507
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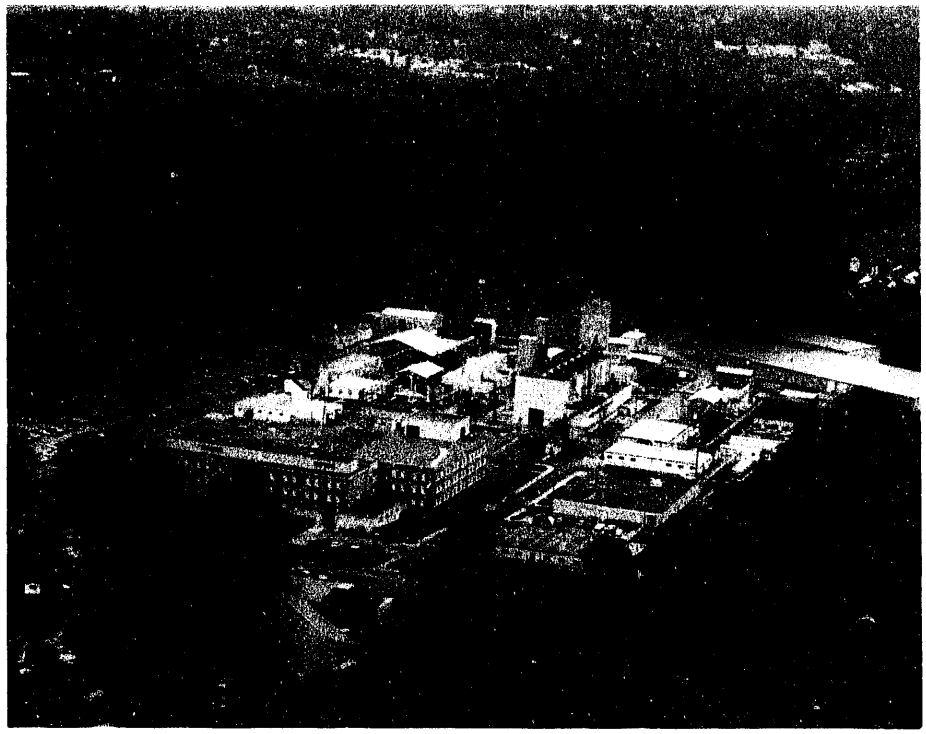
FAX (304) 291-4403

The Morgantown Energy Technology Center (METC) conducts and manages research, development, and demonstrations to enhance the production and use of U.S. fossil energy resources. Activities at METC focus on enhancing the nation's economic competitiveness, environmental quality, and energy security through the development and deployment of clean, low-cost, and efficient products. The goal is for METC products to be marketed by domestic producers for commercial use throughout the world.

In addition to conducting research and development, METC executes other projects through contracts and cooperative agreements with industry and academia. Major missions of METC involve the following fossil energy technologies: surface coal gasification, coal-fired heat engines, fluidized-bed components for coal utilization, fuel cells for stationary applications, unconventional gas recovery, tar sands, oil shale, and utilization of low-rank coal. METC also shares major mission responsibilities for clean coal technology, advanced turbine systems, indirect coal-fired power systems, and environmental restoration and waste management. ■



METC

National Renewable Energy Laboratory

(formerly Solar Energy Research Institute)
Golden, Colorado

Operated by Midwest Research Institute
FY 1993 Operating Budget $157,000,000
FY 1993 Staff 850

Technology Transfer Contact

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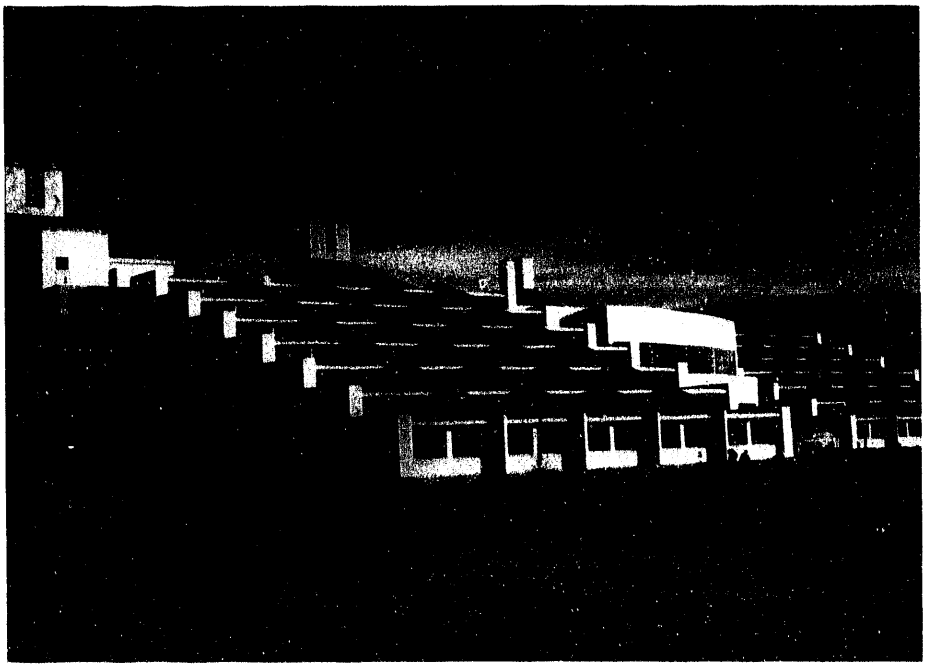
National Renewable Energy Laboratory
Technology Transfer Office
1617 Cole Boulevard
Golden, CO 80401
(303) 231-1198
FAX (303) 231-1997

As DOE's primary laboratory for conducting research on renewable energy, the National Renewable Energy Laboratory (NREL) develops technologies that use the sun, wind, water, plants, and wastes to produce fuel for transportation; generate electricity; heat and cool buildings; light homes and offices; produce plastics, clothing, drugs, and chemicals; clean the water; destroy toxic wastes; and absorb carbon dioxide from the atmosphere. NREL research activities span eight scientific, technical, and analytical areas:

- Materials sciences covers areas from bio-based materials and ceramics to superconductors and solid-state physics.
- Biosciences embraces biocatalysis, biochemistry, genetic engineering, and microbiology.
- Optics includes research on lasers, optoelectronics, and solar concentrators.
- Engineering includes the disciplines of acoustics, structural dynamics, heat and mass transfer, aerodynamics, and chemical processing.
- Photon interaction investigates the role of sunlight in biological, catalytic, chemical, and photosynthetic processes.
- Resource assessment measures and appraises available renewable resources — sunlight, wind, water, and biomass.
- Analysis and measurement specializes in characterizing the crystallographic, electrical, optical, surficial, interfacial, and thermal properties of materials.
- Energy and environmental analysis assesses the environmental impacts of energy, energy markets, and the economics of energy systems.



In October 1993, NREL completed this Solar Energy Research Facility, a 120,000-square-foot complex dedicated to advanced research in photovoltaics.

Oak Ridge Institute for Science and Education

Oak Ridge, Tennessee

Operated by Oak Ridge Associated Universities (ORAU)
FY 1993 Operating Budget $75,500,000
FY 1993 Staff 760

User Facility

University Isotope Separator — Oak Ridge (UNISOR)

Technology Transfer Contract

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Oak Ridge Institute for Science and Education
Technology Transfer Department
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Oak Ridge, TN 37831
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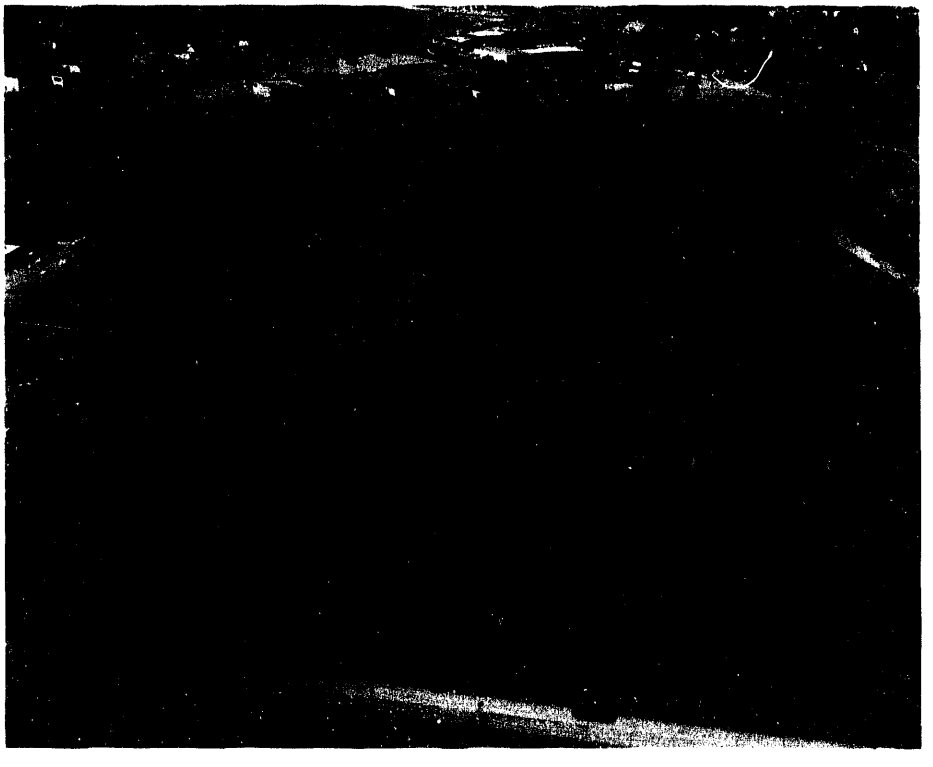
FAX (615) 576-3643

The Oak Ridge Institute for Science and Education (ORISE) carries out national and international programs in training and management systems, medical sciences, science and engineering education, and energy and environmental systems.

The ORISE mission is to provide and develop capabilities critical to the nation's science and technology infrastructure, particularly in energy, education, health, and the environment. Experienced in the skills of networking and collaboration, ORISE supports its mission through partnerships with DOE laboratories and contractors, academic institutions, private companies, state and local governments, and scientists throughout the world. ORISE's core competencies are in the following areas:

- Education and training, with an emphasis in science and mathematics education, performance-based and specialized training, technology transfer training, and workforce and employment needs analyses.
- Biomedical research, concentrating on cytogenetics and biochemistry.
- Environmental and occupational health effects, with a focus on radiation medicine, radiation assistance and training, epidemiology, and occupational medicine.
- Environmental restoration and waste management, stressing environmental surveys and assessments and energy research and systems analysis.

These areas of expertise provide a solid foundation for generating new ideas and innovative approaches to complex issues. ■



ORISE

Pittsburgh Energy Technology Center

Pittsburgh, Pennsylvania

Government Owned and Government Operated
FY 1993 Operating Budget $173,000,000
FY 1993 Staff 320

Technology Transfer Contact

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Pittsburgh Energy Technology Center
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The Pittsburgh Energy Technology Center (PETC) is one of the federal government's principal fossil energy research laboratories. For nearly 50 years, the Center has been a world leader in coal science and technology, developing a substantial amount of expertise in coal combustion and conversion as well as in fundamental coal science.

The PETC mission is to develop cost-effective and environmentally sound technologies to make use of the nation's abundant supply of coal. Its primary responsibility is technical and administrative management of coal-related research and development programs under the auspices of DOE's Office of Fossil Energy. This work includes programs in coal preparation, advanced combustion technology, alternative fuels utilization, flue-gas cleanup, coal liquefaction, magneto-hydrodynamics, conversion of methane to liquids, coal utilization science, solids transport, and management of the University Coal Research Program. Besides its annual operating budget, it receives direct funds to participate in DOE's multibillion-dollar Clean Coal Technology Program.

The Center is located in South Park Township, Pennsylvania, a suburb south of Pittsburgh. It shares a 237-acre site, known as the Bruceton Research Center, with the U.S. Department of the Interior's Bureau of Mines and the U.S. Department of Labor's Mine Safety and Health Administration. Together, these three agencies constitute the nation's largest federal coal research complex. ■

PETC
PITTSBURGH ENERGY TECHNOLOGY CENTER

Princeton Plasma Physics Laboratory

Princeton, New Jersey

Operated by Princeton University
FY 1993 Operating Budget $103,500,000
FY 1993 Staff 850

Technology Transfer Contact

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Princeton Plasma Physics Laboratory
Office of Technology Transfer
James Forrestal Campus
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Princeton, NJ 08543
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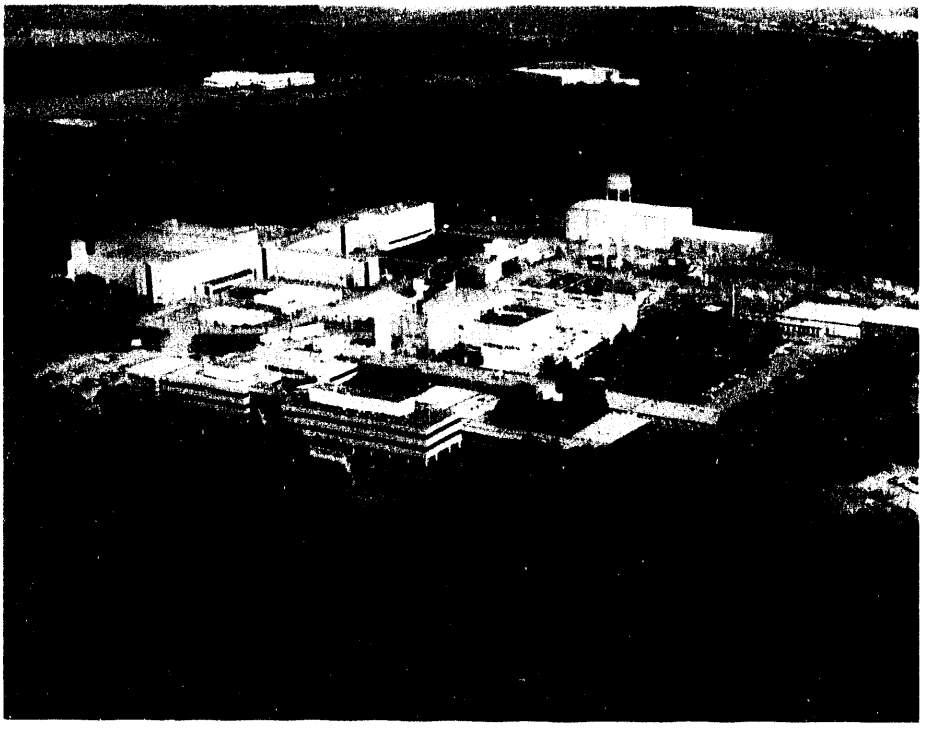
FAX (609) 243-2800

The primary mission of Princeton Plasma Physics Laboratory (PPPL) is research in magnetically confined fusion for the safe, economical, and environmentally acceptable generation of electricity for the long term. The Laboratory is a world leader in plasma research and plasma technology development.

In support of its primary mission, PPPL pursues extensive research and development activities in the following disciplines and topical areas:

- Plasma engineering and diagnostics.
- Magnetic field systems.
- Radio-frequency heating and current-drive technology.
- Neutral beam technology.
- Remote handling of nuclear systems.
- Surface-modification technology.
- Tritium handling, storage, and delivery systems.
- Theoretical and applied physics.
- Soft x-ray lasers.
- Computer systems and diagnostic systems.
- Production of extremely high flux neutral atomic beams to evaluate the erosion rates of materials. ■



PPPL PRINCETON PLASMA PHYSICS LABORATORY

Savannah River Technology Center

Aiken, South Carolina

Operated by Westinghouse
Savannah River Company
FY 1993 Operating Budget $180,000,000
FY 1993 Staff 1,570

Technology Transfer Contact

Dr. John C. Corey
Savannah River Technology Center
Westinghouse Savannah River Company
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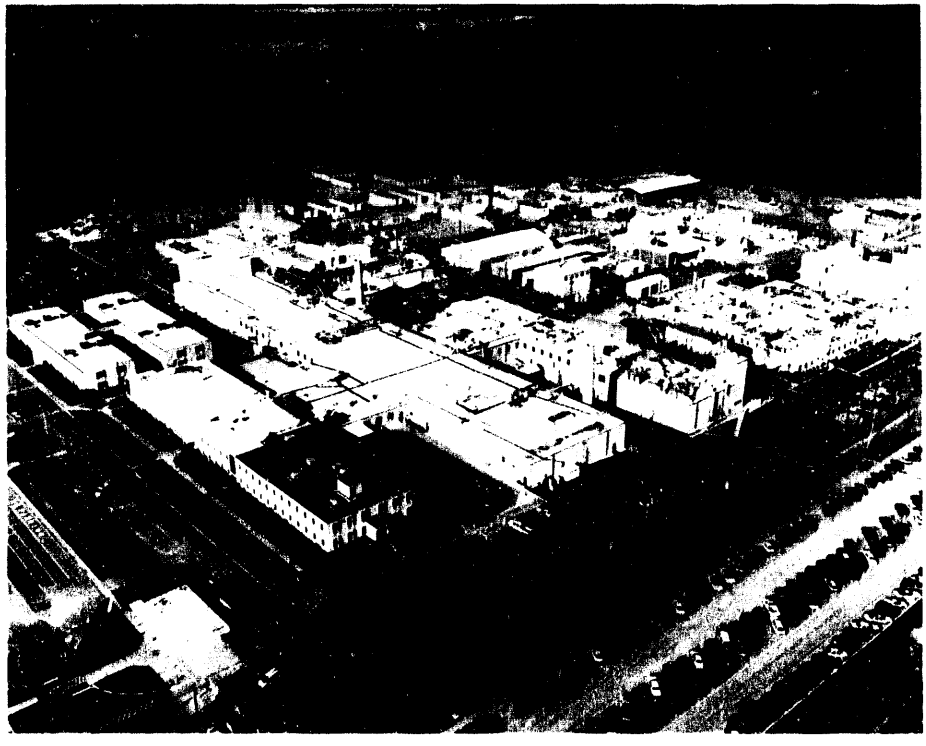
Aiken, SC 29801
(803) 725-3020
FAX (803) 725-5377

The Savannah River Technology Center (SRTC) functions as an applied research and development center, providing technical support for all the major activities and operating facilities at the Savannah River Site. It provides this research and development for the Site through four major programs. The first lends technical support for chemical separation processes and tritium process development. The second program develops state-of-the-art computer codes for use in research and development and provides technical support for reactor operations and the manufacture of fuel and target assemblies. The third area of technical emphasis is safety analysis, which supports both reactor and nonreactor processing operations. Finally, SRTC provides research, process development, and technical support for the management of radioactive wastes and environmental studies and restoration.

In addition to the strong focus on Site operations, SRTC supports a wide range of activities outside the Site. Various initiatives, such as the work-for-others program, increase communication between professionals of the same field to meet the needs of SRTC and U.S. industry. Educational outreach programs also support relationships between SRTC and universities and colleges around the country. ■



SRTC
Savannah River Technology Center

Stanford Linear Accelerator Center

Stanford, California

Operated by Stanford University
FY 1993 Operating Budget $134,600,000
FY 1993 Staff 1,580

User Facilities

Linear Accelerator (LINAC): 50-GeV facility, 2 miles long
Stanford Linear Collider (SLC): 100-GeV (center-of-mass) linear electron-positron collider
Stanford Large Detector (SLD): Detects collision products in the SLC
End Station A (ESA): Fixed-target spectrometer facility
Stanford Synchrotron Radiation Laboratory (SSRL): 3-GeV storage-ring facility, 80 meters in diameter, with 25 experimental stations that provide VUV and x-ray radiation
Positron-Electron Project (PEP): 15 GeV colliding-beam, storage-ring facility, 800 meters in diameter

Technology Transfer Contact

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Stanford, CA 94309
(415) 926-2213
FAX (415) 926-4999
jsimpson@slacvm.bitnet

The Stanford Linear Accelerator Center (SLAC) is a national facility dedicated to research in high-energy physics and those fields that make use of its synchrotron radiation, including biology, chemistry, geology, materials science, condensed matter physics, medical science, and electrical engineering. Universities, other research centers, and businesses throughout the world participate in its programs. SLAC's mission is to:

- Provide the accelerators, detectors, insertion devices, instrumentation, and support needed for national research programs in elementary particle physics and synchrotron radiation.
- Advance the art of accelerators and related devices by developing sources of both high-energy particles and synchrotron radiation and developing new techniques for their scientific exploitation.
- Advance the technologies necessary for the United States to maintain leadership and excellence in accelerator, synchrotron radiation, detector, and related research programs.
- Transfer knowledge and innovative technology to the private sector.
- Contribute to the education of the next generation of scientists and engineers and to the scientific awareness of the public.
- Achieve and maintain excellence in matters of environmental concern and provide for the safety and health of its staff and the public.

Major programs and initiatives include research and development activities in connection with the SLC and SLD; Z physics; polarized beams; fixed-target physics at ESA; PEP II, an update of the PEP ring to be used as a B meson factory; structural molecular biology; synchrotron-radiation studies of materials and biological systems; free-electron laser; the next linear collider; and international collaborations on the Beijing electron-positron collider and the tau-charm factory in Spain.

The Center's core competencies are in electron accelerators, synchrotron radiation, particle detection, and critical technologies. ■

Superconducting Super Collider Laboratory

Dallas, Texas

Operated by Universities Research Association, Inc.
FY 1993 Operating and Construction Budget $517,000,000
FY 1993 Staff 1,950

Technology Transfer Contact

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Superconducting Super Collider Laboratory
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2550 Beckleymeade Avenue
Dallas, TX 75237
(214) 708-1104
FAX (214) 708-0005
amontgomery@sscvx1.ssc.gov

SSC Laboratory

The Superconducting Super Collider Laboratory (SSCL) was established in 1989 to design, build, maintain, and operate the Superconducting Super Collider (SSC). The SSC, which was to have been completed in the early 2000s, would have been the most powerful accelerator of subatomic particles in the world. It would have been used to explore the fundamental nature of matter and energy.

The decision by the U.S. Congress to terminate the SSC project includes an instruction to prepare a plan "to maximize the value of the investment that has been made" in the project. An important part of that investment is the technology developed for and by the project. To safeguard this investment, appropriate measures are being taken to document technologies, identify commercial opportunities, and transfer the technologies to industry or other government laboratories.

Some of the most significant technological developments associated with the SSC project are related to advanced accelerator and superconducting magnet systems, detector components, and computer software and networks. In addition, a significant amount of effort was expended to construct facilities for the project — in particular, the 14-foot-diameter, 54-mile-long tunnel that would have housed the SSC. Identifying important scientific uses for these facilities is an important aspect of maximizing the SSC project investment.

Research and development work for the SSC project has been conducted at the SSCL, other DOE laboratories, and academic institutions across the United States and abroad, as well as by both large and small industrial contractors. Numerous inventions, many of which have commercial potential, originated from work done by the SSCL and its subcontractors. The technology for fabricating the collider's superconducting magnets has already been transferred to industry. Many of the technology transfer activities undertaken by the SSCL were a result of the close cooperation it had developed with industrial partners through procurement contracts (rather than cooperative research and development agreements and other typical technology transfer mechanisms). These contracts promoted technology on a large number of fronts. Now the resulting technological advances can be applied by companies in the commercial sector to develop new or improved products. In addition, about 70 records of invention have resulted from work at the SSCL, and 11 patents have been filed for or awarded. Actitives are ongoing to ensure that all SSC technology is documented and transferred to appropriate organizations. It is anticipated that the SSC intellectual property files will ultimately be transferred to Fermi National Accelerator Laboratory.

ther Laboratories and Facilities

Bartlesville Project Office

Bartlesville, Oklahoma

Government Owned and Government Operated
FY 1993 Operating Budget $60,000,000
FY 1993 Staff 20

Technology Transfer Contact

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U.S. Department of Energy
Bartlesville Project Office
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Bartlesville, OK 74005
(918) 337-4293
FAX (918) 337-441

The Bartlesville Project Office (BPO) is the lead mission field office within DOE's Office of Fossil Energy for planning and implementing research on oil. Its program includes research related to the geosciences, reservoir characterization, and oil extraction and processing. More than 200 individual projects are designed to accomplish DOE's Advanced Oil Recovery Program goals: to arrest the abandonment of marginally productive oil fields and maximize economic recovery of domestic oil resources.

In fiscal year 1994, BPO has added a third reservoir class to its research program, which consists of projects tailored to specific oil reservoir classes. The 25 projects tailored to Class I and Class II oil reservoirs have drawn participation from major and independent oil companies, service companies, consultants, universities, and governmental agencies working in pairs or as teams. Technology resulting from these projects will be transferred to operators in applicable reservoirs, particularly independent oil producers, which constitute an increasingly large share of U.S. oil production.

Bates Linear Accelerator Center

Middleton, Massachusetts

Operated by the Massachusetts Institute of Technology
FY 1993 Operating Budget $12,000,000
FY 1993 Staff 87

Technology Transfer Contact

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Massachusetts Institute of Technology
Bates Linear Accelerator Center
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Middleton, MA 01949
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FAX (617) 245-0901
averill@mitbates

Located 20 miles north of the MIT campus, Bates Linear Accelerator Center is a nationally recognized laboratory that conducts physics investigations, specializing in the interaction of electron beams with matter at energies of 0.2 to 1.0 GeV. A storage ring, 200 meters in circumference, has recently been added to the S-band pulsed-beam facility. It will allow a direct-current stored beam to be used for internal target physics or slowly extracted for an external target/spectrometer system. The electron beams can be polarized or unpolarized by separate appropriate injectors.

The Center is available to scientists throughout the world to conduct experimental programs in nuclear physics for investigating the electromagnetic properties of nuclei, mechanisms by which mesons interact with nuclei, properties of nuclei that can be learned from meson and lepton probes, and fundamental weak and strong interactions. Included as part of the Center's nuclear physics goals is an educational mission to train young scientists. Experiments at Bates supply data for about five Ph.D. theses per year.

Energy Technology Engineering Center

Canoga Park, California

Operated by Rocketdyne
Division of Rockwell International
FY 1993 Operating Budget $35,000,000
FY 1993 Staff 198

User Facilities

Component Handling & Cleaning Facility (CHCF)
Fragility Test System (FTS)
Hydraulic Test Facility (HTF)
Kalina Demonstration Plant (KDP)
Large Leak Test Rig (LLTR)
Liquid Metal Development Labs (LMDL-1&2)
Small Component Test Loop (SCTL)
Sodium Component Test Installation (SCTI)
Sodium Pump Test Facility (SPTF)
Steam Accumulator Blowdown Evaluation Rig (SABER)
Thermal Transient Facility (TTF)

Technology Transfer Contact

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Energy Technology Engineering Center
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Canoga Park, CA 91309
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FAX (818) 586-5118

The Energy Technology Engineering Center (ETEC) occupies 90 acres of the 2,700-acre Rocketdyne Santa Susana Field Laboratory, which has been involved in propulsion and energy development activities since 1947. ETEC's primary mission is applied engineering and testing in support of the commercialization of emerging technologies related to solar, geothermal, fossil, fusion, and fission energy sources and conservation.

The Center's personnel are involved in designing, managing the construction of, and operating test facilities; furthermore, they manage and conduct test programs for evaluating a wide variety of systems and components. Specialty teams manage and monitor nationwide energy projects conducted off-site. ETEC scientists and engineers also manage several on-site environmental restoration projects.

The Center performs work for state and federal governmental agencies, both U.S. and foreign utility companies, commercial entities, and other organizations. ■

Environmental Measurements Laboratory

Government Owned and Government Operated
FY 1993 Operating Budget $10,100,000
FY 1993 Staff 91

Technology Transfer Contact

Mr. Phillip W. Krey
U.S. Department of Energy
Environmental Measurements Laboratory
376 Hudson Street
New York, NY 10014
(212) 620-3619
FAX (212) 620-3600

New York, New York

The mission of the Environmental Measurements Laboratory (EML) is to address important scientific questions concerning human health and environmental impacts by conducting experimental and theoretical research on radioactive and other energy-related pollutants. Through its multidisciplinary staff, EML provides DOE and other federal agencies with the in-house capability to respond effectively and efficiently with regard to quality assurance activities, environmental issues, and related national security issues.

Inhalation Toxicology Research Institute

Operated by Lovelace Biomedical and Environmental Research Institute
FY 1993 Operating Budget $14,400,000
FY 1993 Staff 180

Technology Transfer Contact

Dr. Charles H. Hobbs
Inhalation Toxicology Research Institute
P.O. Box 5890
Albuquerque, NM 87185
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FAX (505) 845-1229
tnlovelacebi@technet.nm.org

Albuquerque, New Mexico

The Inhalation Toxicology Research Institute (ITRI) is dedicated to protecting human health by conducting basic and applied research designed to improve understanding of the respiratory tract and the effects on human health that might result from inhaling airborne toxic substances in the home, workplace, or environment. The Institute's three-part mission involves research, education, and technology transfer. Its primary goals are to conduct high-quality, unbiased research and to link laboratory results with epidemiological findings in order to identify, define, and reduce human health risks. ITRI's focus is on forming collaborations with other scientists, developing research partnerships with industry for problem solving and technology transfer, and serving the scientific community through advisory roles, leadership in professional societies, and research training.

Kansas City Plant

Kansas City, Missouri

Operated by AlliedSignal Inc.,
Kansas City Division
FY 1993 Operating Budget $386,000,000
FY 1993 Staff 4,180

Technology Transfer Contacts

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Kansas City, MO 64141
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FAX (816) 997-5059

Mr. Dennis E. Stittsworth
AlliedSignal Inc.
Kansas City Division
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One of DOE's most diverse production facilities, the Kansas City Plant (KCP) brings together world-class technologies for product development and manufacturing. Traditionally, KCP's mission has involved the manufacture of nonnuclear components for nuclear weapons. With its sophisticated, state-of-the-art expertise in electrical, electronic, optoelectronic, mechanical, rubber, and plastic technologies and related services, KCP provides an exceptional base for work-for-others and technology transfer programs.

Within the Plant's nearly 3.2 million square feet of space are capabilities that facilitate all stages of manufacturing, from prototyping and development to product assembly and environmental testing. Some examples are:

- Electronic support areas for manufacturing assemblies that use digital, microwave, high-voltage electronic, and optoelectronic technologies; facilities for manufacturing thick- and thin-film networks and printed wiring boards (KCP also designs and builds state-of-the-art test equipment).
- A hybrid microcircuit facility that houses a 12,000-square-foot, class 10,000 clean room.
- Precision machining areas for manufacturing complex, miniature mechanisms and large shapes to tight tolerances.
- One of three flexible manufacturing systems in North America — a $15-million state-of-the-art automated facility with integrated coordinate measuring machines; computer-integrated manufacturing techniques; agile manufacturing processes; and in-process, on-line inspection capabilities.
- Evaluation laboratories that provide product and process failure analysis, analytical services, and nondestructive and environmental testing.
- A polymer plant that specializes in material studies to support environmentally conscious manufacturing processes.
- An engineering development shop that uses stereolithography and computer-assisted design capabilities to streamline product development.

As part of DOE's technology transfer initiative, KCP has implemented a regional technology transfer program aimed at helping small and medium-sized companies bolster their competitive advantage. The Office of Technology Transfer in the Kansas City Division of AlliedSignal Inc. works step by step with companies to identify the appropriate technology for their needs. When mutually agreed upon, most information on the technology developed during this collaborative effort is then shared through state- and industry-sponsored assistance networks.

Mound Facility

Miamisburg, Ohio

Operated by EG&G Mound Applied Technologies
FY 1993 Operating Budget $165,000,000
FY 1993 Staff 2,106

Technology Transfer Contacts

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U.S. Department of Energy
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Mr. D. Canon Bradley
EG&G Mound Applied Technologies
Technology Exchange & Commercialization
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FAX (513) 865-4261

Unique among DOE's production agencies, the Mound Facility conducts research and development as well as engages in manufacturing. Research and development activities focus on supporting its production operations; these activities include analysis and characterization of various nuclear materials; separation, purification, and distribution of stable isotopes; and assembly and testing of radioisotopic thermoelectric generators. Production activities concentrate on the manufacture of detonators and other small explosive components for weapons. The Mound mission also encompasses waste management, health and environmental research, and safeguards and security.

The Mound site comprises more than 640 acres, containing special facilities for generic process development; product engineering, manufacturing, and testing; and surveillance of detonators, explosive timers, transducers, firing sets, explosive pellets, and special components and equipment. Mound also possesses environmental sampling capabilities to monitor air, water, soil, and vegetation.

Over the years, Mound has developed a diverse technology base and many specialized support capabilities, as exemplified by the following:

- Extensive capabilities for working with various materials and related technologies: ceramics, cermets, and glass ceramics; metal hydrides; plastics and adhesives; explosives and thermite; radioactive materials, tritium, and radioisotopes; metallurgical and metallographic equipment; technology for thin-film metallic and composite coatings; containment technology; and technology for material compatibility analyses.

- Automated production lines in which manufacturing operations are controlled through computer-assisted design and measurement and through computer-integrated manufacturing; laser-based manufacturing and analytical systems for on- and off-line quality assurance and control; and excimer laser micromachining capabilities.

- Expertise in the integrated development and production of firing sets, detonators, pyrotechnic components, and safing/arming devices.

- Experience in developing and applying techniques and instruments for use in data acquisition, diagnostics, metrology, nondestructive testing, and materials assay.

Mound has been a major producer and distributor of stable isotopes for medical, industrial, and academic research. In addition, it has formed networks with other organizations in the Dayton area to further regional economic development and commercialization of technology.

MSU-DOE Plant Research Laboratory

East Lansing, Michigan

Operated by Michigan State University
FY 1993 Operating Budget $3,692,000
FY 1993 Staff 105

Technology Transfer Contact

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MSU-DOE Plant Research Laboratory
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The MSU-DOE Plant Research Laboratory (PRL) is operated with support from DOE. Its primary mission is to conduct research on plants and to train graduate students and post-doctoral fellows in modern plant biology. An interdisciplinary approach to plant biology — based on techniques from molecular genetics, biophysics, biochemistry, microbiology, and physiology — is used in the research and training programs. Each of the 12 PRL faculty members also holds a joint appointment at MSU.

National Institute for Petroleum and Energy Research

Bartlesville, Oklahoma

Operated by BDM-Oklahoma
FY 1993 Operating Budget $13,000,000
FY 1993 Staff 175

Technology Transfer Contact

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In fiscal year 1994, the National Institute for Petroleum and Energy Research (NIPER) has begun a transition from operation under a 10-year cooperative agreement with IIT Research Institute to operation by BDM-Oklahoma under a five-year management and operating contract. NIPER will continue to provide energy, environmental, and related research services by developing and transferring technologies to help solve problems related to oil recovery and processing. The main areas involved will be geotechnology, chemical and microbial oil recovery, chemical and gas flooding, and thermodynamics and analysis of heavy crude oils. Under the new operating arrangement, NIPER will also assume a broader role in implementing DOE's expanding Oil Research Program.

Nevada Test Site

Mercury, Nevada

Major Management and Operations Contractors:
- Reynolds Electrical & Engineering Company
- EG&G Energy Measurements, Inc.
- Raytheon Services Nevada

FY 1993 Operating Budget $850,000,000
FY 1993 Staff 7,800

User Facility

Liquefied Gaseous Fuels Spill Test Facility

Technology Transfer Contacts

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Located 65 miles northwest of Las Vegas, the Nevada Test Site (NTS) is the nation's only facility for testing nuclear weapons. The 1,350-square-mile site, bordered on three sides by the Nellis Air Force Bombing and Gunnery Range, is a secure facility withdrawn from public access. It was established as a U.S. proving ground in 1950 because of the expense and logistical problems associated with testing nuclear weapons at the Bikini and Enewetak atolls in the Pacific Ocean. Since the nation entered a testing moratorium in 1992, the site has remained in readiness in case the need for nuclear testing should recur.

The NTS is designated a DOE National Environmental Research Park. As such, it is the key element in the educational outreach program being carried out by DOE's Nevada Operations Office. The Office is developing new ways to interface with the educational community and reach students from grammar school through graduate school by making the scientific resources of DOE and its contractors available to them.

The Liquefied Gaseous Fuels Spill Test Facility, completed in 1986, is available for a fee to commercial users. Here they can evaluate the effectiveness of various foams and fire retardants used in accidents involving chemicals and hazardous materials.

The NTS has a strong program in environmental restoration and waste management. This program, developed to manage the cleanup and restoration of facilities affected by nuclear testing, covers four areas: (1) corrective activities to bring NTS into compliance with environmental regulations; (2) environmental restoration activities to assess and clean up NTS to meet prescribed standards; (3) waste management activities to ensure the safe treatment, storage, and disposal of low-level radioactive, hazardous, mixed, and transuranic wastes generated at NTS; and (4) technology development activities to focus on advanced technologies to characterize and clean up contamination caused by radioactive materials.

New Brunswick Laboratory

Argonne, Illinois

Government Owned and Government Operated
FY 1993 Operating Budget $4,100,000
FY 1993 Staff 45

Technology Transfer Contact

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New Brunswick Laboratory, Bldg. 350
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FAX (708) 252-6256

The mission of New Brunswick Laboratory (NBL) is to provide and maintain the nation's Nuclear Material Measurement and Standards Laboratory as a technical response to DOE's statutory responsibility for assuring the safeguarding of nuclear materials.

The Laboratory is a center of excellence in the analytical chemistry and measurement sciences as they relate to nuclear materials. It maintains state-of-the-art capabilities for measuring the elemental and isotopic composition of nuclear materials that are of interest to researchers involved in DOE's energy, defense, and environmental restoration programs. NBL is the nation's certifying authority for nuclear reference materials, and it maintains an internationally compatible reference base for nuclear material measurements. NBL manages inter-laboratory measurement evaluation programs to provide independent documentation of the quality of measurements performed at nuclear facilities.

The Laboratory provides DOE headquarters and operations offices with expertise in nuclear material control and accountability and in assessing compliance with DOE requirements.

Notre Dame Radiation Laboratory

Notre Dame, Indiana

Operated by the University of Notre Dame
FY 1993 Operating Budget $3,350,000
FY 1993 Staff 49

Technology Transfer Contact

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Notre Dame Radiation Laboratory
Notre Dame, IN 46556
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The Notre Dame Radiation Laboratory conducts fundamental research on the chemical processes that result from bombarding matter with ionizing radiation or light. Research focuses on the kinetics and mechanisms of reactions involving short-lived molecular species (e.g., free radicals or excited molecules) and emphasizes reactions in solution and at interfaces. Of particular interest are one-electron transfer reactions, since these are participants in almost all photochemical and biological energy conversion or storage schemes. The Laboratory is a Research Institute of the University of Notre Dame.

Oak Ridge K-25 Site

Oak Ridge, Tennessee

Operated by Martin Marietta
Energy Systems, Inc.
FY 1993 Operating Budget $180,000,000
FY 1993 Staff 4,040

User Facilities

Center for Environmental Technology
Center for Waste Management

Technology Transfer Contact

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Martin Marietta Energy Systems, Inc.
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Oak Ridge, TN 37831
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Located in Roane County, Tennessee, on a 1,500-acre tract of land west of the city of Oak Ridge, the K-25 Site provides a base of operations for programs in environmental restoration, waste management, and related technology development. Through its role as central manager of these programs, the K-25 Site acts as the platform for restoring the environment and managing wastes resulting from DOE activities, and, by so doing, serves other agencies of the federal government and the public as well as DOE.

Formerly known as the Oak Ridge Gaseous Diffusion Plant, the K-25 Site began operations in 1945 as part of the U.S. government's Manhattan Project during World War II. The Site was responsible for the production of highly enriched uranium until 1964, when principal activities were directed toward the production of slightly enriched uranium hexafluoride to be further enriched at other plants and then used in nuclear reactors. From 1964 to 1984, emphasis was also placed on the development and pilot testing of the gas centrifuge method of uranium enrichment. Basic research and development on other enrichment techniques such as laser isotope separation were conducted as well. In 1987, the decision was made to shut down the gaseous diffusion system, and the Site was slated for decontamination and decommissioning. It was then that the focus of Site activities shifted to environmental restoration.

The K-25 Site mission includes management of the Toxic Substance Control Act (TSCA) facility — a unique mixed-waste incinerator; support of risk-based cleanup programs for contaminated facilities and natural resources; safe and legal waste management; development and demonstration of innovative environmental technologies; support of the hazardous waste remedial action program; and provision of cost-effective support and services to K-25 Site users. Along with its focus on environmental restoration and waste management, the Site conducts programs in areas such as technology development, technology transfer, engineering technology, uranium enrichment support, management and administration, engineering, and computing and telecommunications.

Oak Ridge Y-12 Plant

Oak Ridge, Tennessee

Operated by Martin Marietta Energy Systems, Inc.
FY 1993 Operating Budget $601,000,000
FY 1993 Staff 5,000

User Facilities

Centers for Manufacturing Technology

Technology Transfer Contacts

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Y-12 Technology Transfer Program
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Located in the Bear Creek Valley of eastern Tennessee, adjacent to Oak Ridge and about 15 miles from Knoxville, the Y-12 Plant began operations in 1943 as part of the World War II Manhattan Project. Its first mission was to separate uranium-235 from natural uranium by the electromagnetic separation process. At the end of 1946, when gaseous diffusion became the accepted process for enriching uranium, the separators were taken out of commission. Since then, the Y-12 Plant's missions have changed over the years as international tensions have eased and as the Plant's weapon-component production activities have ended.

Today, the Y-12 Plant carries out assignments for the U.S. defense program that include dismantling nuclear weapon components returned from the national arsenal, maintaining nuclear production capability and stockpile support, serving as the nation's storehouse of special nuclear materials, and providing special production support to DOE programs. Another long-standing mission is to support other federal agencies through a work-for-others program. The Plant's technology transfer mission is to adapt its expertise — initially developed for highly specialized military purposes — to a wide range of manufacturing problems in support of the U.S. industrial base. This expertise encompasses all stages of the design process, from conceptualization, to detailed design and specification, to prototype construction, and to the configuration of integrated manufacturing processes.

The Centers for Manufacturing Technology, located on the Y-12 Plant site, apply the skills, capabilities, and facilities developed over the 50-year history of the Oak Ridge complex to a variety of peacetime missions. The knowledge of manufacturing technology that resides at Y-12, combined with the research and development capabilities of Oak Ridge National Laboratory and the environmental restoration and waste management expertise of the K-25 Site at Oak Ridge, form a formidable resource for the nation's industrial community. Major Y-12 programs include metrology (measurement science), machine tool technology, technology applications, manufacturing operations, and gear and thread technology. Manufacturers throughout the nation have easy access to the information and services at Y-12 through a toll-free telephone service that links them directly to scientists, engineers, and other technical experts. ■

Pantex Plant

Amarillo, Texas

Operated by Mason & Hanger-Silas Mason Company, Inc.
FY 1993 Operating Budget $200,000,000
FY 1993 Staff 2,987

Technology Transfer Contact

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The Pantex Plant is located about 17 miles northeast of Amarillo in the Texas Panhandle on a 16,000-acre site. It is responsible for the final stage of the nuclear weapons production process, that is, assembly of the various components from other DOE production facilities into completed weapons.

The Plant's mission encompasses fabrication of chemical explosives; development work in support of DOE's design laboratories; and the assembly, disassembly, testing, quality assurance, repair, retirement, and disposal of nuclear weapons. The Plant possesses the following specialized facilities and capabilities:

- Numerically controlled machine tools, including advanced-design, multiaxis, precision mills, lathes, and boring machines that provide radial tolerances of +0.001 inch or better.
- Laser systems for cutting, welding, drilling, and treating surfaces and for sampling.
- Firing chambers and diagnostics instrumentation and equipment for destructive testing (e.g., digitizing and raster oscilloscopes), laser interferometers, electronic time-interval meters, and high-speed framing and streak cameras.
- Linear-accelerator x-ray and neutron radiography systems for nonintrusive inspection and detection.
- Development laboratories for explosives, robotics, reentry inertial measurement, and telemetric system acceptance.

The Plant also makes use of computer software for manufacturing resource planning called MRP II, which Mason & Hanger-Silas Mason helped enhance so that it applies to disassembly as well as assembly activities.

Pinellas Plant

Largo, Florida

Operated by Martin Marietta Specialty Components
FY 1993 Operating Budget $107,500,000
FY 1993 Staff 1,150

Technology Transfer Contacts

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Since 1956, the traditional mission of the Pinellas Plant has been to develop and produce neutron generators for the nation's nuclear weapons program. These unique components consist of a miniaturized linear ion accelerator and pulsed electrical power supply. To produce these devices, the Plant has acquired facilities and expertise that have broader commercial applicability.

The Plant's facilities occupy 715,000 square feet on almost 100 acres midway between Clearwater and St. Petersburg, Florida. They include special testing laboratories for evaluating gases, metals, ceramics, and other materials used in weapons production and for controlling the process parameters under which these materials are formed.

In addition to obtaining devices for neutron generation and detection, Pinellas has acquired design, development, and production capabilities for an array of related products and technological areas, among which are:

- Alumina ceramics, cermet (electrical) feedthroughs, and glass ceramics.
- Environmentally safe solvents to replace hazardous solvents for cleaning and coating applications.
- Ultraclean, high-vacuum technologies.
- Hermetic seals between metals and glass, ceramics, or glass-ceramic composites.
- Test and process control equipment.
- Equipment for generating and measuring high voltages.
- Specialized electronic components such as lightning arrester connectors, optoelectronics, capacitors, vacuum switches, crystal resonators, and shock transducers.
- Active and reserve battery technologies.
- Sophisticated computer-aided engineering.

A technology transfer program has been established at the Pinellas Plant so its capabilities can be shared with U.S. companies. Its staff's expertise is available to help industries solve product development and manufacturing problems.

Rocky Flats Plant

Golden, Colorado

Operated by EG&G Rocky Flats, Inc.
FY 1993 Operating Budget $978,500,000
FY 1993 Staff 7,200

Technology Transfer Contacts

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FAX (303) 966-4063

The Rocky Flats Plant (RFP) is located 16 miles northwest of Denver, Colorado, on a 384-acre site surrounded by a 6,550-acre natural preserve. Since 1952, it has traditionally been responsible for manufacturing nuclear weapon components from plutonium, beryllium, uranium, and various stainless steel alloys. RFP's principal product has been plutonium triggers.

The Plant's mission has expanded to include plutonium reclamation, environmental remediation, and waste management. As part of an aggressive environmental restoration program, 178 sites at RFP are being investigated and characterized. This effort involves installation of about 750 wells to monitor groundwater quality. Contaminated groundwater can be pumped to an on-site treatment facility, where volatile organic compounds are destroyed by exposure to ultraviolet light and treatment by hydrogen peroxide and where heavy metals and radionuclides are removed by means of ion exchange or cross-membrane filtration.

The Plant also possesses the following unique capabilities and resources:

- Expertise, technology, and facilities for casting, forming, precision-machining, and welding plutonium, beryllium, titanium, and tantalum.
- Knowledge of how to modify tractor trailers, railcars, and other vehicles for transporting nuclear material.
- A broad array of nondestructive testing technologies.

In 1992, industry expressed a need for welders and brazers with certification in advanced joining technologies. A cooperative agreement between the DOE Office of Defense Programs and the American Welding Society established a Precision Joining Center to provide instruction and certification programs. EG&G Rocky Flats, Inc., is supplying curricula and instructors for the Center. RFP is exploring other opportunities to share its capabilities with various U.S. industries to enhance the nation's commercial competitiveness in world markets.

Savannah River Ecology Laboratory

Operated by the University of Georgia
FY 1993 Operating Budget $10,000,000
FY 1993 Staff 180

Technology Transfer Contact

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Aiken, South Carolina

The Savannah River Ecology Laboratory (SREL), founded in 1951, is located at the Savannah River Site near Aiken, South Carolina. Its mission is to gather, explore, and communicate information on ecological processes and principles. SREL accomplishes this mission through three basic activities: research, education and outreach, and service. DOE is the primary source of funding for these activities.

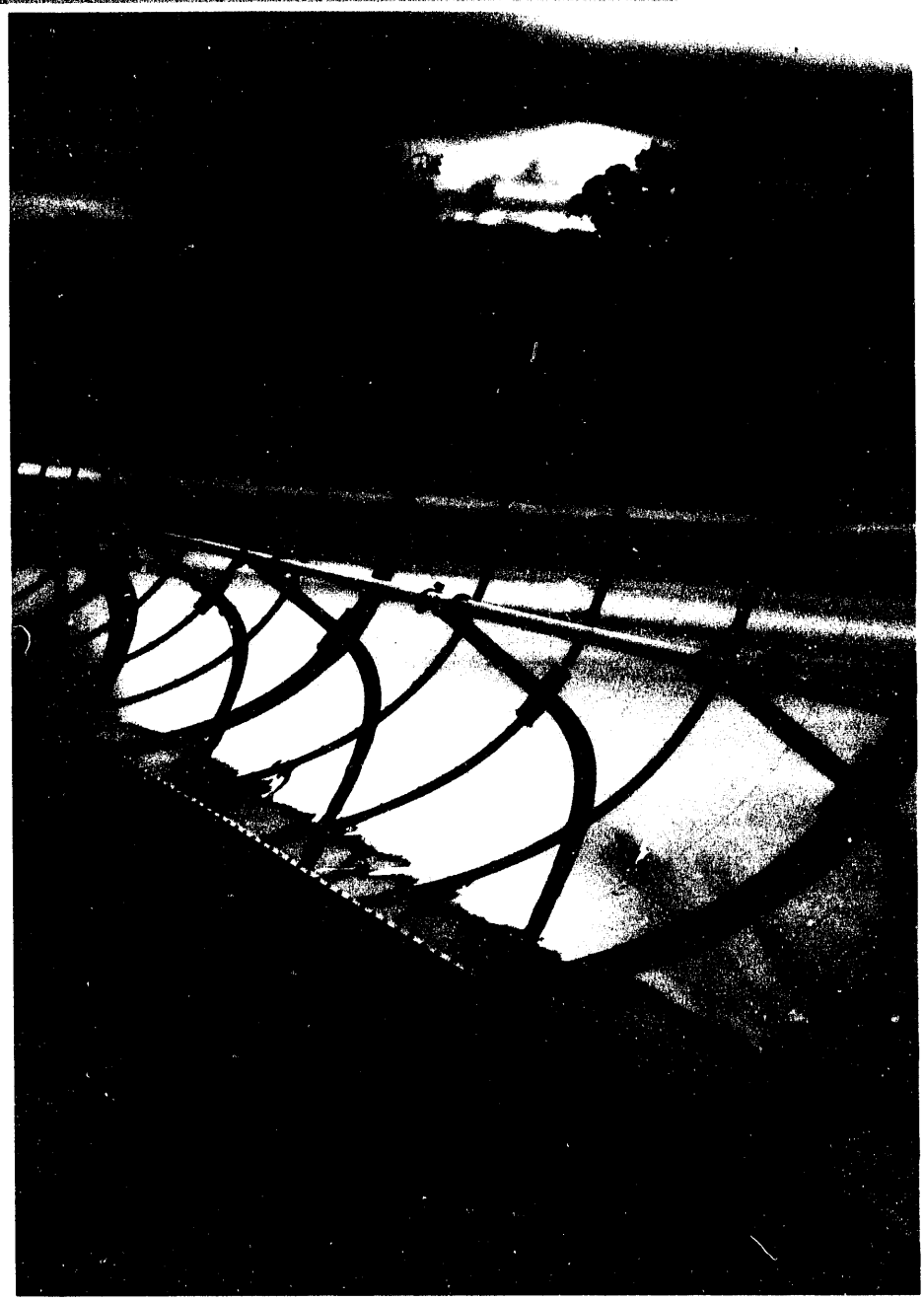
Research at SREL focuses on both freshwater and terrestrial ecosystems and covers a wide range of ecological topics, including environmental restoration and remediation. Information compiled by SREL scientists has been of value to the federal government and the industrial sector and to other researchers as well as to the general public. The Laboratory is recognized by scientists throughout the world, and results of its research have influenced the development of the science of ecology.

The education of students, teachers, and all citizens in ecology and its applicability to modern industry is another important function of SREL. A strong background in ecology is considered the foundation for rational environmental awareness. The Laboratory provides students with practical training for careers in environmental science. It educates the public through an outreach program that includes lectures, exhibits, teacher workshops, tours, and various publications and broadcasts.

The faculty and staff at SREL offer their services and expertise to DOE, other government agencies, academia, and scientific organizations throughout the world. Such interaction helps to promote creativity and ensures that the Laboratory's programs are relevant and of the highest quality.

DOE Offices

The U.S. Department of Energy has eight major research program offices, each of which has technology transfer as an important part of its focus: Civilian Radioactive Waste Management, Defense Programs, Energy Efficiency and Renewable Energy, Energy Research, Environmental Restoration and Waste Management, Fossil Energy, Intelligence and National Security, and Nuclear Energy. Descriptions of these major research program offices and summaries of their missions follow immediately in the first part of this section. Other offices within DOE that have a role in DOE's technology transfer efforts are discussed in the second part of this section.



This mirrored parabolic trough was part of a system that used concentrated sunlight and a photocatalyst to detoxify water contaminated with trichloroethylene (TCE) at a site at Lawrence Berkeley Laboratory. Subsequent testing has shown that unconcentrated sunlight can be as effective as concentrated sunlight and that the system can also be used to purify water contaminated with hazardous organic chemicals other than TCE.

Research Program Offices

Civilian Radioactive Waste Management

Technology Transfer Contact

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Civilian Radioactive Waste Management, RW-10
GF-253/Forrestal
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The Office of Civilian Radioactive Waste Management (OCRWM) was established by the Nuclear Waste Policy Act of 1982, as amended. OCRWM is responsible for managing and disposing of the nation's spent fuel from nuclear power reactors and high-level waste from power reactors and the defense program. Its goal is to protect the environment and the health and safety of the public. To realize these objectives, OCRWM is developing a nuclear waste management program consisting of a transportation system, a temporary central storage system called the Monitored Retrievable Storage (MRS) facility, and a geologic repository for permanent, deep underground disposal. With the exception of the funding for defense program waste, funding for this program is provided by the owners and generators of the waste, who pay fees into the Nuclear Waste Fund according to the amount of nuclear-power-based electricity they have generated and sold.

During 1993, OCRWM's experimental program expanded significantly, both in the supporting national laboratories and in the field — at the Yucca Mountain, Nevada, site characterization location, about 100 miles northwest of Las Vegas. Opportunities for developing new or improved technologies with commercial applications also increased. With the new OCRWM policy — which encourages the commercial use of inventions growing out of OCRWM's experimental program — and the prospect of a large increase in program funding in fiscal year 1995, prospects for the transfer of a significant number of OCRWM-related technologies have been enhanced.

Defense Programs

Technology Transfer Contact

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Defense Programs, DP-4.1
Technology Transfer Division
GP-180/Forrestal
Washington, DC 20585
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The Office of the Assistant Secretary for Defense Programs (DP) is responsible for the research, development, production, and testing of nuclear weapons. It is also responsible for nuclear materials production, weapons safety and surety, weapons dismantlement, and other activities related to national security, such as work for others and technology transfer. The Nuclear Weapons Complex (NWC), which includes the DP laboratories, production facilities, and test sites, is charged with carrying out this mission.

The three DOE laboratories that do work sponsored by DP — Los Alamos National Laboratory, Sandia National Laboratories, and Lawrence Livermore National Laboratory — possess a broad range of capabilities in advanced technologies, which cover the spectrum

from basic research to manufacturing and testing. In addition, the DP weapons production plants have experience in the techniques needed to manufacture a variety of nuclear and nonnuclear weapon components. This technological expertise, which was developed in support of the country's nuclear weapons program, has provided significant support to other federal agencies and industrial concerns.

In recent years, federal technology transfer activities have expanded, and interest in increasing the nation's global competitiveness and developing critical technologies has increased. Technology transfer activities in the NWC — except those conducted as part of ongoing weapons programs — are managed by DOE's Office of the Deputy Science and Technology Advisor/Defense Programs. This Office provides broad oversight, program management, and policy guidance, whereas the actual technology transfer activities are carried out by the individual laboratories and facilities. The objective of these activities is to encourage and facilitate the transfer of federally funded technology to the private sector to enhance the nation's competitiveness and help it maintain a strong industrial base.

The DP technology transfer program focuses on dual-benefit, cost-shared, collaborative efforts with industry for the mutual benefit of both parties. Projects are performed on a cost-shared basis (usually about 50-50), which ensures that technology transfer occurs in areas that the private sector judges to have sufficiently high commercial promise. Major areas of interaction with industry have included (1) commercial applications of the leading-edge computer capabilities of the weapons laboratories; (2) continuing collaboration with the Specialty Metals Processing Consortium; (3) a semiconductor equipment technology development program with Sematech; (4) collaborative efforts with U.S. automobile manufacturers in the areas of lightweight materials, emission controls, and high-performance computer applications; and (5) a broad range of activities with the manufacturing industry that focus on issues such as intelligent manufacturing processes, precision forming and joining, environmentally compliant manufacturing, and nonintrusive inspection and evaluation.

The Office has also developed, in conjunction with the National Institute of Standards and Technology (NIST), the National Machine Tool Partnership, which provides speedy technical assistance to companies needing access to the machine tool technologies of the weapons complex. In addition, a number of education-related projects are underway to enhance training and education in the manufacturing area. These include the establishment of a Precision Joining Center (with the American Welding Society), development of industrial outreach training centers (with the California Community College system), and the Manufacturing Technology Education Development Project (with the state of Tennessee and the National Center for Manufacturing Sciences).

The Office expects to continue to work with representative industrial groups, expand its outreach activities to ensure that small businesses play a significant role in technology transfer projects, leverage resources effectively by working closely with other government agencies, and develop appropriate means of assessing the effectiveness of technology transfer activities. The management and operating contracts for the DP production plants have been modified to authorize them to participate in technology transfer activities, and they are expected to play an increasingly important role in DP projects, especially in the area of manufacturing.

DP Small Business Initiative

SBI Contact

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The Office of the Assistant Secretary for Defense Programs has also initiated the Small Business Initiative (SBI). The SBI, which involves Lawrence Livermore National Laboratory, Los Alamos National Laboratory, Sandia National Laboratories, and the Y-12 Plant at Oak Ridge, focuses on the manufacturing and advanced technology development segments of the small business community. For fiscal year 1993, it was funded at $8 million.

The SBI consists of four basic interrelated program elements:

1. *Technical assistance.* Although technical assistance can take a variety of forms, DOE facilities typically respond to the specific needs of small businesses by providing them with technical information, consultation services, or access to unique, specialized facilities for evaluation of new processes or equipment. Assistance may be provided in the form of one-on-one communication, through a small business association or consortium, or through an intermediary whose purpose is to assist with the technology transfer process. Technical assistance efforts usually consume less than $5,000 in DOE funds per request.

2. *Partnership agreements.* When requests for technical assistance exceed the constraints of short-term assistance, the small business may enter into a collaborative partnership agreement with a DOE facility. These agreements can serve a variety of purposes and can include CRADAs (cooperative research and development agreements), technology licensing, longer-term technical assistance, and user facility agreements. Partnership agreements are limited to less than $50,000 in DOE funds per agreement.

3. *Relationships with intermediaries.* Intermediaries can include state and local governments, universities, colleges, not-for-profit economic development organizations, small business development centers, and business incubators. They facilitate technology transfer by conducting outreach activities and identifying needs for small businesses. They link DOE facilities with small businesses by prequalifying requests for technical assistance and partnerships, forecasting and analyzing small business requirements, providing feedback, and evaluating the effectiveness of program results and opportunities for improvement. Less than 10% of a location's total SBI program funding can be used for intermediary relationships.

4. *Facility utilization.* Facilities and equipment at DOE locations involved in the SBI program are significant resources that can be used by small businesses to get hands-on training and acquire special skills, build unique prototype products, or develop a special process or technology to help improve their economic competitiveness or chance for survival. This element of the SBI encourages the identification and utilization of existing infrastructures that could be beneficial to small businesses.

Energy Efficiency and Renewable Energy

Technology Transfer Contact

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The United States is challenged with securing reliable and abundant energy sources while developing a cleaner environment in which the efficient use of energy results in higher profits and less pollution. Meeting this challenge involves the objective of building a stronger, more competitive private sector able to maintain U.S. leadership in critical world markets. The Office of the Assistant Secretary for Energy Efficiency and Renewable Energy (EE) in DOE is helping the nation achieve these goals by moving forward with programs designed to increase energy efficiency, in part by broadening the use of renewable energy technologies. EE oversees program activities to help industry commercialize promising energy technologies that are environmentally sound, efficient, and competitive in the domestic and international marketplace.

An important component of EE's strategy is technology transfer and deployment. To help ensure success in the research and development process, EE involves industry as soon as possible and makes use of many technology transfer mechanisms that include (1) technical and financial assistance, (2) direct partnerships with industry through cooperative research and development agreements, (3) licensing agreements, (4) cooperative deployment programs with states to provide incentives for industry, (5) assorted technology information dissemination activities, and (6) project review committees.

Four of EE's offices — Office of Building Technologies, Office of Industrial Technologies, Office of Transportation Technologies, and Office of Utility Technologies — address technologies within their respective end-use sectors. A fifth office — Office of Technical and Financial Assistance — provides technology transfer and deployment assistance to programs having applications in more than one end-use sector.

Building Technologies

The Office of Building Technologies (OBT) leads a national effort to meet the energy needs of buildings while holding constant that sector's conventional energy use. In one approach, the target is decreasing building energy demand; in another approach, it is increasing the amount of energy supplied through renewable sources. To achieve its goals, OBT is involved in many projects. For example, manufacturers are required to affix energy efficiency rating score labels to certain appliances. In another example, DOE's technical capabilities are combined with the experience of the U.S. Department of Housing and Urban Development (HUD) to make HUD housing more comfortable and affordable through energy efficiency measures. Most projects of this type also receive funding from such sources as utilities and state and local governments.

Industrial Technologies

Given that the industrial sector uses approximately one-third of all the energy consumed in this country, using this energy efficiently is a key factor in helping U.S. industry maintain its global competitiveness. DOE's Office of Industrial Technologies (OIT) works with industry by forming partnerships to develop innovative, cost-effective processes, materials, and technologies that help companies operate more efficiently, reduce waste, increase energy supplies, improve the environment, and enhance their competitiveness. These partnerships can involve trade associations, universities, DOE laboratories and facilities, and other federal agencies as well as

companies from all industrial sectors, including primary metals, glass, pulp and paper, chemicals, and petroleum. Research and development can involve a multitude of technologies, such as waste-heat recovery, combustion, cogeneration, electric motors, and solar industrial applications.

The Office supports a number of outreach programs, including its Energy Analysis and Diagnostic Centers (EADC) Program, which has performed more than 4,000 energy efficiency audits for small and medium-sized manufacturing plants. In 1994, the EADC Program will be expanded to include industrial waste assessments that will be conducted by selected EADC schools. Another outreach program, the National Industrial Competitiveness through Energy, Environment, and Economics (NICE3) Program, encourages accelerated industrial development and dissemination of energy efficiency and pollution prevention technologies. A joint program of DOE and the U.S. Environmental Protection Agency, NICE3 is a cost-shared grant program administered through the states. A third program, the Electric Motors Challenge Program, sponsors programs to deploy improved electric-motor systems and demonstrate their success. Nearly 70% of the electricity consumed by American industry is used by electric-motor systems.

Technology transfer is a primary mission in all OIT programs. OIT works to enhance communication with DOE's industrial constituencies; leverage federal, state, and local government and industry resources; and provide direct technical, informational, and educational support to the U.S. industrial sector. The Office seeks to close the information gap that often exists between the source of a technology and its potential users through a variety of technology transfer mechanisms, including government/industry partnerships, publications, workshops, demonstrations, and educational programs. Through these mechanisms, it informs industry of the economic and environmental benefits of technologies that increase energy efficiency and encourages acceptance of these technologies in actual industrial applications. OIT also assists end users in developing, applying, and evaluating solar industrial projects. By increasing the use of state-of-the-art technologies that promote energy efficiency, OIT strives to help U.S. industry foster a healthier environment and build a stronger, more competitive economic base.

Transportation Technologies

The Office of Transportation Technologies (OTT) has technology transfer as an integral part of its programs. It helps ensure that results of research and development (R&D) are effectively conveyed to those who will use them. Given the nature of the transportation industry and the technologies that DOE is developing, this audience consists not only of consumers but also of engine, battery, and vehicle manufacturers and related engineering firms.

The Office has worked to establish close, cooperative relationships with industry. As a general rule, its programs are structured to maximize industry participation in both the planning and implementation stages and emphasize collaborations with industry for R&D. This approach facilitates the rapid transfer of technologies and information to industry. Nearly two-thirds of OTT's funds are employed to support private industry R&D. An example of this strategy is the cooperative agreement with the U.S. Advanced Battery Consortium, which marked a milestone in government/industry collaboration on a critical technological development. A

new 5-year program, the Hybrid Vehicle Program, was also recently initiated to support U.S. industrial teams in several areas. Combined efforts in research and testing will expedite product development, allowing competitive teams to explore advances in electric propulsion, energy storage, energy management, and advanced engines adapted and optimized for hybrid uses. Light-duty prototypes will be developed to be progressively more responsive to market requirements. DOE is also engaged in extensive discussions with manufacturers of automobiles and heavy-duty diesel engines to elicit their requirements for emissions reduction technologies and the role to be taken by DOE.

The OTT uses a variety of technology transfer mechanisms, including contractor coordination meetings, information dissemination via professional networks, participation in internal technology exchange agreements, establishment of user centers, personnel exchanges, and testing and evaluation programs for near-term technological developments. The following examples are representative of OTT's technology transfer accomplishments:

- Lawrence Berkeley Laboratory is transferring the advanced zinc-nickel battery technology that it developed with DOE support to Acme Advanced Energy System in Tempe, Arizona, an industrial developer.

- DOE is transferring advanced zinc-air battery technology to Westinghouse Electric Corporation in Pittsburgh, Pennsylvania, for further engineering development.

- For ease of mass production, the electric propulsion system program has modularized the advanced, alternating-current, power-train technology that it developed, and the program has installed the power train in the Ford/Ecostar electric van. The program field-tested the van in 1993, and Ford could begin production in the mid-1990s.

- AlliedSignal Inc., in Morristown, New Jersey, is applying ceramic gas turbine component technology to aircraft auxiliary power units to gain operating experience.

