January • February 1995

# Energy & Technology Review

## STATE OF THE LABORATORY

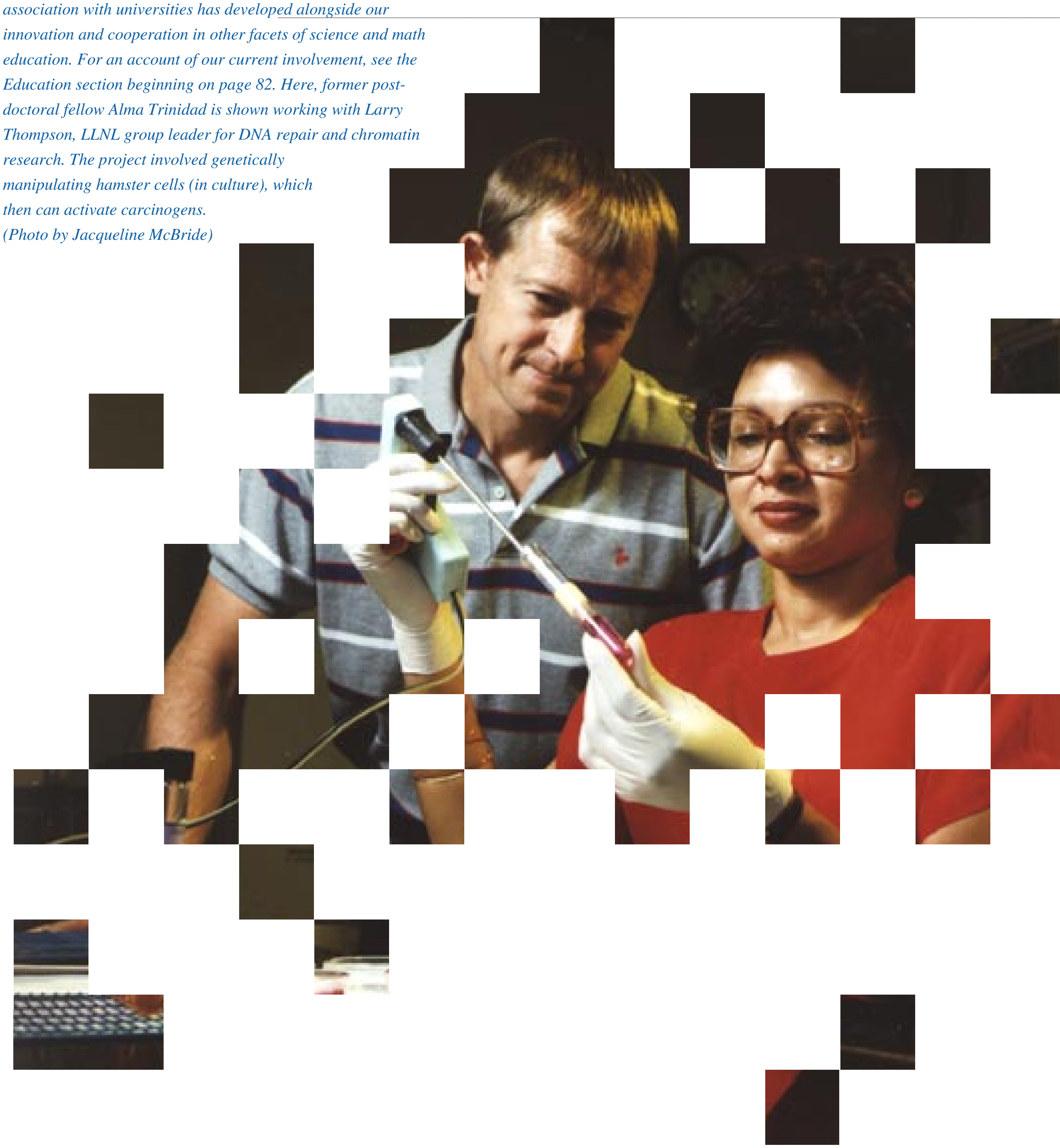
University of California

Lawrence Livermore National Laboratory

## About this Issue

*This issue of* Energy and Technology Review *highlights the Laboratory's 1994 accomplishments in our mission areas and core programs—economic competitiveness, national security, lasers, energy, the environment, biology and biotechnology, engineering, physics and space science, chemistry and materials science, computations, and science and math education. LLNL is a major national resource of science and technology expertise, and we are committed to applying this expertise to meet vital national needs.*

*Photograph: Almost as old as the Laboratory, our long-time association with universities has developed alongside our innovation and cooperation in other facets of science and math education. For an account of our current involvement, see the Education section beginning on page 82. Here, former post-doctoral fellow Alma Trinidad is shown working with Larry Thompson, LLNL group leader for DNA repair and chromatin research. The project involved genetically manipulating hamster cells (in culture), which then can activate carcinogens.*
*(Photo by Jacqueline McBride)*



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*Partial view of Building 111, which houses the director, staff, and scientists of several directorates.*

# State of the Laboratory

## DIRECTOR'S STATEMENT

**C. Bruce Tarter**

*Director*

*As these words are being written, the Galvin Task Force on Alternative Futures for the DOE laboratories is in its final phase, C. Bruce Tarter was recently selected as the eighth Laboratory Director, and Secretary of Energy Hazel O'Leary has just announced Key Decision One to proceed with planning for the proposed National Ignition Facility with Livermore as the preferred site. These events, and those that preceded them, are characteristic of the magnitude of the changes that are occurring in one of the most turbulent and stressful periods in the history of the Laboratory. Despite this turmoil, the technical accomplishments of the past year have been extraordinary. In addition, the Laboratory has developed an overall strategic vision that provides the architecture for our future planning.*

Most of the Laboratory's scientific and programmatic achievements of the past year are discussed in the sections that follow, but a few deserve special mention here. Perhaps the most significant is the development of the case for the proposed National Ignition Facility (NIF), in which 192 laser beams will focus their immense power to implode small targets of deuterium and tritium and produce fusion. This facility will be a centerpiece of our science-based program on stockpile stewardship and provide a superb laboratory for basic science. It also has the potential to establish the scientific feasibility of inertial fusion as a long-term energy source for the nation. Department of Energy (DOE) Secretary O'Leary's October 21 signing of Key Decision One allows us to proceed with vigorous planning for this major facility.

On a purely technical note, the remarkably successful Clementine lunar mission represented a tour de force for the technologies that LLNL developed under the sponsorship of the Ballistic Missile Defense Organization. All seven cameras deployed on the mission were designed and built by the Laboratory, and the first complete mapping of the lunar surface (which has provided a reservoir of data that will occupy scientists for years to come) was carried out with these cameras. Our education program has been instrumental in making this data electronically available to the broad public through the Internet.

Finally, the United States Enrichment Corporation has decided to commercialize our AVLIS (Atomic Vapor Laser Isotope Separation) process, successfully culminating our years of work to develop a process for cost-effectively and cleanly separating the isotopes of uranium for use in fission reactors. This decision will lead to further work by the Laboratory in demonstrating a pilot plant for the process.

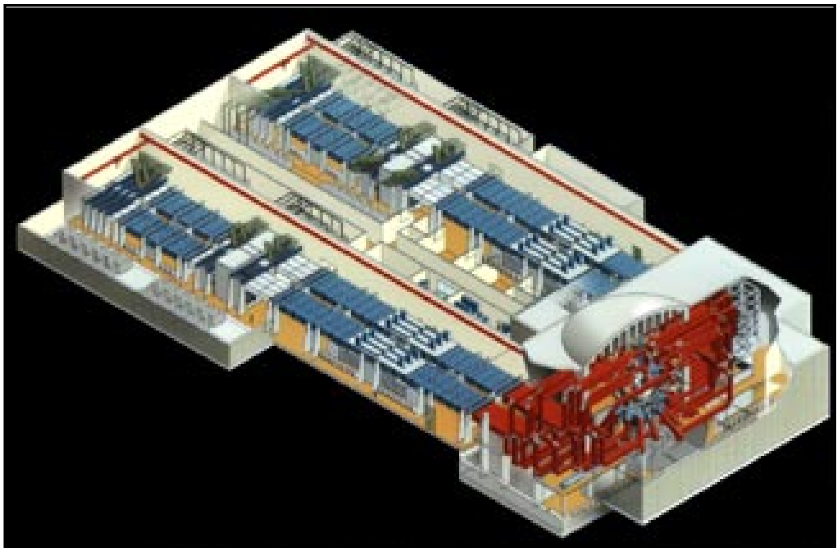
### Programmatic Planning

In June 1994, we published a document entitled *Framing the Laboratory's Future: A Vision for Lawrence Livermore National Laboratory*. This vision statement is the first formal step in laying out our strategic vision for the future. It focuses on three broad areas:

- Global security and reducing nuclear danger.
- Global ecology and harmonizing energy and economic development with the environment.
- Bioscience and applying understanding of human health.

The first of these missions—global security—represents the transformation of our historical nuclear weapons effort for the post-Cold War era. There are three important tasks, all directed at the overall goal of reducing nuclear danger throughout the world: stewardship of the stockpile, development of measures against

*The proposed National Ignition Facility will be a cornerstone of our stockpile stewardship program. It will also allow for the evaluation of inertial fusion energy as an energy source and for experiments in basic science.*



nuclear proliferation, and safe dismantlement of a significant fraction of the strategic arsenal.

Collectively, these important national security responsibilities will challenge our scientists and engineers in the post-Cold War era just as strongly as did our historic mission in nuclear design and testing. During the past year, we have worked very aggressively in concert with the Department of Energy and the Los Alamos and Sandia laboratories to develop an integrated joint program to accomplish these objectives. Of particular note is the innovative program in science-based stockpile stewardship. The absence of nuclear testing requires a much deeper understanding of nuclear weapons science to ensure the safety and reliability of the stockpile. This, in turn, will require new experimental and computational facilities to provide a much more accurate predictive capability for the behavior of weapons. The National Ignition Facility, the first of these proposed new facilities, will greatly enhance our knowledge of weapons physics and will give us a tool to address important stockpile issues.

The second major theme—global ecology—provides an organizing principle for our diverse activities in energy and the environment. Within the Department of Energy (and the other relevant federal agencies) many important projects on energy, transportation, manufacturing, and other technical areas are closely tied to economic development. There are also substantial and varied environmental programs, ranging from waste cleanup and environmental restoration to global climate change research. In addition, there is a large effort devoted to developing, implementing, and ensuring compliance with the labyrinth of environmental regulations.

Our goals in these broad areas are threefold: to provide an improved technical basis for establishing environmental guidelines, to develop the science and technology needed to achieve progress in individual projects and programs, and to organize and articulate the results of our work in the context of an ecological perspective consistent with economic growth. Pragmatically, we also believe such an approach will lead to much better mechanisms for effective funding and for applying the skills we and the other national laboratories have developed in doing large-scale applied science. Putting this integrated approach together and translating it into an action plan is a major goal for the coming year.

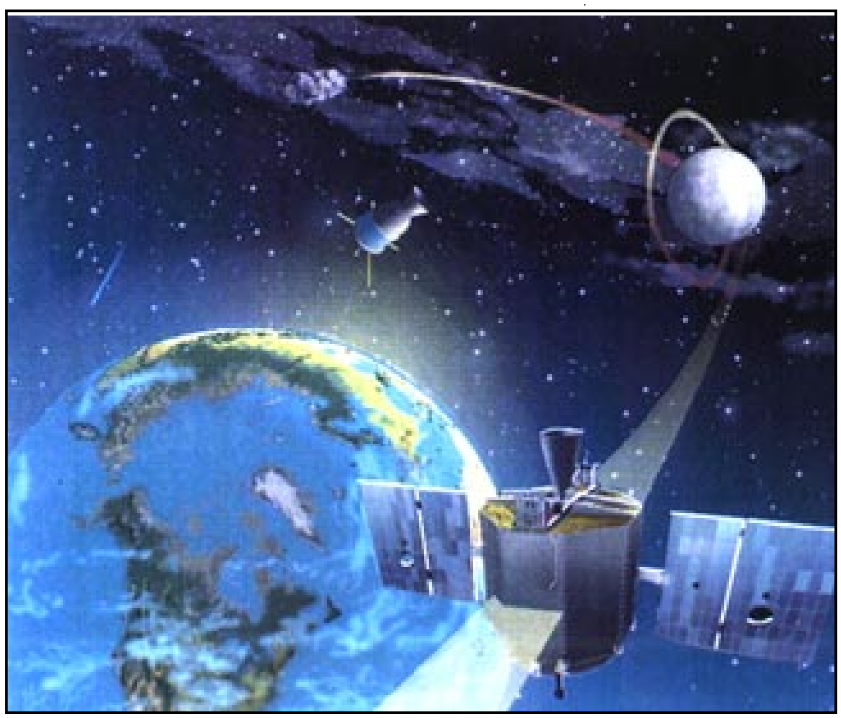
Our third focus area—bioscience—is growing rapidly in large measure because of our extremely successful work on the Human Genome Project. The distinguishing feature of our activities in this area has been the embedding of excellent bioscientists in a physical science and engineering infrastructure. To this end, we have added a new structural biology program to explore the physical basis for some of the genome project's results. We have also established the Center for Health Care Technologies to apply the many innovative engineering and diagnostic techniques available from our other programs to the emerging national mission in cost-effective health care. Some examples of our health-care accomplishments include improved mammography techniques, advances in medical lasers, and the use of microengineering techniques to repair aneurysms.

## Institutional Planning

Perhaps the most difficult task facing the Laboratory is the transition from an institution in which the design and testing of nuclear weapons were our defining rationale to an organization in which the focus of nuclear weapons has changed dramatically, and a multiplicity of programs and customer interests all have significant value. Programmatically, this cultural shift must be accomplished with well-articulated roadmaps in each of our areas of technical emphasis and a set of long-term goals that give meaning to our efforts. It is the purpose of our future strategic planning to integrate national priorities, the DOE mission, and the ideas of the employees into such a detailed vision.

Operationally, there are two basic challenges. First, we must radically restructure our human-resource, business, and site-planning practices to reflect this new multipolar world. Specifically, these practices must enable the Laboratory to respond to a diversity of evolving missions with cost-effective and institutionally friendly methods of interacting with our sponsors. Second, we must respond to the different requirements of a plethora of customers and stakeholders—the fundamental need for accountability of a public institution, the interests of the state and the local community in which we live, the use of our resources and talents to further the technical progress of the nation, the programmatic expectations of those who work, and a commitment to respect the ideas of each individual staff member. All of these principles are embodied in the nature of our long-term management by the University of California, a relationship that continues to strengthen as we move into this new era.

In summary, the future Laboratory will be a more complicated and more diverse organization, even though our overriding mission—serving the nation through the application of science and technology—will not change. Our aim is to create a Laboratory that continues to attract and stimulate the best researchers in the world, where technological achievement is the highest priority, and where efficient and cost-effective systems are the means to accomplish our objectives. Achieving those goals will require major qualitative changes, both functional and cultural, but the resulting institution will serve as a model for national laboratories.



*The Clementine Satellite sent back more than 1.5 million images of the moon at resolutions never before attained. These images were taken with cameras designed by the Laboratory.*

# Nonproliferation, Arms Control, and International Security

*Preventing, responding to, and reversing nuclear proliferation are top priorities for national and global security. We are providing multidisciplinary expertise, response and advisory personnel, and cost-effective technologies to help reduce the danger from foreign nuclear threats and other weapons of mass destruction.*

The detection, control, and monitoring of nuclear weapons and materials plus the response to proliferation threats have become leading challenges for the national security laboratories. To meet the challenges, we refocused and enlarged our nonproliferation efforts two years ago into a new directorate called Nonproliferation, Arms Control, and International Security (NAI). We are concentrating on six areas within a mission that emphasizes the Laboratory's special nuclear weapons expertise and responsibilities. Activities in these six areas include:

- Developing sensors, platforms, and analysis techniques that can detect and characterize signatures of nuclear weapons programs and help verify international arms control agreements.
- Providing intelligence-based assessments to the U.S. government of clandestine and acknowledged nuclear weapons activities worldwide.
- Providing expertise and technology for the U.S. government to establish dismantlement, tracking, and transparency regimes for nuclear weapons and fissile material, and assisting in efforts to control fissile materials worldwide.
- Providing support for arms control policy makers.
- Developing technology that can find and neutralize battlefield and terrorist nuclear weapons.
- Assessing the impact of possible counterproliferation systems and strategies through computer-based conflict simulation and comprehensive systems analyses.

In addition, we support U.S. efforts to reduce the danger from other weapons of mass destruction, and we make our capabilities available to support other emerging defense and civilian needs. To ensure a strong and coordinated DOE program, we work closely with Los Alamos, Sandia, other DOE national laboratories, and other U.S. government departments.

In early 1993, the DOE's three national security laboratories joined forces in areas related to most of the six NAI program areas. Since then, we have made considerable progress, particularly in planning for sensor research and development, which is the area of largest funding and where it is most important to identify savings. In early 1994, the DOE and Department of Defense (DOD) began planning in the area of counterproliferation. With respect to Russian interactions, the laboratories have been working closely with the DOE and DOD and are now increasing efforts with strong support by the State Department.

*We developed a portable chemical-analysis instrument to accurately analyze samples at an inspection site, a key issue related to the Chemical Weapons Convention. The latest generation of this instrument is contained in a small suitcase and weighs only 23 kg (~50 lb).*

## Sensor Development

The DOE Office of Research and Development has tasked the national laboratories with developing remote sensors that can detect signs of an existing or emerging capability to produce weapons of mass destruction. In response, we are developing several new remote detection systems, most of which are in early stages, and other systems for onsite applications, some of which are complete.

### Monitoring in Iraq

The United Nations Special Commission is tasked with implementing the international agreements that require monitoring specific activities and facilities within Iraq. In 1994, the Laboratory demonstrated its fast-response engineering and fabrication capability by providing equipment for monitoring several sites in Iraq. LLNL designed, procured, fabricated, and tested 12 tons of equipment over a six-week period beginning in May 1994, with delivery to Iraq on June 30, 1994. The equipment included

16 self-contained monitoring stations with multiple sensors and onboard, uninterruptible power systems interconnected through a microwave telephone system.

### Forensic Science Center

A key element of our onsite inspection capability is our Forensic Science Center, which we have brought to nearly full operating capability. The center uses various sample analyses to identify minute quantities of materials related to nonproliferation, counterterrorism, law enforcement, narcotics, and environmental protection activities. Analyses of chemicals in water, air, soil, and vegetation can be used to confirm suspected weapons activities and to support various international verification agreements.

### Portable Chemistry Laboratories

A key to Chemical Weapons Convention verification is the ability to analyze samples precisely at an inspection site. We have now demonstrated the ability to transport a self-sufficient chemistry laboratory to an inspection site, to collect a variety of samples, and to analyze them with the same results as would be obtained in a large analytical laboratory.

We also turned over to industry a suitcase-size instrument that can analyze samples extracted from swipes, soil, and water using chemical solvents and solid-phase extraction techniques. This instrument includes a lightweight gas chromatograph and mass spectrometer. Its long operational lifetime and portability should also make it a useful tool for emergency-response personnel trying to identify an unknown chemical spill and for firefighters in identifying potentially hazardous emissions from warehouse fires. A possible follow-on instrument could be about half the size of the existing one.

### Unattended Ground Sensors

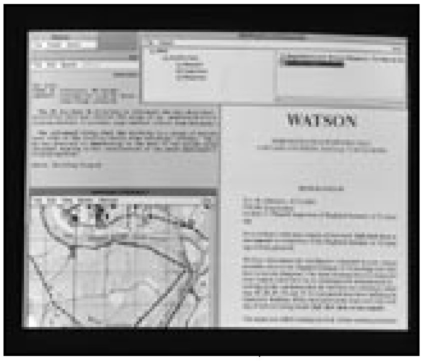
In 1992, over 95,000 apprehensions were directly based on alerts from the Border Patrol's unattended ground sensor network, making it one of the most effective counterdrug tools available. Our new generation of modular, unattended ground sensor systems—called INSENS, for Immigration and Naturalization Service Sensor System—can be linked into existing systems of the Immigration and Naturalization Service. The system uses seismic, magnetic, and passive infrared detectors, and future plans include incorporating hydrophones and imaging systems into the system. Full-scale production of the INSENS system is slated for 1995. The open architecture we developed for INSENS is now being adapted for use by the DOE to support nonproliferation programs.

## Intelligence Assessments

Laboratory people have assessed nuclear proliferation problems on every continent except Antarctica and Australia. Our support to the U.S. government has grown as nuclear proliferation issues increasingly become complex mixtures of international obligations, regional security concerns, and safeguards technology. Specialists in the nuclear fuel cycle, engineers, regional experts,

## Highlights for 1994

- Designed, fabricated, tested, and delivered 12 tons of equipment to help monitor activities and facilities in Iraq.
- Turned over to industry a suitcase-size portable chemical-analysis instrument that can analyze field samples without the delay of returning samples to a fixed site.
- Developed a new, cost-effective information management system, Watson, for use by nonproliferation specialists.
- Expanded our interactions with the New Independent States to support more than 150 collaborations ranging from nonproliferation research to basic science.
- Provided the science advisor to the DOE CTB delegation at the Conference on Disarmament.
- Delivered Lab-developed emergency-response equipment and software to assist two former Soviet republics.
- Advised the U.S. government on the credibility of sales offers and implications of illicit sales of nuclear materials worldwide.
- Pursued several new applications for projects in our Conflict Simulation Laboratory, including assistance in planning operations in Bosnia and Somalia.
- Developed the Virtual Commander—a large-scale, high-resolution computer simulation tool—to model complex tasks with minimal human input.




Watson is a new information management system used to analyze proliferation activites. On the computer screen is an example of the geographic viewer. Given a place name, it can retrieve geographic data (such as maps and satellite images) that contain the place in question. Conversely, if a geographic region is being viewed, it is easy to obtain text documents that refer to place names in that region.

country specialists, and political scientists have been called upon individually and in teams to support U.S. and international efforts to maintain and strengthen the international norms against the spread of nuclear weapons.

### North Korea

Recent tensions over North Korea's disagreements with the International Atomic Energy Agency demonstrate the importance of clear and transparent nonproliferation commitments. They also highlight the importance of the technical details of safeguards on nuclear reactors, nuclear fuel reprocessing plants, and separated plutonium. North Korea's fiery rhetoric and the influence that failure to resolve the North Korean dispute could have on other countries combined to make dramatic headlines. Behind the headlines, Laboratory people provided technical support for wide-ranging U.S. efforts to engage North Korea in productive dialog and convince them to fully open their nuclear program to meet their obligations under the Nuclear Non-Proliferation Treaty.

### Nuclear Materials Tracking and Process Simulation

The control and use of nuclear materials—particularly highly enriched uranium and plutonium—are the focus of concern in countries ranging from the former Soviet Union to North Korea and from Iraq to South Africa. Concern also exists about the shipment, use, and disposition of power-reactor plutonium in Japan and several western European countries.

During the past year, the new International Nuclear Analysis program was established at the Laboratory by the DOE's Office of Nonproliferation and National Security to monitor the worldwide use and disposition of nuclear materials. This program functions as a single stop for information on nuclear reactor fuels and the nuclear materials produced as byproducts from nuclear power and research reactor operations. Data are submitted by all U.S. facilities that use and produce nuclear materials. Each of the research and power reactors worldwide is profiled with regularly updated operational histories, inventories, and projections of future operations. We also analyze production processes associated with special nuclear materials destined for weapons.

### Export Control

The Laboratory has expanded its support of efforts to stem the supply of sensitive nuclear technology to proliferant nuclear programs. The DOE Proliferation Information Networked System (PINS), which was developed mainly at Los Alamos and Sandia, is supported by all the national security laboratories. PINS now provides nearly instant, secure electronic communication between the national laboratories and DOE headquarters. It is used to help regulate the supply of sensitive nuclear commodities, whether exported from the U.S. or retransferred from intermediates. Review of the full range of prospective sales is now done rapidly to facilitate approval of legitimate sales. Retrospective searches of the patterns of sales are also used to find systematic problems and ensure that U.S. export-control policies conform to the specifications of federal law and the Code of Federal Regulations.

### Computer Workstation for Nonproliferation Analysts

We have developed a new information management system, called Watson, for use by an analyst of proliferation activites. Watson was designed to reduce operational costs and to allow a user to browse many data sources. It can access, store, and manipulate text, geographic data, and images. A geographic viewer lets an analyst recenter, resize, do range-bearing measurements, and coordinate displays. Following data retrieval, Watson provides for analysis and publication.

## Arms Control Policy Support and Nuclear Material Control

Our traditional arms-control activities include providing analytical and technical support to treaty negotiators and developing equipment to monitor compliance. In a major new thrust, we are assembling a Laboratory-wide network of expertise to support the government in its interactions with weapon scientists and institutions in the states of the former Soviet Union. The goal is to help speed weapon dismantlement and defense conversion and to build confidence between the U.S. and the new republics.

Our most recent priorities follow from the January 1994 Clinton–Yeltsin summit. At that meeting, the two leaders called for prevention of proliferation and, in particular, a transparent and irreversible process for removing fissile material from weapons.

### Transparency of Weapon Dismantlement and Nuclear Material Storage

With the drawdown of Russian and U.S. weapons mandated by the START treaty and the withdrawal of tactical weapons from Europe, there is concern over the control of nuclear weapons and secure storage of the nuclear materials from dismantled weapons. In the absence of any formal treaty agreements, transparency measures are being pursued to provide insight and increase confidence in dismantlement activities and nuclear material control. Such measures can include declarations of weapons and material quantities and the purpose and capacity of nuclear facilities plus visits to nuclear facilities and inspection techniques.

The President's nonproliferation policy, announced in September 1993, calls for the U.S. to place excess nuclear materials from dismantled nuclear weapons under international monitoring and to seek a global ban on the production of fissile materials for weapons purposes. We have provided technical assistance to the DOE during the drafting of position papers, leading to U.S. policy on these issues.

In a March 1994 meeting between Energy Secretary Hazel O'Leary and a Russian delegation, it was agreed to begin inspections with reciprocal visits to nuclear material storage facilities of the two countries before the end of 1995. In a joint working group meeting in May, the sides agreed to conduct visits to plutonium storage sites in each country, with reciprocal inspections to begin by the end of the year. We have been involved in choosing and evaluating potential nuclear-materials measurement techniques and in assessing the sensitivity of sharing unclassified or classified information with the Russians, if necessary, to carry out inspections.

LLNL's interactions with the states of the former Soviet Union, and particularly the Russian Federation, expanded this year. Much of the expansion results from the Laboratory's continuing strong support of Laboratory-to-Institute collaborations with the scientific community in the states of the former Soviet Union. Today, scientists from 42 institutes, primarily in Russia and Ukraine, are funded on more than 150 projects involving all of LLNL's directorates. The State Department encouraged expansion of this activity to include scientists from other former Soviet states. In support, LLNL led a delegation of experts to the Republic of Kazakhstan and Belarus to begin establishing a Lab-to-Institute program.

We are involved in four other bilateral activities with the former Soviet Union. The Industrial Partnering Program, aimed at improving the industrial base of the former Soviet Union, involves all the DOE laboratories, scientists from the former Soviet Union, and U.S. industries. To assist the Russians in developing technologies for the marketplace, we hosted an entrepreneurial workshop on turning advanced technologies into commercial joint ventures. We support the International Science and Technology Center in Moscow, which now has funding from the European Community and other major western countries. To prevent the theft or unauthorized use of Russian nuclear weapons, components, and nuclear materials, LLNL specialists are also working with our counterparts

*Our interactions with states of the former Soviet Union expanded considerably this year. Natalia Zaitseva from Moscow State University and LLNL's Jim De Yoreo examine KDP crystals grown at Livermore as part of a Laboratory-to-Institute collaboration. Their rapid-growth technique won an R&D 100 award this year.*


*Opening meeting of the Conference on Disarmament held in Geneva, Switzerland, in January 1994. This forum involves 39 member countries plus observer states. LLNL Arms Control and Treaty Verification Program Leader, Bill Dunlop (back row, third from right), serves as science advisor to the DOE CTB delegation. Other people from the NAI program are contributing to the negotiations as technical experts on specific topics.*

from Sandia, Los Alamos, and the Russian nuclear weapons laboratories.

### The Nonproliferation Experiment

A Comprehensive Test Ban (CTB) treaty is being negotiated at the Conference on Disarmament in Geneva, Switzerland. One important issue in the CTB deliberations is how to distinguish nuclear explosions from nonnuclear ones and from earthquakes. In September 1993, LLNL conducted the Nonproliferation Experiment, which provided direct information on this topic. For the first time, we compared seismic and other signals from a large chemical explosion to nuclear explosions of similar yield, which had previously been conducted under similar geologic conditions. Our studies showed that most signals from these two types of explosions are similar, but close-in electromagnetic measurements differ in their onset and rise times. These results indicate that remote discrimination between some non-nuclear and nuclear explosions could be very difficult, that non-nuclear explosives could be used to calibrate discriminants between nuclear explosions and earthquakes, and that confidence-building measures could be instituted if close-in monitoring is permitted on large, announced chemical explosions.

### Regional Arms Control

Three of our current projects are examining steps that could be taken as confidence-building measures in regional areas of tension or concern related to arms control. Our regional seismic monitoring provides information on ambiguous seismic events and assurance that nuclear testing is not occurring. Our project on regional fissile material control is developing a monitoring framework to assure that nuclear material is not being produced for weapons purposes. Our computer similations show that border monitoring using emplaced sensors can potentially allow disengagement of forces and provide increased warning times.

## Nuclear Emergency Response

This part of the NAI program is concerned with technologies that can find and neutralize nuclear weapons in battlefield, terrorist, or other situations. We support many national response capabilities, coordinate the DOE Threat Credibility Assessment program, and oversee the emergency preparedness program for the Livermore site. Here, we focus on some of our most recent accomplishments.

### Support for Dismantlement

We are providing several types of LLNL-developed emergency-response equipment and software to republics of the former Soviet Union. We recently sent a PC-based atmospheric dispersion model to Belarus and will transfer a mobile radiological assay laboratory to that country in 1995. In late 1994, we prepared two liquid-abrasive cutting tools for Russia. In each case, we provided translated training guides and manuals as well as the necessary transport equipment.

### Assessing Illicit Nuclear Sales

Illicit and attempted sales of nuclear material are increasing, mainly overseas. At the request of the U.S. government, we help assess the credibility of sales offers, provide advice on safe handling of materials, and assist in analysis or characterization of any materials exchanged or seized in a sale activity. This role is built on our long-term responsibility for the Threat Credibility Assessment program, in which we determine the credibility of nuclear threats from terrorists or extortionists.

## Counterproliferation

Our counterproliferation program develops “intelligent” methodologies for processing information to discover concealed purposes, considers potential responses to proliferants, and assesses the potential economic, political, and environmental consequences of each response. Our newest work is helping the DOD and others develop a broad-based counterproliferation technology program.

A key facility for our work is the Conflict Simulation Laboratory, which has been supporting military projects for almost 20 years and is now being used for a variety of other projects as well. The adaptability of our computer simulations has made them increasingly useful for situations other than standard war scenarios. For example, the Army recently used our Urban Combat Computer Assisted Training Simulation to plan operations in Somalia and Bosnia. The scenario in both cases focused on operations in and near the major airports in Mogadishu and Sarajevo, where the terrain is both urban and rural. Simulations of law enforcement activities, fire fighting, and response to natural disasters are among the many other nondefense applications we are addressing.

### Virtual Commander

Advances in computer technology promise to revolutionize the way in which the modern military trains, plans, and fights. To be most effective, however, large-scale simulations have to calculate realistic behaviors for tens of thousands of entities and run in real time or better. Both issues pose challenges. Our Conflict Simulation Laboratory is solving this problem by partitioning a huge campaign among many computers. Communication among the computers will use standard protocols and network technology developed by the DOD's Advanced Research Project Agency.

The Virtual Commander (V-Com) project seeks to reduce player requirements substantially by allowing players to control battalions, not just platoons, in large simulated engagements. Plans are derived from minimal player input of high-level objectives, with the computer's analysis of the battlefield filling in the details. The bulk of V-Com's planning and decision making is done as the engagement progresses, based on current estimates of the situation. V-Com continually checks the validity of its plans and corrects them as necessary. V-Com offers a degree of fidelity in modeling responsive behavior that cannot be achieved in a conventional simulation. We have applied V-Com to several complex tasks, such as a mobile rocket artillery platoon, a firefighting brigade, and a search team.