- Engine manufacturers are incorporating advanced turbocharger technologies developed with support from the Heavy-Duty Transport Technology Program into the production of heavy-duty diesel engines.

- More than 83 industrial researchers and more than 66 university researchers are using experimental user facilities at the High-Temperature Materials Laboratory established by DOE at Oak Ridge National Laboratory in Tennessee.

Utility Technologies

The goals of the Office of Utility Technologies (OUT) are to (1) encourage utilities, in their decision-making processes, to consider energy efficiency and renewable energy technologies on an equitable basis with conventional supply technologies; (2) address the technological and institutional constraints that impede utility adoption of renewable energy and energy efficiency technologies; and (3) work cooperatively with industry and the utility sector to realize the full market potential for energy efficiency and renewable energy technologies, in both the United States and other countries.

To achieve these goals, OUT acts as a catalyst in promoting energy efficiency, improving load management techniques, and implementing renewable energy alternatives. Over the long term, it works to accelerate market

entry of the latest developments. In addition, the Design Assistance Center, using renewable technologies applied to electricity supply, provides technical assistance in preparing requests for proposals, performing feasibility studies, reviewing system designs, and identifying potential applications for renewable energy systems. Similarly, the Geo-Heat Center provides technical assistance on direct-use geothermal projects, serving industry across the entire development process. Under OUT's high-temperature superconductivity program, innovative approaches to working with industry have led to the signing of more than 30 cooperative agreements.

Technical and Financial Assistance

The Office of Technical and Financial Assistance (OTFA) administers programs that cut across the four end-use sectors (utilities, industries, transportation, and buildings). Through partnerships with states and other public and private-sector entities, OTFA strives to promote economic productivity and environmental sustainability through the commercialization and fast market adoption of technologies and practices that promote energy efficiency and the use of renewable energy.

The OTFA strategy for moving new technologies from the DOE laboratories and facilities to the public and private sectors is based on three primary objectives: partnership, commercialization, and market conditioning. OTFA builds results-oriented partnerships with states, local governments, private industry, nonprofit organizations, international entities, and other federal agencies to achieve the widespread adoption of technologies and practices that promote energy efficiency and use renewable energy. To accelerate the rate at which these technologies and practices are drawn into the marketplace, OTFA sponsors highly leveraged, competitive commercialization efforts on a national and international scale. Finally, to encourage public support for using these technologies and practices, OTFA administers outreach initiatives to educate the public and private sectors about their potential economic, environmental, and energy security benefits.

The emphasis of OTFA's program is on making the best use of available capabilities by leveraging resources in joint efforts with state and local groups. Through its 10 support offices and in collaboration with the end-use sectors and in partnership with state and local governments and the private sector, OTFA supports programs to deploy existing, cutting-edge, energy-efficient, and renewable energy technologies. The objective of such demonstrations is to foster public acceptance and wider implementation of these technologies.

The Office broadly disseminates information and incentives to encourage the use of energy-efficient and renewable energy technologies. A frequently used technology transfer mechanism within OTFA is financial assistance. For example, the Energy-Related Inventions Program (ERIP) supports commercialization of the most promising inventions submitted by inventors and small businesses. Through its public outreach services, such as the recently combined NATAS/CAREIRS (National Appropriate Technology Assistance Service/ Conservation and Renewable Energy Inquiry and Referral Service) Program, OTFA provides general information and individualized technical engineering and commercialization assistance to help implement energy conservation and renewable energy projects. Another vehicle for information dissemination is OTFA's Technical Information Program (TIP). TIP

develops outreach materials such as publications and exhibits and distributes them to targeted groups.

On the international front, OTFA disseminates information on efficient and renewable technologies through U.S. cooperative membership agreements with other countries. For instance, through CADDET (Center for the Analysis and Dissemination of Demonstrated Energy Technologies), an International Energy Agency (IEA) agreement in effect through 1998, OTFA helps disseminate information on demonstrated energy-efficient and renewable energy technologies to IEA member countries. OTFA also provides assistance through U.S. representation in the Asia-Pacific Economic Cooperation (APEC), a ministerial-level organization established to promote the economic and social well-being of the Asia-Pacific region by cooperating in the economic area. Among the services OTFA provides to APEC's Energy Efficiency and Conservation Program of Cooperation is assistance with (1) the development of energy efficiency workshops, seminars, manuals, products, services, register/vendor lists, and an information system/database; (2) the development of an energy technology greenhouse-gas mitigation program; and (3) projects, policies, and regulations. OTFA also provides U.S. representation in the APEC Energy Efficiency and Conservation Experts Group, which was formed to monitor all cooperative energy efficiency projects. Moreover, through the Committee on Renewable Energy Commerce and Trade (CORECT), OTFA is working with 14 other federal agencies to build international markets for U.S. renewable energy technologies.

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Energy Research

The Office of Energy Research (ER) manages fundamental science and basic energy research programs for DOE in five areas: basic energy sciences, high-energy and nuclear physics, fusion energy, health and environmental research, and applied mathematical and computing science. ER supports user facilities used by both academic and private-sector researchers. It also manages DOE's Small Business Innovation Research Program. Moreover, ER has a laboratory-based technology transfer program designed to support the cost-shared transfer of research and technology from DOE laboratories and facilities to the private sector to meet industry needs.

Basic Energy Sciences

The Office of Basic Energy Sciences (BES) supports long-range, basic-energy-related research and is charged with providing the fundamental scientific foundation for the nation's future energy options. BES sponsors research in selected areas of the traditional scientific disciplines — the physical and biological sciences, geosciences, and engineering. BES supports approximately 1,300 individual research projects, each selected because of its (1) relevance to BES long-range energy research goals; (2) role in a balanced, responsive national research program; and (3) scientific merit.

Five research areas are managed by BES: materials sciences, chemical sciences, engineering and geosciences, energy biosciences, and advanced energy projects. Under advanced energy projects, BES provides overall management for the Small Business Innovation Research Program. This program is described in detail at the end of this section on ER.

Most of the scientists involved in BES research programs are at universities and national laboratories, including two national laboratories that are colocated with universities — Lawrence Berkeley Laboratory at the University of California and Ames Laboratory at Iowa State University.

Support is provided to universities in several ways. These include (1) "financial plan" funding, where funds are allocated for identified projects but the institution is delegated authority to manage the program of research, and (2) special research contracts or grants, which support individual scientists and graduate assistants. The latter is the dominant mechanism.

In addition, qualified scientists from universities and industry are provided access to user facilities at national laboratories. About one-fourth of BES funding is used to support university-based research; most of the remainder is used for facilities and work at the national laboratories.

Besides universities and national laboratories, BES maintains ties with industry. Industrial scientists serve on counseling committees for several BES subprograms; experts from industry participate in the review of research proposals and use the specialized facilities sponsored by BES; industrial scientists participate in program advisory committees at the national laboratories; and industry representatives are invited to attend BES conferences and workshops. Through these and other mechanisms, research results become available to industry as well as the academic community in a timely fashion.

High-Energy and Nuclear Physics

The goals of high-energy and nuclear physics programs are to seek, through experimental and theoretical study, a deeper understanding of the fundamental constituents of matter, the basic forces of nature that govern their interactions, and the structure of nuclei and the dynamics of nucleons and particles in nuclei. Because the primary motivation of this research program is to gain new basic knowledge, and because the benefits are reaped over an extended period of time, it often takes years for the research results to find broad application. However, the knowledge gained from this research is used not only in other scientific fields but also in advanced technology and engineering. In the course of their work, researchers develop spin-off devices, instruments, and technologies that can be used for purposes outside the domain of pure science.

Fusion Energy

The goal of the fusion energy program is to demonstrate the feasibility of fusion as a long-term, safe, environmentally acceptable, and economically competitive source of energy. The ultimate technology transfer objective is the commercial generation of electrical power. In the near term, the program integrates fusion science, called plasma physics, with fusion technology developments in the areas of superconducting magnets, high-power heating and fueling systems, high-heat-flux components, heat transfer systems, advanced materials, high-speed control systems, and sophisticated computing methods. All

these technological developments deal with phenomena that have applications beyond fusion, and the near- and long-term potential for transfer of fusion technology to many diverse fields in the industrial sector is high.

Health and Environmental Research

The goals of health and environmental research are to (1) develop the scientific and technical knowledge needed to understand and mitigate long-term health and environmental consequences from using energy technologies and (2) achieve scientific advances in response to national needs in the areas of biology, medicine, and environmental science.

The research activities support DOE programs, operations, and policies for the responsible development of domestic energy supplies. They also address concerns expressed by legislative and regulatory bodies, industry, and the public about the safe and environmentally acceptable management and use of energy options.

Among the areas supported by the Office of Health and Environmental Research (OHER) is analytical research to improve measurement systems for defining exposures, dosimetry, and risks of radiation and chemical agents. Research is also conducted on the processes that modify and move energy-related materials from their sources through atmospheric, terrestrial, and oceanic environments. OHER supports a Subsurface Science Program, whose goals include (1) evaluating the long-term effects of contamination and remedial actions on natural subsurface systems; (2) developing new and more effective methods for in-situ physical, chemical, and microbiological sampling, characterization, and monitoring; and (3) identifying innovative in-situ concepts for remediating contaminated subsurface environments. Also of interest is how ecological environments adjust to natural and human-induced changes and stresses, the understanding of which is required for developing policies, regulatory options, and mitigation strategies for dealing with greenhouse gases. Attempts are also being made to predict future atmospheric concentrations of carbon dioxide and other energy-related greenhouse gases, the potential rate and magnitude of global climate change, and the impacts of emissions and climate change on biota.

The development and use of biological models to evaluate the adverse health effects of human exposure to radiation and energy-related chemicals are also supported by OHER. The establishment of realistic exposure limits to indoor radon could save billions in control and mitigation costs and preserve real estate values. Also supported is the development of the resources and technologies needed to describe the human genome at the molecular level. The results of such research lay the foundation and create the impetus for advancements in industrial and medical biotechnology (e.g., improving waste cleanup options, biocatalysis and drug designs, biomass yields, genetic disease diagnosis, and risk assessments of and therapy for people susceptible to toxic chemicals and radiation in the environment).

Research in structural biology improves the fundamental understanding of macromolecular structural and functional relationships. OHER also supports efforts to improve diagnostic and therapeutic capabilities and reduce health care costs through advances in biomedical technology and applications of molecular biology approaches to nuclear medicine strategies.

Applied Mathematical and Computing Sciences

The mission of the Applied Mathematical and Computing Sciences (AMCS) research program is to improve DOE's ability to solve scientific and engineering problems that are critical to its mission and the national interest. It achieves its objectives by conducting research in and developing applications for advanced mathematical, computational, and computer sciences. Managed by the Office of Scientific Computing, the AMCS Program involves two ongoing activities: (1) mathematical, computational, and computer sciences research and advanced computation and (2) communications research and associated activities.

Scientific advances have traditionally depended on experiments for data and theories for understanding. However, the enormous power of the supercomputer, coupled with the increased ability to realistically model physical problems, has introduced a third, equally important contributor: computational science. This tool can be used both to study the effects of control parameters on physical systems through computer simulations and to extend theoretical understanding and interpret experimental data.

The main objective of AMCS research is to advance understanding of the fundamental concepts of mathematics, statistics, and computer science. These concepts underlie the complex mathematical models of key physical processes encountered in research and development programs on advanced computer architectures. They could lead to new approaches for applying supercomputers. Research in the major elements of this program — high-performance computer systems, advanced software tools and algorithms, and basic research and human resources — is being carried out by national laboratories and facilities and partner universities, private research institutions, and industrial organizations. The emphasis is on parallel multiprocessor architectures.

In addition, over the last few years, computing research facilities have been established to explore new concepts in large-scale scientific computing at Sandia, Argonne, Los Alamos, and Oak Ridge national laboratories. The advanced computation, communications research, and related activities being conducted have provided the high-performance computing resources and high-capacity network access required by ER investigators and other researchers. The National Energy Research Supercomputer Center (NERSC) operates a four-processor and an eight-processor Cray-2 and a 16-processor C-90 computer. NERSC, which uses the UNICOS operating system, has a storage capacity of more than 3 terabytes.

Access to these resources is provided through the energy sciences network (ESnet), a 19-node backbone data communications network with connections to Europe and Japan. ESnet allows scientists to collaborate and gives them access to existing ER supercomputer facilities.

The AMCS Program is DOE's major contributor to the High-Performance Computing and Communications (HPCC) Initiative and is closely coordinated with HPCC programs of other agencies. In addition, the Office of Scientific Computing is responsible for coordinating DOE's overall participation in the initiative. The goals of the initiative are to extend U.S. technological leadership in high-performance computing and communications, improve U.S. productivity and competitiveness, and accelerate technological innovations. It will

achieve these goals by (1) solving problems through research and development; (2) reducing the financial risk of industrial research and development; (3) improving technologies as a result of the cooperation among government, academia, and industry; (4) supporting the HPPC Initiative's infrastructure; and (5) strengthening the U.S. human resource base to meet national needs.

ER Laboratory Technology Transfer

The goal of the Energy Research Laboratory Technology Transfer (ER-LTT) Program is to enhance U.S. economic performance and competitiveness and the core competencies of ER laboratories and programs.

The major activities of the program are to establish and maintain quick-response centers at the ER laboratories; promote industry-driven, cost-shared spin-off CRADAs (cooperative research and development agreements); and form multilaboratory partnerships with industry. The quick-response centers provide technical assistance to small businesses and promote technology projects, personnel exchanges, small spin-off CRADAs, and regional development projects with state and local governments. Industry has become increasingly aware of the many opportunities for spin-off CRADAs based on the technology resident in the ER laboratories. The program emphasizes evaluation (which includes customer feedback) to build on accomplishments and gain recognition and support for ER basic science programs.

In 1993, the program began its first major multipartner, multilaboratory technology transfer collaboration with the research, education, and technology transfer organizations of the integrated American textile industry. The AMTEX™ Partnership will provide the textile industry with an unprecedented opportunity to use the technologies available at the national laboratories and facilities to improve their global competitiveness. This project will involve all nine of DOE's multiprogram laboratories at first and will eventually involve all DOE program elements. See the writeup on *AMTEX™ Partnership* on page 189 for more information.

Small Business Innovation Research

The Small Business Innovation Research (SBIR) Program, now in its eleventh year, has had increasing success. By providing federal funds to small, innovative firms, it has helped (1) commercialize new products and technologies, (2) strengthen the role these firms play in meeting the nation's research and development needs, and (3) stimulate technological innovation. The SBIR Program provides manifold opportunities for technology transfer.

Eleven federal agencies, including DOE, participate in the SBIR Program. These agencies all have extramural research and development budgets (i.e., funds outside those spent on federal salaries) of more than $100 million. All of them are required to set aside a small percentage of their budgets to fund SBIR projects. From fiscal year (FY) 1986 through FY 1992, this percentage was 1.25%. Public Law 102-564 extended the program until the year 2000 and gradually increased the set-aside percentage from 1.5% in FY 1993 to 2.5% in FY 1997. The DOE SBIR budget in FY 1993 was about $50 million. The SBIR Program is managed by DOE's Office of Energy Research.

All DOE research programs (except for weapons activities and naval reactor

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programs) contribute funds to the SBIR Program. The annual solicitation for applicants for SBIR grants contains about 45 technical topics. Awards are made solely on the basis of scientific and technical merit. Funded projects have covered a wide range of leading-edge technologies, including DOE's research programs in basic energy sciences, health and environmental research, high-energy and nuclear physics, magnetic fusion energy, energy efficiency and renewable energy, fossil energy, nuclear energy, environmental restoration and waste management, and arms control and nonproliferation.

In FY 1994, the SBIR Program expects to make about 200 Phase I awards of up to $75,000 each to explore the feasibility of proposed projects. Phase I grants cover about 6 months of work. Between one-third and one-half of the Phase I recipients will receive funding of up to $750,000 for Phase II for a period of 2 years. Phase II represents the principal research and development effort. Grantees completing Phase II are encouraged to seek capital for Phase III, in which they can obtain nonfederal funds to pursue commercial applications or non-SBIR federal funds to support further work of interest to a federal agency. The DOE SBIR Program has a unique feature compared with the programs of other agencies. It allows for early submission and rapid evaluation of Phase II grant applications, so that Phase II can be started without a gap in funding between Phases I and II. This smooth progression has been accomplished for 10 consecutive years.

The SBIR Program solicitation specifically invites applicants to consider obtaining help from a DOE laboratory and provides the address and telephone number of the Federal Laboratory Consortium locator to help applicants identify sources of technical expertise. Staff members of the DOE laboratories may help applicants prepare grant applications. They also frequently help proposers by acting as consultants. An individual DOE laboratory may also determine that it is in its interest to provide the use of its facilities and equipment at partial cost or even at no cost to support a particular SBIR project. More than 50% of the FY 1991 SBIR Phase I awards secured the participation of a DOE laboratory or university, or both.

The FY 1993 SBIR solicitation resulted in 1,999 applications, 171 of which were selected for awards. Seventy of the 198 Phase I participants during 1992 were chosen to receive Phase II awards in 1993. Total funding attracted for Phase III development by Phase II projects completed between 1986 and 1990 has been more than $230 million — greater than 50% more than the SBIR investment. More than 70% of the $230 million has come from the private sector.

In the past 6 years, a total of 10 DOE-funded SBIR projects received R&D 100 Awards from *R&D Magazine*, which selects the 100 most significant technical products each year. In addition, on the basis of their growth in sales, five DOE-funded awardees were included in the list of the 500 fastest-growing American private companies in the United States in the December 1991 issue of *Inc.* magazine.

Because so many small companies lack the business skills necessary for rapid commercialization of their technologies, DOE has instituted a special training project funded with non-SBIR money. For the past 4 years, successful DOE-funded Phase II awardees have been invited to participate in a training workshop. They have been given individual assistance in how to develop a business plan and prepare a presentation for potential partners, investors, or licensees. Many companies that have been assisted have successfully

negotiated joint ventures and other agreements. Of the companies that participated in the 1991 project, 43% received further funding for their research, resulting in more than $5.5 million of investment. An additional $24 million is expected from option agreements over the next 5 years.

Many Phase II projects have achieved commercial success in Phase III. An outstanding example is described here. In 1985, a Phase II SBIR award was made to Manufacturing and Technology Conversion International, Inc. (MTCI), of Columbia, Maryland, to develop a pulse-combustion gasifier that uses a fluidized bed to process biomass. This project is now in the demonstration phase. This work led to a second Phase II award in 1989 for a similar gasifier for the "black liquor" produced in the paper industry. Weyerhaeuser Paper Company, the California Energy Commission, and others joined with DOE to support a large-scale demonstration of this project; initial funding was more than $3.4 million. In 1990, MTCI found it expe[illegible]orm ThermoChem, Inc., [illegible]pany, to exploit the commerc[illegible] the business under license from MTCI. In 1991, in the fourth round of competition for DOE's Clean Coal Technology Program, for the same basic technology, ThermoChem was selected to participate in a project to convert more than 400 tons a day of subbituminous coal into a medium-Btu-content fuel gas. Total funding for the clean coal power plant is $37.3 million; DOE is providing half of the funding, and a consortium headed by ENSERV, the unregulated arm of Wisconsin Power and Light, is providing the remainder. The plant is to be located in the Powder River Basin, near Gillette, Wyoming, so that the Ther[illegible]ant can be integrated v[illegible] coal beneficiation p'[illegible] use the biogas ti[illegible]ver a gas turbine ar[illegible] power.

The SBIR Program enables DOE to obtain effective, innovative solutions to important problems through the private sector, which has a commercial incentive to pursue the resulting technology and bring it to the marketplace. The growing number of awardees, many of whom started a business as a result of responding to an SBIR solicitation, is becoming a significant resource for DOE in dealing with high-risk problems that demand high-tech solutions. ■

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Environmental Restoration and Waste Management

The Office of the Assistant Secretary for Environmental Restoration and Waste Management (EM) addresses the cleanup of DOE sites contaminated with radioactive and chemical hazardous waste from weapons-related manufacturing. It achieves its objectives by forming collaborative, cost-sharing partnerships with industry to demonstrate and evaluate innovative technologies. Through these partnerships, participants can leverage research and development dollars, support the development and enhancement of technology, apply technology to solve environmental cleanup problems under controlled conditions at DOE waste sites, and interact with other public and private partners across the DOE complex on environmental cleanup challenges.

Through licensing or cooperative research and development agreements (CRADAs), these public-private partnerships give industrial participants of all sizes access to technologies recently developed at DOE laboratories and facilities. EM uses a number of tools —

all of which are consistent with an aggressive technology acquisition strategy — to build public/private-sector partnerships. They include the following:

- Contracting and acquisition mechanisms.
- Financial assistance.
- Other collaborative arrangements.
- Intellectual property management.
- Small business environmental technology development program.

Partnership-building activities sponsored by EM serve two goals. First, they ensure that the best technologies are available to DOE so it can remediate its weapons manufacturing sites by the year 2020. Second, they produce "win-win" arrangements for both DOE and its industrial partners. DOE benefits as it expands its environmental technology base with cutting-edge technology from non-DOE sources. Industrial partners benefit by commercializing technologies successfully evaluated in the DOE test beds.

Major accomplishments resulting from EM's technology development efforts include (1) use of research opportunity announcements for applied research for a broad range of cleanup needs; (2) signing of various CRADAs, with both programmatic benefits and benefits to industry; (3) implementation of a central point of contact to increase opportunities for industry to market cleanup services and technologies to EM program managers; (4) formation of the Summer Institute for Technology Transfer; (5) establishment of a Safe Solvents Testing Laboratory; and (6) development and demonstration of the SEAMIST™ and dynamic underground stripping technologies.

1. *Research opportunity announcements (ROAs).* To forge more effective partnerships with industry, EM has developed a technology acquisition policy. It emphasizes phased contracts to expedite the movement of technology from the applied-concept feasibility stage through full-scale demonstration by using the procurement tools available to DOE. Within this framework, annual ROAs are used to solicit advanced research and technologies for a broad range of cleanup needs. In addition, ROAs accommodate unsolicited proposals for management efficiency and competitive selection. ROAs also provide special provisions to encourage small businesses to increase their participation in research, development, design, testing, and evaluation activities.

2. *Cooperative research and development agreements (CRADAs).* EM supports cooperative agreements to enhance partnership arrangements and increase industry access to DOE-developed technologies. Seventeen CRADAs supporting EM research and development programs have been signed by six national laboratories. Four CRADAs (about 24%) involve a small business as the industrial partner. These EM CRADAs span technological areas from site characterization to robotics to bioremediation. A CRADA between the Idaho National Engineering Laboratory and Rotron to develop and demonstrate a biofiltration technology for treating hydrocarbons in soils was chosen by *R&D Magazine* to receive an R&D 100 Award. A bioremediation CRADA between Oak Ridge National Laboratory and Ogden Environmental Services will be demonstrated on contaminated water at a spent uranium mine in Germany.

3. *Central point of contact (CPOC).* EM is presently operating a CPOC service to increase opportunities for communication between DOE and industry and other external sources of technology. (Its toll-free telephone number is 800-845-2096.) This CPOC provides DOE with a rapid method of gaining access to information on the cost, schedule, and performance of developing environmental technologies. An integral part of the CPOC is the EM Technology Integration Support Network. It supports the CPOC and helps match industry capabilities and technologies with EM needs.

4. *Summer Institute for Technology Transfer (SITT).* The SITT program, conducted by the University of South Carolina in Aiken under the auspices of the South Carolina Universities Research and Education Foundation, calls for a summer intern to evaluate the market potential of invention disclosures from Westinghouse Savannah River Company (WSRC). In 1992, SITT's third year, the number of disclosures evaluated increased by 201%, to 145 from 72 evaluated in 1991. This advance was accompanied by a 43.6% decrease in the disclosure cost (from $2,700 to $1,500 per disclosure). In fact, over the 3-year life of the program, unit disclosure costs were reduced by 67.7%. Of the disclosures reviewed in 1992, 44 (30%) were found to have a high market potential, 25 (17%) to have some, and 76 (53%) to have little or none. Because of its success, the SITT program was continued for a fourth year, and similar programs were instituted at the University of South Carolina and Clemson University at no cost to WSRC.

5. *Safe Solvents Testing Laboratory.* Solvents are used extensively as cleaners, degreasers, and paint strippers in a wide array of processes. These products are often carcinogenic and toxic when exposed to air and water. The Safe Solvents Testing Laboratory is a small, minority-owned business established on the basis of a database and software developed at Idaho National Engineering Laboratory under the DOE/U.S. Department of Defense Solvent Utilization Handbook Program. The business markets its testing and database services to manufacturers claiming to produce safe solvent substitutes. The EM program helped the Safe Solvents Testing Laboratory start up by offering technology transfer services, including support for the identification and assessment of markets, financial and cash-flow analyses, liability and risk-management analyses, and incorporation and marketing assistance.

6. *SEAMIST™ and Dynamic Underground Stripping (DUS).* Advances in characterization and monitoring technologies are required to improve the efficiency and reduce the costs of many site cleanup and waste management operations. SEAMIST, developed through a partnership between Sandia National Laboratories and a small, Albuquerque-based firm, is an in-situ instrumentation and fluid sampler emplacement technique that replaces the need for ex-situ sample analysis. The technology was advanced through research and development at Sandia and is commercially available for borehole lining, liquid/vapor sampling, and permeability measurements. Potential near-term applications include water sampling below the water table, very long (i.e., more than 300 feet) horizontal deployment for landfill monitoring, pipe inspection and characterization, and experiments in and monitoring of large-scale vapor plume movement. These applications can benefit utilities; the chemical, mining, oil, and natural

gas industries; the waste management industry; and U.S. Department of Defense, U.S. Environmental Protection Agency, and DOE cleanup operations.

Volatile organic compounds are among the most prevalent contaminants at DOE sites. The DUS technology, developed at Lawrence Livermore National Laboratory, uses steam injection to rapidly clean up localized underground spills of toxic chemicals. The technology integrates steam injection, vacuum extraction, direct electric heating, and tomographic geophysical imaging to remediate saturated and unsaturated soil zones. This technology has been demonstrated to be 25-40% faster than baseline pumping and treatment technologies. Efforts at Livermore have focused on developing a plan for licensing DUS and numerous spin-off technologies to industry. Potential commercial applications include power plants, fuel pipelines, chemical plants, refineries, and other fuel, chemical, and solvent storage or dispensing operations.

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Fossil Energy

The Office of the Assistant Secretary for Fossil Energy (FE) oversees a national partnership program with industry, academic institutions, and state governments to develop advanced technologies so that fossil fuels can be used cleanly and economically.

With regard to coal, advanced technologies can reduce pollutants associated with acid rain and global climate change, making this abundant domestic fuel more environmentally acceptable. Innovative systems can also boost the efficiency of coal-based power generating processes, potentially lowering costs to consumers.

With respect to natural gas, improved extraction techniques can unlock new supplies, while new storage, delivery, and end-use technologies can expand the market for this clean-burning fossil fuel.

For oil, innovations in exploration and production technologies can prolong the life of known oil fields and perhaps reveal new oil-bearing formations that have been bypassed.

To develop and deploy these new technologies, FE supports nearly 1,000 individual research and development projects involving scientists and engineers in the private sector, academic institutions, and national laboratories across the country. These projects range from cross-cutting research in areas like advanced materials and fundamental geoscience, to the development of complete power-generating systems like high-efficiency gas turbines and fuel cells, to the development of new approaches to finding and producing oil and natural gas.

In fiscal year 1993, the Office gave out awards for the final competition in the multibillion-dollar Clean Coal Technology Program. This program is one of DOE's principal initiatives to move innovative, environmentally sensitive technology over the commercial threshold. The selection of five industry-proposed projects brought to 45 the total number of first-of-a-kind demonstration ventures in the program. Industry and state governments have more than matched the funding contributed by the federal government to this program, providing nearly

$4.1 billion, compared with the government's $2.7 billion. In 1993, this investment began paying off, with companies recording the first commercial sales of technologies demonstrated in the program.

A similar program to transfer new or improved petroleum production technologies to industry also continued to make progress. DOE selected a second set of industry projects for its Oil Recovery Demonstration Program. The 11 new cost-shared field projects were selected to show producers — especially independent oil companies — ways to sustain production from "shallow shelf carbonate reservoirs," a geologic class of domestic oil fields currently facing the threat of near-term abandonment. The projects join 14 other government-industry projects selected in 1992 for a different geologic class of oil reservoirs. As in the initial round, each of the new projects includes an aggressive technology transfer effort.

In addition to carrying out project-specific efforts, FE also began planning for a national technology transfer network made up of oil and gas industry members. Coordinated by an industry-led group, the network would provide a means for linking regional organizations into a nationally connected information-exchange system involving all segments of the gas and oil industry. Plans for the network will be included in a 5-year oil technology transfer plan to be submitted to Congress in fiscal year 1994.

Also in 1993, FE, in conjunction with the Office of the Assistant Secretary for Energy Efficiency and Renewable Energy, initiated a major development program to produce a 21st century natural gas turbine — a key technology that could help expand the role of natural gas in the power generation market. DOE selected its first turbine manufacturing teams to begin the engineering designs of an advanced system that would be significantly more efficient and cleaner than today's turbine technology.

In addition to cofunding private-sector development and demonstration projects, FE supports technology transfer through cooperative research and development agreements (CRADAs). In fiscal year 1993, FE field facilities entered into 22 new CRADAs, bringing to 40 the total number of ongoing or completed FE-originated CRADAs.

In one of the new CRADAs, scientists at the Morgantown Energy Technology Center were able to assist a small company improve the design of a pulse combustor dryer it manufactures for the food, chemical, and polymer industries. Another CRADA applied the supercomputing capabilities of Los Alamos National Laboratory to improve the design of a refinery reaction vessel used to break down heavy crude oil into lighter, more usable feedstocks. A third CRADA gave a natural gas company access to a fuels evaluation facility at the Pittsburgh Energy Technology Center to test a simplified process for reducing nitrogen oxide pollutants. Other CRADAs ranged from work on hot coal gas cleanup sorbents for a Clean Coal Technology project to the development of specialty coatings for commercial gas chromatography columns.

The Office also oversees the Strategic Petroleum Reserve — the nation's emergency oil stockpile — and the Naval Petroleum and Oil Shale reserves, which supply crude oil and natural gas to commercial markets. Although technological advancements are not the primary focus of these efforts, many innovations have been implemented in day-to-day operations. For example, horizontal drilling has been applied at the Naval Petroleum Reserve #1 (Elk Hills) in California, and the Naval Petroleum Reserve #3 (Teapot Dome) is being considered as a test site for advanced oil recovery technologies.

Intelligence and National Security

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The Department of Energy has had a long history of experience with national security programs. The unique expertise available at its nuclear weapons laboratories has been a valuable asset in support of U.S. policy. DOE's Office of Intelligence and National Security provides technical, scientific, and analytical support for the development and implementation of the U.S. nonproliferation policy, designed to combat the spread of weapons of mass destruction.

As a recognized source of knowledge and information and a leader in technology development, the Office carries out technology transfer activities that support the Department's strategy, which involves the following goals:

- Increase the number of U.S.-based industrial partners in DOE research and development (R&D) programs leading to the commercialization of technologies that can support international agreements and treaties.
- Increase the number of projects that actively involve technology transfer — either directly (i.e., through the Office of Intelligence and National Security) or through national laboratory participation — by taking advantage of Congressionally mandated vehicles.
- Develop an internal review and decision-making process to accelerate the mechanisms for technology transfer.
- Expand technology transfer opportunities for small businesses under the Small Business Innovation Research Program.

In fiscal year 1993, the Office made a number of improvements in how it manages its technology transfer activities. For example, the Office of Research and Development was formed to consolidate R&D efforts within the Office of Intelligence and National Security. Through its program guidance documents, the Office of Research and Development recommends that maturing (i.e., already developed) R&D projects include investigations of possible dual-use applications (applications that meet both DOE and commercial needs) for technologies and examinations of potential partnerships for commercializing technologies, where appropriate.

The Office of Intelligence and National Security set aside $1 million in fiscal year 1994 for its technology transfer activities. These projects are oriented primarily toward sensor development and system integration, and they emphasize applications in arms control and the detection and verification of arms proliferation.

Programmatic offices within the Office of Intelligence and National Security are encouraging programmatic and contractor employees to carry out technology transfer activities that complement their missions and goals. They are placing more emphasis on selecting the contractual and administrative mechanisms that will work most efficiently for a given technology transfer project.

Nuclear Energy

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The Office of Nuclear Energy (NE) administers DOE's nuclear fission program. It administers advanced technology programs on nuclear fission power generation and nuclear fuel technology, evaluates alternative reactor fuel-cycle concepts, develops space-related nuclear generating systems, administers Naval nuclear propulsion plants and reactor cores, and develops advanced nuclear fuel enrichment processes. One objective of NE's technology transfer program is to enhance the U.S. nuclear industry's competitive position. It does this primarily through cooperative research and development efforts that are funded jointly by government and industry.

Technologies originating from NE have the potential for nonnuclear applications that could enhance the U.S. industrial sector's competitiveness with respect to a variety of products and processes. Businesses that could benefit from NE technologies include those in the computer software, manufacturing processing, materials, liquid and gaseous separation, medical, agricultural, food and beverage, pharmacological, and petrochemical industries.

Some of NE's research and development (R&D) activities are described below. Spin-off opportunities for enhancing the competitiveness of U.S. industry are mentioned where appropriate.

- There is a great potential for using the technologies that have "spun off" efforts to conduct research on uranium enrichment and develop gaseous diffusion, centrifuge, and atomic vapor laser isotope separation technologies. Spin-off applications include cleaning up environmental waste; enhancing the quality of textile products; enriching food and beverage products; producing cleaner petrochemicals; improving the operating parameters of electric motors; improving products by applying advanced material sciences, desalination, and medical applications (such as trapping viruses contained in the human blood stream); and enriching specialty elements and isotopes.

- Light-water reactor R&D is another area with potential for spin-off technologies. The federal government and businesses in the industrial sector have entered into cooperative research agreements, with shared funding, for the design and development of standardized advanced boiling water and pressurized water reactors. Associated with this R&D program is a cooperative research and development agreement (CRADA) with the Electric Power Research Institute (EPRI) to develop integrated instrumentation and control for improved power plant safety across the power industry.

- Breakthroughs in chemical manufacturing and processing systems have broad applications in the design of small and very high temperature components used in the petroleum, pharmaceutical, and plastics industries. Transfer of technologies can enhance the competitiveness of U.S. chemical products as well as reduce chemical waste at the source.

- Robotics development has led to state-of-the-art capabilities in remote manipulators, robotics navigation, and remote inspection and maintenance. Transfer of these technologies will benefit U.S. industry in robotics applications associated with adverse environments such as those involving toxins, radiation, and high temperatures.

- Waste management and waste removal processes that are being developed could aid in separating and stabilizing mixed metal waste and controlling salt waste, which is a significant problem in industry. These technologies have applications for cleaning up Superfund-designated sites that are contaminated with heavy metals and petrochemicals.

- Instrumentation and control technologies can enhance complex manufacturing processes to achieve high levels of reliability and precise process control while lowering operating costs.

- Technologies used to manufacture large-module configurations for nuclear power plants could benefit other manufacturing processes based on fabricating large-module components. The principal benefit would be to build facilities more quickly and inexpensively.

- The R&D work on electric motors that are very efficient in adverse environments has led to a patented invention: very high temperature insulating materials to be used in self-cooled electric motors of very high current density. The application of this technology allows motors to be used in high-temperature and corrosive environments without requiring the traditional support systems, thereby reducing the cost and potentially increasing the safety of some manufacturing processes.

- Nuclear technology R&D efforts have resulted in advanced materials with both ferrous and nonferrous compositions. These materials are best suited for applications requiring great strength, long life, operation under high temperatures, or resistance to radiation. The materials could enhance U.S. manufacturers' competitiveness by lowering production costs and enhancing product performance.

The Office of Nuclear Energy welcomes inquiries from companies, universities, and other government agencies about collaborative and cooperative arrangements for industrial applications of nuclear technology. ■

ther Offices

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Economic Impact and Diversity

The Office of Economic Impact and Diversity is made up of three former DOE offices (Office of Minority Economic Impact, Office of Small and Disadvantaged Business Utilization, and Office of Civil Rights). This new Office gives more visibility and exposure to small, disadvantaged, and minority businesses. It was formed to advise the Secretary of Energy about the impact of DOE's policies and programs on small businesses and disadvantaged, minority, and women-owned businesses and about DOE's progress in providing opportunities for a diverse work force and managing that effort.

The Office's technology transfer mission is carried out through two distinct programs. The primary program related to DOE's technology transfer mission is the Business and Community Development Program. It incorporates an aggressive communications/outreach effort to identify energy-related minority business enterprises and minority business opportunities that could benefit from the transfer of new and emerging technologies. Its technology transfer efforts should improve the economy of the communities where those businesses exist, specifically by helping to create new job opportunities and empower community residents. The program's objective is consistent with national efforts to develop minority businesses and heighten the awareness that investments in minority businesses are good for the nation's economy and future.

The Business and Community Development Program is implemented through the use of the following:

- The expertise and technology base within DOE's national laboratories and facilities — specifically, their ability to help minority businesses gain access to energy technologies by transmitting information, providing direct technical assistance, training, and facilitating the formation of links with business assistance providers.

- The expert human resources historically available at Black colleges and universities and other minority institutions.

- The experience in and results of research and analysis related to economic trends, marketing feasibility, and penetration of specific energy-related technologies.

The second program, the Small and Disadvantaged Business Utilization Program, manages and oversees DOE's small and disadvantaged business initiatives. DOE facilities engaged in technology transfer activities are encouraged to be sensitive to the special needs of small and disadvantaged businesses and develop innovative approaches to address those needs. The DOE guidelines for increasing the participation of small businesses in cooperative research and development agreements include special

considerations to accelerate the introduction of DOE-developed technology into small businesses. Two examples follow:

- Offering licensing opportunities to small business participants before making them available to other interested parties.

- Giving incentives or special recognition to DOE laboratory inventors and scientists who work with small businesses.

There are two ways in which small businesses are selected to be partners in collaborations with DOE laboratories and facilities. First, a company can initiate the process. A small business can approach a DOE laboratory about a proprietary area it would like to explore under a cooperative research and development agreement. Second, a DOE laboratory or facility can solicit industrial participation. These solicitations are broadly advertised through the *Commerce Business Daily* or other appropriate media. Special consideration is given to small businesses and small business consortia that respond to these requests.

Some examples of technology transfer between small businesses and DOE laboratories and facilities follow:

- Ames Laboratory initiated and signed a CRADA with Layne Environmental Services, Inc., a small business located in Phoenix, Arizona, that specializes in developing and executing innovative and effective drilling techniques for use in contaminated areas.

- A small Chicago-based business, Magneco-Motrel, that produces castable refractory materials for lining blast furnaces, slag troughs, and other extreme heat vessels has thrived during its 5-year experience with Argonne National Laboratory. The company has added new products, expanded its staff, and built a growing export business. Its success is partially based on Argonne's work on refractories for coal gasification vessels.

- A memorandum of understanding was signed between the National Renewable Energy Laboratory and the Small Business Administration to promote technology transfer initiatives with small businesses in 15 states in the Midwest and Rocky Mountain region.

The Office of Economic Impact and Diversity's programs encourage small and minority-owned business enterprises to take advantage of DOE's technology transfer activities.

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Laboratory Management

In June 1993, the Secretary of Energy established the Office of Laboratory Management to ensure the optimum utilization of the DOE laboratory complex to meet the Department's mission objectives. The Office is responsible for all functions related to multiprogram laboratories: policy, planning, coordination, utilization, and general cognizance. It is composed of two functional offices: the Laboratory Management Division and the Office of Technology Utilization.

Laboratory Management

The Laboratory Management Division is responsible for institutional

oversight of DOE's contractor-operated multiprogram laboratories. This responsibility includes carrying out the institutional planning process, which focuses on the mission, well-being, and future development of the Department's laboratories. In this process, 20-year strategic plans and 5-year detailed plans are prepared for each major laboratory. This process is also a mechanism for monitoring and controlling the nature and level of work for others and of laboratory-directed research and development. The Division conducts quarterly meetings involving the laboratory directors and the Secretary of Energy.

Technology Utilization

The Office of Technology Utilization (OTU) is responsible for addressing issues related to technology transfer policies and implementation across the DOE complex. In particular, OTU provided principal support for developing the Department's strategic plan for technology transfer, *Partnerships for Global Competitiveness*. In its capacity as DOE's liaison with U.S. industry, academia, and state and local governments, OTU coordinates all DOE's outreach activities that are directed toward these groups and that involve areas related to technology transfer and the nation's technical competitiveness. Also in this capacity, OTU prepares this annual publication that describes the some of the latest of DOE's technological innovations.

Science Education and Technical Information

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The Office of Science Education and Technical Information was established by the Secretary of Energy in June 1993. Its vision is to provide leadership in leveraging DOE's unique scientific and technical resources to enhance global competitiveness and the development of a diverse, well-educated, scientifically literate work force. The Office provides high-quality and timely scientific and technical information services and educational assistance to a wide range of customers, thus enabling the Department to contribute to the welfare of the nation. It consists of two functional offices: the Office of University and Science Education Programs and the Office of Scientific and Technical Information.

University and Science Education

The Office of University and Science Education Programs is responsible for developing policies and providing guidance on programs directed at using DOE research and development laboratories, facilities, and other resources to support national objectives for science and mathematics education at the precollege and university levels.

Scientific and Technical Information

The Office of Scientific and Technical Information (OSTI) collects, manages, and disseminates scientific and technical information resulting from DOE's research and development programs. In addition to DOE information, OSTI acquires domestic and foreign scientific and technical information on subjects of interest to DOE researchers and program managers. Scientific and

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ESTSC Contact

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Database Contact for DOE and DOE Contractors

Office of Scientific and Technical Information
Integrated Technical Information System
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technical information is available as technical documents from OSTI or as software from the Energy Science and Technology Software Center operated under contract to OSTI. Availability is announced through electronic databases and publications.

The Office of Scientific and Technical Information serves the information needs of DOE and its contractors and ensures public access to DOE scientific and technical information by providing information and announcement products to the National Technical Information Service (NTIS) and the Superintendent of Documents. NTIS is a national clearinghouse that provides public access to federally produced information. The Superintendent of Documents sells publications through mail order and government bookstores and administers the Depository Library Program, which makes selected publications available in libraries throughout the country.

Additional information on OSTI services and access mechanisms and on products relevant to technology transfer are described below.

Software

The Energy Science and Technology Software Center (ESTSC), operated under contract to OSTI, houses the collection of software developed by DOE, the U.S. Nuclear Regulatory Commission, and their contractors. ESTSC serves DOE, other government agencies, business, industry, academia, and the public on a cost-recovery basis. Software, documentation, update information, testing, and assistance are available.

Databases

Databases include the following:

Energy Science and Technology. Bibliographic records of worldwide information related to energy and nuclear science and technology (available on DIALOG database system as *Energy Science and Technology*; available on STN International database system as *Energy*).

Energy Science and Technology Software. Bibliographic records describing scientific and technical software (software announced to the public on *Energy Science and Technology Database* above).

Database Contacts for Industry, Academia, and the Public

DIALOG Information Services
3460 Hillview Avenue
Palo Alto, CA 94304
(800) 334-2564
FAX (415) 858-3847

STN International
P.O. Box 3012
Columbus, OH 43210
(800) 848-6538
FAX (614) 447-3713

Document Contact for DOE and DOE Contractors

Office of Scientific and Technical Information
Information Services
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Document Contacts for Industry, Academia, and the Public

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Superintendent of Documents
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New Technology from DOE. Brief descriptions of DOE research results that have potential for commercialization efforts.

Research in Progress. Descriptions of current or recently completed research projects performed or funded by DOE (available on DIALOG database system as part of Federal Research in Progress [FEDRIP]).

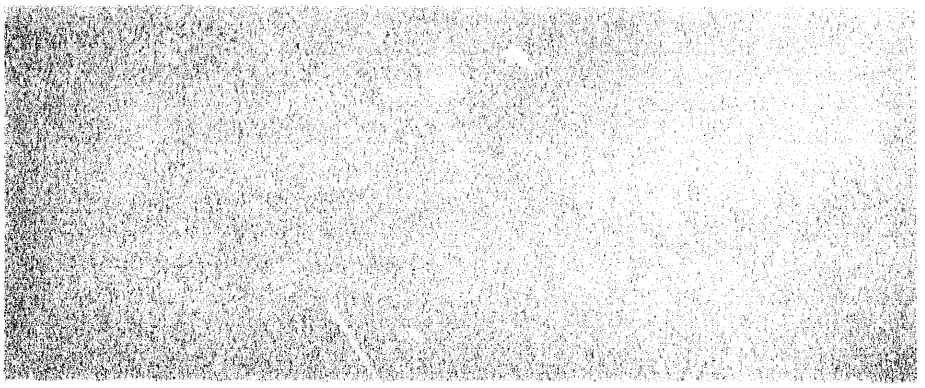
Publications, Reports, and Other Documents

Publications include the following:

Current Awareness. Series of 15 publications that abstract new literature added to the databases, covering a range of topics.

DOE New Technology. Semiannual publication that describes technologies with a potential for commercial applications and that catalogs patent applications and DOE patents available for licensing.

Energy Research Abstracts. Monthly journal that contains abstracts of reports covering the full scope of DOE research and development, demonstration, and technological programs. ■



The information expertise, technologies, processes, and facilities found at DOE laboratories and facilities are the basis for all technology transfer efforts. Two of DOE's highest priorities are to accelerate the application of the technologies it has developed and to put its research results and the know-how of its staff to practical use. This section of the document briefly summarizes some of the major technologies that have been developed at DOE laboratories and facilities. It is divided into the following subsections:

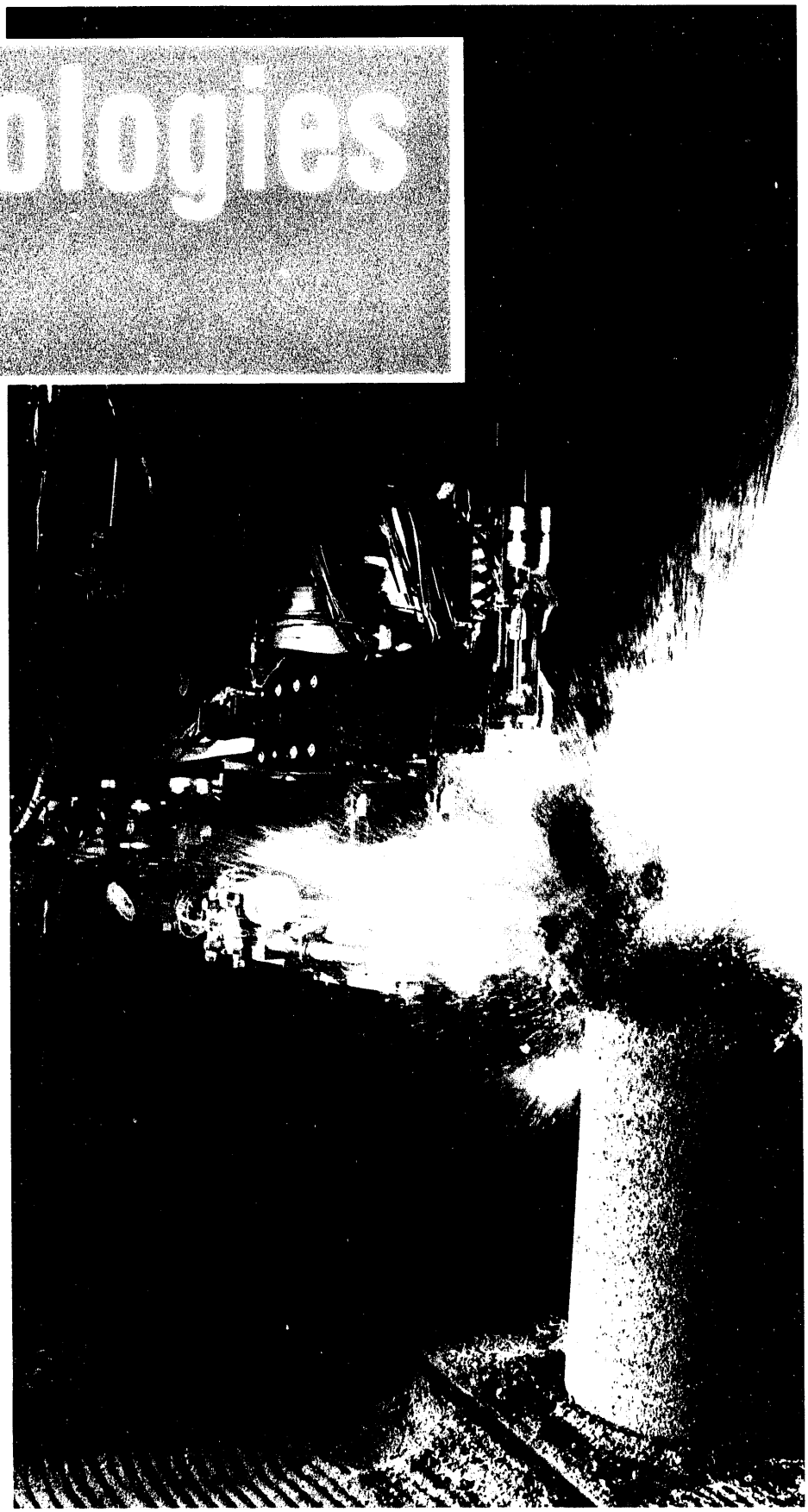
- Energy.
- Pollution Minimization and Remediation.
- Advanced Materials and Advanced Materials Processing.
- Advanced and Computer Enhanced Instrumentation and Sensors.
- Biotechnology.

Technologies

- Manufacturing.
- Information and Communication Software.
- Aerospace and Transportation.

The wide range of these topics illustrates the breadth and depth of the capabilities of DOE and of the research and development activities it supports.

Further information on each technology summarized in this section can be obtained by contacting the person listed next to the writeup. For more information on a particular DOE laboratory or facility, see the *Laboratories and Facilities* section of this document.

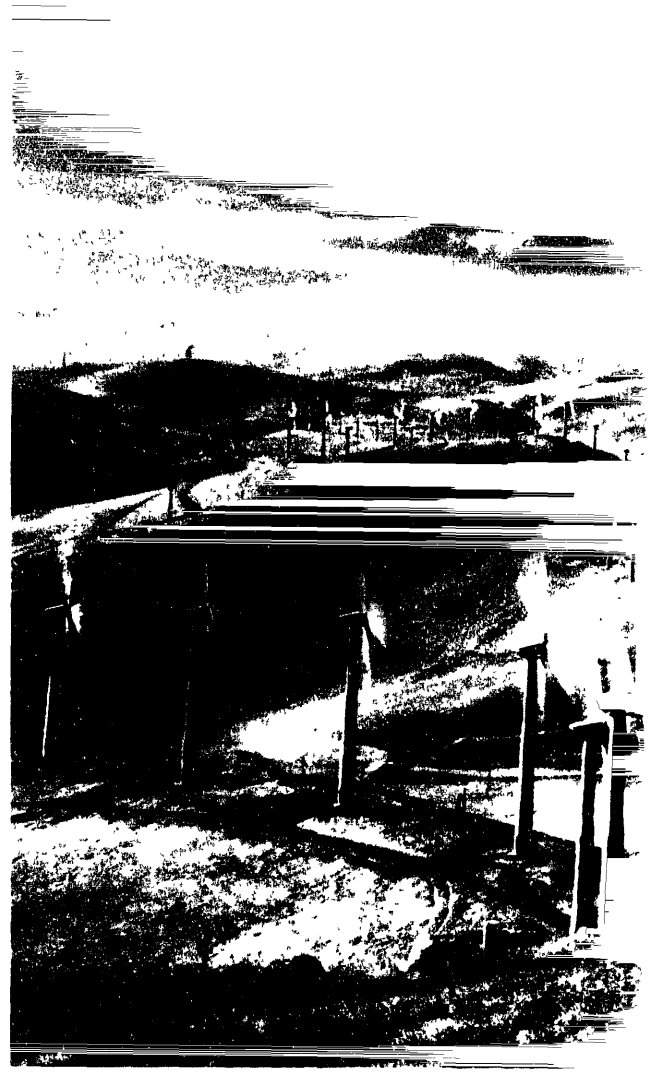


In a mock-up of a waste tank at DOE's Hanford Site, highly pressurized water blasts a simulated radioactive saltcake into manageable fragments. For more information on this technology, see the writeup on *Water Cannon* on page 130.

Energy

There are many challenges facing the United States today with regard to energy development, utilization, and conservation. Reducing energy costs, improving energy storage, and developing ways to use finite oil and coal resources more efficiently are some examples. Industry needs reliable energy sources to operate competitively. The public demands dependable, low-cost energy for everyday life.

The federal government must ensure that the nation's energy resources are used effectively if U.S. energy independence and industrial vitality are to be strengthened. The energy technologies that are developed by DOE laboratories and facilities and transferred to industry are of great importance in securing the nation's well-being.



Researchers at the National Renewable Energy Laboratory expect improvements in wind turbine technologies will enable the United States to exploit a large portion of its vast wind resource to produce inexpensive electricity. For more information, see the writeup on *Advanced Wind Turbine Technologies* on page 94.

Polymer Multilayer Solar Control Film

Optical Coating that Saves Time, Money, and Energy

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Researchers at Pacific Northwest Laboratory (PNL) have been developing a process for fabricating polymer multilayer solar control films. The process is expected to boost the efficiency and lower the costs of technologies that rely on these films. In addition, it is expected to outpace conventional processes in speed of application, cost-effectiveness, and performance.

Solar control films are thin layers deposited on a surface such as glass, metal, or plastic. They selectively filter the different wavelengths of light that pass through them. Although effective, they have been costly to manufacture and buy. Film application has been slow; in some cases, the film can be applied at a rate of only 5 linear feet per minute. In addition, the film material is expensive; it can cost as much as $700 per pound.

The Laboratory's polymer multilayer process is expected to lower both production and material costs and improve product quality for a wide variety of applications. Manufacturers can apply polymer much faster by using this process — at a rate of 1,000 linear feet per minute. The raw materials used for the polymer multilayer coating are produced inexpensively in bulk and are readily available at $3-10 per pound. Capital equipment costs for the process are comparable to or lower than those for conventional processes.

The PNL process makes it possible to deposit polymer films in the same vacuum environment as conventional sputtered or evaporated coatings. Formerly, when polymer/inorganic multilayer coatings were applied, the substrate had to be repeatedly transferred from one deposition system to another. With this new process, all layers can be deposited sequentially, in the same vacuum chamber, in a single pass in an integrated manufacturing process. This capability saves time, reduces handling, and leads to better interlayer adhesion.

The new process is based on vacuum flash evaporation of acrylic monomers. The evaporated monomers are condensed on a substrate, as they are in conventional thin-film deposition processes. However, the condensed monomers remain liquid until cured with an electron beam or ultraviolet light. Like conventional methods, the polymer multilayer process is appropriate for rigid substrates and large-area, flexible-web substrates.

Polymer multilayer films have many potential applications: optical filters (for items like laser mirrors, microwave reflecting coatings, and laser goggles), heat-screening windows, solar converters, packaging and labeling materials, scratch-resistant coatings, and batteries. They have already been used commercially in the manufacture of surface-mount capacitors. PNL researchers are working closely with several companies to refine the polymer multilayer process for specific applications.

The Laboratory's work makes many commercial uses of solar control film more feasible. PNL is actively seeking industrial partners to speed commercialization of this technology.

Intelligent Control of Cupola Furnaces

Making U.S. Foundries More Competitive

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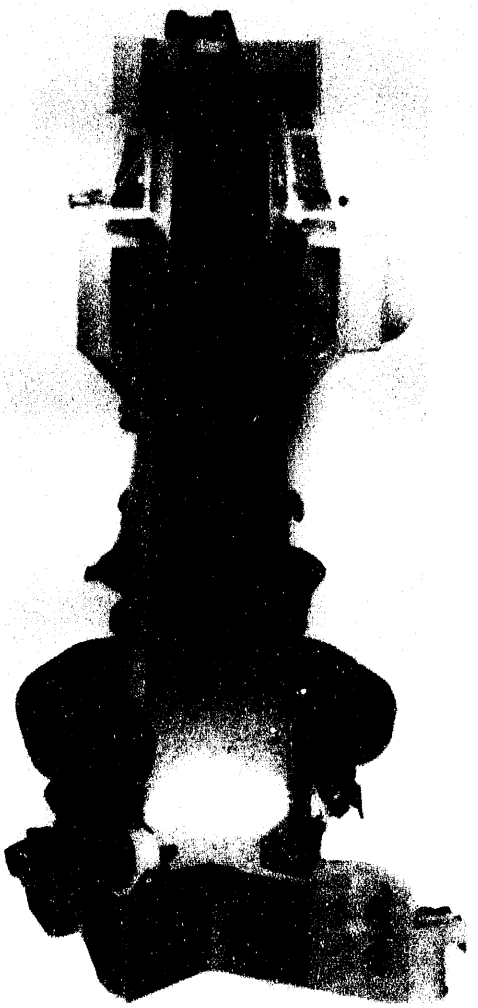
The cupola furnace — a vertical shaft furnace — is the least expensive method for casting metal quickly (5 to 100 tons per hour) and the only one able to operate continuously. For these reasons, about 75% of the cast iron produced in the United States has been melted in cupolas. This casting process produces about 7.5 million tons of castings for the automotive, machinery and equipment, mining, and other markets each year.



The efficiency of this drop-bottom cupola for casting metal could be improved through use of an intelligent control system.

Idaho National Engineering Laboratory has entered into a partnership with the U.S. Bureau of Mines, Idaho State University, and the American Foundrymen's Society to develop an intelligent control system for cupola furnaces to improve their efficiency. The partnership received a $150,000 grant from the National Technology Transfer Center of the National Aeronautics and Space Administration in recognition of the system's potential for transfer from research settings to foundry floors. The new control technology could stimulate domestic economic development and make U.S. foundries more competitive in the international marketplace.

A mathematical model of the cupola furnace process has been developed under a separate DOE agreement in which costs were shared by 17 companies belonging to the American Foundrymen's Society. This one-dimensional model takes into account most of the chemical reactions occurring in the cupola, along with heat and mass transfer. It models the process by means of finite-difference equations that achieve a steady-state solution. By revealing relationships between the input and output parameters for the resultant steady-state process, the model enhances researchers' understanding of the process, which helps them develop an effective control system for it. Although the model takes too long for use in real time, a neural network could be trained to learn the input/output relationships from the model and then use them for the control system in real time.

Duct Injection Design Handbook and Mathematical Models

Helping Utilities Select the Best Pollution Control Systems

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Important decisions lie ahead for utility managers who must devise pollution reduction strategies by the year 2000 to address the requirements of the Clean Air Act Amendments. The Pittsburgh Energy Technology Center (PETC) has prepared a handbook that simplifies selecting a duct injection technology — particularly for older, smaller plants. Duct injection is a postcombustion sulfur dioxide emission control technology for existing coal-fired power plants.

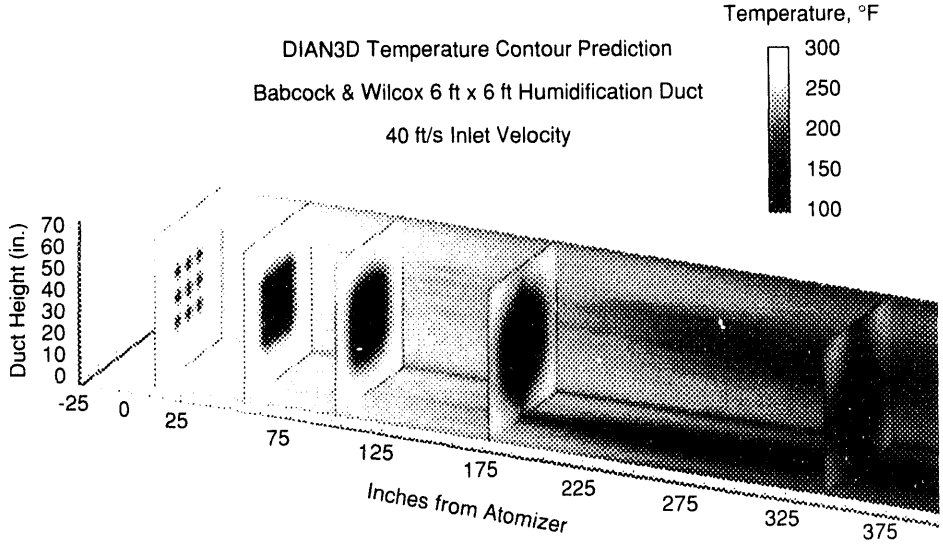
The Center has developed an integrated information base to promote commercialization of duct injection technology. Included are a handbook and mathematical models that provide information for comparing duct injection technology with other sulfur dioxide reduction strategies.

Utilities traditionally install wet scrubbers on large coal-fired units. Although they are highly efficient and cost-effective, scrubbers may not be the most economical way of reducing sulfur dioxide emissions. Several alternatives, while less effective, have a lower capital cost. Utilities could purchase pollution allowances, use a clean or low-sulfur coal, or install injection system control equipment such as a duct injection system. Duct injection can be a good option, particularly for plants that are older, have a finite lifetime, or contain limited space for retrofitting sulfur dioxide control technology.

Duct injection involves either in-duct spray drying or dry sorbent injection. In either case, a utility adds emission control equipment in the flue-gas duct between the air preheater and the particulate collection device, usually an electrostatic precipitator (ESP). Duct injection removes 50-75% of the sulfur dioxide but raises at least three technical issues: effect on the existing ESP and ash-handling system; potential for solids deposition; and potential for corrosion of the ESP's outlet, ductwork, and chimney liner.

The PETC handbook deals with these issues by proposing plant modifications. Step-by-step design of a retrofit duct injection system, detailed information on equipment sizing and design, and sample equipment bid specifications are given. Also provided are guidelines for estimating total capital costs, as well as operating and levelized costs for a complete retrofit system. Case studies of both dry and slurry injection demonstrate feasibility.

The Center also developed three mathematical models to accurately predict performance of duct injection technology at specific plants. A three-dimensional process model, DIAN3D, describes the performance of the duct injection process upstream of an ESP. A simpler, one-dimensional model, DIAN1D, estimates droplet evaporation and sulfur dioxide removal. A separate model used in conjunction with DIAN3D and DIAN1D predicts ESP performance.



The DIAN3D mathematical model helps predict performance of duct injection technology.

Adjustable-Phase Undulator

Tunable X-Ray Source for Synchrotrons

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Synchrotron radiation — the electromagnetic radiation emitted when high-energy charged particles are accelerated along curved trajectories — is an increasingly important research tool in biological, chemical, and materials studies. The intense x-ray and ultraviolet light generated in synchrotrons, optimized by magnetic "insertion devices," enables researchers to investigate microstructures and chemical reactions in unprecedented detail.

An undulator is a magnetic insertion device used in electron storage rings to create intense x-rays. Undulators have two rows of magnets, one above and the other below the electron beam pipe. When electrons pass through the magnetic field, they oscillate rapidly from side to side, emitting synchrotron radiation with a characteristic frequency that corresponds to the strength of the magnetic field. Conventional undulators vary this strength by precisely changing the gap between rows. In this configuration, undulator components must move against large magnetic forces; therefore, they are mechanically complicated, which means they are expensive to design and build.

A physicist at the Stanford Synchrotron Radiation Laboratory (SSRL), a division of the Stanford Linear Accelerator Center, has invented a new, "adjustable-phase" undulator that tunes the x-ray energy spectrum by varying the longitudinal position, or phase, of one row of magnets with respect to the other. The effect on the x-ray spectrum is the same as that produced by conventional undulators.

The adjustable-phase undulator is simpler and less costly to build because static machine elements control the horizontal motion of its rows of magnets. Moreover, the new device does not adversely affect focusing and steering of the electron beam, as adjustable-gap devices do. Beam adjustments made by a user at one experimental station on the storage ring do not change the beam characteristics for users at other stations. Because most synchrotron radiation facilities are multiuser facilities, this feature represents a significant improvement.

Work on the adjustable-phase undulator by SSRL has led to the development of similar devices that can produce x-rays with circular polarization. The polarization can be changed by adjusting the phase. These devices are intended for synchrotron radiation research in which crystals or other media absorb right-polarized and left-polarized components of light unequally.

Given its improved overall performance and versatility over conventional undulators, the adjustable-phase undulator could become the magnetic insertion device of choice at advanced synchrotron radiation facilities.

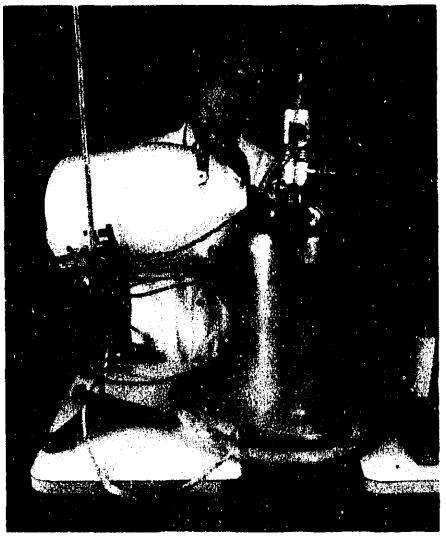
The adjustable-phase undulator received a 1992 R&D 100 Award from *R&D Magazine*. A patent on this innovative undulator is pending.

Simple, Low-Cost Method for Coating Superconductor Substrates

Producing Long Superconducting Wires and Tapes

Because superconductors carry electricity with zero loss due to resistance, they could significantly improve the way we use energy. Utilities and electrical suppliers are especially interested in finding economical ways to produce long superconducting wires and tapes for equipment such as generators and transmission lines. Until now, the brittle nature of most superconducting materials has prevented them from being drawn into long, flexible shapes.

A low-cost coating method developed at the National Renewable Energy Laboratory (NREL) may help solve this problem. Because of the potential commercial applications of the process, the General Electric Research Center of Schenectady, New York, joined the Laboratory in a cooperative research and development agreement (CRADA) to take a closer look. General Electric and DOE are each contributing $50,000 to the year-long effort.



Researcher pours liquid nitrogen into a device that measures the current-carrying ability of thallium-based superconductors.

Both General Electric and NREL have been experimenting with thallium-based superconducting materials for several years. The Laboratory's novel approach uses electrochemical deposition to place a thick film of thallium, calcium, barium, and copper on a suitable substrate. This precursor film passes through a two-zone vapor reactor, where it is annealed in the presence of a thallium source. The process is simple, fast, and scalable and can coat substrates having many different shapes. The resulting thallium-based material superconducts at relatively high temperatures and has excellent current-carrying ability.

General Electric's experiments with thallium-based materials use spray pyrolysis to deposit the precursor film. The CRADA allows researchers to compare the two approaches to find the most practical way of making long superconducting tapes for electrical equipment.

As overseer of more than $2 million in subcontracts for superconductivity research, NREL will benefit from General Electric's extensive experience with the two-zone vapor reactor. General Electric researchers are using electrodeposited precursor films to determine the effect of sample temperature, thallium oxide vapor pressure, and process schedules on the superconducting properties of the final film.

Researchers are also investigating films prepared from thallium, strontium, calcium, and copper oxides, both with and without lead and bismuth additions. Electrodeposited films from this family of materials are processed by using the two-zone reactors at NREL and General Electric. The Laboratory is also fabricating superconducting tapes longer than 1 meter.

If the superconductivity coating process proves practical and economical, General Electric will have a competitive edge in a promising market.

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Advanced Wind Turbine Technologies

Providing Clean, Affordable Electricity

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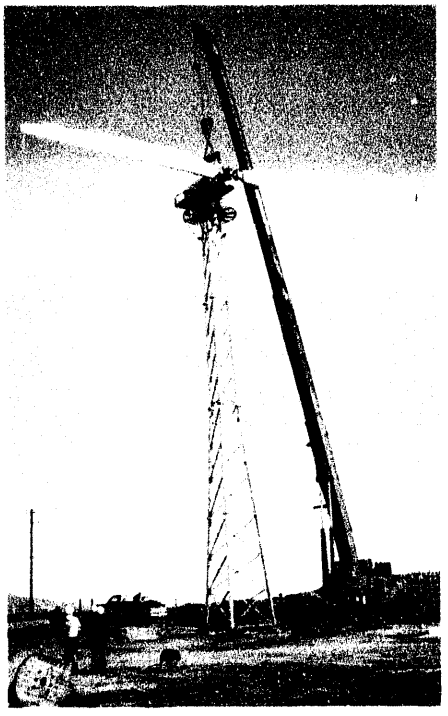
This prototype advanced wind turbine, operating at a California wind farm, features an advanced rotor system and new wood/epoxy blades that increase energy production.



The next 5 years are critical for U.S. industries working with wind energy. Market opportunities here and abroad are multiplying rapidly as governments, utilities, and citizens realize that wind energy has the potential to deliver clean, affordable electricity. The National Renewable Energy Laboratory (NREL) and DOE are helping to maintain U.S. competitiveness by supporting four companies as they develop and integrate advanced technologies into utility-grade wind turbines.

Under DOE's Advanced Wind Turbine Program, NREL has awarded $9 million in cost-shared subcontracts to R. Lynette & Associates of Redwood, Washington; Atlantic Orient Corporation of Norwich, Vermont; Northern Power Systems of Moretown, Vermont; and Carter Wind Systems of Burkbarnett, Texas. These companies are working to improve the designs of existing wind turbines. The goal is to generate economical electricity at annual average wind speeds of 6.9 meters per second at hub height, which would allow wind plant developers to take advantage of windy areas in the Pacific Northwest, the Great Plains, and the Midwest.

Lynette & Associates is testing a prototype advanced turbine at a California wind farm. The machine features an advanced rotor system built by Gougeon Manufacturing Corporation of Bay City, Michigan. Use of the new 12-meter wood/epoxy blades increases energy production by more than 50% over the original ESI-80 design. Researchers are also testing new tip brakes, which deploy at high wind speeds to prevent damage to the rotor.

Atlantic Orient is improving the Enertech 44 turbine by incorporating 7.5-meter wood/epoxy blades with advanced, NREL-designed airfoils. The new blades, produced by Gougeon Manufacturing Corporation, passed grueling fatigue tests at the National Wind Technology Center in Golden, Colorado. The turbine is being tested at the U.S. Department of Agriculture's wind energy test facility in Bushland, Texas, under a cooperative agreement with that agency.

Northern Power Systems has launched an advanced turbine project to develop and test new aerodynamic controls (ailerons). The company combined its ideas with information from earlier DOE-sponsored work with the National Aeronautics and Space Administration. The new ailerons performed well in field tests on two machines.

Carter Wind Systems has designed a 300-kilowatt wind turbine that uses a flexible, lightweight rotor with distinctive cuffs near the blade roots. The design, which is already used in the United States and the United Kingdom, features a tall pole tower that can easily be lowered to allow ground-level maintenance of the rotor and drive train.

The next phase of the Advanced Wind Turbine Program will include development of next-generation technology. DOE expects next-generation machines to feature a variety of innovations, some of which were identified in earlier conceptual design studies. These innovations should significantly reduce costs and improve performance, allowing utility-grade wind turbines to produce electricity for 4¢ per kilowatt-hour at 30-meter hub heights by the year 2000.

Mild Coal Gasification Process

Producing High-Quality, Clean Liquid and Solid Fuels

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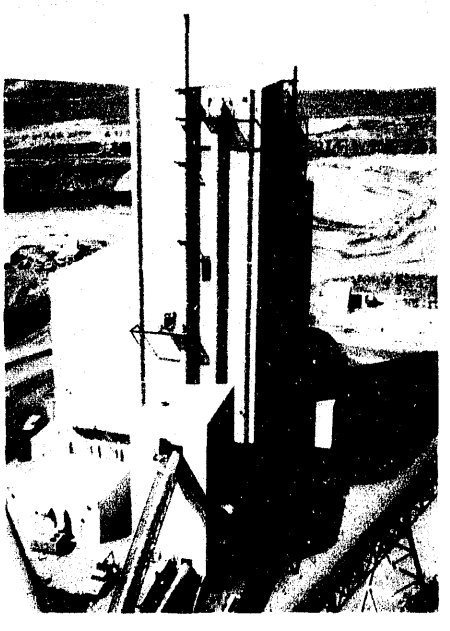
The ENCOAL Corporation of Gillette, Wyoming, was the first participant to build an operable "clean coal" plant under DOE's Clean Coal Technology III Program. Design and construction of the plant were completed in April 1992. The demonstration facility near Gillette uses the Powder River Basin's generous reserves of low-sulfur, high-moisture, low-heating-value subbituminous coal — about 1 million kilograms per day.

Two commercial fuels — a low-sulfur coal-derived liquid fuel and a low-sulfur process-derived solid fuel — are produced from subbituminous coal. The liquid fuel resembles No. 6 fuel oil, a fuel used in industrial boilers. Under an agreement with ENCOAL, TEXPAR Energy of Waukesha, Wisconsin, purchases coal-derived liquid fuel as a substitute for No. 6 fuel oil. Process-derived solid fuel is similar to high-rank eastern bituminous coals, but it is low in sulfur. Under an agreement with ENCOAL, The Wisconsin Power & Light Company (Madison, Wisconsin) purchases process-derived solid fuel.



The first operating clean coal technology plant produces coal-derived liquid fuel and process-derived solid fuel.

The ENCOAL Corporation uses a mild coal gasification process (i.e., the technology operates at atmospheric pressure and at temperatures lower than those typical for coal gasification). Called the "liquids-from-coal" process, it is particularly well suited to the low-rank coals from Wyoming, Montana, North Dakota, and the Gulf Coast. Raw coal is heated under carefully controlled temperatures and pressures, which chemically converts the coal to the two fuels. The coal is heated by hot gases to remove moisture, then conveyed to a second pyrolyzer vessel, where it is heated further to about 538°C to remove a portion of the volatile components. Released gases are cleaned in a cyclone, then cooled to condense the liquid product. The noncondensed gases are combusted to provide heat for the process. The process-derived fuel has a high heating value (12,000 Btu per pound), which makes it desirable for use in utility boilers.

The facility's advanced computerized control system makes it possible to adjust for changes in the feed coal composition and customize the quality of the product fuels, depending on specific market needs. Two on-line analyzers, supplied by Gamma-Metrics of San Diego, California, monitor the moisture, ash, sulfur content, and heating value of the coal.

Since becoming operational, the plant has completed 15 test runs, for a total of about 1,800 hours of operating time. The process has produced about 20 tank cars of commercial-grade coal-derived liquid fuel and 15 hopper cars of commercial-grade process-derived fuel. Demonstration test runs are scheduled to continue through September 1994. The plan is to operate the plant as a commercial power plant.

Hot Dry Rock

Developing a Clean, Efficient, and Environmentally Benign Source of Energy

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Heat-mining technology has been under development for nearly 20 years. Tests conducted by Los Alamos National Laboratory (LANL) at the Fenton Hill Hot Dry Rock (HDR) Facility recently confirmed the practicality of mining natural heat stored in rock formations deep within the earth. Enough heat is present at reachable depths in hot dry rock to meet the world's energy needs for thousands of years.

In heat mining, a well is drilled to the depth required to reach the hot dry rock. Water is then pumped into the well under sufficient pressure to open natural joints in the rock. The pressurized water flows into these openings and is superheated by contact with the hot rock. This process creates an artificial geothermal reservoir that consists of a relatively small amount of water dispersed in a large volume of hot rock.

One or more additional wells can then be drilled into the reservoir at some distance from the first well to tap this pressurized hot water and bring it to the surface. After its thermal energy has been extracted, the water can be pumped back into the hot rock to recharge the artificial geothermal reservoir. When carried out as a continuous, closed process, HDR heat mining should have almost no environmental impact because only heat is permanently removed from the earth.

Heat mining has been demonstrated during the past decade, but only recently have scientists addressed questions concerning long-term operation of HDR heat mines. An extended flow-test program at Fenton Hill has indicated that HDR reservoirs can be expected to produce hot water continuously for long periods of operation and that water loss in reservoirs similar to the one at Fenton Hill should be extremely low. These flow tests also indicated that HDR heat mining is environmentally benign. The circulating water picked up only small amounts of minerals and gases; thus, during normal operations, an HDR facility would release only heat to the atmosphere.

The Fenton Hill tests also showed that the research facility could have produced about twice the electricity needed to run the Facility. Because the Fenton Hill HDR Facility was not designed for optimal commercial operation, a heat-mining facility equipped with state-of-the-art design and technology could produce much more electricity.

The Laboratory has signed a memorandum of agreement with Geolectric Power Company of Reno, Nevada, to pursue joint development of HDR resources. Another private organization is evaluating the practicality of converting the Fenton Hill HDR site to a commercial power plant. Given the promising flow-test results, plans are being made for a joint industry/government project to construct an HDR heat-mining facility to produce and market electric power. DOE is soliciting industrial participation in this project.

Scientists at the Fenton Hill Hot Dry Rock Facility have confirmed the practicality of mining the natural heat stored in rock formations buried deep within the earth.

Rolling Float Meter

Measuring Drilling Fluid Outflow Rates Simply and Accurately

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Researchers at Sandia National Laboratories have developed the rolling float meter to provide an easy yet accurate means for measuring the flow rate of drilling fluid as it flows out of a well during drilling. A comparison of this outflow rate with the rate of the fluid as it enters the well can help in determining the onset and severity of fluid loss to the rock formation. Such lost circulation causes drilling problems that account for about 10-20% of the drilling costs and 3-10% of the total costs of a typical geothermal project. Rapid detection and characterization of loss zones can improve the chance for a successful drilling operation and reduce the costs associated with plugging these zones. The rolling float meter can also be used in petroleum reservoirs to detect gas kicks before they reach the surface, thereby giving the driller time to take measures to prevent the blowout of a well.

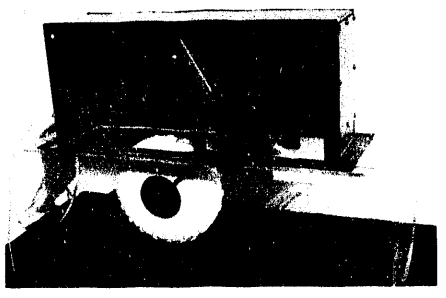
Operating the meter is simple. The device consists of a buoyant wheel or float, which rides the surface of the drilling fluid in the return line leading from the wellbore to the mud pit. The float is counterbalanced so it is relatively lightweight and does not sink much below the fluid surface. The height of the fluid in the inclined, partially filled return line is determined by using a pendulum potentiometer to measure the angle of the pivot arm to which the float is attached. Fluid height is a sensitive function of the flow rate; therefore, the potentiometer reading can be correlated with flow rate to provide an accurate measure of the drilling fluid outflow rate. Accuracies of 0.5-2.0% have been confirmed in the field.

A key factor in the meter's ability to measure flow rates is the design of the rolling float itself. The float consists of a 9-inch-diameter polyurethane foam wheel about 3 inches wide. Treads on the wheel's outer circumference provide traction with the fluid and make the float spin at up to 200 revolutions per minute as it rides the fluid surface. The flow of fluid around the submerged portion of the spinning float results in dynamic pressures that attract the float to the fluid surface. Attraction causes the float to track the surface extremely well, because even though the float is counterbalanced to a very light weight, it does not bounce free of the surface in response to surface waves traveling down the return line in the turbulent fluid. The spinning effect also prevents drilling mud from accumulating on the float and causing its buoyancy to change over time.

The rolling float meter has undergone extensive laboratory testing to optimize its design and verify its long-term reliability. It has been field tested in conjunction with the two standard instruments used to measure fluid outflow rates — the paddlemeter and acoustic level meter — and found to be significantly superior to them in terms of its accuracy and resolution. This simple meter can be fabricated by the user for less than $2,000.

The rolling float meter is currently being evaluated by industry. Eight units have been fabricated and loaned to service companies interested in testing them. The meter is being used on a rig in the Coso geothermal field in central California and is slated for tests on two hot geothermal wells in Japan. In addition, it is being tested and evaluated by the petroleum industry for use in kick detection; it has been installed on both land and offshore rigs. Information and detailed design drawings are available to interested parties.

The rolling float meter is installed on a clear, simulated, return flow line.



Low-Emission Weak Swirl Burner

Reducing Nitrogen Oxides While Maintaining Fuel Efficiency

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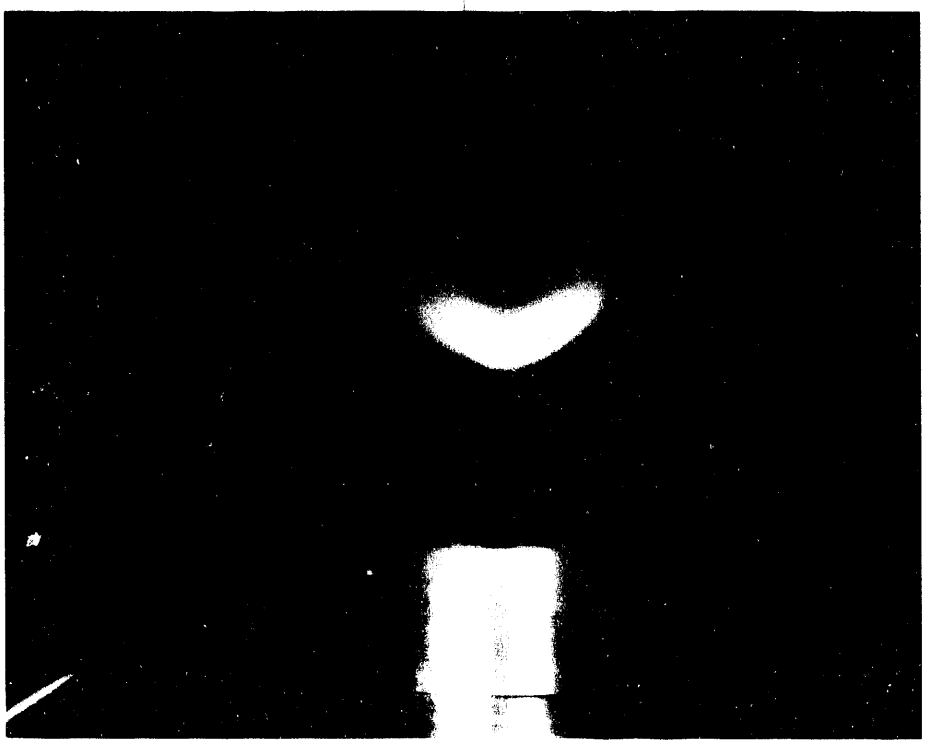
Gas-fired burners are used in industry for a wide range of applications such as water heaters, power generators, boilers, and heating, ventilating, and air-conditioning systems. Consumer applications include water heaters, heating systems, and clothes dryers. Conventional burners of this type, which use natural gas, operate at a high flame temperature. They emit high levels of nitrogen oxides (NO_x), which are among precursors to ozone formation in the lower atmosphere.

Researchers at Lawrence Berkeley Laboratory (LBL) have designed a new weak swirl burner that reduces NO_x emissions without sacrificing design simplicity or fuel efficiency. With government regulation of burner emissions pending, the demand for this type of "green" burner technology should increase dramatically. More than 100 U.S. cities have ozone levels that exceed federal health standards. Many of these cities are considering limits on the number of conventional natural gas burners that could be installed. Governmental energy-saving and pollution-control incentives like those for more efficient lighting and reduced auto emissions should also contribute to market expansion. The LBL burner is poised to take advantage of such opportunities.

The Laboratory researchers originally developed the weak swirl burner as a means of stabilizing the flame for scientific studies. The premixed, open flame is stabilized by injecting tangential air into the co-flow of a concentric burner. This innovative technology has several major advantages. First, it supports ultra-fuel-lean combustion, which results in the extremely low NO_x emission concentration of 4-7 parts per million. Second, its simple design eliminates scaling and tolerance problems, thereby simplifying its manufacture. Third, the LBL design is the best choice for replacing most medium- and small-scale burners having flame temperature requirements below 2,600°F. Finally, its operating range is broad, which limits the risk of blowoff and flashback.

A large U.S. water heater and boiler manufacturer and LBL, which has finished work on a laboratory model of this burner, have received funding from DOE through a cooperative research and development agreement. They will work together to bring this invention to market. A patent is pending on the technology.



This bench-scale test model of a new weak swirl burner has a very low nitrogen oxide emission rate.

Kalina Cycle Demonstration Plant

Producing Electricity More Efficiently

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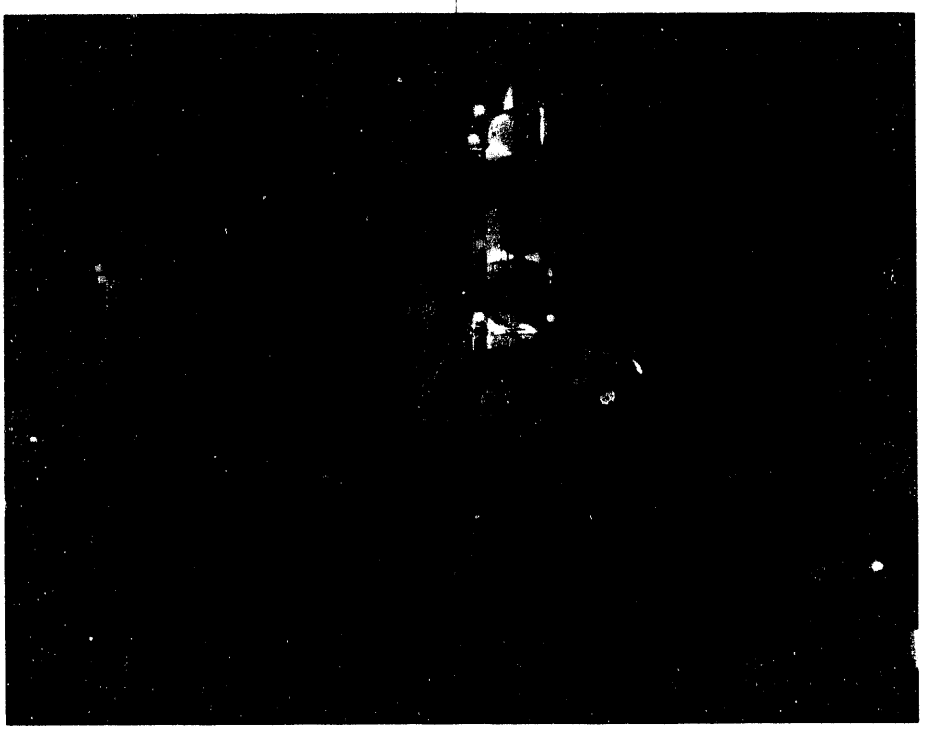
The Kalina cycle demonstration plant is located at DOE's Energy Technology Engineering Center (ETEC). Waste heat from an adjacent steam generator test facility provides the energy input to the process. The plant became operational and first demonstrated the cycle process in December 1991. Since that time, nearly 3,000 hours of operation have been logged, with an on-line turbine generator producing approximately 2.5 megawatts of electricity.

The Kalina cycle's major feature is the use of a working fluid mixture (ammonia and water) whose composition varies throughout the cycle. This additional degree of freedom improves the manner in which heat is admitted and rejected from the cycle. The Kalina cycle efficiency should exceed the state-of-the-art Rankine steam cycle efficiency by 10-25%.

Exergy, Inc., of Hayward, California, funded the construction of the demonstration plant and is funding the test program. Stone & Webster Engineering Corporation of Boston, Massachusetts, performed the engineering and design work for the demonstration plant and provided advisory services for operator training and plant checkouts and start-up. The Rocketdyne Division of Rockwell International Corporation is providing the operating staff and managing the project for DOE. During the design phase, Rockwell also coordinated the environmental permitting (for status as a cogenerator) and engineering interfacing needed to integrate the plant into existing facilities at ETEC.

On the basis of early testing results, General Electric obtained a worldwide licensing agreement for the Kalina cycle from Exergy. General Electric is currently developing the first commercial application for the Kalina cycle as a bottoming cycle for its combined-cycle power systems.

The Kalina cycle can be applied to power generation systems that use virtually any fuel or heat source, including coal, natural gas, nuclear, geothermal, and solar. It can produce electricity more cheaply than conventional technology. In addition, the Kalina cycle would lower fuel consumption, with a concomitant reduction in pollutant emissions.



This demonstration plant is using the Kalina cycle, characterized by an ammonia/water working fluid, to generate electricity.

Mulled Coal Process to Recover Coal Wastes

Recovering Wet Coal Fines for Use as Fuel

Millions of tons of discarded coal fines at coal preparation plants, together with billions of tons of fines held in black-water ponds and waste coal impoundments, constitute a vast "repository" of potentially marketable coal. These coal fines currently have no value and require disposal.

Energy International Corporation, a small Pittsburgh-based business, has discovered a better way to handle wet coal from coal-cleaning plants. The new process converts streams of fine coal into a clean, tractable form called mulled coal. Energy International developed this process while working under contract with the Pittsburgh Energy Technology Center (PETC).

The Center has historically supported coal preparation research aimed at removing mineral matter and sulfur from coal. This research has produced clean coal products, usually beneficiated wet cake. With a moisture content of up to 50%, wet cake is difficult to store, transport, and handle.

Energy International researchers discovered a low-cost additive that easily converts wet cake into a dust-free, granular material that handles, stores, and burns well, even though it retains a high moisture content. The proprietary additive is mixed with wet cake in a muller, which resembles a cement mixer. Mulled coal is then processed into a sandlike, granular material that looks and handles like a dry product because the additive has trapped moisture within the agglomerated particles. The particles flow freely, do not stick to each other, and can be transported pneumatically. Mulled coal can then be easily converted into a coal slurry by adding a second reagent. The slurry can be pumped, handled, and atomized before being combusted.

Energy International projects that the technology behind its mulled coal process could lead to other applications. The most important of these could be facilitating the use of more deeply cleaned coal. Operators of coal preparation plants think they will have to grind more coal into smaller sizes to achieve greater coal desulfurization through increased liberation of pyrite. Grinding coal for this purpose produces more coal fines. The mulled coal process could convert the coal fines into forms, such as agglomerated solids, that could be blended with newly mined coal. The process could also serve as a less expensive alternative to thermal drying of wet coal fines. In addition, it would avoid the problem of fugitive dust from thermal drying.

In related applications, mulled coal could be used as blast furnace fuel or as secondary combustion fuel to reduce nitrogen oxide emissions. Energy International holds a patent for the process.

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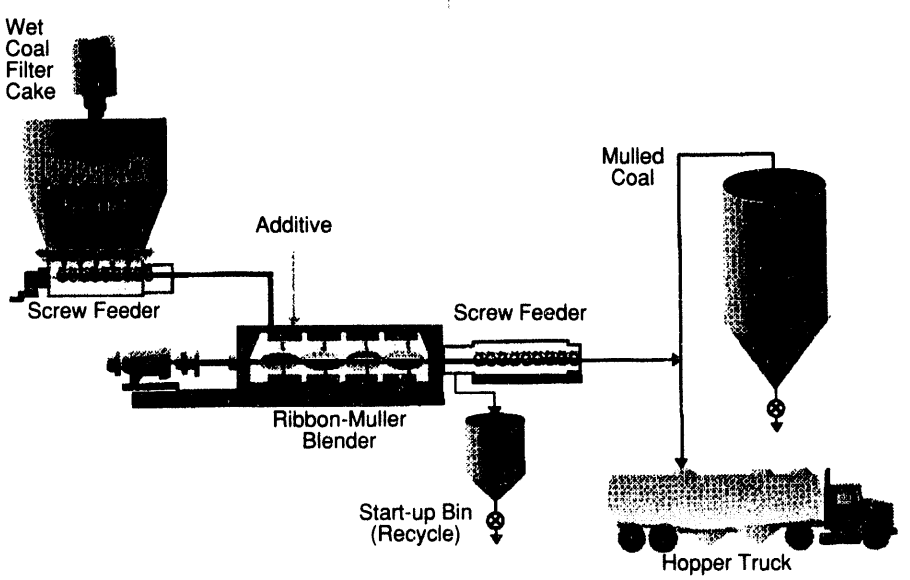
A wet coal filter cake is blended with a proprietary additive to produce agglomerated coal particles that are easily handled before being burned.

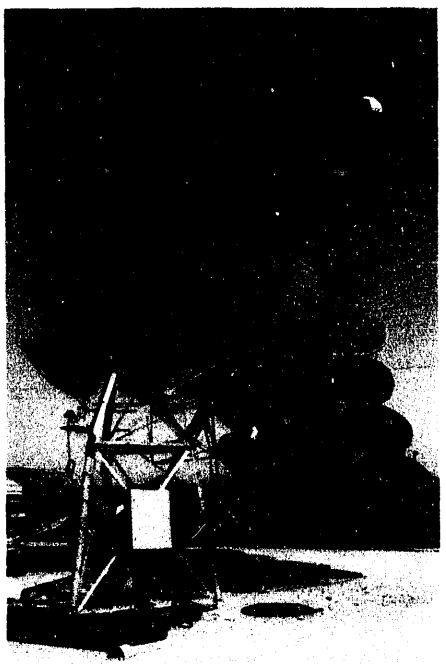


Dish-Stirling Technology

Low-Cost, Nonpolluting Solar Electrical System

A low-cost, environmentally friendly solar power system is being developed in a joint venture involving Sandia National Laboratories; Cummins Power Generation of Columbus, Indiana; Sunpower, Inc., of Athens, Ohio; and Thermacore, Inc., of Lancaster, Pennsylvania. This venture combines Sandia's leadership in developing solar concentrators and receivers with the marketing, design, and manufacturing expertise of Cummins. Sunpower and Thermacore are supplying components. The goal is to move dish-Stirling technology into the electric power generation marketplace.

The system under development is similar to the dish-Stirling technology that was built by Advanco Corporation and demonstrated in 1984. That technology converted sunlight to electrical energy with a net efficiency of 29.4% — still a world record.



This demonstration dish-Stirling system is low in cost and environmentally benign.

All dish-Stirling systems have three basic components: a dish-shaped concentrator that tracks the sun and focuses its rays, a receiver that absorbs the concentrated solar energy, and a Stirling engine/power converter that generates alternating-current electricity from the mechanical motion produced by the absorbed heat. Next-generation components will help these systems achieve the efficiency, durability, and reliability required to deliver competitively priced electricity.

The Cummins system uses 24 low-cost, stretched-membrane mirror facets to concentrate sunlight onto a heat-pipe solar receiver. The innovative facets are made of aluminized polymers backed by a slight vacuum to give them the proper curvature. Sodium metal acts as an intermediate heat-transfer fluid to convert uneven heat from the facets to uniform-temperature heat on the Stirling engine's heater heads. The receiver can also use fossil fuel combustion for heat when sunlight is not available. The free-piston Stirling engine, which converts the thermal energy to mechanical energy and drives an alternator, has only two moving parts (a displacement piston and a power piston) and requires no lubrication and little maintenance.

The first commercial units should be ready for limited production in early 1997. Rated at 7.5 kilowatts and with a 20-year product life, these systems will target markets such as outlying villages, remote hotel sites, and isolated water pumps that do not have access to established power grids. The anticipated commercial cost (including installation) for the Cummins dish-Stirling system will be about $30,000 per unit.

This joint venture won a 1993 R&D 100 Award from *R&D Magazine*, which recognizes the 100 most significant technical products developed each year.

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Successful Slant-Hole Well Completion Test

Drilling Horizontal Gas Wells in Colorado

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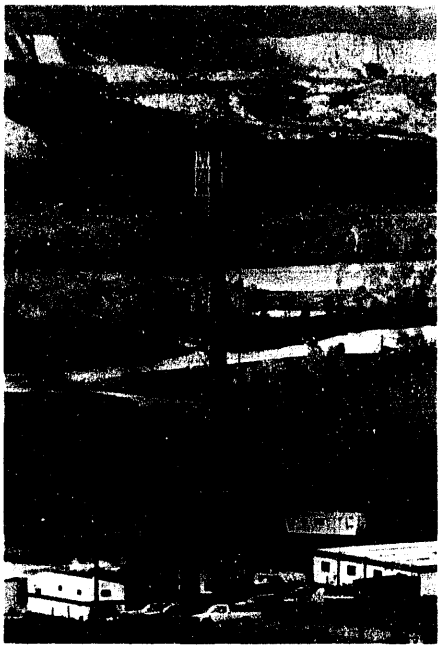
Slant-hole tests have been conducted in the Colorado River valley to the west of Rifle, Colorado.



The U.S. Department of Energy has demonstrated the commercial viability of using slant-hole wells to produce natural gas from tight formations (i.e., those with low porosity and permeability). Tight formations are estimated to contain vast natural gas resources. For example, Piceance Basin's Mesaverde Formation in western Colorado may contain 400 trillion cubic feet. Conventional vertical gas wells completed in such formations are often marginally commercial to uncommercial.

Work to evaluate and demonstrate the effectiveness of slant-hole drilling in low-permeability reservoirs began in 1990 under a multiyear contract between DOE and CER Corporation of Las Vegas, Nevada. This field research has shown that any additional expenses necessitated by drilling slant-hole wells can be more than offset by increased production.

Production testing of a 300-foot-long horizontal hole drilled into the Cozzette sand of the Mesaverde Formation near Rifle, Colorado, showed that uncased wells with only natural fractures produce gas 5 to 10 times faster than vertical wells in the same area. Barrett Resources, a Denver-based independent producer, and partner Meridian Oil, Inc., of Houston, Texas (both active in the Piceance Basin), responded to this news by drilling their own horizontal well into the Cozzette sand on acreage next to the DOE slant-hole test site. Barrett is also actively drilling on an eight-well slant-hole development program in western Colorado.

The slant-hole test targeted two completion intervals: (1) a 60°-inclination hole through a 450-foot-thick interval of interbedded, tight, fluvial-channel sands and gassy coal seams and (2) a horizontal hole in the underlying Upper Cozzette blanket sand. Multiple, open, natural fractures intersected the cores, and large gas shows (i.e., kicks) were frequently encountered during the coring.

The Cozzette interval was thoroughly tested in the spring of 1992 to evaluate and demonstrate the production potential of horizontal wells. The well produced more than 150 million cubic feet of natural gas during 5 months of testing, which included 5 weeks when the well produced at a steady rate of 3 million cubic feet per day and other periods when the well was shut down for pressure-buildup tests or was flowing at lower rates. A gas deliverability test predicted an absolute open-flow potential of 19 million cubic feet per day.

Members of the gas industry have been following this DOE field research throughout the drilling and subsequent test operations. Evidence of their interest includes numerous visits to the site, attendance at technical meetings, exchanges of information about field test results, and the drilling of multiple horizontal and high-angle wells. During drilling, the encouraging gas shows and the evidence of fractures were the focus of attention; more recently, the production test results have led to commercial ventures in horizontal drilling.

Recently, the success of DOE's slant-hole test was recognized by industry when it received the 1993 *Western Oil and Gas World*'s "Best New Well" award in the annual "Best of the Rockies" competition.

Fuel from Renewable Sources

Making Extra Ethanol from Corn Fiber

An industry that is already improving air quality and contributing to energy independence is getting a big boost from a cooperative research and development agreement between the National Renewable Energy Laboratory (NREL) and New Energy Company of Indiana. New Energy will use a fiber conversion technology developed at NREL to squeeze extra ethanol from corn. This technology for making ethanol from corn fiber was recently honored by *R&D Magazine* as one of the 100 most important innovations of 1993.

Ethanol is used as an additive to improve combustion in about 9% of the gasoline sold in the United States. Because the Clean Air Act Amendments of 1990 require use of oxygenated fuel, the demand for ethanol could triple by the year 2000.

Ethanol is produced from the starch in corn kernels. The starch is converted to sugar, the sugar is fermented, and the resulting "beer" is distilled to extract ethanol. Because only about 72% of the corn kernel is starch, other materials remain after the distillation process. Among these are fiber (cellulose, hemicellulose, and lignin), protein, fats, and some starch. This mixture is dried and used for an animal feed called "distillers dried grains and solubles."

Various technologies developed at NREL can be used to convert cellulose and hemicellulose to sugars and ultimately to ethanol. New Energy's pilot plant will apply fiber conversion technologies to distillers dried grains and solubles. Using the carbohydrates from this material should increase ethanol yields by about 13%. An animal feed supplement will still be produced, but without cellulosic material. The new animal feed supplement, which will be reduced in volume, will contain more protein. Because the price of animal feed is based largely on its protein content, the smaller volume of protein-rich feed should command a higher price, meaning no loss of income for the ethanol producer. The new feed may even be worth more to the producer because shipping costs will be reduced.

Most of New Energy's pilot plant, including two 8,000-liter fermentation tanks, is complete and operational. Research results should provide New Energy with enough information to plan for full-scale operation.

Ethanol production from corn kernel starch could probably be increased fivefold without unduly affecting grain prices. In such a case, ethanol could displace about 4% of our nation's gasoline consumption. If this process proves feasible for feedstocks such as corn kernels, ethanol could eventually meet the entire U.S. demand for transportation fuel. Lignocellulosic feedstocks such as corn cobs and stover (husks and stalks) are also promising. Other possible feedstocks range from specially grown grasses or trees to wastepaper.

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Newly developed technology can convert about 13% more corn fiber into ethanol, a clean-burning transportation fuel.

Electricity for Rural Brazil

Providing Electricity with Photovoltaic System

In Brazil, about 36 million people live in remote areas without electricity. The National Renewable Energy Laboratory (NREL) is helping to change this situation through a joint venture that will bring cost-effective photovoltaic power to homes, schools, and medical clinics in two Brazilian states. Photovoltaic devices use semiconducting materials such as silicon to transform sunlight into electricity.

In the first phase of the Brazilian Rural Electrification Project, more than 400 homes in 14 villages in the state of Ceara are being wired for photovoltaic-powered lighting. The photovoltaic systems will also provide electricity for refrigeration, educational television in village schools, and street lights in common areas. Two villages with medical clinics will get the power they need for lights and for refrigerating vaccines. In the state of Pernambuco, photovoltaic systems will supply power for 200 homes and about 150 streetlights. Using these systems is expected to be more economical than extending existing power lines or installing, fueling, and maintaining diesel generators. Eventually, the systems could supply power to more than 500,000 rural homes, schools, and medical clinics throughout Brazil, creating a significant new market for U.S. companies.

The project began when a protocol of intent was signed by representatives of DOE and the two Brazilian states. It called for a joint research and demonstration project to be implemented by DOE and the states. DOE designated NREL to carry out the project.

The Laboratory subcontracted CEPEL, the Brazilian Center for Electric Energy Research, to provide in-country project management. The Center is now working with state-owned utilities to obtain balance-of-system components not provided by the subcontracted supplier, Siemens Solar Industries of Camarillo, California. CEPEL will also help evaluate system performance, operations, and maintenance. Siemens Solar Industries is supplying the 50-watt, 12%-efficient, crystalline-silicon photovoltaic modules as well as the storage batteries and charge controllers required for rural electrification. Equipment arrived in Brazil in May 1993, with installation by two Brazilian utilities scheduled for completion in 1994.

After the project's dedication ceremony in late 1992, six other Brazilian states sent letters of interest to DOE for comparable demonstration projects. DOE and NREL have been reviewing proposals to see if they meet DOE's requirements. They must be at least 50% cost-shared by the participants and, if successful, lead to a large-scale financing request through The World Bank or another acceptable agency.

Commitments are being firmed up with the states of Bahia, Amazonas, and Acre to explore the use of photovoltaic systems for agricultural irrigation, diesel

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Solar panels mounted on and around a Brazilian school provide much-needed electricity for lights, water pumps, refrigerators, and communication equipment.

fuel displacement, water purification, and basic electricity for schools and medical clinics. These pilot projects will be implemented in fiscal year 1994. With other projects now underway, they will provide a wealth of information on the technical, economic, and social impacts of using photovoltaic systems for rural electrification throughout South America.

Transportable Reflecting Environment Communication System

Wireless Communication in Hot Cells

Engineers at Oak Ridge National Laboratory (ORNL) have developed a method of wireless communication that, for the first time, will allow robots to operate freely in the hazardous environment of "hot cells" used for reprocessing highly radioactive nuclear fuel.

Until recently, wireless communication in large-volume hot cells had been considered impossible because the metal walls of the cells cause electromagnetic echoes, or reflections, that confuse robots. The new method employs directional radio waves of very high frequency to reduce the reflections to an acceptable level while also eliminating difficulties associated with tangled and damaged wires. The new system eliminates the large cable bundles that would otherwise be required between the walls of the cells and the operating robots.

The ORNL engineers have tested the new concept by constructing a transportable reflecting environment communication system (TRECS), a radio computer system that sends signals to the robot's computer. TRECS enables the robot to perform its duties within a cell about the size of a football field.

The TRECS electronics are designed to withstand temperatures up to 60°C and doses of gamma radiation up to 1 million rads. Although it is relatively maintenance-free, the system is designed modularly to make remote maintenance feasible.

Fully developed and tested, TRECS is ready for commercialization. As part of a cooperative agreement between DOE and the Commissariat a l'Energie Atomique (CEA), French researchers recently tested the system on robotic equipment installed in metal-lined facilities in France. The tests were very successful. TRECS also has been tested in similar facilities in Japan. Researchers expect the system to be adopted in hot-cell applications toward the end of this decade.

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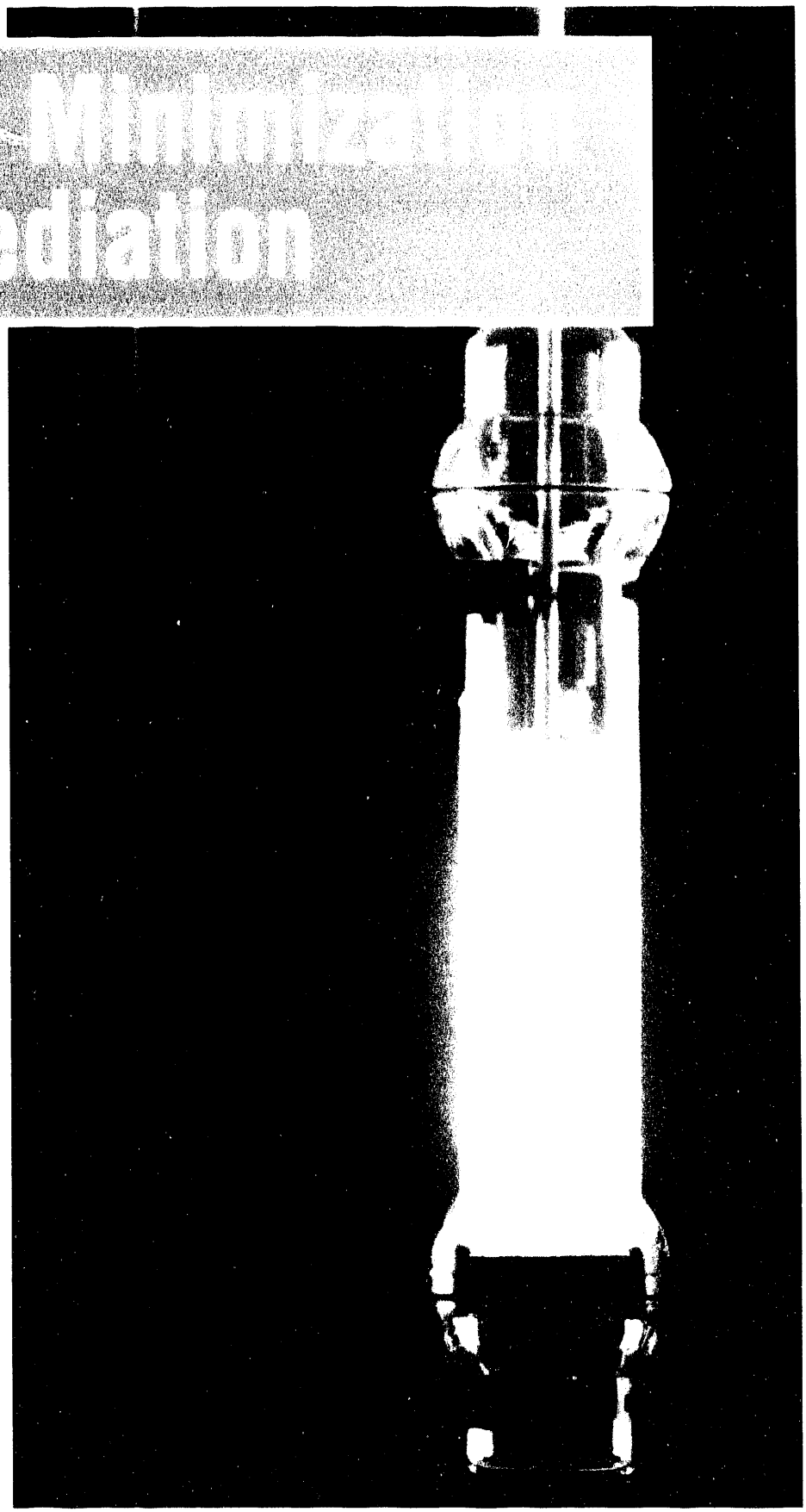
Pollution Minimization and Remediation

As human activities are altering the world's ecosystems, the need for technologies to identify, characterize, monitor, control, and remediate pollutants and conserve energy is becoming urgent. If the United States is to remain in the forefront of environmentally relevant research and development work, the results of basic research must be deployed in commercially attractive forms. As stringent regulations are requiring businesses to employ environmentally sound technologies, the use of advanced pollution-prevention and accurate, rapid environmental measurement technologies will help private companies gain a competitive edge in world markets.



This scale model of the high-energy corona reactor, which uses strong electrical fields to destroy organic contaminants at or near room temperature, was developed at Pacific Northwest Laboratory. For more information, see the writeup on *High-Energy Corona Technology* on page 121.

Membrane Technology

Providing New, Effective, Economical Separation Devices

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The membrane ("barrier") technology developed by DOE laboratories to produce enriched uranium is expected to have significant technical and economic advantages over membrane technologies now used in the private sector. Scientists at the Oak Ridge K-25 Site are developing inorganic membranes that should help improve the efficiency and competitiveness of U.S. industry. These new, effective, and economical separation devices are especially well suited for environmental restoration and waste management applications. The technology should compare favorably in cost with existing organic membrane technologies, and the new membranes are as durable as expensive, state-of-the-art inorganic membranes.

For more than 40 years, DOE and its predecessors have been perfecting membrane technology to separate uranium isotopes. DOE's gaseous diffusion plants have successfully used membrane technology on a large industrial scale.

Membranes are materials that selectively allow or block passage of fluids (gas or liquid), thereby separating mixtures into products and waste streams. They can greatly improve efficiency in petroleum refining, natural gas and petrochemical production, food (especially dairy) processing, beverage clarification, process gas separation, biotechnology purification (for protein, yeast, and other microorganism separations), and other chemical and water purification processes.

Inorganic membranes have a long operating life and tolerate harsh (high-temperature and corrosive) environments. On the basis of its extensive experience with this membrane technology in the uranium enrichment arena, K-25 expects these versatile membranes to significantly reduce production costs compared with those of current inorganic membranes.

Related projects under development at the K-25 site include:

- Ceramic membranes to separate hot hydrogen from gasified coal.
- Permanent, cleanable, high-efficiency particulate air filters to remove hazardous and radioactive particles from gas streams.
- Inorganic membranes to remove, by means of reverse osmosis, pure water from brackish water or seawater.
- Membrane systems to remove hazardous volatile organic compounds from groundwater.
- Photocatalytic membranes to decompose hazardous organic compounds in liquid streams.

These development efforts and future applications for inorganic membranes represent a large return to American taxpayers for investments made in the DOE Uranium Enrichment Program.

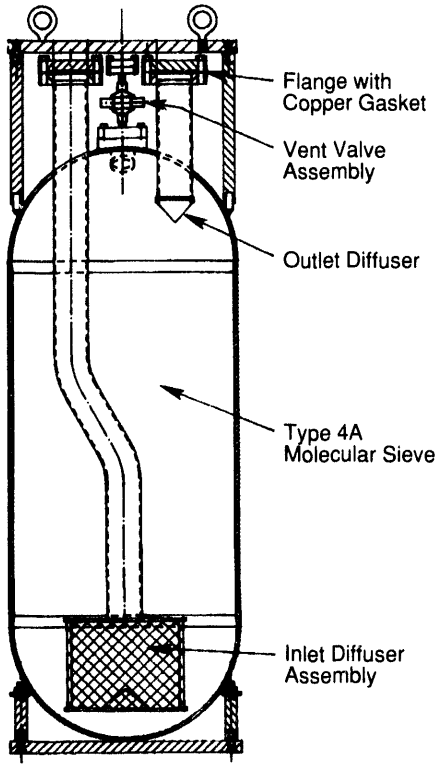
Negotiations to establish two cooperative research and development agreements to transfer the technology to the private sector are in progress.

Type B Disposable Molecular Sieve Bed

Disposable Device for Processing Tritium Oxide Waste

Princeton Plasma Physics Laboratory (PPPL) engineers have developed, as part of the tritium processing system for the tokamak fusion test reactor, a Type B disposable molecular sieve bed (DMSB) for processing tritium oxide waste. The Type B DMSB is designed to fit into the UC-609 shipping package, an approved shipping container used by DOE for transporting Type B quantities of tritium, defined as more than 1,000 curies.

With this design, tritium can be recovered as scrap at DOE's Savannah River Site. Also, with the addition of the pressure rupture disk assembly and a high-integrity container, the Type B DMSB has been approved for disposal of radioactive materials at the Hanford Site in Richland, Washington.



The Type B disposable molecular sieve bed is used for processing and storing tritium oxide waste before it is recovered at DOE's Savannah River Site.

The Type B DMSB, which can contain 3 pounds of water and up to 18,000 curies of tritium, is designed to interface with tritium processing systems at the tokamak fusion test reactor. These systems process the gas stream at a rate of about 50 standard cubic feet per minute and a pressure of 15.2 pounds per square inch (absolute) with 1,000 parts per million of water. The Type B DMSB is 30.75 inches in height, with an outer diameter of 9.875 inches. The vessel, which contains 30 pounds of Type 4Å molecular sieve, is constructed of stainless steel and uses all welded construction. The inlet and outlet connections are capped by means of blind flanges with knife-edge sealing surfaces and copper gaskets. This provides a metal-to-metal seal to ensure tight shutoff and prevent leakage.

The total weight of the Type B DMSB, including molecular sieve and tritiated water, does not exceed 120 pounds, the maximum weight allowed in the UC-609 package. The design pressure is 550 pounds per square inch (gauge), and the test pressure is 825. Pressure builds up in the unit as a result of hydrogen production from the beta radiolysis of water and helium production associated with the tritium content of 18,000 curies. The unit is capable of withstanding the anticipated pressure buildup for 120 years, the time span required for 99.9% of the tritium to decay. The completed Type B DMSB is helium-leak-tested for a maximum leak rate of 10^{-7} standard atmospheric cubic centimeters of helium per second when checked with a helium mass spectrometer.

The Type B DMSB provides an excellent barrier for the containment of tritium. It utilizes an all-stainless-steel (welded construction) 4Å molecular sieve to absorb tritium oxide from the process gas; the tritium oxide is converted to solid form to reduce the risk of leakage.

The Type B DMSB is available for licensing or can be purchased from PPPL fabrication facilities.

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Drain Train for Detecting Radioactivity and Physical Defects

Remotely Controlled Robotic Device to Characterize Underground Piping

For years, scientists at Westinghouse Hanford Company have used robotic devices to characterize radioactively contaminated piping at the Hanford Site. The drain train is the sixth generation of motorized crawlers designed to determine piping integrity and levels of radioactive and hazardous contamination in closed-piping systems. Smaller than its predecessors, the remotely operated drain train was developed and built at a cost of about $50,000. It does the potentially dangerous characterization job more quickly, safely, and cheaply than conventional methods.

The underground piping system at the DOE Hanford Site was installed in the 1950s as a sewage system for liquid waste from laboratories and other research facilities. Closed in 1979, it is now undergoing characterization as part of the overall Hanford Site cleanup effort. The only access to the drain system is through a 6-inch cleanout port. The drain train enters the piping system through this port, makes a 90° turn, and travels 1,000 feet through the pipe, which is 10 feet underground.

The drain train has a gamma radiation detector and two video cameras that send color pictures back to a monitor in a control van. The camera at the back of the device can turn 180°, allowing operators to get excellent views of the inside of the piping system to find cracks and irregularities. This crawler also has an encoder that tells the operator where it is in the pipe. A 1,000-foot electrical cable powers the robotic device's engine and lighting system.

At present, the system is not available commercially. ■

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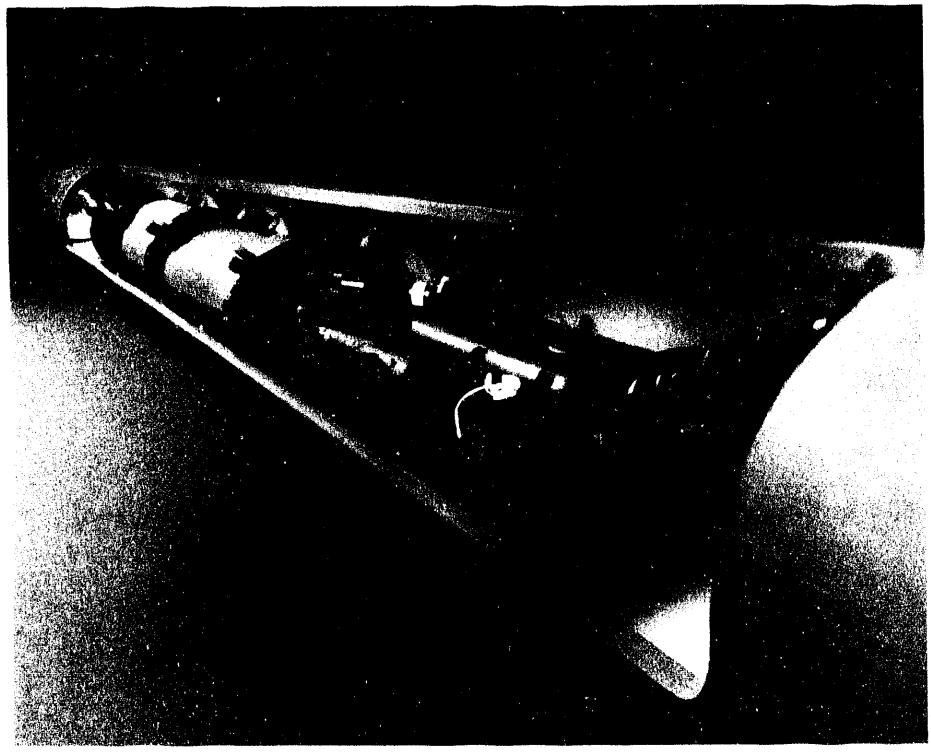

A drain train rolls down a 6-inch-diameter pipe to safely detect radioactivity and structural flaws. The power unit in the foreground pushes the device; cameras and an encoder allow operators to monitor its progress.

Bacteria-Based Adsorption of Heavy Metals

Removing Uranium and Other Contaminants from Waste Streams

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A researcher examines a column containing bacteria immobilized in gel beads. When contaminated water is passed through the column, the bacteria adsorb heavy-metal contaminants.

It has long been known that certain microorganisms will adsorb metals, but only within the last few years have researchers tried to apply that knowledge to waste management. For example, researchers at Oak Ridge National Laboratory (ORNL) are developing an environmental remediation technology that takes full advantage of some microscopic organisms' ability to adsorb toxic heavy metals. In cooperation with Ogden Environmental and Energy Services Company, Inc., of Fairfax, Virginia, ORNL is incorporating microorganisms into a removal technology designed to treat waste streams contaminated by uranium, arsenic, and other metals.

This project is part of DOE's 5-year plan, which contains its strategy for restoring the environment at DOE sites and facilities throughout the United States. Ogden will test this technology on water from a pond in eastern Germany that is contaminated by uranium mill tailings. ORNL's initial role will be to identify the best medium to remove heavy metals under the conditions at the demonstration site. The chosen medium will likely be "gel beads," which were invented at ORNL and patented by DOE. Gels used in this work come from natural sources, such as seaweed.

Each bead, which is about the size of a pinhead, contains millions of immobilized, naturally occurring bacteria. In operation, a column — called a packed- or fluidized-bed bioreactor — is filled with beads. Contaminated water is passed through the column, and the dissolved heavy metals are adsorbed by the bacteria. If the water leaving the column need not be handled as waste, the residual waste material would be only a small fraction of the volume of the original waste stream.

In 1 day, 5 to 10 gallons of beads, held in a column about 2 feet in diameter and 4 to 5 feet tall, can reduce the metal in 1,000 gallons of water from an initial concentration of 50 parts per million to no more than 50 parts per billion.

At this point, one of two things could be done. The organisms could be forced, by altering the chemical environment, to release the metals, which could then be retrieved. Alternatively, the beads could be discarded and replaced with new ones. Because the microorganisms and the gel material in the beads are mostly water, the discarded material could be dried, reducing the mass by more than 80%, or incinerated, leaving only metal compounds.

Different microorganisms have an affinity for certain families of heavy metals. The gel beads containing bacteria able to remove uranium may not be equally effective in removing arsenic. However, there is no reason to believe that a bioreactor could not be tailored, by combining microorganisms, to remove several waste constituents simultaneously.

Because Ogden and DOE are both involved in site remediation, the results of their cooperative research and development agreement are expected to support efforts at a number of remediation sites.

Magnetic Separation to Remove Cesium from Milk

Making Milk Produced in the Ukraine Safe to Drink

Argonne National Laboratory (ANL) scientists have successfully tested a magnetic separation (MAG*SEP) process that removes radioactive cesium-137 from milk produced in the Ukraine. The milk is contaminated above safe drinking levels as a result of the 1986 Chernobyl nuclear power plant accident. Up to 1 million gallons of contaminated milk is destroyed each day.

Removing radioactive materials from contaminated milk is crucial to the health of Chernobyl-area residents; more than 80% of their diet-related radiation exposure is due to milk consumption. Dairy cows produce contaminated milk because they ingest cesium when they graze on grass growing in contaminated soil.

The MAG*SEP process, developed and patented by Bradtec, a British company, uses specially coated magnetic particles that adsorb heavy metals and radioactive contaminants. The type of contaminant removed depends on the type of resin used to coat the magnetic particle. In milk decontamination tests at ANL, the magnetic particle was coated with clinoptilolite, a naturally occurring mineral that strongly attracts cesium. The MAG*SEP process successfully removed up to 94% of radioactive cesium-137 from milk, thereby making the milk safe for human consumption. ANL and Bradtec are also working to demonstrate the MAG*SEP process on groundwater and soils contaminated with heavy metals and plutonium.

The ANL-Bradtec relationship developed from a DOE project. The Bradtec-Ukraine relationship developed when a joint-venture company in the Ukraine put Bradtec in touch with the Ukraine Research Center for Radiation Medicine to see if MAG*SEP technology could be applied to water contaminated as a result of the Chernobyl accident. The Center then inquired whether the technology could be applied to milk.

Bradtec scientists visited the Ukraine and ran tests on the Chernobyl-contaminated milk. Results were similar to those from the tests run at ANL. ANL and Bradtec are seeking funding to develop a portable magnetic separation treatment system.

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A magnetic separation device successfully removes 94% of radioactive cesium-137 from milk contaminated as a result of the 1986 Chernobyl nuclear power plant accident in the Ukraine.

Control of NO_x Emissions

Reducing Pollution from Coal Combustion

Consolidated Natural Gas Company (CNG) of Pittsburgh is using a DOE test facility at the Pittsburgh Energy Technology Center (PETC) to evaluate "iNOxulation," a proprietary process used to reduce nitrogen oxide (NO_x) emissions from pulverized-coal combustion. CNG expects this process to be compatible with conventional and low-NO_x burners and to be more cost-effective than reburning natural gas.

In iNOxulation, natural gas and/or its combustion products are injected into various locations of a pulverized-coal burner. A key consideration is whether natural gas should be used upstream of the boiler. A high-temperature oxygen-depleted transport gas (primary air), for example, could improve the operation of the coal pulverizer.

The Fuels Evaluation Facility, a pilot-scale combustion facility, was used to test iNOxulation, a Consolidated Natural Gas Company process that reduces nitrogen oxide emissions from coal combustion.

The iNOxulation process is being developed in PETC's Fuels Evaluation Facility under a cooperative research and development agreement between PETC and CNG. This state-of-the-art pilot-scale combustion facility simulates the time-temperature history of full-scale utility boilers. Nominally rated at 500,000 Btu per hour of coal, the facility includes a down-fired, cylindrical combustion chamber and a horizontal convective section. An on-line flue-gas analysis system measures NO_x and other emissions. Although primarily used to evaluate the relative combustion performance of advanced coal-based fuels, the facility can be adapted for other uses.

Tests were conducted at baseline conditions: coal-firing rate of 0.45 million Btu per hour, 20% excess air, 0.7 secondary air swirl number, and secondary air preheat temperature of 500°F. Under these conditions, baseline NO_x emissions were 0.75 pound per million Btu (coal-fired basis) for washed Pittsburgh seam coal. Subsequent iNOxulation tests reduced NO_x levels by as much as 50%, resulting in NO_x emissions as low as 0.35 pound per million Btu. In additional testing, NO_x levels were reduced by 20-35%.

Further tests will include longer tests with particulate sampling to see if iNOXulation affects fuel burnout. Other applications for the iNOxulation process include reducing NO_x emissions from the gas turbine exhaust recycle envisioned for the high-performance power systems contemplated for DOE's Combustion Program and use with low-NO_x burners.

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Light-Aided Decontamination

Cleaning Contaminated Surfaces with High-Energy Light Beams

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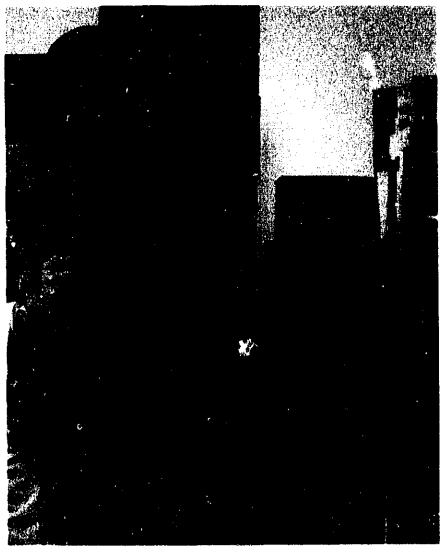
Energy from laser or xenon flash lamp beams can be used to remove radioactive material from surfaces. Careful control of light frequency allows for the treatment of selected surface coatings and substrates.



The light-aided decontamination (LAD) technique uses energy from a beam of light from a laser or xenon flash lamp in the 1-megawatt range to remove unwanted materials from surfaces. In recent years, the technique has been used to remove paints, finishes, and corrosion products from surfaces in a variety of industrial and commercial applications. For example, the surfaces of statues, paintings, and fabrics that are thousands of years old have been cleaned by LAD.

Westinghouse Hanford Company is adapting the LAD technique for two applications: to clean radioactive contaminants from a concrete basin and to remove contaminated paint from surfaces. Westinghouse Hanford has established a laboratory equipped with a laser and xenon flash systems at the DOE Hanford Site. Portions of a decommissioned nuclear power plant are being examined at the laboratory to demonstrate these applications.

The LAD technique makes use of two characteristics of light energy — its absorption and its conversion to heat (photopyrolysis) — to selectively remove coatings or contaminants from surfaces. For a given frequency of light, some surfaces reflect the beam, others transmit it, and still others absorb it and convert it to heat.

To develop LAD for a specific application, researchers need to determine the light-absorbing and light-reflecting properties of both the contaminated surface material (i.e., coating or soil) and the substrate. They then need to select the light frequency that takes advantage of these specific properties, so energy from the light beam is absorbed by the unwanted surface material and reflected by the substrate. If the light intensity is high enough, a surface can be heated to 1,000 to 2,000°C in microseconds without affecting the substrate.

With each light pulse, some surface material is transformed into a high-temperature gas or plasma that erupts from the host surface. The plasma produces a brilliant flash of light and a supersonic shock wave. Photochemical and thermochemical reactions occur within the plasma. There is no flame because the shock wave pushes ambient oxygen away from the plasma.

Because the ablation advances through the surface material faster than thermal conduction occurs, heat is removed from the surface in the ablating gases, with the result that the underlying substrate remains cool. Once the light beam removes all the surface material, exposing the substrate's surface, the ablating action stops. Because of the substrate's reflective properties, only a little heat develops, and this small amount diffuses into the substrate before it can cause any damage.

Because LAD uses no abrasives or chemicals, no secondary wastes are produced. Organic coatings, like some of the materials found in paints and adhesives, are partially destroyed in the cleaning process. Consequently, the volume of waste is often smaller than the original volume of the coating.

Westinghouse Hanford Company expects light-aided decontamination to be used for environmental cleanup, and possible cooperative ventures are being investigated.

Nuclear Testing Technologies for Environmental Assessments

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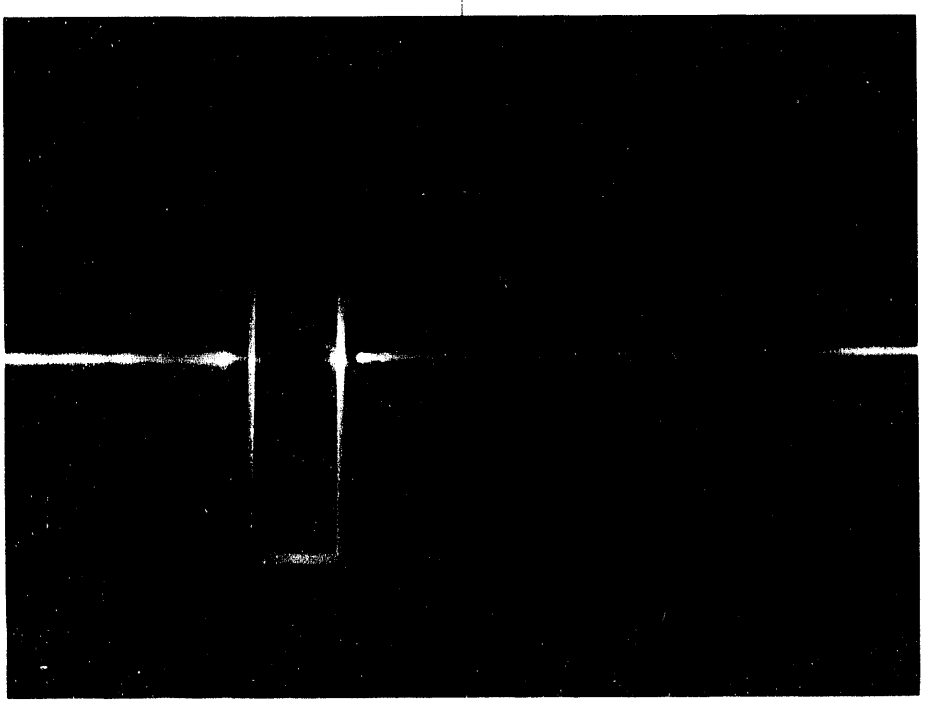
Detecting Radioactive Species to Prevent Environmental Problems

The technical and scientific base that provided contributions for nuclear testing is now the foundation of a national environmental assessment program. In the first phase of the program, areas of concern (e.g., nuclear facilities and military bases that have shut down and hazardous materials being stored underground) are being assessed, and remediation projects are being ranked according to how severely the problems associated with the hazardous materials at each area might affect the population. The program also includes assessments of whether ongoing activities could aggravate any problems.

Lawrence Livermore National Laboratory (LLNL) is contributing to this effort in a number of ways. Its facilities can handle both radioactive and nonradioactive samples, and they can perform radiochemical separations and detect radiation for a wide range of isotopes and radioactivity concentrations. Because of its ready access to the Center for Accelerator Mass Spectrometry, LLNL can precisely measure radioactive or stable isotopes that are present in either high or low concentrations.

The Laboratory has developed a unique, personal-computer-based system that can determine the radioactive content of samples around nuclear test sites from a remote location. The system incorporates a unique set of "hands-off" computer codes that can quickly and easily determine concentrations of radioactive materials. It can identify and measure the amount of alpha-emitting particles in almost any sample and accurately interpret the results, enabling researchers to understand the sample's origin. It can quantify a small amount of one isotope, even when large amounts of other radioactive isotopes are also present. Isotopic imaging is also very useful in characterizing parameters such as groundwater origin and flow direction. This information is extremely valuable in at least two areas: studying water runoff from agricultural fields containing pesticides and studying water management processes, a critical area in California.