### Minefield Analysis

Our state-of-the-art battle simulation codes are used to determine optimum force levels. In one analysis, we used LLNL's combat simulation, the Joint Conflict Model, to study the use of anti-personnel mines to suppress fixed enemy artillery systems in support of a military campaign. We demonstrated that anti-personnel mines are credible and economical, especially when applied against an enemy that has located much of its artillery forces in hardened sites that are difficult to destroy. This type of simulation allows military planners to use low-cost, quantitative data to identify cost-effective solutions to difficult tactical problems.

*One of two liquid abrasive cutters we provided to Russia to assist in their dismantlement efforts. The equipment operates in remote locations, and the cutter can be used safely on weapons containing high explosives.*

## Summary

A reduction of the international nuclear threat is one of the greatest challenges of this era. Serious dangers associated with nuclear proliferation, theft of nuclear weapons or fissile material, illicit sales, clandestine activities, and terrorism remain. Our highest priority is to support the nation's nuclear nonproliferation policy. We also continue to support U.S. arms-control activities in cooperation with nuclear inheritor states of the former Soviet Union. Some of our analysis techniques, including sensors and computer simulations, are finding important civilian applications in diverse areas, such as search and rescue, fire fighting and response to natural disasters, law-enforcement activities, and environmental protection.

***For further information contact Robert T. Andrews (510) 422-5006 or George G. Staehle (510) 422-5006.***

# Defense and Nuclear Technologies

*The past few years have seen a major restructuring of the Laboratory's nuclear weapons program to address post-Cold War national security requirements—in particular, to provide for science-based stewardship of the U.S. stockpile, to oversee the dismantlement of retired LLNL-designed weapons and the disposition of weapon materials, and to apply nuclear weapon expertise to the problems of nonproliferation and counterproliferation.*

The national security programs have undergone profound changes as a result of significantly altered U.S. defense needs. The DOE's Office of Defense Programs has shifted its focus to address post-Cold War national security requirements. In concert with DOE and the other national security laboratories, we at Livermore have responded by redirecting our scientific and technical resources to address the highest national priorities. The major activities of LLNL's Defense and Nuclear Technologies directorate are directed toward

- Ensuring the safety, reliability, and security of the U.S. nuclear stockpile.
- Overseeing the dismantlement of LLNL-designed nuclear weapons and the disposition of weapon materials.
- Applying our expertise in nuclear weapon science and technology to prevent and counter nuclear proliferation.
- Analyzing current and evolving U.S. military requirements.
- Developing technologies for conventional (non-nuclear) defense.
- Developing and demonstrating technologies for the cleanup and environmental restoration of the nuclear weapons complex.

Our activities benefit not only national security but also civilian science and technology and U.S. industrial competitiveness.

*With this new gamma-ray camera, we can obtain more accurate and more informative images of imploding primaries in flash x-ray experiments. In particular, this camera produces images of much higher resolution (at least double that possible with previous instruments) and therefore much greater detail; it can also obtain images at much later stages in the implosion process.*

## National Security Priorities

President Clinton has stated that a safe, reliable nuclear deterrent remains a cornerstone of U.S. national security policy. In a speech on July 3, 1994, he said:

"To assure that our nuclear deterrent remains unquestioned under a test ban, we will explore other means of maintaining our confidence in the safety, the reliability, and the performance of our own weapons. We will also refocus much of the talent and resources of our nation's nuclear labs on new technologies to curb the spread of nuclear weapons and verify arms control treaties."

The President has called for the establishment of a stockpile stewardship program and has directed the DOE and the DOD to develop the framework for such a program. Support of the national stockpile stewardship program constitutes the bulk of the efforts of our Defense and Nuclear Technologies directorate.

We are also working with the Laboratory's Nonproliferation, Arms Control, and International Security directorate to respond to the DOD's Counterproliferation Initiative. For example, we have designed and deployed the only device capable of disabling some terrorist weapons.

In addition, we support DOE's arms control efforts. In 1994, working closely with DOE's Office of Arms Control and National Security, we provided technical assessments of the activities that various countries might conduct under a comprehensive ban on nuclear testing and on the potential arms control and proliferation impacts of building the National Ignition Facility.

In our advanced conventional weapons program, we are supporting DOD efforts to improve its conventional capabilities with new sensors, materials, and munitions.

## Nuclear Weapon Technology Programs

The thrust of the nation's weapons program is no longer weapon development, testing, and production. Today the nuclear weapons issues facing the country and the Laboratory involve responsible stewardship of the U.S. nuclear stockpile and halting the spread of nuclear weapon technology. These issues present major scientific and technical challenges, and our highest priority is to enhance our experimental and computational resources. The science and technology we have developed in the last two years is considerable and presages the advances that will be required in the future. Current programs and recent accomplishments are summarized below.

### Stockpile Stewardship

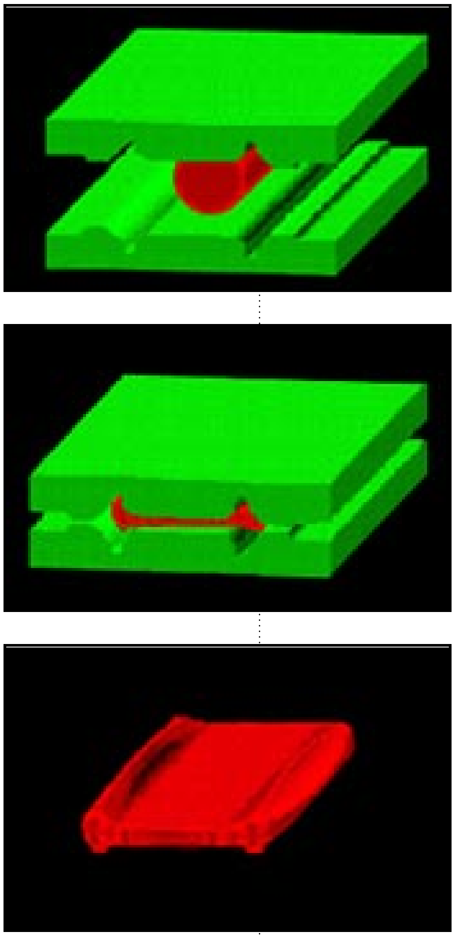
We have taken a leadership role in defining the science-based stockpile stewardship program. In support of this program, we are placing heavy emphasis on developing a fundamental, first-principles understanding of weapon safety, security, and reliability. Even with severe budget constraints, we have increased our efforts to achieve maximum utilization of existing state-of-the art experimental facilities and computers. Together with Los Alamos, we are making heavy use of the Nova facility for weapons-physics experiments. We have developed a gamma-ray camera with which we can obtain higher resolution and more accurate images of imploding primaries in flash x-ray experiments. In addition to upgrading our existing facilities, we are defining the major advances in capabilities, such as the proposed National Ignition Facility, an Advanced Hydrotest Facility, and an advanced massively parallel processing computer facility, which will be needed to resolve future stockpile issues.

### Preventing and Countering Nuclear Proliferation

Dealing with the problems of nuclear proliferation is a high national priority. Whereas the fear of a nuclear war between superpowers is greatly reduced, a new threat, as stated by the Secretary of Defense William Perry, is "a handful of nuclear weapons in the hands of some terrorist organization or terrorist state, perhaps delivered by unconventional means." In such an event, the Nuclear Emergency Search Team (NEST)—created in the early 1970s with strong LLNL

### Highlights for 1994

- Implemented a new strategic plan for the Defense and Nuclear Technologies directorate that is responsive to the changes in U.S. defense needs.
- Refocused the organization on science-based stockpile stewardship and made major contributions to the Stockpile Stewardship and Stockpile Management program plans.
- Continued our vigorous efforts in stockpile surveillance and weapon system safety and performance evaluation.
- Contributed to solving the problem of disposing of weapon materials from dismantled weapons.
- Made major progress in program integration with the Los Alamos and Sandia laboratories to eliminate unnecessary duplication of activities yet ensure adequate peer review.
- Led the development of new nuclear-weapon detection and render-safe capabilities.
- Studied the implications of interdiction of proliferant nuclear activities.
- Confirmed that NIF will be able to access regimes of interest for stockpile stewardship.



*Our ALE3D code is unique in its ability to model complex flows of many different materials. Here, at the start of the forging process, an aluminum billet (red) is positioned in a die (green). After the process, the result is an aluminum part. We have joined with Alcoa Aluminum in a CRADA to investigate the behavior of aluminum as it is formed into complex-shaped parts.*

participation—would be called upon as part of a government-wide response team to deal with the emergency. Many believe the capabilities of NEST should be expanded to meet the new challenges.

Anticipating future needs, we are developing innovative approaches for detecting clandestine nuclear devices and rendering them safe. We have also begun to examine the consequences of interdicting proliferant activities.

### Consolidation of the Nuclear Weapons Complex

The nation's nuclear weapons complex is being downsized, consolidated, and modernized. With no weapons in development or production, various production plants and facilities have been closed. Similarly, the activities and facilities at the national security laboratories—Livermore, Los Alamos, and Sandia—are being examined to eliminate unnecessary duplication of effort and facilities. The goal is to consolidate weapon-related activities around major facilities and capabilities. This consolidation began in the late 1980s with activities related to nuclear testing, and it now covers the full range of efforts in nuclear weapon science and technology.

The first use of the smaller, consolidated complex will be for weapon dismantlement. Thus, activities related to weapon dismantlement and modernization of the weapons complex are intertwined. As a result of the START I and II treaties and unilateral disarmament decisions, thousands of U.S. nuclear weapons are slated for dismantlement. In the future, the modernized complex will be used to support stockpile surveillance and the fabrication or remanufacture of weapon components to resolve safety or performance concerns that may arise.

The national security laboratories have adopted a "lead laboratory" approach to create a single integrated national program. Each institution has lead responsibilities in specific technical areas where they have demonstrated technical strengths, with the other laboratories providing support as necessary. In areas where independent review and judgment are essential (particularly in those areas where there is no industrial or university base of expertise), complementary programs exist at more than one laboratory.

### Weapon Dismantlement and Disposition of Weapon Materials

We are developing safer and faster methods for dismantling retired stockpile weapons and for disposing of their materials. We played a major role in resolving a problem at the Pantex Plant that temporarily halted dismantlement activities. We have built and demonstrated a self-contained apparatus to turn plutonium-containing pits from dismantled weapons into a form suitable for disposition. We are also developing methods to dispose of excess high explosive without open burning.

### Technologies for the Future

The capability to maintain and fabricate weapons in the future will require materials and manufacturing technologies that generate less hazardous waste, improve worker safety, and are environmentally benign. To this end, we have developed a precision die-casting method for producing plutonium components; since this method involves casting within a mold instead of machining, almost no hazardous waste is generated. We also pioneered the concept of reusing plutonium components from retired, dismantled weapons and are developing the facility to implement this idea. Reusing plutonium components obviates the need to manufacture new components to correct safety or performance problems with stockpile weapons. These efforts are integral to the major role we are playing in providing the technical basis for a downsized, consolidated, cost-effective nuclear weapons complex.

## Preserving a Unique Knowledge Base

World-class facilities and important scientific challenges are required if we are to continue to retain, attract, and motivate the top scientific talent essential for addressing future nuclear weapons issues. Declining budgets in the last ten years, together with several voluntary retirement incentive programs, have led to the loss of some of our most experienced weapon scientists and engineers. Demographic projections show that we can expect further dramatic declines in experienced staff in the next ten years. Accordingly, our experienced scientists and engineers are training our newest people. We are analyzing experimental data from the stockpile and from past nuclear tests and are performing new experiments, in the laboratory and on the computer, so we can base our understanding of nuclear weapons on the most up-to-date scientific interpretation. To motivate our people and keep their skills sharp, we are using new tools and working on new challenges. In cooperative R&D partnerships with industry, our people are applying their technological capabilities to improve the nation's economic competitiveness. Our scientists and engineers are also applying their unique technological capabilities to solve important problems in conventional defense.

## Experimental Facilities and Computational Capabilities

Science-based stockpile stewardship requires that we enhance and upgrade existing experimental capabilities and design and construct several new facilities. We must also enhance our computational capabilities; in particular, we must make the move to massively parallel processing in order to increase the accuracy, completeness, and resolution of our simulations.

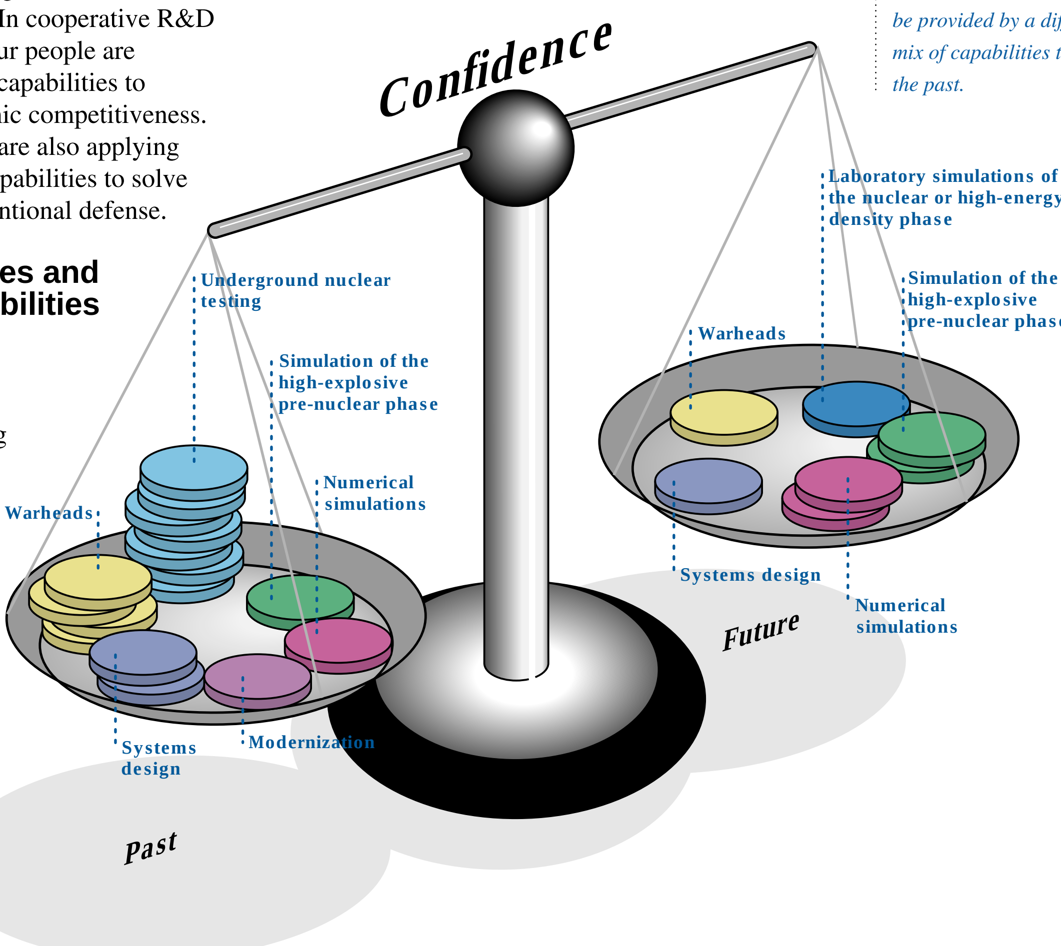
## Flash X-Ray Facility

We are upgrading our Flash X-Ray (FXR) facility, located at Site 300, to provide two pulses, and hence two images, during a hydrodynamics test. These tests, in which mock nuclear material is used in place of the fissile material, are our only non-nuclear means of testing and evaluating the implosion of a nuclear weapon's primary stage. We are also defining a contained firing capability at the FXR to meet future environmental restrictions that might affect open air firings.

## Advanced Hydrotest Facility

The double-pulse FXR data will be critical in defining an Advanced Hydrotest facility. We are working with a team of Livermore, Los Alamos, Sandia, EG&G, and AWE (Atomic Weapons Establishment, U.K.) researchers to develop plans for the Advanced Hydrotest Facility. This facility will provide multiple beams and multiple pulses

*Confidence in the safety, security, and reliability of the nuclear stockpile will be provided by a different mix of capabilities than in the past.*



of x rays and, hence, three-dimensional CAT-scan-like movies of the interior of an imploding device.

### High Explosives Application Facility

Our High Explosives Application Facility will continue to play a major role in developing safer high explosives and in conducting studies to characterize other energetic materials. We are improving existing processes and operations and developing new methods for formulating and handling energetic materials to reduce costs, minimize waste, enhance worker safety, and remain in compliance with increasingly strict ES&H regulations.

*Much of the special expertise developed for nuclear weapons is finding application in conventional (non-nuclear) defense such as the Patriot Missile.*

### National Ignition Facility

With the proposed National Ignition Facility, we will be able to address a wide range of high-energy-density phenomena beyond the capabilities of current facilities. Like LLNL's Nova laser facility, where the Livermore and Los Alamos weapons programs conduct one-third of all the experiments carried out, the National Ignition Facility will be used for weapons physics work as well as for many other scientific investigations. Currently, we are studying the arms-control implications of building the National Ignition Facility, in particular, the impacts on nonproliferation and on achievement of a comprehensive test ban.

### Secure Computing Facility

The Defense and Nuclear Technologies directorate supports more than 90% of the operating costs of the Laboratory's Secure Computing Facility and 100% of the costs for acquisition of new equipment. The state-of-the-art computing capabilities at this facility benefit virtually all Laboratory programs.

In the past year, we acquired the Meiko CS-2 computer. This massively parallel processor (MPP) consists of 256 nodes, with each node containing 16 million words of memory. The first and second halves of the machine were delivered and recently installed. We are in the process of learning to use the MPP to take full advantage of its capabilities; we are transferring our application codes onto this new machine and are integrating it into the Secure Computing Facility.

The experience we are gaining with the Meiko MPP will be extremely valuable in defining the DOE's Accelerated Super Computing Initiative (ASCI). The DOE laboratories and industry are working together to define the ASCI. As currently envisioned, it will involve three elements: (1) collaborating with manufacturers to develop new supercomputer technologies, (2) developing software to take maximum advantage of new machine architectures, and (3) providing the infrastructure to manage supercomputing resources (e.g., compilers, graphics capabilities, data-management and data-storage devices).

### National Storage Laboratory

We are also working with 20 other laboratories and universities on the National Storage Laboratory (NSL), located at LLNL's National Energy Research Supercomputer Center. LLNL is playing a major role in developing the NSL capability for advanced storage of archival information; this effort involves writing the software to access a variety of storage media. The NSL is based on the Unitree storage capability that we developed initially for our weapons work.

## Summary

Fulfilling our national security and stockpile stewardship responsibilities requires tremendous scientific and technical breadth: from esoteric theoretical physics and computational modeling to materials science and precision engineering. Because there exists no broad industrial or university base from which to draw expertise in nuclear weapon science and technology, we rely heavily on formal peer reviews and informal exchanges with our sister laboratory at Los Alamos. Our relationship with the University of California and the challenging nature of our work have enabled us to recruit and retain top scientific and engineering talent, and we are committed to attracting such talent in the future.

LLNL has an important, long-term role in the nation's nuclear weapons program. We are responsible for four of the ten weapon systems in the enduring U.S. stockpile (three of nine after 2002), including the only systems that incorporate all modern safety features. For years to come, we will be responsible for these weapons and for the problems that will inevitably arise. Our nuclear expertise will also play a crucial role as the U.S. attempts to deal effectively with the threat of nuclear proliferation.

This past year brought the culmination of our response to profound changes in the nation's defense needs as we restructured and refocused our activities to address the Administration's goal of reducing global nuclear danger. We made major contributions to important national security issues in spite of severe fiscal constraints.

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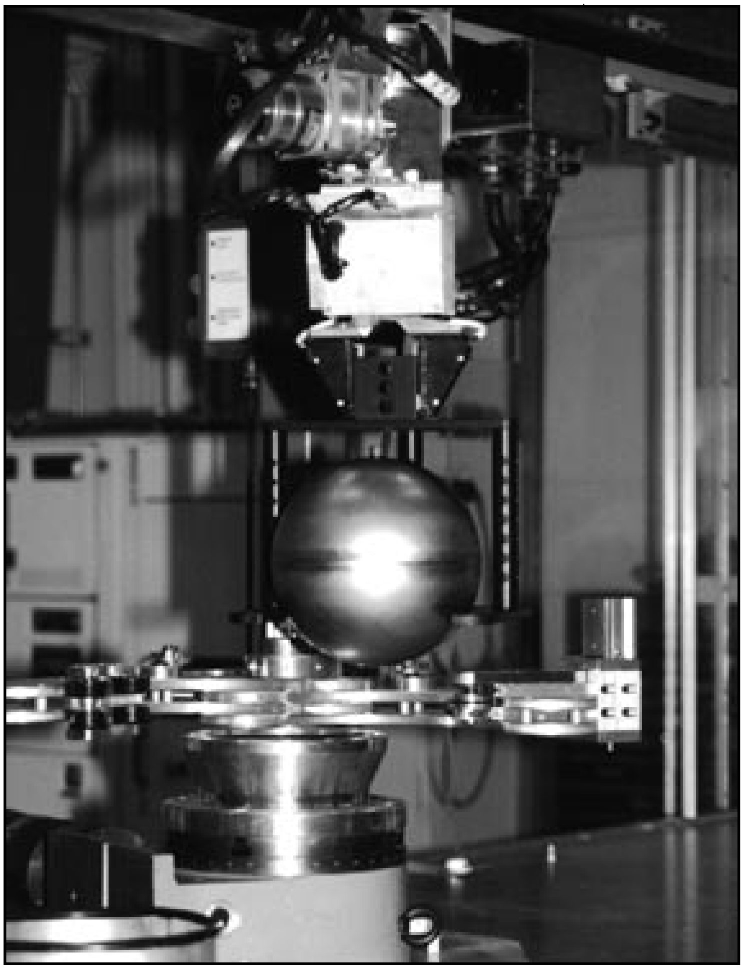

*Disassembly of nuclear weapons and the disposition of their materials continue to be important national issues. The Laboratory has developed an innovative, automated technique to disassemble weapons and remove material by a hydride/dehydride process. The spherical unclassified mock object above was used to develop this technique.*

# Experimental Science

*Recognizing the changes mandated by the two-year-old U.S. moratorium on underground nuclear testing, LLNL is using its testing expertise to support other program areas. With 40-plus years in the "testing business," our goal in the last year has been to enter areas that can benefit from our unique experience.*

With changing national priorities, the demands for LLNL's nuclear testing expertise changed, too. However, we expect the national demand for challenging and complex technologies to continue, and we believe we must be ready to respond to meet other needs in global security. Thus, our focus is threefold: retain our core competencies in nuclear testing through experimental and calculational studies, redirect our specialized technologies to new nationwide priorities, and restructure our organization to respond to new sponsors and customers. Our structural changes are indeed under way: the Nuclear Test and Experimental Science directorate was dissolved mid-year. Projects once solely within the directorate are now broadly integrated with other Laboratory programs, into areas such as nonproliferation, weapon physics, and earth sciences.

*The sub-picosecond x-ray streak camera for the ultrashort-pulse laser target chamber is shown with its developer, Ronnie Shepard. The camera will be combined with a high-resolution x-ray spectrometer to measure time-resolved emission spectra from buried layers in short-pulse targets for determining plasma opacity.*

Of particular importance now is our participation in experimental science for LLNL's science-based stockpile stewardship program. This year we emphasized secondary-weapon physics applications to stockpile stewardship and the initiation of participation by the Department of Energy/Nevada field contractor in primary weapon-physics experiments. Our secondary-weapon-physics experiments were centered on technologies for producing and diagnosing plasmas with applicable temperatures and densities. We used these laser-produced plasmas to drive radiation transport, opacity, and interface instability experiments.

## Weapon-Physics Experiments

### Ultrashort-Pulse Laser

Our ultrashort-pulse laser project heats target materials to kilovolt temperatures so rapidly they have no chance to expand, thus creating a short-lived, solid-density, high-temperature plasma appropriate for research into weapon-condition physics. The ultrashort-pulse laser gives us a unique capability to produce and study hot dense matter at well-defined density and temperature conditions similar to stellar interiors, inertial fusion plasmas, and nuclear explosions. We can currently focus up to $6.6 \times 10^{18}$ W/cm$^2$ of 800-nm light on target for about 100 fs. Most importantly, we have developed techniques to assure that the low-power precursors in the light pulse, which once preheated and expanded target material prematurely here and elsewhere, have been eliminated.

To control the precursors, we built and tested a pulse stretcher with optical components that allow us to control the phase distortion of pulse experiences during stretching, compression, and amplification. We have been able, with near perfection, to recompress 100-fs-pulse input to the amplifier to a duration of 105 fs. Our recompressed pulse displays a higher fidelity than any in previous work. We believe continuous phase control represents the next step in the evolution of chirped-pulse amplification and will permit the generation of cleaner and even shorter pulses for high-intensity laser–matter interactions.

We have used our high-contrast ultrashort-pulse laser at 400 nm at intensities to $10^{18}$ W/cm$^2$, where the laser has excellent contrast and no precursors, to measure the energy absorption of 100-fs pulses by a variety of transparent, metallic, and high-atomic-number materials. The data from this first quantitative study of material-dependent absorption with clean ultrashort pulses at high intensities may show new absorption mechanisms and are consistent with the production of solid-density surface plasmas with the ultrashort-pulse laser.

The transport of energy from the hot surface into bulk target material is predicted to take place supersonically, leading to larger volumes of heated high-density plasma in the bulk. To measure this effect, we built a new magnetically separated, ion time-of-flight spectrometer to observe the velocity distribution of ions from tracer layers buried at varying depths below the target surface. We will use the data, which indicate that ultrashort laser pulses produce temperatures in excess of several hundred volts, to refine our model of energy transport in the plasma.

We are designing equation-of-state (EOS) and opacity experiments using the unique features of the ultrashort-pulse laser. We are also constructing an optical probe with a time resolution down to 20 fs to measure the plasma expansion after the pulse and, thus, the EOS effect in the expansion. Opacity measurements will be made using time-resolved emission spectra from buried layers in short-pulse targets. For these emission studies, we will combine our subpicosecond x-ray streak camera with a high-resolution x-ray spectrometer. As a direct measurement of plasma opacity, we will use a short burst of x rays from a secondary target to backlight the sample and then, by spectrally resolving the attenuated backlighter, measure the plasma opacity of low-temperature samples.

### BEEF

To better understand nuclear weapon primary stages, we applied our nuclear test skills to establish a Big Explosives Experiment Facility (known as BEEF) at the Nevada Test Site (NTS). BEEF will allow the Laboratory to conduct large hydrodynamic experiments using charges far larger than those allowed at Site 300. Charge size at the NTS is essentially unrestricted, the infrastructure developed for nuclear testing is in place, and buried, reinforced concrete structures from atmospheric testing days are modifiable and usable.

Working with B-Program, we developed a facility design with a five-station, high-speed optics recording facility and control room and a laser illumination system. X-ray radiography will be possible by using Febetron electron accelerators housed in hardened chambers on the firing table. In early 1995, we will conduct certification tests using up to 2300 kg of

## Highlights for 1994

- Dissolved the 40-year-old test program.
- Improved ultrashort-pulse-laser quality by controlling low-power precursors in energy delivery to the target.
- Built a spectrometer to determine temperatures within ultrashort-pulse-laser targets by analyzing ion velocities from buried tracer layers.
- Established a hydrodynamic test facility at the Nevada Test Site.
- Built a high-sensitivity mobile gas-analysis system that will be field-tested in 1995.
- Designed a radiation detector 10 to 100 times more sensitive than current detectors.
- Determined unique isotopic “fingerprints” for specific stockpile weapons.
- Developed a portable high-resolution gamma detector with a miniature mechanical cooling system.
- Improved ion-probe resolution and sensitivity for analyzing isotopic content of even microscopic environmental samples.
- Used test techniques to track groundwater movement by age and source.
- Interconnected computers in clusters using high-bandwidth electro-optic expertise.
- Brought fabrication costs for electro-optic systems in line with requirements for mass production.
- Studied new materials for opto-electronic and photonic applications.

*A major construction project at the Nevada Test Site, BEEF (Big Explosives Experiment Facility) is using underground bunkers from atmospheric tests (seen unearthed here) as a base facility for large-mass hydrodynamic diagnostics experiments.*

explosives to certify diagnostics bunkers for manned operation.

## Test Readiness

### Exercises

We maintained test readiness by conducting realistic exercises focused on arming and firing, timing and control, and diagnostic data-recording systems, as well as on downhole emplacement, device delivery, and installation at ground zero. In collaboration with Los Alamos National Laboratory and the U.K.'s Aldermaston Laboratory, we also conducted two postshot drilling and sample-recovery operations to test all aspects of a normal drillback. These exercises allowed us to review, evaluate, and document operations not normally performed during a test moratorium, and they served as opportunities for training.

### Hydronuclear Experiments

We explored cost-effective ways to maximize the data return from low-yield (less than 1.8 kgs TNT-equivalent nuclear yield) experiments should they be authorized. We also used analytical and computer simulations to describe an emplacement and containment scheme that reduced burial depth to that accessible by inexpensive auger drilling. This plan was reviewed by the DOE Containment Evaluation Panel as part of a training exercise.

Anticipating that compliance with future treaties may require us to measure the nuclear yield of such experiments, we determined that fission-product gas diagnostics is the most cost-effective and accurate measurement method and joined with EG&G to build a mobile gas analysis system. This system, which will be field-tested in 1995, replaces and improves on equipment used for gas sampling in nuclear explosion diagnostics. It is centered around a quadrupole gas mass-spectrometer and a gas-handling manifold suitable for either gas or water samples.

### Dual-Benefit Technologies

DOE has authorized the use of defense-program resources for activities sponsored by others, provided those activities are synergistic with defense-program goals for maintaining test readiness. LLNL and contract personnel have both worked in a number of such projects.

### Groundwater Characterization at NTS

The DOE's long-term groundwater characterization project to assess the role of groundwater in transporting radioactivity away from testing centers brought our logging experts together with IT Corporation to define the saturated and vadose zones at the NTS. Conventional petroleum practices do not always work well at the NTS, so we developed custom data-processing procedures for these logs. We also used our expertise in seismic reflection techniques to develop a data-acquisition program to help the project eliminate several holes from its drilling program.

Near-field studies recommended by our radiochemists and hydrologists will define our research program over the next several years. These studies will incorporate refinements of our radionuclide source-term inventory of debris from all 825 underground tests from 1957 to 1992, kinetic studies of the solubility of nuclear explosive melt glass and debris, and equilibrium geochemical modeling of cavity waters. We will also review test phenomenology and assess the nonradiological contaminant inventory that underground testing introduced to groundwater.

### Radiation Detector Development

The detector technologies once required by the test program are now finding use in materials management, international safeguards, proliferation response, waste characterization, and environmental monitoring. Work to develop advanced detector systems, signal-processing techniques, and spectral analysis methods is in progress.

We completed the initial design of a gamma-ray detection system composed of an array of high-purity germanium crystals that will provide detection sensitivities 10 to 100 times higher than currently available. The signals from the detectors are processed with an event-mode data-acquisition system to obtain sensitive signatures of isotope decay on samples of interest, such as in the radiochemical analysis of nuclear materials or explosion debris. We also performed Monte Carlo calculations of several array geometries and did preliminary tests with a two-detector system.

In the past year, we began a proof-of-principle experiment to use high-frequency information from gamma-ray signals recorded on high-purity germanium detectors. This information, which is lost in the conventional signal-shaping process, is useful for improved background suppression and for determining where in the detector a gamma ray has interacted.

## Nonproliferation and Counterproliferation

### Attribution and SNM Origins

We continued work with LANL and the Air Force Technical Applications Center on the attribution of special nuclear materials (SNM) and nuclear explosion debris. Using analytic techniques now being developed, we will be able to provide country-of-origin data in time of crisis, allowing national leaders to respond appropriately and with confidence.

We demonstrated unique isotopic "fingerprints" specific to U.S. stockpile weapons and, by inference, to other devices and components. For example, we analyzed a sample of uranium radiochemically and derived methods to determine the date of last chemical separation, the reactor irradiation of feed materials, the chemical steps used in purification or casting, and the signatures of other heavy elements in the production plant.