The Laboratory has also developed spectroscopic techniques to examine the oxidation state of actinide ions and



A laser-based photoacoustic spectrometer is used to investigate actinide chemical behavior in very dilute solutions (10^{-7} molar).

identify the counter ions associated with them (speciation) in groundwater. Researchers can measure the parameters necessary to determine whether the actinide will migrate from the source into the geosphere and assess the environmental fate of various species. In addition, the Laboratory has developed photothermal spectroscopic capabilities that use a pulsed dye laser, which provides the same information as conventional absorption spectroscopy yet is more sensitive by two to three orders of magnitude. Optical absorption spectra of actinides in solution can be used to identify an element, its oxidation state, and its complexation behavior.

Detection of radioactive species in various samples provides important information for scientists in environmental restoration, hydrology, and nuclear material safeguards, nonproliferation, and cleanup. Measuring nuclear decay particles (e.g., alpha, beta, gamma, x-ray, neutron, and fission fragments), which is among the most sensitive of analytical techniques, can be done at LLNL.

Because radioactive laboratory components can be extremely hazardous, LLNL has developed a fully automated system to detect and analyze low-energy photons (E < 2 MeV) — resulting from the decay of radioactive materials — in residue on ordinary laboratory waste (e.g., glassware and paper products). This detection system greatly reduces the potential for human exposure to hazards.

Cleaning Waste Streams

New Way to Remove Hypochlorite from Process Streams

Chlorine, which ranks eighth in production among manufactured chemicals worldwide, is a by-product of many industrial and environmental processes. If introduced into waterways, chlorine waste streams such as chlorine bleach can kill aquatic life.

Martin Marietta Energy Systems researchers at Oak Ridge National Laboratory and the Oak Ridge Y-12 Plant have invented a new way to remove hypochlorite (chlorine bleach) from process streams. The new method costs less and is more effective than currently available chemical methods. It is also safe for the environment.

According to R&D Solutions, a company based in Oak Ridge, Tennessee, hypochlorite in a waste stream can be reduced from a level of 26,500 parts per million (ppm) to less than 0.1 ppm in minutes by means of the new method. The method changes the waste stream from one containing hypochlorite into one containing oxygen and salt. Furthermore, the catalyst used in the process lasts for many months before becoming inactive, compared with just a few days for others now being used.

The new treatment process was patented by DOE. R&D Solutions has licensed the process from DOE and, working with the catalyst manufacturer, United Catalyst, Inc. (Louisville, Kentucky), continues to refine it. Martin Marietta Energy Systems, R&D Solutions, and United Catalyst jointly received an R&D 100 Award from *R&D Magazine* for having developed one of the top new technologies for 1993.

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Octapod

Streamlining Surveys of the Earth's Subsurface

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Electromagnetic (EM) surveying and direct-current earth resistivity surveying are geophysical methods used to study earth materials for subsurface groundwater and environmental studies and engineering purposes. EM surveys measure the electromagnetic properties of the earth, and resistivity surveys measure its electrical resistance. The EM surveying techniques are rapidly replacing resistivity surveying methods because the former are less labor intensive, time consuming, and costly. The EM techniques developed for rapid data acquisition in airborne mineral exploration are effective except in areas near conductive metallic buildings or areas subject to intense radio-frequency transmissions.

To overcome current limitations in both EM and resistivity surveying, Argonne National Laboratory (ANL) constructed an electrode array called the Octapod. Used in horizontal ground resistivity applications, it eliminates a cumbersome, time-consuming procedure commonly needed in this type of geophysical surveying. In traditional horizontal surveying, four conducting electrodes — two potential and two current — are arranged in a linear pattern. Surveyors must hand carry these electrodes and drive them into the ground at places targeted for study of the earth's electrical properties.

To stabilize the array as it is carried and to decrease electrode-to-ground resistance, ANL devised a paired electrode system in which four current electrodes — two left and two right — are fixed at the two ends of the array, and four potential electrodes are spaced — two left and two right — in a symmetrical pattern between the four current electrodes. The distance between the left and right electrodes can be varied, as needed.

The electrodes are steel or aluminum dishes sized to permit towing with an all-terrain vehicle over uneven terrain, while keeping the electrodes in contact with the ground. The coupling between the dishes and ground is enhanced with water, as required. Gravity allows the water to drain through a flexible plumbing system connected to the dishes. The electrical coupling between electrodes and ground is further enhanced with copper-coated steel grounding rods inserted through a conductive metal shaft attached to the center of the dish electrodes. Surveyors can determine resistivity by connecting the array to any standard resistivity meter, a device that simultaneously measures current and voltage.

A switch box added to the array allows surveyors to make resistivity readings in several modes: using electrodes only on the left side, only on the right side, or on both sides of the Octapod. Using both the left and right electrodes connected in parallel halves the contact resistance between electrodes and ground and results in a mean apparent resistivity beneath the array.

The Octapod has undergone field testing at Aberdeen Proving Ground, Maryland, and has proved to be robust, field-worthy, and nearly maintenance-free. Only one person is needed to operate the Octapod. Repeat observations can be made in several tens of seconds instead of in the 5 to 10 minutes required by conventional surveying techniques.

Coal Preparation Technology

Evaluating On-Line Control of New Column Flotation Process

Pittsburgh Energy Technology Center's (PETC's) Coal Preparation Process Research Facility is used for scale-up testing of emerging coal beneficiation technologies. Process Technology, Inc., in Lexington, Kentucky, became the first industrial partner to use the research facility, which can accommodate continuous testing of advanced coal-cleaning processes. In a 12-month cost-sharing project, Process Technology evaluated the potential of its on-line process control system — a system designed to optimize column flotation for separating clean, fine coal from refuse (i.e., noncombustibles).

Of paramount importance in coal cleaning is a high-quality, consistent product. Normal inconsistencies in the feed material entering the flotation column can lead to widely varying product quality, resulting in "clean coal" that fails to meet market specifications or is lost with the refuse. Most flotation circuits now used in the coal industry lack control systems. Process Technology's on-line control system can remedy this problem.

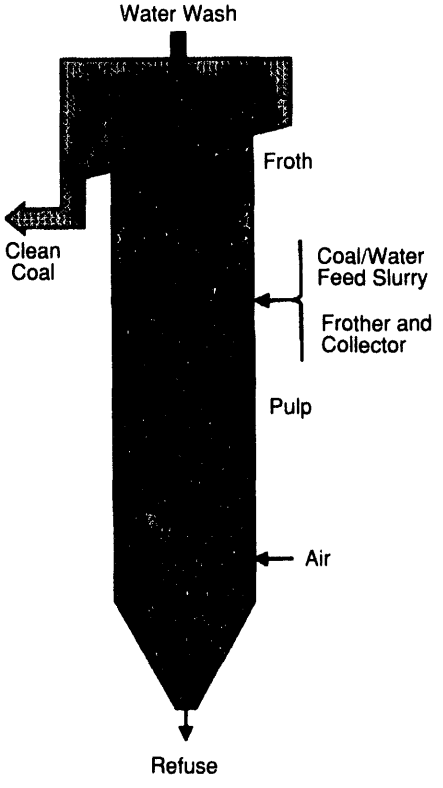
Coal flotation is sensitive to coal characteristics (e.g., ash content, size distribution, and surface oxidation) and operating variables (e.g., solids concentration, air rate, reagent dosage, and coal feed rate).

When added to the flotation system, Process Technology's control system monitors product ash and solids as well as tailings solids. A three-level feedback control sequence compensates for feed variations by correcting the reagent dosage, air addition rate, and froth height in the column.

Results of the program test showed that Process Technology's control system increases the quantity of marketable clean coal by about 3-5% while producing a consistently better product. The increased product yield means that the analyzer and control system will pay for itself in about 1 year.

The Process Technology/PETC cooperative program illustrates how the Center's research facilities can be used to interface with industry; more significantly, each partner benefitted from the program. Process Technology's engineers and technicians quantified components and approaches that work well and identified areas for improving the control system. PETC obtained valuable feedback on the daily functioning of its facility.

The Center offers a sophisticated state-of-the-art test facility along with technical expertise to support private-sector programs. A second cost-sharing project between Virginia Polytechnic Institute and the facility is in progress, and a third with AMAX R&D Center is scheduled for next year. Ultimately, such partnerships will lead to faster commercialization of emerging coal-preparation technologies.



Column flotation is used to clean finely pulverized coal.

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From Trash to Transmission Lines

Manufacturing Refuse-Derived Fuel Pellets

Americans discard up to 240 million metric tons of trash every year. With almost half the nation's landfills approaching capacity, alternative methods of disposal need to be developed. The National Renewable Energy Laboratory (NREL) and four partners are exploring the possibility of using combustible garbage to generate electricity.

A recent cooperative research and development agreement (CRADA) teams NREL with Otter Tail Power Company of Fergus Falls, Minnesota; Green Isle Environmental Services of Hopkins, Minnesota; XL Disposal of Crestwood, Illinois; and Argonne National Laboratory near Chicago, Illinois. Research is aimed at developing a comprehensive database for a process that compresses garbage into thumb-sized pellets, which are then mixed with coal and burned in utility-type boilers.

An important step in manufacturing refuse-derived fuel pellets is the addition of lime, which acts as a bonding agent to hold the refuse together. Lime also neutralizes the sulfur dioxide released from burning coal, thereby reducing air pollution. Researchers are studying emissions generated by burning these pellets at Otter Tail's power plant in Big Stone, South Dakota. Green Isle Environmental Services and XL Disposal supply the pellets, and NREL and Argonne supervise the combustion tests and help analyze the results. If results are promising, the partners will develop a strategy to encourage other utilities to adopt the technology.

A significant industry already exists for converting garbage into energy. The National Solid Wastes Management Association reports that about 140 waste-to-energy plants — 2,400 megawatts of electricity-generating capacity — are processing about 16% of America's trash. An additional 11 plants are either planned or under construction, representing another 1,800 megawatts of electricity-generating capacity. The National Energy Strategy predicts that waste-to-energy plants could contribute more than six times as much energy as they do today.

More widespread use of refuse-derived fuel pellets would help diminish the millions of tons of municipal solid waste added to landfills each year, while helping coal-burning utilities reduce sulfur dioxide emissions, as mandated by the Clean Air Act Amendments of 1990.

This CRADA is providing electric utilities, communities, and industry with more accurate data on this promising technology. Decision makers can use this information to examine alternative trash-management options for specific locations, with full consideration of energy, environmental, and economic effects.

A promising new technology that converts combustible garbage into electricity could help solve the waste-management problem presented by our nation's overflowing landfills while reducing air pollution.

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Clean Salt Process to Separate Mixed Waste

Cleaning up Radioactive Saltcake in Underground Storage Tanks

Scientists at Westinghouse Hanford Company have adapted one of the simplest purification techniques — fractional crystallization — to separate mixed waste. They are using this clean salt process to extract nonradioactive sodium nitrate from mixed waste stored as saltcake in underground storage tanks.

In the clean salt process, water and nitric acid are combined with mixed waste, and a controlled evaporation process separates the soluble portion of the saltcake from the insoluble portion, which contains the radionuclides. The radioactive waste — as little as 10% of the volume — can then be treated to remove cesium (a thermally hot radionuclide) or shipped to a permanent storage site. The sodium nitrate product (a salt) can be stored as nonradioactive waste or recycled for use by industry.

The potential benefits of this technology are great. For example, at the DOE Hanford Site alone, it could reduce the amount of mixed waste in underground storage tanks by 90% (i.e., by 25 to 45 million gallons). Such a reduction would lessen the need for waste storage and treatment, saving billions of dollars and improving the environment. At present, this technology is not available commercially.

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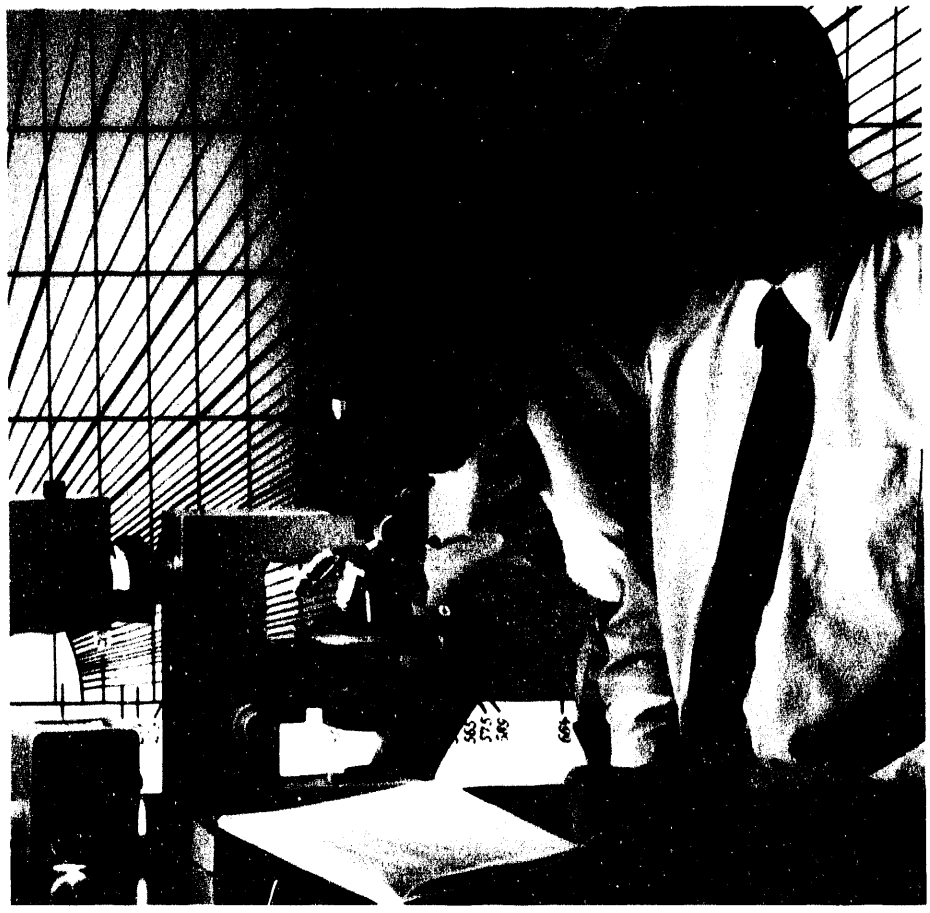

As part of the clean salt process, scientists use a polarized-light microscope to identify the optical properties of crystals. In the background is a Michel-Levy color chart used in the identification process.

Type A Containment System and Waste Package

Processing Tritium Oxide Waste Streams

Princeton Plasma Physics Laboratory (PPPL) engineers have developed a containment system and waste package for processing tritium oxide waste from its tokamak fusion test reactor (TFTR). The PPPL-tritium waste package, which has been qualified as meeting all federal and state transportation requirements, has been accepted for disposal of radioactive materials at the Hanford Site in Richland, Washington.

To meet transportation requirements, the containment system for the PPPL-tritium waste package consists of an outer and an inner drum. The outer drum is an approved, unmodified U.S. Department of Transportation (DOT) 17C 55-gallon painted drum. It has a removable head, 12-gauge ring with a rubber gasket, and closure bolt. Within the outer drum sits the inner drum, which consists of a disposable molecular sieve bed (DMSB) that contains the radioactive material. The DMSB package — the 17C inner drum plus the DMSB — can hold 8 pounds of water and up to 1,000 curies of tritium. Designed to interface with the TFTR's tritium processing systems, the DMSB can process the gas stream at a rate of about 50 standard cubic feet per minute and a pressure of 15.2 pounds per square inch (absolute) with 10,000 parts per million of water.

The DMSB consists of a modified DOT 5C corrosion-resistant drum with inlet and outlet valves and additional protection in the form of impact-absorbing structural material. The valve outlets are capped by means of blind flanges with knife-edge sealing surfaces and copper gaskets. This configuration provides a metal-to-metal seal to ensure tight shut-off and prevent leakage. A hydrogen catalytic recombiner fabricated of 20-mesh stainless-steel screen is attached to the inside top of the DMSB. The recombiner contains at least 3 cubic centimeters of mixed catalyst consisting of equal amounts of Englehard catalyst (a palladium-on-alumina substrate) and Atomic Energy of Canada Limited No. 85-42 or 85-42-R catalyst (a hydrophobic, platinum-on-silica substrate). The catalyst causes any hydrogen and oxygen that may be present to recombine to form water vapor, which is then adsorbed onto the molecular sieve.

The DMSB is placed inside the outer drum, and all void spaces between the two drums are filled with sand, which acts as a cushioning, heat-absorbing, and packing material. The DMSB tubing, flanges, and valves are all

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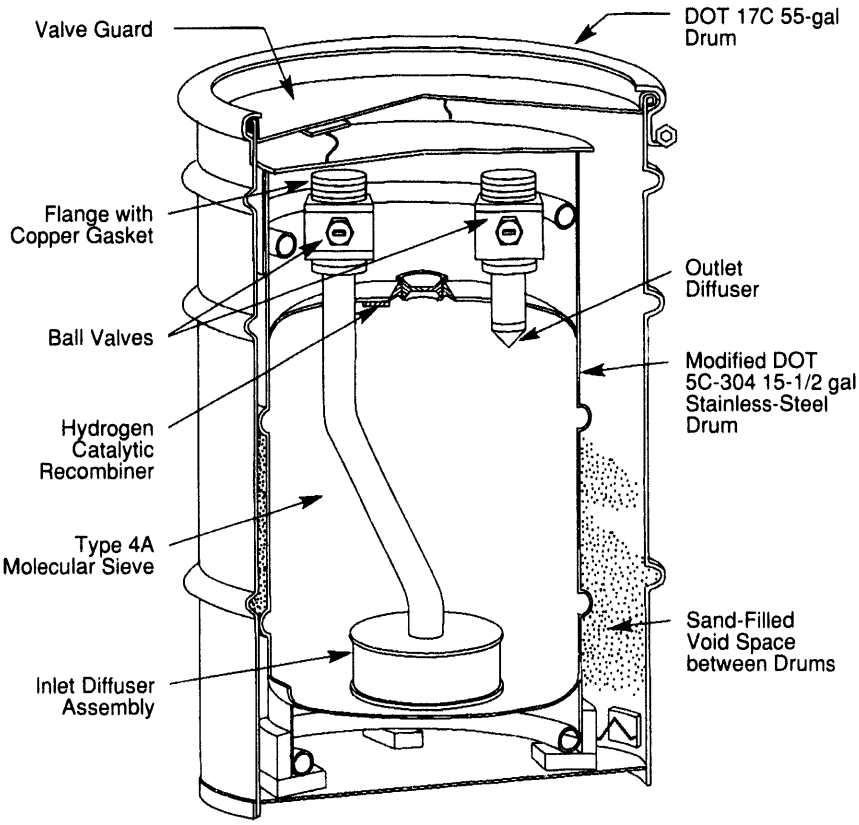
The tritium waste package processes and stores radioactive materials prior to their transportation and final disposal.



helium-leak-tested for a maximum leak rate of 10^{-6} standard atmospheric cubic centimeters of helium per second.

The DMSB provides an excellent barrier for the containment of tritium waste. An all-stainless-steel, welded-construction, Type 4Å molecular sieve absorbs the tritium oxide from the process gas; the tritium oxide is converted to solid form, which reduces the risk of leakage. Tritium diffusion through the stainless-steel vessel of the DMSB is negligible for normal variations in temperature during storage, transportation, or burial.

This package is available for licensing to private industry or can be purchased from PPPL fabrication facilities.

High-Energy Corona Technology

Efficient, Cost-Effective Decontamination of Hazardous Wastes

By the end of this century, an estimated 490 million tons of hazardous waste will have been generated each year in the United States. Cleanup of contaminated sites is a $10-15 billion-per-year industry, and costs are mounting rapidly. To address these problems, Pacific Northwest Laboratory (PNL) has developed a high-energy corona technology that can destroy or decontaminate hazardous liquids and gases. This system can process significant amounts of waste quickly, cost efficiently, and without hazardous by-products. In 1993, it received an award as one of the top 100 technologies of the year from *R&D Magazine*, a tribute to its promise for environmental cleanup applications.

The technology can be applied to any liquid or gaseous wastes containing hazardous organic compounds. In the system, air and contaminated waste are passed through plasma, a high-energy (12,000 volts per centimeter) electrical field. The plasma accelerates ions and electrons in the air and waste. The ensuing collisions and reactions either destroy the contaminant molecules or reduce them to nontoxic materials such as carbon dioxide, water, and table salt. Contaminant destruction rates higher than 99% have been demonstrated at concentrations as high as 2,000 parts per million. The compounds are destroyed in less than a second in the gas phase.

Its low energy requirements, affordability, and simplicity of operation (no moving parts) make the high-energy corona technology ideal for projects in the field. It has been demonstrated successfully in a program at DOE's Savannah River Site in South Carolina, and a mobile prototype system is scheduled for use at other waste sites in 1994.

The factors that make the technology suitable for site remediation also make it attractive to industry. Many businesses — from textile manufacturers to paint retailers — need to decontaminate and reduce the volume of their waste streams, but time and cost have acted as barriers. PNL researchers foresee that the high-energy corona technology will help companies reduce waste disposal costs and meet their environmental quality goals.

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Pyrochemical Processes to Recover and Recycle Transuranium Actinides

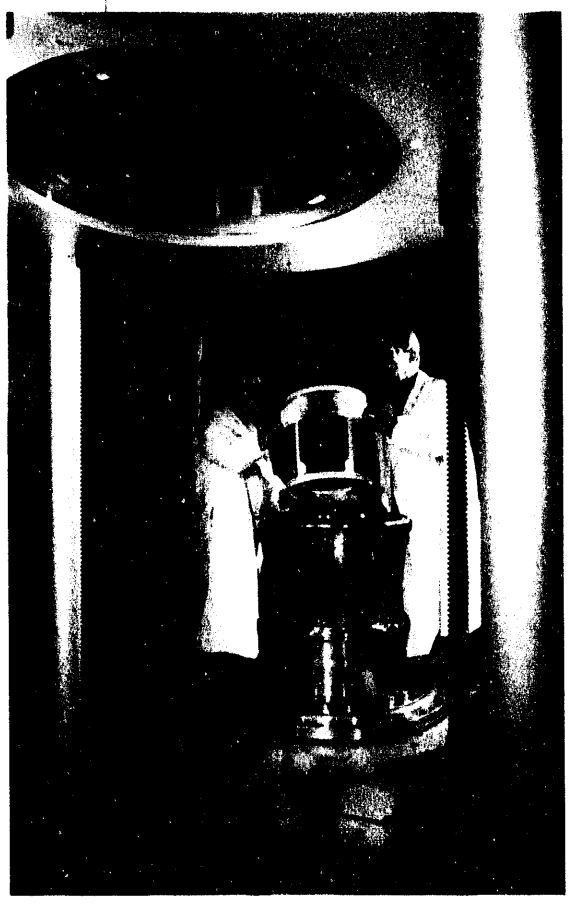
Burning up Radioactive Waste

The metal-fueled, sodium-cooled integral fast reactor (IFR) being developed at Argonne National Laboratory (ANL) has the unique ability to fission transuranium (TRU) actinides. These TRU actinides are major heat generators in spent reactor fuel and are potentially the greatest long-term biological hazard in radioactive waste. Accordingly, ANL is developing pyrochemical processes that enable recovery and recycle of the TRU actinides. These processes allow recovery of TRU elements from spent fuel from the IFR and other reactors, as well as from residues and wastes. In the IFR fuel cycle, actinides are recycled until they are "burned up," that is, converted into fission products and energy. Plutonium from dismantled nuclear weapons is easily introduced into this recovery and burnup cycle.

Argonne has extensive expertise in pyrochemical technology as a result of continuing research that began in the 1950s. Early programs included processing spent fuel from the Experimental Breeder Reactor II, developing engineering operations with liquid-metal and molten-salt systems, and acquiring a wealth of basic and applied chemical technology related to pyroprocessing. ANL scientists have used this expertise in analyzing and solving processing problems.

Pyrochemical processes are being developed to recover TRU actinides as a group from refractory oxides, metals, slags, and salts and to separate them from unfissioned uranium, fission products, structural and cladding metals, ceramic materials, halide salts, and ash. Recovering the TRU elements as a group will protect the product from being diverted for use in weapons. The emphasis is on minimizing wastes through reagent recycling and the production of compact, inert waste forms.

Laboratory-scale development and testing of pyrochemical processes have been completed with actual and simulated spent metal and oxide reactor fuel and with several important residues from defense programs. Engineering-scale experiments have been completed with simulated spent metallic fuel and have begun with simulated spent oxide fuel. Demonstration of the process with actual spent metallic fuel is scheduled for the near future.



Technicians assemble a device that will enable an advanced nuclear reactor to burn nuclear waste as fuel, thereby reducing the volume of waste produced and the number of years it must be stored.

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Liquefied Gaseous Fuels Spill Test Facility

Testing Hazardous Fluid Spills

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What happens when a truck filled with liquid hydrogen overturns and explodes? How would you put out the fire? How fast could a dangerous vapor cloud travel? Could the cloud be contained before it reached populated areas?

The Liquefied Gaseous Fuels Spill Test Facility, located in a remote area of the Nevada Test Site, can provide answers to such questions. This $79 million facility is the only place in the nation where federal agencies and private companies can test the characteristics of hazardous liquids and gases.

At this facility, hazardous fluids are released under carefully controlled conditions to determine patterns of dispersion, test mitigation techniques, and develop cleanup technologies and procedures. Favorable meteorological conditions and its distance from population centers make the facility ideal for experiments of this nature.

The spill test facility is composed of large cryogenic and pressurized storage tanks, extensive piping, control systems, and a data recording building. Controlled spills of hazardous liquids are set up, observed, and measured for flammability, dispersion of vapors, and other effects. Typically, a measured volume of hazardous fluid is discharged onto a specially prepared surface. Diagnostic sensors are placed up to 16 miles downwind to collect data. The spill is carefully monitored and controlled from the data recording building. This command post, located 1 mile from the spill area, enables observers to collect data safely.

The spill test facility is available for use by federal agencies and private industry on a user-fee basis. An environmental impact statement that has been approved allows an agency or company to test any of 30 chemicals without having to prepare additional impact statements. These chemicals are ammonia, bromine, butane, carbon dioxide, chlorine, chlorosulfonic acid, cyclohexane, ethylene, fluorosulfonic acid, hydrazine, hydrogen chloride, hydrogen fluoride, hydrogen sulfide, liquid natural gas, liquid propane gas, methane, methylamines, methyl trichlorisilane, nitrogen tetroxide, oleum, phosgene, phosphorous oxychloride, phosphorous trichloride, propane, silicon tetrachloride, sulfur dioxide, sulfur trioxide, titanium tetrachloride, trichlorosilane, and unsymmetrical dimethyl hydrazine.

Specialized equipment enables researchers to control the spill of a hazardous liquid and then observe and measure effects, including flammability and dispersion of vapors.

Coal Cleaning with Micronized Magnetite

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Transferring the Micro-Mag Process to Industry

The Pittsburgh Energy Technology Center (PETC) has developed and patented an advanced heavy-medium cycloning method for separating clean coal, specifically very fine coal, from refuse (i.e., noncombustibles). This method — called the Micro-Mag process — is licensed to and marketed by Custom Coals International, located in Pittsburgh. DOE's Clean Coal Technology Program also awarded a grant to Custom Coals to conduct a full-size demonstration of this process in conjunction with Custom Coal's own complementary technology.

The process uses micronized magnetite for the heavy medium. The magnetite is ground to a substantially smaller size (less than 5 micrometers [μm], or about the size of paint pigment) than is used in conventional cyclone separation processes. Use of very fine grained magnetite allows coal fines as small as 20 μm to be cleaned. Industry had previously been limited to cleaning coal no finer than 150 μm in heavy-medium processes.

The micronized magnetite is then mixed with water to a desired specific gravity — typically between 1.3 and 1.6. Raw coal fines are added to this aqueous medium, and the mixture is pumped into a small-diameter cyclone. The high gravity forces attained in the cyclone produce coal that is low in ash and pyrite. After dewatering and drying, the coal is ready for use.

For the cyclone separation process to be economical, the magnetite must be recovered for reuse. As magnetite and coal particles decrease in size, it becomes more difficult to recover the micronized magnetite. However, using magnetite that is proportionately finer than the coal leads to a more homogeneous and stable suspension. A stable suspension improves the separation of coarser coal particles and extends the effective range of cleaning to include 20-μm particles.

Micronized-magnetite cycloning is similar to conventional heavy-medium processes and thus can be retrofitted at coal preparation plants without major modifications, expansion, or increased capital costs. This process will enable coal users to buy local coals that require extra cleaning rather than pay for transporting coal that meets needed specifications with little or no beneficiation.

Custom Coals is marketing this process in the United States and in former Communist Bloc countries. For example, it has signed an agreement with the government of Poland to design, construct, and operate two commercial cleaning plants that will incorporate this process. Beneficiated coal processes in these plants will remove about 75% of the ash and 90% of the pyritic sulfur from locally mined coal. Such reductions will help alleviate the acute air pollution in Poland's Upper Silesian region.

Further research and development on this process will be conducted at PETC by AMAX Research and Development Corporation of Golden, Colorado, under a cost-shared contract.

Bacterial Degradation of TNT

Cleaning up Toxic Munitions Sites

A family of "bugs" able to desorb and degrade trinitrotoluene (TNT) is being put to work cleaning up old munitions production sites, some of which date back to World War I. The bugs are actually a group of bacteria isolated by a researcher at Oak Ridge National Laboratory, who discovered them while studying a site contaminated with trichloroethylene (TCE). A novel aspect of this discovery is that the bacterial group was isolated from amoebas and bacteria that live together in the same environment.

Researchers entering a site where toxic waste is present first isolate amoebas collected from the site. They then isolate the bacteria from within the amoebas. These bacteria often have useful properties, such as the ability to degrade certain contaminants.

A solution of the desorbing and degrading bacteria is circulated through TNT-contaminated soil. Desorption and degradation of the TNT is indicated by color changes in the wash fluid. The pathway by which the bacteria break down contaminants is not yet defined; however, test results indicate that they do an excellent job of degrading TNT.

The bacteria also produce dispersants, a capability that may prove useful in detaching contaminants from soil and in cleaning up oil spills.

The bacteria have been licensed to EODT Services, a firm headquartered in Oak Ridge, Tennessee. The company plans to exploit the bacteria in a biologically based technology for converting TNT into nontoxic materials.

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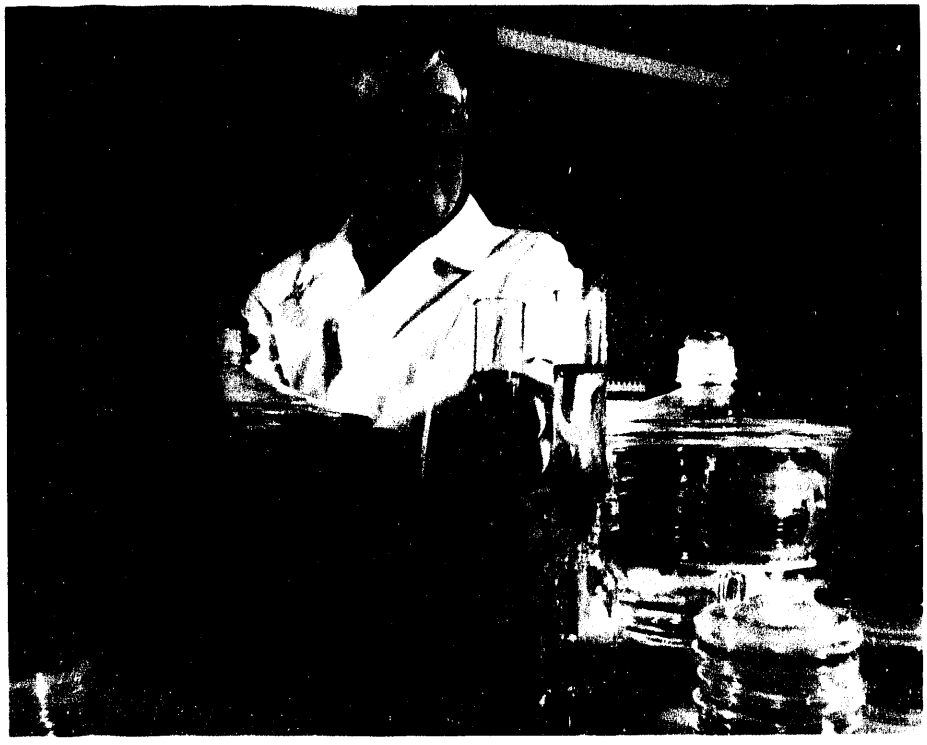

A researcher adjusts a laboratory-scale bioreactor containing bacteria that desorb and degrade TNT. Desorption and degradation of the TNT are indicated by a color change.

Microbial Remediation of Hydrocarbon Vapors

Using Bacteria to Remove Hydrocarbons from Subsurface Soil

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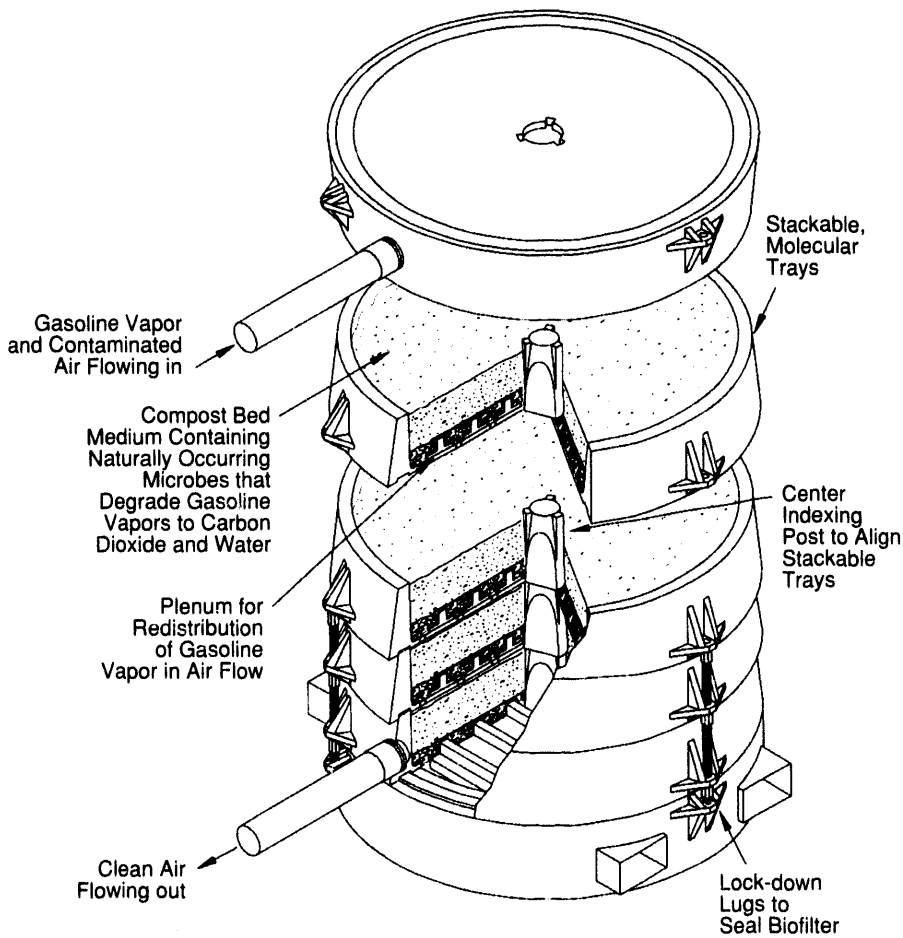
Scientists at Idaho National Engineering Laboratory collaborated with engineers at EG&G Rotron of Saugerties, New York, to develop the Biocube Aerobic Biofilter™, a tool that degrades hazardous hydrocarbon vapors removed from subsurface soil and also controls odors. Developed through a cooperative research and development agreement, this tool received an R&D 100 Award from *R&D Magazine* in 1993.

Leaking underground petroleum tanks (like those under gas stations) are a significant source of environmental problems in the United States. The Biocube biofiltering process, now commercially available, makes use of a group of microorganisms that occur naturally in compost to remediate hydrocarbons emitted from leaking tanks.

More specifically, the process is used in conjunction with the vapor-vacuum-extraction process, which draws gases that emit hazardous petroleum vapors from subsurface soil to the surface. As the gases are drawn, they pass through the modular Biocube, which consists of trays of compost. In those trays are the microorganisms that break down the hydrocarbon vapors so the products (carbon dioxide and water) can be safely released to the environment. Because this effective natural process can be slow, the Biocube optimizes environmental conditions like moisture, temperature, and contact between the microbes and the vapor. The microorganisms are therefore able to do their best work. The system design also prevents channeling, the condition by which gases escape bioremediation by moving along pathways that bypass the treating medium within the biofilter.

The Biocube can also be used for treating emissions from industrial and chemical processes and environmental processes like treatment of air-stripper off-gases. It produces no hazardous wastes, is an economical and efficient alternative to other remediation methods, and can be configured to fit the needs of specific projects.



The Biocube Aerobic Biofilter™ holds trays of compost containing naturally occurring microorganisms that degrade hydrocarbon vapors to carbon dioxide and water.

Miniature Elastic Backscatter Lidar

Using a Portable System to Monitor Air Pollution

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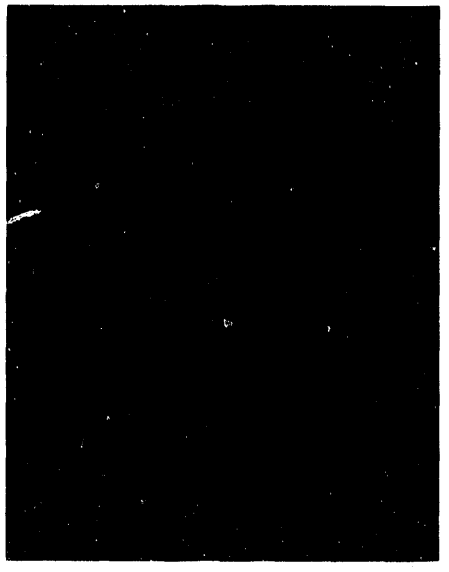
The miniature elastic backscatter lidar system analyzes information on particulate matter in the atmosphere.



Los Alamos National Laboratory (LANL) has developed the miniature elastic backscatter lidar to help detect, measure, and analyze airborne pollutants. This miniature lidar can also track key physical and chemical processes in the atmosphere.

All light detection and ranging (lidar) systems use pulses of light much as radar uses radio waves. Lidar sends a pulsed laser beam into the atmosphere. Gases, aerosols, and particles in the atmosphere reflect the laser light; a telescope collects this return signal and focuses it onto a detector. This system allows scientists to scan the atmosphere and then map concentrations of airborne pollutants.

The LANL miniature lidar improves the usefulness of lidar data and helps researchers understand events leading to severe pollution. Data collected by this device help scientists develop a three-dimensional "movie" of atmospheric motion and turbulence, wind and weather behavior, and chemical reactions involving pollutants.

The miniature lidar is the only portable, compact system capable of performing rapid-volume aerosol density scans of 30° azimuth by 30° elevation, in 0.5° steps, in approximately 70 seconds. This system has a range of 10 kilometers and operates off a 3-kilowatt generator. It fits in three cases that meet airline cargo requirements, and it needs only two people for setup and operation. Although the system is small, it contains a complex subsystem: laser, positioning system, receiver hardware, data acquisition computer, and computer control and analysis software.

The device is a totally integrated program package that not only controls all functions of the data acquisition process but also provides several data analysis routines. Although it is difficult to represent three-dimensional data in two dimensions, IBM has overlaid aerosol data collected by the device onto topographic maps to show how geographical features such as mountains and human-created characteristics such as traffic patterns affect aerosol movement.

Although the miniature lidar is used primarily for atmospheric modeling, the system shows promise for detecting forest fires, tracking hazardous smoke from chemical fires, monitoring illegal drug manufacturing operations, and aiding nuclear nonproliferation by searching for emissions related to weapons production.

The miniature lidar is the first system capable of collecting data anywhere in the world on a moment's notice. It has traveled to Mexico City to assist in a 3-year pollution study and to Barcelona, Spain, to quantify the effects on air quality of ground-transportation restrictions imposed during the Olympics; and it has been used in Albuquerque, New Mexico, to identify sources of local pollution.

The Laboratory and IBM are working with Santa Fe Technologies of Albuquerque on a commercial version of the system specifically configured for air pollution monitoring. The miniature elastic backscatter lidar received a 1993 R&D 100 Award from *R&D Magazine*.

Rad Rover II: Mobile Monitor of Contamination

Creating Detailed Maps through Linkage to Navstar Satellites

Westinghouse Hanford Company has equipped a farm tractor with a computerized radiation detection system. Called Rad Rover II, this second-generation mobile unit monitors surface and subsurface contamination. It has mapped the precise locations of chemical and radioactive contamination on the 1,450-square-kilometer DOE Hanford Site. This work has proved critical because earlier records are sometimes inaccurate or unavailable.

Until the first Rad Rover was developed, groups of 10 or more technicians had to survey the Site by foot, carrying small radiation detectors and writing down data by hand. The mobile monitor was developed to improve worker safety and increase mapping accuracy and efficiency. It can survey in about 5 minutes an area that would take several hours to survey by conventional methods.

The Rad Rover II can detect more types of contamination in smaller amounts than its less sophisticated prototype. It has a double cab, with room for both a driver and an instrument operator. Climatic and environmental controls ensure the safety and comfort of occupants. While the vehicle travels at about 2 miles per hour, it can survey a 9-foot-wide ground area. It stores data in an onboard computer, which is used to generate a variety of maps.

The radiation detection system consists of three plastic sandwich-type detectors mounted in front of the tractor on hydraulically controlled booms. An alarm warns occupants if the vehicle enters an area where radiation levels are unacceptably high.

The Rad Rover II is linked to Navstar satellites that track it and pinpoint its position to within 10 feet anywhere on the Hanford Site. The linkage allows the Rad Rover to create highly accurate maps with enhanced graphics that clearly delineate areas containing surface and subsurface radioactive material. ■

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Radiation detectors on the front boom of the Rad Rover II are linked with the Navstar satellite system to generate accurate maps of contamination on and below the surface of the Hanford Site. The mobile monitor allows detection and mapping to be accomplished quickly and safely.

Integrated Management and Disposal of Waste

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Containment of Hazardous Materials

A research team, led by Princeton Plasma Physics Laboratory (PPPL) and including two major U.S. industrial firms (Edison Welding Institute of Columbus, Ohio, and Brush Wellman, Inc., of Cleveland, Ohio), has devised containment and closure technologies applicable for managing a wide range of hazardous wastes. This program, which includes efforts to process large metal components and develop welding techniques for joining thick plates, has resulted in a series of patent applications.

The containment method is suitable for storing nuclear, biological, and chemical materials. For nuclear materials, the container-closure system addresses the needs to secure and store the hazardous material at a local utility, transport it to a medium-term storage facility or processing operation, and store it at a repository for the long term. For applications involving biological and chemical materials, the container can be reused after closed incineration.

The containment material is a precipitation-hardenable, copper-based alloy with an adjustable combination of physical strength and conductivity. The closure weld employs an age-hardenable, copper-beryllium alloy as a weld filler. The process, successfully demonstrated in structural applications, exhibits high physical integrity.

The threaded open end of the container body interfaces with a threaded lid; both container and lid are compatible with standard remote-manipulation techniques and equipment. The first-level containment barrier is a mechanically actuated, metal-to-metal seal that can be resealed repeatedly. As the lid assembly is rotated into the container, the metal-to-metal seal engages the container seal surface and, through plastic deformation of the seal material, establishes a series of concentric metal-to-metal seals. The seal designs are characterized by multiple, concentric, high-vacuum-quality, metal-to-metal barriers that can be reestablished as needed.

Once the mechanical seal is complete, the weld between the lid and container body forms a high-integrity container closure. The closure welding process is a metal arc-welding technique optimized for maximum mass transfer and arc stability. The process was developed to use automated equipment and is compatible with standard remote operation. As the weld filler, the process uses a copper-beryllium alloy that is slightly beryllium-enriched over the container body alloy. The closure is a 1-inch-deep, five-pass, continuous-bead weld.

Postweld heat treatment enhances the physical integrity and thermal and electrical conductivity of the weld filler. Postweld processing largely restores the strength and conductivity of the heat-affected zone to the pre-weld condition, such that the physical properties of the weld region approach those of the surrounding material. The weld zone exhibits 80% of the strength of the parent material.

The procedure for securing the hazardous material is completely compatible with remote operations. The waste is loaded into the container body, which is integrated with a fixture to guide waste loading and protect the threaded areas and metal-to-metal seal surface. Next, the lid-seal assembly is

threaded onto the body of the container. The lid weld-preparation edge, aligned with the weld-preparation edge of the container, forms the closed-gap geometry required for the eventual closure weld. The integrity of the metal seal is verified by means of a tracer gas. At this stage, the container contents can be retrieved for inspection, or the container can be opened for additional filling and resealing.

The secured container is rotated into the optimal position for the closure weld. To complete the process, a heat-treatment fixture is attached to the container, and the properties of both the weld bead and heat-affected weld zone are enhanced.

Both the containment technology and the closure weld technique are available for licensing.

Water Cannon

Using Pressurized Water to Dispose of Radioactive Waste

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The water cannon, or rubblizer, was developed for the mining industry by Quest Integrated, Inc., of Kent, Washington. It is used to fracture rocks and break up materials in areas where the use of explosives could be hazardous. A multicontractor team coordinated by the Westinghouse Hanford Company is investigating whether the water cannon can be adapted to break up radioactive waste stored as saltcake into manageable fragments that could be further processed and disposed of.

The team placed a water cannon attached to a robotic arm inside a mock-up of a waste storage tank. The simulated tank was installed in a demonstration test bed at the DOE Hanford Site. The cannon has a spring-loaded recoil system designed to reduce stress on the robotic arm when the cannon is fired. When a valve in the cannon opens, which takes 2 milliseconds, a pint of water pressurized to 40,000 pounds per square inch is released. This water, traveling at 1,000 to 2,000 feet per second (up to three times the speed of sound), slams into the waste. Under normal operating conditions, the process can be repeated about every 10 seconds.

Demonstration tests have shown that despite the great pressure, the water blast does not damage the steel interior of a waste tank, even though it will remove caked material from pipes and other hardware very effectively. With only minor modifications, the water cannon can be used in radioactive environments. It can also be used in flammable environments because it does not generate heat or sparks.

In tanks in which the addition of water would pose a problem, the rubblizer can be modified to use liquid carbon dioxide. Since the liquid immediately evaporates into a gas, the carbon dioxide can be drawn off by the air system. This step ensures that no additional liquid is added to the waste in the tank.

Gel-Bead Ion-Exchange Technology

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Research chemist examines microspheres that function as inorganic ion exchangers. The small, porous beads remove radionuclides and other contaminants from liquid waste streams.

Cleaning up Liquid Radioactive Waste Streams

Researchers at Oak Ridge National Laboratory (ORNL) have modified a process previously used in the production of nuclear fuel, adapting it for liquid-waste treatment. The method works on the same principle as in-home water-purification systems.

In-home water purifiers remove metals such as calcium and magnesium from drinking water by means of devices called "ion exchangers." The new method gives the ion-exchange technique a much higher degree of utility through an entirely new form of exchange material.

The ORNL scientists produce inorganic ion exchangers in the form of small, highly stable, porous microspheres, or beads, that resist clumping. The beads are made of hydrous metal oxides and phosphates of zirconium, titanium, iron, aluminum, or other appropriate metals. By giving up nonhazardous ions of sodium, potassium, or hydrogen in exchange for the ions of hazardous materials in solution, the exchangers transform highly radioactive solutions into low-level liquid waste that can be handled more easily and disposed of more safely.

As an example, to reduce the concentrations of radioactive contaminants resulting from laboratory experiments, the beads are placed in a wire-mesh basket that fits inside a tubelike canister. High-level radioactive solutions are poured into the canister and allowed to permeate the beads, which attract, concentrate, and remove radioactive materials.

This method permits treatment of radioactive solutions at the source. Once the beads are loaded with radionuclides or other waste, the liquid can be poured off, and the beads dried and sealed in the canister for disposal. The process removes more than 95% of some radionuclides, greatly reducing the volume of high-level waste that must be sent to waste-management evaporators for further processing. The sealed canisters containing the dried beads can be placed in waste-storage vaults or encased in concrete. The beads can first be made into a stable glass through a process called vitrification. This treatment significantly reduces the possibility of contaminants leaching from the beads if the canisters are later breached.

The beads have already proven more successful than conventional powdered or granulated material in treating many waste streams in ORNL laboratories. The ORNL-produced microspheres can also be tailored to suit the type of waste targeted for treatment. For example, natural leaching of uranium from the ground into rivers and their tributaries results in its presence in seawater. Hydrous titanium oxide has proven effective in removing uranium from seawater as well as from other liquid waste streams.

If an effective exchange material for the targeted waste already exists, the ORNL development team prepares beads of the proper ingredients. ORNL researchers are also performing extensive laboratory work to identify exchange materials for treating a variety of radionuclides.

VOtect™ Infrared Fiber-Optic Sensor

Helping Industries Detect Hydrocarbons

VOtect™ is an infrared fiber-optic sensor system developed at Pacific Northwest Laboratory (PNL) to protect humans and the environment by detecting vapors emitted by hydrocarbons such as gasoline, diesel oil, and natural gas. The sensor system is small, lightweight, and easily portable.

The VOtect sensor is basically a hand-held probe consisting of a collimating lens and a retroflective mirror. Infrared-transmitting optical fibers route light from a laser source to the sensor. If hydrocarbon vapors are present at the probe tip, light from the laser is absorbed and detected by the sensor electronics. The higher the concentration of hydrocarbons, the higher the optical absorption at the probe tip. More specifically, the hydrocarbon concentration is directly proportional to the net decrease in infrared radiation or signal intensity.

Two relatively new electrooptical technologies made VOtect possible. The first is commercially available, infrared-transmitting optical fiber made from zirconate glass. Conventional optical fiber, which is made from silica glass, cannot transmit light at wavelengths beyond 2 micrometers. However, detection of hydrocarbons requires good optical fiber transmission at wavelengths between 3 and 4 micrometers. The new fiber transmits effectively at wavelengths from the visible to the near infrared spectral region (0.5 to 5 micrometers). The second technology is an inexpensive infrared helium-neon laser source with an emission wavelength of 3.39 micrometers. This wavelength permits detection of vibrations resulting from the stretching of hydrogen-carbon bonds in hydrocarbon compounds.

The Laboratory originally designed the VOtect technology to monitor hydrocarbon contamination of soil and groundwater at hazardous waste sites. However, the sensor has several other environmental and industrial applications. It can be used at waste sites to monitor the atmosphere, and it can monitor combustion by-product emissions for environmental or diagnostic purposes. It can detect explosive vapors at factories and, by comparing the detector signal with a threshold value, it can trigger an alarm, thus enhancing worker safety.

Because VOtect incorporates fiber optics, it is immune to electrical interference and well suited and safe for use in flammable or explosive environments like mines that must be monitored for methane concentrations. VOtect can also be used for real-time process control and process stream monitoring in industrial plants, where the monitoring of hydrocarbon vapor concentrations is important.

VOtect's performance has been demonstrated successfully in the laboratory with a variety of optical absorption sensing schemes (i.e., photoacoustic, Fourier transform interferometry, and conventional narrow-band infrared absorption) for a number of gases. PNL invites inquiries from industrial firms interested in commercializing this technology.

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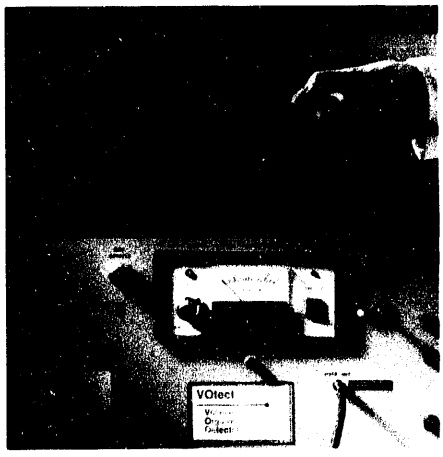
The VOtect™ sensor could be used to detect hydrocarbon vapors in automobile exhaust and in flammable or potentially explosive environments such as coal mines.



Advanced NO_x Control Concept for Coal-Fired Boilers

Using the CombiNOx Process to Reduce Nitrogen Oxide Emissions

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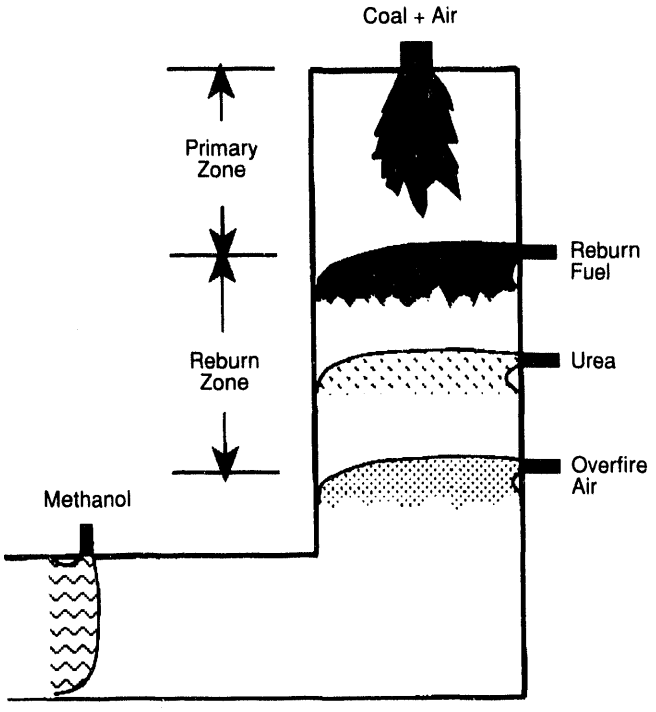
Coal-fired boiler systems emit nitrogen oxides (NO_x), which are precursors to acid rain and contributors to the formation of smog. Following fossil fuel combustion, NO_x are traditionally removed by a postcombustion technology called selective catalytic reduction. Although this catalyst technology is effective, it is costly and has not been applied to coal-fired boilers that burn high-sulfur coal.

Under contract with the Pittsburgh Energy Technology Center, Energy and Environmental Research Corporation (EER) of Irvine, California, developed a process to reduce NO_x emissions. This process, called CombiNOx, could substantially reduce NO_x at costs lower than those of selective catalytic reduction.

The CombiNOx process exploits an EER-patented process called advanced reburning, in which a selective noncatalytic reduction agent is injected along with the reburn fuel. Downstream of the reburn zone, more air is added to complete the combustion of unburned products. Methanol is then injected into the flue gas downstream of the reburn system to convert NO_x to nitrogen dioxide. The nitrogen dioxide is subsequently removed in a wet limestone sulfur dioxide scrubber under slightly modified conditions.

CombiNOx combines three NO_x control technologies: reburning, selective noncatalytic reduction, and methanol injection. These processes are integrated to take full advantage of associated chemical reactions. EER evaluated each of the NO_x control technologies, separately and combined, in both bench- and pilot-scale tests and then in simulated full-scale tests. The integrated tests were conducted at EER's 10-million-Btu-per-hour tower furnace, which compares well with full-scale utility boilers. Finally, the economic aspects of the integrated process were analyzed according to methods given in the Electric Power Research Institute's *Technical Assessment Guide.*

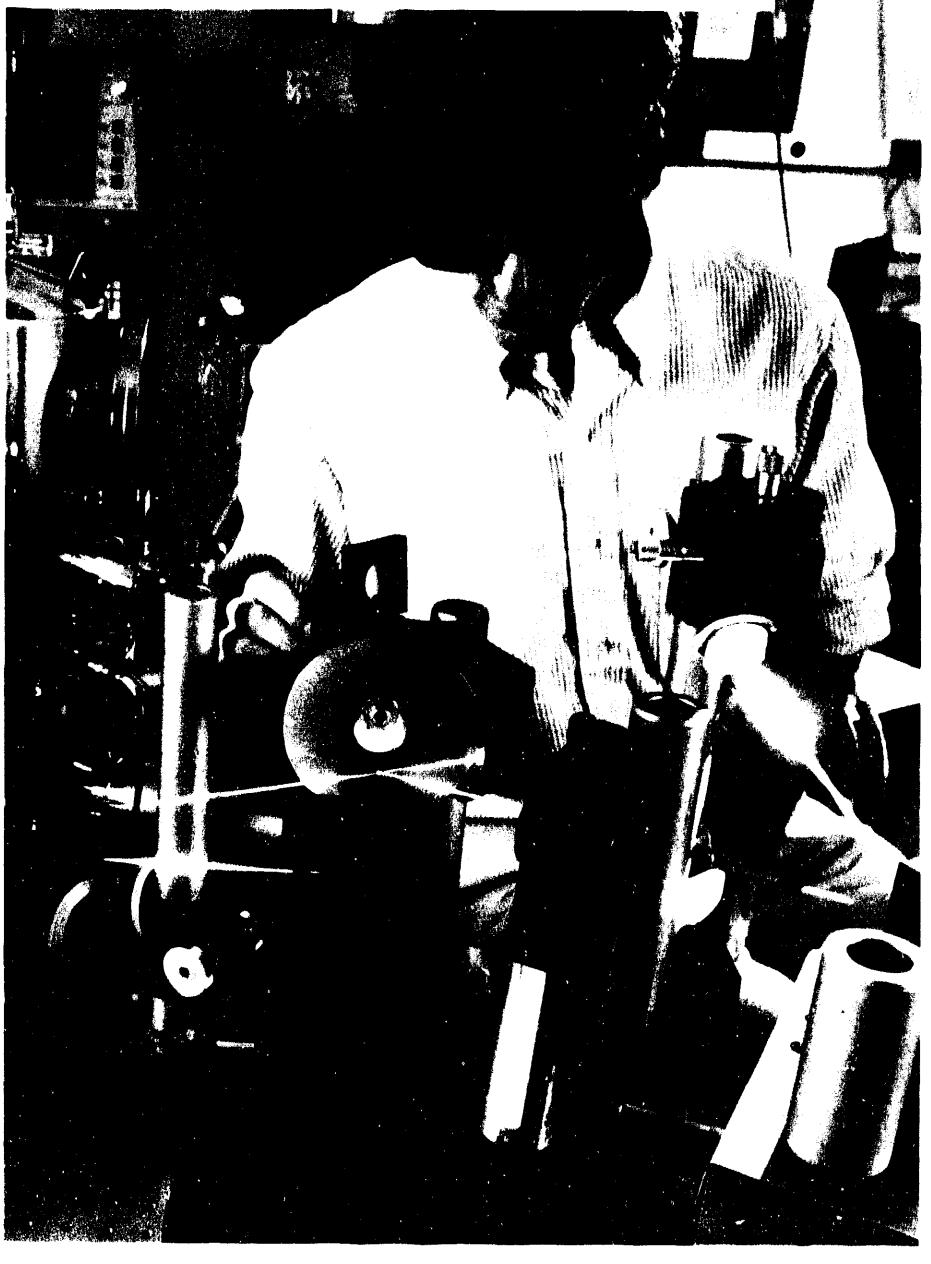
In pilot-scale tests, CombiNOx reduced NO_x emissions by up to 92% at a cost that was about 25% lower than that for selective catalytic reduction. The CombiNOx process did not corrode or otherwise adversely affect the boiler or its operation. The process promises to be a relatively low cost alternative to selective catalytic reduction for coal-fired boiler operators.



The CombiNOx process, which reduces nitrogen oxide emissions from coal-fired boilers, integrates advanced reburning followed by air and methanol injection.

Advanced Materials and Advanced Materials Processing

The development of new materials and new ways to process them is essential to progress in all technological areas. Improvements in advanced ceramics, semiconductor deposition technologies, coatings and lubricants, hard-surfaced polymers, advanced ceramics, and nondestructive evaluation techniques can result in products that cost less and perform better. Use of these advanced materials and processes is also critical for any companies wanting to maintain their competitive edge in the global marketplace.



A researcher at Lawrence Berkeley Laboratory is working with a hard disk mounted on a Raman facility. For more information, see the writeup on *Coatings to Protect Computer Hard Disks* on page 144.

Trace-Impurity Analysis for Advanced Integrated Circuits

Using Synchrotron Radiation to Control Microcontamination of Silicon Wafer Surfaces

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Being able to analyze for trace impurities on silicon wafer surfaces is essential to the development of competitive integrated circuit technologies. Even at very low concentrations, transition elements on nominally clean silicon wafer surfaces can impair the performance of the high-density circuits fabricated on those wafers. Developing the means to remove all such impurities and to test for their absence (in order to verify the effectiveness of the cleaning procedures) has become increasingly important.

Current methods for chemically identifying and quantifying impurities on or near wafer surfaces include grazing-incidence x-ray fluorescence techniques, which rely on conventional x-ray sources. However, these sources fail to deliver the high-quality radiation needed for analyzing the efficacy of future generations of silicon-integrated circuit processes.

The results of benchmark experiments at the Stanford Synchrotron Radiation Laboratory (SSRL), a division of the Stanford Linear Accelerator Center, indicate that grazing-incidence x-ray fluorescence methods can be extended to meet the near-term needs of the leading-edge silicon circuit industry. This capability can be provided even by second-generation synchrotron sources such as that at SSRL when appropriate monochromator, detector, and sample handling technologies are employed.

The technique of total reflection x-ray fluorescence — in which x-rays are reflected from a surface below the critical angle, and the fluorescence resulting from impurities on the surface is measured — has recently been applied to the detection of trace impurities on silicon wafers. Even with the best conventional x-ray equipment, this technique is limited by the background from scattered radiation caused by the lack of collimation and polarization of standard high-power x-ray tubes. The high degree of collimation and polarization supplied by synchrotron radiation greatly reduces the background from scattered radiation. Experiments with an SSRL "wiggler magnet" source have shown that the detection limit for impurities that constrain the performance of advanced integrated-circuit technologies can be improved by up to a factor of 100 over the current state of the art.

Because of strong interest from local industry, SSRL has proposed the development of a dedicated facility, which would include a specialized monochromator and an automated end station housed in a class 10 clean room. Ancillary wafer-cleaning facilities would also be required. This program is using the expertise of SSRL scientific staff as well as leading researchers from Hewlett-Packard Laboratories of Palo Alto, California; Intel Corporation of Santa Clara, California; and Fisons, Inc., of San Carlos, California.

Solid-Phase Reactants Condensed from Gases

Producing High-Quality Oxide Films on Substrates

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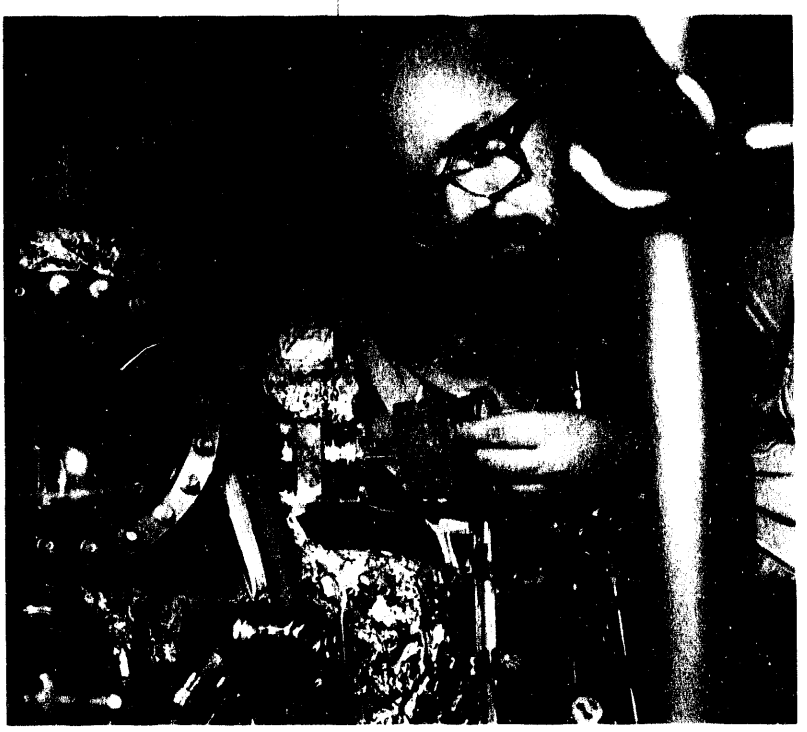
Scientists at Brookhaven National Laboratory (BNL) have developed a new method for growing thin films from a variety of inorganic compounds on semiconductor substrates. The procedure can be easily integrated with a variety of surface processing techniques, such as photon-induced chemical vapor deposition or etching. It may also be applicable to growing films on high-critical-temperature superconducting oxides.

The technique employs a cryogenic cooling system to condense gas-phase reactants normally used in conventional reactive deposition schemes onto the substrate surface. Here they are used as a solid reactive matrix for physical vapor deposition. For example, aluminum was deposited onto solid oxygen and ammonia layers to make thin oxide and nitride films, respectively, on a gallium arsenide substrate. Stable, atomically well-defined interfaces were formed between the gallium arsenide and the oxide and nitride films.

The use of solid-phase reactants condensed from gases minimizes the use of such gases and provides opportunities to control thin-film and interfacial structure and composition at the atomic level.

The advantages of this method are that it controls interfacial and thin-film properties; facilitates the use of thermally unstable reactants; allows minimal use of toxic and environmentally sensitive reagents; permits easy integration with electron-, ion-, and photon-beam processing; and allows easy incorporation in molecular-beam and electron-beam evaporation equipment.

The BNL process provides the microelectronics industry with an economical, effective technology for the fabrication of thin films. It also uses smaller quantities of reactant gases than do existing technologies, a difference that may be of environmental significance for industry. ■



A researcher adjusts a cryogenic cooling system to prepare for the production of an insulating film by reactive deposition of aluminum.

Commercial Production of Phase-Pure Superconductors

Fabricating Superior High-Temperature Superconductors at Lower Cost

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A unique processing technique allows production of pure, high-temperature, superconductor powders at significant cost and energy savings.

An efficient fabrication technique recently developed by Argonne National Laboratory (ANL) is being used for the commercial production of pure, high-temperature superconductors with superior properties. The technique enables development of a new class of materials that will have many practical applications, resulting in significant savings in both energy and money. Potential applications for high-temperature superconductors include the generation, storage, and transmission of electricity, as well as magnets for medical imaging.

The ANL fabrication technique allows rapid, single-step production of phase-pure superconductors at lower temperatures. In conventional processing, mixed salts are ground intermittently as they are heated to about 1,650°F for more than 100 hours. The grinding media introduce undesired contaminants. Also, the gaseous species released when the salts are heated react with the superconductor to form nonsuperconducting compounds that lower the current-carrying ability of the final product. These conventional processes are time-consuming and result in coarse particles that lead to poor electrical and mechanical properties.

In ANL's new process, mixed salts are first heated under reduced total oxygen pressure at 1,470°F for 4 hours and then cooled in ambient-pressure oxygen. Because this single-heating process results in phase-pure powder, total processing times are drastically reduced, and the low processing temperature and short time produce small, uniform particles. Evolved gases are removed rapidly and efficiently, with no need for intermittent grinding. Compared with conventional techniques, this new technique considerably improves the quality of the superconductor powder and significantly reduces energy consumption during powder production.

Conventional techniques also produce superconductors with very low (about 300 amperes per square centimeter [A/cm^2]) current-carrying ability, which drops drastically when a small, external magnetic field is applied. However, samples fabricated by the new, improved technique show high (about 1,000 A/cm^2) current-carrying ability, and the drop in current-carrying ability in the presence of external magnetic fields is very small.

The unique ANL technology was transferred to scientists from Superconductive Components, Inc., of Columbus, Ohio, a company that manufactures and sells the phase-pure powders.

A patent on the technique was issued in February 1992. The invention won a 1993 R&D 100 Award, given annually by *R&D Magazine* to the 100 most significant technical products of the year.

Advanced Light-Absorbing Material for Optical Systems

New Applications for Carbon-Carbon Composites Used in Space Probes

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Researchers at Oak Ridge National Laboratory (ORNL) have developed an improved light-absorbing material for use on devices ranging from telescopes and cameras to advanced weapon systems. The broadband optical absorber represents an entirely new application for low-density carbon-carbon composites currently used as thermal insulation on deep-space probes.

Light-absorbing materials are used in optical devices to reduce the amount of reflected light within the equipment. In general, less reflected light means clearer images. Conventional optical materials are often fragile and cannot be shaped to a required form before being applied to a surface. For instance, in coating the barrel of a telescope, the entire instrument must be dipped into a solution so an electrical process called anodization can produce a thin coating on the barrel. If this brittle coating is touched or subjected to vibration, it may flake off.

The new absorber, composed of multiple layers of interwoven carbon fibers, is lightweight, rigid, and three-dimensional in structure. If a layer is scraped or chipped off, the material underneath is exactly the same; therefore, the absorber is virtually immune to surface damage. Advantages offered by the new broadband optical absorber include the following:

- It can be produced in quantity and then cut and shaped manually or precisely machined to fit the equipment.
- The large, uniform pores between the carbon fibers of the broadband absorber allow much longer wavelengths of light to be captured than do the relatively small openings of etched or anodized surfaces.
- Compared with conventional materials, the new absorber is not as apt to deteriorate when exposed to vibration, moisture, radiation, or extremely high temperatures.

High-tech weapons locate incoming warheads by detecting infrared wavelengths emitted when the missiles become heated as they enter the earth's atmosphere. Because the broadband optical absorber can capture longer, cooler wavelengths than conventional materials, system detectors that used the new absorber would be able to detect a missile earlier in its descent.

Other devices that could benefit from the broadband optical absorber include infrared night-vision viewers and laboratory optical equipment in which laser beams are used.

The original development of carbon-bonded, carbon-fiber thermal insulation was supported by DOE's radioisotope thermal generator program. Optical development work was supported by the U.S. Army Strategic Defense Command under an interagency agreement with DOE.

Researcher inspects sample forms made from the broadband optical absorber, a new type of light-absorbing material for use on devices ranging from telescopes and cameras to night-vision viewers.

Laser Processing Consortium

Promising Free-Electron Laser for Industrial Processes

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Although the Continuous Electron Beam Accelerator Facility (CEBAF) is not yet in operation, efforts of facility scientists to develop and transfer technology have already proven fruitful. An Industrial Advisory Board, formed in 1991 to identify technology transfer opportunities and obtain industry advice, identified CEBAF's superconducting radio-frequency cavities as a promising driving mechanism for high-power free-electron lasers (FELs). Such lasers could provide tunable, monochromatic laser light for industrial research and development.

Recognizing the commercial potential of a cost-effective, high-power, versatile FEL-based industrial laser processing system, CEBAF and its industrial partners formed the Laser Processing Consortium.

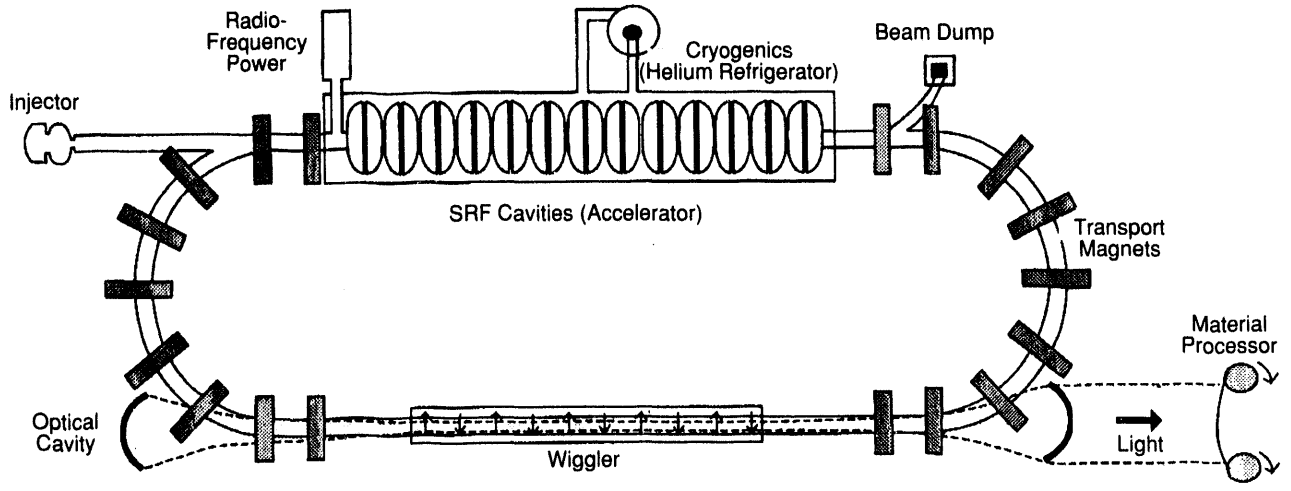
The United States, which developed both the FEL and superconducting radio-frequency technologies, now enjoys a substantial lead in these areas. Other nations, notably Germany and Japan, are also considering use of FELs for industrial processing. The capabilities and facilities currently available at CEBAF offer the fastest, most economical route to large-scale industrial processing by means of FELs.

The proposed FEL will deliver more than 20 times the average power previously achieved by the most widely used high-power excimer laser. It will offer industry tunability across the entire wavelength band of interest (mid-infrared to deep ultraviolet).

Consortium members anticipate that the principal impacts of such a laser will be in the shaping and forming of materials (a $320 million industry in 1992) and in polymer processing (currently $230 billion in sales). In addition, laser processing offers an environmentally friendly alternative to wet chemical processes in many areas of industrial activity.

The Consortium is led by a number of prominent U.S. firms (DuPont, Newport News Shipbuilding, 3M, IBM, Xerox, and AT&T) and includes a group of universities (Old Dominion University, the College of William and Mary, the University of Delaware, and Hampton University) as well as CEBAF. ■

The free-electron laser brings high power and precise tunability to bear in processing industrial materials.



Plasma-Source Ion Implantation

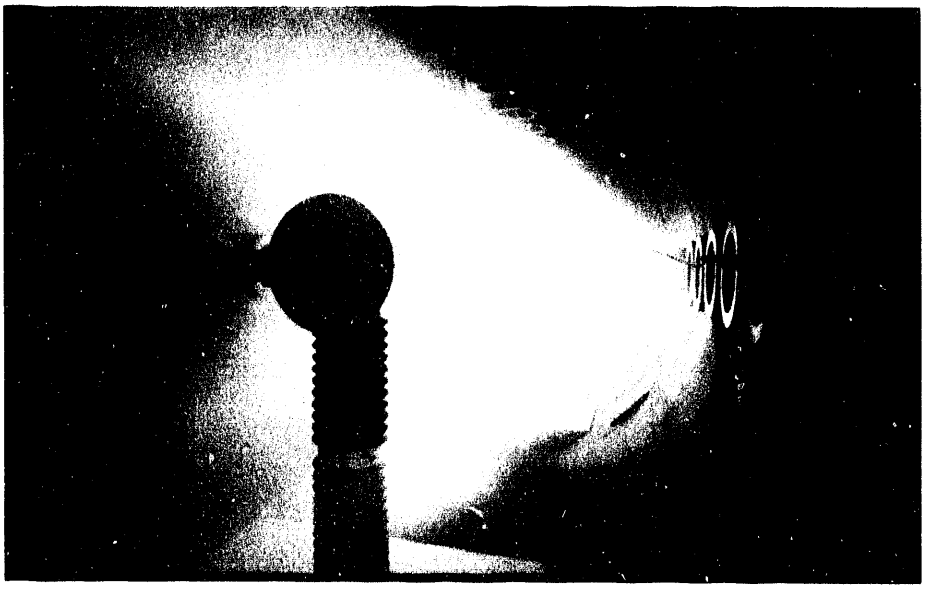
Making Longer-Lasting Components

Los Alamos National Laboratory (LANL), General Motors, and the University of Wisconsin are developing a process that will lead to harder, longer-lasting components for automobiles, aircraft, machine tools, and prosthetics. The plasma-source ion implantation (PSII) process will be a cost-effective, large-scale system that can operate in a production environment and process assemblies weighing up to several tons.

Ion implantation has traditionally been used to produce low-friction, biocompatible prosthetic joints, high-strength ball bearings, and camshafts for performance vehicles and military equipment. The PSII process offers several advantages over conventional ion implantation techniques: increased speed, reduced cost, and the ability to treat all surfaces of large objects simultaneously. In addition, PSII is an environmentally sound alternative to conventional wet electroplating processes. Because PSII does not require chemical solutions, it does not produce chemical wastes.

In the PSII process, a gas is introduced at very low pressure into a steel vacuum chamber where oscillating radio-frequency waves strip electrons from the gas atoms to create positively charged ions. Solid metal targets such as automobile components are immersed in this pool of ionized gas. Short pulses of negative voltage are then applied to the targets, resulting in the positively charged ions being accelerated and burying themselves in all surfaces of the targets. Thus, PSII is not a coating process but a way of transforming near-surface layers of products such as machine tools, ball bearings, and automobile components into an integrated, protective layer. PSII could extend the lifetimes of some products as much as a hundredfold.

At LANL, scientists are conducting large-scale tests of the process at a new PSII facility. The facility consists of an 8-cubic-meter vacuum chamber originally built for magnetic fusion research and a 100-kilovolt, 2-ampere, average-current power source originally developed for Strategic Defense Initiative work. The facility allows



A hollow aluminum shaft mounted on high-power insulators inside a vacuum chamber is bombarded by ions from the surrounding nitrogen plasma.

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surface treatment of large numbers of manufactured components at currents more than 100 times greater than those available by other methods, making the process many times faster. To assist in the testing, LANL's Center for Materials Science will prepare and characterize materials.

General Motors is identifying ways to use the technology to improve automotive manufacturing. It is also providing parts for testing, coordinating field tests, and providing test data from separate experiments at General Motors. The University of Wisconsin will continue to use its own 0.76-cubic-meter PSII chamber to explore the fundamental physics of the process and improve the concept.

In 1992, LANL and General Motors signed a $13 million, 4-year cooperative research and development agreement to develop PSII. The University of Wisconsin is participating as a subcontractor to LANL. LANL has proposed classification of PSII hardware as a DOE user facility, which would make PSII more accessible to U.S. industries and manufacturers.

New Sulfide Ceramics for High-Temperature, High-Strength Materials

Innovative Materials with Wide Application

Argonne National Laboratory (ANL) has developed a new class of ceramic materials based on sulfides instead of conventional oxides, nitrides, or borides. Sulfide ceramics display special engineered properties, stability in highly corrosive environments, and high-strength bonding to other materials. These desirable properties have encouraged development of new devices.

One such device is a large-diameter metal/ceramic seal. This type of seal is used in a new high-temperature, molten-salt bipolar battery that has to function well in a severely corrosive, high-temperature (400-450°C) environment. The "Big Three" Automakers are developing this battery for use in a high-performance electric car.

Traditional metal/ceramic seals are diffusion-bonded under high temperature and high pressure, a process that requires costly equipment and results in low production rates. Some commercial sealing approaches use gold and other precious metals. Sulfide ceramic materials use commonly available elements and are therefore less expensive than other ceramic materials. Articles manufactured with sulfide ceramics also exhibit increased durability and can be produced at high speeds at lower cost.

Sulfide ceramics are up to 20 times stronger than other metal/ceramic bonding agents and resist corrosion in high-temperature molten salts. Their bond strength and engineering properties allow formation of metal/ceramic seals with diameters almost 10 times as large as those previously achieved. Sulfide ceramics are also versatile and can be used to bond various materials, including other ceramics, graphite, and refractory metals.

In addition, sulfide ceramics can be used as a ceramic frit within a battery, as a coating to substitute for expensive metal components, and as probes and

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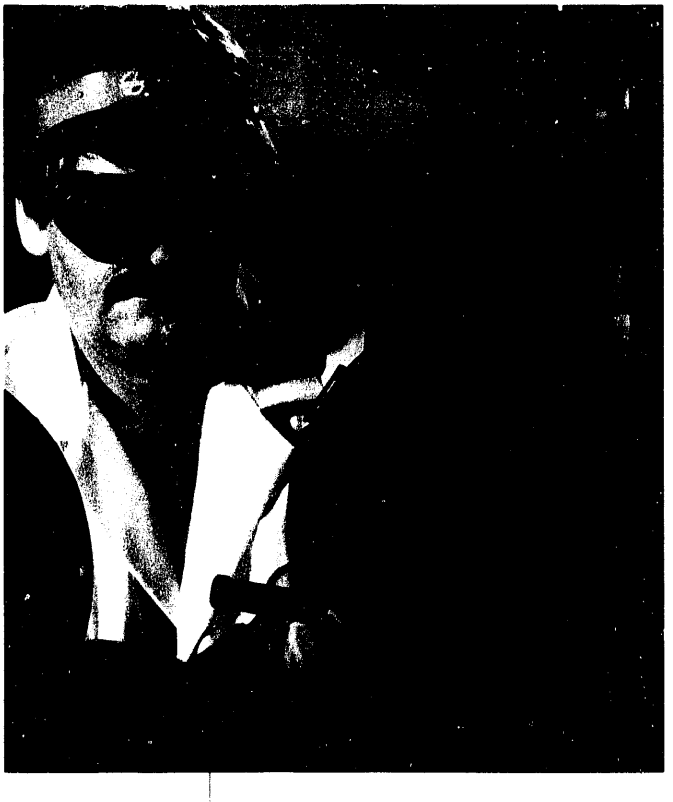

Large-diameter, metal/ceramic seals created from sulfide ceramics are used in high-power, lithium-iron sulfide, sealed, bipolar batteries. The batteries are built by stacking disk-shaped cells housed within each seal.

electrical-feedthrough components for metal production and refining processes. Components made from these materials lead to greater process safety and efficiency. Devices and processes that use molten-salt or molten-metal heat exchangers also require corrosion-resistant ceramic materials as protective coatings and structural components.

Sulfide ceramics are promising for applications requiring high-temperature corrosion resistance: aluminum production, light metal refining, nuclear fuel disposal, molten-salt heat exchangers in high-temperature solar energy convertors, space-based solar energy convertors, and liquid-lithium and sodium-metal cooling systems for advanced nuclear reactors. Many of these applications will lead to a cleaner environment and more efficient use of natural resources. Sulfide ceramics, by promoting development of these technologies, could reduce world dependence on oil. The ANL-developed sulfide ceramics received a 1993 R&D 100 Award, given annually by *R&D Magazine.*

Optics Manufacturing Operations Development and Integration Laboratory

Accelerating the Transfer of Optical Component Fabrication Techniques to Industry

The Optics Manufacturing Operations Development and Integration Laboratory (MODIL), a research and testing facility, was established in 1988. Here, engineers and scientists from three DOE sites in Oak Ridge (Oak Ridge National Laboratory, the Y-12 Plant, and the K-25 Site) have combined their talents to work with industry, universities, and other federal laboratories to find new ways to manufacture high-quality optical components at less cost and in a timely manner.

The Optics MODIL has been involved in numerous cooperative research and development agreements to leverage the resources of the government and of industry. For example, a joint effort with Martin Marietta is aimed at developing faster, more efficient, and less costly methods of fabricating

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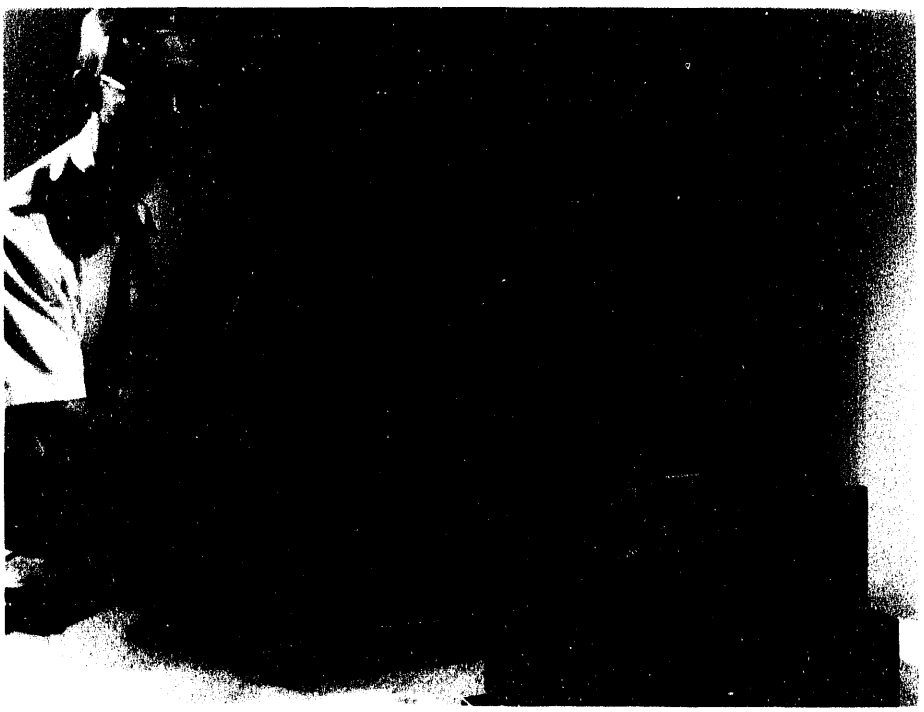
mirrors from beryllium. Beryllium is the material of choice for many space applications because of its great strength and light weight. MODIL researchers are seeking to streamline the process used to manufacture beryllium mirrors while enhancing their quality.

A joint effort with Contour Fine Tooling, Inc., of Malborough, New Hampshire, has elevated the diamond tool industry's standard for highly accurate, natural diamond tools. The shape and reflective finish of the mirrors used on tracking and surveillance weaponry must be very close to perfect. In single-point diamond turning of mirrors, technicians must rely on highly accurate diamond tools to produce smooth, uniform surfaces that are devoid of microscopic flaws. According to company representatives, the quality of Contour Fine Tooling's best diamond tools exceeded its ability to measure them within its own facilities. Optics MODIL scientists succeeded in inspecting tool edges and verified that they were accurate to about 5 millionths of an inch.

With United Technologies Optical Systems of West Palm Beach, Florida, researchers at Oak Ridge are determining the best procedures for making high-precision mirrors from silicon carbide, a widely used industrial ceramic material previously considered too brittle to be used extensively for optical components. The material is ground to the desired shape by means of a wheel surfaced with very fine diamond grit. The Optics MODIL manufacturing techniques are aimed at eliminating the lengthy and expensive polishing phase of mirror production, reducing both cost and manufacturing time.

A recent designation as a DOE user facility (with the name of Ultraprecision Manufacturing Technology Center) provides another avenue for researchers to perform high-risk/high-benefit experiments without extensive investment in equipment and instrumentation. Through such hands-on activity, companies can quickly move new technology into their operations. ■



The scanning Hartman device, which uses laser light to confirm the shape of diamond-turned optics to better than one-eighth of a wavelength, is one of several advanced devices installed in the Optics Manufacturing Operations Development and Integration Laboratory established to help the U.S. optics industry.

Coatings to Protect Computer Hard Disks

Increasing the Storage Capacity and Reliability of Hard Drives

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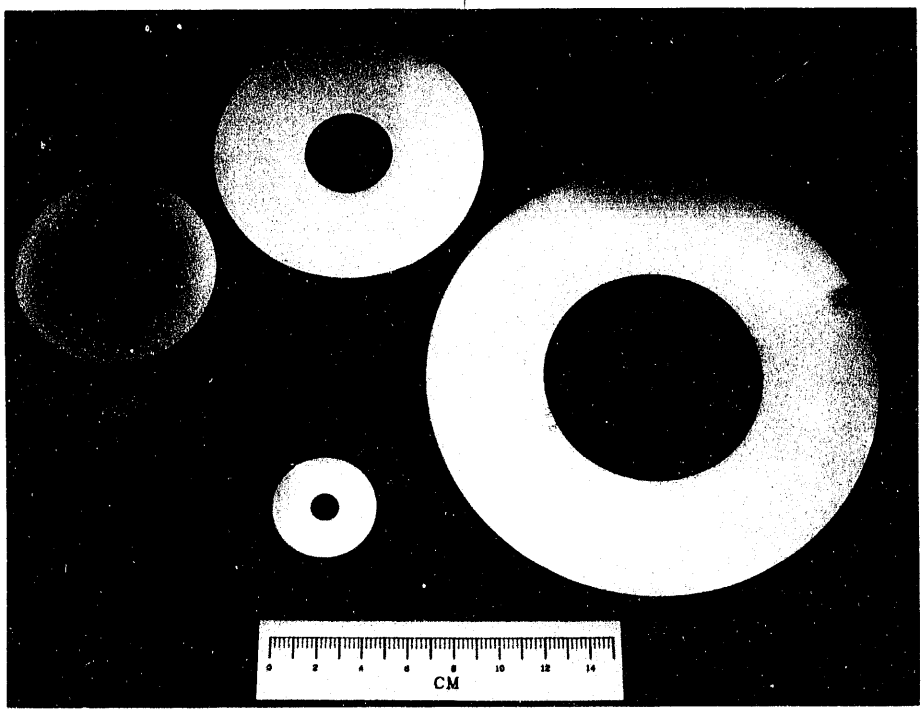
Lawrence Berkeley Laboratory (LBL) and Seagate Magnetics, a firm in Fremont, California, that manufactures computer disk drives, signed a $520,000 cooperative research and development agreement to develop a better process for making the carbon coatings that protect hard disks. Under the terms of this agreement, $285,000 in DOE funding will be provided over the next 3 years through LBL, and $235,000 in research costs will be contributed by Seagate.

The goal of this joint venture is to develop new types of the amorphous carbon coatings that are applied over a hard disk's thin magnetic layer. Considered a key requirement for increasing the storage capacity and reliability of hard drives, these coatings protect the magnetic layer from the wear and tear that occurs during computer start-up and operation.

Critical to achieving the goal of the LBL-Seagate agreement is the ability to characterize carbon coatings at the atomic level. Such characterization is expected to reveal much about the relationship between atomic structure and material properties, which could lead to the development of ways to optimize manufacturing processes and thereby improve the material's performance.

Scientists at LBL have developed a unique Raman spectroscopy technique. It determines properties associated with changes in the position of atoms with respect to one another across the surface of a material thousands of times faster than before. Use of the advanced characterization method reduces the need for destructive, time-consuming, mechanical testing of coatings. This technique, along with other research findings, will be passed on to experts at Seagate to apply to their work. LBL and Seagate will also collaborate in designing new experiments that should further increase the importance of Raman spectroscopy in manufacturing computer disk drives.

The LBL-Seagate collaboration originated as a successful DOE-sponsored industry-laboratory personnel exchange. In the process, LBL's expertise and unique apparatus were used to further Seagate's research and development efforts.



This series of hard-drive disks shows advances achieved in miniaturization.

Rapid Thermal Decomposition of Precursors in Solution

Making Nanoscale Powders for Stronger, More Resilient Products

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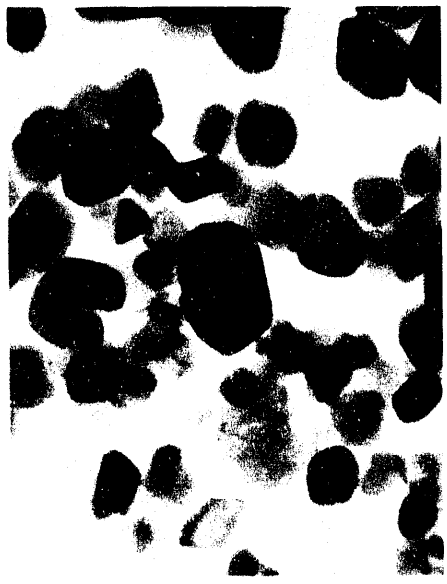
Engineers at Pacific Northwest Laboratory (PNL) have developed a new process for producing nanoscale crystalline powders of a predictable, uniform size. The new process of synthesizing the powders, called rapid thermal decomposition of precursors in solution (RTDS), enables high-quality products to be manufactured in large quantities at a reasonable cost.

The powders can be compacted into very dense, impact-resistant materials, diffused throughout a fluid to serve as high-surface-area catalysts, or used to create pigment. PNL researchers are collaborating with industry to refine the powders for specific applications.

Until now, nanoscale powders have been difficult and expensive to make and have not been manufactured in bulk. The bench-scale RTDS process produces 1 to 5 pounds of the powder per day; other bench-scale processes produce only a gram or less daily. For large-scale industrial purposes, the new process is advantageous in that it operates in a continuous flow-through mode rather than a batch production mode. It can also be easily scaled up for mass production and industrial use.



This typical high-surface, highly crystalline, nanoscale powder (highly magnified) was produced by using the RTDS process.

To synthesize powders by using the RTDS process, a specially prepared solution is pressurized and heated. After a few seconds, the fluid is collected, and the particles that formed in it are separated and dried. The process is very efficient; one solution produces 90% precipitation in one cycle. Businesses in the chemical, plastics, and petroleum industries, all of which use these powders as catalysts, expect the RTDS process to reduce costs by speeding reaction time, decreasing the amount of catalyst needed, and reducing reactor vessel size. Manufacturers anticipate that integrating the powders into the ceramic components of items like gears, ball bearings, engine blocks, knives, and turbine blades will improve their strength and durability. The powders should give these companies an important advantage in the international marketplace by improving product quality while lowering production costs.

The RTDS process could also serve industry by removing contaminants from hazardous liquid waste streams. Costs of hazardous waste disposal are high; once the contaminants are removed, the waste becomes nonhazardous and can be disposed of inexpensively. Such removal is also important because contaminated fluids at environmental cleanup sites pose major storage and disposal problems.

A 1993 R&D 100 Award was given by *R&D Magazine* for this technology. PNL is seeking partners to commercialize the process.

Plasma Quench Process

Producing High-Quality Metal Powders for Manufacturing

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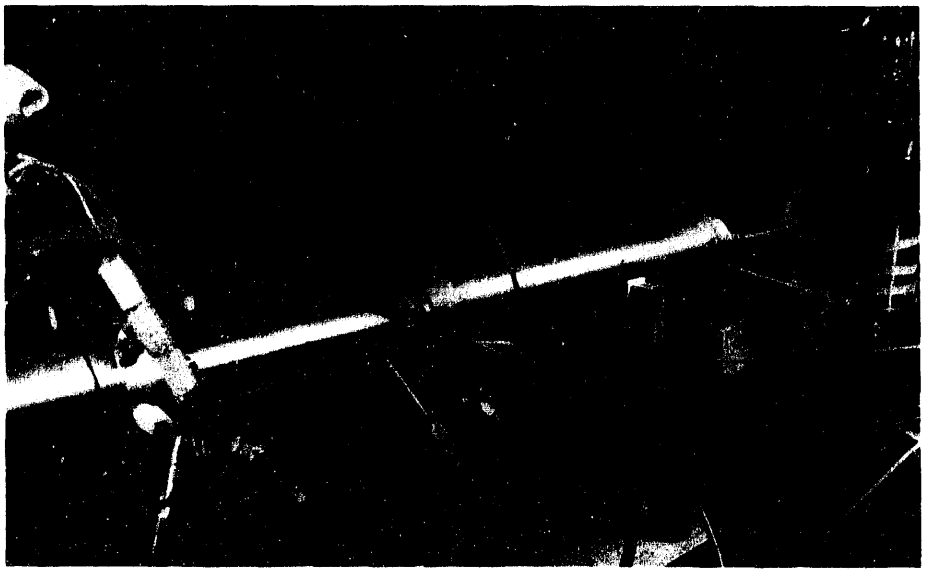
Idaho National Engineering Laboratory (INEL) researchers have developed the plasma quench process to produce high-quality metal and ceramic powders for manufacturing stronger, more ductile, and lighter products. The process uses a small reactor or chamber to heat a metal or ceramic precursor material such as a liquid solution to a high temperature (5,000 K, for example). The heating breaks the material down to its basic composition in vapor form. The vapor is then quickly cooled upon exiting the chamber. The cooling prevents undesirable back reactions and converts the vapor to a uniform, fine-grained powder. The powder can be used to produce parts that are close to their final shape.

The plasma quench process is faster and less costly and results in much less waste than current technologies for casting ingots to be machined into parts. It also has the potential to greatly reduce the waste streams associated with conventional processes for producing metal powder. For example, the widely used Kroll process for producing titanium results in large volumes of magnesium chloride. This problem is eliminated in the plasma quench process, which does not use magnesium.

A spinoff company, Plasma Quench Technologies, Inc., was formed by three INEL employees and a professor from the University of Idaho in 1992. It holds exclusive rights to commercialize the plasma quench process for manufacturing nanocrystalline titanium powder, which can be used to make lightweight automobile engines and aircraft parts and even to replace human bones.

The plasma quench process can be applied to other metals and ceramics in a wide range of manufacturing environments. In fact, ongoing development has brought together seemingly unrelated technologies. For example, researchers used arc-jet thrusters originally developed for the U.S. Air Force and the space program to create plasmas for the quench process.

Scientists expect to have results from a pilot reactor being tested by Plasma Quench Technologies in early 1994.



Titanium powder is produced in this plasma reactor. Shown are the plasma torch, powder being formed, and collection apparatus.

Mercuric Iodide Crystal Technology

Growing Crystals for Radiation Detectors

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Scientists are perfecting for the Nevada Test Site a vapor technique for growing mercuric iodide crystals suitable for room-temperature, solid-state, radiation detectors. Other radiation detectors require a bulky cooling apparatus. The mercuric iodide crystal detector — a small, hand-held instrument the size of a pocket calculator — is expected to combine the advantages of room-temperature operation and high resolution with high efficiency and low power consumption. New encapsulation methods allow for stable detector performance for up to 5 years.

To grow crystals suitable for radiation detectors, tiny ruby-red seed crystals of mercuric iodide are placed in a glass container (ampoule) with a pulverized source material. When the ampoule is heated, the mercuric iodide powder slowly vaporizes and condenses onto the seed to form a large crystal.

Detectors based on mercuric iodide crystals are used primarily to monitor radiation levels. The crystals convert radiation into measurable electrical charges. Promising applications include monitoring domestic and foreign nuclear power plants or prospecting for oil and minerals.

Mercuric iodide crystals are used primarily in detectors that monitor radiation levels.

Radiation detectors made with mercuric iodide crystals could also be used in medical diagnostic systems and space instruments for high-energy astrophysics research. More specifically, telescopes incorporating mercuric iodide crystals could make it possible to view radiation emissions from stars and comets, and such crystals in surgical instruments could help locate small tumors in hard-to-see places. Mercuric iodide detectors have already been successfully applied in x-ray and gamma-ray spectrometers, photocells to detect scintillation lights, two-dimensional monolithic arrays for gamma-ray imaging, gamma-ray burst detection studies, solar flare studies, and elemental analysis.

In 1985, researchers redesigned existing crystal growth furnaces to accommodate experiments on the space shuttle. Much of what is presently known about the physics of crystal growth in space has come from the high-quality mercuric iodide crystals grown on the first International Microgravity Laboratory mission in 1992.

A comparison of space- and earth-grown crystals has helped to increase understanding of vapor transport, crystal and electronic properties, and nuclear detector response, and it should ultimately result in improving the quality of earth-grown crystals. Scientists regularly produce crystals larger than eggs and weighing more than 2 pounds.

Researchers are continuing their studies in material synthesis and purification, crystal growth, detector fabrication, and detector testing. They recently entered into a cooperative research and development agreement through DOE with

Xsirius, Inc., of Marina del Rey, California, to aid in the commercialization of mercuric iodide detectors and instruments.

Mercuric iodide crystal technology is expected to be used in x-ray fluorescence analyses related to geological and planetary exploration.

Ultrafast Infrared Spectrometer

Providing Unique Information on Molecular Dynamics

Researchers at Los Alamos National Laboratory (LANL) have developed an ultrafast infrared spectrometer that allows scientists to "see" changes taking place in molecules during chemical processes — changes that occur in less than a trillionth of a second. Bond making and breaking, electron transfer, isomerization, and vibrational relaxation are examples of such changes. They reveal important information about mechanisms of chemical reactivity, material dynamics, energy conversion and storage, catalysis, and chemical processes essential for life, such as photosynthesis and respiration.

The ultrafast infrared spectrometer uses a "pump-probe" approach to measure infrared absorbance. The device generates ultraviolet and infrared pulses, each a trillionth of a second long. The ultraviolet (pump) pulse is absorbed by the sample, initiating the events to be measured. The infrared (probe) pulse allows monitoring of changes induced by the pump.

The ultrafast infrared spectrometer generates an ultraviolet and an infrared pulse. The former initiates a reaction in the sample; the latter probes the ultrafast changes in molecular structure taking place during the reaction.

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By measuring the amount of infrared light absorbed by the sample, scientists can gather direct, unique information about structural transformations that occur during chemical processes. Because infrared absorption spectra are sensitive to such properties as the strengths of interatomic bonds and the masses and locations of bound atoms, this measurement technique enables scientists to take a series of closely timed "snapshots" that capture changes in a sample's molecular structure.

By using the speed of light as a clock, the ultrafast infrared spectrometer determines the speed at which changes take place during the pump-probe experiment. (Conventional electronics devices are not fast enough to track these ultrafast changes.) By varying the distance traveled by the pump pulse, and hence the time lag between the pump and the probe pulses, scientists can measure absorbance versus time at a given infrared wavelength and thus measure the speed of specific structural changes.

This new spectrometer has unique design features. Specific filters and refractive media allow scientists to select from a wide range of pump and probe wavelengths, providing essentially unlimited versatility for study of molecular systems. In addition, the device can record a substantial portion of the infrared spectrum while maintaining ultrafast time resolution. The spectrometer converts the probe pulse into a multiwavelength continuum, disperses the pulse into its spectral components after it passes through the sample, and then measures the dispersed pulse by means of a detector with simultaneous multiwavelength capability.

The ultrafast infrared spectrometer is a research tool for studying the basic steps in molecular dynamics. Although it was developed to observe energy conversion and storage processes in proteins and photochemical systems, this tool is also widely applicable to problems in chemistry, catalysis, bioscience, solar energy conversion, and materials science.

The ultrafast infrared spectrometer won a 1993 R&D 100 Award from *R&D Magazine.*

High-Tech Materials Processing

Improving Metals Processing through Joint Research

The Oak Ridge Y-12 Plant has created a new crucible, that is, a special container for heating metals to the high temperatures needed to make alloys. Blasch Precision Instruments of Schenectady, New York, has licensed the patent for Y-12's crucible and used the concept to devise a two-piece crucible that is superior to traditional designs.

Conventional crucibles contain graphite — a form of carbon. As metal is heated, it absorbs carbon from the crucible. Hard carbide particles form and cause the metal to become brittle and susceptible to breakage. Components shaped and machined from the "hard" carbide alloy can damage the surfaces of machine parts. The carbide pieces act like grains of sand streaking across a bar of soap. They create a "comet tail," or a groove, that disrupts the smooth, machined, metal surface.

Finding a material with the same properties as graphite but without its

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undesirable characteristics proved to be a difficult task. Graphite is inexpensive, easily machined, and thermal-shock resistant. In addition, graphite heats metals evenly in a standard induction heating furnace. Alternative heating methods such as electron beam melting would be expensive.

The two-piece crucible developed by Blasch is composed of aluminum oxide and silicon carbide, a composition that virtually eliminates the carbon absorption problem. Although the crucible still has some carbide, the metal absorbs only a small amount. The crucible is separated to prevent cracking when it is heated to extreme temperatures. The "free-floating" bottom deters cracking and works in standard induction furnaces with the aid of a "thermal can," another Y-12 device that consists of a stack of metal rings fitted around the crucible to ensure uniform heat transfer and thus avoid cracking.

In addition to licensing the two-piece crucible, Blasch has entered into a cooperative research and development agreement with Surface Alloys, Inc., of North Chicago, Illinois, and Y-12 to develop a carbonless crucible. Researchers plan to design a crucible that is lightweight, inexpensive, and capable of uniform heat transfer.

Crucibles are used in the aerospace, automotive, and electronics industries as well as other industries. Several companies have expressed interest in the technology, which is promising for such products as uranium penetrators to penetrate army tanks, prosthetic devices, and aircraft and submarine components.

Characterization of Chemical Vapor Deposition Processes

Using Synchrotron Radiation as an Analytical Tool

In collaboration with researchers from AT&T Bell Laboratories and IBM, scientists at the Stanford Synchrotron Radiation Laboratory (SSRL), a division of the Stanford Linear Accelerator Center, are using intense x-ray beams to study chemical vapor deposition environments.

Chemical vapor deposition is used widely in applications in which conformal, high-quality coatings are needed. In these processes, chemical precursor compounds are introduced into a reaction zone, together with the part to be coated. Through decomposition or chemical reaction between the precursors, a thin film of the desired material is deposited.

The properties of the films or coatings are controlled through careful selection of the process parameters: temperature of the part to be coated, pressure of the reaction chamber, reactant concentration, and flow rate. However, such characteristics as adhesion and electrical, optical, and magnetic properties are controlled not only by the deposition parameters but also by the detailed mechanisms of the deposition chemistry. For example, the impurity concentration of electronic materials is strongly controlled by the choice of precursor compounds.

Because of the harsh conditions usually present during chemical vapor deposition, few useful probes are available to characterize and control the process. Not only are highly reactive source compounds used, but the environment

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frequently involves elevated temperatures and ambient pressures that vary by more than two orders of magnitude. Therefore, such common analytical tools as electron diffraction and spectroscopy techniques cannot be used to study these important processes.

Researchers in this unique, multi-institutional collaboration are investigating processes that control the growth of gallium arsenide, an important semiconductor, by means of x-rays produced at SSRL. The x-rays serve as an attractive probe in hostile environments because they are unaffected by ambient gases and can penetrate chamber walls so that no other ports are needed.

The SSRL's ultra-high-intensity x-ray beams reveal, in real time, details of the formation of microstructures at scales ranging from nanometers to micrometers. Such techniques are enabling scientists to learn how chemical vapor deposition of gallium arsenide occurs by observing the buildup of individual atomic layers. Both structural information (e.g., film roughness, crystal structure, and ordering) and chemical information (e.g., chemical reaction rates and products) can be collected. Such information will greatly increase the understanding of chemical vapor deposition processes.

Advanced and Computer-Enhanced Instrumentation and Sensors

Brookhaven National Laboratory physicist applies the technique of positron-annihilation spectroscopy to characterize a sample. For more information on this technology, see the writeup on *Determination of Interfacial States in Semiconductor Structures* on page 163.

Donor-Acceptor-Donor Molecular Switch

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Exploiting the Speed Inherent in Photo-Induced Electron Transfer

The design and production of energy-efficient, state-of-the-art electronic devices depend increasingly on the ability to produce ever-higher densities of circuit elements within integrated circuits. Scientists at Argonne National Laboratory (ANL) have developed a light-intensity-dependent optical switch — the electron donor-acceptor-donor (DAD) molecule. The DAD molecule performs logic operations, making it possible to develop molecular electronic devices based solely on electron motion within donor-acceptor complexes.

Promising applications for such devices include molecular electronic switches, wires, and microsensors for chemical analysis, as well as optoelectronic components for optical computing. The main advantages for using molecules in these applications are high component density, increased response speed, and high energy efficiency. These advantages derive from the picosecond (ps) speed with which photo-induced electron transfer processes within molecules take place.

Photochromic molecules, or molecules that change color reversibly in strong light, can be used as optical switches and as components in optical memory devices. Until now, such molecules depended on breaking and reforming chemical bonds to manipulate information. These processes are slow, taking from microseconds to milliseconds. Also, it is highly desirable to implement information storage devices in the solid state. In solids, most known photochromic molecules respond in seconds or not at all.

Like silicon-based semiconductors, the DAD molecular switch uses electron movement only. The advantage of the organic DAD switch over silicon systems is its 10-ps response time for electron movement and photochromic changes. The advantage of the DAD switch over existing photochromic materials is the speed (10 ps) with which electron movement and thereby photochromic changes occur in the solid state relative to the sluggishness (seconds) of these responses in other photochromic materials.

The ANL molecular switch is the first molecular system to manipulate information through electron movement alone. This switch is the result of an extensive research program aimed at understanding how electrons move from molecule to molecule. The DAD molecule is a product of a complex set of carefully determined design criteria for achieving more-than-99%-efficient, photo-driven electron movement in solid-state molecular systems.

Argonne's methodology and design criteria can be used to (1) tailor molecular systems to achieve precise control over the speed of electron movement from one component to another; (2) obtain the exact, desired change in optical properties, such as absorption, at specific wavelengths; and (3) achieve these changes in a molecular assembly that is stable in solid-state media.

The DAD molecular switch received a 1993 R&D 100 Award from *R&D Magazine*.

Dual-Wavelength Laser Surveying Instrument

Compensating for Atmospheric Turbulence

A novel precision laser surveying technique has been developed by Brookhaven National Laboratory (BNL) researchers. It achieves greater positional accuracy by compensating for error caused by atmospheric variations in temperature, pressure, density, or turbulence. This technology is capable of advancing the state of the art in atmospheric beam positioning as well as in general surveying.

In the BNL method, a correction factor is determined on the basis of a precisely measured physical separation between two color components of a dual-wavelength light beam. To make this determination, the researchers connected a charge-coupled-device (CCD) camera to a computer. The computer's software effectively fixes the position of the two color components observed by the CCD camera and measures the physical separation between them.

From the measured separation between the color components, the absolute displacement of one wavelength component of the beam from its truly straight line of sight for that beam can be determined by an algorithm. The result is a precise beam-position correction factor.

This technique was granted a patent in 1993 (U.S. Patent No. 5,233,176). Efforts are underway to incorporate this novel technique into current commercial surveying applications. ■

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The dual-wavelength laser surveying instrument can compensate for variations in atmospheric temperature, pressure, density, and turbulence to improve measurement accuracy.

Multiple-Event Recorder

Characterizing Multiple Output Signals Simultaneously

For automated test equipment developed at the Kansas City Plant, engineers were required to continuously monitor multiple outputs from units undergoing testing for long periods. However, no commercial equipment was available to economically and accurately characterize multiple signals simultaneously.

The engineers developed a distributive processing technique that incorporates event recorders to acquire test data on various outputs at the same time. Since one microprocessor-controlled event recorder — with its own memory, analog-to-digital converter, programmable comparators, and event timer — is dedicated to each product test point, the technique is flexible and eliminates competition for measurement resources. The event recorders are also much faster and much more reliable than single-processor test equipment.

The technology consists of a specially designed, microprocessor-driven board that can measure time of occurrence and amplitude. Data are recorded as time/voltage pairs. Measurements such as pulse width, pulse spacing, frequency, voltage drop, current, and energy output can then be calculated. The use of time/voltage pairs has the benefit of compressing data to a higher degree than normal digitized sampling. The interchangeable, remotely configurable event recorder boards are also easier to maintain, expand, and adapt to new products.

Hundreds of the first three generations of event recorders have been used to test a wide variety of products. The fourth-generation event recorder is now being developed. Each generation is faster, more accurate, and more compact than the previous one. ■

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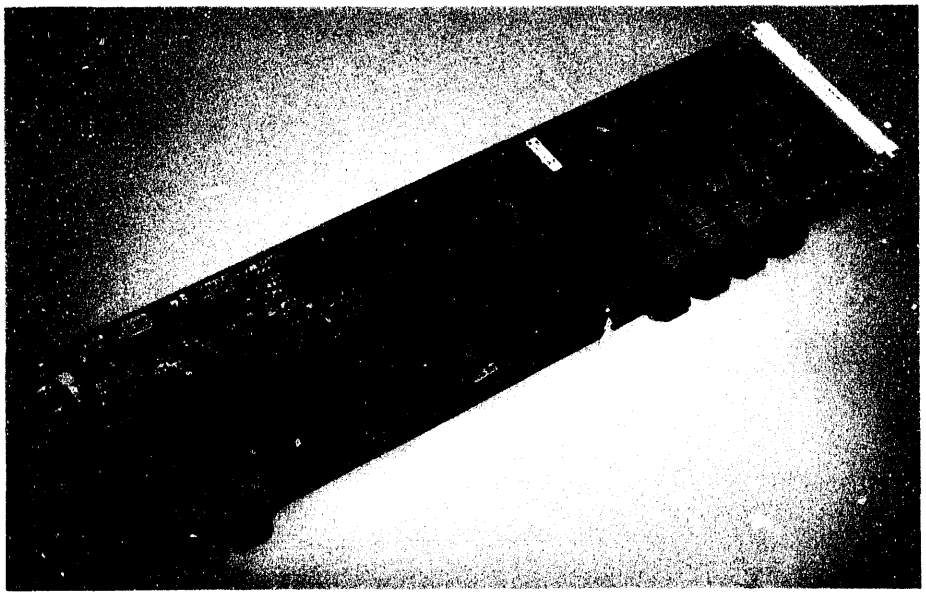

Pictured here is one channel of the third generation of event recorders, which characterize output pulses. Because each board has stand-alone measurement capability, one can be dedicated to each signal.

World's Largest Optical Telescope

Employing a Powerful yet Less Massive and Costly 36-Segment Mirror

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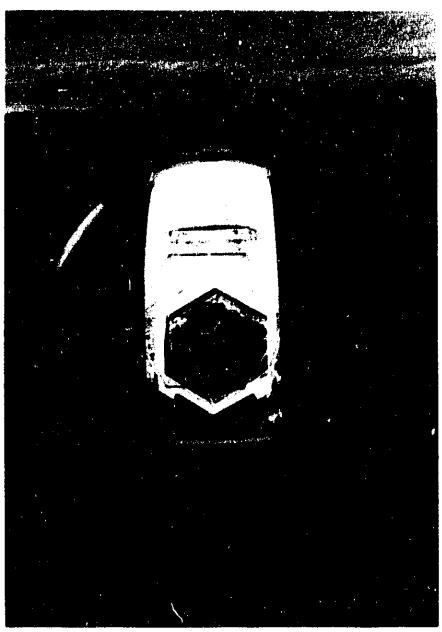
The 10-meter Keck telescope, on top of Mt. Mauna Kea in Hawaii, has a unique, 36-section mirror visible inside the observatory.



The recently commissioned Keck telescope, atop 13,796-foot Mt. Mauna Kea on the island of Hawaii, is the largest optical telescope in the world. Its unique, 10-meter, 36-segment, hexagonal mirror is twice as big as that of the Hale telescope, the former world-record holder. This triumph of engineering will aid in the exploration of the universe.

Conceived at Lawrence Berkeley Laboratory (LBL) and built in partnership with the California Institute of Technology and the University of California, the Keck telescope is a novel solution to the formidable engineering problems posed by scaling up existing single-mirror technology. It represents the first major departure in telescope design since Newton devised the reflecting telescope almost 300 years ago.

An LBL astrophysicist conceived of using 36 separate mirrors in a hexagonal pattern to avoid the extreme cost and mass that a single-piece, 10-meter mirror would entail. The resulting design weighs about half as much as a single, 10-meter mirror and can be created at approximately one-tenth the cost.

To make this elegant design work, two major problems had to be solved: how to polish the mirror segments to obtain the parabolic shape needed to focus light and how to develop a control system that would ensure proper alignment of the telescope at all times. The first problem was solved by using "stressed mirror polishing," in which each blank is carefully warped with clamps to exact, predetermined stresses derived with the use of a computer and then polished spherically. When the forces are removed, the blank assumes the desired parabolic shape. The second problem was solved through the use of real-time computer sensing and control. To correct for atmospheric conditions, precise alignment of each segment is continuously achieved through a computer-operated active control system employing 108 sensors (three per mirror) and 168 actuators. The system determines and adjusts the position of each segment with respect to its neighbors two times a second and maintains an alignment to within 1 millionth of an inch at all times.

Acting as a virtual time machine, the Keck telescope will allow scientists to see objects up to 10 billion light years away, such as quasars and other objects from the earliest stages of the universe. With the assistance of a second telescope of identical design being built nearby, the Keck will participate in one of the most exciting quests in astronomy today: the search for other planetary systems. The two telescopes will function as an interferometer, with a resolution in the thousandths of an arcsecond range; that is, good enough to see Jupiter-size planets orbiting the hundred nearest stars.

The LBL-developed mirror technology won an Award for Technological Innovation in the category of sight from *Discover* magazine in 1993. A small U.S. telescope manufacturer is ready to collaborate with LBL to develop this technology on a 2-meter scale for sale to high schools, colleges, and overseas researchers — a market estimated to be worth roughly $100 million. ■

Scanning Defect Mapping System for Semiconductors

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Bringing Silicon Defects to Light

Crystal growers have longed for a reliable, quick, and easy system for analyzing defects that affect the performance of silicon solar cells. The National Renewable Energy Laboratory (NREL) has developed an innovative new scanning defect mapping system (SDMS) based on optical scattering that can quickly and accurately map defect distributions and grain boundaries in semiconductor wafers. This compact, self-contained, high-speed laser scanning system captured a 1993 R&D 100 Award from *R&D Magazine.*

To map defects, a crystal sample is given a chemical bath called the "Sopori etch." This step wears away the wafer material that surrounds dislocations. Unlike other defect etches, the Sopori etch produces etch pits with constant optical scattering at dislocation sites, which makes counting defects easy and accurate. The process also marks grain boundaries with V-shaped grooves that scatter light, making them easier to detect.

Once etched, the sample is scanned by a laser beam. A dislocation detector and a grain-boundary detector collect scattered light. These detectors are positioned so that they can differentiate between light dispersed by dislocations and light dispersed by grain boundaries. The signals from the two detectors are fed into a computer, along with the position of the sample. Researchers can rapidly produce maps of grain boundaries and defect distributions. Because the information is stored in a computer, the distributions can be analyzed in detail.

The major advantages of the SDMS over other systems are its speed, accuracy, and ability to repeat results. Defect maps of large wafers — about 10 centimeters square — can be produced in less than 2 hours. Other systems take up to 2 months to perform the same task, making them unsuitable for production control or even for research on the large wafers required for solar cells. In addition, the SDMS accurately maps the defects of small wafers, with repeatable results. With other systems, subsequent countings may differ by a factor of two; with the SDMS, they are repeatable to plus or minus 2%.

The SDMS is primarily used to analyze defects in silicon wafers and improve growth in silicon crystals. However, the proper defect etch would allow the SDMS to map defects in other materials such as gallium arsenide and cadmium telluride. Minor modifications would allow monitoring and control of surface contamination of microelectronic circuits.

The scanning defect mapping system quickly and accurately produces separate maps of a semiconductor's grain boundaries and defect distributions.

All-Purpose, Near-Ideal Digital Filter

Improving the Accuracy of Digital Signal Processing

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A new method discovered at the Stanford Linear Accelerator Center (SLAC) for the design of digital filters promises to substantially improve digital filter technology. This technology is a key component in telecommunications, acoustics, ultrasonics, radar, and other fields that require digital signal processing.

Digital filters extract the signals from the noise in a set of data by a process based on frequency differences among data components. Conventional digital filters are commonly designed either by means of complicated mathematical approximations or by using the discrete Fourier transform (DFT) technique. Filters designed through mathematical approximations have high signal-loss characteristics and are single-purpose; that is, a low-pass filter allows only low-frequency spectral components to pass, and so on. The performance of the DFT-designed filter is adversely affected by the so-called "Gibbs phenomenon," which causes unwanted oscillations at both ends of the data train. Errors resulting from the Gibbs phenomenon can be reduced by forcing the value of the end points of the data to be zero, but this practice distorts the waveform, induces spectral leakage, and exacerbates the nonideal attributes of such filters.

The SLAC method uses a technique called "data flipping" to suppress the Gibbs phenomenon. In this technique, problems related to forcing a value to the end points of the data set are avoided. Data flipping completes the periodic cycle, thereby eliminating Gibbs-phenomenon errors.

A fast Fourier transform is performed on the flipped data, and the unwanted frequency bands are deleted from the spectra. The "passed" spectral bands are then inversely transformed back to accurately represent the original data without the noise. This filter is nearly ideal: it needs neither a window nor a band transition, it introduces no waveform distortion or spectral leakage, and its end-effects are minimal.

Filters designed by the SLAC method are also all-purpose devices; they can be used as low-pass, band-pass, high-pass, band-stop, notch, or single-frequency-pass filters simply by selecting the appropriate frequency band limits. ■

Motor Current Signature Analysis

Licensing Diagnostic Technology

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Even small companies can benefit from DOE-sponsored research. Predictive Maintenance Inspection, Inc. — a Madison, Alabama, company specializing in condition monitoring — recently was granted a second license for motor current signature analysis technology developed at the Oak Ridge Y-12 Plant. The company was granted rights in 1989 to the original motor current technology developed at Oak Ridge National Laboratory.

Motor current signature analysis is a nonintrusive method for monitoring the condition of electric motors and the equipment driven by them. The load (demand) on an electric motor changes constantly as it responds to conditions within the system being

driven. "Signals" of these load fluctuations are reflected back into the motor, which responds instantly. Changes in the system's condition, such as deterioration or wear, are determined by analyzing the signals caused by the load fluctuations.

The Plant's motor current signature analysis technology makes it possible to monitor a motor's condition from a remote location by using the motor as a transducer. Predictive Maintenance uses this technology on-site to examine the condition of motor-driven systems, thereby enhancing reliability and availability, increasing production time, and reducing maintenance costs. A representative of Predictive Maintenance explained that the cost of motor current technology is "extremely reasonable and cost-effective to a small business." Furthermore, the new technology makes it possible for the company to have "complete condition-monitoring services in a van." ■

Inspection Rabbit

Pinpointing Leaks in Small-Diameter Pipes

An inspection rabbit developed by researchers at Savannah River Technology Center (SRTC) can pinpoint leaks in pipes only 2 inches in diameter. The 3-foot-long, modular device was designed for use in pipes that pass through hazardous environments (e.g., radioactive waste tanks), where inspections cannot be performed in any other fashion.

The highly maneuverable rabbit consists of a miniaturized eddy-current device, battery pack, and wire communication spool. It is pushed or pulled through the piping in a closed loop by means of a positive-displacement pump. The device can squeeze through narrow spaces, making sharp turns as the piping bends. All components of the rabbit are designed so that they can pass through a 90° elbow of short radius, the most limiting geometry encountered in any piping system.

The SRTC inspection rabbit is produced in two versions. The tube version is easier to manufacture; the molded version is hardier. With further development, the device could be made not only to locate leaks but also to patch them from the inside. ■

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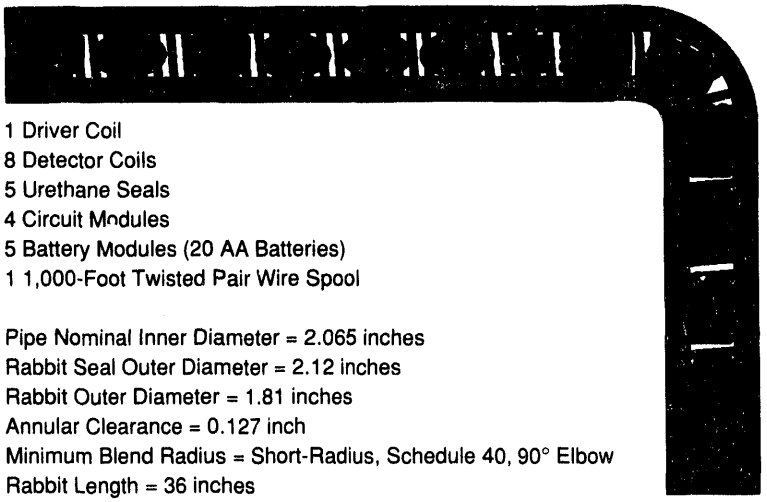

The inspection rabbit is a miniaturized eddy-current device used to inspect small-diameter piping.

Single-Shot Transient Digitizer

Computerized Electrical Signal Sampling to Replace Oscilloscopes

Measuring single-event, subnanosecond laser transients usually requires digitizing recorders like high-speed oscilloscopes. Lawrence Livermore National Laboratory (LLNL) has developed the single-shot transient digitizer (SSTD) to replace these costly, cumbersome oscilloscopes. The SSTD functions as a combination oscilloscope and digitizing camera.

The SSTD can record an electrical event that lasts from only 30 picoseconds to 20 nanoseconds. Its speed results from its use of Schottky diode samplers that are periodically tapped onto a broadband transmission line. An input signal propagating along the transmission line is physically spread out along its length. The periodically spaced samplers take a "snapshot" of the signal waveform as it appears along the line. The snapshot is stored on charge-holding capacitors for later readout to a high-resolution (12-bit) analog-to-digital converter. The samples that make up the snapshot are carefully reconstructed to yield a smooth output waveform comparable to one from a good analog oscilloscope.

The LLNL engineers explored many architectural variations to optimize the device's signal bandwidth, transmission line reflections, and sampler linearity, yet make it easy to manufacture. They placed the digitizer in a computer-automated measurement and control (CAMAC) module to lower costs and increase flexibility.

The SSTD has all the advantages of solid-state technology and none of the disadvantages of vacuum tube technology. Compared with commercial solid-state digitizers that cost five times more, the SSTD is smaller, more robust, and more accurate, and it consumes less power. It also makes measurements with a higher dynamic range, and its repetition rate is 1,000 times faster.

The SSTD can be used for many applications, including high-energy pulsed-power measurement, transient radiation testing, accelerator diagnostics, fluorescence decay, telecommunications, and high-speed digital chip testing. In the future, it will be able to capture the extremely short optical transients presently handled by fast streak cameras. The SSTD could also enhance impulse radar systems, such as subsurface probing radar, which require a high repetition rate. It can improve the impulse radar signal-to-noise ratio by more than 1,000 times.

The solid-state SSTD is built from off-the-shelf, low-cost, surface-mount components and is inexpensive to upgrade. Its developers are working on a similar system having more than three times the sampling rate. This technology won an R&D 100 award in 1993 from *R&D Magazine* for being one of the top 100 new inventions of the year.

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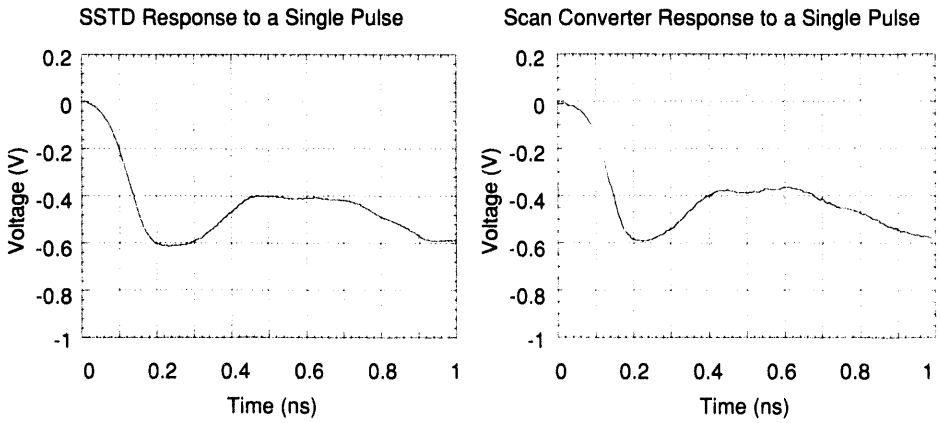
A single electrical transient one nanosecond in length is captured on the SSTD; for comparison, the same event is recorded on a wideband scan converter oscilloscope.



Fiber-Optic Temperature Sensor

Functioning Accurately over Broad Temperature Ranges

Researchers at Savannah River Technology Center (SRTC) are developing a class of highly accurate fiber-optic temperature sensors that function well over very broad temperature ranges. As an example, one sensor of this type can measure temperatures between -196 and 500°C with a precision of plus or minus 1°C.

Whenever a device must function over a very wide temperature range, SRTC's fiber-optic sensor is likely to prove useful. Applications include monitoring radio-frequency and microwave heating and measuring temperatures of high-voltage equipment such as generators and transfer switches.

The sensor technology is based on temperature-induced shifts in the absorption spectra of selected materials. For example, in a neodymium-doped glass sensor, light from a fiber-optic cable shines through the neodymium glass and is reflected onto a second fiber-optic cable. Light from this second cable is measured by a diode array spectrophotometer. The absorption spectrum of the neodymium glass is used to compute the temperature.

The fiber-optic sensors, which can be located hundreds of meters from the spectrophotometer system, are rugged. Because they are made from nonconductive materials, they can function in areas with high electromagnetic fields. The risk of electrical shock is also reduced.

The new sensors are inexpensive to use. The unit cost is relatively low; as many as 50 of them can be operated from a single instrument; and they do not require individual calibration. ■

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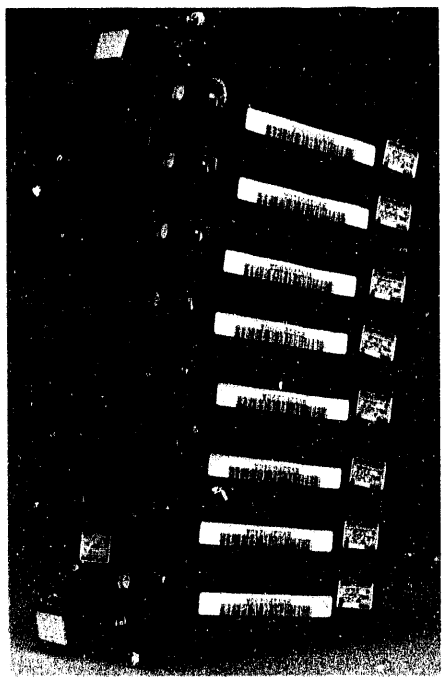
Researchers work with a glass blower to establish fiber-optic sensor specifications.

VME-Based, High-Voltage Power Supply

Computer-Controlled Supply for Performance and Versatility

Particle detectors for high-energy physics experiments require high-voltage power supplies of high quality and versatility. Based on the VME (Versabus Module European) electronics industry standard, Fermilab's high-voltage power supply delivers up to 8,000 volts at currents up to 1 milliampere. Entirely computer-controlled, this device was originally developed for use with the systems of multiple drift chambers used in the DZero detector at Fermilab. It also has applications in nuclear instrumentation.

Three types of power supplies are currently in use at Fermilab, all of which are "drop-in compatible," with a setting error of less than 1.5 volts across the entire range. The first two are positive- and negative-polarity devices capable of delivering between 10 volts and 5.6 kilovolts at 1.0 milliampere, in steps of 1.36 volts. The third type is a positive-polarity supply that delivers 10 volts to 2 kilovolts at 3.0 milliamperes, in steps of 0.49 volt. All three types are designed to be operated by a host computer that can read and write to the supplies' built-in VME-bus memory chips.



Computer-controlled, high-voltage power supplies meet challenging requirements for accurate performance and special, user-configured functions.

Total computer control has permitted many special features to be incorporated, such as user-defined control and monitor groups, variable ramp rates, and advanced histogram and graphic functions. Experimenters' requirements for nearly 1,000 channels of compact, accurate power supplies are met. The power supply was designed around the VME-bus standard, with up to 48 supplies per standard VME crate.

The power supplies were designed to be as simple as possible. Complete computer control allows, for example, a common ramp rate to be defined in a group of up to four crates (192 power supplies) and a maximum-difference voltage to be set between any two supplies in the group. The computer monitors the voltage and current of each supply (keeping a running time history of current drawn) as well as the temperature of the module and the values of the low-voltage supply voltages. Both personal-computer and VAX software programs have been developed that use digital filters to increase the accuracy of the readback signal and correct for hardware inaccuracies in the supply.

The VME-based, high-voltage power supply is covered by U.S. Patent No. 4,888,673, which has been licensed nonexclusively. The technology is available for additional licensing. ■

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Determination of Interfacial States in Semiconductor Structures

Using a Variable-Energy Positron Beam to Characterize Defects

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Semiconductor structures — the backbone of computers and electronic devices — are most commonly produced by growing a protective silicon dioxide layer on silicon. If a semiconductor device is to function properly, this interface must be as free of defects as possible. However, the method widely used in industry to find defects destroys the structures.

Brookhaven National Laboratory (BNL) physicists have developed a novel, nondestructive method to identify and characterize these defects. The method, positron annihilation spectroscopy, is a depth-sensitive evaluation technique that can locate open-volume-type defects at a level as small as one in 10 million.

The positron annihilation technique is particularly suitable for interface studies. The incident positron energy is controlled to bring positrons into the vicinity of the interface under investigation. The gamma rays generated by the annihilation of these positrons are used to characterize the defect centers. This annihilation signal is sensitive to the nature and density of the trap centers at the interface. In particular, BNL researchers have shown that positron-annihilation signals are sensitive to the density of interface trap centers with an areal sensitivity limit of 1×10^9 per square centimeter per electron-volt, much better than many conventional probing techniques.