### Safeguards

We have been working on remote-location detector systems as part of a program to safeguard plutonium and highly enriched uranium. To avoid weight limitations and meet field-support requirements, we developed a germanium gamma-ray detector that has a miniature cooling unit to maintain the detector's 80-K operating temperature. The next step is a portable, robust package that is fully competitive with liquid-nitrogen-cooled detectors.

We have already developed a cadmium–zinc–tellurium solid-state detector that can do an accurate isotopic assay of uranium samples when operating at room temperature. Tests with two sizes of detectors and uranium samples of varying enrichment showed good results (10% accuracy) with a detector energy resolution of less than 3.5 keV.

### Ion Probe

To improve our measurement of elemental abundances and isotopic ratios in even microscopic samples collected in and around suspected nuclear-proliferation sites, we have been developing several hardware improvements for the ion microscope, including upgrading its secondary-ion system. This upgrade will lower detection thresholds, provide higher mass-resolving power, and significantly improve imaging capability at a tenth of the cost of a new microscope.

### Remote Sensing

We have been using our LIFTIRS (Livermore Fourier-transform infrared spectrometer) imaging spectrometer to form images of invisible atmospheric trace gases. It works by taking 128-by-128-pixel spatial

*Ken Neufeld holds an innovative mechanical cryogenic refrigerator, developed in collaboration with an industrial partner, to integrate with a germanium detector to be the heart of a portable very-high-resolution gamma spectrometer for safeguards applications in the field.*

*This hot-water drilling experiment's results—tracing radionuclide migration in NTS groundwater—are being used for broader application. Assessments are being made of other groundwater phenomena into and out of the area.*

images through an interferometer. Between frames, a mirror moves, allowing each pixel to record the wavelength spectrum of incident light. By cross-correlating the spectrum recorded at each pixel with the signature spectrum of a gas or mix of gases, we can display an image of the corresponding gas. This allows us to monitor plumes from stacks or leaks from reservoirs, check industrial operations for evidence of illegal activities, and study atmospheric phenomena.

We also developed a mobile laboratory so LIDAR (the laser analog of radar) can probe aerosols in the atmosphere. We have demonstrated our ability to locate vehicle exhaust plumes even when they are subvisible and to locate sources by mapping the distribution of plumes in space. To evaluate sensors for pollution and proliferation monitoring, we helped establish a remote-sensor test range at the NTS. This range can release test plumes of more than 12 toxic gases at concentrations up to 1000 ppm and can test instruments, on the ground or in airborne platforms, up to 10 km away.

### Isotope Measurements for Groundwater

We have been using techniques for measuring isotope tracers in diagnostics to study the movement of groundwater, which supplies about half of California's water needs. Noble gases, hydrogen, and oxygen isotopes tell us the temperature, altitude, and degree of evaporation of water as it enters the saturated zone of an aquifer where, without further atmospheric interactions, trace isotope concentrations are preserved. This knowledge helps us identify recharge irrigation water and distinguish between water entering the aquifer at different elevations and temperatures.

We can also determine the age of water by the amount of radioactive tritium and $^{14}C$ it contains. For example, tritium and its stable daughter $^{3}He$ can accurately date water that is less than 50 years old, while new techniques using accelerator mass spectrometry to measure $^{14}C$ can date groundwater between about 1,000 to 40,000 years of age.

We provided the Kansas Geological Survey with water age and origin measurements to calibrate a hydrogeological model of groundwater movement in the Dakota aquifer. In Yosemite National Park, we determined recharge locations and groundwater ages to help the U.S. Geological Survey (USGS) quantify the size of rechargeable (and therefore usable) groundwater resources in the Wawona Valley. We also helped the USGS assess the characteristics of water flow in fractures by injecting five noble gas tracers into an artesian well in fractured granite, subsequently measuring their concentration. In addition, we helped California's Orange County Water District determine the age of injected reclaimed water to ensure that it had been underground long enough to satisfy potability requirements.

### Communications, Computing, and Data Interconnects

Last year, we described innovative high-bandwidth electro-optic components that are advancing state-of-the-art communications. Similar technologies are now being applied to communications between computer processors and memory. Because the bandwidth requirements for such communications often exceed those attainable with metallic interconnects, particularly at high processor clock speeds and long interconnect distances, we are working with the Optoelectronics Technology Consortium on an optically interconnected workstation cluster whose interconnect distances could be tens of meters.

One impediment to the widespread use of optical interconnects within a computer is the cost of the high-performance components. A key driver of this cost is the precision required to attach fiber-optic “pigtails” to the guided-wave optical device, a job currently done by highly trained technicians who must look through a microscope to manipulate the elements. With LLNL’s binocular machine-vision technology and a coarse–fine automated positioning strategy, we will use robotics for a hundredfold reduction in cost. This work is being done in collaboration with United Technologies Photonics, ORTEL, Newport–Klinger, and the MIT Manufacturing Institute.

We will assure further automation by positioning the fiber-optic pigtail on a silicon microbench formed by precision etching. Once positioned, the solder-tinned pigtail can be affixed to the silicon substrate by using polysilicon heaters in the substrate to reflow the solder.

### Opto-Electronics and Photonic Materials

We have been studying silicon nanocrystals (porous silicon) and electroluminescent polymers for opto-electronics and photonic applications such as color flat-panel and three-dimensional displays, light-emitting diodes (LED), and lasers. In collaboration with UC Davis, we made silicon nanocrystals that photoluminesce throughout the visible. We also made arrays of miniature, porous, silicon-based LEDs that emit throughout the visible and infrared, as well as inexpensive, mechanically flexible LEDs of electroluminescent polymers.

We have also been studying fullerenes—soccer-ball-shaped carbon molecules consisting mainly of 60 or 70 carbon atoms—for applications like optical switching, nonlinear waveguides, and optical limiting. Fullerene switches are competitive with optical-fiber switches but are smaller, easier to fabricate, and potentially faster. Recently we used a thin film of $^{70}C$ and a new device design to demonstrate the first fullerene-based, all-optical switch.

### Nuclear Physics

We continued to explore enhanced nuclear stability near the predicted deformed shells at Z=108 and N=162 with scientists at the Joint Institute for Nuclear Research in Dubna, Russia. To analyze reaction products, we used an on-line, gas-filled electromagnetic separator and a position-sensitive surface-barrier detection system preceded by the Dubna U400 cyclotron and a rotating wheel target. From $^{34}S$ bombardments of $^{238}U$, we discovered a new nuclide of element 108, with mass 267, the heaviest atomic nucleus yet discovered. We will continue to study this region in hope of discovering element 110 in 1995.

We are using Berkeley’s Gammasphere multidetector array and heavy-ion reactions to study extremely deformed lead nuclei at high angular momenta. These nuclei exhibit gamma-ray band structures called superdeformed bands. Recently, we identified two such bands in both $^{193}Pb$ and $^{195}Pb$. The constant differences in energy exhibited by the gamma rays in both bands differed from all other superdeformed bands in the lead nuclei, which showed a gradual decrease in energy differences. Although current theoretical calculations attribute this decrease to a steady loss of proton and neutron pairing, further investigation will be needed to fully understand the discrepancy.

## Summary

Despite the dissolution of the directorate, our people continue to find new applications for our expertise in underground nuclear testing. We expect our fully developed capabilities—as well as our ever-expanding wealth of new technologies—to help us respond to current needs in global security. Maintaining capabilities, supporting stockpile stewardship, and developing new applications for our work is evidenced by advances in such diverse fields as spectral imaging, fiber-optic telecommunications, and groundwater quality.

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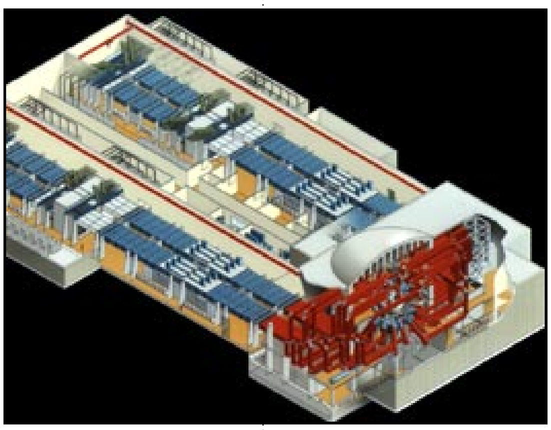
# Lasers

*Our contributions in laser technology and its applications range from new visions in industry and defense to improved vision for people, and from concept to design of the National Ignition Facility.*

Imagination appears to be the only limit on the uses of the laser and related technologies. This is echoed by the Laboratory's efforts in science, technology, and engineering within the Laser Program. In the traditional laser-oriented portions of the program, these efforts range from thermonuclear physics to uranium enrichment for nuclear power plants. The program also encompasses the National Ignition Facility, which offers a science-based stewardship of our nation's nuclear stockpile and the promise of exciting research capabilities and high-technology jobs in the next century.



*The proposed National Ignition Facility (shown here) will contribute to DOE's vision of science-based stockpile stewardship without underground testing.*

Outside the traditional laser programs are other applications programs that have evolved because of needs that could be met by LLNL technologies. They include the Imaging and Detection Program, which explores defense and civilian applications in signal and image processing, detection theory, radar systems, remote sensing technologies, and airborne platforms, and the Advanced Microtechnology Program, which includes advanced lithography, magnetic storage, flat-panel displays, and micro-optics for human vision correction.

## Inertial Confinement Fusion

The mission of the Inertial Confinement Fusion (ICF) Program is to develop a science and technology base that can demonstrate significant fusion energy yields in the laboratory and to identify and develop applications using that capability. For the near term, we are developing ICF technology to better understand issues in nuclear-weapon physics. A long-term goal is to explore ICF's feasibility as a clean and inexhaustible source for commercial electric power production by inertial fusion energy (IFE).

### The National Ignition Facility

Conceptual design of the National Ignition Facility (NIF) was completed during the past year by a project team from Los Alamos, Sandia, and Livermore national laboratories. On October 21, 1994, the Secretary of Energy made a positive recommendation on Key Decision One, which, if accepted by Congress, would provide funding for detailed engineering design of the NIF starting in FY 1996. The Secretary also announced that DOE would hold a series of public meetings to address several issues, including the nuclear nonproliferation implications of the NIF. A positive assessment of NIF's value to the nuclear nonproliferation issue would be required prior to Key Decision Two, a commitment for construction.

The NIF's neodymium glass laser will supply about 1.8 MJ of energy, at a wavelength of 351 nm, to a fusion target. The laser will consist of 192 individual beams in 48 four-beam groups. In 1994, the NIF baseline multipass architecture was verified on a single aperture of the Beamlet scientific prototype system. This system, operating at a wavelength of 1053 nm, produced fluences equivalent to those required for the NIF and achieved excellent beam quality (in terms of low peak-to-average fluence modulation and small wavefront aberration). The Beamlet's output beam was converted to the third harmonic at a wavelength of 351 nm, demonstrating the NIF harmonic conversion efficiency and fluence requirements.

### Nova Experiments

We continued our collaboration with Los Alamos National Laboratory on the 12 ignition-physics goals defined by the Nova Technical Contract.[1] This past year we demonstrated, using

Nova, five critical parameters of NIF hohlraums (cavities that convert the energy in laser beams to a near-isotropic bath of soft x rays for imploding the fusion fuel capsule):

- Soft x-ray, black-body radiation temperatures up to 300 eV.
- Time-averaged symmetry of soft x-ray radiation drive to a few percent.
- Low levels of backscattered laser light from plasmas similar to those in NIF hohlraums, which indicate efficient energy coupling to the target.
- Implosions with convergences (the ratio of fuel capsule's initial to final radius) up to 24 with little fusion-generated neutron yield degradation.
- Hydrodynamic growth factors up to 100, values which are beginning to approach the calculated growth factors for NIF targets.

The partial declassification of the ICF program allowed the publication of four letters on the Nova x-ray drive experiments in the October 24, 1994, issue of *Physical Review Letters*.

We also collaborated with the University of Rochester on experiments relevant to direct-drive inertial-fusion designs. Other experiments on issues relevant to light-ion-driven targets were conducted by researchers from Sandia National Laboratories.

### Target Development/Modeling

Our progress in ICF target design was significant. We focused our target modeling efforts on NIF-scale plasma physics, NIF target design, and time-dependent symmetry diagnosis; and we designed long-scale-length plasmas in both open (gas-bag) and closed (gas-filled-hohlraum) geometries to mimic anticipated NIF conditions. Plasma temperatures and densities were diagnosed by spectroscopic methods, and Nova experiments were performed to confirm all of the above. To calculate the interplay between filamentation instability and stimulated Brillouin scattering and to help explain Nova observations, we developed a three-dimensional plasma code. We also performed complex, fully integrated (hohlraum-plus-capsule) two-dimensional LASNEX simulations of three separate NIF target designs and developed new methods for diagnosing time-dependent drive symmetry, using x-ray-backlit, low-density foam balls.

To determine potential NIF uses for IFE development, we sponsored a national workshop and published major power-plant design studies based on heavy-ion drivers and diode-pumped solid-state lasers. We also contributed to the successful test of the Induction Linac Systems Experiment beam injector, which was completed at Lawrence Berkeley Laboratory.

## Isotope Separation and Advanced Manufacturing Technology

Isotope Separation and Advanced Manufacturing Technology has two major

## Highlights for 1994

### Inertial Confinement Fusion

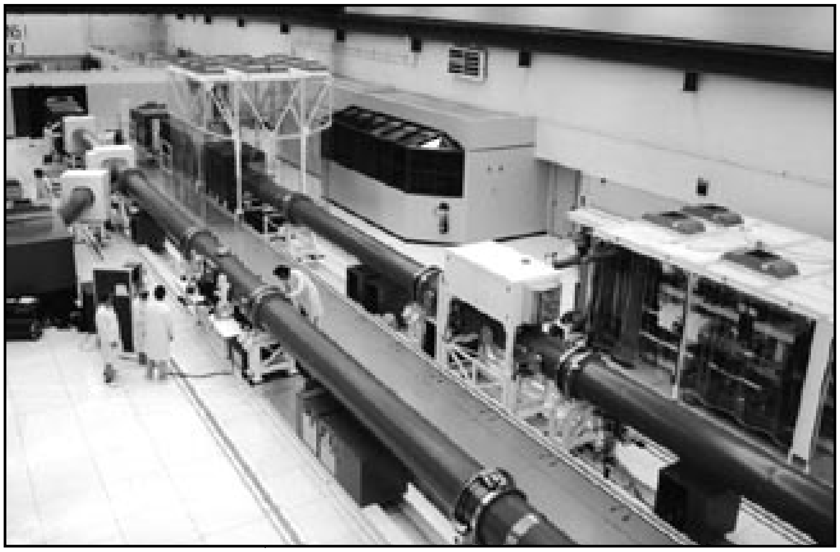
- Received the Secretary of Energy's positive recommendation on Key Decision One for the National Ignition Facility (NIF).
- Completed conceptual design of the NIF.
- Successfully demonstrated NIF performance with the Beamlet laser.
- Began demonstrating the scalability of target performance toward NIF-scale targets.

### Isotope Separation and Advanced Manufacturing

- Established LLNL's largest-ever technology-transfer initiative with AVLIS when USEC began commercialization.
- Began large-scale gadolinium-enrichment experiments.
- Established CRADAs for E-beam and laser-materials processing technology-transfer activities.

### Other Applications

- Successfully explored advanced concepts in imaging systems and applications.
- Used advanced microtechnology patents to obtain $50 million in new projects in lithography, information storage, and human vision correction.
- Developed high-average-power, diode-laser-based technology for x-ray lithography, remote sensing, materials processing, medical, and other applications.
- Deployed laser-guide-star adaptive optics system at Lick Observatory.



*The Beamlet laser, a full-scale, single-beam prototype of the NIF design demonstrated laser fluences at infrared wavelengths equivalent to those required for the NIF.*

programs: Atomic Vapor Laser Isotope Separation (AVLIS), which focuses on the enrichment and associated chemical processing of uranium and other heavy metal isotopes, and Advanced Manufacturing, which explores manufacturing applications of AVLIS technology.

## AVLIS

The mission of AVLIS is to provide the world's lowest-cost, uranium-enrichment method for commercial power-plant fuel. With this method, precisely tuned laser light and uranium vapor are brought together in a separator vacuum assembly. In the separator, atoms of the $^{235}U$ minor isotope in an atomic vapor stream of natural isotopic composition are selectively optically excited and photoionized by laser light. The selectively ionized $^{235}U$ isotope is then collected to generate a product enriched in this isotope. Once enriched, the metal product is processed into nuclear fuel.

Uranium AVLIS is now funded solely by the United States Enrichment Corporation (USEC). In July 1994, USEC's board of directors voted unanimously to begin commercializing AVLIS, not only ensuring its continuance, but making it the largest and most significant technology-transfer initiative in LLNL history. The USEC also accepted an AVLIS proposal to use the same hardware and technology to investigate the enrichment of gadolinium in the odd isotopes $^{155}Gd$ and $^{157}Gd$. Natural gadolinium is used as a burnable absorber in light-water nuclear power plants. The odd isotopes have much larger absorption cross sections for thermal neutrons than the even isotopes. The use of an isotopic mixture enriched in the odd isotopes in place of a natural isotopic mixture as a burnable absorber would improve the economics of light-water reactor operations. Sales of enriched gadolinium are projected at approximately $100 million per year.

**Laser Activities.** Laser technology development continued to support the future deployment of an AVLIS plant. Efforts continued to eliminate the chlorofluorocarbons (CFCs) used to cool electronic components in the copper laser system. Our latest laser oscillator eliminates CFCs in favor of air and water cooling, and our newest amplifier eliminates CFC cooling of the high-voltage power supply. We also have been developing a method for cooling the amplifier pulse-power modulator—a challenge because of its high average power (nearly 100 kW), high output voltage (80 kV), and short risetime (tens of nanoseconds). Tests of promising oil-cooled modulators will be completed soon, allowing system retrofits to begin.

We also installed and are activating the Plant-Scale Dye Laser System (PDLS), a full-scale version of an AVLIS plant's dye laser module. All copper pump light in the PDLS is supplied by large-core optical fibers. Hybrid refractive/refractive telescopes (which reduce the dye chain's length as much as 50%) transport dye laser beams through the optical system. Alignment of both the copper and dye laser beams is remotely monitored and controlled.

**Separators.** We focused our attention on activating a second-generation separator pod. The run duration (more than 260 hr) and throughput rate (near plant value) achieved by this pod in 1993 were records for AVLIS and represented important steps toward our goal of 600-hr pod lifetimes. We operated the pod again in 1994 for gadolinium vaporization, modifying the electron-beam magnetic transport system to minimize the magnetic field in the photozone. The pod operated smoothly and easily produced the desired gadolinium vaporization rates.

### Advanced Manufacturing

**Electron-Beam Materials Processing.** We are using AVLIS technology to produce injection molds currently manufactured by expensive and time-consuming conventional and electric-discharge machining. In this new process, an electron-beam vaporizer deposits metal on a mandrel (or negative of the desired mold). By carefully controlling vaporization parameters and the mandrel temperature, we can build up 1-cm-thick deposits in a few hours. We have already produced several demonstration molds and have entered into a CRADA with industry to develop and commercialize this technology.

We are using new diode-laser-based sensors to monitor and control the vapor composition of complex alloys whose components have widely varying vapor pressures. Controlling the vapor composition extends the use of electron-beam evaporation (which produces the highest coating rates of any physical vapor-deposition process) to the manufacturing of complex alloys. The same technology is being used to manufacture metal-matrix composite materials for the U.S. aerospace industry.

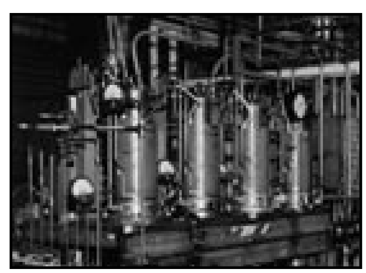
**Laser Materials Processing.** We are using beams from our copper, dye, and diode-pumped solid-state lasers for advanced manufacturing. By combining diffraction-limited beam quality with precision laser-beam scanning technology, we can drill circular holes of 100 to 200 $\mu$m in diameter through 1-mm-thick stainless steel with better than 10-$\mu$m accuracy. We can also drill noncircular holes with almost arbitrarily shaped (such as square or triangular) cross sections, which gives laser machining a unique advantage over electric-discharge machining.

We use pulsed-laser ablation to produce high-quality, diamond-like carbon films for flat-panel displays, artificial joints for human prostheses, and nonferrous tools. With copper vapor lasers, which produce laser radiation in the visible wavelength at high pulse-repetition rate and high average power, we have increased film growth rates by a factor of 100 over other laser or chemical vapor-deposition methods, potentially reducing film costs.

## Imaging and Detection

LLNL is technical manager of U.S. activities in the Imaging and Detection Program's (IDP's) largest project, the joint U.K./U.S. Radar Ocean Imaging Program, which studies the use of radar to detect surface manifestations of moving submarines and surface ships. IDP's main goal is to assess submarine detectability by airborne and spaceborne radars, using a comprehensive model constructed from fundamental physics considerations, statistical models, and empirical data.

The IDP is also responsible for the Super-High-Altitude Research Project, the world's largest light-gas gun of its kind. This gun, which was originally designed to launch payloads into space, uses a fuel–air combustion first stage to drive a piston that heats and compresses a hydrogen-fueled second stage. We have been using the gun to launch 6-kg projectiles and have



*The major components of AVLIS technology include lasers (two photos top and middle left), separators (bottom left), computers and controls (top right), and uranium processing (bottom right).*

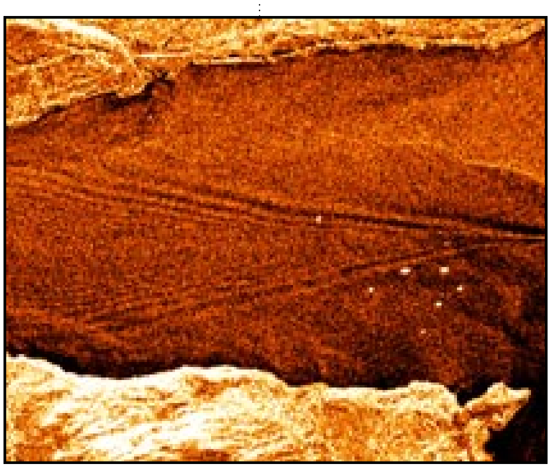
established a world-record kinetic energy of 24 MJ at a projectile velocity of more than 2 km per second. In collaboration with Rockwell International, we also set a benchmark for supersonic combustion ramjet (SCRAMJET) performance, achieving inlet start (at a speed of Mach 8) for a hydrogen-fueled projectile. Future side-injected light-gas guns could reduce the cost (by a factor of 20) of placing G-hardenable payloads into space.

Currently, we are working on a prototype ultrawide-bandwidth, remote-sensing, impulse radar system for high-resolution microwave imaging, as well as associated algorithms for image formation. The system, which will also be used for wave-tank studies of ocean-wave scattering physics and for detecting and imaging personnel in closed rooms or buildings, will extend our high-resolution radar-imaging capabilities from meters to centimeters and allow us to form recognizable targets for defense or law-enforcement applications. It will also allow us to do detailed studies of scattering physics, provide accurate spill and contaminant mapping, and enhance sensitivity for detecting ocean currents and wave spectra.

## Advanced Microtechnology

The Advanced Microtechnology Program (AMP) is one of the fastest growing industrial outreach activities at LLNL. In its largest project, extreme ultraviolet lithography, AMP collaborates with two other national laboratories and eight industrial partners. The goal of the project is to provide a capability for short-wavelength (13-nm) projection lithography for the mass production of integrated circuits having features of 0.13 μm and smaller. Other projects include

*L-band synthetic-aperture-radar image of a surface-ship-generated internal wave.*



- An advanced magnetic head (patent pending) for use in computer hard-disk storage systems that should be more sensitive and less costly than current magnetic heads and increase storage density by a factor of 200.
- A flat-panel display project to produce field-emission display structures that, because of AMP's capability in submicron interference lithography, should be brighter, faster, and less costly than liquid-crystal displays.
- A microthin (about 25.4-μm-thick) lens for the human eye, which should correct the chromatic aberrations normally associated with diffractive optics, could potentially make conventional cataract surgery obsolete and might eliminate the need for conventional eyeglasses and contact lenses.

## Other Activities

### Average-Power, Solid-State Laser Technology

In concert with government and industry, we have been developing compact and efficient solid-state lasers to extend the state of the art in average-power, solid-state laser technology. The development of laser-diode array packages (diodes, microchannel coolers, and microlenses for beam collimation) that produce high-average powers in the near-infrared continues to be an important part of the program. These packages can be stacked together to produce multikilowatt laser arrays for direct use or for pumping other solid-state lasers. Efforts are currently ongoing to transfer this capability to industry.

During the past year we built average-power, solid-state lasers for several applications, such as the advanced illuminators now being tested for military applications. Our advanced lasers were also used in the industrial sector for R&D in semiconductor lithography, materials processing, and medical treatments. In addition, we continued to improve our base laser capability, extending our diode capability toward the blue-wavelength region and demonstrating a record 360 W/cm$^2$ of continuous output power at 690 nm. We also produced a 2-kW, peak-power, diode-array operating at 900 nm for pumping a ytterbium-doped crystal of potential use for inertial fusion energy.

### Laser Guide Star

The laser guide-star project develops technology to implement adaptive-optics systems on ground-based telescopes, using laser-generated guide stars in the upper atmospheric sodium layer to correct the effects of atmospheric turbulence and improve resolution. Last year, we began construction of a smaller version of the AVLIS dye laser system that had demonstrated the brightest sodium-layer laser guide star in 1993, and we operated a natural guide-star adaptive-optics system at the University of California's Lick Observatory. The laser, control system, and launch telescope are still being constructed. The dye laser will be mounted directly on the 3-m-aperture Shane telescope at Lick and energized by light that is delivered by optical fibers from remotely located solid-state lasers. The adaptive optics system, which forms the other major guide-star subsystem, was operated on the 1-m Nickel telescope at the Lick Observatory and corrected resolution by an order of magnitude. It has since been relocated to the Shane telescope for use with the new laser system in FY 1995 and has already improved the resolution capability using natural guide stars. This laser guide-star system is expected to produce near-diffraction-limited performance for observations in the near-infrared region.

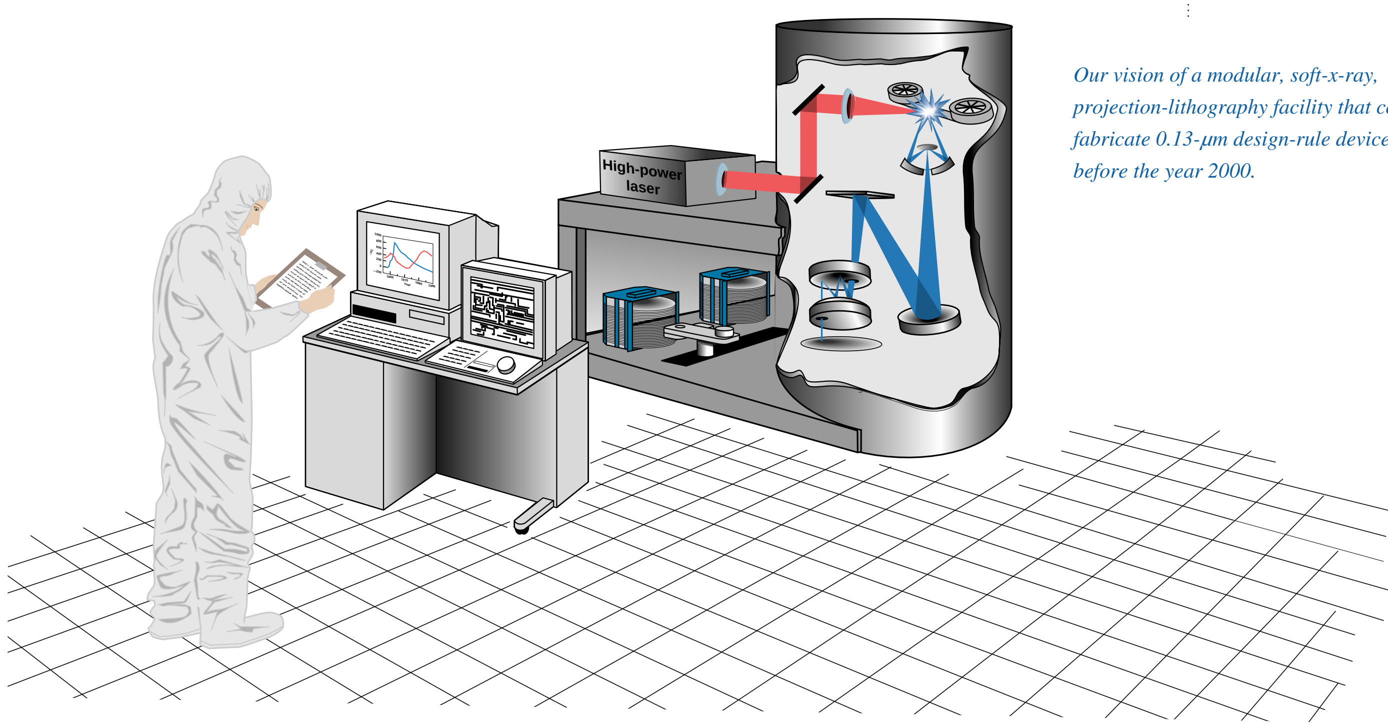
## Summary

The scope of our research in laser and related technologies has grown over the years and has attracted a broad user base for applications within DOE, DOD, and private industry. Within the next few years, we expect to begin constructing the National Ignition Facility, to make substantial progress in deploying AVLIS technology for uranium and gadolinium enrichment, and to develop new radar sensing techniques to detect underwater objects. Further, we expect to translate LLNL patent ideas in microlithography into useful industrial products and to successfully apply high-power, diode-based laser technology to industrial and government applications.

**Reference**

1. National Research Council, *Second Review of the Department of Energy's Inertial Confinement Fusion Program*, Final Report (National Academy Press, Washington, D.C., 1990).

***For further information contact E. Michael Campbell (510) 422-5391 or Hao-lin Chen (510) 422-6198.***




*Our vision of a modular, soft-x-ray, projection-lithography facility that could fabricate 0.13-μm design-rule devices before the year 2000.*

# Environmental Research and Technology Development

*Preserving the environment is an ongoing challenge facing the U.S. As one of the nation's largest environmental research and development groups, we are assessing the biological and health effects of exposure to various substances of concern. We are also developing new equipment and processes to minimize or treat waste and maintain a clean environment.*

In 1994, most of the Laboratory's environmental research, development, and demonstration projects were consolidated into one organization, the Environmental Programs Directorate. Our activities extend from basic research in geological, atmospheric, and environmental phenomena to applied research and pilot-scale testing of technologies for environmental remediation and waste management.

Our projects draw on expertise from across the Laboratory in areas such as microbiology, laser technology, engineering, computer science, chemistry, and nuclear physics. The products of our work include policy analysis, model and technology development across many disciplines, environmental remediation technologies, hazards mitigation and emergency assistance, and basic research.

## Geophysical and Environmental Research

The following sections highlight our recent work in geophysical and environmental research.

*Artist's rendering of the new Atmospheric Emergency Response Facility at LLNL. This building will house the national ARAC operations and training center. Construction began in August 1994, and we expect to move into the facility in January 1996.*

### Regional Atmospheric Sciences

We investigate atmospheric processes on local to regional scales for applications of regional and national importance. One focus is on applying models to predict the dispersion and deposition of hazardous emissions in the atmosphere. Another is to develop new models to refine our understanding of important atmospheric phenomena, including cloud formation and dissipation, precipitation and water-basin loading, turbulence and energy dissipation, stratified flows, and flows over complex terrain. We are also developing infrared-laser technology for remote sensing of the atmosphere.

Our evolving technical capabilities converge in the Atmospheric Release Advisory Capability (ARAC). ARAC operates as a national center for the DOE's Emergency Response Program and several DOD programs, and for other federal and state agencies. ARAC provides state-of-the-art, real-time, model-derived assessments of the health and environmental impacts of atmospheric releases of radionuclides and other hazardous materials. Assessments, which are available worldwide and 24 hours a day, incorporate detailed terrain effects, continuously updated three-dimensional meteorological data, and nationally approved health impact factors. In 1994, ARAC began assessments related to nonproliferation issues. Our new Atmospheric Emergency Response Facility, scheduled for completion in early 1996, will house the national ARAC operations and training center.