The positron-annihilation spectra originating around a trap site are sensitive to the chemical environment around the trap site. The positron signal indicates to the investigator whether the defect site is empty or a negatively charged hole.

The role of the positron-annihilation technique as a noncontact, nondestructive, depth-sensitive characterization tool for the technologically important silicon dioxide/silicon interface is being investigated with potential industrial licensees and research collaborators. ■

VXI Data Acquisition System

Achieving High Channel Density and High Sampling Speed

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The Kansas City Plant, in collaboration with the Superconducting Super Collider Laboratory (SSCL), has developed the modular input VXI ("MIX") board to use with the standard VXI bus. The new board (also called a card or digitizer) was developed because the SSCL planned to collect vast amounts of data very quickly, a requirement that could be met only by boards with both high channel density and high sampling speed. The boards already available for the VXI bus had only one or the other of these features, not both. In addition to digitization, the SSCL also required on-board signal conditioning.

The MIX board is a general-purpose, C-size VXI digitizer with eight channels for data acquisition. Each channel has its own signal conditioning, 10-bit analog/digital converter, and a storage capacity of 256 kilobytes for sample readings. Because timing and trigger

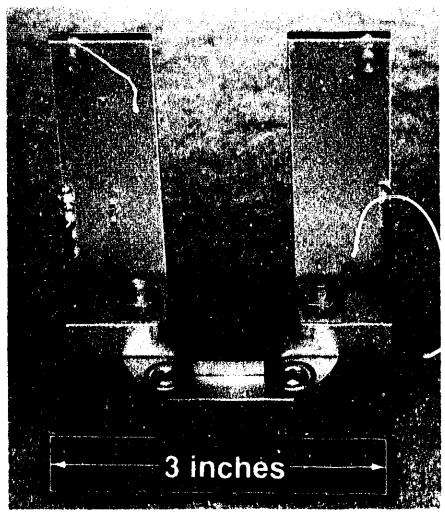
control are common to all channels, the eight channels can be sampled simultaneously. The multiple trigger and clocking options available on the VXI bus are jumper selectable. The signal conditioning is done on plug-in daughterboards, which receive information on range selection from the motherboard. The daughterboards in the system contain multirange current-to-voltage converters, but other signal-conditioning modules can be easily adapted to the daughterboards. No conditioning is required if the signal is -0.5 to +0.5 volt at 50 ohms.

Multiple MIX cards can be installed in a single VXI system, and the VXI backplane can be used to synchronize multiple MIX card systems. When 12 cards are installed in a single rack, 96 channels can be sampled simultaneously at a maximum rate of 20 million per second, the speed SSCL required. A licensing agreement is being negotiated to commercialize this technology. ■

Stringed Diagnostic Instruments

Making High-Energy Particle Beams More Precise

The Kansas City Plant (KCP) has been developing harps and wire scanners to help align and characterize linear-accelerator-generated particle beams. These diagnostic instruments have been designed for DOE's Superconducting Super Collider Laboratory and the Stanford Linear Accelerator Center. KCP has reduced wire-to-wire spacing and improved wire placement accuracy, which provides more accuracte information to accelerator scientists.



Designed to align and characterize linear-accelerator-generated particle beams, this stringed diagnostic instrument could also be used to treat cancer.

The new harps detect a particle beam by using an array of carbon wires, which range in diameter from 4 to 33 micrometers (μm) and are spaced as close as 200 μm apart. Previous instruments achieved only 1,000-μm spacing. KCP has been able to fabricate harps with carbon wire spacing and density not previously available by applying hybrid microcircuit technology (i.e., ceramic thick-film network with solid-phase bonding of the carbon). The density of wires is important because it yields more information for scientists.

The harps and wire scanners could also be used in the medical field. Cancer treatments that require precisely aimed particle beams to avoid destruction of healthy tissue could be improved if calibration instruments based on this technology were used. In addition, techniques like computerized axial tomography, positron emission tomography, and magnetic resonance imaging could be made more precise so their diagnostic ability could be enhanced.

The application of advanced microelectronic manufacturing technology to the production of stringed diagnostic instruments offers businesses many opportunities to form development and commercialization partnerships with KCP. ■

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Sol-Gel Indicator

Measuring pH by Flow-Injection Analysis

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By incorporating sol-gel indicator technology, researchers at Savannah River Technology Center (SRTC) have designed a unique flow cell. It measures pH by flow-injection analysis, an analytical technique used to automate chemical analyses of solutions.

A thin layer of sol-gel is deposited on the windows of the flow cell. The acid-base indicator bromophenol blue is the color reagent in the sol-gel glass matrix used to measure the pH of aqueous solutions having a pH from 4 to 7. Preliminary results indicate resolution at a level of 0.25 pH units or better. The sol-gel indicator is completely reversible and reusable, appears to be robust and dependable, and remains intact for an extended period of time.

Combining flow-injection analysis with sol-gel technology has many advantages. The flow cell increases the analysis rate to at least 60 samples per hour, eliminates cumbersome manual procedures, increases the efficiency and productivity of personnel, reduces (by up to 95%) the volume of liquid analysis waste, eliminates preparation of reagent solutions, and reduces (by as much as 98%) the time during which the analyst is exposed to or in contact with hazardous and toxic solutions.

Ongoing development work is focused on examining additional indicators, expanding and broadening the pH range, and determining other ions of interest, including heavy metals and organic compounds classified as priority pollutants. ■

Researchers have combined sol-gel indicator technology with flow-injection analysis to develop a flow cell for rapidly and precisely measuring the pH of aqueous solutions.

Ultra-High-Performance Cathode-Ray Tube

Measuring High-Speed Electrical Signals

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A team from the Nevada Test Site (NTS) has developed an ultra-high-performance cathode-ray tube system that records very fast, single-transient electrical signals of a speed beyond the capability of current single-transient measuring systems. Very high speed electrical signals are recorded and displayed to more than 30 gigahertz — a first in the field. This feature is possible because the system's sensitivity/bandwidth curve descends very slowly beyond its -3 decibel point of 10 gigahertz. The previous industry -3 decibel standard had been 6 gigahertz.

The cathode-ray tube is contained in an oscilloscope, an electronic instrument that produces a plot on a phosphor screen. The electron beam created in the electron gun passes through deflection and sweep structures, which results in the amplitude of the signals being recorded on the screen as a fraction of time. The incoming electrical signal passes through a specially designed high-bandwidth balun (a balanced converter) before entering the deflection structure. In this structure, the electron beam is deflected vertically in an amount proportional to the size of the incoming signal. The sweep structure steadily sweeps across the phosphor face, thereby creating a visible graph (signal amplitude versus time) on the screen.

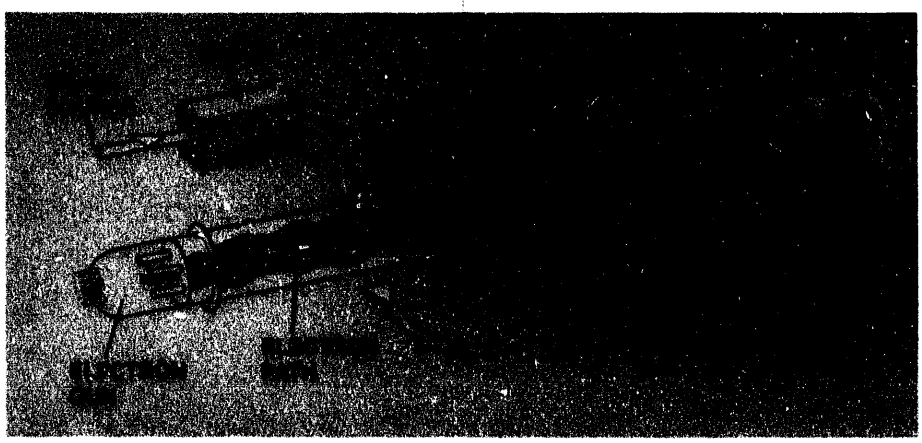
A single sweep of the trace reveals signals that until now had been unrecordable, if they were non-repetitive. (High-bandwidth sampling oscilloscopes measure repetitive signals.) The tube's novel physical configuration reduces signal distortions inherent in conventional systems to a negligible value. In addition, the new cathode-ray tube has no detectable precursor up to at least 10 gigahertz and perhaps well beyond this bandwidth. Together, these features make it possible to study previously unobservable electrical signals with a degree of accuracy previously unattainable.

Cathode-ray tube technology is useful for recording the super-fast electronic signals common in laser and nuclear fusion research and in characterizing the behavior of particle accelerators.

The improved tube design incorporates unique components that use microwave design principles. In developing this system, the NTS team has surpassed all current U.S. commercial research efforts in this area as well as those underway in France and the former Soviet Union.

The ultra-high-performance cathode-ray tube received a 1991 R&D 100 Award from *R&D Magazine*. As design and manufacturing improvements have been made, the device has evolved into a system with even better radio-frequency characteristics, which enable unprecedented high-bandwidth performance.

The ultra-high-performance cathode-ray tube system measures high-speed, single-transient electrical signals with extremely low distortion.



MACHO Camera

Leading the Search for Dark Cosmic Matter in the Milky Way

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The MACHO camera system was originally designed to investigate whether MACHOs make up all or some of the cosmic dark matter. (MACHO, which stands for massive compact halo object, is a generic term for all dark, massive objects in the largely unstudied Milky Way.)

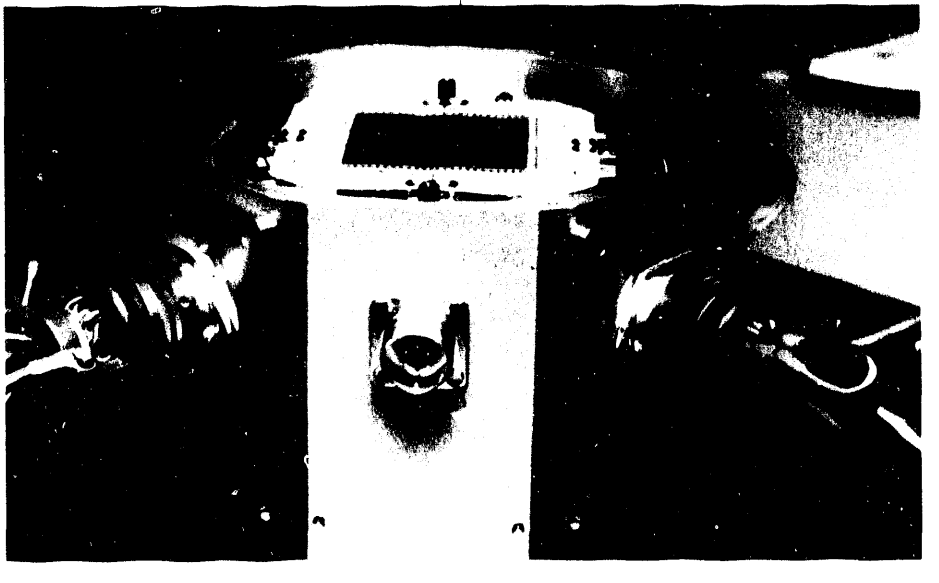
This fully integrated, two-color, digital camera and image processing system fully exploits the new generation of large-format (34 million pixels) charge-coupled device (CCD) imagers. It takes eight two-color images per hour, processes all image data on-line, and immediately archives the data onto tapes while simultaneously writing the data onto magnetic disks. The images are then reduced to photometric measurements, which are archived onto an optical disk "jukebox." The system can make more than 4 million photometric measurements each hour.

A MACHO camera system, which was given an award by *R&D Magazine* as one of the 100 most important new inventions of 1993, was installed in a 1.3-meter telescope at Mount Stromlo Observatory in Australia. Here it will survey up to 10 million stars for a minimum of 4 years. The system will measure most of the stars in the Large Magellanic Cloud two times each night. In its first 3 months of operation, the MACHO camera system recorded more photometric measurements than have been made in the history of astronomy.

The MACHO camera system can be used for any astronomical projects that require frequent surveys of large areas and immediate data processing. For example, a new system is being prepared to search for asteroids whose path might cross that of the earth, with catastropic consequences. Early detection of such bodies could allow enough time to deflect them into a safe orbit.

The use of a MACHO camera coupled with a telescope with a wide field of view is being considered for tracking and cataloging space debris, thereby enhancing the safety of manned space missions. Having two systems simultaneously observe a piece of orbiting debris allows key orbital parameters to be calculated.

Many applications in astrophysics and remote sensing require digital image data to be gathered and rapidly processed. The MACHO camera system could serve as the model for these new designs. ■



The MACHO camera is the largest digital camera in the world. Here its face is removed to show the detector.

Biotechnology

In recent years, advanced imaging and other computer-related technologies have greatly expanded the horizons of basic biological, biochemical, and biomedical research. Also providing impetus to the development of biotechnology have been the needs to explore techniques for environmental remediation and to understand and manipulate genetic systems.

Worldwide competition in the field of biotechnology is intensifying. For the United States to remain a leader in this area, the federal government, industry, and academia need to collaborate on research and development projects and then find avenues for rapidly deploying the results of these efforts.

A researcher prepares a tin-117m DTPA sample for biodistribution studies. For more information on this radiopharmaceutical developed at Brookhaven National Laboratory, see the writeup on *Tin-117m (Stannic) DTPA* on page 171.

High-Speed Camera System for Three-Dimensional Mapping

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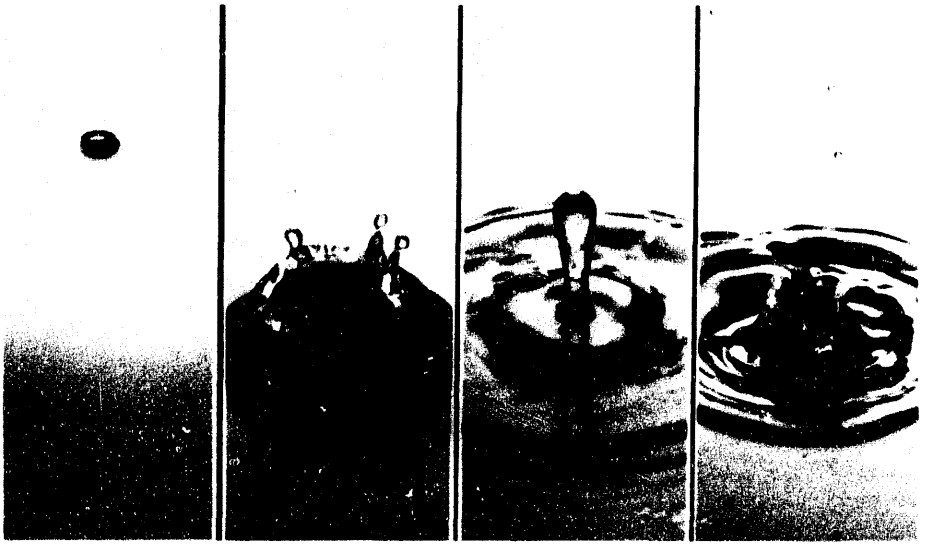
Multipurpose Inspection Tool

Lawrence Livermore National Laboratory (LLNL) has made unique contributions in expanding the capabilities of three-dimensional imaging and broadening its field of applications. The history that led to LLNL's involvement began at the end of the Vietnam War, when the U.S. Department of Defense needed help in identifying the remains of U.S. service personnel. The U.S. Army Institute of Dental Research (USAIDR) proposed using a three-dimensional mapping technique that incorporated standard biostereometric imaging technology. In this technology, two cameras image an object, and because the relative positions of the two cameras are known, triangulation techniques can determine the position of the object in three-dimensional space. How hat time, the technolo to complete the project di .

Later, USAIDR patented an optical device that produced thousands of coherent beamlets when illuminated by a laser. Thus, thousands of points on an object could be lit, a critical feature when a smooth, featureless surface like that of a tooth needs to be imaged.

Then, in 1989, ferric liquid crystals that could be used as spatial light modulators were developed. These crystals allowed unique patterns of beamlets to be selectively turned on and off, at up to 1 kilohertz. LLNL advanced this imaging technology by making us coupled device cameras essors to get highl to the user advances opene ustrial as well s m ions.

The technology has been used in forensic medicine, where topographical data on patients have enabled surgeons to make more accurate dental and orthopedic reconstructions more easily. The high-speed camera system can also be used to inspect products and airport baggage and for industrial process control. Moreover, by using an adaptation of this technology to locate explosives, LLNL expects to reduce costs and double the accuracy of the process. ■



This sequence of images of a falling water drop simulates the capabilities of the charge-coupled device camera.

Laser Fluorescence to Open New Biotechnical Horizons

DNA Sequencing Aided by Multiplex Microfluor Technology

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Scientists at Ames Laboratory have designed an innovative optical spectrometric technique to sequence DNA 1,000 times faster and at less cost than traditional methods. The multiplex microfluor technology is expected to have a major impact on efforts to map the human genome and determine the sequence of DNA bases. This task has been delayed because of the immense challenge of deciphering the 3 billion base pairs that constitute the human genetic code. Hidden within this code are clues that may help cure genetically based diseases like Alzheimer's disease and muscular dystrophy.

The first step in DNA sequencing — separation of components — has been performed by a technique called capillary gel electrophoresis (CGE). The technique uses very small capillaries that can tolerate high electrical fields to quickly separate components. In fact, multiple CGE separations have been run simultaneously. However, because the separated components are present in such small amounts, extremely sensitive methods are needed to detect them. The lack of such detection methods has limited the overall rate at which sequencing can be performed.

The new multiplex microfluor technology addresses this limitation by building on the detection capability of the microfluor detector, a 1991 R&D 100 Award-winning device that detects and quantifies concentrations as low as 10^{-10} moles per liter. The microfluor detector detects the sample by sensing the intensity of fluorescent light emitted when the sample is irradiated by a laser beam.

To "multiplex" this process to work in conjunction with multiple CGE, Ames scientists modified the way the laser light is collected and distributed. The new design offers two alternatives for distributing laser light to many capillaries. In one, light from a single laser source can be directed through optical fibers that have been inserted into multiple capillaries. In the other, laser light can be directed onto the capillaries from the outside. Both alternatives use a scientific-grade camcorder, known as a charged-coupled device, to rapidly and precisely measure the frequency and intensity of the fluorescence emitted from the individual samples. This approach allows simultaneous screening of up to 1,000 samples.

The multiplex microfluor detector could reduce the time to sequence a human genome from 10,000 years to 35 days.

Currently, the best laboratories can read (i.e., sequence) about 100,000 bases per year at a cost of approximately $5.00 to sequence one base. Thus, it would take about 10,000 years and cost about $15 billion for a laboratory to sequence a human genome. The new multiplex microfluor technology makes it possible to sequence a genome in 35 days at a cost of $150 million.

Although the most urgent need for multiplexing is in DNA sequencing, the technology has numerous applications in clinical analysis, where it can be used to study hundreds of samples simultaneously. Testing new drugs or testing for cancer on a single cell could thus be done much less expensively. Ames has filed a patent application for this innovative design and is pursuing commercialization.

Tin-117m (Stannic) DTPA

Radiopharmaceutical to Relieve Bone Pain in Cancer Patients

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A radiopharmaceutical developed at Brookhaven National Laboratory (BNL) — tin-117m (stannic) diethylenetriamine pentaacetic acid (DTPA) — offers great promise for relieving bone pain in breast and prostate cancer patients. In animals, it has been demonstrated to have high concentrations in bone lesions, relative to normal bone and soft tissue. The short-range emissions from tin-117m are less damaging to radiation-sensitive bone marrow than the high-energy beta particles associated with the currently used phosphorus-32.

Studies on patients have been started to measure human biodistribution of tin-117m DTPA. Imaging of the distribution of tin-117m in five human subjects has shown no specific organ uptake, other than in bone, over a period of 1 week. The uptake in bone was quantitatively similar to that in previous laboratory animal studies. In comparison with technetium-99 MDP (methylene diphosphonate) imaging procedures in the same subjects, the preferential uptake of tin-117m at sites of metastatic spreading of malignant cells was essentially identical.

By using estimates based on the data, BNL researchers have calculated the absorbed dose to be 27.4 to 54 milligrays per megabecquerel (100-200 rads per millicurie) to bone surfaces and 2.5-4.87 milligrays per megabecquerel (9.2-18 rads per millicurie) to marrow. The bone-to-marrow ratio of 11 is more favorable than that of any other agent now in use or under investigation. These results promise improved treatment of bone pain in patients suffering from advanced breast and prostate cancer with extensive bone metastases. With the use of tin-117M DTPA, it should be possible to administer larger amounts of therapeutic radiation before encountering dose-limiting bone-marrow toxicity. Therapeutic trials are expected to begin soon.

Promising applications include relief of bone pain, bone cancer therapy, and skeletal scintiphotography (for photographic recording of the distribution of a radiopharmaceutical) for patient follow-up.

Novel Materials to Stabilize Proteins

Enabling Enzymes and Antibodies to Live Longer in Harsh Environments

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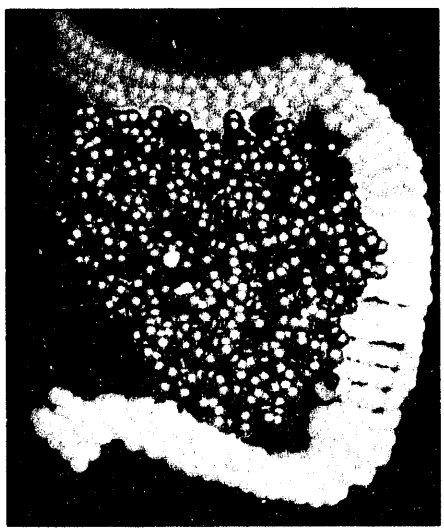
This computer model shows a carbohydrate-based polymer enveloping the proteolytic enzyme subtilisin. The polymer acts as a protective framework to stabilize the protein in high temperatures and harsh solvents.



Novel materials that allow proteins to remain active in hostile industrial environments have been developed through a joint effort by researchers from Lawrence Berkeley Laboratory (LBL), the University of California at Berkeley, Ohio State University in Columbus, and Cargill Corporation of Wayzata, Minnesota. Proteins covalently enveloped by a new series of carbohydrate-based polymers form carbohydrate protein conjugates (CPCs). These CPC-enzymes and CPC-antibodies exhibit enhanced catalytic and binding activities at elevated temperatures and in organic solvents.

The use of enzymes as synthetic tools has been limited by the sensitivity of virtually all proteins — including enzymes — to high temperatures and by their general inactivity in organic solvents. At the same time, enzymes have the potential to revolutionize the synthetic chemistry of materials because they offer high catalytic activity and selectivity. These attributes translate into lower costs for some products and make some otherwise unavailable products available. In addition, enzyme catalysis significantly decreases energy consumption, because enzymes function well at low temperatures and pressures. Enzyme catalysis also greatly decreases or, in many cases, eliminates the production of toxic or wasteful by-products.

Reflecting their biological origins, most proteins function well at body temperature, in aqueous solutions, or when embedded in biological membranes. However, they rapidly lose their binding or catalytic activities at temperatures only moderately higher.

Antibodies, another class of proteins, are critical in detecting disease-causing organisms and can be adapted to detect other biologically important molecules — including toxins and residual pesticides — some of which are not water-soluble. Like other proteins, antibodies are unstable after exposure to organic solvents.

Because many useful industrial syntheses require long catalyst life and the presence of organic solvents, the increased stability of enzymes and other proteins in organic solvents and their improved tolerance of high temperatures are essential. The CPCs of several enzymes that cleave peptide bonds in proteins (CPC-proteases) are stable at elevated temperatures and in the presence of organic solvents. In addition, the catalytic lifetimes of the CPC-proteases are many orders of magnitude longer than those of native enzymes at all temperatures, and some CPC-proteases retain activity at temperatures near the boiling point of water. Further, a conjugated antibody (CPC-antibody) that binds the pesticide aldrin was stable in the organic solvent acetonitrile, retaining 96% of its binding ability after 5 hours. In contrast, the native antibody lost all of its binding capability under these conditions.

This novel CPC approach is applicable to a vast and diverse array of industrial reactions, offering a general solution to increasing protein stability at elevated temperatures and in organic solvents. Potential applications include industrial use of enzymes, diagnostic testing, drug delivery systems, medical devices, and protein synthesis.

Because of the broad extent of its possible commercial impact, this work won a 1993 Federal Laboratory Consortium Award for Excellence in Technology Transfer as well as a 1993 R&D 100 Award from *R&D Magazine*. ■

Cyclohexyl EDTA Monoanhydride

More Effective Tumor Imaging and Therapy

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The potential of radiolabeled antibodies formed from a single cell to serve as selective carriers of radioactivity to specific antigens in living tissue has focused interest on the development of such antibodies for imaging and therapy. However, current techniques that target tumors by attaching radiometals to antibodies are unsatisfactory, because the radiometal-antibody combinations (radioimmuno-conjugates) produced are unstable. This lack of stability results in uneven distribution of radioactivity throughout the organism.

Brookhaven National Laboratory researchers have synthesized the monoanhydride of a semirigid molecule, trans-1,2-diaminocyclohexane N,N,N',N'tetracetic acid (cyclohexyl EDTA monoanhydride, or CDTA-MA), that produces metal chelates with high stability in living organisms. This compound has been attached to antibodies through an anhydride substituent (a replacement group), labeled with a variety of radiometals, and evaluated in nude mice bearing human tumor implants.

Labeled with such radiometals as indium-111, cobalt-57, and scandium-47, which have small ionic radii, these radioimmuno-conjugates produce a much-improved biological distribution, with high and prolonged tumor uptake combined with high tumor-to-normal-tissue ratios. These improvements, which are expected in human patients as well, would allow the use of CDTA-MA-antibody conjugates for more effective SPECT imaging (indium-111), PET imaging (cobalt-55), and therapy (scandium-47).

Likely biomedical applications of this process include (1) radiometal labeling of monoclonal (single-cell-originated) antibodies, for tumor imaging or therapy and for imaging other pathologies, and (2) use as a bifunctional chelating agent for labeling various useful biomolecules. ■

Researchers purify CDTA-MA conjugates by means of high-performance liquid chromatography.

Stereolithography for Generating Biomedical Models

Reducing the Time and Cost of Medical and Genetic Research

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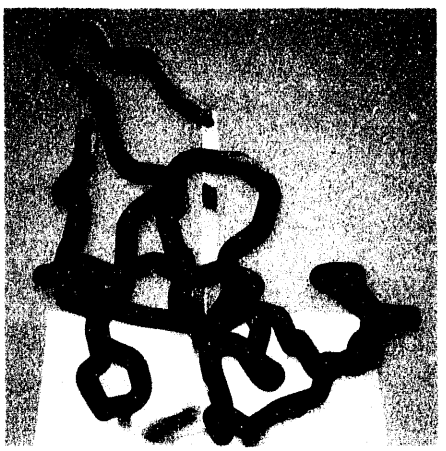
Stereolithography is a process by which solid model data are transferred into a three-dimensional solid object through the use of a laser process and ultraviolet-curable polymers. It has not traditionally been employed by biomedical or genetic researchers in a manufacturing environment. However, the Kansas City Plant (KCP) has linked these two unrelated disciplines by producing the first stereolithographic model of the HIV-1 virus protease monomer.

Stereolithography could also be used to make other three-dimensional models of biopolymers such as DNA, proteins, and viruses. These models could be helpful to instructors and facilitate research in the pharmaceutical industry by reducing the amount of time needed to bring new medicines and treatment methods to market and by lowering the costs of treatment, education, and research.

The stereolithographic method uses a laser beam to make models. The beam first draws a picture, which can be thought of as a sectional view of a solid object, on the surface of a liquid known as a photopolymer. The liquid surface hardens to a very thin film that is a plastic "picture image." Hundreds of such thin film layers are drawn so as to build a model that replicates the laser beam's motion in the form of a three-dimensional, solid model.



This model represents the alpha carbon backbone of the HIV-1 virus protease monomer (produced from Brookhaven National Laboratory's protein data bank file 2HVP), an enzyme critical in the life cycle of the AIDS disease. The model was fabricated from Exactomer™ 2201 resin by using stereolithography.

The stereolithographic method has many beneficial features. It can make some medical and genetic models that are impossible to create by any other method. It reduces the cost of the first model built to about half the cost of one built by any other method; much lower unit costs can be achieved if copies are made by molding. The method results in models that are as precise and accurate as the input data and are as good or better than those produced by previous methods. It shortens the fabrication time for routine models from weeks to days. In fact, with additional development, the method could result in overnight turnaround. Finally, it is amenable to additional innovation; small businesses could tailor the method to their needs by using different materials and processes.

Engineers who have been using stereolithography to make models at KCP sent computer tapes of three-dimensional models to several small stereolithography shops throughout the United States; they have successfully used the method to manufacture parts. The transfer of this technology to U.S.-owned companies is likely to create new jobs and reduce the amount of time needed for biomedical research. ■

Computer-Assisted Mammography Screening

Biomedical Image Processing

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Early detection is the best defense against breast cancer. Sandia National Laboratories has developed new computer software that enables subtle cancer indicators to be discovered during the early stages of tumor formation.

When radiologists evaluate an x-ray for cancer, they search for three primary signs: microcalcifications, circumscribed lesions, and stellate lesions. Stellate lesions, which are star-shaped distortions in breast tissue, are the most difficult to detect visually. They generally appear as tiny variations in normal breast patterns. Sandia's new system analyzes digitized x-ray films for certain visual features indicative of breast cancer. If found, it marks them for further examination by a radiologist. The image analysis system focuses on stellate lesions, which are almost always associated with a malignancy.

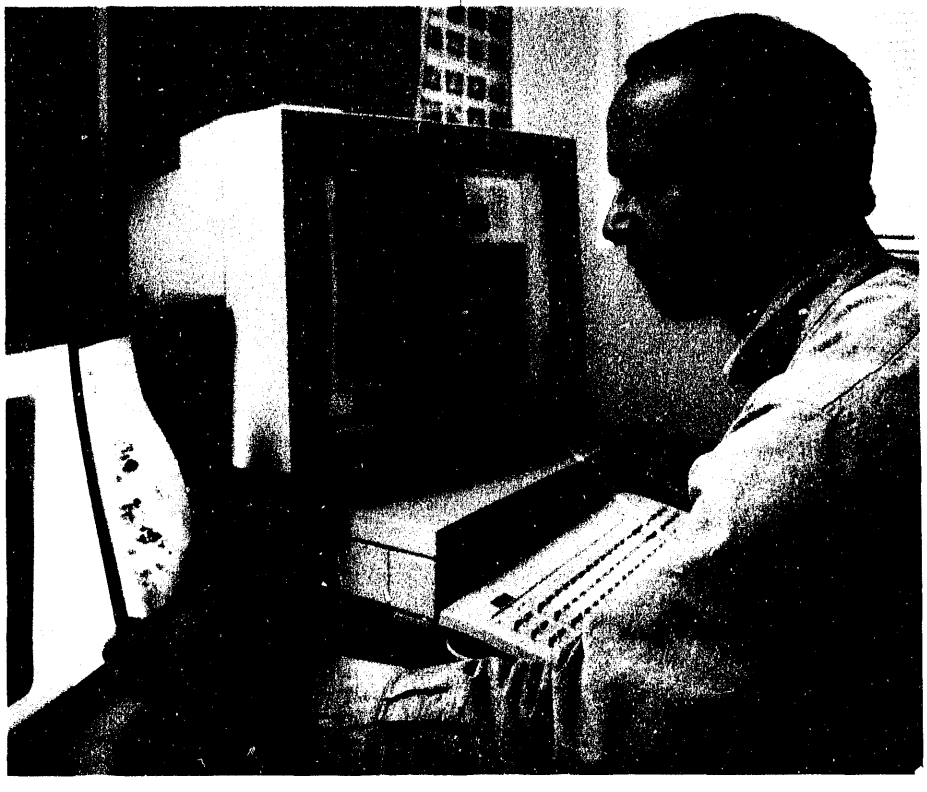
Conventional mammography fails to detect cancer 10-20% of the time. The failure rate can be even higher when radiologists are inexperienced or when fatigue or high volumes of x-rays lower their visual acuity. By functioning as a second reader of mammograms, the software can help reduce the chance of missing suspicious lesions.

The primary feature used to detect stellate lesions is an algorithm called ALOE (analysis of local oriented edges). This algorithm provides a new method for describing radial textures. Local image features, ALOE, and other features are extracted (on a per-pixel basis) from the known images. These elements are then used to grow binary decision trees for labeling each pixel of a mammogram with its probability of being located on a stellate lesion. Fine discriminations are made on the basis of subtle changes in the visual texture of the image.

In a retrospective clinical study, these algorithms were tested on a set of 85 four-view mammography cases compiled from the film library at the Scott and White Research Clinic in Temple, Texas. Represented in the set were 49 normal and 36 cancer cases. Cancer was detected in all 36 cancer cases. By using the software, radiologists increased their ability to detect tumors by an average of 10%, with no increase in the false-alarm rate.

Breast cancer kills 40,000 American women annually. Mammographic screening is currently the most effective method of early detection. An automated image analysis system that would make a radiologist's screening efforts more efficient and accurate could help prevent some of these deaths. ■

New computer software is being used to analyze digitized x-ray films for the presence of stellate lesions, which are strong indicators of cancer. It circles suspicious areas on a mammogram for further scrutiny by a radiologist.



Method to Promote the Specific Alignment of Short Primer Molecules on Nucleic Acids

Increasing the Efficiency of DNA Sequencing

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Biologists at Brookhaven National Laboratory (BNL) have developed a method for promoting the specific alignment of short molecules used as primers on a nucleic acid polymer. Applications of the method include priming DNA (deoxyribonucleic acid) synthesis and template-directed binding of biological compounds. High-capacity sequencing machines can employ this method to sequence DNA more than 10 times faster and at a substantially lower cost than current methods.

Scientists at BNL have radically improved and simplified a standard sequencing method called "primer walking." Because only 500 of the 3 billion base pairs of human DNA can be identified, or read, at a time, DNA chains must be sequenced in steps. Once part of the sequence of a DNA chain is known, scientists can make a primer for it. A compound known as DNA polymerase then extends this primer to read the next 500 bases. Knowing the new sequence, scientists can then make another primer and read another 500 bases. Successive primers are used to "walk down" the entire template chain, with about 500 bases being read in each step.

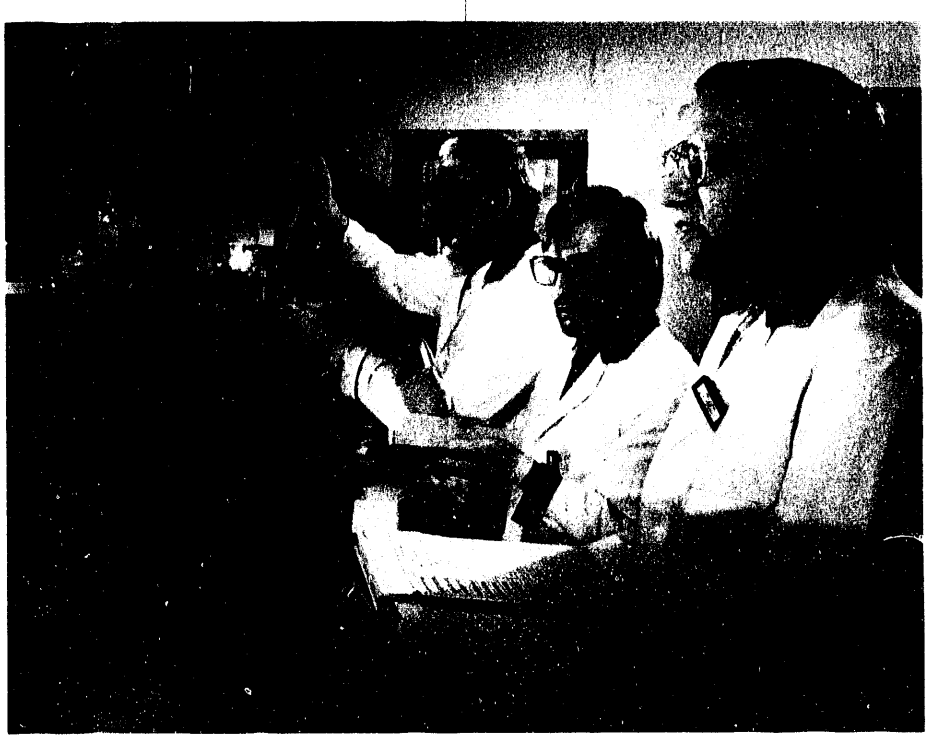
Chains of DNA are made up of different combinations of only four kinds of bases: A,T, G, and C. To be sure of priming at only one place in the template chain, scientists have been using primers about 15 to 20 bases long. Such primers cost about $50 each and take at least 1 or 2 days to prepare.

The BNL researchers' idea for making primer walking cheaper and faster was to use shorter primers but to join them together to form longer ones. The researchers found a way to prime DNA sequencing by using a combination of three hexamers — primers only six bases long. This breakthrough promises to increase the speed of DNA sequencing at least tenfold.

How can such small primers work? The scientists found that coating the template DNA with a protein called SSB keeps individual hexamers away from the DNA. However, three hexamers that can pair to the template exactly next to each other can "elbow aside" the SSB and prime effectively.

The nucleic acid polymer is incubated in a solution containing a single-stranded DNA-binding protein and a large number of hexamers that are perfectly complementary to distinct, adjacent regions of a predetermined

Biologists display a new method for speeding up DNA sequencing by promoting specific alignment of short hexamers of six bases each on nucleic acid polymers.



nucleotide sequence in the nucleic acid polymer. The hexamer sets anneal to the polymer to form a contiguous region of double-stranded nucleic acid.

Priming with hexamers will make sequencing much less costly. The four original bases (A, T, G, and C) in hexamer chains can be combined in 4,096 possible ways, so each hexamer will be used over and over in sequencing the 3 billion base pairs of human DNA. A single preparation provides enough hexamers to prime thousands of times, so the cost for each priming can be reduced from $50 to less than a penny. Hexamers will also make sequencing much faster and easier. A "library" of all 4,096 hexamers can be accumulated, making any primer immediately available. Scientists will no longer have to wait for a primer to be made.

Extensive testing with all 4,096 hexamers will be needed to see how efficient and reliable the method is for large-scale sequencing. If the method fulfills its promise, automating the process should be relatively easy. BNL is now exploring possible licensing arrangements and partnerships to further develop and commercialize this technology. ■

MAP: Software Tool for the Human Genome Project

Mapping Chromosomal DNA Fragments

Los Alamos National Laboratory (LANL) scientists have developed an interactive computer program called MAP to help researchers order (map) fragments of DNA for the Human Genome Project. The Human Genome Project is an international research effort designed to unravel genetic information that is contained in the human genome.

Chromosomes are too complex to be studied in their entirety, so researchers cut them into fragments for easy handling and analysis. Individual DNA fragments provide important information, but thorough understanding of the human genome comes from knowing the linear arrangement of the fragments. Such information on the spatial organization of genes and other chromosomal regions will lead to better understanding of gene regulation and function.

The key to organizing the thousands of DNA fragments that make up individual chromosomes lies in finding regions common to two or more fragments. These overlapping regions are then used to deduce the fragments' linear arrangement.

The MAP program analyzes data about overlapping regions to determine possible arrangements for a given collection of DNA fragments. The program applies probabilities and graph theory (a type of mathematical modeling that focuses on the structure of graphs and networks) to this analysis. MAP displays arrangements both graphically and linearly so users can review its suggestions in several formats. Furthermore, the program suggests preferred alternatives, that is, the most probable arrangements for the overlapping regions.

The MAP program was originally designed to evaluate the effectiveness of other automated mapping

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programs. MAP found these programs to be error-prone because they did not consider the possible combinations of fragments before determining the "absolute" order. MAP's interactive program accommodates newly assembled data and considers users' knowledge of particular genomic regions. In addition, MAP detects inconsistent data. Data that cannot be easily converted from graphic to linear representation probably contain physical inconsistencies. MAP offers strategies to resolve these problems.

Researcher studies an autoradiograph of DNA fragments to collect data on overlapping regions. A graphic representation of possible overlaps is shown below the autoradiograph.

Compared with manual techniques, MAP orders fragments faster, more accurately, and less expensively. Manually shuffling the DNA overlap data from thousands of fragments to ensure that all overlap possibilities have been tried would be time-consuming and expensive. MAP's computational and statistical abilities help determine the most likely order for DNA fragments.

Although currently used for organizing genomic DNA fragments, MAP can also help solve interval-related relational problems. Its interactive format enables users to make informed choices about virtually any type of linear-interval data that can be organized according to graph theory. Other specific applications include geological time-sequencing of rock strata, computer chip layout and design, computer network design, or routing paths for air travel. MAP will eventually become an application of a larger graph tool called LINK, which will combine object-oriented coding and design theory with graph theory to provide a comprehensive modeling package. Current development plans for MAP include commercialization in the near future. ■

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Selenium-Based Reagents

Enhancing the Evaluation of Chiral Molecular Structures

Chiral drugs consist of right- and left-handed molecular structures that are mirror images of each other. Although nearly identical structurally, these molecular forms can have significantly different clinical effects. One form may have a desired effect, and the other may have an undesired effect, or it may be less potent, inactive, or harmful.

In response to the need to detect and evaluate the properties of chiral drugs, scientists at Los Alamos National Laboratory (LANL) collaborated with chemistry researchers at the University of South Carolina to develop certain selenium-based chemical reagents. When these reagents react with a chiral molecule, they detect the presence of and quantify the proportion of right- and left-handed molecules in

the sample. This flexible and sensitive analytic technique for quantitating and characterizing chiral molecular systems is expected to be useful to the pharmaceutical industry as well as to chemists performing basic research.

Because of the potential dangers of chiral mixtures, the U.S. Food and Drug Administration issued new guidelines on the marketing of chiral drugs. These guidelines attempt to address issues that arose because of the thalidomide birth defect tragedy in the 1950s as well as recent progress in chiral chemistry and other drug efficacy issues. Most drug companies have now elected to market chiral drugs containing only the desirable, pharmacologically active form.

A major advantage of selenium-based reagents is the sensitivity of the chiral signal. A selenium-based reagent can detect chirality when as many as nine atomic bonds separate the selenium nucleus and the molecule's chiral center. In contrast, the signal of nonselenium reagents is frequently lost when the chiral reporter group is bound five or six atomic bonds away from the chiral center.

Another advantage is that selenium-based reagents can also be attached to a wide variety of chemical groups or compounds. Nonselenium reagents can be attached only to alcohols and amines or to carboxylic acids.

The potential benefits of selenium-based reagents to the pharmaceutical industry are incalculable. It can use these reagents to quantitate and evaluate the various three-dimensional forms of chiral drugs. Of the 1,327 synthetic drugs on the market, 528 exist as mirror-image forms. Yet only 61 of the 528 drugs are marketed in their pure forms; the rest are sold containing both forms.

In 1990, the global market for pure chiral drugs was valued at $1.8 billion. Sales of products used to manufacture pure chiral drugs are projected to increase to $2.8 billion in fewer than 10 years. Selenium-based reagents used to evaluate chiral drugs will be an important factor in this market.

A patent for selenium-based reagents was issued to the University of South Carolina. Selenium-based reagents received a 1993 R&D 100 Award from *R&D Magazine.*

Scientist examines a computer-generated model of a selone molecule.

Diagnostic and Laser Debridement System for Burn Patients

Speeding Recovery and Reducing Health Care Costs

Sandia National Laboratories and Wellman Laboratories of Photomedicine, located at Massachusetts General Hospital in Boston, are collaborating to optimize two experimental systems for treating burns that were initially developed by Wellman. The first system, which uses sensors to diagnose the depth of a burn injury, will be integrated into the second system, which uses a high-speed laser to perform the microscopically precise removal of burned, dead skin. The four-year project will be conducted through a cooperative research and development agreement.

The endeavor combines Wellman's novel approach to burn diagnosis and therapy with Sandia's expertise in systems integration, risk analysis, computer modeling, microsensors, robotics, and engineering design. The new system promises to accelerate patient recovery by increasing skin graft success and decreasing blood loss and infection risk. It could also lower health care costs by minimizing the need for blood transfusions, reducing the number of days a patient must spend in the hospital, shortening anesthesia and operating room times, and limiting debridement to areas of deep burn injury.

Under conventional treatment methods, surgeons use a scalpel to remove dead skin before performing skin grafts. This cutting results in massive bleeding that makes grafting difficult or, at times, unsuccessful. Because surgeons must rely on sight to define where dead tissue ends and healthy tissue begins, they may remove large amounts of healthy tissue, which reduces the chance of a successful graft, increases the possibility of infection, and can lead to patient death in severely burned patients.

The new sensor technology will enable the depth of the injury to be better understood. First, a fluorescent dye will be injected into the patient's bloodstream, and the intensity of the fluorescence will be measured under ultraviolet and infrared lights to determine burn depth. (Blood does not flow through burned areas.) Next, the surgeon will use laser technology to debride the correct amount of tissue and prepare the burn area for grafting. The laser's principal advantage is that the laser ablation process burns an additional thin layer (100 to 200 micrometers) of live skin, which stops the profuse bleeding that occurs under current surgical methods but allows nutrients to reach the tissue.

The initial focus of the work will be to develop an experimental system for detailed studies of tissue ablation and sensor techniques. Sandia will also concentrate on the analysis and elimination of potential safety problems. Subsequently, Sandia's systems engineering capability will be applied to help integrate safety features, robotics, optics, image processing, computer modeling, sensors, and control systems to create the prototype burn debridement and laser ablation system. Researchers are investigating the use of a pulsed carbon dioxide laser for the prototype system.

With more than 100,000 burn victims being admitted to U.S. hospitals annually, resulting in direct health care costs of more than $2 billion per year, the potential benefits from this new method could be enormous. Possible future applications include treatment of frostbite and skin ulcers and resection of skin tumors.

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Crystal Structure of a Protein Involved in Cell Division

Developing Drugs to Prevent Cancer

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Scientists at Lawrence Berkeley Laboratory and the University of California at Berkeley and at San Francisco have, for the first time, identified the three-dimensional structure of a key protein that is directly involved in controlling cell division. Since uncontrolled cell division is the hallmark of cancer, knowledge about the structure of this protein could lead to development of drugs that inhibit cell division.

The protein is called CDK-2, for cyclin-dependent protein kinase. (Kinases are a category of enzymes.) CDK-2 and CDC-2 (cell division cycle protein kinase) are crucial proteins that represent the last signals in the chain of events leading to cell division. In particular, CDC-2 may give the final signal for a cell to divide into two equal halves, and CDK-2 is thought to trigger the "start," the point at which the cell irrevocably commits itself to division.

Two types of cancer have been linked to this protein, in that they involve a mutation in the gene coding for proteins called cyclins that are needed to activate CDK-2. One type, liver cancer (hepatocellular carcinoma), is apparently triggered when the hepatitis B virus slips into the middle of the cyclin A gene and disrupts it. The other type, a parathyroid tumor, is triggered when the cyclin D1 gene is rearranged. In both cases, cyclin is overproduced, which may overstimulate CDK-2 and CDC-2 and drive the cells to divide continually, producing a tumor.

Although there is no hard evidence in mammals that hyperactivation of CDKs leads to uncontrolled cell division, researchers think it probable. If they are correct, designing an effective inhibitor of CDKs would be the perfect way to shut down cell division.

Knowing the three-dimensional structure of CDK-2, drug designers can now try to design molecules that latch onto the protein and inhibit or even inactivate it. One possible target is the area where cyclin attaches to the protein. Another potential target is the protein's active site.

Drug designers can try to control cancer by targeting proteins involved at the beginning of the signal chain, when the initial cell growth signal comes in; in the middle of the signal cascade; or at the end. The CDK-2 and CDC-2 proteins are the last points at which one can intervene.

Structure of human CDK-2 complexed with Mg^{2+} ATP. The α-helical sections are shown as helical coils, ß-strands are arrowed ribbons, and connecting loop regions are curved strings. Bound ATP is shown as sticks, and magnesium ions are shown as a ball.

Three-Dimensional Ultrasonic Imaging to Design Artificial Limbs

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Researcher lowers a "phantom" limb used for testing purposes into the tank of an ultrasonic scanner. The instrument will create a three-dimensional map of the limb, showing precise locations of tissue and bone. This information will be used to fabricate a well-fitting prosthetic device.

Increasing Patient Comfort and Reducing the Cost of Prostheses

Researchers at Sandia National Laboratories have demonstrated a three-dimensional ultrasound imaging system that scans a below-the-knee amputee's residual limb and produces a geometrical map showing the location of bone and tissue. The resulting image can be used in fabricating a comfortable prosthesis at a cost far below that of conventional prostheses. The new system was developed in collaboration with the University of Texas Health Science Center, San Antonio, which had already developed a laser-based system. The ultrasound system provides the advantage of below-the-surface mapping, giving better information on pressure points. The key to a good fit is to avoid pressure on bony surfaces.

The current method for fabricating prostheses is time-consuming, costly, iterative, and imprecise. The artificial limb is created by making a plaster mold of the patient's residual limb, making biomechanical adjustments on the mold, building the prosthesis, and making final adjustments. The prostheses rarely fit well on the first try and must be readjusted. An incorrectly fit artificial limb can lead to pressure sores, blood supply problems, tissue damage, and discomfort.

The cost for one prosthesis can range from $3,000 to $10,000. Most amputees need from three to five prostheses during the first 3 years because of muscle atrophy; thereafter, they need new ones about every 4 years. Researchers estimate that by using Sandia's method, an artificial limb could be created for less than $1,000 more quickly than it could be by conventional methods.

Biomechanical adjustments to improve fit could be made with the aid of computer software. The geometrical map produced by the ultrasound system is similar to magnetic resonance imaging (MRI) or computer-aided tomography (CAT) scans. However, whereas MRI or CAT scan equipment costs about $1 million, the ultrasound equipment costs less than $100,000. Another benefit of the ultrasound system is that mobile units could serve rural areas.

The system works by lowering the patient's residual limb into a water-filled tank equipped with an ultrasound transducer. The transducer circles the circumference of the tank, recording several hundred two-dimensional images that are rendered into a three-dimensional image through custom software. Image-processing software is used to filter noise, remove motion, and extract surfaces to clarify the image of the limb. The final computer model can be used by a "computer numerically controlled" (CNC) machine or other rapid prototyping equipment that mills and lathes.

The new system has the potential to help many patients. Of the almost 200,000 prostheses produced in the United States each year, about 60% are for below-the-knee amputations. In addition, Sandia has had inquiries from foreign countries seeking help for war casualties. ■

HIV Protease-Inhibitor Complex Structure

New Strategies to Control the AIDS Virus Infection

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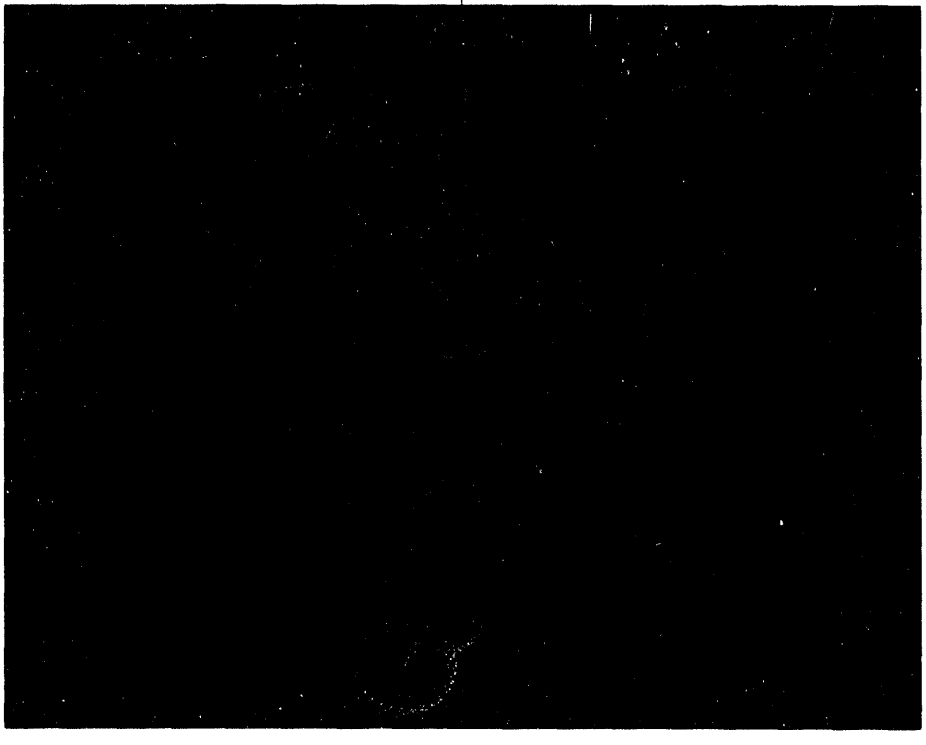
The human immuno-deficiency virus (HIV) associated with acquired immune deficiency syndrome, or AIDS, reproduces itself inside infected host cells. In the replication process, the virus makes six different proteins at the same time, in the form of a single, long amino acid chain. An enzyme called HIV protease attaches itself to this many-protein chain and cuts it into its component proteins. Because this chain-cutting process is unique to HIV (proteins are made individually in humans) and is required for viral replication, the HIV protease represents a promising point of attack against the virus. The current strategy is to inhibit the enzyme's activity without disrupting the metabolism of the host cell.

X-ray crystallography of the macromolecules involved in the AIDS infection cycle — with synchrotron radiation providing a source of intense, tunable x-rays — is one research tool used in efforts to control and stop this viral infection. The Stanford Synchrotron Radiation Laboratory (SSRL), a division of the Stanford Linear Accelerator Center (SLAC), is collaborating with the Institute of Bio-organic Chemistry of Syntex Research in Palo Alto, California, to determine the structure of chemical complexes that incorporate HIV protease inhibitors designed and synthesized by Syntex. The team has succeeded in growing crystals of one such complex and has used SSRL's facilities to collect diffraction data on the macromolecules involved. From the diffraction data, the structure of the complex has been determined.

Detailed views of the structure reveal the key features that enable the enzyme to bind to the viral chain and then cut it into its components. The inhibitor blocks the active site of the enzyme where the chemical reaction takes place.

By determining the structure of complexes linking HIV protease and its inhibitors, researchers in the SLAC-Syntex collaboration can determine which features of the inhibitors are functionally important. Syntex Research will then be able to design more effective inhibitors that retain these features but also are highly soluble and can readily cross the host cell's membrane to reach the HIV protease. ■



A synthetic inhibitor molecule is shown blocking the "active site" (where chemical reactions take place) of the HIV protease enzyme.

Photocatalytic Degradation of Organic Contaminants

Destroying Chlorinated Aromatics in Drinking Water

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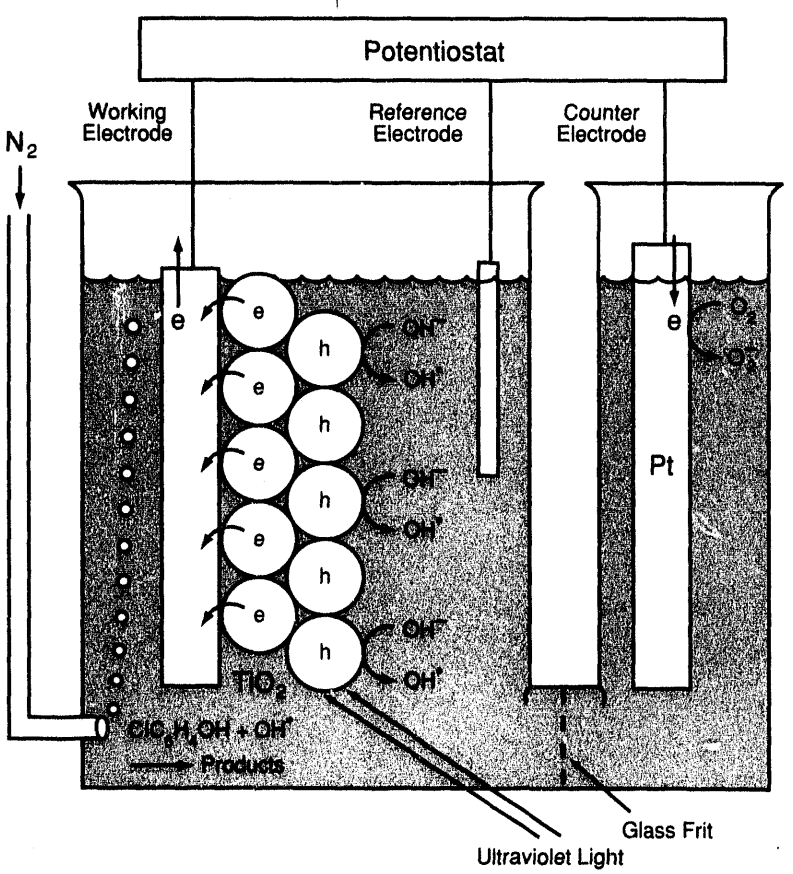
By using ultrasmall semiconductor particles as photocatalysts, researchers at the Notre Dame Radiation Laboratory (NDRL) have successfully destroyed a variety of organic contaminants typically present in drinking water. The key to the technique is the ready oxidation of haloaromatics, such as 4-chlorophenol, when they are placed on the surfaces of semiconductor particles in the presence of ultraviolet radiation.

Engineering researchers from Notre Dame's Civil Engineering and Geological Sciences Department, working with DOE scientists, have employed NDRL's flash photolysis and pulse radiolysis facilities to explore the mechanistic and kinetic details of the photodegradation processes. Through an understanding of the dependence of photocatalytic efficiency on light intensity, catalyst concentration, and promoters such as oxygen, investigators have succeeded in optimizing reaction conditions.

In experiments with electrochemically assisted photocatalysis, researchers have immobilized titanium dioxide particles on transparent, conducting glass surfaces to produce semiconductor particulate films. Improved photodegradation rates and yields have been achieved by applying an electrical potential to these films.

Coupled semiconductor systems and photosensitization techniques are also being developed for using visible light to degrade organic dyes, in particular textile dyes.

This work is being conducted under the auspices of the Notre Dame Center for Bioengineering and Pollution Control, of which NDRL is an institutional member. The Center provides a framework in which NDRL's resources can be matched with those of the University's academic departments to address multidisciplinary questions. ■



In this schematic representation of an electrochemical cell, ultraviolet light strikes an electrode coated with a layer of colloidal particles. Hydroxyl radicals produced in the resulting photochemical reaction destroy chlorophenol in the solution.

Deep-Frozen Fruit Flies

Putting Fruit Flies on Ice for Future Use

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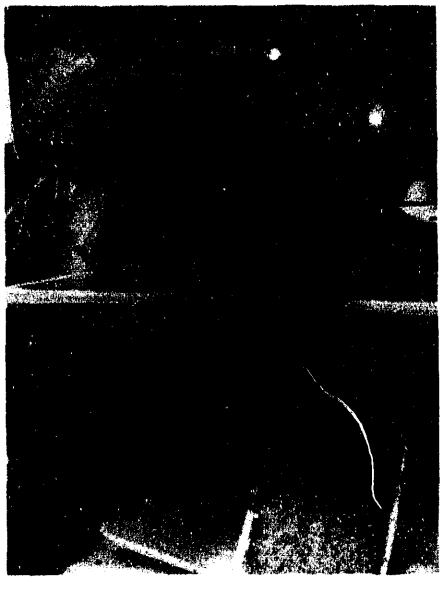
Geneticists find the fruit fly very useful because its genome is like the human genome. A new way of preserving the embryos of fruit flies through cryopreservation techniques has been developed.



Millions of taxpayer dollars could be saved each year by a new technique for deep-freezing fruit fly (*Drosophila*) embryos. Biologists at Oak Ridge National Laboratory (ORNL), in cooperation with University of Chicago scientists, developed the successful technique.

The new method can preserve embryos for an estimated 1,000 years, and it has a 20% success rate for thawed embryos hatching into fertile adult flies. According to ORNL researchers, cryopreservation (using extremely low temperatures) also could ensure a more genetically consistent stock of the flies for future research.

Because it is readily cultured in the laboratory, and its chromosomes are often large enough to be easily seen through a microscope, even at the larval stage, *Drosophila* is highly useful for genetic research. Because of its genetic likeness to the human genome (the whole of an organism's genetic information), the fly's genome has been listed as one of the five most significant genomes to be sequenced as part of the worldwide Human Genome Project.

Particularly convenient for geneticists is the fly's 10-day life cycle, which makes it relatively easy to study genetic mutations throughout many generations. However, this short lifetime makes it necessary to constantly breed the flies to maintain sufficient laboratory stocks. This task is both expensive and risky. The major risk is genetic drift, wherein spontaneous changes occur in the organism's genetic blueprint from generation to generation; in addition, the possibility always exists of flies being incorrectly labeled, which could contaminate the stock. Maintaining a single stock costs roughly $200 a year, and 10,000 to 30,000 different genetic stocks are now maintained.

Compounding the ordeal of keeping thousands of stocks of fruit flies has been the frustrating fact that only about 20% of them are in use at one time or another. Yet the remaining 80% must be maintained as part of the record of past research or as the subjects of future studies.

For decades, scientists searched for an effective method for deep-freezing fruit fly embryos without damaging them. The eggs are highly sensitive to cold, and they are shrouded in a protective, waxy membrane that resists water and other solutions used in the cryogenic process. Attempts prior to 1990 had been unsuccessful.

Cryogenic preservation of 80% (those not in use) of 15,000 stocks by means of the new technique could save a conservatively estimated $2.4 million annually. The savings would increase to $6 million per year if 100% of 30,000 stocks were deep-frozen.

The ORNL research team, in consultation with a *Drosophila* expert at the University of Chicago, identified critical steps in the freeze/thaw process to achieve success. *R&D Magazine* deemed the technique one of the year's 100 most significant achievements, bestowing upon it a 1993 R&D 100 Award. ■

Substituted 6-Nitroquipazines

Treating Depression and Other Serotonin-Related Conditions

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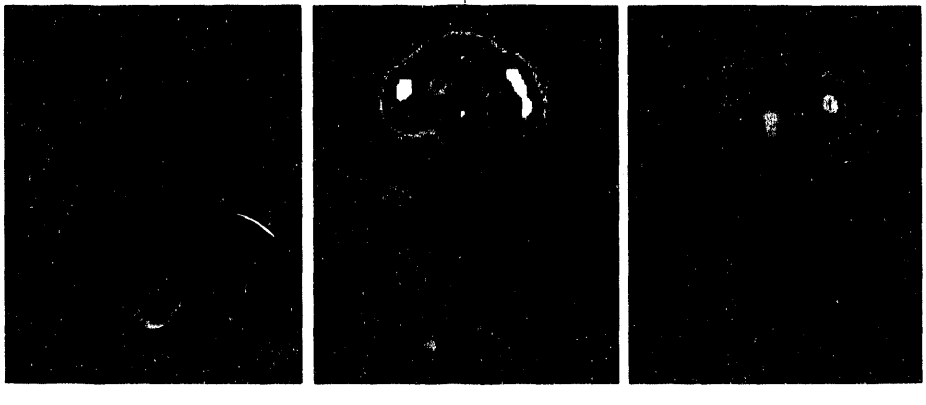
Researchers at Lawrence Berkeley Laboratory (LBL) have synthesized a new family of pharmacologically active compounds — substituted 6-nitroquipazines. They expect these compounds to be useful in both diagnostic and therapeutic arenas. As an example, methods are under development for using them as imaging agents for serotonin reuptake terminals in the brain. Work is now focusing on imaging by means of the noninvasive techniques of single-photon emission-computed tomography and positron emission tomography.

The pharmacology of these substituted 6-nitroquipazines suggests that they might be therapeutic in treating depression and other serotonin-related diseases. Serotonin, a neurotransmitter in the brain, has been linked to a variety of functions. For example, patients suffering from depression and neurological disorders such as Alzheimer's disease and Parkinson's disease characteristically exhibit reduced activity of serotonergic neurons. LBL researchers have found that substituted 6-nitroquipazines bind to serotonin reuptake receptors with exceptionally high specificity and affinity. Therefore, imaging procedures using these compounds may serve as valuable diagnostic tools for selecting patients to be treated.

Tricyclic compounds such as imipramine, amitiptyline, and nortriptyline have been used in the clinical treatment of mental disorders, particularly depression. Tricyclic drugs inhibit the uptake of monoamines, including serotonin. However, they also bind directly with receptors for other neurotransmitters in the brain. This nonspecific interference with other neurotransmitter receptor functions is believed to contribute to certain undesirable side effects, such as dry mouth, dizziness, blurred vision, constipation, urinary retention, tachycardia, memory dysfunction, drowsiness, and weight gain.

Fluoxetine (i.e., Prozac) is a potent and specific inhibitor of serotonin reuptake that has fewer side effects than tricyclic amines. Extensive studies at LBL have found that substituted 6-nitroquipazines have considerably higher affinity for binding to serotonin reuptake sites than Prozac or the newly introduced sertraline, Zoloft. The studies suggest that lower doses of substituted 6-nitroquipazines could be used as an alternate treatment for depression and other serotonin-related conditions, with fewer side effects. The market for antidepressant drugs of this type is enormous. In 1991, sales of Prozac totaled more than $1 billion; those of Zoloft totaled more than $200 million.

The Laboratory is seeking companies interested in collaborative arrangements related to diagnostic or therapeutic applications or in licensing these patent-pending compounds. ■



This magnetic resonance image demonstrates the coronal section of a primate's brain (left). These single-photon emission-computed tomographic images show ^{123}I-5-iodo-6-nitroquipazine uptake in the brain 1 hour after injection (center) and 5 hours after injection (right). Immediately after injection, the uptake of the tracer is homogeneous, reflecting blood flow. By 5 hours, the tracer is washed out from brain regions with a low density of serotonergic terminals and retained in the brainstem, a region with a high density of serotonergic terminals.

Phase-Sensitive Flow Cytometer

Resolving Multiple Fluorescent Probes and Quantifying Fluorescence Lifetimes

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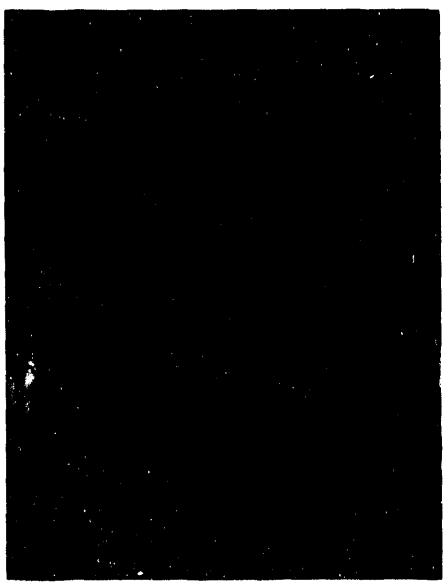
The flow chamber of the phase-sensitive flow cytometer is illuminated by an intensity-modulated laser beam, which is used to excite cells, subcellular components, and other particles labeled with fluorescent dyes. The large, circular area in the background is the front surface of the fluorescence detector light-collection lens.



Flow cytometry quickly measures differences between cells and between subcellular particles and distinguishes among individual cells and particles within populations or subpopulations. Developed at Los Alamos National Laboratory (LANL) in the 1970s, flow cytometry has become an important tool for use in clinical and biomedical research laboratories. The technology dominates world markets and forms the basis for an $800-million-a-year business for three U.S. companies.

Los Alamos is leading the way in flow cytometry research and development. The Laboratory's single molecule detector — a technology derived from flow cytometry — received a 1991 R&D 100 Award from *R&D Magazine*. The phase-sensitive flow cytometer — a novel instrument that expands the range of this important laboratory tool — received a 1993 R&D 100 Award.

In addition to making conventional flow cytometry measurements, the phase-sensitive flow cytometer electronically resolves signals from different dyes. This capability facilitates the use of multiple dyes on the same sample. Because dyes bind to specific targets, this capability also increases the number of properties that can be analyzed simultaneously. In the past, many such procedures were limited by the availability of dyes having both common excitation regions (so that a single excitation source could be used) and the availability of emission spectra sufficiently distinct to allow optical filters to separate them.

Unlike conventional flow cytometers, which use direct, unmodulated laser light, the phase-sensitive flow cytometer uses a high-frequency, intensity-modulated (sinusoidal) laser beam to excite the cells. A detector picks up fluorescence emission signals and then processes them in one of two ways. Signals can be passed through a filter that removes the high-frequency component, thereby converting the signals to low-frequency, conventional flow cytometry signals. Alternatively, signals can be processed through phase-sensitive detection electronics, which resolve individual signals that can be used to determine the lifetimes of individual dyes. The differences in these lifetimes can be used to separate the signals from multiple dyes. By separating signals electronically, the phase-sensitive flow cytometer eliminates the light loss — and hence, data loss — caused by optical filtering. Phase-sensitive measurement capabilities can easily be added to existing commercial flow cytometry systems.

This novel cytometer can be used for virtually any clinical or research application that requires analysis of cells (including plant cells and microorganisms) or subcellular components stained with fluorescent dyes directed to specific targets. The device can track minute changes that occur as cells change from normal to abnormal or analyze changes in subpopulations of cells, such as the shifts in a patient's immune cells as AIDS progresses.

The phase-sensitive flow cytometer is sensitive enough to analyze chromosomes. In addition, it can use fluorescence lifetime as a spectroscopic probe to study interactions of dyes with their targets for structural biology studies. Additional applications include characterizing microorganisms; analyzing plant genetics, diseases, and nutritional requirements; studying cellular physiology and pharmacology; and assessing the quality control efforts of pharmaceutical and biotechnology companies.

Manufacturing

Although the United States has historically been considered a world leader in manufacturing, it has been losing its competitive edge in this century, as other countries have expanded their capabilities. It is critical that the most advanced manufacturing technologies possible be available to U.S. manufacturers. The processes and equipment used to design, engineer, and manufacture products and the organizational technologies, methods, and expertise needed to manage production and commercialization must be continually researched and updated if the U.S. manufacturing sector is to take its place in the vanguard of the worldwide community of manufacturers.

As seen through an infrared viewer, a new solid-state laser cuts through a piece of steel 1/16th of an inch thick. For more information on this laser developed by Lawrence Livermore National Laboratory and General Motors, see the writeup on *New Laser Technology for More Reliable and Flexible Manufacturing* on page 202.

AMTEX™ Partnership

Multilaboratory Collaboration with the Textile Industry

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A multiyear partnership between the textile industry and several DOE laboratories represents a dramatic breakthrough in government-industry cooperation. For the first time, national laboratories will formally integrate research and applied technology efforts with each other under one master cooperative research and development agreement (CRADA) to serve industry needs and increase U.S. competitiveness.

The American Textile Partnership, or AMTEX™, is a consortium of five textile research and development organizations and 10 DOE laboratories. It was formed in response to a textile trade deficit of $31.6 billion in 1992 and the loss of 500,000 textile industry jobs over the past 12 years. (The textile industry contributes $53 billion to the gross national product and supplies 12% of all manufacturing jobs.) The CRADA between DOE and the textile industry was signed 90 days after discussions began; research projects began less than a year after the AMTEX program was initiated. AMTEX is expected to help the industry regain its international competitive edge, develop new processes, and create more jobs for a broad range of American workers.

Pacific Northwest Laboratory (PNL) held the initial discussions with the textile industry. Then, realizing that the industry — being vertically integrated and having complex needs — was particularly well suited to benefit from the expertise available throughout the DOE complex, PNL approached other laboratories. Textile industry leaders identified five nonprofit research, education, and technology transfer organizations to serve as the interface between the industry and laboratories. They also identified five areas in which they needed assistance: improving materials and processes; analysis, simulation, and computer integration; environmental quality and waste minimization; energy; and automation.

Each DOE laboratory assigned personnel as team leaders and members in areas of its choosing. The teams are working closely with industry to identify needs and develop research and technology application projects. PNL staff will provide guidance on strategy and intellectual property issues and manage CRADAs between the laboratories, educational and research institutions, and the textile industry. Within 3 years, AMTEX members expect to have received specific and quantifiable benefits from the partnership.

The AMTEX partnership is expected to become a model for future DOE and integrated industry partnerships. The consortium has articulated the principles that will guide its efforts:

- Rapid completion of measurable goals.
- Integration of research and technology transfer among the laboratories and throughout the industry.
- Direct service to meet industry and national needs. ■

CimStation Inspection Software

Enhancing Computer-Simulated Manufacturing

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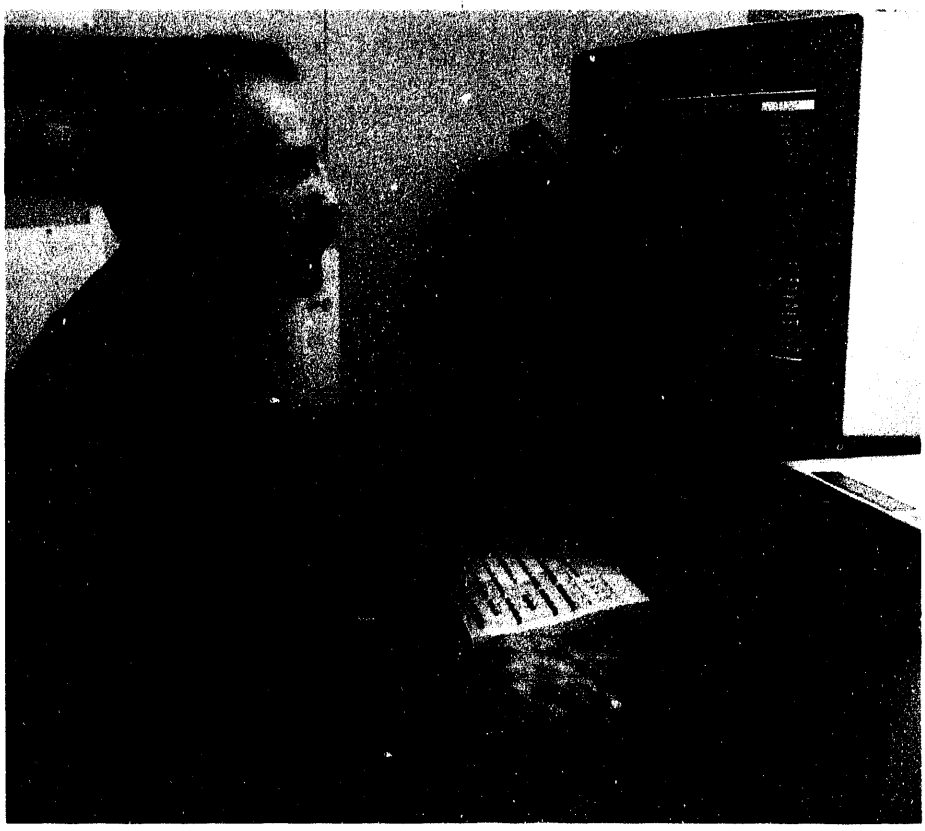
The Oak Ridge Y-12 Plant and SILMA, Inc. — a Cupertino, California, company specializing in computer-simulated manufacturing — have developed a new software package called CimStation Inspection. A quality inspection tool, it creates, provides simulation, and edits programs for coordinate measuring machines (machines used to ensure that parts conform to quality standards). Researchers at the Y-12 Plant are experienced in designing quality inspection methods to ensure that machinery gives precise results. A cooperative research and development agreement between Y-12 and SILMA has enabled transfer of Y-12's expertise to the private sector.

Instructions for acceptable tolerance allowances and probe movement in coordinate measuring machines were programmed manually in the past. CimStation Inspection now makes it possible to create programs off-line by simulating both the part and the coordinate measuring machine, thereby allowing users to check the accuracy of programs before downloading.

Errors in programming (e.g., geometric and probe-motion errors) frequently occur when users first program coordinate measuring machines. CimStation Inspection's innovative graphics simulation feature increases the confidence in the programming from 70% to 95%, while reducing the time spent programming a coordinate measuring machine by 50%.

The Y-12/SILMA collaboration is expected to improve quality inspection tools, specifically software designed to assist manufacturers in programming machines to inspect manufactured parts.

The CimStation Inspection package is available from SILMA and is being marketed primarily to Fortune 1,000 manufacturing companies, including many in the aerospace, automobile, and machinery industries. ■



An engineer creates a computer program to inspect manufactured parts.

Partnerships for Training and Technology Transfer

Making Manufacturing Technologies Available to Local Small and Medium-Sized Businesses

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In June 1991, Lawrence Livermore National Laboratory (LLNL) entered into a unique agreement with eight California community colleges that have Centers for Applied Competitive Technologies (CACTs) and the California Manufacturing Technology Center (CMTC), one of seven centers funded by the National Institute of Standards and Technology (NIST).

The goal of this training and technology transfer partnership is to help small and medium-sized California businesses increase their productivity and become more competitive, by giving them access to new and advanced technologies being developed at various DOE facilities and by helping them solve specific manufacturing problems. The CACT and CMTC staffs offer a wide range of services to individual companies, including customized training programs and on-site, state-of-manufacturing assessments.

The partnership provides satellite telecasts that address environmental aspects of manufacturing and highlight relevant technologies that DOE has developed or refined. Subjects covered have included electroplating and substitutions for cleaning solvents. In February 1993, the six other NIST Manufacturing Technology Centers showed the programs in their states. LLNL has also telecast the programs to local businesses.

The partnership offers technical workshops to instructors, representatives from the CACT's local businesses, and CMTC technical staff. In addition, through 6- to 8-week summer internships, the partnership enables community college instructors to learn about the technologies and integrate them into their courses. The partnership provides access to technical expertise and appropriate LLNL-developed software and has placed more than $750,000 worth of equipment at CACTs.

The program received the California Community Colleges-Economic Development Network's 1992 Industry Award in the Public Sector. In January 1993, DOE presented the program with an Innovation in Technology Transfer Outreach Award. ■

Summer internships give community college instructors hands-on experience working with the latest DOE-developed, manufacturing-related technologies.

Materials Testing to Lower Product Costs

Producing Shear Pins In-House

By taking advantage of the materials expertise at Ames Laboratory, Northern Natural Gas Company in Redfield, Iowa, is producing shear pins in-house instead of purchasing them from an outside source. This move has reduced the company's costs by 80%.

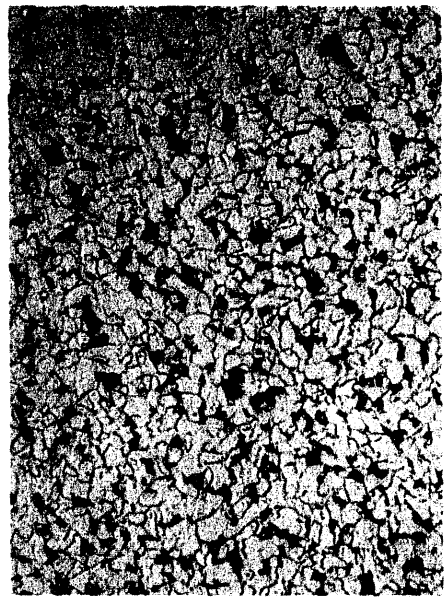
Shear pins are fail-safe mechanisms that protect the gear teeth of pumps used in underground gas wells. Northern assembles the pins into pump units. Because the pins are fairly expensive, a Northern employee suggested that they be produced in-house at the machine shop located in Ogden, Iowa.

To determine whether in-house production would be cost effective, Northern needed to identify the exact composition of the pins. However, it lacked the materials testing equipment and expertise to accomplish this job. In addition, to duplicate the quality and reliability of the pins, the company also needed to be able to conduct a thorough materials analysis of the molecular structure and annealing process, at the least.

After checking with materials testing facilities and finding their capabilities limited, personnel at the Ogden machine shop contacted the Materials Preparation Center (MPC) and Referral System and Hotline, a user facility located at Ames Laboratory that works closely with the state-funded Iowa Companies Assistance Program.

By using the MCP facilities through the assistance program, metallurgists identified the shear pin material as an annealed, low-carbon steel. They also determined its hardness, tensile strength, and microstructure. Results from mechanical property tests were sent to Northern within 1 week of when the MCP received the sample pin. On the basis of this information, the Ogden shop purchased the appropriate grade of steel. MPC scientists also advised shop personnel on the best way to carry out the annealing.

Since hundreds of pins are used in field equipment each year, savings are quickly multiplying. Additional savings are anticipated as Northern shares results with machine shops at its four other subsidiaries in Minnesota, Kansas, Oklahoma, and Texas. Company spokespersons say the positive interaction has also alerted them to look for similar state and federal technology assistance programs throughout the country. ■



This microphotograph helped metallurgists identify the composition of shear pins so Northern Natural Gas Company could fabricate them and save money.

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Nondestructive Evaluation Techniques

Inspecting Parts and Controlling Manufacturing Processes in Auto Plants

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Lawrence Livermore National Laboratory (LLNL) and Chrysler Corporation have signed a 3-year, $6 million cooperative research and development agreement. As part of that agreement, LLNL will help Chrysler use nondestructive evaluation (NDE) technology to improve manufacturing processes and quality. Training will be a major element of the project, since the equipment can be extremely complex to operate and the data can be hard to interpret. Because LLNL has been responsible for overseeing the production of nuclear weapons, it has the necessary expertise, having relied on leading-edge NDE technology to ensure that the weapons are of the highest quality.

Nondestructive evaluation technology lets engineers look inside complex manufactured parts while they are being built to make certain the job is meeting exacting standards. At Chrysler's Kokomo complex, ultrasound testing and two types of x-ray analysis will enable engineers to see inside a transmission or other complex castings. The quality of the materials and assembly processes (e.g., automated welding) will thus be monitored without destroying the parts. Chrysler already owns the equipment for this NDE work. LLNL will help Chrysler assess the information and integrate it into manufacturing processes.

Ultrasound testing, which uses sound waves to detect flaws and irregularities in gear assembly welds, gives engineers immediate feedback on manufacturing processes, so they can make adjustments before serious defects result.

One of the two x-ray techniques, real-time radiography, is a powerful system that can display x-ray images on a television screen as they are taken (instead of recording images on film that can be seen only after developing). This technique is used for gear welds that cannot be easily inspected by ultrasonic methods. Like ultrasound testing, it allows immediate feedback to control manufacturing processes. Faster and thus more efficient process control can help cut manufacturing costs.

The other x-ray technique, computed tomography, produces detailed, three-dimensional images of the inside of metal castings. Like medical CAT (computer-assisted tomography) scans, these three-dimensional images are made by taking x-rays of many narrow slices through a part and then assembling the slices electronically into a whole. Computed tomography is used to detect improperly formed castings. ■

Ultrasonic testing, a nondestructive evaluation technique, is used to characterize a transmission gear.

Polyphosphazene Membranes

Giving Industry Valuable Separation Capabilities

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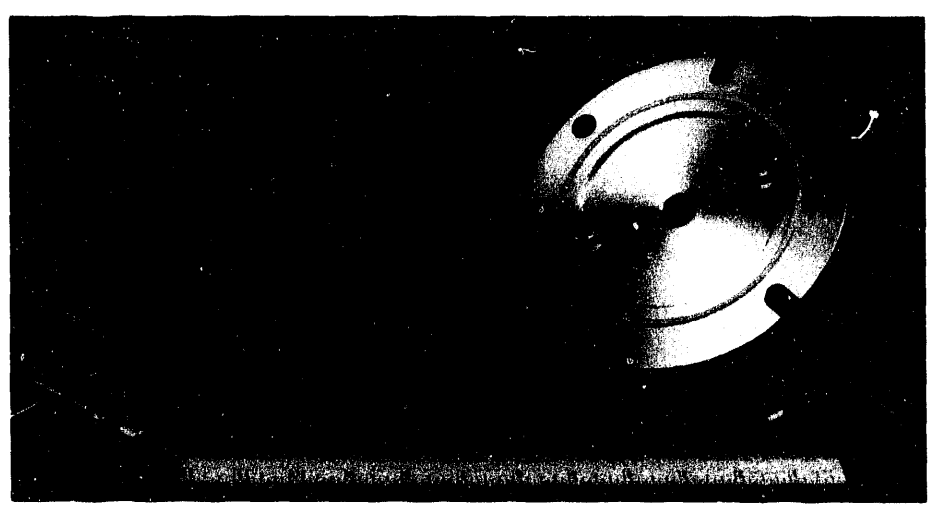
Most industrial-scale separation processes involve methods like distillation, evaporation, and freeze crystallization. These methods are very energy-intensive; for example, DOE studies indicate that 28% of the energy used in all U.S. chemical plants and petroleum refineries is consumed by distillation systems. Scientists at Idaho National Engineering Laboratory (INEL) are developing inorganic polyphosphazene membranes to replace some of these processes. These membranes could save industry time and money and reduce oil consumption by more than 34 million barrels per year.

Membranes separate mixtures into their components by discriminating among them on the basis of their physical or chemical attributes, such as molecular size, electrical charge, or solubility. For example, more than half the world's desalinized potable water is produced by means of membrane separation. The membrane allows water but not salts to pass through it.

The INEL polyphosphazene membranes are special in that they can be used under conditions in which organic membranes cannot survive, such as high-temperature, radioactive, and harsh chemical environments. They can be custom-designed to meet user needs as well.

A growing application for membrane separation is groundwater remediation. Groundwater contaminated with organic compounds such as trichloroethylene and carbon tetrachloride is a serious problem at many industrial and governmental sites. Separation systems need to be designed both to remove pollutants from contaminated sites and to prevent future contamination.

The Laboratory currently is a party to four cooperative research and development agreements with various industries, one of which is studying the use of membrane separations for the remediation of contaminated water at an abandoned mine. Several other agreements are being negotiated. ■



Polyphosphazene membranes cast in the laboratory are usually a few inches in diameter; those cast for industrial uses can be many hundreds of square feet in area.

Deterministic Engineering Approach for Design

Machining System to Cut Materials Accurately and Precisely

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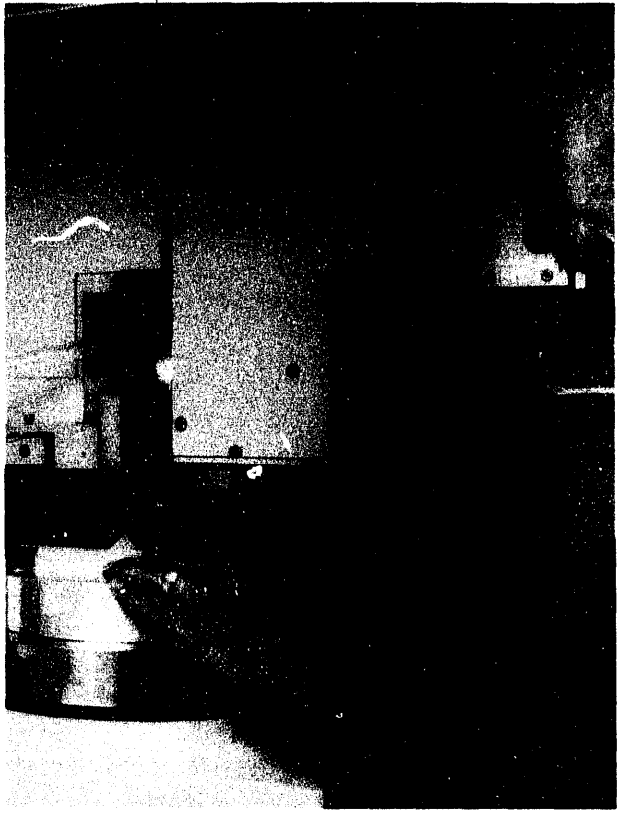
An improved machining system called Alpha Nanometre 250 is the product of a partnership between Lawrence Livermore National Laboratory (LLNL) and Industrial Tools, Inc. (ITI), a small business in Ojai, California. The system cuts hard-to-machine materials to an accuracy of within 0.5 micrometer. The new precision technology can slice materials such as ceramics, carbides, glass, silicon, and plastics.

The Laboratory brought its deterministic engineering approach to the project with ITI. Deterministic engineering does not recognize random events; it assumes every event has a predictable, quantifiable cause. The approach includes error budgeting analysis, which involves examining and predicting the effects of every potential design error. Compiling a systematic account of every possible error allows the effects of individual components and parameters to be predicted. For example, this approach found that to maintain an accuracy of 0.5 micrometer, the temperature of the air surrounding the cutting system must stay within 0.5°F. Thus, even the body heat of the operator could change the temperature enough to exceed the machine's tolerance.

Industrial Tools chose LLNL for this project because of its reputation in precision tool design and its experience designing in the submicrometer range. Another factor was LLNL's experience with air-bearing slide systems, which allow parts being machined to be moved with extreme precision. DOE provided LLNL with funds to assist ITI.

The deterministic approach has made a significant difference to ITI. Revenues from known markets for the Alpha Nanometre 250 are expected to be about $25 million over the next 5 years. Six systems have already been sold to manufacturers of computer disk drives. They use the machine to cut recording heads made of aluminum-titanium carbide. The technology can also be used in the semiconductor industry for cutting silicon wafers into chips and in the defense, aerospace, and medical equipment fields. ■



A ceramic wafer is loaded onto a precision-slicing machine called the Alpha Nanometre 250. A deterministic engineering approach was taken in designing the machine, which cuts ceramics, glass, silicon, and other materials to an accuracy of within 0.5 micrometer.

Superconducting Magnet Technology

Transferring Advanced Fabrication Methods to Industry

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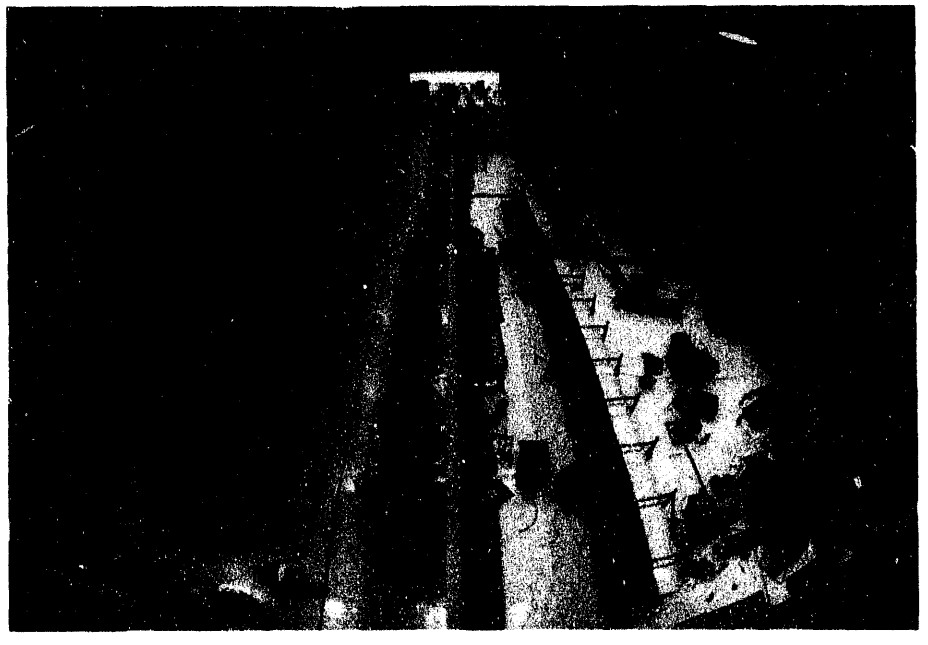
The Superconducting Super Collider (SSC) would have used more than 10,000 superconducting magnets in its high-energy booster and in the two collider rings. About 8,600 of these magnets would have been dipoles, the remainder being quadrupoles and various types of corrector magnets. The technology for building these magnets originated in four DOE laboratories — Fermi National Accelerator Laboratory, Brookhaven National Laboratory, Lawrence Berkeley Laboratory, and the Superconducting Super Collider Laboratory (SSCL).

Undertaking a project of the SSC's size and scope — in particular, procuring the large numbers of superconducting magnets — required a close partnership between the U.S. government and industry, including both large and small companies. Thus, it was crucial that any technology related to superconducting magnets be transferred from the laboratories to industry. The SSCL staff worked with industrial companies to refine the magnet designs, particularly with regard to the cost and the ease with which the magnets could be manufactured.

The superconducting magnet program involved three major U.S. corporations: General Dynamics and Westinghouse for the dipole magnets and Babcock & Wilcox for the quadrupole magnets. The design of the prototype dipole magnets was the result of a combined Brookhaven/Fermilab/SSCL effort. General Dynamics and Westinghouse personnel, located at Fermilab and Brookhaven so they could learn how to build the magnets, built 12 collider dipoles. Five of these industrially assembled magnets were successfully operated in the accelerator-system string test, which was completed at SSCL.

The 15-meter-long dipole magnets need be built to very exacting tolerances to function correctly. For example, very accurate coil winding and curing is required, to an accuracy of about one-tenth of a millimeter over the 15 meters. Also required are collaring (to prestress the coil against Lorentz forces), very precise yoke and shell welding, and cryostat assembly.

General Dynamics, Westinghouse, and Babcock & Wilcox equipped their factories for magnet production and began to build magnets; they were assisted by SSCL personnel, some of whom were stationed at the factories. The SSCL also had its own Magnet Development Laboratory, which was to be used to produce low-volume specialty magnets for the interaction and utility regions of the main collider ring. This facility was also used for technology transfer to magnet contractors.



Superconducting magnets have been developed at the Magnet Development Laboratory located at the Superconducting Super Collider Laboratory site.

Three small, minority-owned companies were awarded technology transfer contracts through competitive bidding; one was to have built 300 high-energy booster quadrupole magnets. Engineers from all three companies were to have been located at SSCL and participated in the building of prototype magnets.

The transfer of superconducting magnet technology to private companies is expected to result in improvements in performance and lower production costs for magnets used in various types of medical equipment, such as magnetic resonance imaging facilities. Magnets for use in such future applications as superconducting energy storage and magnetically levitated trains may also benefit from present technology transfer efforts.

In 1993, SSCL and Fermilab personnel received a special Award of Merit for Excellence in Technology Transfer from the Federal Laboratory Consortium. ■

Porcelain-Coated Radio-Frequency Antenna

Versatile, Durable Antenna for Clean Plasma Generation and Ion Implantation

Lawrence Berkeley Laboratory (LBL) researchers have developed a long-lasting, versatile radio-frequency antenna for generating clean plasmas and other applications. The porcelain-coated antenna improves the ion and plasma sources used to generate positive, negative, or neutral particle beams. It is ideal for plasma-processing applications such as ion implantation to harden automotive parts and medical tools. Pacification of semiconductors is another promising application, because the antenna works well with corrosive gases, has a much longer lifetime than conventional sources, and does not require expensive electronics.

The antenna takes advantage of the superior properties of radio-frequency power used to generate plasmas. Such power sources are better than filament or other conventional plasma generators because radio-frequency power coupling produces cleaner plasmas and ion implants. (A conventional filament source in a very hot, corrosive plasma environment will soon begin to degenerate, sputtering its material and contaminating the plasma.) In addition, radio-frequency power sources are available commercially and easily controlled, eliminating the need for expensive custom-built electronics. Through its versatility and durability, LBL's antenna enhances the benefits of radio-frequency power coupling.

The thermal coupling between the antenna's hard porcelain enamel coating and the water-cooled metal-tube substrate allows it to operate at high temperatures for long periods. Because the antenna is cooled, it will not cause radiative heating problems in ion implant applications. Cooling also protects the antenna chamber mount. The hard coating that prevents unwanted sputtering also ensures a lifespan at least 10 times longer than that of standard ion sources and keeps the antenna electrically nonconductive, which makes it about twice as efficient as an uncoated radio-frequency power source. The antenna can survive mechanical impacts, heat stress, and a hot plasma environment because of its exceptionally sturdy construction.

The antenna's nonreactive properties make it ideal for ion implantation applications with corrosive gases, such

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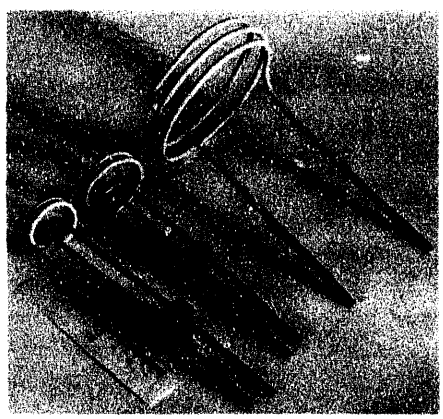

Their hollow-tube construction allows porcelain-coated radio-frequency antennas to be cooled while in use.

as boron trifluoride, and for applications requiring continuous operation. It has demonstrated radio-frequency power coupling of more than 25 kilowatts in a continuous mode and more than 50 kilowatts in a pulsed mode. Finally, it exhibits an advantageous narrow implant profile during operation with oxygen.

Because radio-frequency power is easily pulsed, and because the antenna avoids the radiative heating problems associated with conventional filament-type sources, the antenna can evenly implant ions on irregularly shaped objects, like an entire engine block. This capability represents a major advance in plasma processing. The antenna can also be applied in high-energy accelerators like mass spectrometer cyclotrinos, medical proton therapies, and fusion research. In the environmental arena, it can be used in neutron tubes for wellbore logging and in accelerators for treating chemical and radioactive waste.

With regard to ion source applications, this technology is fully developed and has been already used in injector accelerators at DOE's Superconducting Super Collider Laboratory and cyclotrons around the world. A small version is part of a wellbore logging neutron tube system. Further work is underway at LBL to determine other substrate/porcelain combinations. For ion implantation applications, a proof-of-principle prototype has been completed. A patent is pending on the invention, which is now available for licensing. ■

Aqueous Chelating Etch System

Etching Superconducting Circuits Precisely and Inexpensively

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Scientists from Sandia National Laboratories and the National Renewable Energy Laboratory (NREL) have developed a system for etching thin films for advanced electronic devices and circuits — an accomplishment that may make superconducting communications and computer systems a reality. *R&D Magazine* recently recognized the aqueous chelating etch system as one of the most important technological innovations of 1993.

The high-temperature superconducting oxide thin films ($YBa_2Cu_3O_7$, $Tl_2Ca_2Ba_2Cu_3O_{10}$) can conduct current with zero resistance at liquid-nitrogen temperatures. These new superconductors could significantly improve upon conventional silicon microelectronic circuits in a number of areas, including size, speed, power consumption, and cost. The aqueous chelating etch system achieves precise, submicrometer-size features at a low cost, without degrading the high-temperature superconducting surface or superconductive properties.

Previous systems for making circuit patterns are not well suited to the new oxide thin films. Bromine-alcohol etches are usable only with negative photoresists, not with the positive photoresists required to get submicrometer-size features. Inorganic acid etches degrade the surface of the remaining film oxide, increasing its surface resistance and reducing its superconductive properties. Destructive beam processes, such as ion milling, require expensive equipment and cause some peripheral ion damage, which reduces the precision of the pattern and causes some surface deterioration.

The Sandia-NREL team sought a water-based etch that could be used with positive photoresists. The key to

avoiding surface deterioration was to prevent reprecipitation of the etched metal ions. Therefore, the team looked at chelating agents — organic compounds that use multiple, coordinated bonds with metals to securely sequester the captured metal ions. Use of standard coordinating acid for heavy metals was successful, but the real breakthrough came with use of simpler carboxylic acids such as citric and adipic acids.

Each of the acids used in this system has a different configuration of binding sites, so mixtures are tailored to the composition of the metals in the oxides. Submicrometer-size features are sharp and easily attainable; edge profiles can be either vertical or sloped, depending on the acid used. Oxide films can also be thinned without being totally etched away. Of value for heterostructural devices is selectivity; that is, the etch does not affect underlying layers. Surface resistance (a key parameter for high-speed, high-temperature superconducting devices) for etched films increases by less than 7%. With hydrofluoric acid as an activator, the new etches also work well on ferroelectric materials and high-temperature superconducting substrates that are used extensively in microelectronics.

The Sandia-NREL system can etch patterns in high-temperature superconducting oxides and similar materials with greater precision, with less surface degradation, and at less cost than other systems. The system is now being used in the private sector to develop new superconducting microelectronics. ■

A new aqueous chelating etch system achieves precise patterns in oxide thin films without degrading their superconductive capabilities.

Precision Multiaxis Seam-Tracking Sensor

Low-Cost Sensor that Reduces Labor and Material Costs

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Many manufacturing operations, such as welding, dispensing, edge finishing, and painting, require that the gap or seam between mating parts be precisely located and tracked. Most current manufacturing applications involve precise fixturing of the mating parts. The location and orientation of the seam are then "taught" to a robot that is programmed to follow the trajectory of the joint. This approach works well for large operations in which the costs of precision forming, machining, fixturing, and teaching can be amortized over thousands of units. However, it is too costly and inflexible for small-volume or agile manufacturing operations.

The multiaxis seam-tracking sensor can reduce the cost of manufacturing processes that require seams on mating components to be precisely located and tracked.

A multiaxis seam-tracking (MAST) sensor and control system was developed by the Intelligent Systems and Robotics Center at Sandia National Laboratories. This system reduces the cost of manufacturing processes that require precise locating and tracking. The prototype system was developed through a cooperative research and development agreement between Sandia and Rocketdyne Division of Rockwell International in Canoga Park, California, to reduce the labor and material costs associated with the manufacture of rocket engine nozzles.

The automated system consists of a MAST sensor, a six-axis robot on a track, and precision dispensing equipment. The noncontacting MAST sensor, an inexpensive five-layer circuit board, measures changes in capacitance (ratio of the charge stored on two conductive surfaces to the voltage between the two surfaces). The robotic system uses information from the sensor to map the center of the surface and to track the seams. Variations in the position of the component can be accommodated with little or no teaching of the robot. In the Rocketdyne system, the robot tracks nonuniform seams so it can apply even amounts of a silver-palladium alloy paste used to furnace-braze cooling tubes together.

The MAST sensor provides more advantages and costs less than conventional sensors. For example, touch probes cannot follow narrow or varying gaps or determine tool orientation. Structured lighting sensors, which cost between $35,000 and $60,000, can determine the location but not the orientation of seams. The MAST sensor can simultaneously provide information about all six degrees of freedom, even when there is significant noise and interference, at a cost of about $500 for components.

Modular High-Power Laser Diode Array for Pumping Lasers

Less Costly Packaging Technology that Removes Waste Heat

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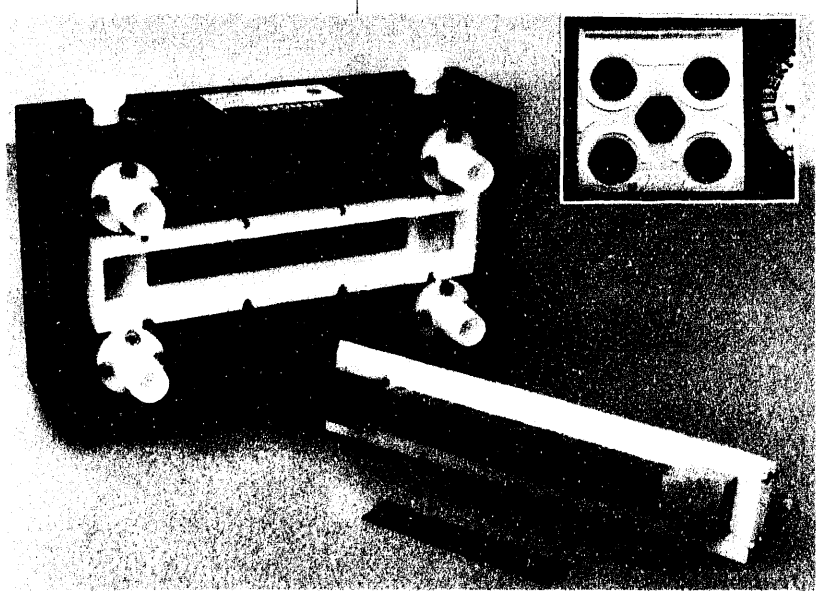
The high heat flux generated by laser diodes and the low temperature required for their operation pose a problem for engineers working with high average-power lasers. (Average power describes the rate of power delivery for pulsed power.) To solve this problem, Lawrence Livermore National Laboratory (LLNL) has developed a packaging technology to package large, two-dimensional arrays for pumping solid-state lasers. This modular high-power laser diode array package allows high average-power operation of laser diodes while efficiently removing the very high fluence of generated waste heat.

The array enables laser diodes to be operated in a continuous "on" mode at extremely high output power. Its low-temperature operation is critical for maintaining the efficiency and reliability of the temperature-sensitive laser diodes. The basis for the module's thermal performance is microchannel cooling, in which very thin, high-aspect-ratio water channels close to the heat source are used to remove waste heat.

By using this diode packaging technology, LLNL designed and built a 1-kilowatt, average-power Nd:YAG laser, the highest average-power, diode-pumped, solid-state laser demonstrated to date by a factor of five. The technology was ideal for this application because high average-power, diode-pumped, solid-state lasers require densely packed diode arrays operating at a high duty factor. (Duty factor refers to the fraction of a cycle that power is being delivered.)

The modular diode package is compatible with LLNL's microlens technology. The microlens collimates diode radiation, making it possible to deliver the output from large arrays to the end of a rod laser. Rod lasers, which can generate several hundred watts of average optical output power, are being studied for industrial and medical applications.

The LLNL diode array has many advantages. Because of its continuous operation (duty factor of 100%), the cost per average watt of diode radiation is much lower than that of competing diode packaging technologies, which have duty factors of 20% at most. The modular design enhances flexibility: large, two-dimensional arrays stacked on a centering bolt can be easily built and maintained. A single module from a stack can be replaced in a few minutes, and electrical and hydraulic connections from module to module are made automatically during the stacking process. A finished stack has a single set of water and electrical connections, another advantage over existing arrays that greatly simplifies the integration of these devices into systems. In addition, well-developed anisotropic silicon etching techniques are used to fabricate the diode array's cooling channels (i.e., heat sinks),



This large, two-dimensional laser diode array, assembled by stacking 150 modules on top of each other, has an average power capability of 15 kilowatts. The array is used to pump the high average-power Nd:YAG slab laser visible in the background. The inset shows a 100-watt, average-power, modular, microchannel-cooled laser diode array. This package, which is 2 centimeters square, contains 1.8 linear centimeters of laser diode array visible along the top edge of the package under the wire bonds.

which makes the entire manufacturing process amenable to economical mass production. Costs are low because no exotic, high-thermal-conductivity materials are required for fabrication.

The LLNL package is expected to revolutionize industrial applications that require high average power, such as metal working and welding. The use of the modular package with microlens technology allows end pumping of laser rods, which will greatly accelerate the introduction and use of highly reliable, diode-pumped, solid-state lasers in the industrial laser machining community. The modular high-power laser diode array won an award from *R&D* magazine as being one of the top 100 new technologies in 1993.

New Laser Technology for More Reliable and Flexible Manufacturing

Automation through Fiber-Optic Transport of Beams

Lawrence Livermore National Laboratory (LLNL) and General Motors (GM), under a cooperative research and development agreement, are developing a solid-state laser that could vastly improve the way automobiles are manufactured. It could also be used for surgical applications, materials processing of electronic circuits, and machining small holes in aircraft components and in aerodynamic surfaces.

Several technological advances at LLNL enabled scientists to develop this laser. Cost-effective solid-state lasers are now pumped with semiconductor lasers rather than flash lamps. In addition, residual optical distortions have been tailored to preserve optical beam quality. Finally, new optical resonator designs and technology are being fully exploited.

The new laser technology, which will be used to cut and weld sheet metal, will offer many benefits to GM. First and foremost, GM will be able to automate any factory that uses the lasers because they are so reliable and because the fiber optics can be easily interchanged. GM will also be able to cut and weld more parts in any position with lightweight robot beam directors, and the welds could be as strong or stronger than carbon dioxide laser welds. Furthermore, GM anticipates that the new lasers will require less maintenance, thereby reducing costs.

Manufacturing flexibility will be enhanced because the high-power laser beams will be transported through optical fiber. This type of transport allows robots to be used in inaccessible locations. Because the arm of a robot can move quickly over a large work piece, the manufacturing process is accelerated. Current far-infrared industrial gas lasers require mirrors to direct their beams. Beams transported through fiber optics can be directed to multiple workstations and still be tightly focused.

The new laser will be brighter than existing lasers; in other words, it will concentrate light more intensely at a focal point, resulting in more effective cutting and drilling. Not only can this compact, powerful, efficient, and reliable laser outperform existing lasers, it can also perform some functions that they cannot.

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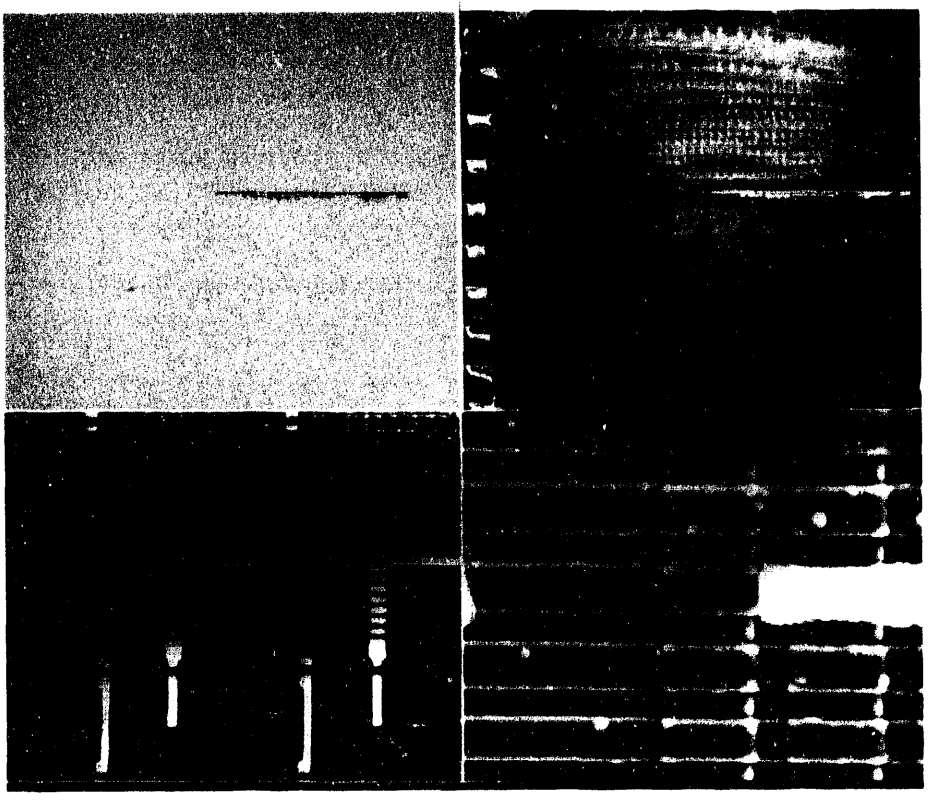
Charge-Induced Voltage Alteration

Speeding the Analysis of Integrated Circuit Failure

Finding out why an integrated circuit has failed is a tedious, time-consuming task. Failure may be caused by an open metal conductor having a tiny crack that blocks transmission of an electrical signal. Since cracks can be only about one-billionth of a meter wide, searching for them is difficult. The task can be compared to looking through a hole in a car floorboard for a crack in the road that is one-eighth of an inch wide, while driving from New York to Los Angeles. When conventional electron beam and production test equipment is used, looking for an open metal conductor can take weeks. Nevertheless, the search is important to manufacturers, because open conductors may be responsible for 50% of integrated circuit failures.

Researchers at Sandia National Laboratories have developed a new method that can detect open metal conductors in times as short as a few minutes. Charge-induced voltage alteration (CIVA) is a highly selective imaging technique that uses a scanning electron microscope. CIVA images are produced by monitoring the voltage fluctuations of a constant-current power supply as an electron beam is scanned over a microchip surface. Variations in contrast occur at broken or weak spots in the microchip's conductors. By examining the entire integrated circuit die and noticing the abnormalities, a failure analyst can locate an open conductor. CIVA can also be used to locate weakly driven conductors and defects lying underneath the metal layers.

The CIVA technique is more cost effective than conventional integrated-circuit diagnostic procedures. The most expensive equipment it requires — a scanning electron microscope — can be found in most microelectronics laboratories. The constant-current source for CIVA costs about $4,000, and the required amplifier equipment is about $3,000. Industry partners that have already taken advantage of the technique through cooperative research and development agreements include Philips Semiconductors of Albuquerque, New Mexico; National Semiconductor of East Jordan, Utah; Analog Devices of Santa Clara, California, and Woburn, Massachusetts; and LSI Logic of Milpitas, California. ■



This photograph, taken with an electron microscope, shows four views of an open conductor. The view in the upper left shows a CIVA signal from an entire integrated circuit die. The one in the upper right shows the same CIVA signal superimposed with a topology image of the die for registration. The bottom two images show the same failure site at higher magnifications.

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National Machine Tool Partnership

Providing Expertise and Technology to the Machine Tool Industry

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The U.S. Department of Commerce and DOE have established the National Machine Tool Partnership to work with the U.S. machine tool industry to enhance its global competitiveness. Partnership members include five DOE facilities — Los Alamos National Laboratory (LANL), Lawrence Livermore National Laboratory, Sandia National Laboratories, the Oak Ridge Y-12 Plant, and the Kansas City Plant (AlliedSignal Inc.) — and one U.S. Department of Commerce agency, the National Institute of Standards and Technology.

The Partnership's primary activity is to make federally developed technologies such as plasma-source ion implantation available to U.S. machine tool and die manufacturers and to precision and special machining companies. Each partner has established a Machine Technology Access Center to facilitate industry's access to such technology and to help industry with problems that require capabilities not commercially available.

The Center provides immediate and short-term technical support to machine tool companies of all sizes. Technical support includes consultation, evaluation, testing, and analysis; machine tool analysis, design, characterization, and application; environmentally responsible manufacturing; testing and inspection technology; manufacturing process development; nontraditional manufacturing technologies; and education and training.

The Center at LANL has helped various machine tool companies solve problems. In one case, the Laboratory performed a failure analysis on a tool die for a company. In another, LANL analysts worked with a company's designers to analyze machine tools during their design.

The Partnership provides machine tool companies with up to 80 hours of technical assistance. If a company requires services for more than 80 hours, a formal cooperative agreement must be developed in which the company must provide in-kind contributions. The Center chosen to respond to a problem is selected on the basis of whether its technology and expertise are appropriate and whether it is located close to the company.

Future plans for the National Machine Tool Partnership include applied technology projects, information sharing, standards development, an advanced technology working group, and an education and training project. Applied technology projects will be collaborative projects that will last for months and involve machine tool manufacturers and purchasers and one or more national laboratories.

To facilitate the machine tool industry's access to the centers, the Partnership has established a toll-free hot line. The hotline operator answers both simple and complex questions or arranges for technical assistance at either the requesting company's location or at the Center. The hotline number is 800-358-6651. ■

A 1,200-watt carbon dioxide laser welds a 507 combustor liner (photo courtesy of Laser Fare, Smithfield, Rhode Island).

Improved Ceramic-to-Metal Bonding Technique

Brazing Titanium Alloys to Alumina for Custom Applications

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Researchers at Princeton Plasma Physics Laboratory (PPPL) have developed a technique based on the use of titanium hydride for brazing titanium alloys to alumina. The technique is especially suited for fabricating custom equipment such as flanges and waveguide windows for high-energy or plasma physics applications. Brazed parts produced with the new technique include 50-inch (nominal diameter) rings approximately 1-inch thick, rectangular solids, and alumina (98%) cone bushings with a copper-plug center conductor and stainless-steel outer can.

Because ceramic-metal joints in the required geometries were commercially unavailable, PPPL engineers developed the brazing capability in-house. The Laboratory has applied the technique to provide customized products for the international high-energy-physics community.

The PPPL technique offers advantages over conventional brazing techniques that use molybdenum-manganese. Because the brazing takes place in a vacuum at approximately 800°C, the resulting titanium hydride/alumina reaction metallizes the ceramic as the brazing occurs.

A variety of shapes can be brazed. The difference in thermal-expansion coefficients between the metal and the ceramic makes noncircular shapes, such as rectangular sections, more difficult to braze, but the PPPL engineers have overcome this difficulty. Shapes produced with the new technique include solid brazed disks up to 8 inches in diameter and rectangular sections measuring 10 by 1.5 by 2.5 inches. Manufacturers using the molybdenum-manganese brazing technique have been reluctant to produce or guarantee results for such large pieces and noncircular geometries.

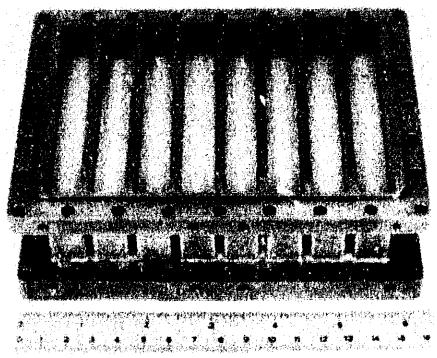
The temperature at which the needed flanges function is typically about 500°C; higher temperatures are possible if different titanium braze alloys are employed. The titanium hydride process enables larger brazed parts to be produced without using the molybdenum-manganese ceramic-coating brazing process.

The PPPL process is adaptable to various ceramic-metal systems, provided the coefficients of thermal expansion of the two materials are compatible. Any ceramic containing molecular oxygen or ozone free radicals is a potential candidate for the titanium hydride brazing technique. PPPL researchers have also brazed Corning's machinable glass to stainless steel.

With the titanium hydride process, any flaws in the braze can be repaired without loss of the ceramic, which minimizes costs. To repair a brazed piece, researchers apply additional hydride and alloy.

Possible commercial applications for the new technique include microwave applications, high-temperature ovens, vacuum-tight insulators, klystron windows, radar and other high-voltage applications, and other installations for which high-temperature insulating breaks are required. Both the PPPL titanium hydride process and the windows themselves are available for licensing from Princeton University.

The 800-megahertz waveguide window for the Princeton Large Torus, PPPL's tokamak, was constructed by using a new technique for brazing titanium alloys to alumina.



Processes for Patterned Adhesion of Copper on Teflon®

More Tightly Packed Circuit Boards at Higher Frequencies

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Researchers at Sandia National Laboratories have developed four new processes that enable copper to be deposited, with excellent adherence, onto off-the-shelf Teflon® substrates. The Sandia methods work by controlling the copper's access to the surface or by patterning the reaction with the surface.

The processes can be applied to the manufacture of high-frequency electronics, particularly printed circuit boards. Poly(tetrafluoroethylene), known by the Du Pont trade name Teflon, is an ideal substrate for printed circuit wiring boards because it provides excellent insulation, low power loss, and a low dielectric constant, which minimizes electrical interference. However, copper conductors do not easily adhere to the surface of Teflon because of its chemical and physical inertness.

Printed circuit boards are now made by hot-pressing acid-etched copper foil together with Teflon filled with either glass or ceramic fibers. The circuits themselves are produced by removing unwanted copper. These industry practices yield, at best, 3-mil (0.003-inch) resolution between lines. The process can be compared to creating a system of city streets by laying asphalt on the city and scraping away everything that is not a street.

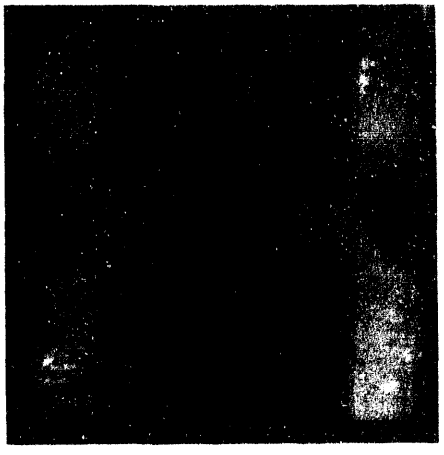
The first of the four processes — the product of a collaboration between Sandia and the University of New Mexico in Albuquerque — involves three steps: patterned irradiation of the Teflon surface, chemical etching of the entire sample, and either copper chemical vapor deposition or electroless copper deposition. After chemical etching, the copper adheres only to the areas that were not irradiated.

In the second process, copper adhesion is achieved by patterned laser ablation of etched Teflon surfaces. The central feature of these two inexpensive, simple, additive processes is control of the spatial extent of the copper adhesion. They each can yield resolutions better than 1 mil. However, they require new processing equipment. Also, given the isotropic nature of the copper deposition step, problems could occur with respect to resolution and sidewall definition.

To eliminate the dependence on specialized equipment and to better control resolution, Sandia developed the third and fourth processes. They combine chemical etching of Teflon, standard thin-film photoresist technology, and copper deposition. In both processes, only procedures currently available to the electronics industry are used, and conductors can be made of any metal that can be electrodeposited, such as gold, copper, or silver. On the first attempt, these processes yielded 0.8-mil resolution (the current industry limit is 3 mils), with excellent sidewall definition.

Despite problems with the current technology, the electronics industry has been moving toward tighter packing of circuits at higher frequencies. These new processes could be applied in mass-market electronics (for example, communications and telephone systems) or any system that requires rapid switching. A number of companies have shown interest in these widely applicable processes. ■

Enlargement of a Teflon® substrate shows 8-mil gold lines electrodeposited on the surface. The dark lines, which are the spaces between the electroplated metal, have a resolution of 0.8 mil.



Automatic Lithium Withdrawal System

Developing a Safer Way to Produce Lithium

Under a cooperative research and development agreement with the Lithium Division of FMC Corporation of Bessemer City, North Carolina, the Oak Ridge Y-12 Plant is designing an automated lithium withdrawal system for the electrolytic cells used to produce lithium metal. The goal is to develop a system that can be operated either automatically or remotely.

Lithium ore contains low concentrations of lithium. Chemical purification of lithium ore produces the compound lithium chloride, which is the feed material for the electrolytic cells in which chlorine is removed. Because these production cells operate at about 800°F, operators have been concerned that lithium will react volatilely with atmospheric moisture. The automated lithium withdrawal system allows operators to control the purification process from a protected location, thereby increasing safety.

The Y-12 Plant's extensive experience in producing lithium comes from manufacturing components used in nuclear weapons. This expertise provides a strong basis for expanded lithium research, the results of which will benefit the private sector. For example, companies use lithium in the production of batteries, glass, rubber, pharmaceuticals, and other products. ■

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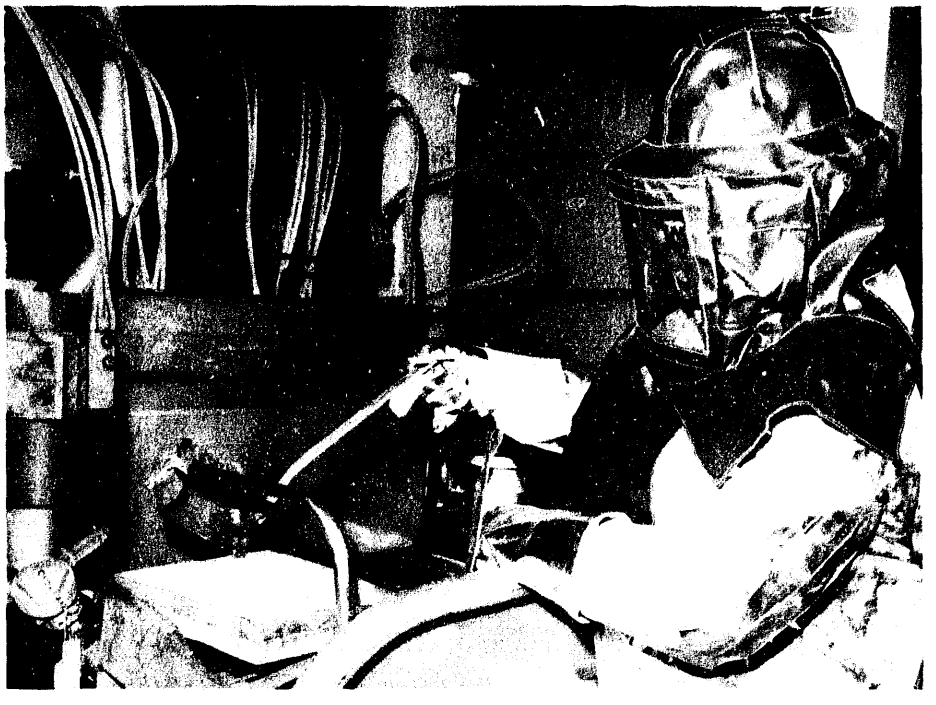

A technician in protective clothing uses traditional methods to extract lithium metal from electrolytic production cells. A new automatic withdrawal system is expected to allow remote extraction of lithium metal.

Omnidirectional Holonomic Platform

Greater Efficiency and Dexterity for Wheeled Vehicles

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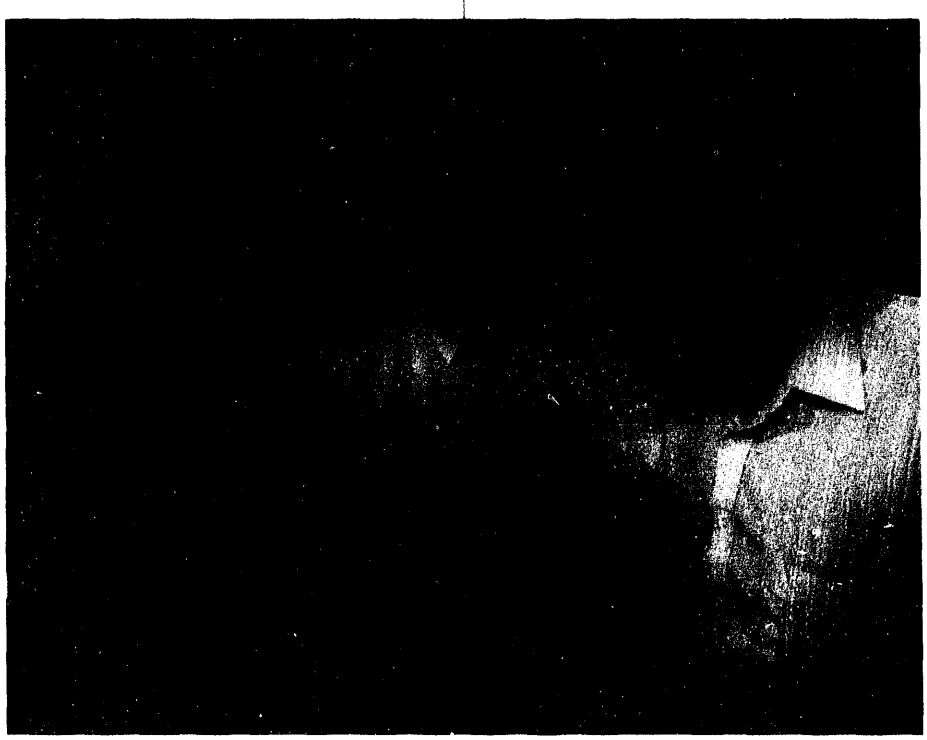
The omnidirectional holonomic platform promises big improvements for wheeled devices. The platform can move in any direction while simultaneously rotating.



The omnidirectional holonomic platform (OHP), a new technology from Oak Ridge National Laboratory (ORNL), promises major improvements for wheeled devices. Conventional wheeled vehicles cannot move in all directions from a given starting position while simultaneously rotating. Such a capability arises from a mathematical property known as holonomy. The OHP functions in accordance with the principle of holonomic motion.

The platform is a disk that sits on a Y-shaped rolling system. Unique wheel assemblies and their individual motors make up the three arms of the Y. The wheels, which have very little hub area, constitute an almost completely spherical rolling surface. Each arm of the Y has a set of two wheels, aligned at 90° angles to one another. The OHP owes its success to the 90°-angle wheel assemblies and to the innovative computer technology, developed at ORNL, that controls them. By adjusting the speeds of the three motors that drive the wheels, the computer program achieves the platform's unique means of locomotion. The OHP can be operated remotely by means of a joy-stick control, or it can move about autonomously, using sensors to avoid obstacles. Its basic structure and function are elementary. Its parts are easy to manufacture and assemble, yielding a readily accessible, low-cost item.

The OHP may first be used for autonomous robots that inspect crowded and tight spaces in factories and plants. Some robotics manufacturers see this system as an attractive alternative to current wheel technology, particularly when simultaneous rotational and translational (straight-line) motions of the robot are required.

For devices such as motorized wheelchairs, holonomic motion offers unprecedented mobility. Starts and stops for changing direction can be eliminated, and moving in tight quarters will be easier. Factory floor transport vehicles, such as forklifts and wheeled carts, can achieve exceptional dexterity, saving time and trouble. Other promising applications include autonomous transport vehicles in warehouses, outdoor vehicles, construction equipment, and perhaps even home vacuum cleaners. Inverted groupings of the wheel assemblies could serve as superior conveyor belts, on which objects could be smoothly transported and manipulated for precise machining as well as for cargo loading when minimal shear or strain on the object being carried is desired.

R&D Magazine has cited the invention as one of the year's top 100 new technologies, awarding its developers a 1993 R&D 100 Award. ■

The Occasional Trainer's Handbook

Effective, Efficient Guidance on Training Coworkers

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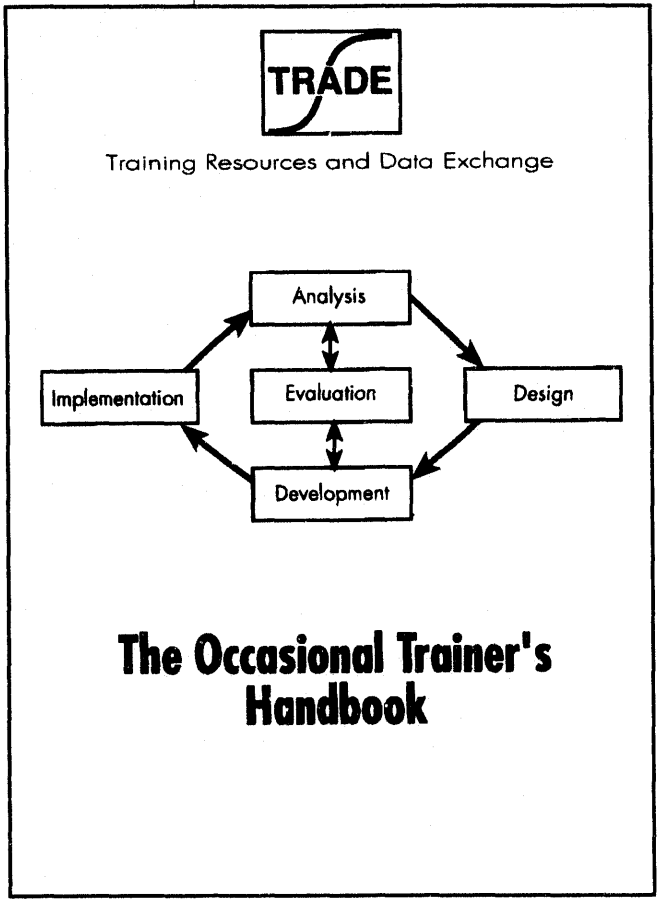
In today's highly competitive world, rapidly evolving technologies and an ever-stricter regulatory environment require employers to provide constant training to keep employees' knowledge and skills up to date. Because the need for specialized, professional trainers far exceeds their availability, employees who are experts at their jobs are sometimes called upon to design training materials and programs and provide training. These "occasional trainers" need to use a systematic, structured approach to produce effective materials. *The Occasional Trainer's Handbook*, developed by the Training Resources and Data Exchange (TRADE) for DOE, offers an approach aimed at ensuring that instruction is focused, relevant, and easily transferred to the job setting.

The *Handbook* discusses a five-step training program: (1) analysis (gathering information pertinent to the training), (2) design (determining goals and objectives and how to attain them), (3) development (writing lesson content), (4) implementation (arranging and practicing the training session), and (5) evaluation (assessing trainee performance and the effectiveness of the training session). These steps form the foundation for performance-based training, a highly effective method that focuses on job performance criteria rather than on the instructor's preferences and familiarity with the material.