### Global Climate Research

To improve our understanding of potential climate changes that could occur as a result of human activities or natural events, we develop, test, and apply global climate models. We conduct research on the chemistry and biogeochemical cycles of trace species and aerosols in the troposphere and stratosphere. Our models describe the chemistry and physics of interactions from the micro scale to the global scale. Other research topics include the physics of clouds and their radiative properties, climate variability, and studies of heat, momentum, and water budgets. Our ultimate objective is to develop a coupled system model that represents the full set of coupled physical, chemical, and biological processes that govern the behavior of the climate system.

We have carried out the first climate simulations that include the effects of both increasing greenhouse gases and increasing aerosols. Aerosols are the minute solid or liquid particles produced both naturally and by human activities, such as burning fossil fuels. For several decades, researchers have recognized that aerosols could affect the amount of solar radiation reaching Earth’s surface. Aerosols reflect some incident sunlight back to space (the direct effect), and they can also serve as nuclei for the condensation of water vapor (the indirect effect), causing an increase in the global cloud cover. Both effects cool the atmosphere and, globally averaged, tend to offset warming caused by increases in greenhouse gases, such as carbon dioxide. Our study considered the combined effects of increasing greenhouse gases and the direct aerosol effect, taking into account the nonuniform geographic distribution of aerosol sources. The results show a complicated pattern of climate change, with cooling in some regions and warming in others. Thus, the pattern of climate change caused by human activities could be quite different from that predicted by most current global climate models, which do not account for aerosols.

The Atmospheric Model Intercomparison Project, which is led by our Program for Climate Model Diagnosis and Intercomparison, is being carried out in cooperation with the United Nations’ World Climate Research Programme. This project is the largest internationally coordinated test of atmospheric models ever undertaken. In all, 30 different models are being used to simulate the atmosphere’s behavior from 1979 to 1988. We are assembling an archive of model results and observed data from this project for use by the climate-modeling and diagnostic communities.

### Health and Ecological Assessment

Our research in this area includes the development of methods and instruments to detect and quantify environmental pollutants from DOE and related operations. This work ranges from environmental characterization and models to predict the transport of contaminants through all environmental media to the exposure of people. We are developing biological dosimetry capabilities for radionuclides and chemicals, evaluating ecological responses and restoration methods, and developing expertise in dose and risk assessment. This research is the basis for field assessments of contaminated sites, such as those at LLNL, the Nevada Test Site, and the Marshall Islands. Our Risk Sciences Center serves as a focal point for risk-related research at the Laboratory and as a bridge to researchers at UC campuses.

We are developing an innovative method for estimating human exposure to the radioactive iodine released at Chernobyl to correlate this exposure with thyroid cancer. Iodine concentrates

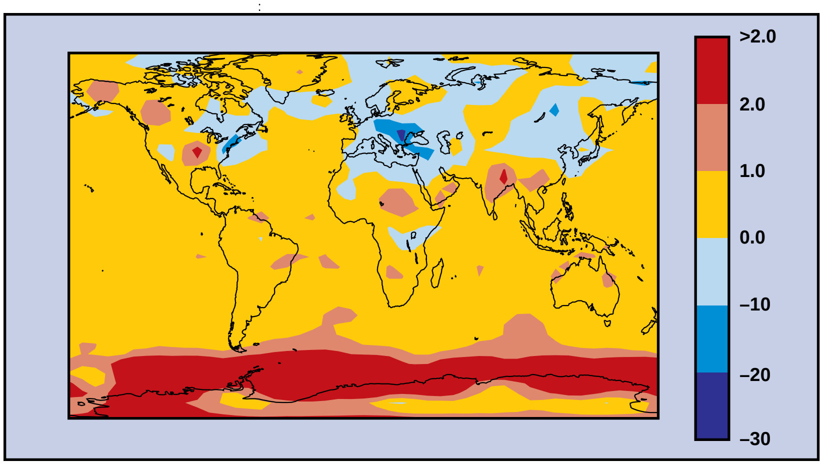
## Highlights for 1994

- Broke ground for a new facility that will house the Regional Atmospheric Sciences Division and ARAC, which currently occupy several facilities.
- Received DOE authorization to proceed with the next phase of planning and construction of the Mixed Waste Management Facility at LLNL. This pilot-scale facility will allow us to test new treatment processes for the destruction and immobilization of mixed waste.
- Conducted the first field study of the biofilter concept at the Kennedy Space Center in Florida; these filters can degrade TCE in groundwater.
- Demonstrated the Dynamic Underground Stripping technology for the in-situ cleanup of fuel hydrocarbons in the subsurface.
- Conducted the first integrated study of the effects of atmospheric aerosols on global climate, showing that aerosols must be considered in any analysis of global warming caused by an enhanced greenhouse effect.
- Continued working with Caltrans and the California State Seismic Safety Commission to assist the state in its seismic assessments of highway and bridge structures.
- Worked with California state meteorologists to explore improved weather prediction methods that, in the future, could assist the state in managing its water resources.
- Constructed the 1500-liter bioreactor facility, which will allow LLNL and other DOE and UC scientists to grow large quantities of bacteria for use in large-scale research, industrial, and environmental applications.

in the thyroid, and exposure to radioactive $^{131}$I is known to cause thyroid cancer. The 8-day half-life of $^{131}$I, however, causes it to decay to undetectable levels within a few months, making it impossible to measure how much was deposited following the accident.

The Chernobyl accident also released another isotope of iodine, $^{129}$I, in a known proportion to $^{131}$I. Both species have identical chemical behavior and should have been released and deposited in the same way following the accident. Because of its 15.7-million-year half-life, essentially all the $^{129}$I that was released is still present. This means that we can use the current abundances of $^{129}$I to calculate the amount of $^{131}$I that was deposited in an area.

Because concentrations of $^{129}$I are extremely low, they cannot be measured using conventional counting techniques. We can, however, use the capabilities of the LLNL Center for Accelerator Mass Spectrometry to make the necessary measurements. Working with scientists from Belarus, Ukraine, and Russia, we collected more than 200 soil samples from 10 settlements in Belarus that are part of an ongoing thyroid cancer study; the aim of this study is to measure the health impact of the Chernobyl accident on children. Our preliminary measurements indicate that we can reconstruct $^{131}$I exposures from Chernobyl. If successful, the same methodology could be used to reconstruct iodine doses resulting from other atmospheric releases.




*Our new climate simulation of the direct aerosol effect and the effect of increasing greenhouse gases takes into account the nonuniform geographic distribution of aerosol sources. In response to summertime increases in aerosols and $CO_2$, the simulation predicts areas of cooling and other areas of warming.*

## Earth Sciences

We are developing innovative technologies to characterize and remediate subsurface contamination and are researching advanced methods for defining and quantifying earthquake hazards. Our seismology group, with its long history of treaty verification research, is examining issues related to nonproliferation. We support the Weapons Program by studying the properties of nuclear materials at extreme pressures and temperatures. We are also helping to resolve issues related to the geochemistry, hydrology, thermomechanical response, and radionuclide transport in the environment that would surround waste packages at the candidate high-level nuclear waste repository at Yucca Mountain, Nevada. We are responsible for understanding the long-term, in-repository behavior of high-level nuclear waste.

Other energy-related research includes geophysical and seismological studies of geothermal fields, studies of the chemical kinetics of petroleum formation, and seismic, geochemical, and geophysical studies related to oil and gas exploration and production. We have an extensive basic research program in areas ranging from the tectonics of the earth, to underground imaging technologies, to studies of the physical, chemical, and transport properties of geological and other materials at high temperatures and pressures. Our basic research program continues to be enriched by the Center for Geosciences of the Institute for Geophysics and Planetary Physics, which promotes collaborative research with scientists at UC campuses.

## Center for Accelerator Mass Spectrometry

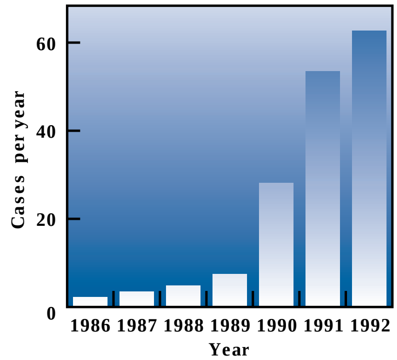
The Center for Accelerator Mass Spectrometry is becoming the world's most versatile and productive facility of its kind. We now routinely measure the low-abundance isotopes $^{3}$H, $^{7}$Be, $^{10}$Be, $^{14}$C, $^{26}$Al, $^{36}$Cl, $^{41}$Ca, and $^{129}$I at levels of 1 part in $10^{12}$ to $10^{15}$. No other facility can measure more than two or three of these tracers or chronometers. Furthermore, we can switch among these isotopes relatively easily and quickly.

We ran approximately 13,000 research samples last year for investigators at LLNL and at many other places, including the DOE, University of California (UC), and other universities, federal agencies, and various institutes and corporations. Our research programs are diverse, including archaeology, art history, dosimetry of carcinogens and mutagens, oceanic and atmospheric chemistry, paleoclimatology, forensic reconstruction of Hiroshima, dosimetry at Nagasaki and Chernobyl, and identification of signatures of nuclear fuel reprocessing. New applications with joint UC and DOE sponsorship include investigations in nutritional science and dermatology, the calcium chemistry of heart cells during cardiac stress, the hydrological record of Northern California watersheds, biogeochemical processes in the carbon cycle, and new techniques for archaeological dating. We expect the number of participating researchers, now totaling nearly 380, to increase as our capabilities grow.

### Geologic and Atmospheric Hazards Program

LLNL has been assessing the hazards associated with natural phenomena since the 1970s. The DOE is concerned about possible damage to its facilities from such natural hazards as earthquakes, storms, floods, lightning, volcanic eruptions, and extreme heat or cold. Because of our comprehensive capabilities, LLNL has become the hazards mitigation center for the DOE in the area of natural phenomena.

Recently, we began to develop a new method to evaluate the effects on structures of large earthquakes originating from specific faults. The aim is to define more realistic engineering standards. Our approach integrates three disciplines: seismology and geomechanics provide an estimate of expected ground motion, whereas structural dynamics provides the dynamic response of the structures themselves. The calculations use the sophisticated nonlinear, three-dimensional, finite-element codes developed at LLNL. With Caltrans, we have applied our methodology to two bridges in California: the Painter Street overcrossing of Highway 101 in Rio Dell, and the Dumbarton Bridge spanning San Francisco Bay. In 1994, the state of California asked us to assess a highway interchange in the Bay Area so that they can compare the predictions with those of a conventional analysis. (See *E&TR*, Sept.–Oct. 1993.)

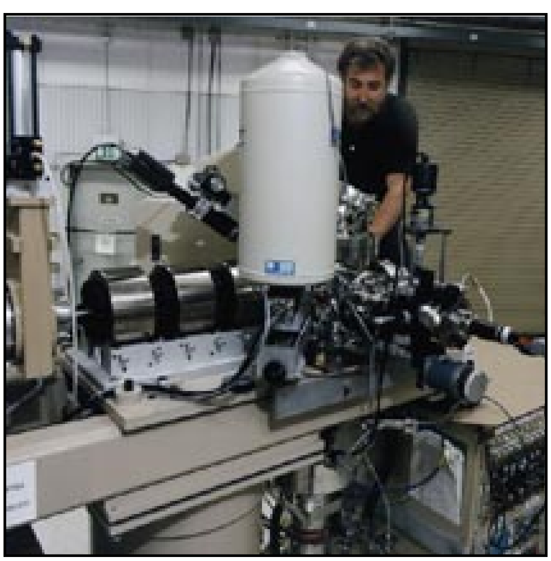



*About 25% of Belarus is radioactively contaminated. The incidence of thyroid cancer in children living in Belarus has been steadily increasing since the Chernobyl accident in 1986 and is now at alarming levels. We are reconstructing thyroid doses to children from radioiodine using the grass-cow-milk pathway.*

We are also developing a system that could warn of the impending arrival of a damaging seismic wave from an earthquake. The system relies on an array of seismographs deployed throughout a seismically active area and broadcasts a radio warning signal if the magnitude is of concern. Because seismic waves propagate at very slow speeds relative to radio signals, locations several tens of kilometers from the epicenter of an earthquake will receive a warning signal 10 to 25 seconds before an earthquake arrives. Advance warning could be used to shut down hazardous operations, start emergency generators, open the garage doors of fire stations, and so forth. A similar system could also be used to warn of large aftershocks, making it possible to reduce the danger to which emergency workers are exposed.

## Environmental Technologies Program

Many ideas for new environmental technologies come from basic research; others result



*The Center for Accelerator Mass Spectrometry can now routinely switch, daily or at shorter intervals, among eight low-abundance isotopes that serve as tracers or chronometers. One of our collaborators, Dan Morse from Sandia National Laboratories, is making adjustments to the new microprobe beamline.*

from new applications of existing technologies. One of the strengths of a multiprogram laboratory such as LLNL is the cross-fertilization of ideas from people working on different projects. The role of our applied technology programs is to turn ideas into working systems and to demonstrate their effectiveness. Below are highlights of some of our recent efforts.

### Optical Fiber Sensors

To measure the concentration of contaminants in groundwater today, investigators must withdraw water from a well, transport a sample to a laboratory, and make measurements with analytical instruments. Our approach involves optical fibers that are pushed into the ground using a device called a cone penetrometer. The aboveground end of the fiber is connected to a briefcase-size instrument that quickly measures and displays the abundance of contaminants. Optical fiber sensors emplaced in wells continuously sense the concentrations of groundwater contaminants and are cheaper and much more convenient than conventional sampling techniques.

### Dynamic Underground Stripping

Developed jointly by UC Berkeley and LLNL, this technique combines steam and electrical currents to heat soils and enhance contaminant recovery. Collection wells bring the contaminants to the surface, where they are treated and disposed. An underground imaging method, called electrical resistance tomography, monitors and controls the process. In 1994, we demonstrated the dynamic stripping technology to clean up gasoline that leaked many years ago from several underground tanks at LLNL. We removed more than 29,000 liters of gasoline from 600,000 $m^3$ of soil at depths of 25 to 45 m. Our cleanup took only a few months compared to the decades estimated for traditional processes. We are exploring this technique to clean up chlorinated solvents, such as trichloroethylene (TCE) and perchloroethane (PCE), and we are using tailored steam chemistry to enhance the removal of toxic or radioactive metals from soils.

*Teams of LLNL scientists go into the field after major earthquakes to study how and why structures are damaged. Our investigations included damage done by the January 1994 earthquake in Northridge, CA.*

### Microbial Filter

To prevent the spread of groundwater contamination, we have been developing a concept involving the injection of bacteria in a resting state to form a subsurface barrier of microbes. We previously tested the concept in the laboratory using a strain of naturally occurring aerobic bacteria that can co-metabolize toxic chlorinated hydrocarbons, such as TCE. Last year, we conducted the first in-situ test at a site at the Kennedy Space Center in Florida. The purpose of the test was not to remediate but, rather, to determine the capacity of the bacteria to degrade contaminants in an actual subsurface environment. We monitored groundwater pumped through several columns that were inoculated with our strain of bacteria. Results from two test wells showed that the bacteria retain their ability to degrade chlorinated and fluorinated hydrocarbons under the conditions present at that site.

We constructed a large-scale bioreactor facility that was completed in late 1994. The centerpiece of the facility is a 1500-liter bioreactor for growing the large quantities of bacteria needed to conduct full-scale field tests. The facility also includes microbiology laboratories to identify and isolate bacterial strains, and smaller bioreactors for laboratory experiments. These facilities are unique in the DOE complex and the UC system, and we expect many researchers to use them for other applications.

### Waste Treatment and Disposal Technologies

Maintaining a clean environment demands new techniques for treating and disposing of hazardous waste. Of particular concern are mixed wastes, which contain both radioactive and toxic materials—typically organic chemicals. Such materials are generated by medical research, hospitals, industry, and the military, but there are few accepted ways to process such wastes and make them suitable for disposal. Incineration, for example, has met with considerable public opposition. We have developed the following alternatives to incineration, each optimized for a particular class of waste.

**Molten Salt Destruction.** Developed with Oak Ridge National Laboratory and the Energy Technology Engineering Center, our molten salt process simultaneously destroys organic materials and traps inorganic and radioactive constituents in the salt. This process is promising for treating medical mixed waste that cannot be incinerated and hazardous wastes from industry and the military.

**Mediated Electrochemical Oxidation.** This aqueous, room-temperature process generates silver and cobalt ions in an electrochemical cell. The ions are extremely effective at decomposing toxic organic compounds into carbon dioxide gas and water vapor that can be safely vented into the atmosphere after treatment.

**Photolytic Destruction.** Photolytic destruction combines ultraviolet (UV) light and hydrogen peroxide ($H_2O_2$) to destroy trace organic compounds in a wastewater stream. We have been working to develop high-efficiency, short-wavelength UV lamps that greatly reduce the electrical power demand and improve the economics of the process.

**Measurement and Characterization.** We are developing smart systems for recognizing and sorting waste, tomographic techniques for noninvasive measurements of the contents of waste drums, and advanced radiation detector systems for verifying the uranium and plutonium concentrations in wastes.

## Mixed Waste Management Facility

The Mixed Waste Management Facility at LLNL, slated to be completed in 1997, is a key element in the deployment of effective and environmentally acceptable treatment processes as alternatives to incineration for low-level organic mixed waste. Our pilot-scale demonstration facility will provide a bridge between bench-scale demonstrated technologies and full-scale deployment and operation of facilities anticipated in response to the Federal Facilities Compliance Act. The facility will address development, engineering, process integration, and activation issues and allow for public participation. For initial operations in the facility, molten salt oxidation and mediated electrochemical oxidation have been selected as the primary process technologies. The process support systems will provide all essential support functions required of a fully integrated plant.

*LLNL scientists recently conducted a feasibility test of the microbial filter concept at the Kennedy Space Center in Florida. This work revealed that aerobic bacteria can degrade chlorinated and fluorinated hydrocarbons under the conditions present at the site.*

## Summary

Our goal is to better understand geological, atmospheric, and environmental phenomena as well as to contribute substantially to the nationwide effort to clean up the environment and come up with better ways to design and manufacture effective products. Many of our new technologies are making their way into the commercial sector, and many more are on the drawing boards. The continued dedication of researchers from institutions like LLNL is helping to make the U.S. environmentally clean and economically competitive.

***For further information contact Jay C. Davis (510) 423-1414.***

# Environmental Restoration, Protection, and Waste Management

*We are cleaning up contamination from past activities and developing strategies to ensure that current and future activities do not adversely affect the environment.*

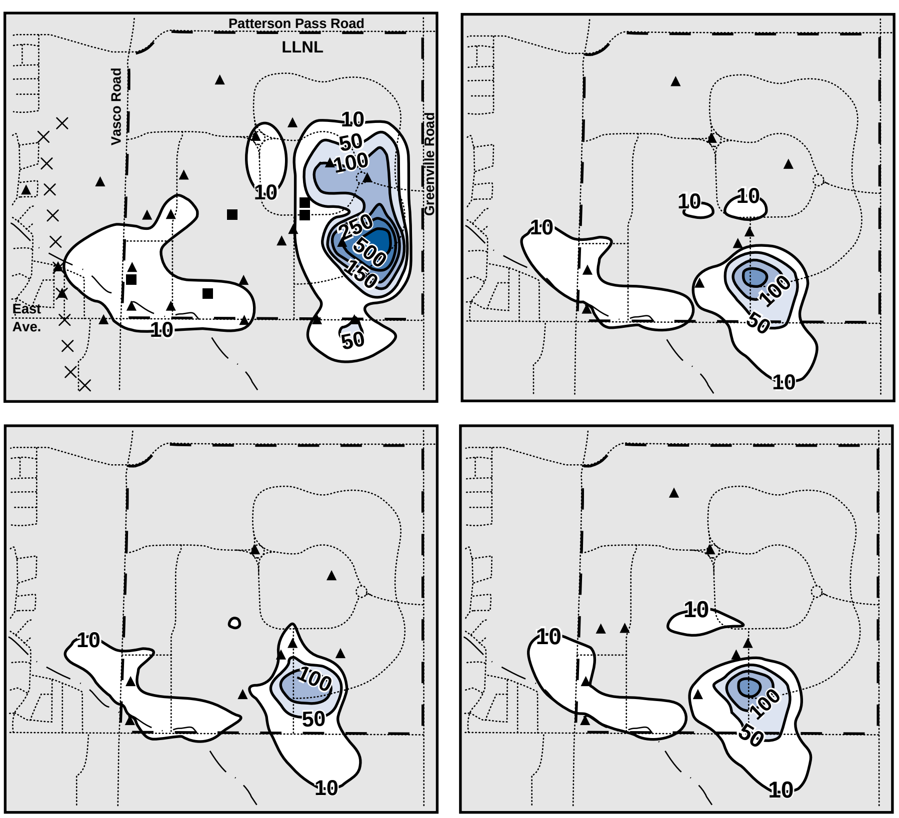
*Computer simulations using artificial neural networks (ANNs) help identify optimal groundwater cleanup strategies.*

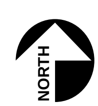
Many environmental concerns now facing LLNL are unforeseen and unintended consequences of activities that span more than 50 years—from its use as a Naval Air Station during World War II through its 40-plus years as the site of intensive research and development activities.

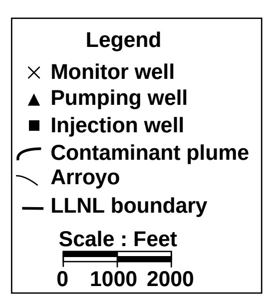
At LLNL, we are concerned about the impacts of environmentally harmful activities and are committed to complying with local, state, and federal environmental regulations. This commitment is expressed by our activities in environmental restoration, health and safety, hazardous waste management, air and water quality, and general environmental issues.

Specifically, we are

- Designing and applying cost-effective technologies for site restoration and remediation.
- Developing practices for monitoring, preventing, reducing, and cleaning up air emissions, wastewater discharges, and hazardous wastes and obtaining appropriate permits or exemptions.
- Conducting monitoring, risk assessment, and chemical analyses to meet regulatory requirements.
- Developing and implementing strategies to minimize waste and prevent pollution.
- Designing and implementing cost-effective ways to manage hazardous and nonhazardous waste streams.
- Implementing ways to mitigate potential impacts to natural and cultural resources.




## Restoration and Remediation

Environmental restoration activities are aimed at restoring contaminated groundwater and soil to appropriate health and environmental levels. To accomplish this, we investigate hydrology, geology, soil properties, hydrogeology, contaminant fate, and transport mechanisms at both Livermore and Site 300. We also install piezometers; drill monitoring and extraction wells; analyze soil and groundwater; test aquifers; develop and apply computer and conceptual site models; assess health risks from contaminants in air, soil, and groundwater; and test and implement technologies for environmentally responsible cleanup.

Through predictive modeling, we evaluate the fate, transport, and potential health risks of contaminants in groundwater and soil; select extraction and injection well locations; and optimize hydraulic control and contaminant removal in remediation designs. Modeling helps cut cleanup time, thus reducing groundwater remediation costs.

### Smart Pump and Treat

Conventional flow-and-transport models are generally quite slow to predict the effectiveness of some groundwater remediation pumping strategies. Thus, we have been using a "smart" pump-and-treat approach, that is, employing artificial neural networks (ANNs) trained to predict time, effectiveness, and cost data, then harnessed to search for strategies that balance timely and effective cleanup with minimum cost.

In one training simulation, we analyzed 28 LLNL locations (areas thought to contain groundwater contamination and required to be cleaned up within 50 years) to identify the lowest-cost subset that was as effective as the full 28-location set. Analyses showed that treating 8 to 13 locations could meet our containment and removal goals and cost less than 35% of treating all 28 locations.

In the current simulation, we are using a grid of 225 pumping sites to evaluate strategies involving 50 extraction and 10 injection pumps. The use of ANNs is crucial to find low-cost alternatives to reduce the time and maximize the extent of cleanup in five-year management periods.

### Vadose Zone Modeling

We are using the one-dimensional VLEACH model to simulate trichlorethylene (TCE) migration through partially saturated, fractured sandstone and claystone to the regional drinking-water aquifer below part of Site 300.

We assign infiltrating rainwater a TCE concentration of 1600 ppb—the area's maximum in shallow groundwater samples—based on Site 300's arid climate and the water content (less than 17%) of the bedrock strata. We assume that TCE partitions into infiltrating rainwater and that 10% of the average (25 cm) annual precipitation infiltrates and migrates downward. We further assume vertical vapor diffusion transports the TCE through the fractures and use VLEACH to estimate transport through unfractured media. Then we use VLEACH to calculate the critical length (about 75 m) of a vertical fracture, or series of interconnected fractures, that would cause concentrations to exceed EPA's maximum 5-ppb contaminant level for drinking water.

Modeling shows fractures across 85% of the vadose zone (subsurface soil or rock lying above the groundwater) do not cause aquifer contamination. This suggests that extensive fracturing in a vadose system with lower water

## Highlights for 1994

- Used automated neural networks to aid in selecting fast, low-cost, groundwater cleanup strategies.
- Used vadose-zone modeling to estimate the impact of contaminant transport through fractured media at Site 300.
- Developed a track-mounted camera system to traverse animal burrows and transfer findings to surface observers and videotape.
- Maintained a radionuclide-release detection network, and developed a system to assess exposures to and deposition of tritium releases.
- Developed a microwave digestion system to increase the efficiency of the preparation of hazardous waste samples for radiological analyses.
- Developed an air emissions measurement and information tracking system (EMITS) to calculate air emissions by source and regulatory program.
- Implemented an expandable, automatic, archiving remote reagent system for treating wastewater.
- Built a microfiltration unit to remove radioactive particles from liquid waste streams.
- Organized and set up a CHemical Exchange Warehouse (CHEW) for collecting, storing, and exchanging excess usable chemicals.
- Implemented a waste certification program at the AAICF Facility, Ann Arbor, Michigan, so the mixed and radioactive waste could be shipped.

*The truck-mounted miniature optic lair explorer (MOLE) is used to locate, identify, and protect endangered animals at Site 300.*

content may not increase contamination. In the future, application of models like VLEACH will help assess the potential for groundwater contamination with vadose-zone contamination.

The two-dimensional NUFT flow and transport code, recently developed at LLNL, is being used in carrying out DOE and LLNL commitments to clean up contaminated soils and groundwater at LLNL. Simulations using NUFT in conjunction with field data were recently carried out to help understand the multiphase flow and transport of volatile organic compounds (VOCs) in the sediments. The objective of this modeling work was to evaluate potential impacts to groundwater from VOCs in the vadose zone.

The NUFT code resolves more realistic conceptualizations of the actual heterogeneous subsurface with both advection and diffusion of gases and liquids, including rain and infiltration fluxes, which would not be fully resolved in our previous semi-analytic analyses and other numerical codes. In the future, three-dimensional modeling with NUFT will be used to evaluate cleanup system performance, extraction-well configurations, and cleanup-time estimates.

## Monitoring and Analysis

Eliminating or mitigating potential releases from current activities requires accurate measurement and monitoring techniques. LLNL has a network to detect significant effluent emissions. The 150,000 analyses made in 1994 demonstrate that the impacts of our activities are below regulatory limits. Evaluations of potential radionuclide emissions demonstrate compliance with standards and a decrease from past years.

Last year we worked with others to create a system to directly assess tritium releases and radiological exposures to people. The system, which combines real-time tritium monitoring and meteorological dispersion analyses, updates assessments of emissions from LLNL's Tritium Facility every 15 minutes. It also allows us to plan and control tritium releases and improve our reporting of impacts.

### Chemical and Isotopic Analysis Methods

The characterization of potentially contaminated environments is a powerful diagnostic when effluents have distinct isotopic compositions that are different from global background. We use mass spectroscopy (MS) to measure radionuclides because it is faster than traditional radiation counting methods and independent of radionuclide decay rate and mode.

Using inductively coupled, plasma-source spectroscopy (ICP–MS)—one MS method—we now can measure the amount and composition of uranium isotopes at trace levels in groundwater. Present methods of detection levels, expressed as minimum detectable activity, are better than $10^{-13}$ curies (Ci) per liter for $^{234}U$ and much better than $10^{-15}$ Ci per liter for $^{235}U$, $^{236}U$, and $^{238}U$. The technique is also more precise than conventional radiation counting for measuring minute amounts of anthropogenic uranium and more flexible and cost-effective than thermal ionization mass spectrometry.

Analyzing waste for possible radioactive contamination is expensive. We have implemented an automated microwave digestion system to reduce costs and increase analysis speed. The system can complete the digestion process in about an hour and uses less than 10% (0.1 liter/sample for oils) of the chemicals (i.e., nitric acid) required by the manual method, which required nearly two weeks to complete. In addition, automation also ensures reproducible chemical procedures and provides a safer work environment.

The system is operated by a personal computer. Commands are routed through a controller to a robotic arm manipulator, 6 reagent pumps, a

16-sample carousel, and a microwave oven. The system, which digests one sample at a time, allows different chemical procedures to be performed on each sample, provided the total number of reagents for all samples does not exceed six.

### Natural Resource Protection

The remote and relatively undeveloped Site 300 is a potential habitat for both common and protected animals. To locate, identify, and protect some of these burrowing animals, we developed a small subterranean, track-mounted vehicle known as a MOLE (Miniature Optic Lair Explorer). The MOLE maneuvers through the tunnels of ground squirrels, burrowing owls, badgers, and the like, carrying a camera with 360 degrees of rotation, high resolution, and infinite focus; it also has lights to illuminate underground dens. Camera images are transferred to the MOLE's surface monitor, which is also used to drive the MOLE. This allows us to study den structure, occupation, reproductive success, animal age, and species distribution. The images can also be recorded on videotape for future evaluation.

## Pollution Prevention and Waste Minimization

We are evaluating LLNL activities to find options that can reduce potential pollutants and waste. Successful options include using recyclable paint thinner in the Site 300 paint shop; using a nonhazardous cutting oil in defense-related programs; recycling metallic lead bricks, hammers, and shot; and using electronically generated graphics to eliminate photoprocessing waste.

When waste streams cannot be eliminated, we work with waste generators to minimize the amount of waste produced and retain those streams until they meet release requirements. We also developed a model "ideal" retention-tank system to facilitate tank design for new and upgraded wastewater retention-tank systems.

### Pollution Prevention

We are conducting pollution-prevention opportunity assessments (PPOAs) to help waste generators evaluate processes that generate pollution and identify prevention options. Staff engineers help process operators define material and energy flows for a given process and develop ways to reduce pollution at its source or to make the process more energy-efficient. They also evaluate the cost and technical feasibility of each option and prepare a final implementation report. Waste generators who invest in such options generally reduce operating and management costs. Options include using less hazardous raw materials, implementing a closed-loop system to eliminate discharge, and implementing controls for greater process efficiency. PPOAs are also consistent with DOE's commitment to quality and help us meet waste minimization measures in the contract between the DOE and UC.

*Air-monitoring stations are part of LLNL's environmental surveillance network.*

### Nonhazardous Waste Minimization

We minimize nonhazardous waste through information networks, new-product testing, policy analysis, and promotional announcements. We also report on minimization planning and accomplishments such as the doubling of LLNL's voluntary paper-recycling program. Programs for recycling cardboard, ferrous and nonferrous metal, and wood are expanding, and we are now evaluating the recycling of colored paper, magazines, newspapers, and polystyrene.

### Tracking Air Emissions

We monitor Title III and Title V requirements under the 1990 Federal Clean Air Act Amendments. We also respond to the Precursor Organic Compound "No Net Increase" provisions of two local air districts and follow California's AB2588 reporting and risk assessment requirements. This means we must sort emissions, understand how each emission source contributes to each regulatory program, and manage facility emissions to ensure we do not cross critical thresholds. To simplify these tasks, we created an emission measurement and information tracking system (EMITS) that uses material safety data sheets, air-district emission factors, and updated throughputs to calculate emissions by source and regulatory program.

*Our ideal tank-system model facilitated the design of this upgraded retention-tank system.*

Industry is interested in adopting EMITS for its own facilities, and cooperative agreements are in progress.

## Hazardous Waste Management

We work to ensure that hazardous wastes have a negligible effect on the environment. This includes investigating cost-effective methods for waste handling, stabilization, treatment, and disposal and designing and acquiring innovative facilities. Four Livermore facilities treat and store hazardous, low-level radioactive, transuranic radioactive, and mixed wastes. LLNL does not produce high-level radioactive wastes.

### Remote Reagent System

We implemented a remote reagent handling system to treat LLNL wastewater. This system interfaces to instruments that provide continuous-level readouts of the tank volume, content pH and temperature, and valve position. It is designed for easy expansion, automatic control sequencing, and archiving and uses a programmable logic controller, CRT displays, and backlight alarm annunciator panels. It also improves efficiency and operator and environmental safety. From the control and monitoring stations, operators can view the treatment facility, identify and respond to alarms, and control and monitor the treatment process. New process interlocks prevent unsafe operation.

### Microfiltration Treatment System

We constructed a microfiltration unit to determine whether all DOE-added radioactive particulates could be removed from liquid waste. The unit has a 100-gallon tank with two turbine mixers, a diaphragm metering pump, a temperature sensor, four inline filter housings, a bypass line, quick-disconnect sampling ports, a backflush line, a support rack, a skid, and a computer to log data during run time.

The first filter housing has polypropylene or compressed activated carbon; the second and third contain polypropylene fiber filters with smaller pores. The last, either a fibrous or etched pore filter, has pores of 1 $\mu$m or less. Liquid waste from the tank is pumped through the outside and toward the center of the first filter. It then travels through the annulus outside the housing and into the next filter. As the wastes deposit solids on each filter's outer surface, the pressure across the filter drops. When the liquid has penetrated all the filters, it is deposited in a drum near the microfiltration skid.

Preliminary tests show radioactivity drops a hundredfold when this technique and 1-$\mu$m filters are used to treat contaminated machining oils. We are negotiating with industry to use a membrane-separation technique to remove soluble metals, radioactivity, and water in oil-water wastes and to filter particulates in the remaining oil phase.

### Chemical Exchange Warehouse

LLNL's Chemical Exchange Warehouse stores excess usable chemicals and offers them free to LLNL users via a database. These chemicals, once part of the hazardous waste for disposal, can now be collected, identified, stored, and exchanged. At least 25% of them will be captured, and 25% of that volume will be recycled. The savings in procurement and disposal costs alone will offset transportation and storage costs once startup costs are paid.

## Radioactive Waste Certification

The Waste Certification Program ensures that LLNL's generation and management of radioactive waste meets the requirements of all waste-treatment, storage, and disposal facilities. Our quality assurance plan covers all aspects of radioactive waste management, particularly shipment of low-level radioactive waste to the Nevada Test Site (NTS). We achieved a critical milestone when waste shipments to NTS resumed after a three-year suspension. We have now received approvals for shipments of 23 waste streams, with 6 additional ones pending approval.

We submitted plans to sample and analyze waste streams such as liquid decontamination wastes, gravels, contaminated soil, high-efficiency particulate-air filters, and mixed wastes that have been stabilized to render them radioactive only.

NTS has approved four plans; two more await approval. In a related project, we developed a database system to document and evaluate the process knowledge used to characterize these waste streams. The use of process knowledge is critical in characterizing waste when sampling is not practical because of radiation exposure concerns.

At DOE's request, we sent a team to the Ann Arbor Inertial Confinement Fusion (AAICF) Facility at Ann Arbor, Michigan, to establish a waste management certification program that permits it to dispose of its radioactive waste at NTS. We also agreed to provide technical expertise to the facility. This project showed that LLNL's waste certification program could be deployed to a remote site and implemented in a timely and cost-effective manner.

## Environmental Training

We provide remediation training in both the U.S. and overseas to promote the transfer of U.S. environmental technology to European markets and to facilitate partnerships with European scientists and engineers. We also help LLNL employees comply with regulations and hope to develop a resource center to teach others how to apply state-of-the-art environmental technologies.

Domestically, we offer short courses under UCLA's Extension Engineering and Computer Science Program and expect to offer a soil and groundwater remediation course in 1995. Internationally, we gave a course on cleaning contaminated soils and groundwater, and we expect to offer another in 1995 on risk management issues at the International School of Innovative Technology for Cleaning the Environment in Erice, Italy. We also offer a course at the Joint Research Centre of the Commission of the European Communities at Ispra, Italy.

In 1994, we trained all required LLNL personnel (about 4000 employees) to meet Resource Conservation and Recovery Act (RCRA) provisions and radioactive waste certification. Other offerings included environmental laws and regulations, air-source management, tank management, spill prevention, controls and countermeasures, emergency response, and SARA/OSHA regulations. We provided support to DOE Headquarters in preparing a guidance document on RCRA training to be distributed to the DOE Defense Program sites. We are also developing training materials and trainers for equipment such as:

- HOTSPOT, a computer-based, atmospheric-dispersion system that models radioactive releases and provides data to formulate appropriate responses to accidental releases.
- A nonthermal, liquid abrasive cutter that workers dismantling nuclear arms and equipment can use to cut aluminum, stainless steel, titanium, bulletproof glass, and armor.

These projects will facilitate the transfer of accident-response equipment to the former Soviet Union.

## Summary

Our efforts to clean up contamination at the LLNL sites and ensure that current activities do not adversely affect the environment focus on developing a sound scientific foundation for risk-based environmental protection. As a national laboratory, we promote using the latest technologies and develop new technologies to reduce the cost of protection and cleanup. In that line, we evaluate groundwater and soil cleanup techniques and develop technologies for pollution prevention, waste minimization and management, environmental restoration, and environmental monitoring. Because the same technologies have wide use in industry and other government facilities, many will be made available through through potential partnerships with the private sector and educational institutions.

***For further information contact Harry Galles (510) 423-7983 or Ellen Raber (510) 422-3985.***

*Our environmental analysts receive specialized training in handling hazardous waste.*

# Energy

*Energy research at LLNL balances the complex demands of the economy with the overall needs of the environment. The technologies we are now developing will provide both short- and long-term benefits to the nation and the world.*

Clean, safe, and plentiful energy is essential to sustain a robust national economy without causing harm to the environment. The Laboratory's energy research and development efforts focus on the following areas:

- Improving the safety of nuclear power and minimizing its environmental impact.
- Developing fusion as a clean, safe form of energy for the 21st century.
- Exploring the use of alternative and renewable energy technologies while making better use of existing fossil-fuel sources.
- Working with industry to develop advanced manufacturing processes that increase efficiency and reduce waste.
- Developing transportation technologies that reduce energy use and pollution and increase efficiency and safety.

In our research, we are collaborating with other national laboratories and government agencies, large and small U.S. industries, academia, and international partners.

*We have established a Nuclear Systems Safety Center as an on-line national resource for nuclear facilities across the United States. Barbara Davis, Deputy Associate Program Leader, Information Technologies, was responsible for setting up the center.*

## Nuclear Energy and Systems Safety

LLNL's expertise in nuclear energy spans the entire nuclear fuel cycle, including the safe operation of fission reactors, all aspects of reactor fuel materials and nuclear wastes, and systems and procedures for the safe handling and storage of nuclear materials and the security of nuclear facilities. We work closely with the DOE, the Nuclear Regulatory Commission (NRC), and other U.S. agencies to develop standards and provide objective reviews and analyses.

### Nuclear Safety

In the area of nuclear safety, we develop technical acceptance criteria; conduct technical reviews; provide technical oversight for compliance for the handling, transportation, and storage of nuclear materials; and work to minimize the environmental consequences of energy production and use. For example, we are performing criticality calculations to help the DOE's two gaseous diffusion uranium enrichment plants operate safely. We have also reviewed more than eight current designs of spent-fuel storage casks for the NRC to permit continued operation of two nuclear power plants. Finally, our expertise in high-reliability software helped the NRC meet the DOE's schedule for advanced light-water reactor licensing.

With the breakup of the Soviet Union, Ukraine can no longer ship spent fuel from its operating reactors to Russia. Therefore, Ukraine is developing safety regulations for handling and storing nuclear materials within its own boundaries. We are working with the NRC to advise Ukraine in establishing a regulatory framework for transporting and storing nuclear materials. We are also supporting the DOE in the procurement of highly enriched uranium from Russia and in related issues.

### Yucca Mountain Repository

We continue to work with the DOE in studies for a potential permanent repository for high-level radioactive waste at the Yucca Mountain site in southern Nevada. (U.S. law mandates a mined geological disposal system for the waste.) We are responsible for establishing the scientific bases for the design of the waste package. Central to this effort is a determination of the surrounding geologic environment that can affect the performance of the waste package. We continue to explore our "extended dry" concept—a method using the heat released from the radioactive decay of the nuclear waste to keep moisture away from the waste package for tens of thousands of years. This concept could cost less, improve performance, and garner greater public and scientific acceptance of the potential Yucca Mountain site.

We are preparing to simulate repository conditions in a large block of rock at the site to study the effects of heat, stress, hydrology, and geochemical changes.

### Nuclear Facility Safety

We support the DOE in meeting security requirements at LLNL and other DOE nuclear energy-related facilities. Argus is an interconnected computer-based personnel access system that serves LLNL's Livermore and Site 300 facilities. We are developing an Argus installation for the Pantex Plant in Texas to meet the latest security requirements, and installation work is under way. Recently, the DOE selected Argus as the standard automated electronic security technology to be used by the entire DOE complex because of its reliability, adaptability, and high performance.

We are developing an upgrade to the systems used by the Office of Personnel Management and the DOE to process new security clearances and reinvestigations. This upgrade will replace the current paper-intensive process with privacy-enhanced electronic data entry and communications to shorten the clearance cycle and greatly reduce costs.

### National Performance Review

In 1994, we assisted the Administration's National Performance Review (NPR) organization in understanding and using the National Information Infrastructure. The NPR's objective is to "reinvent" government to be more responsive to the public. The electronic tools we provided are helping to make NPR information available electronically and to collect public comments via the Internet.

## Magnetic Fusion Energy

In the 21st century, magnetic fusion could be the source of large amounts of electricity without contributing to global warming or acid rain. The U.S. goal is to have a magnetic fusion Demonstration Power Reactor online by the year 2025. LLNL continues to collaborate in developing the next generation of tokamak fusion reactors, including both the Tokamak Physics Experiment (TPX) and the International Thermonuclear Experimental Reactor (ITER). (See pp. 22–23 for an account of our work in inertial fusion energy.)

### The DIII-D

A major design concern for current tokamaks is that the exhaust of most of the power is through the plasma edge, where it is concentrated in a small area called the divertor. A primary focus of our collaboration with General Atomics in San Diego is to lead the development of a new concept for an improved divertor that will spread the heat flow. In 1994, we installed a microwave interferometer to measure electron density in the divertor region and applied theoretical codes to determine the details of the divertor structure. We have now begun final design of a radiative divertor for the DIII-D tokamak. This work will also guide the design of both TPX and ITER.

Our work with General Atomics on the DIII-D is also supporting advanced tokamak concepts, in particular, with measurements of the plasma current profile, especially at the plasma edge. We are using a new diagnostic instrument

## Highlights for 1994

- Developed a concept for a practical, hydrogen-fueled, five-passenger hybrid-electric vehicle that has a gasoline equivalent mileage of more than 90 mpg and a 300-mile range.
- Received an award from the American Chemical Society for work in modeling hydrocarbon combustion in internal combustion engines.
- Tested a prototype electromechanical battery at reduced speeds, and exceeded a specific power of 8 kW/kg with a measured recovery efficiency of more than 92%.
- Received an R&D 100 award for the air-bearing LVDT amplifier we developed, which advances the state of the art in contact measurement.
- Helped Ukraine establish a regulatory framework for transport and storage of nuclear materials within that country's boundaries.
- Prepared to simulate repository conditions in a large block of rock for the Yucca Mountain nuclear-waste repository site.
- Began the major implementation phase of the Argus personnel-access security system at the Pantex facility in Texas.
- Began final design of a new radiative divertor for the DIII-D tokamak at General Atomics, based on a concept we developed.
- Installed new diagnostics on the DIII-D tokamak, including a new microwave interferometer to measure electron density in the divertor region and eight new channels of a diagnostic instrument to measure the edge-plasma current profile.
- Continued leading a national team in designing the proposed Tokamak Physics Experiment (TPX) to demonstrate continuous operation of a tokamak.

*For the Yucca Mountain Project, we will use this large block of rock to simulate repository conditions and to study the effects of heat, stress, hydrology, and geochemistry.*

to determine the current profile in different regimes of operation. In 1994, we installed eight new channels to measure the edge-plasma current profile.

We are also developing and implementing high-performance communications networks and distributed computing for conducting tokamak experiments from a distant site. This network would allow researchers to work at various national research facilities without having to leave their home institutions.

### The TPX

The Tokamak Physics Experiment is a national initiative—now in the design stage—to demonstrate continuous tokamak operating modes with both high plasma pressure and enhanced confinement. The advanced modes are based on experimental results from present pulsed devices. The proposed TPX facility will provide data that will lead to more compact, economically attractive fusion reactors—including the Demonstration Power Reactor. The TPX is envisioned as a national facility, to be located at the Princeton Plasma Physics Laboratory. It is being designed by a team of researchers from several U.S. fusion institutions (including LLNL), with the Laboratory's Keith Thomassen serving as Program Director.

### The ITER

We have been a major participant in the International Thermonuclear Experimental Reactor—a collaboration among the European Community, Japan, the Russian Federation, and the United States—since the conceptual design began in 1987. Now, during the engineering design activities, we have personnel on both the U.S. ITER Home Team and the Joint Central Team that will design the 1.5-GW facility. We are supporting both the engineering and physics design, have a primary role in the research and development of the superconducting magnets, and are performing additional work on the divertor design and on systems analysis.

### FENIX

The Laboratory's Fusion Engineering International Experiment (FENIX) Facility is the premier test facility for superconductors of the size and type needed for the next generation of tokamaks, such as the TPX and ITER. We have begun testing sample superconductor materials for the ITER from the European Community and Japan. Data from such tests will allow tokamak designers to calculate the performance of system elements using various possible materials. FENIX permits the testing of large samples (5 m long) under realistic conditions, with magnetic fields up to 14 T and currents up to 45,000 A.

### Numerical Tokamak

We continue to develop the theoretical understanding and computer codes needed to interpret and support magnetic fusion research. We are developing a "numerical tokamak," which is a physics-based computational model of an entire fusion device. The model is being made possible only now with the advent of more powerful supercomputers. A national consortium (of which we are a member) has progressed in developing codes to simulate the turbulent transport of energy out of the core of the plasma, a critical problem in fusion research. We have also developed and demonstrated techniques to integrate the output of such codes into a comprehensive simulation.

## Hydrogen as an Alternative Fuel

Hydrogen is a potential vehicular fuel that can be produced from various domestic sources. Its use as a transportation fuel would improve the U.S. balance of payments and increase national energy security. The use of hydrogen would also have environmental benefits because it produces no hydrocarbon, CO, or $CO_2$ emissions when burned.

### Hybrid Hydrogen-Electric Car

In 1994, we designed a conceptual hybrid-electric car that uses hydrogen as a fuel burned in an optimized internal combustion engine, gets the equivalent of more than 90 mpg, has a 300-mile range, and produces far less pollution than a gasoline-powered vehicle. We also developed a hybrid vehicle evaluation code that simulates vehicles made from various components. This code allows us to integrate the infrastructure issues necessary to support a hydrogen-fueled transportation economy, particularly in the transition from gasoline to hydrogen as a vehicle fuel. Our studies indicate that, in addition to having environmental benefits, the high efficiency of hydrogen-fueled vehicles would make their cost competitive with today's gasoline-powered cars.

### Hydrogen from Municipal Waste

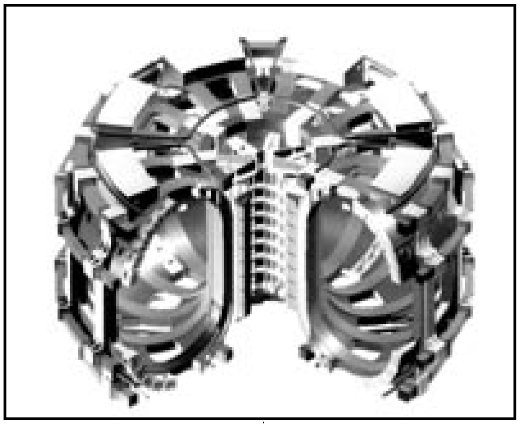
We are working with Texaco Inc. to develop a commercial system for gasifying municipal solid waste to produce hydrogen. Such a process would solve two problems: the effective disposal of significant quantities of waste and the production of an environmentally benign fuel.

### Hydrogen Storage Technologies

Other work involves materials that can be used as effective storage media for hydrogen, either on board a vehicle or for transporting hydrogen between production and utilization points. We are investigating the use of carbon aerogels for on-board use to supplement high-pressure storage. We are also investigating glass microspheres, similar to laser fusion targets, as a practical and safe method to transport bulk hydrogen over long distances.

### Fuel Cells

When fuel cells become more cost-effective, they are viewed as the "right technical choice" for hydrogen-powered electric vehicles (instead of internal combustion engines). In 1994, we began to apply our ultrathin-film techniques to fabricate advanced solid-oxide fuel cells that are more efficient and lighter, and that operate at lower temperatures, making their use more likely in vehicles. This project could result in methods to fabricate fuel cells that have dramatically higher power densities, specific power, and reliability and that have a strong potential for low production costs.



*We are responsible for the superconducting magnet systems for the planned Tokamak Physics Experiment. This will be the first tokamak with fully superconducting magnetic field coils using advanced conductors. This computer model shows the magnets (orange) and the magnet structure and casings (blue).*

## Energy, Manufacturing, and Transportation Technologies

The following sections highlight our technologies in energy production, manufacturing, and transportation.

### Oil Field Imaging

Much of the remaining oil in the U.S. lies within existing fields, but it is currently unavailable because of the geological complexity of the reservoirs. New technology, such as our underground imaging tools, is needed to tap this resource. Our technology uses radio-frequency electromagnetic radiation—and high-resolution imaging software developed in conjunction with industry—to monitor the movement of steam injected underground to enhance the recovery of oil. Our technology can also be used to locate bypassed oil, to monitor saltwater intrusion into aquifers as a result of oil or gas production, and to support environmental remediation. We are testing this technology at an oil field in central California and have a CRADA with an oil-field service company for further developmental work.

### Combustion Research

We developed and tested a computer model for analyzing the combustion in industrial burners and applied that model to the problem of reducing the emissions of NOx, unburned hydrocarbons, and volatile organic compounds. The Clean Air Act regulates the allowed level of such emissions; the model we developed will make it possible to design economical burners that comply with those limits.

In related work, we established a consortium with Sandia National Laboratories, UCLA, and six

*A prototype of our electromechanical battery, which is based on the flywheel concept of energy storage. Top to bottom: the high-speed rotor, the rotor in motion, the enclosed battery.*

petroleum refiners to study emissions from refinery processes. The consortium's work will lead to a better understanding of the combustion processes and to modifications for reducing emissions.

Our work on modeling hydrocarbon combustion in internal combustion engines has received the American Chemical Society's Thomas Midgley Award. The award recognizes our "outstanding research contributions in the field of chemistry related to the automotive industries." This was the first time a national laboratory received this award.

### Electromechanical Battery

We are developing modular electromechanical batteries that are based on the flywheel concept of energy storage. Small modules (1-kWh) could be used in electric or hybrid-electric vehicles, and larger modules (2- to 25-kWh) could be used for power conditioning, load shifting, and distributed energy storage. We expect these modules to have a maintenance-free lifetime of 10 years or more.

Our batteries consist of a high-speed fiber-composite rotor, supported by a magnetic bearing system, integrated with a special ironless generator/motor, and housed in a sealed, evacuated enclosure. One prototype module has been tested at reduced speeds (40,000 rpm) and exceeded a specific power of 8 kW/kg with a measured recovery efficiency of more than 92%.

Power glitches—brief interruptions or surges—are a major problem for facilities with sensitive computer chips. We recently signed a CRADA with Trinity Flywheels Batteries Inc. and Westinghouse Electric Corporation for development and testing of electromechanical batteries to be used in smoothing out the flow of electricity for factories, computer centers, and other facilities. We have also entered into a CRADA with General Motors Corporation for evaluating these electromechanical batteries as part of a system to power future automobiles.

### LVDT Amplifier

We developed a high-precision, low-noise amplifier that measures displacement in high-precision machine parts. This air-bearing linear variable differential transformer (LVDT) amplifier, which received an R&D 100 award in 1994, was developed under a CRADA with Lion Precision, Inc. It can be used by machine tool builders, metrologists, and quality inspection departments. More accurate measurements will help reduce costs and minimize material waste in manufacturing.

### Diesel Engine Inspection

Under a CRADA with Caterpillar Inc. we are developing technologies to monitor and inspect diesel engine components made from both traditional and nontraditional materials. The nontraditional materials—which include ceramics, metal matrix composites, and fiber composites—are used to produce diesel engines that are more efficient and less polluting, and that have a longer service life.

The inspection technologies include computed tomography (CT), digital radiography, and film-based and filmless imaging. In this work, we have optimized medium- and high-energy CT systems to inspect engine components, and we have performed radiographic and CT inspections on 12 different kinds of components. We routinely transfer this technology to Caterpillar, and a prototype system is planned for a Caterpillar production line soon.

### Nondestructive Inspection

For the Federal Aviation Agency, we are developing heat-stimulated dual-band infrared (DBIR) pulsed-thermal imaging technology to quantify corrosion on aircraft. DBIR thermal imaging has potential for developing a fast, safe, noncontact tool for wide-area coverage, thus reducing both the costs and time involved in inspection. We are also studying the feasibility of using DBIR thermal imaging to inspect concrete bridge decks for hidden defects for the Federal Highway Administration. We proved that this technology can determine simulated defects 10 cm deep in an asphalt-covered concrete slab. Our next step will be to design and build a mobile DBIR imaging system to inspect bridge decks from a moving vehicle.

### Partnership for New Generation Vehicles

The Laboratory is a participant in President Clinton's Partnership for A New Generation of Vehicles initiative. All projects involve collaboration with other DOE laboratories and with the Big Three U.S. automotive manufacturers. Our focus is on low-emissions catalysis, NOx sensors and systems (engine management) for diesel engines, advanced composite material modeling, and computational fluid dynamics for combustion analysis, drag reduction, and under-the-hood thermal management.

### Radio-Frequency Vehicle Identification

We demonstrated the feasibility of radio-frequency technology to remotely identify vehicles fitted with electronic tags (i.e., small receivers with read/write capability). A reader sends a signal to activate the tag, which, in turn, sends encoded data back to the reader.

We are assisting the Federal Highway Administration in developing a national vehicle-to-roadway standard for identifying commercial vehicles. This technology can automatically clear trucks at highway speeds upstream from a weigh station.

In partnership with the California Department of Transportation, we developed a prototype system for automating toll collections. Without pausing, the tagged car signals roadside equipment to automatically debit an account for the toll. This system could also be used for on-vehicle probes to provide information about traffic conditions.

### Refuelable Battery for Fleet Electric Vehicles

We are testing a zinc-fueled battery that can provide electric vehicles with a 300-km range, safe acceleration, and rapid refueling in 10 minutes. Because the battery is refueled with user-recycled zinc rather than recharged, it can operate nearly 24 hours a day and requires no commercial infrastructure for support. Zinc particles are gravity-fed to the cells from an internal hopper and react with air to generate liquid zinc-oxide products and electricity. A simple low-cost unit refuels the batteries by hydraulically removing the reaction product from a storage tank in the battery and returning a fresh slurry of zinc particles. The overall energy efficiency of zinc-fueled electric vehicles (with regenerative braking) is roughly comparable to conventional automobiles using gasoline. This battery could increase the feasibility of fleet electric vehicles by increasing their range and allowing nearly continuous use.

### Crash Testing by Computer

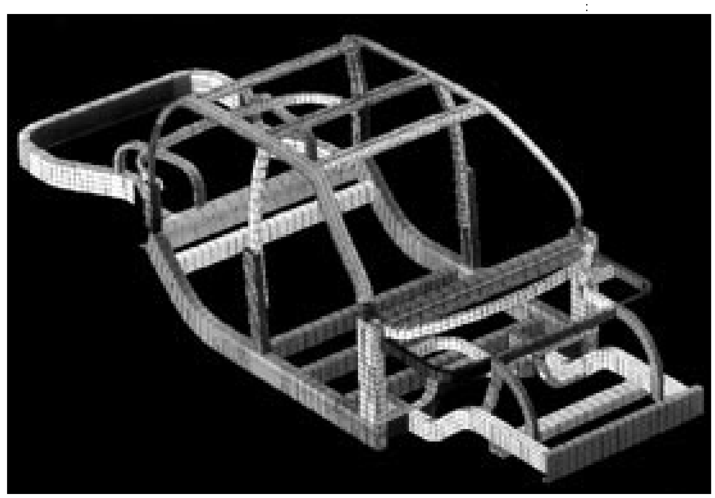
Computer codes that we developed (DYNA3D and NIKE3D) have been used to analyze how vehicle structures react in a crash and to assess the crashworthiness of particular vehicle designs. In conjunction with Kaiser Aluminum and Chemical Corporation and as part of the CALSTART consortium, we are designing and analyzing a crashworthy aluminum frame that could be used for electric vehicles.

## Summary

Our near-term goals include the development of innovative technologies, such as electro-mechanical batteries, that will have a major impact on the nation's transportation industry, and the development of hydrogen as a practical and economical transportation fuel. We will expand our technology base in fission energy and systems safety, applying it to both nuclear and non-nuclear projects. We will also contribute to the national magnetic fusion energy program on the DIII-D, TPX, and ITER projects, with special focus on improving the tokamak concept.

***For further information contact David E. Baldwin (510) 423-1415.***

*We are designing and analyzing a crashworthy aluminum frame that could be used for electric vehicles. We are working as part of the CALSTART consortium and in conjunction with Kaiser Aluminum and Chemical Corporation.*



# Biology and Biotechnology

*Our research in biology and biotechnology serves to improve human health, advance fundamental bioscience, and minimize health care costs through improved prevention and diagnosis of illness and more effective delivery of health care.*

A formal biomedical and environmental research program was first established at LLNL in 1963 to study the radiation dose to humans from radioactive releases into the environment. Primary concerns were from underground weapons testing and Plowshare applications. Since then, the program has responded to changing national needs and new technologies. We still study the environment's effects on humans, but our interests have broadened to include other important national health issues.

Today, the Biology and Biotechnology Research Program provides a scientific foundation for understanding the health consequences of the environment and our use of various energy resources. As our name implies, we develop technological solutions to problems related to health assessment and fundamental biology, usually at the genetic or molecular level. Our research is based on the long-term goals of the DOE, particularly the Office of Health and Environmental Research.Within the Laboratory, which is undergoing a dramatic transition in emphasis because of changing international conditions, biology and biotechnology research is identified as a major growth area.

*Scientist Bart Beeman digitizes an ethidium-bromide-stained agarose gel with a two-dimensional gel image reader, an alternative to capturing the images on Polaroid film. These gels are used for routine DNA analysis.*

## Our Mission

The missions of the Biology and Biotechnology Research Program are to initiate and conduct top-quality basic and applied research in the health and life sciences in support of national objectives; develop and sustain a multidisciplinary, talented, and motivated research team; and ensure the transfer of our knowledge, science, and technology to all sectors, including industry, universities, and the general public.

We strive to serve our customers well in performing our mission. The agencies who fund our work include both industry and our traditional sponsors—the DOE and other federal agencies. We regard these customers as true partners in our research, and we seek feedback from them, our scientific peers, and the public on our direction and performance. We also strive to play a special role in educating the public regarding the scientific basis of our research and the ways in which it benefits them.

## Our Vision of the Next Century

Our planning is driven by our vision of biology and biotechnology as the revolution of the 21st century. A primary driver is the international Human Genome Project, its extensions to other species, and its applications to improving health, agriculture, the environment, and the economy. The DOE has played a founding role in this initiative, and LLNL has been involved from the outset. We aim to retain our existing expertise in cellular and molecular biology of DNA, as well as strengthen other areas for future needs. With that framework, we will enter the next century equipped with a creative, flexible, and diverse workforce able to confront changing scientific priorities.

Building for the next century, we will add at least three additional competencies: assessing protein structure and function, characterizing human variation in relation to induced mutation and disease, and applying our existing expertise in the health sciences, physical sciences, and engineering to develop new, cost-effective, health-care technologies. The first two competencies will draw on the information, materials, and technologies developed by the human genome project. The third will depend upon the expertise of the entire Laboratory, especially skills that were first developed in the defense programs. We expect these competencies to enable us to extend the scope of our research to agriculture and the environment.

## Core Competencies and Research Objectives

Our existing core competencies are in molecular genetics and genomics, DNA repair, human mutation assessment, molecular toxicology, bioinstrumentation, and bioinformatics. They are embedded in all our research projects. Our global scientific objectives are to:

- Understand the nature of genetic organization and unravel the genetic code in appropriate organisms as necessary to study the consequences of adverse environments on living systems.
- Identify, isolate, and characterize the genes that can repair DNA damage and understand their role in damage prevention or amelioration.
- Develop and apply methods to assess the risk to humans from exposure to radiation and chemicals.
- Develop and apply biophysical techniques to understand protein structure and function.
- Couple our bioscience strengths to health care needs.
- Develop industrial partners to transfer the results of our science and technology to the commercial sector.
- Transfer our knowledge and experience to industry, the academic world, and the general public through research activities and education at all levels.

Technology transfer has a high priority. We foster a team research environment internally and encourage collaborations worldwide. In the Human Genome Center alone, we maintain well over 150 active collaborations. We also have several interactions with industry, many of which have resulted in licenses, material transfers, or CRADAs. Collaborative research areas include flow cytometry, diagnostic antibodies, DNA

### Highlights for 1994

- Continued constructing a high-resolution physical map of human chromosome 19. To date, 80% of the chromosome has been spanned by ordered elements. More than 300 genes and markers, including more than 40 of the highly informative genetic markers, have been assigned to cosmids and localized on the map.

- Cloned a gene involved in the first autosomal linkage. This knowledge is useful in cell surface recognition.

- Developed a method to automatically integrate a dozen types of DNA physical mapping data into a global ordered map.

- Completed the sequencing of more than 240 kilobase pairs of human chromosome 19 from cosmids. These include the chromosome regions surrounding three DNA repair genes and the corresponding regions in the mouse genome.

- Completed a high-resolution map for a 700-kilobase-pair region on chromosome 19 encompassing the pregnancy-specific glycoprotein gene family.

- Identified defects (a necessary first step in repairing DNA damage) in one of the XP gene cells from xeroderma pigmentosum group D and sun-sensitive trichothiodystrophy patients.

- Developed a new diode-laser-based flow cytometer, which incorporates a novel detection system and allows for perpendicular and forward light-scatter measurements, potentially useful in a clinical environment.

- Developed a prototype DNA sequencing instrument to increase throughput 40- to 100-fold and signed a CRADA for commercialization.

- Showed that by coupling high-performance liquid chromatography with AMS, we can quantitatively measure metabolites of potential mutagens at levels as low as $10^{-19}$ moles.

- Developed chromosome painting probes for the mouse and rat for quick and simple microscope analyses.

- Identified the probable cause for the inactivity of the enzyme lactate dehydrogenase.

- Predicted, with computational biological techniques and biophysical measurements, the three-dimensional structure of the PhIP molecule and a segment of DNA containing the adduct.

*Molecular biologist Stephanie Stillwagon loads a DNA sample into an automated DNA sequencer as part of the Human Genome Project. Researchers are also working with an industrial partner to build the next generation of such instruments.*

primers, chromosome painting probes, electrophoresis, and bioanalysis software.

We have provided materials, know-how, and the use of our facilities to qualified scientists, students, and teachers. In 1994, we sponsored more than 50 students and 35 visiting scientists. Most students enter through our summer program; others are in residence to attain an advanced degree at one of our collaborating universities. Our Institute of Genetics and Genomics is the conduit to the university environment.

We believe that a diverse workforce is a most important investment for the future. In 1993, we received an award from the Director of the Laboratory for our diversity efforts.