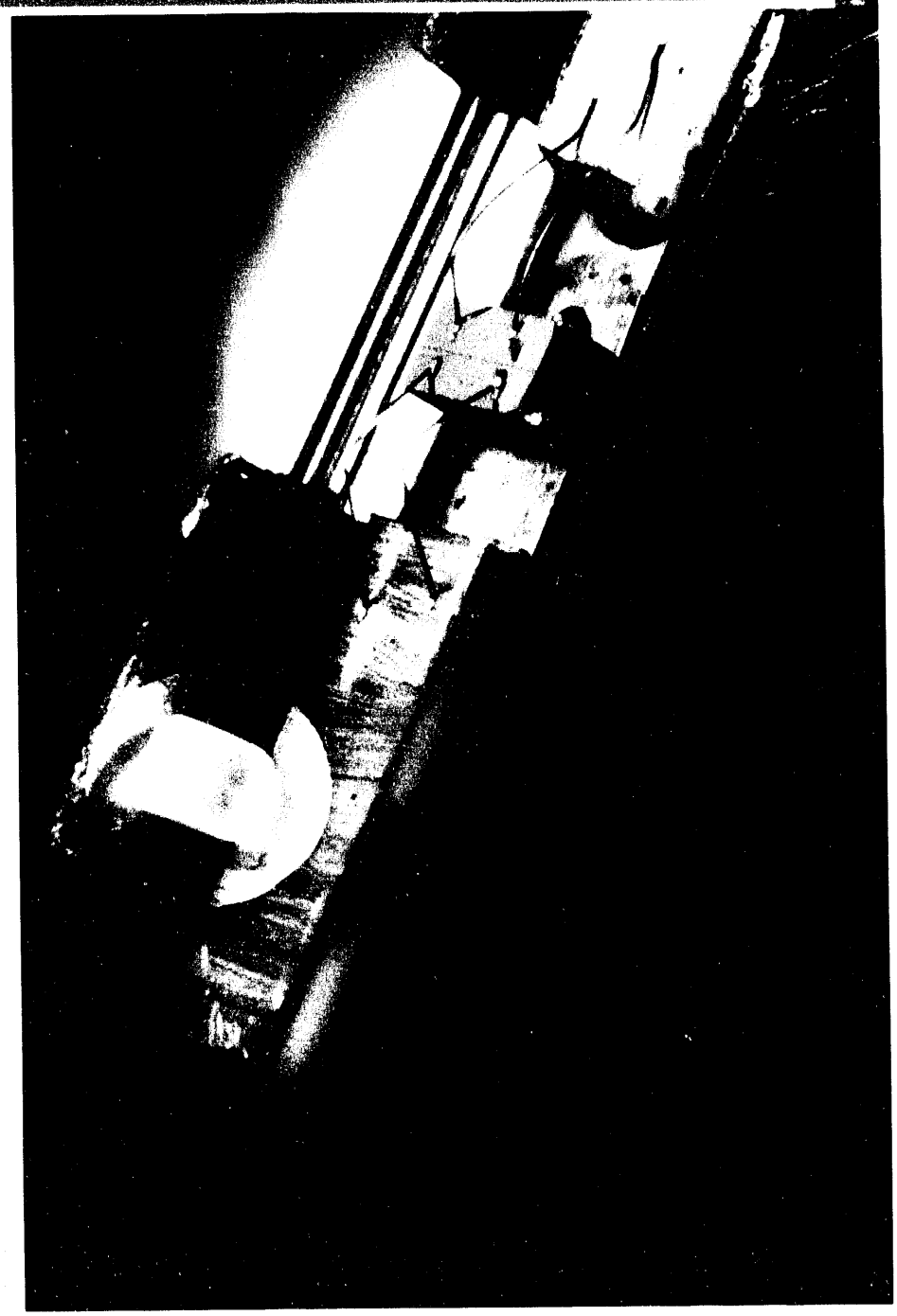
The enthusiastic response of *Handbook* users in the DOE system led Oak Ridge Associated Universities (the management and operating contractor that administers the Oak Ridge Institute for Science and Education) to license the *Handbook* to Educational Technology Publications, Inc., of Englewood Cliffs, New Jersey. Educational Technology Publications is distributing the *Handbook* to private facilities. ■



The cover of the publication, *The Occasional Trainer's Handbook*, shows the five-step performance-based training method it sets forth.

Information and Communication Software

With good reason, the last half of the twentieth century has been called the "Age of Information." Advances made at DOE laboratories and facilities in plant and process diagnostics and control, distributed and fault-tolerant computer systems, and data storage and retrieval may have a major impact on virtually every sector of the economy and are critical to national security. The United States is striving to maintain its leadership in the worlds of software, networks and communications, and computer design.



This gallium arsenide semiconductor optical amplifier (SOA), a single quantum well laser diode, was fabricated at Lawrence Livermore National Laboratory. It is packaged with a virtual point source beam shaping lens. Packaged SOAs may provide low-cost optical amplification in future high-speed optical communication and data-processing systems. To indicate size, a single grain of table salt is shown in the circled area.

Management of Chemicals and Hazardous Materials

Generating Waste Reports that Satisfy Applicable Regulations

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Princeton Plasma Physics Laboratory (PPPL) engineers have developed a software system that tracks chemicals from the time of their arrival at a facility until they leave the facility as chemical waste. Toxic and hazardous wastes are controlled by means of bar code technology. The system produces local, state, and federal waste reports that comply with all applicable regulations.

Each of the software's chemical inventory files contains all the information that might be needed by management or safety personnel. Information about the locations of chemicals is electronically linked to floor plans. Disposal data are stored for electronic linking to the portion of the program that tracks waste disposal. The system prints SARA (Superfund Amendments and Reauthorization Act of 1986) reports, including SARA Title III reporting forms: Part 1 (Identification and Certification) and Part 2 (Chemical Inventory).

The waste-tracking and report-generating portion of the system produces these forms: GM (Waste Generation and Management), OI (Off-Site Identification), IC (Identification and Certification), PS (Waste Treatment or Recycling Process Systems), and WR (Waste Received from Off-Site).

This software system, which provides total chemical and hazardous materials management, has the potential for reducing the labor required to prepare state and federal reports by more than 50%. Because of its flexibility and versatility, the system can be used in the manufacturing, academic, and process environments, as well as in the research and development environment. Designed and developed for use on Macintoshes, the system is being modified to operate under both the Windows and UNIX operating systems.

This technology, currently the subject of a cooperative research and development agreement, is available for purchase or license. ■

EPICURE: A Fixed-Target Control System

Flexible, Expandable Network of Cooperating Processors

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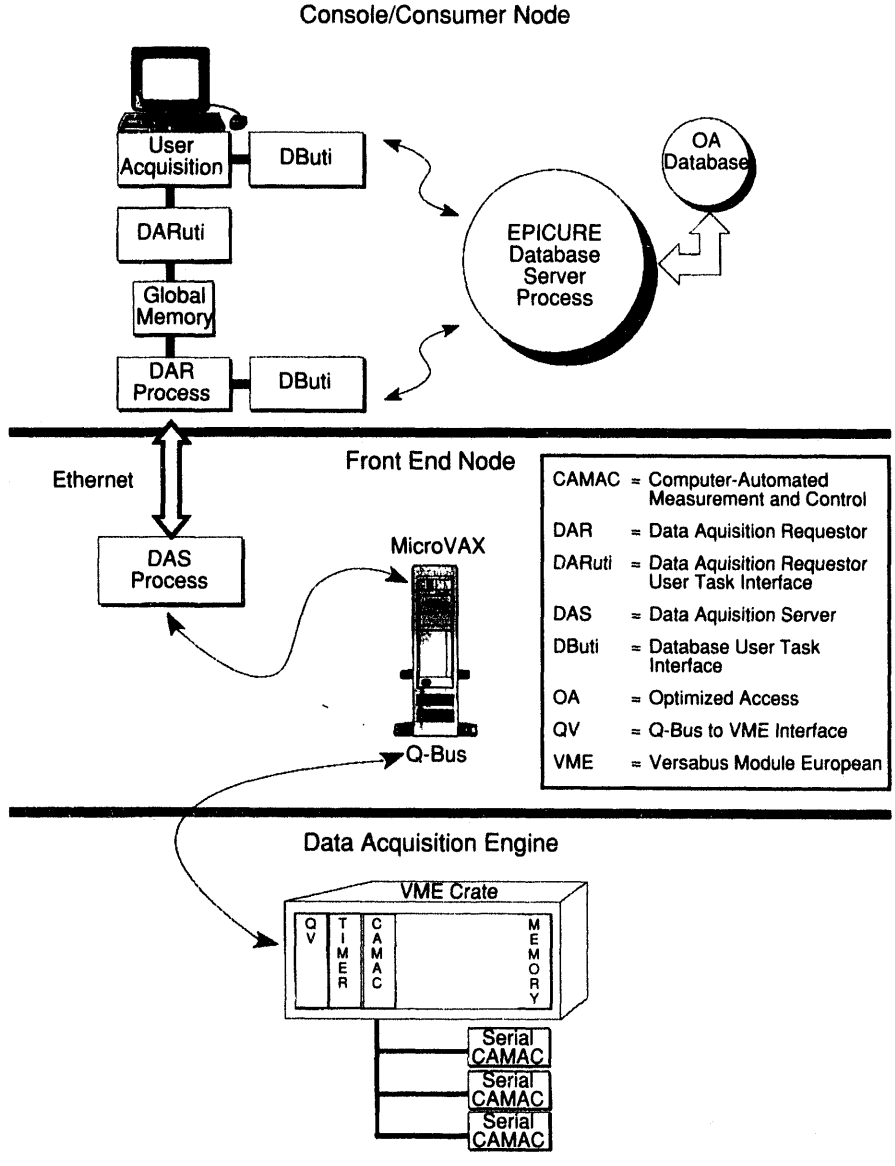
Fermilab recently commissioned a control system called EPICURE (Experimental Physics Interactive Controls User Resource Enhancement) for fixed-target, high-energy physics experiments. EPICURE, which can be thought of as a network of cooperating processors, runs the beam transport systems and instrumentation in the experimental areas at Fermilab, including all extracted beams for fixed-target physics. Medical accelerators and electric utilities that require consolidated readback of highly distributed instrumentation could take advantage of EPICURE technology.

The EPICURE system consists of multiple layers of interfaces for communication between logical tasks. The use of multiple layers allows specific portions of the system to be upgraded independently of surrounding layers, providing flexibility and expandability. Tasks such as data acquisition, database

lookups, and computation are distributed among numerous minicomputers, workstations, and intelligent modules. The system is accessible via any DECnet node and can be installed on any VMS (Virtual Memory System)-based VAX on DECnet. Therefore, EPICURE users can be located virtually anywhere at Fermilab and still have access to the entire control system. The EPICURE system was designed so it could evolve. Future needs are expected to be met by upgrades and enhancements rather than replacements.

System services are made accessible to the application programmer through standard software routines. These routines provide a straightforward way to access EPICURE services via any Fortran or C application. EPICURE's flexible architecture allows for user customization; it supports dumb terminals and provides an easy means of linking user-written applications without the user needing to understand details of the system architecture. EPICURE is available for licensing. ■



The fixed-target control system known as EPICURE, an expandable network of cooperating processors, offers ready access and easy integration of user-written application programs.

Electronic Mail for the Future

Ensuring Prompt Global Delivery through Standardization

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The Kansas City Plant (KCP) has formed a team of experts dedicated to the deployment of open computer systems based on international standards. These open systems allow computer systems to communicate with each other, regardless of the type of hardware or operating system.

The team has been focusing on applying the open systems concept to electronic mail. Electronic mail systems, which are used internally by many businesses, cannot easily be extended to allow communication with customers and suppliers because of differences in the ways various systems are implemented. However, these implementation barriers can be overcome by applying a common language, defined by international standards.

In a worldwide electronic mail system, as in a paper mail system, the content and format of each address must be standardized to ensure proper delivery. Each address must also be globally unique. Team members have been working closely with the American National Standards Institute's Registration Authority Committee to develop and establish guidelines for defining a national registration procedure for standardized electronic mail addresses. Each country is responsible for developing a unique national system.

Team members have also supported the formation of a consortium of electronic mail carriers and service providers. The consortium is creating a National Message Transfer System for the United States. People in other countries will be able to submit electronic mail messages to the system for delivery anywhere in the United States. Because a particular carrier or service provider will not have to be specified as part of the address, addresses will be shorter and more stable, and the system should be easier to use.

The University of Missouri at Kansas City worked with KCP to establish an open systems laboratory and research center. In 1992, the university received the Interop Achievement Award in the education category from Interop, Inc., of Mountain View, California, for its success in proving this electronic mail application of open systems technology.

Open mail systems are now being implemented throughout DOE. To facilitate implementation, classes based on the results of research conducted by the open systems laboratory are being offered to DOE personnel.

The team's next goal is to apply the open systems concept to directories in support of electronic mail. The first step will be to define a directory structure for DOE that will be accessible to people throughout the world. The overall structure will represent all of DOE, but portions of the data will be maintained by individual departments in DOE. The team also expects to begin research on applying the open systems concept to support electronic commerce and requirements for remote database access. ■

Employees of DOE are being trained to use open electronic mail systems at a training laboratory at the University of Missouri in Kansas City.

Multimedia Environmental Pollutant Assessment System

Computer Program to Speed Environmental Cleanup

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Site remediation specialists need consistent, defensible, and objective data and reliable analytical tools to make accurate predictions. They also need to accelerate the site analysis process; it can now take years to study all the factors that affect remediation.

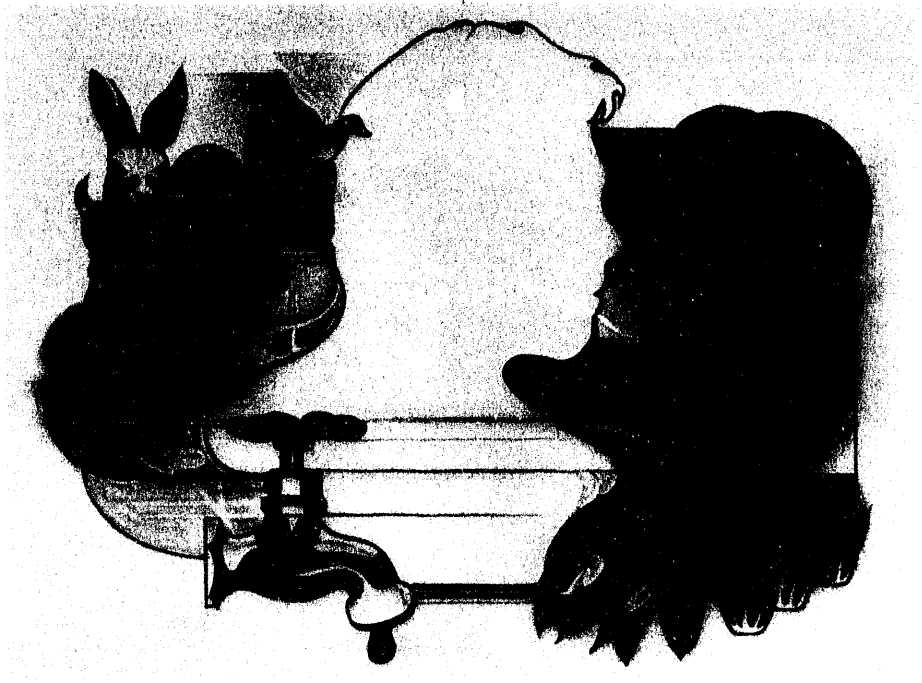
In response to these needs, Pacific Northwest Laboratory (PNL) developed the Multimedia Environmental Pollutant Assessment System (MEPAS). This program for personal computer and UNIX systems organizes and speeds analyses that quantitate the risk of contaminants to humans. To do so, it integrates risk assessment modeling codes and provides an overall risk evaluation for a site or an incident. Because MEPAS can process information very rapidly, multimedia risk assessments that were too difficult or time-consuming to be practical can now be performed in just a few hours for sites of any size and complexity.

Previous programs modeled only one contaminant medium (such as soil, air, groundwater, or surface water) or one contaminant pathway to humans (such as ingestion, inhalation, or skin contact). MEPAS integrates results from separate models of contaminant behavior in various media and identifies all possible pathways. The software prompts the user for information, integrates and analyzes data, computes risks for the site in question, and ranks environmental problems according to their potential for affecting human health. It displays this information as easily readable tables designed to help technicians assign priorities for cleanup efforts.

The MEPAS program was the driver for a unique collaboration involving a government laboratory, a private company, and an educational institution. The MEPAS developers at PNL transferred the technology to Mesa State College in Colorado, for which they received a Federal Laboratory Consortium Award for Excellence in Technology Transfer. The students, in turn, with the assistance of the MEPAS project manager and in conjunction with a project funded by AT&T, developed layouts, user interfaces, and innovative data transfer structures that are more user-friendly. PNL then hired a student to continue to work on MEPAS after graduation.

Now being used as a teaching tool at a number of universities, MEPAS will be used by DOE and probably be used by the Department of Ecology in Washington, the Colorado Center for Environmental Management, and several agencies of the Canadian government. The MEPAS software is available for commercial licensing. ■

The MEPAS computer program simulates the release of contaminants into the environment and their transport along multiple environmental pathways such as air, soil, and water. It quickly assesses risks to humans from various contamination scenarios.



Computational Testbed for Industry

Enhancing Economic Competitiveness through High-Performance Computing

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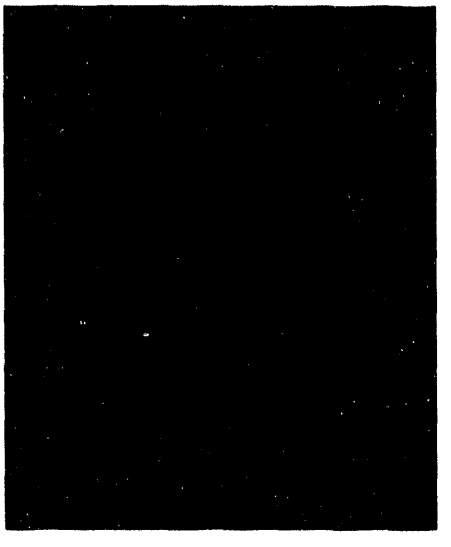
Computing and computers are assuming a role of ever-increasing importance in the operation of American companies, regardless of the nature of a company's business. The Computational Testbed for Industry (CTI) has been established at Los Alamos National Laboratory (LANL) to accommodate the growing industrial demand for supercomputing capability.

The CTI is a technology transfer center that offers U.S. companies access to supercomputing resources — hardware, software, and expertise — found in LANL organizations like the Advanced Computing Center and the Central Computing Facility. The CTI also educates industrial users in the use of supercomputing through internships, conferences, and workshops. The services and resources offered through the CTI are not free; each customer pays a user or membership fee. However, workshops offered to small businesses are free to participants.



This simulation, performed with the Pagosa massively parallel hydrocode on the CM-5 connection machine, shows shaped explosive charges used for perforating well casings and oil-bearing rock formations.

Through the auspices of the CTI, representatives of the petroleum, chemical, automotive, pharmaceutical, and biomedical industries are actively engaged in computational projects at the Laboratory. For example, interns from Schlumberger, Xerox, and Rocket Research are studying visualization, photocopy image development and charge transfer, and rocket thruster design, respectively. Other collaborators working with the CTI include Du Pont, Gillette, Amoco, IBM, EDS, and Biosym.

The CTI sponsors computational science workshops that offer hands-on training in high-performance computing, numerical methods, and software tools. Some workshops address specific industrial needs. Past workshops have covered topics such as criticality safety for the nuclear industry and seismic imaging and management for the oil industry. Future workshops will cover environmental modeling, materials modeling, and high-performance computing for small business.

The CTI provides U.S. industry access to LANL supercomputing resources and a forum in which Laboratory personnel interact with industrial scientists and engineers and learn about the problems faced by U.S. industry. Such interactions help LANL be more responsive to the needs of U.S. industry. In addition, experiences at CTI help LANL personnel gain new knowledge that they can apply in other Laboratory programs. ■

3D-Flow Parallel Processing System

Improving Performance and Cost Effectiveness of Data Processing

Developed for the detector systems associated with major high-energy particle accelerators like the Superconducting Super Collider (SSC), the 3D-flow parallel processing system is a new concept in processor architecture, system architecture, and assembly architecture. Compared with the electronics used in conventional systems, the new approach offers improved performance; reduced cost, size, and complexity of the hardware; and easy assembly, disassembly, upgrading, and maintenance of different interconnection topologies.

The 3D-flow architecture is designed to acquire multiple data in parallel (i.e., up to 100 million frames per second) and process them at high speed (e.g., digital filtering of input data, pattern recognition, and data moving and formatting). The system is suitable not only for particle-identification applications in high-energy physics (e.g., calorimeter data filtering, processing and data reduction, and track finding and rejection) but also for applications such as pattern recognition in radar systems, studies of biological molecules, and graphics processing.

The main advantages of the 3D-flow system are its programmability, scalability, capacity for high-speed communication, and low cost. The architecture allows construction of a parallel processing system with six-directional communication between neighboring processors. Except for the 3D-flow chip itself, standard, commercially available components are used to minimize costs. One-, two-, and three-dimensional interconnection topologies are implemented by arranging the system in a planar, cylindrical, or spherical assembly, respectively. A cylindrical topology is applicable to many particle detectors. The interconnection length is kept to a minimum, and the interconnection topology ensures both short cable lengths and minimum differences in these lengths. These conditions permit operation at very high speeds, low power consumption, and reduced processor pipelining.

Three patents have been applied for on various aspects of this system. Technology transfer is being pursued through numerous technical presentations and discussions with interested parties. Possible licensing opportunities are also being explored. ■

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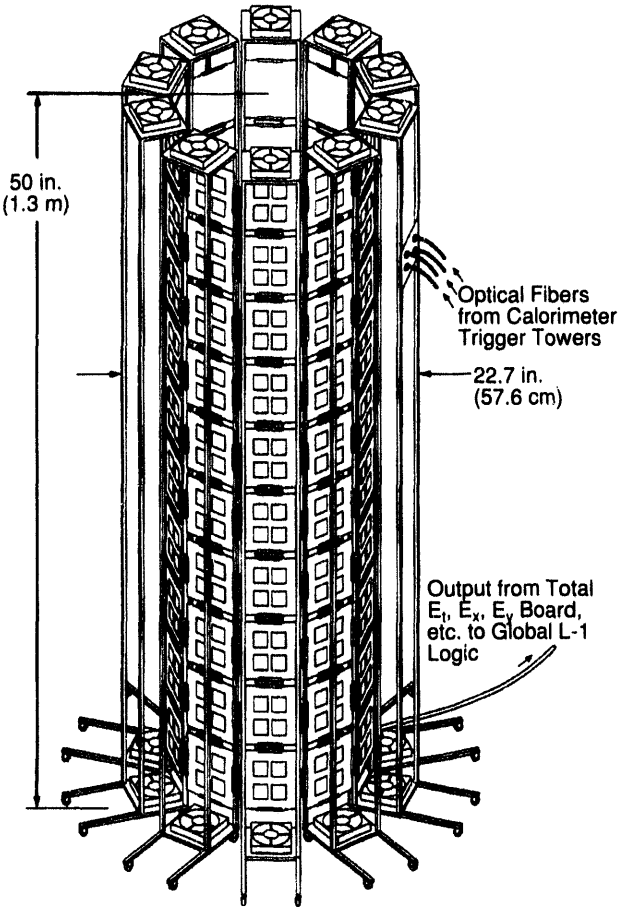

The cylindrical assembly configuration of the 3D-flow parallel processing system is well-suited to particle-detector applications.

Emergency Operations and Information Management System

Providing Vital Site Information during Emergencies

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The Princeton Plasma Physics Laboratory (PPPL) has designed a software program to provide information to emergency responders (fire fighters, security guards, hazardous-materials personnel, emergency medical technicians, and others) that will help them operate effectively during emergencies. The program addresses such typical emergency situations as fires, floods, earthquakes, chemical accidents, terrorist acts, and hostage situations. The program is also expected to be of value to community planners.

The Emergency Operations and Information Management System software can store archival information for any type of facility or building. Typical kinds of information would include locations of emergency exits, fire equipment, and electric-power panels; electrical isolation information; chemical inventories and locations; special hazards analyses; locations of elevators for people with disabilities; emergency evacuation routes; and fire department connections.

The Emergency Operations and Information Management System is an outgrowth of the Computer-Aided Management of Emergency Operations (CAMEO) Program, designed by the National Oceanic and Atmospheric Administration and the U.S. Environmental Protection Agency to help community emergency planners and first responders safely handle chemical accidents. The PPPL designers have significantly expanded CAMEO's capabilities to deal with fire and emergency situations at a particular facility.

The Laboratory received a "noteworthy practice" award from DOE for this software. PPPL is seeking opportunities to apply its unique capabilities in emergency planning and operations and to transfer its technology to state and federal governments and private companies. ■

The Emergency Operations and Information Management System provides ready access to information needed by those responding to emergency situations.

Mesh-Generation Software to Speed Product Design Cycles

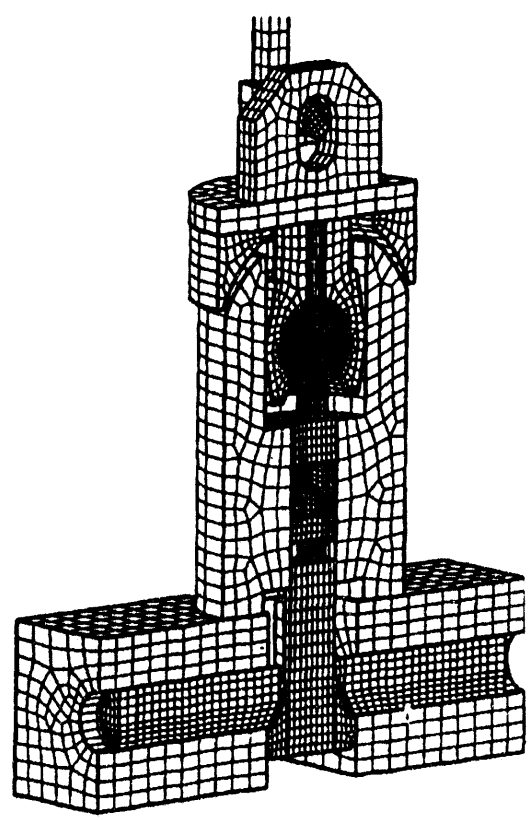
Timely Marketing to Boost U.S. Competitiveness

Innovative mesh-generation software that can help shorten product design cycles is the focus of a consortium made up of Sandia National Laboratories and four U.S. businesses. Sandia has developed, tested, and used the computer-aided design algorithms and adaptive analysis techniques and will continue refining the algorithms. The companies will adapt, commercialize, and market the software. In addition, some of them will integrate the software into their own design processes. For example, Ford Motor Company of Dearborn, Michigan, plans to use the package to design vehicles and other products.

Meshes must be generated to apply computer analysis to the design of any complex industrial product. Mesh-generation software, capable of meshing complex geometry in two and three dimensions, speeds the design process. More specifically, it improves finite-element analysis, a powerful numerical method for determining the physical behavior of an object or geometric region. Sandia is developing two tools to improve automation of finite-element mesh generation. A "paving" technique automatically generates three-dimensional surface meshes, and a "plastering" technique fills in the three-dimensional solids.

Current industry methods for mesh generation limit the speed with which design analyses can be conducted. For example, generating the mesh for a computer simulation of a car crash takes 6 to 8 weeks. Sandia's software relieves analysts of this time-consuming job and gives them the tools they need to describe the geometry of the meshing process and exercise control over it. Because the analysts are freed to perform more design iterations, a product's quality and time to market can be improved.

The paving mesh-generation algorithm won a 1993 R&D 100 Award from *R&D Magazine*, which recognizes the 100 most significant technical products developed each year. The advanced meshing technology could be used by any company relying on analysis to improve its product designs.



Shown is a customized, computational, three-dimensional mesh of a pull-out switch. The mesh was constructed by combining, translating, and rotating two-dimensional meshes by means of innovative mesh-generation software.

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AdaSAGE Computer Programming Tool

Reusable Software for Creating New Programs

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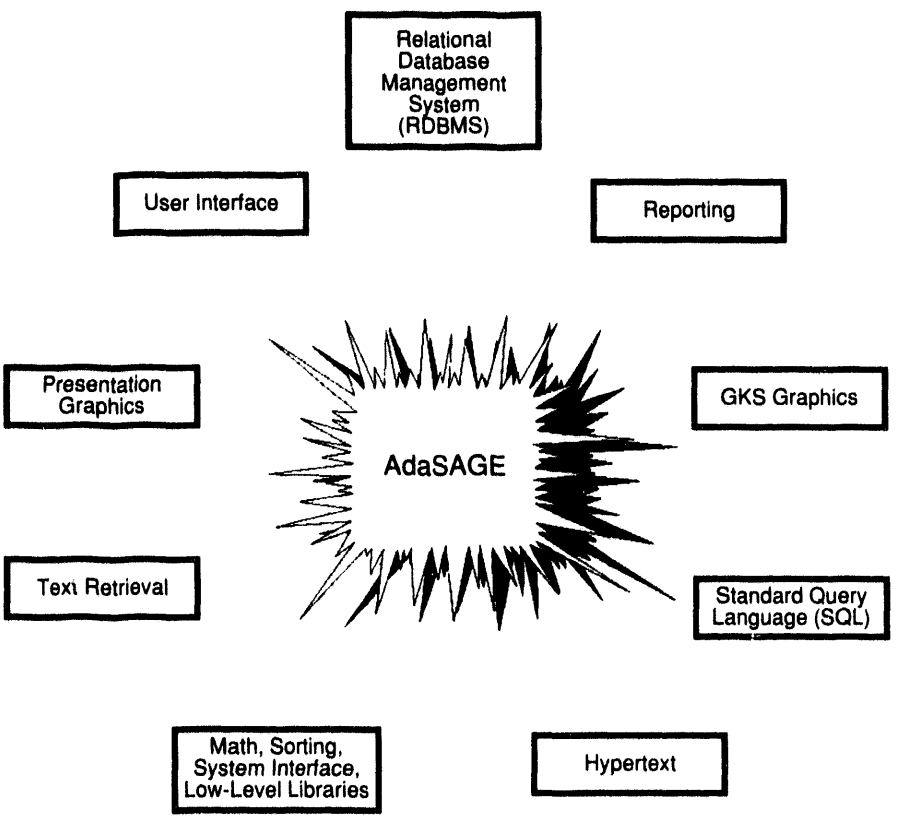
Ada, a computer language originally developed by the U.S. Department of Defense, is now being used by various U.S. governmental agencies. AdaSAGE is a software tool developed by Idaho National Engineering Laboratory (INEL) to build new application programs written in Ada. By offering a high percentage of reusable code, AdaSAGE enables system developers to construct applications without having to create new systems. Programmers use this flexible, high-performance tool to design software tailored to their needs. Examples include probabilistic risk assessments, military applications in support of Desert Storm-type missions, and management information systems for task loading, logistics, and scheduling. AdaSAGE increases programmer productivity during application development and decreases requirements during maintenance.

AdaSAGE is implemented as a set of Ada packages and a set of executable programs used as support utilities during the development and operation of an application. Consisting of more than 300,000 lines of code representing some 250 person-years of effort, AdaSAGE provides about 60 reusable packages for relational database management; screen, menu, and report formats; graphics; hypertext; communications; on-line help; sorting; data movement; and file operations. Offering state-of-the-art technology, each package can be efficiently implemented and easily integrated into an AdaSAGE application.



The AdaSAGE environment integrates reusable components in several common application domains by means of a cyclic development methodology. Software development organizations throughout the government have successfully implemented AdaSAGE applications, thereby significantly reducing their development and maintenance costs.

AdaSAGE started out in the early 1980s as a product called SAGE, which was designed to facilitate database access and provide a friendly interface for scientific, engineering, and analyical systems developed at INEL. Initially, SAGE was written in FORTRAN for Control Data Corporations's Cyber computers at INEL. Four years later, SAGE was ported to the IBM PC microcomputer environment, first in Pascal and then in Modula-2. In 1987, when the U.S. Marine Corps asked INEL for a prototype Ada-based system, SAGE was once again converted to another language and became AdaSAGE. It is now a government-domain product available to developers in academia and private industry as well as governmental agencies. It has been successfully used to develop systems for the U.S armed services, National Oceanic and Atmospheric Administration, and U.S. Nuclear Regulatory Commission and is currently being used by the U.S. Department of Energy, U.S. Department of Defense, and other agencies.

Over the last 7 years, AdaSAGE has been ported to a number of hardware platforms, including IBM PC/DOS, EVEREX/UNIX, PRIME/UNIX, IBM RS-6000/UNIX-AIX, AT&T 3B2/UNIX, and SUN SPARC 2/UNIX. AdaSAGE is available for the Alsys, Meridian, and Verdix Ada compilers.

In 1993, AdaSAGE received *Computerworld*'s Object Application Award as an excellent example of object-oriented software that uses a non-object-based tool. ■

Physics and Detector Simulation Facility

Designing an Advanced System of Integrated Computer Workstations

One of the benefits of the Superconducting Super Collider (SSC) project was the technological advances achieved by the nation's computer industry as it worked to develop hardware, software, and fiber-optic techniques for the project. Several commercial vendors are now producing computing systems similar to the system developed by the team of scientists at the Superconducting Super Collider Laboratory (SSCL).

The Physics and Detector Simulation Facility (PDSF) was built at SSCL to perform critical design studies of the SSC detectors and simulate their interactions. About 500 scientists from around the world were using the facility to plan experiments and design the detectors.

This unique computing facility is capable of creating intricate models of proton-proton collisions and the massive electronic tracking devices that chart the results. It features a parallel processing architecture that is both powerful and economical. The system of integrated computer workstations can execute 3 billion instructions per second. The resulting computational power is the equivalent of about 60 conventional mainframe computers. Moreover, the PDSF was designed and built for $3 million (a single mainframe computer can cost as much as $20 million). The facility's capability for parallel processing makes it possible for its computers to work on many event simulations simultaneously.

The facility employs a novel concept of computing that uses an integrated network of distributed RISC/UNIX workstations. Computational tasks are organized into many separate subtasks that are worked on in parallel by many

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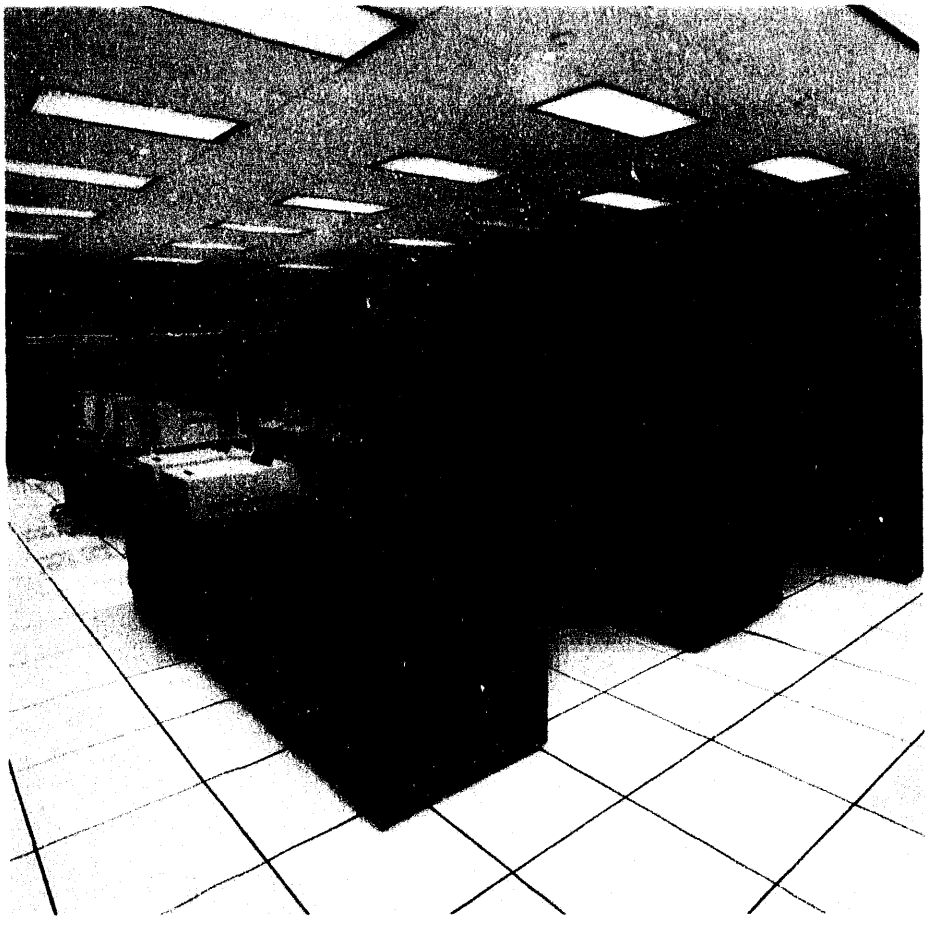
individual computers in the network. The powerful yet less costly RISC/UNIX workstations use open (nonproprietary) systems and conform to industry standards that permit the integration of equipment from different manufacturers. In the past, each computer manufacturer designed operating software that could be used only on its own equipment, precluding its use with equipment produced by competitors. By insisting on open standards, equipment selections were optimized to achieve the best performance in each component area, regardless of manufacturer.

The facility can provide batch and interactive processing from a "ranch" of computers networked by fiber optics and organized in four "corrals." Two contain 16 SUN Sparkstation 2's; the other two contain 16 Hewlett Packard Model 9000/720 workstations. Silicon Graphics multiprocessors act as the data server to the four corrals.

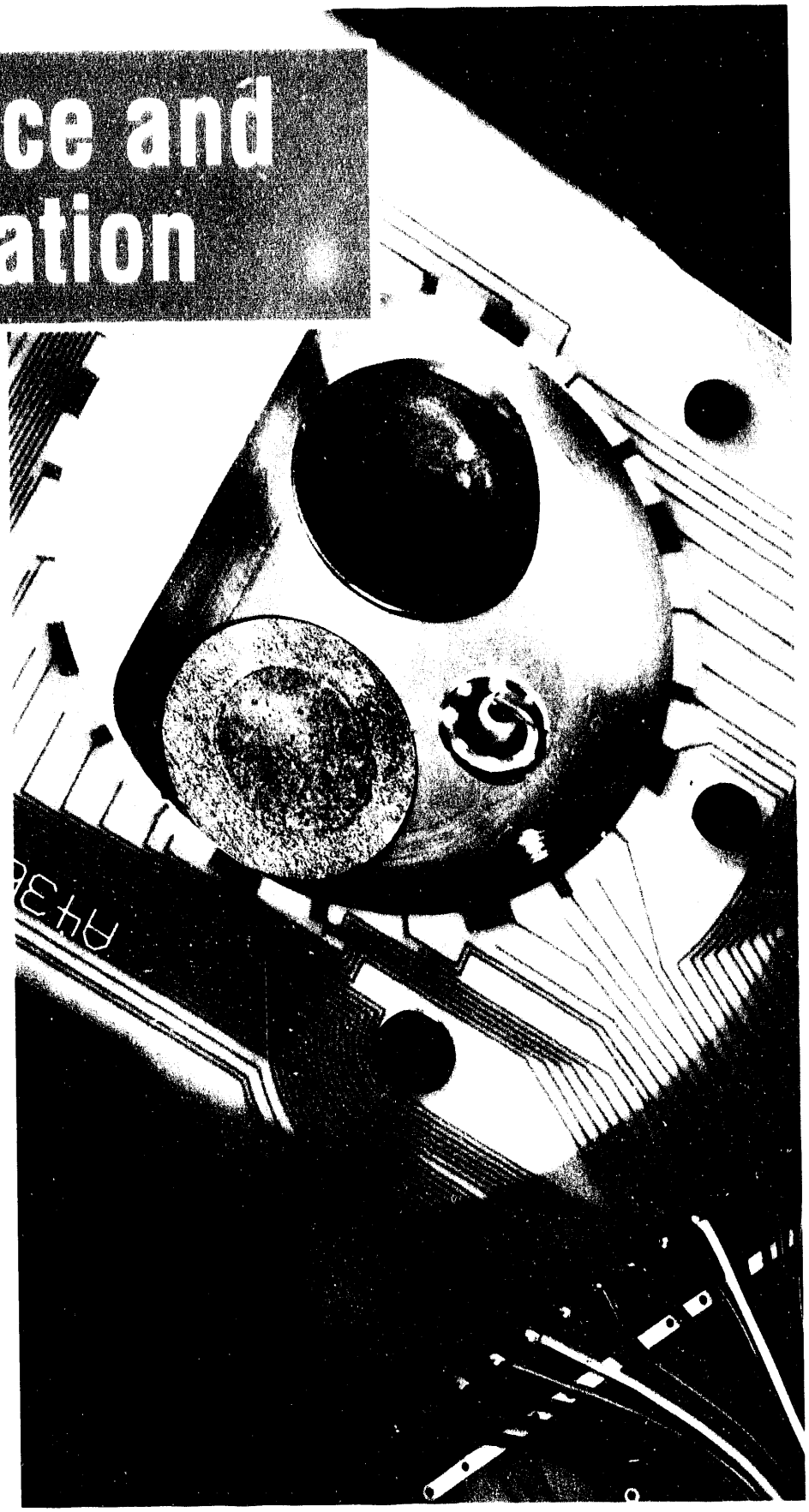
The PDSF is the world's most powerful computing facility for simulating high-energy physics. An upgrade that would cost about $1 million could double the facility's capability from the current 2,000 VAX equivalents to 4,000. ■



The Physics and Detector Simulation Facility is located at the site where the Superconducting Super Collider was to have been built.

Aerospace and Transportation

In increasing numbers, humans are on the move, both across the earth and into space. Such transport adversely affects the environment; in particular, it affects the world's natural resource base. At the same time, new methods of transport are being developed. Magnetically levitated vehicles that use superconductors may revolutionize intercity transportation. Advanced battery technologies hold promise for zero-pollution electric vehicles and other applications. As the United States strives to be competitive in world transportation markets, it is currently meeting challenges from abroad in aerospace markets.



This new instrumented head gasket developed by Sandia National Laboratories enables researchers to monitor combustion inside a working automotive engine. For more information, see the writeup on the facing page.

Instrumented Head Gasket for Monitoring Engine Combustion

More Efficient Engines that Emit Fewer Pollutants

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An instrumented head gasket recently developed by Sandia National Laboratories can monitor the combustion process inside an automotive engine. Such monitoring provides designers with the information needed to make engines more efficient and less polluting. This engine diagnostic tool received an R&D 100 Award from *R&D Magazine* as one of the top 100 developments in 1992.

The modified gasket consists of a multilayer printed circuit board with a circular array of ionization probes. The probes detect the instant at which the flame front (area of burning gases inside the engine cylinder) passes. The board is made of a temperature-resistant, glass-reinforced polyamide material. Different layers of circuits can be used to provide different probe patterns.

In addition to the ionization probe electronics, Sandia developed personal computer software to acquire and process data from the gasket. The gasket complements an earlier Sandia development, a fiber-optic spark plug probe. Both instruments enable automotive engineers to nonintrusively diagnose the combustion process inside a working engine cylinder.

Although ionization probes had been used before in engine research, they were always installed through machined access ports. However, the instrumentation is built into this gasket, so an engine can be tested without requiring the engine block or head to be modified. This feature allows the gasket to be applied more easily to production engines.

The gasket can also be used to measure the direction and magnitude of the swirling motion of the fuel-air mixture in the cylinder. The swirl enhances the combustion rate. When one of the ionization probes is used as an ignition source, the swirl velocity can be determined by tracking the location of the flame with the remaining ionization probes.

The instrumented head gasket can be used to optimize the design of the combustion chamber and related components of automotive engines. It can also be used to investigate sources of the unburned hydrocarbons that cause engine knock.

The V-6 Powertrain Division of General Motors (GM) of Flint, Michigan, has used this instrumented head gasket to investigate combustion performance in one of its developmental engines. DSP Technology, a major manufacturer of analysis systems in Fremont, California, has delivered 20 gaskets based on Sandia's design to GM and plans to develop further hardware and software components. The Southwest Research Institute of San Antonio, Texas, is using the system for contracted clients. In addition, GM Research Laboratories of Warren, Michigan, Ford Scientific Research Laboratories of Dearborn, Michigan, and Sloan Automotive Laboratory at the Massachusetts Institute of Technology are also evaluating these head gaskets. ■

Superplastic Forming Technique

Producing Lightweight Materials for Vehicles and Other Uses

Using aluminum instead of steel in transportation systems could dramatically reduce the weight of vehicles — an effective way of decreasing fuel consumption and thereby vehicle emissions. Researchers at Pacific Northwest Laboratory have teamed with manufacturers, aluminum suppliers, and university researchers to develop new techniques for producing lightweight materials for the automobile and transportation industry. One of the most promising techniques is superplastic forming.

Superplastic forming permits high levels of deformation, and single structures (instead of multipart components) can be formed in one automated step. The weight of a part can be significantly decreased when external support structures are replaced by internal ones and when steel is replaced with aluminum. Compared with current production methods, superplastic forming can reduce the number of components, decrease tooling costs and processing times, and simplify manufacturing operations.

Superplastic forming of aluminum results in light, complex structures with a wide range of uses outside the transportation industry. For example, the material is ideal for subways, where it can replace plastic and fiberglass panels, thereby reducing the potential for toxic fumes in case of fire. Superplastic forming could also benefit manufacturers of heavy equipment and structural supports.

The Laboratory has formed an alliance with Washington State University to develop a superplastic forming facility where researchers can demonstrate this high-rate process and provide hands-on training for engineers, scientists, and manufacturers. ■

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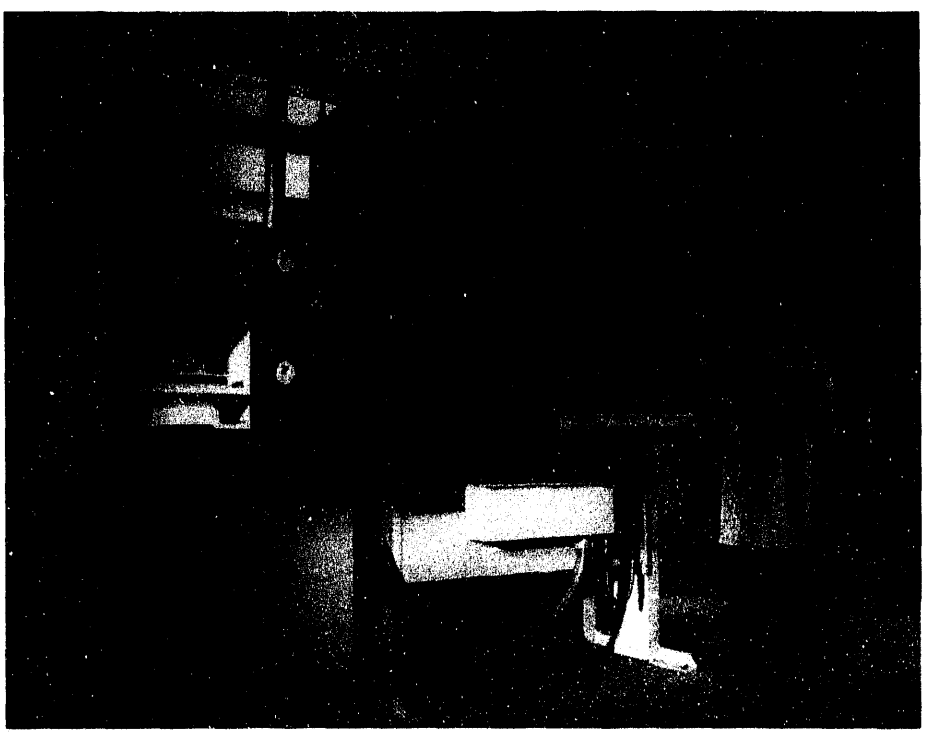

Researcher checks a superplastic forming unit. This innovative technology enables manufacturers to replace steel with aluminum, thereby reducing the weight of automotive components and other items.

Weigh-in-Motion Technology

Weighing and Classifying Highway Vehicles Accurately and Cheaply

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Researchers at Oak Ridge National Laboratory (ORNL) have developed a technology with the potential to revolutionize weigh stations like those found along interstate highways. Their fiber-optic vehicle weigh-in-motion (WIM) and classification system calculates vehicle weights more accurately and less expensively than conventional portable systems. Potentially, it could measure the weight of a vehicle while it is moving at highway speeds faster than current systems allow.

Although the existing WIM systems are relatively accurate at low speeds, their size, installation requirements, and high cost have hindered their general adoption. The new technology makes possible the first truly portable, practical, and cost-effective system capable of reliably weighing and classifying vehicles. ORNL's fiber-optic vehicle-weighing system has many likely applications for a wide range of users.

The system is the first portable one successfully developed both to accurately weigh and classify vehicles. In addition to calculating a vehicle's weight, it can also measure the space, width, and number of its axles; the width and number of its tires; and its velocity and rate of acceleration.

A simple silicone rubber fiber is the key component of ORNL's fiber-optic vehicle WIM and classification system. When weight, such as that of a rolling tire, is applied, fiber-optic sensors are compressed. The intensity of the light transmitted through each fiber changes with the amount of weight applied on the fiber. A computer analyzes the data collected and provides detailed information about the vehicle passing over the system.

The system is inexpensive, easy to use, and flexible. Processing the light signals — by measuring changes in light intensity — does not require the sophisticated signal-processing capabilities required by other systems.

Accurate systems currently being used to measure vehicles weigh thousands of pounds and are permanently installed. The ORNL system's heaviest component weighs only 65 pounds, and researchers are working hard to reduce that to 50 pounds. When the portable system is completed, it will be less expensive to build and will require less time and labor to install.

The system's biggest advantage will be reduced cost to the taxpayer. ORNL's fiber-optic vehicle WIM and classification system will help highway transportation and law enforcement personnel enforce weight limitations, leading to less wear and tear on highways.

The system has other potential uses. Landfill operators could weigh and classify vehicles entering and leaving landfills, monitor incoming waste by weight, and assess fees to landfill users. Airports could monitor the weight distribution of aircraft prior to departure for increased flight safety and improved fuel efficiency. Toll roads could weigh and classify vehicles automatically to improve traffic flow, assess toll fees more accurately, and monitor trends in certain road areas to reduce congestion.

SIMPLEV Simulation of Electric Vehicle Performance

Allowing Researchers to Test Hypothetical Electric Vehicles

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Idaho National Engineering Laboratory (INEL) engineers have designed a versatile computer program called SIMPLEV (Simple Electric Vehicle Simulation Program). It is the only publicly available software that models the performance of electric and hybrid vehicles, that is, those employing batteries and/or heat-engine-driven generators as the energy source. While many research institutions support design programs, SIMPLEV is a performance evaluation tool.

In 1987, INEL researchers began writing SIMPLEV for internal use. As researchers in academia and industry became aware of the program, they convinced the INEL software designers of their need for it. By 1993, when a second version of the software was available and a third was under development, about 30 organizations had obtained the first version and four more had requested the second. Users have included (1) educational institutions like the Colorado School of Mines, Cal-Poly State, New York Institute of Technology, West Virginia University, and Texas A&M; (2) companies like Westinghouse Electric Corporation, Chrysler Corporation, and General Electric Company; and (3) various governmental entities like DOE laboratories, the Advanced Research Projects Agency, and the U.S. Environmental Protection Agency.

This mathematical model enables parametric studies of vehicle performance to be conducted for specific driving cycles. The interactive program guides users to provide all essential inputs by entering values for a wide range of factors like road condition, wind speed and direction, road grade, type of motor, type of catalytic converter, and battery capacity. With this information, SIMPLEV simulates the vehicle's battery and powertrain performance. The software's greatest value lies in its ability to help researchers predict the performance of hypothetical vehicles. It can be used with any IBM-compatible personal computer. The software, available for a licensing fee, can be obtained through the DOE Energy Science and Technology Center or INEL. ■

Metallic Thermal Storage Unit

Improving Energy Storage for Satellites

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Researchers at Oak Ridge National Laboratory (ORNL) have developed a new type of energy storage system for solar-dynamic power units on low-orbiting satellites. The new system collects, stores, and uses thermal energy more efficiently than conventional systems. It also simplifies fabrication and reduces system size and weight, which could cut launch costs by as much as $10 million per launch.

The metallic thermal storage unit collects thermal energy during the sunlit part of a satellite's orbit and stores it (as latent heat) to be used while the satellite is in the earth's shadow. Canisters filled with germanium — a "phase-change" metal that melts and resolidifies as the satellite moves from sunlight to shade —

collect solar energy. The canisters are attached to a gas manifold inside a large receiver container. Sunlight entering the receiver heats the canisters, and the heated gas in the manifold drives a turbine to power the satellite's generator.

Current satellite power systems use photovoltaic cells on large mechanical arrays to collect solar energy, which is stored in batteries for use during the shaded period. Batteries do not function well when they are repeatedly charged up and drained. Therefore, satellite batteries must be built to overcapacity to ensure that they are never completely drained. The use of such massive, heavy units means higher launch and operational costs. By contrast, thermal-dynamic power units, for which the ORNL system was developed, use heat directly as a power source, eliminating the need for batteries.

When a satellite is deployed in earth orbit, its large photovoltaic-cell arrays unfold like wings. For low-orbiting satellites, however, atmospheric drag is still a factor. The drag on the arrays slows the satellite, which eventually falls from orbit. ORNL's metallic thermal storage system has no photovoltaic cell "wings." The mirrors that guide sunlight into the receiver are small relative to the standard-size photovoltaic array, minimizing drag and increasing the useful life of the satellite.

The new system also improves on similar devices that use fluoride salt as a phase-change material. Thermal conductivity is enhanced tenfold with germanium, so the units are smaller and lighter. Weight savings are critical to reducing launch costs, which are roughly $25,000 per kilogram for low orbit. Other advantages over the salt-based variety are as follows:

- The graphite container can survive temperatures twice as high as those traditional vessels can endure, providing a safety margin against overheating.
- Temperature variations in the phase-change material, which vary as much as 200°C with fluoride salt systems, are virtually eliminated.
- The volume change of germanium upon freezing or melting is about one-fifth that of fluorides, reducing the likelihood of void-induced hot spots that can deform or rupture the container.
- A simple, threaded closure is adequate to contain the molten germanium, whereas the containers for fluoride systems require electron-beam welding.

The metallic thermal storage system was originally developed for use on the National Aeronautics and Space Administration (NASA) space station, Freedom. Although the budget for the space station has been reduced, NASA officials still recognize the merits of the new energy storage system. One of its most important aspects is its potential for minimizing costs. The new system enhances the opportunity for future generations to continue exploring outer space.

In addition, this unit could have many applications when used on solar-energy collection systems such as desert "power towers," in which many mirrors focus a large area of sunlight on a central point for steam generation.

The metallic thermal storage unit is a new type of energy storage device for low-orbiting satellites; it collects, stores, and uses solar energy more efficiently than conventional systems.

Proton-Exchange-Membrane Fuel Cell

Developing Cleaner-Burning, More Efficient Engines

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Los Alamos National Laboratory (LANL) and the General Motors Allison Gas Turbine Division have been developing technologies for a proton-exchange-membrane (PEM) fuel cell system that could provide clean, efficient power to passenger cars. PEM fuel cells could substantially reduce U.S. dependence on petroleum and decrease pollution.

An Allison Gas/LANL team is conducting feasibility studies sponsored by DOE through a research and development contract with General Motors. The goal is to produce a 60-kilowatt electrochemical engine for a prototype vehicle before the end of 1997.

Unlike internal combustion engines, electrochemical fuel cells convert the chemical energy in hydrogen-rich fuels directly into electrical energy for vehicle propulsion. Because no intermediate heat-generating step occurs during energy conversion, fuel cell power systems are highly efficient; furthermore, projections indicate they have the potential for 90% lower hydrocarbon and nitrogen oxide emissions and 40% lower carbon dioxide emissions than standard internal combustion engines.

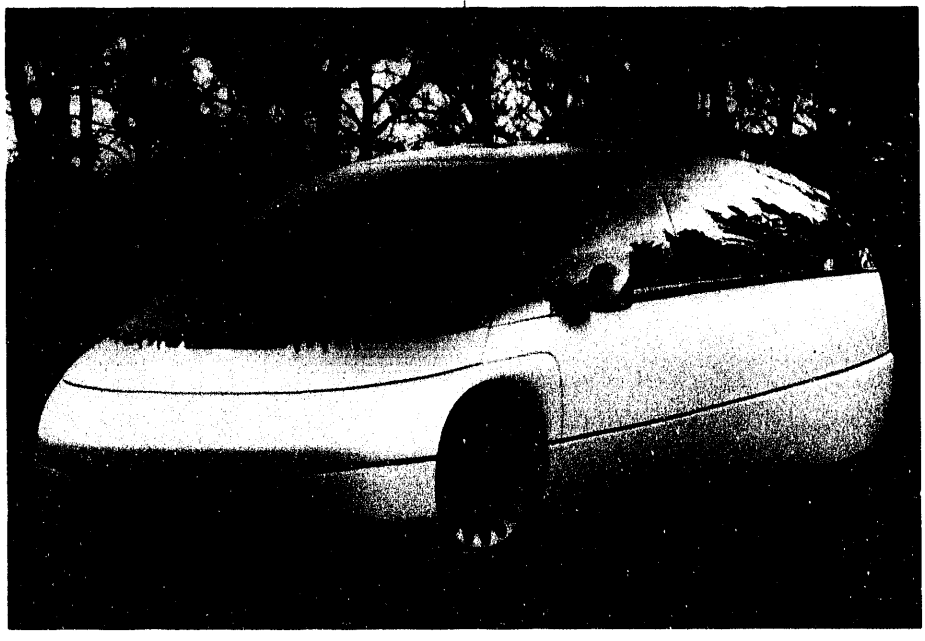
The heart of the electrochemical engine is the PEM fuel cell. Three other major system components are required for producing and regulating power delivery: (1) a fuel processor to convert methanol to hydrogen gas, (2) auxiliary equipment to maintain the proper environment for optimal energy conversion, and (3) an electromechanical control system.

This complex relationship of chemistry, electronics, and mechanics is being studied by using sophisticated computer and benchtop physical models. LANL and General Motors are operating a 10-kilowatt demonstration system. Dow Chemical Company and Ballard Power Systems are also participating in the fuel cell development program.

The Laboratory is also investigating ways to make fundamental improvements in PEM fuel cells. Early ones required large amounts of a costly platinum catalyst. LLNL scientists reduced the amount of platinum needed by 90% by mixing the metal with carbon dust and forming a film with some of the electrolyte. This method improves catalytic efficiency and simplifies the fuel cell fabrication process.

The Laboratory also discovered a simple solution to carbon monoxide poisoning of the platinum catalyst. Besides hydrogen gas, the most convenient fuel for PEM fuel cells is methanol. Methanol must first be steam-reformed to produce hydrogen gas, which produces small amounts of

The General Motors HX3 concept hybrid electric vehicle is shown here.



carbon monoxide (CO). At levels of 10 parts per million, the CO causes a 90% loss in the power obtainable from the cell. If small amounts of air are injected into the fuel cell with the methanol, the CO is converted into carbon dioxide, which cleans out the platinum electrodes.

SIMSICK Biocybernetic Device

Measuring Levels of Simulator Sickness

Researchers at Oak Ridge National Laboratory (ORNL) have developed a biocybernetic device called SIMSICK that anticipates the conditions that cause flight-simulator sickness, an ailment similar to motion sickness. Data obtained from a Navy operational flight trainer show that the device can predict the degree of sickness likely to be caused by various combinations of conditions.

Dynamic parameters associated with simulator use include acceleration, inferred visual cues, and energy accumulated from previous simulator exposure. Also significant are human physiological data gathered from studying pilots during day-to-day operations, such as the number of days since the most recent simulator flight or the amount of sleep the pilot had the night before.

The SIMSICK device measures the ways flight simulators can be manipulated, adds a human susceptibility factor, and employs a mathematical model to combine the parameters and make its predictions. Given the dynamic and physiological data, SIMSICK can accurately evaluate an individual pilot's susceptibility to simulator sickness. And, because the onset time and severity of sickness vary from pilot to pilot, SIMSICK could prove useful in determining the amount of time an individual pilot should wait after simulator training before flying a real aircraft.

For years there has been speculation as to why simulator sickness occurs. Because it pinpoints the specific spatial, visual, and temporal aspects that induce symptoms, SIMSICK helps researchers determine which movements are most likely to produce symptoms on the basis of when they occur during the training routine and the amount of energy absorbed by the pilot. Such information is vital in ensuring that simulator routines are properly planned so pilots can be evaluated consistently.

Equally important is SIMSICK's use in evaluating flight simulators; for example, checking how effective they are at simulating actual flights. In the past, poor assessments of real aircraft performance parameters have made such comparisons difficult. Theoretically, the cues that a pilot experiences in a simulator should correspond with real-life scenarios. When researchers had an individual test pilot perform in the simulator the same movements that he had made in an aircraft, under "identical" conditions, they found major differences in response times. By using SIMSICK's ability to measure the motion parameters on operating aircraft, simulators can be designed and tested to model actual events more closely.

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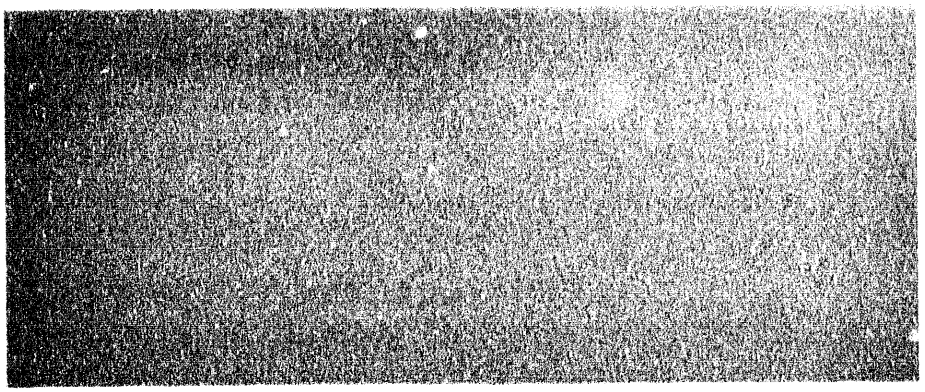

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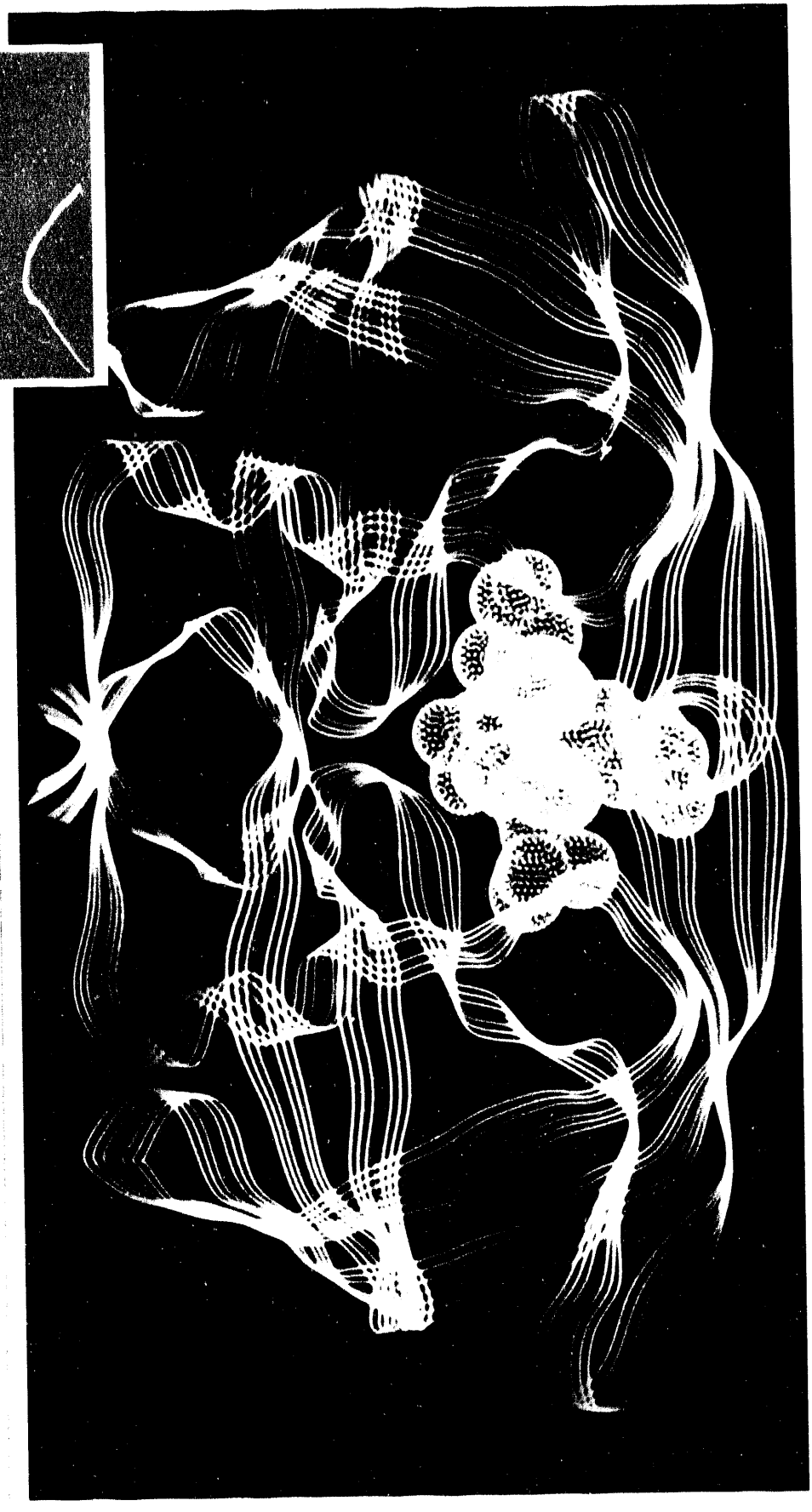

The Stanford Synchrotron Radiation Laboratory, a division of the Stanford Linear Accelerator Laboratory, is collaborating with the Institute of Bio-organic Chemistry of Syntex Research to determine the structure of HIV protease inhibitors. This image shows the full, three-dimensional structure of the HIV protease enzyme with a synthetic inhibitor molecule bound to it. The HIV protease represents a promising point of attack against the virus associated with AIDS. For more information, see the writeup on *HIV Protease-Inhibitor Complex Structure* on page 183.

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The rapid solidification of powders provides superior high-temperature microstructural stability and strength for commercially valuable alloys of iron, aluminum, copper, titanium, and other metals. At the Idaho National Engineering Laboratory, new discoveries in this technology have resulted in two R&D 100 Awards from *R&D Magazine.* Access to the Laboratory and this technology has been provided through six cooperative research and development agreements.

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