## Genomics

Genomics is the study of the organization and function of genetic material, that is, DNA. Our interest revolves around the goals of the international endeavor to construct physical maps and sequences for the human genome. We are focusing our attention on developing resources in molecular biology, computations, and instrumentation to support these goals. Our unique contributions include chromosome-specific libraries, fluorescence in-situ hybridization techniques to paint whole chromosomes and measure distances along DNA, mapping software, new DNA-sequencing instrumentation, robotics for laboratory automation, and flow systems for analyzing and purifying cells and chromosomes.

So far, we have concentrated on the construction of a high-resolution cosmid map of chromosome 19. Cosmids are relatively small, cloned fragments of DNA. With this phase of the project nearing completion, greater emphasis will be placed on validating the map, completing the fine-structure mapping, finding the estimated 2000 genes on this chromosome, and determining the sequence of the nucleotide bases, or chemical units, within the cosmids along the chromosome. When we began mapping in 1987, only 55 genes or other types of DNA segments had been linked to chromosome 19. We have now located more than 300 genes or genetic markers on chromosome 19, including the structural defect associated with the muscle disease myotonic dystrophy. As the next step in our long-term effort, we are planning to dramatically increase our efforts in DNA sequencing. We have already sequenced more than 240 kilobase pairs of chromosome 19, including the DNAs and genomic regions associated with three human DNA repair genes.

We consider two major applications of the Human Genome Project to be of particular interest to DOE: structural biology and the characterization of human genetic variation. Consequently, we are working in structural biology to take advantage of the information available from the genome project and other efforts in our program. Identifying all the genes and their protein products should provide an economic incentive for industries interested in developing specific pharmaceuticals. Regarding genetic variation, we have identified unique repeating sequences of DNA that can discriminate among some human groups and can thus be applied in forensic analysis. We are exploring new methods to rapidly assess mutations in humans using automated approaches to determine the underlying DNA sequence. As our technologies advance, we envision applying our mapping and sequencing strengths to microbes of importance in basic research, plants that are valuable in the energy cycle or potential agricultural crops, and animals whose genomes remain unexplored.

## DNA Repair

We are especially interested in those genes that increase susceptibility to disease. One family of such genes includes those that repair DNA damaged by exposure to radiation or chemicals. Repair plays a critical role in reversing environmental damage that can lead to cancer or birth defects, and it is closely intertwined with other aspects of DNA metabolism. DNA can be damaged by strand breaks, oxidized bases, and chemical adducts arising from exposure to sources of ultraviolet and ionizing radiation (including radon) and a multitude of chemicals associated with fossil energy and other technologies. DNA repair acts on these kinds of damage, plays a critical role in the response of tumor cells to radiation and chemical agents, and probably helps to retard the aging process.

As a participant in the international genome study, our goal is to identify and clone the human genes that determine repair. The cloned genes become the key for overproducing and purifying repair proteins so that their biochemical mechanism of action can be determined. We want to understand whether certain repair genes are the rate-limiting factor in cellular resistance to radiation and chemical exposure, although we recognize that there is likely to be wide variability in the repair capacity among individuals. Our major emphases are on identifying new repair genes, purifying and analyzing repair proteins, understanding the role of these proteins in human diseases, and creating new strains of mice (transgenic mice) in order to study human repair disorders.

We are relating the DNA repair genes to human genetic diseases in which repair is faulty, particularly the xeroderma pigmentosum (XP) gene. Xeroderma patients are extremely sensitive to sunlight and are at high risk for skin cancers. We have identified mutations in one of the XP genes (D) of several affected individuals, and we have cloned another gene (ERCC4) that is a good candidate for a different clinical form of xeroderma pigmentosum. We have also cloned a third DNA repair gene, XRCC1. Defects in this gene increase a cell's susceptibility to damage from ionizing radiation.

## Molecular Toxicology and Human Risk Assessment

We also are developing techniques to estimate the biologically relevant exposure to genotoxic agents, carcinogens, and mutagens as a step toward estimating risk. The biomarkers or surrogates currently being used in human studies include the classical cytogenetic endpoints of structural aberrations and sister chromatid exchange. The newer chromosome-painting techniques are also being used to identify persistent translocations long after exposure. Using the painting technology for high-speed measurement will allow us to obtain data on more individuals and to estimate the damage following low-dose exposures. Chromosome painting has also been developed for use in mice, further enhanced by multicolor painting techniques. The mouse models should allow us to look at specific factors that affect cytogenetic damage (i.e., metabolism, repair, exposure) that might be manifest in humans as genetic differences in susceptibility.

Biomarkers developed at LLNL have been combined with those developed by others in coordinated multiple-end-point epidemiological studies (funded by the National Institutes of Health) to quantify the exposure in several populations, including smokers, pesticide workers, and "liquidators" (cleanup workers) from the Chernobyl nuclear power plant accident. Such studies are becoming more closely linked to health consequences, cancer, and pregnancy outcome. These analytical techniques will continue to be key components of efforts to estimate the potential health consequences of population exposures.

We have enhanced our ability to predict low-dose effects from chemical exposure using LLNL's accelerator mass spectrometer (AMS) and have initiated experiments to couple the measured exposure to biological outcome. This method is sensitive enough for us to measure $^{14}$C-labeled adducts following dietary intake of food-mutagens by mice at levels that are equivalent to the normal dietary intake for humans. We have expanded our AMS studies to quantify low-level exposures to

*Mechanical engineer Don Masquelier works on a miniaturized flow cytometer, which uses fiber-optic data collection inside the flow stream. Compared with conventional flow cytometers, this instrument's novel signal-detection system yields a signal that is less noisy and an order of magnitude stronger.*

Biomedical scientist Ed Salazar loads DNA samples into an agarose gel for analysis. He is working as part of the DNA Repair Group on a repair gene called ERCC2, which is involved in one form of the disease xeroderma pigmentosum.

benzene. A significant part of these studies is the linking of new technologies such as AMS to traditional separation methods such as electrophoresis. We have used this approach to show that benzene is associated with the spindle fibers needed for DNA replication and may be responsible for cytogenetic damage through its ability to bind specific critical proteins. This finding is possible only because of the ultrasensitivity that AMS brings to these types of measurements. Also, as previously mentioned, many researchers are interested in using AMS technology to monitor low-level presence of chemicals in environmental samples and in humans. This use has been demonstrated for benzene, drugs, heterocyclic amines, and pesticides in rodents and for heterocyclic amines in monkeys.

## Structural Biology

A new effort in structural biology has been initiated to expand our program's capabilities in three-dimensional structure analysis of proteins, nucleic acids, and the complexes they form with each other and with other molecules. This effort is relevant to DOE's growing interest in structural biology and to the increasing national interest in identifying how defects in molecular structure cause cancer and genetic disease. The research is expected to support the human genome effort by producing the tools needed to predict the structure (and possibly the function) of proteins that belong to many of the gene families for which DNA sequence information is becoming available.

Our initial efforts have focused on resolving the structures of several different types of molecules, including chemical mutagens that bind to and damage DNA and proteins that repair damaged DNA, inactivate entire genomes, and replicate the DNA molecule. Studies of small chemical mutagens such as PhIP, a heterocyclic amine produced when foods are cooked, employ computational and other methods to predict the physical structure of the molecule and reactive intermediates, identify the structure of the complex it forms with DNA, and determine how such molecules damage DNA and cause cancer.

We are using various forms of spectroscopy, computer modeling, and x-ray diffraction to resolve the unusual structure adopted by a small, highly charged protein (protamine) when it binds to DNA, so we can determine how it inactivates all the genes and understand how defects in the process cause male infertility and early fetal deaths. Homologous modeling methods are being used to predict the structure of unusually thermostable enzymes, such as a DNA polymerase isolated from *Thermus aquaticus*, and inactive enzymes, such as the Guaymi Indians' variant of lactate dehydrogenase, and to discover how changes in protein structure modulate its function. In the future, many of these same techniques will be applied to the analysis of a whole series of proteins that repair damaged DNA.

The results of this work will help explain the mechanisms responsible for DNA adduction by small molecules, increase our understanding of how molecular lesions lead to mutations and

Biomedical scientist Cindy Thomas (left) and summer student Sarah Henson remove samples from a liquid nitrogen tank. Viable cells are routinely frozen for later use as part of epidemiological studies to quantify damaging exposures in several populations, including smokers, pesticide workers, and "liquidators" (cleanup workers) from the Chernobyl nuclear power plant accident.

cancer, provide new tools for predicting the structure (and possibly the function) of many proteins of interest to the medical community, advance our knowledge of what structural features of the DNA-protamine complex are essential for male fertility, and provide new information about the molecular structure of the enzymes that synthesize DNA.

## Technology Development

During the last year, we have increased our emphasis on technology development, which we see as a mechanism for accelerating all our research. Our technologies focus on aspects of molecular biology (e.g., vector development), molecular genetic applications (e.g., chromosome painting and high-resolution fluorescence in-situ hybridization), software development for database interaction, networking in a client–server mode, and bioinstrumentation. Our emphasis in bioinstrumentation has been to improve methods for analyzing cells and chromosomes by flow systems, image analysis for cytogenetic automation, robotics for automating microbiology and chemistry techniques, and microfabrication technology to create miniaturized chambers for high-throughput chemical analysis and increased throughput and sensitivity of electrophoresis for DNA sequencing. Many of these technologies have been transferred to other laboratories and to industry.

## Center for Health Care Technology

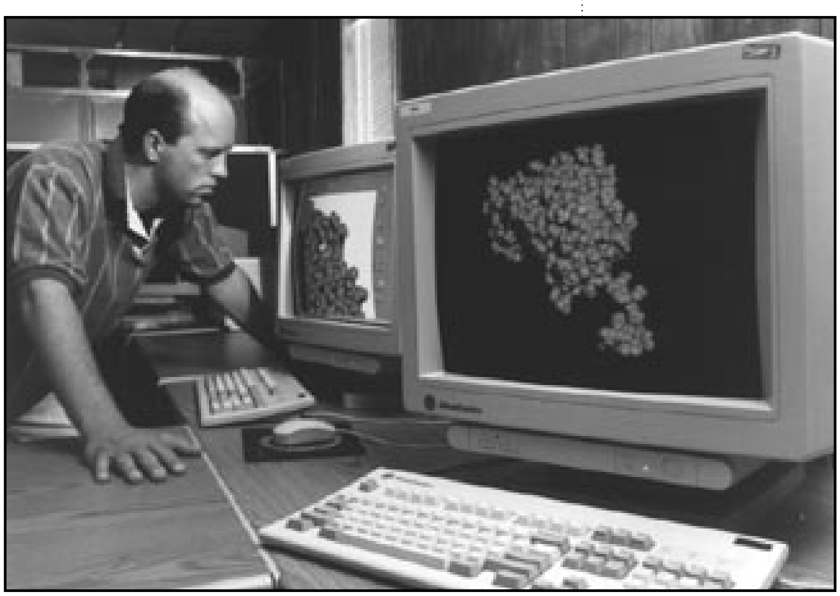
Industry and medical facilities are becoming increasingly interested in receiving assistance from LLNL in developing new technologies that can be used in medicine and health care. At the same time, the downsizing of defense programs has created a growing interest on the part of the involved scientists and engineers in applying the expertise developed in defense projects to the health care field. LLNL's Health Care Center, which serves the entire Laboratory, grew out of this mutual interest. Currently funded projects include an NIH-sponsored effort to use x-ray tomography to examine osteoporosis. We also are developing microsurgical tools for insertion in catheters, imaging methods and hardware to improve laparoscopic surgery, innovative hardware and software for mammography, and software and networking tools for medical information management and transfer. Lacking, however, is the coordination needed to minimize redundancy, provide a strong and unified image to potential partners and sponsors, and market ideas and attain long-term funding. The Center was formed to fill this need.

## Summary

Our goals have broadened considerably to align with the changing priorities of the DOE and changing national and global needs. Our present programs cover many aspects of biotechnology research, including molecular genetics and genomics, molecular toxicology, instrumentation development, and health care technology development.

***For further information contact Tony Carrano (510) 422-5698.***

*Biophysicist Nick Hud uses sophisticated molecular modeling algorithms to better understand interactions between DNA and other molecules. The results are displayed graphically. Computer modeling is one of several tools used by scientists in the Structural Biology Group.*



# Engineering

*We are supporting Laboratory programs, industrial competitiveness, and national needs by turning scientific ideas into working technology.*

Engineering focuses its efforts on developing the staff, tools, and facilities needed to support current and future LLNL programs and technologies critical to the nation. These efforts are guided by a dual-benefit research and development strategy that encourages nuclear deterrence to enhance national security and partnerships with U.S. industry to increase economic competitiveness.

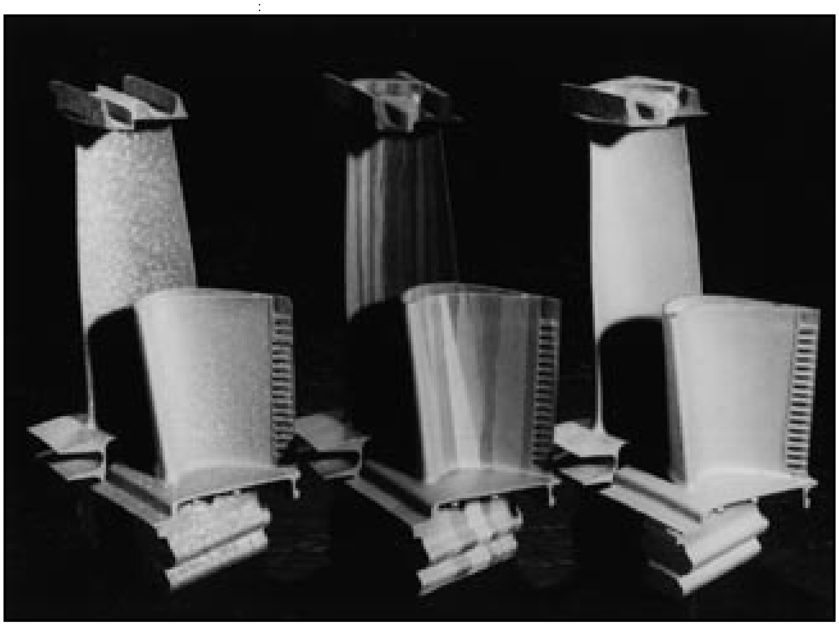
The engineering personnel who design, fabricate, test, and install prototype systems to support LLNL programs are skilled in many disciplines. These broad skills allow them to work on projects throughout the Laboratory. The cutting-edge technologies they develop in doing these projects often suggest new programmatic directions. At the same time, new programmatic goals may stimulate ideas for engineering research and development.

Engineering's efforts are organized into seven integrated activities:

- Computational electronics and electromagnetics.
- Computational mechanics.
- Diagnostics and microelectronics.
- Fabrication technology.
- Materials science and engineering.
- Nondestructive evaluation.
- Power-conversion technologies.

As a natural outgrowth of our work with unique materials, microelectronics, and ultrahigh-precision machining, we have developed a spectrum of special facilities. They include facilities for materials fabrication, nondestructive evaluation, materials development, measurement and endurance testing, and microelectronics fabrication.

*Turbine blades cast using (from left) the equiax (randomly grown, equisized crystals), polycrystal (unidirectional crystals), and single-crystal (one unidirectional crystal) processes.*



## Computational Electronics and Electromagnetics

Computational Electronics and Electromagnetics develops and implements theory and techniques into codes for analyzing electronic and electromagnetic phenomena. We also focus on the design of electrical devices. In 1994, we assessed the performance of high-speed interconnects, developed techniques for millimeter-wave sintering of ceramic materials, and used electromagnetic tomography to characterize reservoirs for oil-well logging. Under the auspices of the Department of State, we also collaborated in microwave electronics with institutes and companies in the former Soviet Union.

We have joined in cooperative research and development agreements (CRADAs) with industry to develop components for communication electronics, opto-electronics and photonics, and microwave heating systems for magnetic fusion energy. Internationally, we participate in Europe's 1-MW Free-Electron-Maser experiment. We also analyze and design components for high-current particle accelerators for fusion energy and radiography, analyze defects in laser mirrors for the proposed National Ignition Facility, and perform electromagnetic interference and radar cross-section computations for electrically large structures such as aircraft.

### Parallel Mesh Generation

We are moving our three-dimensional simulation codes to massively parallel processors. The task of generating the meshes needed for simulation belongs to the Parallel Mesh Generation project, which is developing a code to construct large (up to 1 billion elements) polyhedral meshes. When completed, it will support three-dimensional physics codes for electromagnetics, structural mechanics, thermal analysis, and hydrodynamics and significantly enhance LLNL's capabilities in physical simulation.

## Computational Mechanics

Computational Mechanics develops general-purpose software for heat transfer and for solid, structural, and fluid mechanics. This software has achieved international fame as part of our collaborators program. The codes have also formed the basis for several technology transfer initiatives and were extended to industrial uses in casting, metalforming, and automobile crash dynamics. They continue to be the cornerstone of support for LLNL programs.

In FY 1994, we worked on ParaDyn, our next-generation solid/structural mechanics code, which will be used on massively parallel computers and extend performance from gigaflop to teraflop power. We also moved DYNA3D, our best-known code, to the Meiko CS-2 256 parallel processor, emphasizing research into parallel algorithms for automobile crash dynamics; did a comprehensive seismic analysis of the Dumbarton Bridge for Caltrans; perfected the simulation of superplastic forming of metals in NIKE3D for two CRADAs; and demonstrated the PING code for large-scale acoustics simulation on the Cray YMP, later moving it to the Cray T3d for an even larger simulation.

### Casting Process Modeling

We are working with Howmet Corporation and UES, Incorporated, to develop a single computer code to predict the strength, porosity, deformation, and shape of cast metal parts (such as aerospace alloys) prior to casting. Our NIKE and TOPAZ codes are currently used with the UES-developed ProCAST code for fluid–thermal–mechanical analyses of the process for casting turbine blades for jet engines. Howmet, which produces such blades, is supplying experimental casting data for software validation. When completed, this effort should improve casting quality, reduce manufacturing time and design costs, and improve Howmet's competitiveness in the international aerospace industry.

## Diagnostics and Microelectronics

Diagnostics and Microelectronics concentrates on microfabrication-based technology (largely using semiconductor materials) such as gallium-arsenide and silicon microelectronics. This includes miniature electrophoresis channels for DNA analysis, polymerase chain-reaction chambers for DNA replication, and miniaturized flow cytometers. It also includes diagnostics for environmental and health-care uses and microtools for endovascular techniques.

## Highlights for 1994

- Developed parallel mesh generation to construct polyhedral meshes on massively parallel computers.
- Combined our NIKE and TOPAZ codes with an industrial modeling code to analyze casting of jet-engine turbine blades.
- Developed in conjunction with Biology and Biotechnology a flow cytometer to sort biological cells via light scattering, using a semiconductor diode laser as a light source and a silicon photodiode/preamp module as a detector.
- Developed smart microtools for minimally invasive intravascular surgery.
- Designed a diamond grinding wheel for glass optics and ceramic parts.
- Devised an accelerated lifetime methodology to predict and enhance fiber-polymer composite strength and durability.
- Developed a cheaper, safer radioactive-waste-drum inspection system to eliminate radiation risk.
- Developed nondestructive procedures to evaluate materials for automobile engine parts.
- Produced a compact power source for solid-state laser-diode arrays.

At LLNL's Microtechnology Center, we design and build microanalytical instruments, micromechanical sensors and actuators, and semiconductor diode lasers and optical amplifiers. We also build electronic and photonic devices for high-speed transient data acquisition in biology, biotechnology, health care, and nuclear nonproliferation.

### Flow Cytometer

We replaced the ion-laser light sources in flow cytometers (which use light scattering to classify and sort biological cells) with semiconductor diode lasers and substituted silicon photodiode/preamp modules for their photomultiplier-tube light detectors. We also invented (patent pending) a method for collecting right-angle-scattered light by trapping it in the liquid flow stream, which acts as an optical waveguide, and allowing it to propagate through a fiber optic to the silicon-based light detector. This method increases the signal by an order of magnitude, produces less background noise, and is two to three times more accurate.

*With 1 to 2 volts of input power, this 400-μm-long intravascular microtool from the Microtechnology Center will curl up and stretch out in liquid. The Center's ongoing research into microscale actuators includes their use in areas such as optics, biomedical instruments, and micropart packaging.*

### Intravascular Microtools

We are working with the UC San Francisco Medical School to develop smart microtools to improve minimally invasive intravascular techniques. Our efforts focus on fabricating and demonstrating microtools that incorporate robotic steering, microactuation mechanisms, and sensors. We are also attempting to improve the imaging ability of commercially available intravascular imaging systems with enhanced computer-vision algorithms. This work is expected to produce smart intravascular catheter systems for remote therapeutic intervention.

## Fabrication Technology

Fabrication Technology focuses on building a manufacturing technology base adequate to conduct future Laboratory business. We are studying and characterizing fundamental fabrication processes, building general-purpose and fabrication models, and transferring technology to LLNL programs and industry. We also have relationships with industry and academia to advance our collective understanding of fabrication processes. Our niche, however, will continue to be precision engineering.

We sponsored three projects in FY 1994. The first was in molecular modeling technology, which helps us understand fabrication processes on the scale of atoms and molecules. As precision processes continue to be refined, the molecular level will define our ultimate limits of precision. The second project characterized the limit to which a commercial double-sided lap process can generate flat optical components, which prepared us for purchasing flat components for the proposed National Ignition Facility. In the third, we used a diamond–metal composite to develop a single-layer, precision, diamond grinding wheel.

### Diamond Grinding Wheel

A programmatic need for a precision grinding tool to manufacture glass optics and ceramic parts led to a diamond grinding wheel. This wheel has a single layer of fine diamond powder chemically attached to a substrate of high precision and complex shape. We have already produced several wheels using commercially available diamond powder in the 6- to 12-mm size range. Analyses show a single layer of diamonds uniformly dispersed over the resulting surfaces. This success has led to four more grinding wheels and several prototype cutoff saw blades for test and evaluation.

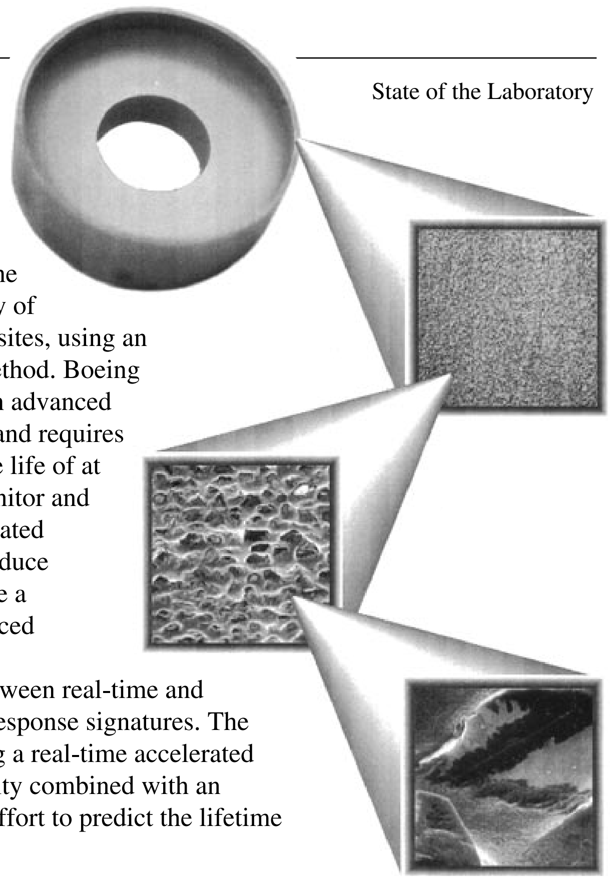
## Materials Science and Engineering

Materials Science and Engineering studies relationships between the processing, structure, and properties of materials of interest to LLNL and industry to enhance our understanding of the physical and mechanical behavior of structural materials. We use LLNL finite-element codes in an iterative fashion to further our capabilities in material processing, particularly composites (such as metal-matrix and polymer composites) and superplastics (crystalline solids capable of extremely high elongations).

In FY 1994 we achieved diffusion bonding of Aluminum 7475 concurrently with superplastic forming in a low-pressure argon atmosphere. We also characterized the metal/ceramic interface of $Al/Al_2O_3$ by measuring the interface strength and toughness of specimens prepared by ultrahigh-vacuum diffusion bonding. We studied the lamination process of two metal composites, one made of ultrahigh carbon steel and brass and another made of Al 5182 and Al 6090 (with 25% SiC particulate for strength), which were prepared by hot-pressing alternate layers in an argon gas atmosphere. Then tensile properties and fracture toughness were measured and correlated to processing conditions, such as surface treatment, relative volume fractions of component materials, and heat treatments. We also designed and built a biaxial gas pressure apparatus, which we are using to examine the effect of hydrostatic pressure on cavitation and thinning characteristics of superplastic aluminum alloy 7475.

### Continuous Fiber–Polymer Composites

We joined Boeing Commercial Airplane Group in a five-year, $18.5-million CRADA to predict and enhance the strength and durability of fiber–polymer composites, using an accelerated testing method. Boeing uses these materials in advanced aviation applications and requires them to have a service life of at least 13 years. To monitor and verify that our accelerated method does not introduce artificial aging, we use a combination of advanced techniques to develop comparative maps between real-time and accelerated material response signatures. The focus is on developing a real-time accelerated materials testing facility combined with an integrated modeling effort to predict the lifetime material response.



*Single-layer diamond grinding wheel. The photographs show the uniform distribution of diamond powder (low magnification, top), the swarf relief that surrounds it (medium magnification, middle), and the good metal-matrix-to-diamond bonding (high magnification, bottom).*

## Nondestructive Evaluation

Nondestructive Evaluation provides cutting-edge technologies for the advancement of inspection tools. We inspect finished parts and complex objects to detect flaws and fabrication defects and to determine their physical and chemical characteristics. We also design sensors and monitors for process control and in-service damage.

In FY 1994, we converted three-dimensional tomographic data for CAD/CAM systems and produced dimensional measurements with a semiautomated reverse engineering process that provides rapid turnaround for prototyping and manufacturing parts. We are also developing infrared computed tomography to find hidden corrosion. Using a technique that detects small temperature differences from heat-flow anomalies, we can predict airframe, bridge-deck, and pipeline damage before it occurs. We have already shown the feasibility of using a dual-band infrared system for concrete bridge-deck inspections. Furthermore, we have been working with ultrasonic evaluation, which uses sound waves to detect flaws or anomalies and to identify material parameters. We have looked at replacing traditional ultrasonic nondestructive evaluation with a laser-generated ultrasonic method, which has potential to measure material parameters and shapes during in-process manufacturing and allows remote, noncontacting evaluation to be performed in a furnace or kiln.

### Waste-Drum Inspection

We are working with Bio-Imaging Research, as well as with LLNL's Nuclear Chemistry and A-Division and UC San Francisco, on a drum inspection system called waste-inspection tomography (WIT). This system will allow inspectors to look into but not open the hundreds of thousands of drums of radioactive waste produced by the government, industry, hospitals, and universities. Currently, these drums must be inspected before they can be transported from temporary sites to permanent storage, but opening them costs $10,000 to $100,000 per drum and entails the risk of radiation exposure to inspectors and the environment. WIT, in contrast, could reduce inspection costs to $250 to $400 per drum and eliminate radiation releases.

WIT will allow inspectors to measure internal drum radiation to identify and find radioisotopes, determine the presence and volume of waste items, and locate nonradioactive materials such as gloves and beakers. It will also be faster than noninvasive radiographic inspection techniques and provide sharper, three-dimensional images of the drums' contents. Further, it should satisfy regulatory requirements for treating, shipping, and permanently storing radioactive waste.

### Evaluation of Lightweight Materials

General Motors is evaluating new lightweight materials, particularly metal-matrix composites, as alternatives to cast-metal parts for automobile engines. We have recommended nondestructive evaluation methods for production-line testing in the manufacturing environment. To screen every part that passes through the production line, these methods must be fast, rugged, inexpensive, and reliable. We will also design a production-line ultrasonic scanner to detect unacceptable porosity in the earliest possible manufacturing stage.

## Power-Conversion Technologies

The microwave and pulsed power group changed its name to Power-Conversion Technologies to reflect its expanded emphasis and scope to address more power-conversion issues. At the same time, we began developing new technologies to prepare our engineering directorate


*A waste-inspection tomography unit allows inspectors to measure the radiation inside drums without opening them. The unit provides sharper images than other radiographic techniques and is safer and less expensive.*

to meet future program needs and to help solve national problems related to the efficient use of electrical power. We focus on the use of advanced power electronics, energy storage, and dense packaging technologies, emphasizing ways to improve compactness, efficiency, cost, and reliability for future power-conversion technologies.

We support several technologies to align with LLNL programmatic interests and potential industrial collaborations. In the ground-penetrating imaging radar project, we are developing impulse radar technologies to inspect roadbeds and bridge decks for construction flaws and age- or wear-related degradation. In the ferroelectric emitter project, we are evaluating ferroelectric materials as new electron beam sources for Site 300's FXR accelerator. For the high-gradient insulator project, we are examining the application of "micro-stack" insulator technologies for very compact, high-voltage generator designs. In the compact power-source project, we are developing a compact, solid-state power source for driving solid-state laser diodes.

### Compact Power Supplies

High-power laser-diode arrays are finding application in areas from advanced manufacturing to medicine. Unfortunately, power for such arrays has been supplied by one large power source external to and isolated from the array, which is too cumbersome to be practical. To correct this, we are developing a standard power source that is simple to operate, efficient, compact, cost-effective, and integral to the diode array. By integrating laser diodes and local decision-making capability with a solid-state power control called MOSFET (metal-oxide semiconductor field-effect transistor) and an insulated-gate bipolar transistor, we produced a "smart" power source that can respond quickly to changes in temperature or fault conditions, which will preserve performance, protect the diodes, and improve diode products.

## Personnel Development

Our directorate joined Stanford University, UC Davis, and CSU Chico in 1971 to set up a two-way instructional television program for LLNL and Sandia engineers. It is transmitted on 29 color channels to 500 LLNL locations and affiliated with the National Technological University. Through the program, UC Davis has awarded 100 graduate (M.S. and Ph.D.) degrees; Stanford and CSU Chico have also issued many graduate degrees.

In addition, we sponsor more than 60 on-site courses in current and new technologies. The latest group of classes helps managers, investigators, and administrators better understand program development. During FY 1994, we had a total of more than 12,000 participants.

We also completed a pilot mentoring program with 16 mentoring pairs and expanded the program in September 1994. Our goals are to fully use all engineers, increase awareness of diverse workforce needs, enhance new employees' knowledge and abilities, and provide career tools. Most program graduates learned more about career steps and department resources; others improved their listening skills and ability to use constructive criticism.

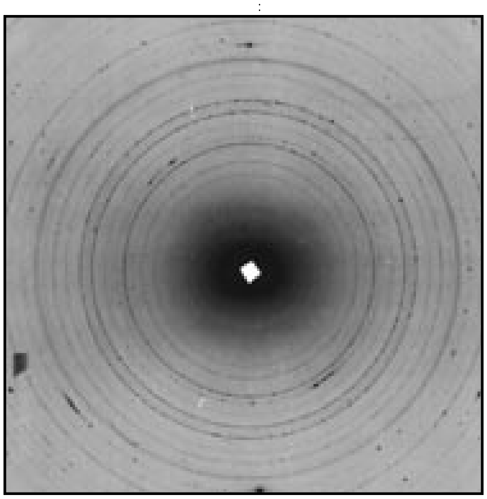
***For further information contact***
***Dave Pehrson (510) 422-8351.***

# Physics and Space Technology

*In 1994 we made important progress in many areas, including condensed matter physics, plasma processing, nuclear science and technology, atomic physics, and space science and technology.*

Physics at the Laboratory originated as a pursuit of long-term research in the behavior of nuclear explosives. Space technology at the Laboratory originated in research and development for the Strategic Defense Initiative. Today, Physics and Space Technology encompasses a range of activities, from fundamental research to advanced technology development, that are relevant to the broadened mission of the Laboratory. Included are the maintenance of a safe, reliable U.S. stockpile; enhanced efforts in nonproliferation, treaty verification, and counterterrorism; the design of inertial confinement fusion experiments leading to the National Ignition Facility; and contributions to U.S. industrial competitiveness. Some areas of current emphasis are summarized below.

*The angle-resolved diffraction pattern of laser-heated silicon in nitrogen at 1400 K and 2 GPa, showing a formation of b-$Si_3N_4$. The b-$Si_3N_4$ can be recovered at ambient condition. The diffraction pattern was obtained using an image plate detector and monochromatic x rays at the Stanford Synchrotron Radiation Laboratory.*



## Physics of Materials

There is increasing interest in the creation of materials with novel properties, including enhanced energetic content, superhardness, and useful electronic or optical characteristics. We are engaged in designing such materials using supercomputers and synthesizing them under high pressure and temperature. We work at the atomic level to optimize the properties of these materials for specific applications. A combined theoretical and experimental effort in shock and high-pressure physics has determined the equation of state of materials under unusual conditions.

### Optical Properties of Lead Fluoride

The need to efficiently detect gamma and x rays in medicine, health and safety, and nonproliferation has motivated a search for new scintillator materials with improved radiation-detection capabilities. Lead fluoride ($PbF_2$) may be such a material. We are studying its dynamical and electronic properties. We have experimentally verified that $PbF_2$ transforms into an alternative phase with increasing pressure, and we have recovered it as a stable compound at ambient conditions. Our theoretical work suggests that structural imperfections are responsible for the observed scintillation in this phase of $PbF_2$.

### Temperature of Shock-Compressed Hydrogen

We measured the temperature of shock-compressed liquid hydrogen and deuterium for the first time. Our results may significantly affect target designs for inertial confinement fusion. While the temperatures of singly shocked $H_2$ and $D_2$ agree well with previous models up to pressures of about 20 GPa, reshocking these fluids at pressures up to 85 GPa and temperatures of over 5200 K produces shock temperatures that are significantly lower than predicted. The molecules absorb energy to break the bonds between the atoms; the absorption of energy reduces the temperature. Our new theoretical model correctly accounts for the dissociation of molecular hydrogen and deuterium at these extreme conditions.

### Laser Heating Materials at High Pressures

We have applied x-ray diffraction techniques to materials laser-heated at high pressures in a diamond-anvil apparatus to study their structure at pressures and temperatures far beyond the reach of other technology. For example, we discovered a new phase of iron at 2000 K and 40 GPa, and we demonstrated the metastability of the existing iron phase. These results imply that the iron phase diagram needs major modification and provide a crucial constraint for models of the Earth's core. We have also applied the technique to synthesizing superhard materials and metastable energetic phases. We have found the direct reactions of nitrogen with the light elements beryllium, carbon, and silicon. Some of these reactions yield technologically important nitride ceramics; others are very energetic.

## Plasma Processing

LLNL's plasma processing program has two major goals: to discover and demonstrate the role of ionized gases in the destruction of hazardous gases and to develop new methods of using plasmas in materials processing, with particular emphasis on dry etching of semiconductors.

### Diesel Engine Exhaust

We have collaborated with the Cummins Engine Company to demonstrate that nonthermal plasmas, by producing radicals that react with unwanted molecules, can reduce the nitric oxide in diesel engine exhaust. Since no after-treatment systems are currently available and tuning engines for low nitric-oxide emissions penalizes fuel efficiency, a commercially viable plasma cleaner would significantly improve diesel engine technology. Research is under way to reduce the energy requirements of the plasma cleaner and to produce acceptable byproducts. Working in collaboration with the Pacific Northwest Laboratory, we have shown that similar techniques can destroy volatile organic compounds, such as chlorinated hydrocarbons, and we have compared the relative efficiency of several plasma devices.

### Large-Area Plasma Processing Reactor

The performance of semiconductor devices has been rapidly improved by simultaneously shrinking the individual features in silicon chips and increasing wafer size. Replacing wet etching techniques with plasma reactors has improved process control while reducing the use of toxic chemicals. We have been working with AT&T, IBM, and Sematech to develop processes using high-density reactors, based upon U.S. technology, to compete with the electron-cyclotron resonance machines marketed by the Japanese. We have constructed a large-area (75-cm-diameter) radio-frequency inductive reactor that permits a fourfold increase in processed wafer area and also accommodates flat panel substrates up to 62 cm in diagonal dimension. The U.S. Display Consortium has asked us, in collaboration with Lam Research Corporation, Xerox, and the University of Wisconsin, to develop and demonstrate plasma-etching techniques for manufacturing even larger screens.

## Highlights for 1994

- Observed at the MACHO Observatory an unexpectedly large number of gravitational microlensing events of stars, a finding that is generating new theories about the inner structure of the Milky Way.

- Obtained over 1.5 million images, at high resolution, of the lunar surface using LLNL-built lightweight imaging sensors on the Clementine satellite, the first U.S. spacecraft to the Moon in more than two decades.

- Measured for the first time the temperature of shock-compressed liquid hydrogen, producing results that require improved models of the interior of the planet Jupiter.

- Developed a new technique, which combines x-ray diffraction imaging with laser heating of materials under high pressure, and used it to discover a new phase of iron and to synthesize novel materials.

- Calculated the electronic properties of a specific class of mutagens to determine their mode of binding to DNA and the origin of observed differences in mutagenic potency.

- Worked with an industrial partner to demonstrate a nonthermal plasma technique for reducing nitric oxide emission in diesel engine exhaust.

- Continued to design and fabricate critical components for the PEP-II high-energy accelerator of the B Factory.

- Developed a new computer code that combines computed-tomographic images of the human body with Monte Carlo radiation transport and evaluated nuclear data bases to accurately calculate dose distribution for radiation therapy.

- Built and tested a new atomic particle trap to confine very cold, highly charged ions to observe novel forms of nonneutral plasma.

- Flew for the first time an instrument package containing a high-resolution gamma-ray imager and a prototype 10-$\mu$m infrared remote sensor on a high-altitude balloon.

- Flight-tested the ASTRID rocket to demonstrate how a new pumped-propulsion technology would perform in atmospheric flight.

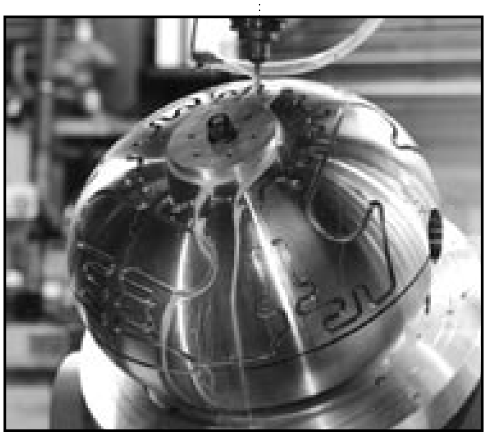
## Nuclear Science and Technology

The Laboratory's strengths in nuclear science and technology make it a welcome partner in major projects in both elementary particle physics and nuclear physics. We are also exploiting our nuclear and atomic data bases and computational expertise to improve radiation treatment plans for cancer patients.

### The B Factory

Recently President Clinton announced the awarding of a $300 million project to a partnership of the Stanford Linear Accelerator Center (SLAC), LLNL, and the Lawrence Berkeley Laboratory to construct and operate a high-luminosity asymmetric energy electron–positron colliding beam accelerator and detector. The facility, the B Factory, sited in a tunnel at SLAC, will produce copious pairs of b-quarks and their antiparticles so that we may study their decay in time. We want to determine why a fundamental symmetry in nature, called the charge parity symmetry, is violated in nature. The violation of this symmetry is one of three essential conditions for explaining why the universe evolved from the Big Bang with a predominance of matter over antimatter.

The B Factory project consists of the PEP-II accelerator and a detector, called BaBar, to study the decay products from the quark–antiquark pairs coming from electron–positron collisions. LLNL will design and build part or all of several systems in the accelerator. In virtually every system, the very high beam currents push the design and performance specifications to the extreme. An example is the 34 high-power RF cavities. LLNL has led a laboratory–industry consortium to develop the manufacturing process for these cavities, which involves precision deep electron-beam welding of complex shapes and diamond turning of the interior cavity surface, in order to handle the 150-kW power per cavity.



*Cooling channels are being milled into the first high-power 476-MHz cavity for the PEP-II accelerator, in a numerically controlled five-axis machine in the Building 321 shop.*

The BaBar detector must measure the spatial separation of the decay vertices of the b-quark and its antiquark—only a few hundred micrometers—as well as identify the type, momentum, and energy of all their decay products. LLNL designers have made innovative and important contributions to the detector. For example, we performed precision processing of the crystals for the 11,000-element cesium iodide detector array for measuring electrons and photons at high resolution.

### RHIC and the Alternating Gradient Synchrotron

We are studying nuclei at extreme densities and temperatures to find both new phenomena and a primordial state of matter. The experiments are performed at the Brookhaven National Laboratory (BNL) accelerator complex, where the Alternating Gradient Synchrotron currently delivers beams of gold ions at 11.7 GeV per nucleon. BNL will soon begin to inject those beams into the new Relativistic Heavy Ion Collider (RHIC), where two beams will be accelerated to 200 GeV per nucleon and counter-circulated for colliding beam experiments.

As a result of experiments in which nuclear matter densities have exceeded five times that of normal nuclear matter, we have a better understanding of the production mechanisms and the distribution of reaction products as a function of collision orientation, and we have gained insight into the density, dimensions, and fundamental physics of the nuclear fireball.

The RHIC program will employ two large detectors, PHENIX and STAR. LLNL is the lead institution for designing and fabricating the PHENIX magnet system and is the principal U.S. coordinator for constructing the central tracking chambers. The goal of the PHENIX experiment is to look for evidence of the quark-gluon plasma—a primordial state of matter that last existed a few microseconds after the Big Bang—by measuring the photons, hadrons, electrons, and muons produced in gold–gold collisions in the RHIC.

### The PEREGRINE Project

Ideally, radiation therapy delivers a lethal dose to a tumor while minimizing dose levels to nearby sensitive organs. Thus, distributing a dose requires careful calculation to avoid unnecessary damage. Current computational methods use interpolated data from dose measurements made in water, and inhomogeneities such as bone and airways that significantly affect the dose distribution are treated crudely or ignored. We have developed PEREGRINE, a computer simulation code that combines computed tomography (CT) medical images with a Monte Carlo radiation transport code specifically written for radiation therapy application. PEREGRINE, which uses our evaluated nuclear data bases, extended to the higher energies (~250 MeV) necessary for this application, simulates all major forms of external radiation therapy as well as the effects of internal radioisotope sources. By determining the materials and densities from the patient's CT image, and using the Monte Carlo calculation to explicitly account for the effect of three-dimensional inhomogeneities, PEREGRINE will allow clinicians to predict dose distributions with greater accuracy using a wider range of therapy beam types than any other dose calculation method.

## Atomic Physics

We have made significant progress in increasing our understanding of the properties of very highly charged ions and of the behavior of atoms in very strong laser fields.

### Highly Charged Ions

The Electron Beam Ion Traps (EBIT and Super EBIT) at LLNL are unique experimental devices for producing, trapping, and extracting ions in extremely high charge states. The Super-EBIT (with beam energy up to 200 keV) allows us to produce and trap any ion, including bare uranium from which all 92 electrons have been removed. For the first time, we accurately measured the removal of the last, most tightly bound electron from very heavy ions. Our measurement for uranium gave a much lower removal rate than the previous experimental value inferred from stripping high-energy uranium beams.

We designed and built a cryogenic particle trap called RETRAP to confine cold, very highly charged ions without any electrons present. It will enable us to experimentally investigate novel states of matter, such as crystals of strongly interacting ions. Our first proof-of-principle experiments raised the maximum charge state of ions confined in such a trap by more than a factor of 6 and showed that slow ions, produced and extracted from EBIT, can be captured in a secondary trap where they are accessible for further cooling.

*Results of a 3D PEREGRINE calculation of three 14.1-MeV neutron beams incident on the center of the left lung. The dose distribution is overlaid on the anatomy as defined by a CT-scan of a chest. The brighter colors represent higher dose regions.*

### Intense Laser–Atom Interactions

High-intensity, ultrashort-pulse lasers allow us to investigate the fundamental process of ionization of atoms and ions in large external electromagnetic fields. Many previous experiments have confirmed the basic theoretical models of the ionization mechanisms appropriate for different laser intensities and pulse lengths. Using LLNL's ultrashort-pulse laser facility, we discovered a new effect: excess production of doubly ionized atoms at laser intensities below the threshold predicted by accepted theories.

To understand the interaction of intense lasers with gaseous media, we must accurately characterize how the energy is transferred from the laser field to the atoms in the gas. Experiments have demonstrated that electrons stripped from atoms by very intense optical laser pulses ultimately have energies in the keV range. Our calculations firmly established that this surprisingly large transfer of energy occurs during a single cycle of the oscillating electromagnetic field of the laser. We have also shown unambiguously that the coherent short wavelength radiation ($\lambda < 10$ nm) and the incoherent x-ray emission that have been observed in experiments are due to collisions of these energetic electrons, either with their parent ions or with other atoms nearby in the gas. We plan to exploit this effect for the production of very short pulses of x rays.

## Space Science and Technology

Our expertise and research in space science and technology have led to important new results in astronomy and lunar exploration, as well as to the

*The TAISIR and GRATIS instrument package just before launch on a high-altitude balloon. TAISIR provided high-resolution images of thermal emissions on the Earth from space, while GRATIS provided images of astronomical gamma-ray sources.*

development of advanced instrumentation for balloon- and satellite-borne platforms.

### The MACHO Project

Measurements of the observed motions of stars in the Milky Way suggest that the total mass of the galaxy is 10 to 100 times greater than the estimated total visible mass. Thus, most of the matter in our galaxy must take the form of invisible components called “dark matter.” We are continuing our observations to test the hypothesis that the dark matter is made up of massive compact halo objects (MACHOs) such as brown dwarf stars or planets like Jupiter or black-hole remnants of primordial stars.

We are using our charged-coupled-device camera system, the “Super Camera,” at the Great Melbourne Telescope in Australia to make photometric measurements of about 8 million stars, looking for gravitational microlensing events as the signature of MACHOs. Since September 1993, when the first unambiguous detection of gravitational microlensing was made, we have observed many more microlensing events than were thought possible. The first events were observed by looking toward a galaxy called the Large Magellanic Cloud (LMC). Subsequently, looking toward the center of our own galaxy, the Milky Way, we detected 45 microlensing events, including one in which the star was amplified by a factor of 17! These discoveries have raised serious doubts about conventional descriptions of our galaxy’s structure. The implied mass in stars between us and the center of the galaxy is so high that our observations have generated a variety of new theories about the inner structure of the Milky Way.

The Super Camera is also revolutionizing the study of time-variable stellar phenomena. The sampling of the light curves of variable stars over several years provides details of their variability never seen before, and we are discovering many more variable stars. The Cepheid variables in the LMC, for example, are key in measuring the size of the universe, and their standardization depends upon understanding their behavior as a function of time.

### Stellar Opacities

The opacity of light elements plays an important role in the modeling of laser-produced and stellar plasmas. Because unsuccessful attempts to model some observed properties of stars suggested that the opacities were being underestimated, we developed a new computer code that includes improved theoretical models of equation of state, atomic physics, and spectral line broadening. Our calculations show that previous models underestimated the opacity of iron in the 20–120 eV energy range by orders of magnitude. Even with the low abundance of iron in stars, this increases the calculated opacity of stars by factors of 3 to 4 at temperatures near $3 \times 10^5$ K. Our predictions have been confirmed by experiments on laser-produced plasmas using LLNL’s Nova laser.

The substantial changes in the opacity of light elements have required that many earlier simulations of stellar phenomena be repeated with the new LLNL-produced opacities. This effort has produced several noteworthy successes. For example, the predicted pulsation period of classical Cepheids and RR Lyrae, the nonradial acoustic oscillation spectrum of the Sun, the abundance of lithium in the Hyades cluster stars, and the wind velocity leading to mass loss in classical novae are all in better agreement with observation.

### TAISIR and GRATIS

In 1994 we fielded the first high-altitude balloon flight of an instrument package that combined a gamma-ray imager and a remote-sensing experiment prototype system for the TAISIR program. A 10-$\mu$m narrow-band infrared imager was piggybacked onto the Gamma Ray Arcminute Telescope Imaging System (GRATIS) operating between 30 and 150 keV. The flight reached an altitude of 40 km and remained aloft for 12 hours, allowing a great deal of data to be taken by both the infrared and gamma-ray instruments.

Although TAISIR is a remote-sensing system intended for future deployment on a satellite platform, high-altitude balloon flights allow tests at a relatively low cost and with a very quick turnaround time. The TAISIR prototype takes advantage of the extremely stable platform developed for the imaging gamma-ray telescope to demonstrate the performance of a diffraction-limited infrared imager. In its first flight, the infrared instrument worked flawlessly, obtaining over 5000 images.

GRATIS also obtained 10 hours of gamma-ray data during the flight, locking onto and tracking three astronomical gamma-ray sources: X-1, an x-ray pulsar; Cyg X-1, a prime black-hole candidate; and Cyg X-3, an unusual x-ray binary system that emits throughout the gamma-ray band. The GRATIS package will fly from the Southern Hemisphere next, where it will image the Galactic center at unprecedented angular resolution.

### The Clementine Satellite

The Clementine satellite (the first U.S. spacecraft to the Moon in more than two decades) was launched from Vandenberg Air Force Base on January 25, 1994. Sponsored by the Ballistic Missile Defense Organization, the Clementine experiment was primarily designed to demonstrate lightweight imaging sensors and component technologies for the next generation of Department of Defense spacecrafts, using the Moon, the near-Earth asteroid Geographos, and its own solid-rocket motor as imaging targets. Its secondary mission was to provide scientific data on the mineral content and topology of the lunar surface and on the formation of planets in our solar system. The satellite circled the Moon for over two months beginning February 19. The technology demonstration and lunar-mapping parts of the mission were an unqualified success: the LLNL-developed, on-board cameras returned more than 1.5 million images of the Moon at spatial resolutions never before attained.

### Pathfinder and the Development of Solar Rechargeable Aircraft

We are working for the Ballistic Missile Defense Organization to develop unmanned aircraft for protecting our military forces and our allies from attack by theater ballistic missiles. Such aircraft may function as reusable, relocatable, geostationary platforms operating within the atmosphere. Engineers from AeroVironment, Inc. and LLNL have designed and completed flight testing of a solar-powered airplane called Pathfinder. The Pathfinder is a flying testbed for proving key technologies, critical system-integration approaches, and flight-control issues essential to achieving solar-powered flight at high altitude. Fuel-cell technology has been demonstrated to the point that unitized rechargeable fuel cells are possible. Such an energy-storage system weighs less than one-third the weight of the best rechargeable batteries available. The next step would be to build a plane like Pathfinder that has wing dimensions that can accommodate the weight of the rechargeable energy-storage system while enabling it to operate continuously at altitudes of 20 to 25 km.

*Operating in the thermal infrared region of the spectrum (8 to 9.5 $\mu$m), the long-wave infrared camera was used in the Clementine satellite mission to measure thermal emission from the Moon's surface.*

## Summary

LLNL scientists conduct physics research ranging from the subatomic to the extra galactic. We design and build devices to investigate the innermost workings of atoms, nuclei, and exotic particles. We also design and build instruments to collect information about the planets and astronomical objects. We use first-principles physics and massively parallel computers to custom-design materials that do not yet exist and to understand the interaction of laser light with matter. Physics research at the Laboratory advances our understanding of the universe and its building blocks, and the development of advanced technologies makes it possible to observe the world around us at an unprecedented scale.

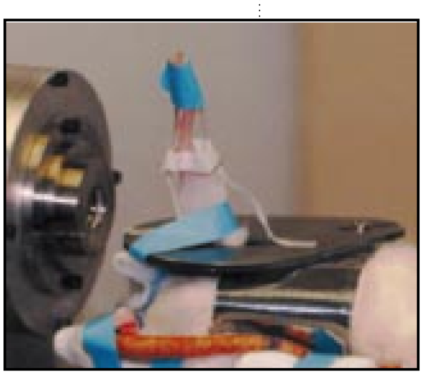
***For further information, contact Andrew Hazi (510) 422-4574.***

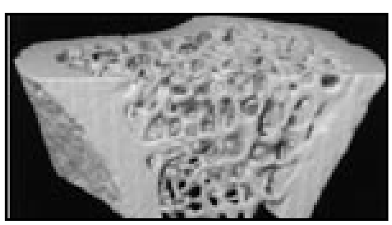
# Chemistry and Materials Science

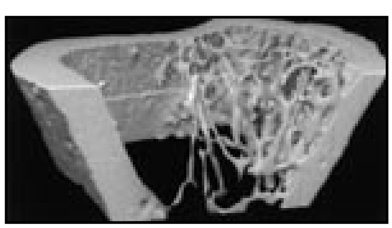
*We continue to synthesize new materials, characterize their structure and properties, and evaluate their suitability for specific applications.*

Chemistry and materials science is a field of study leading to applications that affect almost every aspect of our lives. We make direct contributions to each of the three major missions of the Laboratory, i.e., global security, global ecology, and the biosciences. Examples include science-based stockpile stewardship; U.S. economic competitiveness; the production of cleaner, cheaper energy; and cost-effective health-care projects. The Chemistry and Materials Science (C&MS) Directorate directly supports LLNL programs, performing both basic and applied research and development, and we also initiate leading-edge science and technology programs that will develop into major programs of the future.

An understanding of the field of chemistry and materials science is usefully viewed from the perspective of the steps by which new materials or processes are developed and then put to use. Thus, we view C&MS activities according to the methods we use in our research: (1) synthesis and processing of new materials, (2) characterization of the structure and properties of the materials, and (3) evaluation of material performance for specific applications. In each step, theory, modeling, and simulation provide essential guidance and feedback.







*X-ray tomographic microscopy images of a live rat's femur. The lower image shows bone loss due to osteoporosis. At left, the rat is mounted on a goniometer stage variously positioned for the x-ray imaging detector to obtain cross-sectioned images for the 3D composites at right.*

Our main activities in these areas are summarized below.

- **Materials Synthesis and Processing.** We are studying bicrystals, composites, advanced alloys, energetic materials, glasses and laser materials, lightweight porous materials, ceramics, electronic materials, coatings and surface modifications, nanoengineered materials, catalysts, chemical processing, surface physics and chemistry, aerogels, superplasticity, welding, and joining.
- **Characterization and Performance Evaluation.** We have core strengths in electron and probe microscopies, photoelectron spectroscopies, photon and neutron scattering, magnetism and transport, femtosecond spectroscopy, nuclear magnetic resonance (NMR) imaging, Mossbauer spectroscopy, mechanical and micro testing, ion-beam characterization, surface analytical techniques, mass spectroscopy, and trace analysis.
- **Theory, Simulation, and Modeling.** Our theoretical efforts involve materials by design, such as alloys, interfaces, heterogeneous materials, adhesives, molecular solids, and materials for microelectronics and opto-electronics. They also include molecular dynamics of surface processing, film growth, plasma processing, machining of metals and ceramics, transport phenomena, burn fronts and detonation, and equations of state (mathematical expressions that relate the volume of a material to pressure and temperature).

In the following sections, we highlight recent C&MS projects that incorporate important accomplishments made this year. These projects are multidisciplinary, cutting across the traditional boundaries of the scientific disciplines. Every project—be it primarily synthesis and processing; characterization and evaluation; or theory, simulation, and modeling—is inspired by one of our laboratory's major mission areas.

## Studies with Synchrotron Radiation

The intense radiation that is generated when electrons are accelerated around a synchrotron enables the production of highly monochromatic, precisely tunable x-ray beams that can be used as a powerful diagnostic tool. This year, we used radiation from beam lines at the Stanford Synchrotron Radiation Laboratory and the Advanced Light Source (the premier facility for soft x-ray work at Lawrence Berkeley Laboratory) to study the near-neighbor arrangement of atoms in solids. To obtain details on atomic coordination and bonding in the solids, we used our new "quick" version of a measurement technique called extended x-ray atomic fine structure (EXAFS). This technique allows us to carry out the measurement in a few seconds, bringing us closer to the observation of material transformations in real time.

Our work with synchrotron radiation also allowed us to take the lead in developing photoelectron holography, an imaging technique that is loosely considered the electron analog to laser holography. Experimentally, photoelectron holography is the same as photoelectron diffraction (an effective tool for determining surface structure) except that the diffraction (interference) between the core-level electron measured directly from the photoemitter (the reference beam) and the same photoelectron wave that has scattered off neighboring atoms (the object wave) forms a true hologram. Thus, with photoelectron holography, we have successfully studied the detailed atomic structure of a buried interface. Because the core level from which the photoelectron is excited is very slightly altered by the electronic surroundings of the atom, we can selectively distinguish an atom at a buried interface from an identical atom one or more monolayers removed from the interface. This is made possible by the extremely high monochromatic selectivity possible with synchrotron radiation.

Another exciting development this year, also made possible by synchrotron radiation, was our study of x-ray diffraction of crystal structures in real time. We collected certain components of diffraction patterns in times as short as 100 ms. This technique allowed us to follow the rapid reaction sequences that occur in a combustion front during high-temperature synthesis of a material. We are now using it to characterize the rapid structural changes that occur in industrial welding. The results of this study will help us develop a better understanding of weldment microstructures and properties.

We also applied synchrotron radiation to the study of osteoporosis, a medical condition characterized by decreases in bone mass and density and the enlargement of bone spaces. Using microtomographic techniques developed within the chemistry and materials science directorate, we successfully probed the complicated composite structure of the femur of a rat, without harming

### Highlights for 1994

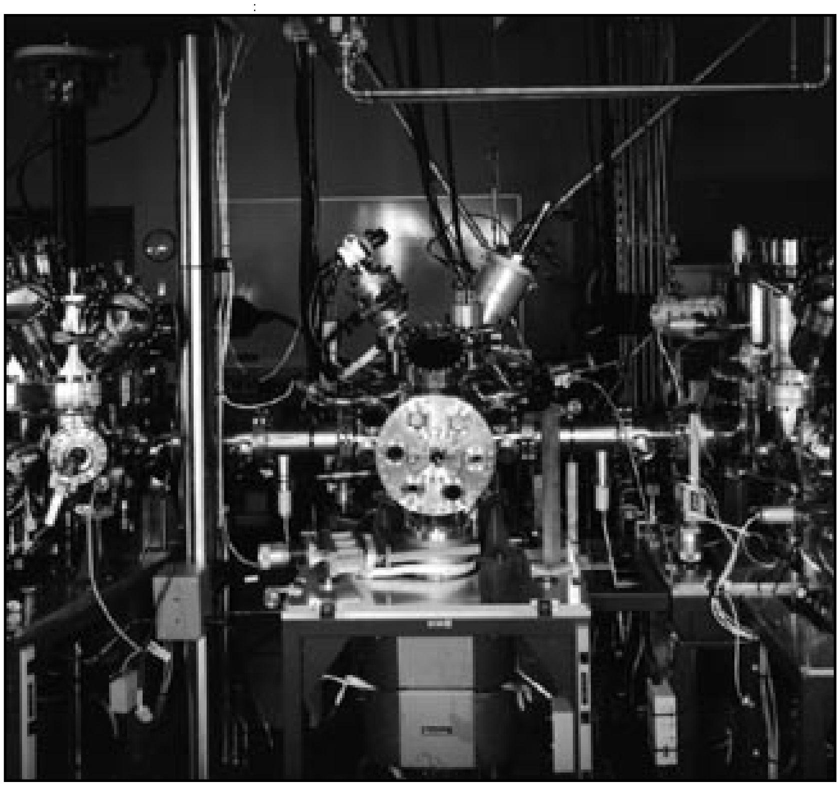
- Developed a rapid, extended x-ray atomic fine structure technique to study atomic coordination and bonding in solids. The new technique allows us to carry out fine structure measurements in a few seconds, bringing us closer to observing material transformations in real time.
- Used photoelectron holography to study buried interfaces in solid-state materials. This was made possible by the extremely high monochromatic selectivity of synchrotron radiation.
- Collected certain components of diffraction patterns in times as short as 100 ms, allowing us to study the changes in crystal structures in near real time. This permits us to follow the rapid sequence of events that occur during industrial welding processes.
- Developed a new instrument that will enable us to diffusion-bond very flat, clean crystals in an ultrahigh vacuum ($10^{-10}$ to $10^{-11}$ Torr) at up to 1500°C.
- Developed microtomographic techniques to probe the composite structure of a rat femur, without harming the rat, allowing us to follow and analyze the degeneration of bone structure in a single animal.
- Developed a very detailed understanding of the design and performance of reactive multilayers that could lead to a variety of industrial applications.
- Demonstrated the utility of aerogels in the deionization of aqueous solutions.

the animal. With this technology, the scientists and doctors collaborating on this project can continuously follow and analyze the degeneration of the bone structure in a single animal.

## Interface Studies

The structure and strength of an interface—the region that forms the boundary between two materials—can have a major effect on the behavior of an engineered structure such as a bridge, aircraft, or integrated circuit. This relation is evident in the welded, brazed, and diffusion-bonded joints of structures. In addition, the behavior of an engineered structure is also affected by the properties of its materials, for example, the strength and ductility of its metals, alloys, or ceramics. These properties are determined by intrinsic properties of the material and also by its microstructure, which is in turn influenced by an interface—in this case, the boundary between two individual grains, or crystals.

*The ultrahigh vacuum diffusion-bonding machine.*



One fundamental problem associated with understanding and predicting interface properties is that we cannot accurately fabricate, characterize, and modify the composition and atomic structure of an interface. This year, we took an important step in addressing the issue by completing the development of a new instrument called the ultrahigh vacuum diffusion-bonding machine. Although we designed this machine as the next generation of a similar machine located in Germany, it is unique in its own right. It will enable us to diffusion bond, in an ultrahigh vacuum ($10^{-10}$ to $10^{-11}$ Torr) at up to 1500°C, very flat (to tens of nanometers), clean crystals aligned to a precision of 0.2 deg. Eventually, we will also be able to carry out controlled doping of interfaces to simulate the effects of grain boundary segregation in real metals and alloys.

We have used this instrument to study the atomic structure of grain boundaries in niobium metal. We constructed interfaces of known symmetry and orientation and then experimentally characterized the atomic arrangement at the interface using a high-resolution transmission electron microscope capable of resolving individual atomic positions. This information has allowed us to distinguish the relative validity of two widely used theoretical approaches. We also used the facility to characterize the detailed failure mechanism of an aluminum/aluminum oxide joint, which provided us our first experience with a joining problem at an interface. We expect this facility to enable us to achieve other breakthroughs in the science of interface behavior.

## Waste Management Technologies

In support of the Laboratory's waste management efforts, we are participating in the investigation of three different technologies that could be used to destroy organic wastes in the Mixed Waste Management Facility: mediated electrochemical oxidation, UV/$H_2O_2$ (ultraviolet hydrogen peroxide) oxidation, and molten salt pyrolysis. Our responsibility is to provide the analytical measurements to support bench testing of the processes for each technology under consideration. We are measuring total inorganic and total organic carbon to measure process efficiency and characterizing residual and breakdown products of UV/$H_2O_2$ oxidation of chlorinated hydrocarbons, such as trichloroethylene.

In addition to our work in waste management, we operate a state-certified laboratory to assist in all aspects of managing hazardous waste that is generated on-site.

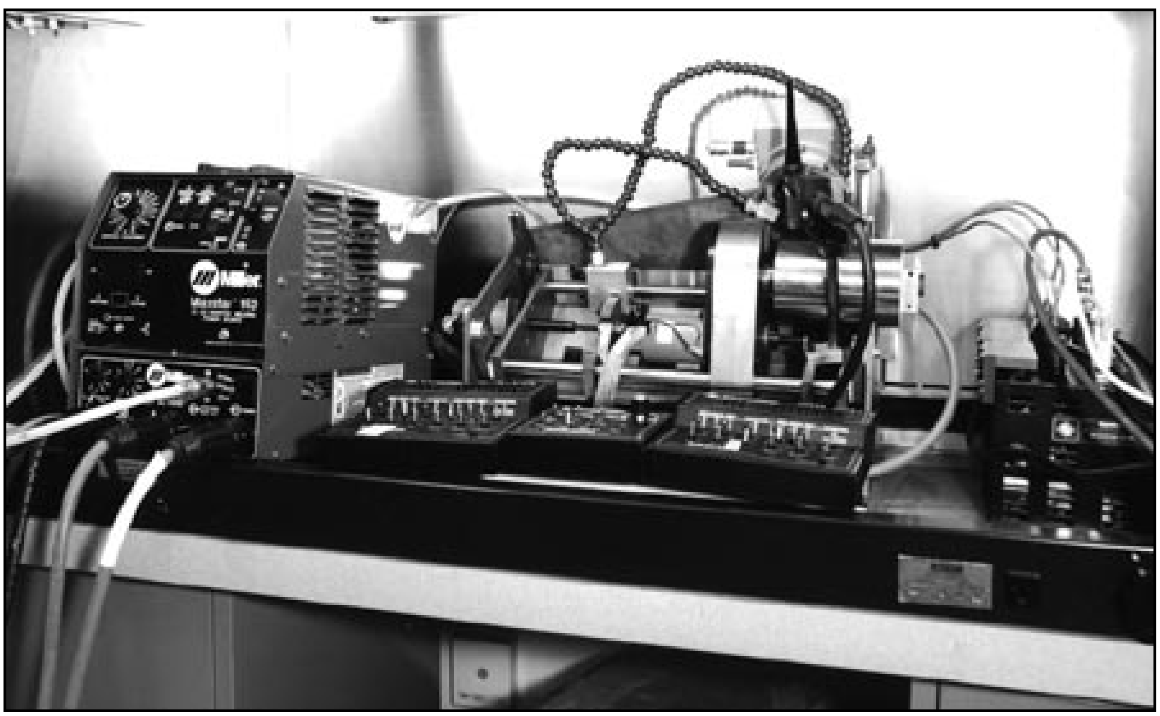
## Sensing and Detecting Methods

To support the Laboratory's efforts in nonproliferation, arms control, and intelligence, we are developing highly sensitive and specific methods for detecting chemical warfare agent precursors and hydrolysis products and seeking new ways to miniaturize instruments for field use. For example, we are developing an aircraft-mountable, time-of-flight mass spectrometer for real-time identification of volatile airborne solvents and a laser-spectroscopy-based method for remote sensing of effluent plumes, such as those that might escape from a chemical processing plant. This work is closely associated with the work we are doing for the Treaty Verification Program, i.e., to develop sampling kits for on-site detection of nuclear weapon capabilities.

We are also supporting the Laboratory's evolving mission in biomaterials and health care by developing new instrumentation for mass spectrometry. This instrumentation will be used in mass spectrometric analyses of large, biological molecules.

## Characterizing Laser Materials

In support of Nova and the National Ignition Facility, we are characterizing the materials used in



*We are characterizing the rapid structural changes that occur during industrial welding with spatially resolved x-ray diffraction. This photo includes the LLNL-developed system, which can be used with most any synchrotron source x-ray beam.*

nonlinear optical components, such as potassium dihydrogen phosphate (KDP). We are developing methods for determining trace metal impurities and using nuclear magnetic resonance spectroscopy to measure the deuteration levels. In the realm of target fabrication, we provide detailed analyses of the gases in an ICF target and of the helium in the Nova laser's line-of-sight. We determine the purity of the laser dyes and solvents used by laser program personnel. We assess separator performance in the uranium-atomic vapor laser isotope separation process by measuring the elemental and isotopic compositions of the material deposited during the process as a function of location in the separator.

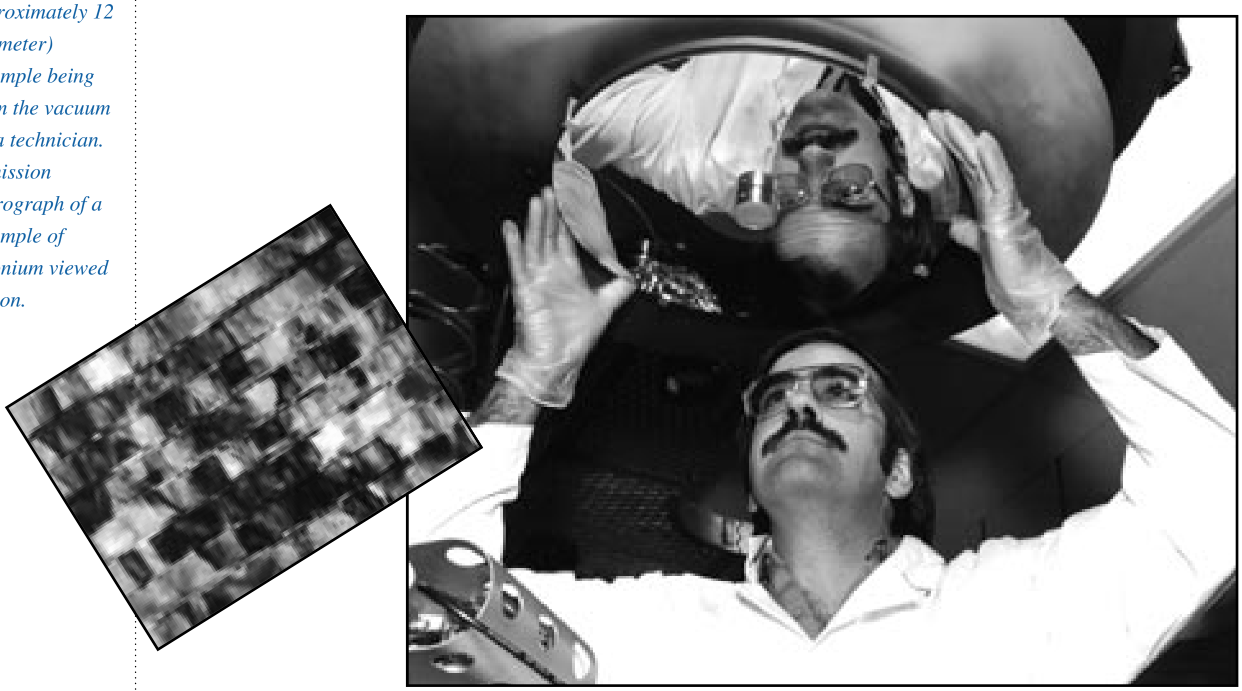
## Nanostructured Materials

The demand for better performance from materials has resulted in new methods of synthesizing materials in a novel structure. One way to structure a material is to take advantage of properties that arise from specific material features at the nanometer scale, such as those found in multilayers and aerogels.

We refer to multilayers as nanoengineered materials because we construct them atom by atom with a predetermined arrangement and goal in mind. This is a radical departure from classical material synthesis, sometimes referred to as "ingot metallurgy," where, for the most part, we accept the atomic arrangement dictated by nature and manipulate properties through the optimization of microstructure. Multilayer synthesis allows us to prepare metastable arrangements of atoms that are unobtainable by other means and that possess unusual and outstanding properties.

Our most important recent advance in multilayer synthesis has been our ability to prepare dielectric layers with carefully and reproducibly controlled atomic structure and composition. This is important in current industrial applications associated with aircraft engine development, and it also opens a new realm of applications. For example, we are exploring the fabrication of high-voltage

*A large (approximately 12 inches in diameter) multilayer sample being removed from the vacuum chamber by a technician. Inset: transmission electron micrograph of a multilayer sample of copper–zirconium viewed in cross section.*



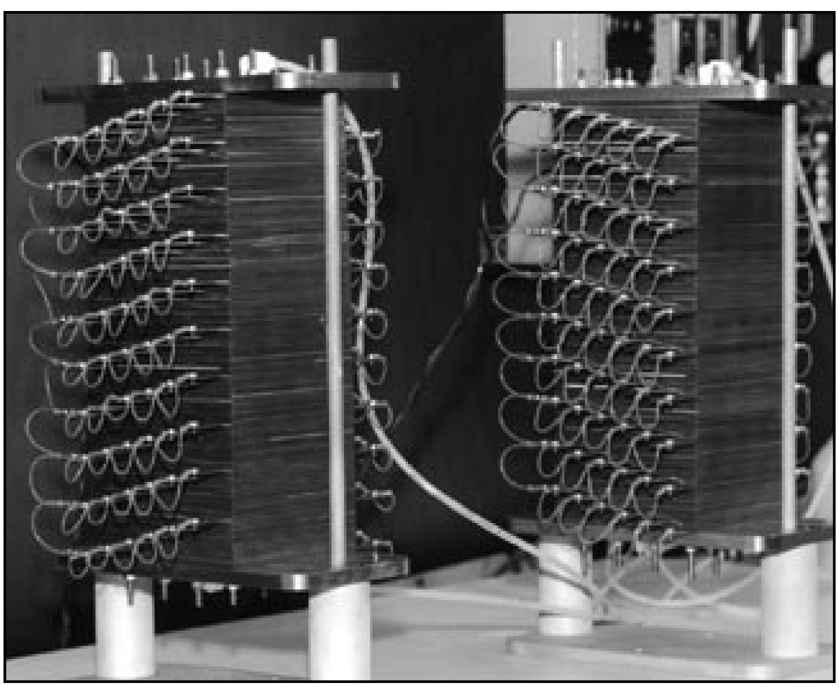
capacitors with unprecedented energy storage and very rapid energy delivery. We have also explored the fabrication of reactive multilayers—materials whose stored energy may exceed that of high explosives but is released in milliseconds rather than microseconds without the production of a shock wave. In the last year, this work led to a very detailed understanding of the design and performance of these materials and a strong expectation of important future industrial applications.

Aerogels, unlike multilayers, provide a wide range of unusual properties associated with a specific nanostructural arrangement. In the past year, we have taken advantage of these properties to demonstrate the utility of these unique materials in the deionization of aqueous solutions. We have developed an aerogel-based unit with a tremendous capacity for removing ions from aqueous solution (as in desalinization). This unit consumes only a fraction of the electric power required by conventional approaches, and it is easily regenerated by reversing the potential.

## Summary

Our work in chemistry and materials science exemplifies disciplinary research and programmatic support. The disciplinary research is intended to sharpen the skills of our scientists, advance the frontiers of scientific knowledge, and provide the seeds for programs of the future. The programmatic support provides the very best scientific and engineering talent for Laboratory programs and offers the potential for new program areas. We are convinced that chemistry and materials science will be key to the future success of the Laboratory whatever its mission, and we are firmly committed to supporting this mission with the very best in scientific talent.

***For further information contact Jeffrey Wadsworth (510) 423-2184 or Lawrence R. Newkirk (510) 422-5476.***



*Prototype aerogel system for the deionization of aqueous solutions. It is based on multiple cells containing carbon aerogel as the active component.*

# Computations

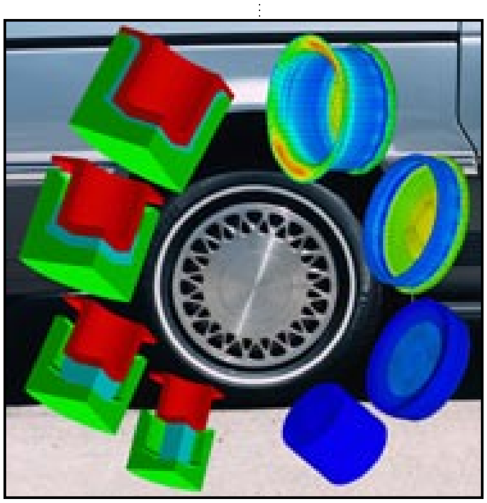
*Today, a large part of research and development at the Laboratory combines computer simulation and experimentation, reducing the need for expensive experiments.*

Computers have enabled us to extend our design and predictive capabilities and therefore our ability to make breakthrough discoveries in virtually every field of science—from physics, materials science, and chemistry to engineering, geology, biology, and medicine. Among our activities this year, we:

- Created the Center for Computational Science and Engineering to provide a focal point for research in computational science.
- Launched the Industrial Computing Initiative, a collaboration of LLNL, Los Alamos National Laboratory (LANL), and an industry group of 16 organizations headed by Cray Research, Inc.
- Participated in the DOE's consolidated/collaborating SuperLab, an effort to link LLNL, LANL, and the two Sandia labs into a "virtual" laboratory.
- Integrated a massively parallel computer into our production work flow and began extensive conversion of supercomputer codes to parallel architecture.
- Began upgrading the communications capability of the Energy Sciences Network.
- Expanded our collaborations with other laboratories and private industry through additional Cooperative Research and Development Agreements (CRADAs).

The following represent accomplishments in Computations areas for the past year.

*The DYNA3D computer program is one of our most successful industrial partnerships. The LLNL-developed code to analyze impacts upon structures helps American industry maintain a competitive position in the world market. Here the codes are depicted as they apply to automobile wheel components.*



## Center for Computational Sciences and Engineering Established

The Center for Computational Sciences and Engineering (CCSE) was established to develop and apply advanced computational methodologies to solve large-scale scientific and engineering problems arising in DOE mission areas involving energy, environmental, and industrial technology. The Center's staff pursues a wide range of research activities in areas including computational fluid dynamics, flow in porous media, particle and chemical kinetics, plasma modeling, and general numerical methods for solving large-scale differential/algebraic systems problems.

Technology transfer and industrial collaborations form a major component of Center research activities. For example, we are working with collaborators at LANL, UC Berkeley, and the Courant Institute at New York University to develop sophisticated techniques for modeling industrial combustion problems—techniques that an engineer could use to understand how pollutants such as NOx are formed in an industrial burner.

Researchers from CCSE and other LLNL areas are working with IT Corporation under a CRADA to deploy massively parallel computers for modeling flow in heterogeneous porous media. Detailed simulations of large sites will play a key role in the design of remediation techniques to clean up contaminated groundwater at sites throughout the world. We also initiated a collaboration with a large oil and gas service company to develop a massively parallel simulator for the design of nuclear well-logging tools (probes used to determine lithology and fluid characteristics in the regions around boreholes).

## The Industrial Computing Initiative

The Industrial Computing Initiative represents a three-year collaboration between LLNL and LANL and 16 industrial participants to demonstrate that economical solutions to grand-challenge-scale computational problems can provide a competitive advantage in the marketplace. Multiple CRADAs are used to define the relationships and the deliverables among the participants. We intend to develop applications whose added dimensionality and enhanced realism and accuracy create a distinct economic advantage for the companies involved. With each laboratory using a 128-processor Cray Research T3D MP computer, the various projects are targeted at developing either efficient application codes or software that facilitates the use of parallel computers.

## The SuperLab Project

The long-term objective of the SuperLab program is to develop the software infrastructure for linking LLNL, LANL, and the two SNL laboratories by means of high-speed digital communication into a single "virtual laboratory." Scientists and engineers at the four sites then will be able to collaborate more closely and more easily share their computing resources, secure as well as unclassified. Many of the technical components of the SuperLab are strongly synergistic in discharging the Defense Program's missions. For example, an "intelligent archive" project would be useful in a full range of applications, from environmental data structures to weapons-design data-legacy files.

## Massively Parallel Computing Integrated into Production Workloads

As we continue to move from conventional supercomputing to a massively parallel environment, the Livermore Computer Center is using its Meiko CS-2 MPP (more than 64 of its 256 processors are now operating) and a migration strategy called the Livermore Model, which enables us to partition a massively parallel environment so that monoprocessing, multiple processing, and massively parallel processing can be performed simultaneously. Since we are just beginning to convert our key applications to massively parallel operation, we are initially running a large number of serial jobs simultaneously on separate nodes (that is, running them in a capacity mode). We are migrating them to parallel operation one package at a time, starting with those that will benefit most from the increased capability (that is, the simultaneous focusing of many nodes on a single parallel application). For example, we completed the parallelization of a Monte Carlo package used in several important codes. Eventually, all applications will be completely parallel-capable. A small number of parallel applications in areas such as global climate modeling and electromagnetic propagation can immediately use the full power of the CS-2 to reach very high levels of performance.

## Isotope Separation and Advanced Manufacturing Program

The Laser Program's Isotope Separation and Advanced Manufacturing (ISAM) Program develops and supports computer-based control,

### Highlights for 1994

- Began work on the "SuperLab" project, the goal of which is to establish a distributed computing environment spanning LLNL, Los Alamos National Laboratory, and the Sandia National Laboratories in Albuquerque and Livermore.

- Partnered with Los Alamos National Laboratory and an industry group headed by Cray Research in the Industrial Computing Initiative of DOE's High Performance Parallel Processing Project.

- Formed the Center for Computational Sciences and Engineering to develop and apply advanced computational methodologies to solving large-scale scientific and engineering problems arising in DOE energy and environmental and industrial technology mission areas. It is also the organizational home of the High Performance Parallel Processing Project (H4P).

- Began upgrades at ESnet sites to enhance communications capability.

- Upgraded the central computing resource of the National Education Supercomputer Program from a single processor Cray-XMP to a four-processor Cray-YMP-EL.

- Began limited production use of the Meiko-CS2 massively parallel computer, integrated it into the classified supercomputer center supporting defense programs, and began working with users to develop a new generation of parallel-capable applications.

- Formed a CRADA with IT Corporation, a large environmental contractor, to develop a massively parallel simulator of groundwater flow and contaminant migration.

diagnostics, information management, and communications systems for the Uranium Atomic Vapor Laser Isotope Separation (U-AVLIS) effort. ISAM has developed approximately 100 integrated applications in the areas of diagnostics, wavefront control, separator controls and diagnostics, data analysis, data distribution and management, and human–machine interfaces.

U-AVLIS "proof-of-principle" runs are being conducted as part of a plan that will lead to a commercial manufacturing plant. The group is preparing for a major 200-hr run of the separator and a major physics experiment. In the stimulated Raman scattering experiment, the interaction of uranium ions and the laser beam causes changes in the frequency of the scattered beam that conveys structural information.

*Joel Buenaventura, a participant in the Science and Engineering Research Semester (SERS), is working with a graphical browser developed for the Human Genome Project.*

For the Laser Program's Inertial Confinement Fusion (ICF) Program, Computation Organization code developers perform compiler and application code development, user services, and program maintenance functions for the users of LASNEX (a computer program for modeling the physics of ICF targets). Over the past year, we have been moving this extremely large, computationally intensive program from Cray to workstation platforms in order to significantly reduce run costs and make the code available to a wider audience.

## Advanced Scientific Visualization

This year, we developed techniques for understanding the flow fields that are typical in many simulations (such as winds or the propagation of contaminants in groundwater). These new techniques maximize the use of advanced graphical workstations to achieve highly interactive results. For global climate modeling, we have applied volume rendering (for showing a 3D volume in a 2D display) to represent the interaction between winds and clouds, and we have other techniques that represent the flow at specific areas, such as around or through surfaces. Our simulation techniques suit a broad range of applications, including groundwater studies, fluid-flow simulations, and interstellar cloud formations, to name a few. The techniques are being integrated into standard commercial visualization systems to make them available to a greater variety of users.

## Applied Computations

The Laboratory is developing advanced computational methodologies to solve large-scale scientific and engineering problems for specific applications in DOE mission areas involving energy, environmental, and industrial technology. Although a multidisciplinary approach is fundamental in this research, we rely heavily upon the strength of our long-standing applied mathematical sciences research program, which emphasizes basic numerical research in computational fluid dynamics, flow in porous media, particle and chemical kinetics, plasma modeling, and general numerical methods for solving large-scale differential/algebraic systems. This algorithmic technology is complemented by the development of advanced software strategies for exploiting state-of-the-art computational hardware, including high-end visualization systems, workstation clusters, and massively parallel computers.

## Energy Sciences Network

The Energy Sciences Network (ESnet) is a nationwide communications network for disseminating computer data to support multiple-program, open scientific research. Managed and funded by the DOE's Energy Research (ER) Office of Scientific Computing, ESnet is intended to facilitate remote access to major scientific facilities and resources; provide information dissemination among scientific collaborators throughout all ER programs; support remote experimentation, distributed computing, and collaborative environments; provide widespread access to existing ER supercomputer facilities; and support technology evaluation and prototyping for the technologies that will be important to the development and implementation of the emerging

National Information Infrastructure, the Clinton Administration's initiative to promote the "information superhighway."

## The Human Genome Project

The Laboratory's role in the Human Genome Project is to develop efficient biological and computational techniques for chromosome mapping. Our work has become a cornerstone of the entire project, accentuating the importance of software engineering in biomedical research. This year, one task was to automatically integrate more than 10 types of genome physical mapping data. We solved this problem, which had never been attempted on this scale, by turning it into an optimization problem using simulated annealing (a technique for finding a global near-minimum without getting trapped in local minima, analogous to annealing molten glass.) Integrating a 1200-×-300-object physical map on a single workstation took about four days; since we modified the algorithm to run in parallel on a network of 45+ workstations, it can process a 3000-×-750-object physical map in four to six hours. We rewrote our graphical browser tool to handle new types of genome mapping data and to effortlessly link the different modes of map display. We are also providing increased consulting on genomic databases and algorithms to the human- and plant-genome communities.

## The Computer Security Technology Center

National and international computer networks are subject to ever-increasing numbers of attacks, attacks recently aided by new automated tools that steal passwords or search for vulnerable computers. The Computer Security Technology Center (CSTC) conducts research and develops innovative ways to prevent harm to computer systems. For example, a tool called the Security Profile Inspector assesses the security of UNIX- and VMS-based systems, reporting system configuration vulnerabilities, bad passwords, and system file integrity violations. Its menus and help features spare system managers the need for extensive system security training.

For Ethernet-based networks, we are developing the Network Intrusion Detector to identify and analyze suspicious traffic and connections. If an incident is suspected, the evidence collected can be shown to site security personnel, law enforcement, or the DOE Computer Incident Advisory Capability (CIAC). CIAC is perhaps the most visible and most critical effort within the CSTC. This team is responsible for helping during computer incidents anywhere within the DOE, and often helps other individuals and organizations around the world. CIAC provides operational support and is the single point of contact for incidents such as computer break-ins, computer viruses, and widespread automated network attacks. This team gathers fast-breaking vulnerability and threat information and disseminates it to the DOE community and elsewhere.

The Department of Energy faces the daunting task of reviewing some 4 billion pages currently in DOE archival storage to determine their suitability for release to the public. CSTC has been very active in this truly challenging project, called the Text Analysis Project. Documents will be read and searched for signs of sensitive information. By automating the process of review, through parsing, root-word analysis, parts-of-speech detection, and similar techniques, we will provide a secondary check of human reviewers to increase assurances that no classified or other sensitive information is accidentally released.

## Electronic Commerce

We continued to work with Wright-Patterson Air Force Base to refine the Electronic Commerce project for paperless procurement. The system, in full production this past year, processed over 75% of all commodity procurement actions for an estimated savings of $1.5 million. We received inquiries regarding the design and implementation of this system from within various agencies of the U.S. government and from

*LLNL's National Energy Research Supercomputer Center (NERSC) provides high-end computing services to the national community under Energy Research funding. This system serves 500 users at 200 national and international institutions.*

Canada and Australia. We plan to adapt Electronic Commerce technology to LLNL departments of Finance and Procurement in 1995.

## Numerical Tokamak Project

Tokamak reactors of a scale that will produce electrical power for commercial use are larger than today's research tokamaks; the production-scale systems can be analyzed only by computer simulation. We participate in the Numerical Tokamak Project, a national consortium to simulate the turbulent transport of plasma in tokamak fusion experiments. These simulations will predict the scaling behavior of plasma transport in tokamaks so that we can ascertain the ultimate performance of these devices at production scale. Massively parallel computing and high-speed communications have enormously increased the information available for understanding and appraising solutions to this nationally important scientific problem. We have also created an extensive graphics post-processing system designed to enable computer-supported collaborative work. Collaborators who are widely dispersed can interactively and simultaneously create and view scientific visualizations of the results from large turbulence simulations.

## A Preprocessor for High-Performance Computing

The Parallel Data Distribution Preprocessor (PDDP) project is a software effort to implement an efficient parallel programming model. The project is meant specifically for distributed-memory machines, to give the programmer a mechanism for dealing with the nonuniform memory access of these machines. For the past two years the project has focused on a variant of the High Performance Fortran model that is becoming popular among the vendors of massively parallel processing machines. The model is a shared memory model and works by using the parallelism in the program and the locality of data to the advantage of the programmer. Data is worked on locally in each of the processors to get maximum memory bandwidth.

PDDP operates on the BBN TC2000 and Meiko CS-2 computers, and is being ported to the Cray T3D, allowing the same source code to execute on all platforms. Results from applications are very encouraging—performance scales well, and programmers appreciate the simpler model.

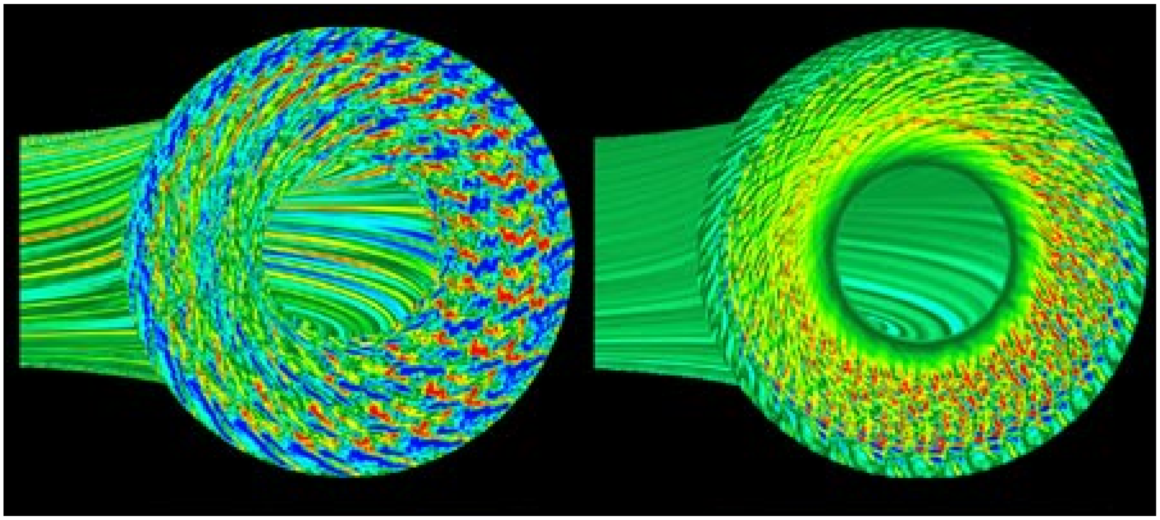
## CRADA with Citibank

Although the use of credit cards and electronic funds transfers continues to rise dramatically, the use of paper checks also continues to increase at about 4% per year, and is expected to do so for the next 5–10 years. The handling of checks is costly, error-prone, and time-consuming. There is a clear need to capture checks electronically as early in the processing cycle as possible (i.e., at the first bank the check encounters on its trip through the banking system), to move only electronic bits thereafter, and finally to archive only the electronic images. A key factor is to capture the check with sufficient image quality while minimizing the number of electronic bits. We are in the second year of a three-year CRADA with Citibank on various aspects of check imaging, such as research in Interbank Check Image Exchange and Truncation.

As a consequence of our association with Citibank, we have been instrumental in forming a consortium of major U.S. banks and other financial service providers and equipment vendors. The Financial Services Technology Consortium (FSTC) is conducting a program of precompetitive research, development, and deployment of solutions to problems of privacy, security, reliability, etc., that are encountered when financial services are provided over open public networks. FSTC expects to play a major role in the development of electronic commerce in the U.S.

## Open Systems Laboratory

This year, LLNL established the Information Technology Open Systems Laboratory (OSL). The OSL is one of several regionally based sites in the U.S. to provide services on a nationwide scale. It has two comprehensive goals: supporting internal Laboratory programmatic and administrative



*These computational models were developed by LLNL researchers for the Numerical Tokamak Project. High-performance computers allow high-resolution visualization of how turbulent mixing of hot core plasma with cool edge plasma prevents fusion ignition (left) and how certain conditions can reduce turbulence (right).*

functions, and increasing the effectiveness and efficiency of doing business electronically by promoting the rapid integration of technologies into the Clinton Administration's National Information Infrastructure initiatives.

OSL will promote these goals by working to achieve critical operational goals:

- Develop, commercialize, and deploy computation- and communication-based information systems to facilitate improvements in the financial, education, health care, manufacturing, and government-services sectors of the U.S. economy.
- Provide an information technology testbed and information-systems laboratory for demonstrations, prototyping, and pilot projects.

This laboratory will be used by vendors, systems integrators, and university and national laboratory teams to develop databases, instrumentation systems, communications systems, and software components to model widely distributed information environments. These basic "information superhighway" technologies and applications include functions supporting information analysis, data navigation tools, storage environments, collaboration and telepresence capabilities, and inter-networking and information surety and security.

## National Storage Laboratory

High-performance mass storage systems need improvements of two or more orders of magnitude in performance and capacity plus corresponding improvements in architecture and functionality.

LLNL is participating in the National Storage Laboratory (NSL), which was established to investigate, demonstrate, and commercialize new mass storage system architectures to meet such needs. The NSL and closely related projects involve more than 20 participating organizations from industry, DOE, other federal laboratories, universities, and the National Science Foundation supercomputer centers.

Two software development projects are in process: NSL-UniTree and the High Performance Storage System (HPSS). NSL-UniTree features network-attached storage, dynamic storage hierarchies, and capabilities for extensive storage system management. NSL-UniTree has demonstrated more than an order of magnitude improvement in storage-system performance. Release 2 of NSL-UniTree was delivered to IBM for commercialization and is currently used at over a dozen federal agencies. HPSS is focused on developing the next generation of scalable, standards-based, general-purpose, distributable storage systems. It can support storage capacities from gigabytes to petabytes, high-speed data transfers for workstation cluster, and parallel computers through both sequential and scalable parallel storage and retrieval techniques. HPSS is currently in integration testing and planning for its first release. The NSL continues to work on future releases to extend HPSS functionality.

***For further information contact C. William McCurdy (510) 422-6383 or J. Joseph Brandt (510) 422-7043.***

# Economic Competitiveness

*The Laboratory works with private industry toward goals neither might reach alone. LLNL's important national goals involve defense, energy, and the environment, while industry's goals in working with us involve furthering their technologies. We both require cost-effective results. Together we contribute to the country's economic strength by providing technologies required for successful competition in a global economy.*

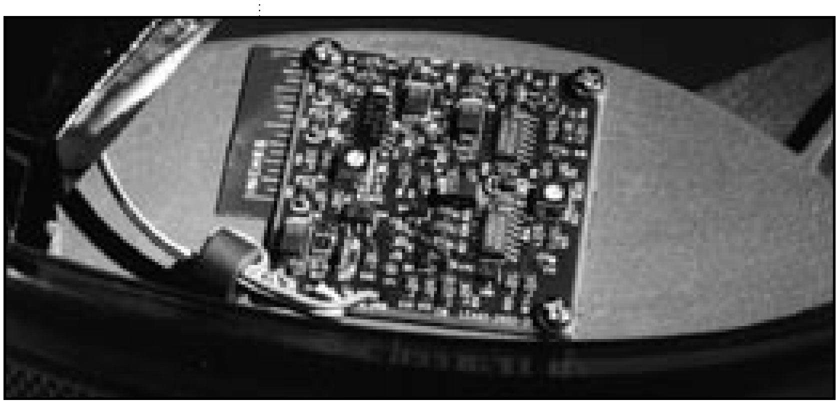
Cooperation with industry is an integral part of much of our work at Livermore. The aim is to realize our core programmatic goals—such as those in defense, energy, and the environment—in the most cost-effective way, while often simultaneously contributing to the nation's economic success.[1] The projects vary according to the nature and complexity of the technology, its degree of development, its perceived applications, and its proprietary status. Some are set up as licensing and consulting agreements,[2,3] while others are carried out as cooperative research and development agreements (CRADAs).[4] Those agreements involve partnerships in which, generally, government funds are used to support the Laboratory's work, and industry funds are used to support its work. Each organization may have separate applications in mind, but by each doing a specialized portion of the project, all benefit from the synergistic results and savings.

Last year, about 6% of the Laboratory's budget supported efforts at forming industrial partnerships. Results have been impressive.

- From March 1992 to November 1994, we amassed 137 CRADAs worth $480 million in government and industry funds. These partnerships support a variety of technologies related to our core competencies: 30% of these agreements in materials and manufacturing; 18% in computing and communications; 14% in semiconductors, microelectronics, and photonics; 11% in electronics manufacturing; 8% in biotechnology and health care; 7% in modeling of industrial processes; 7% in environmental remediation; and 5% in energy-related technologies or processes.
- Over the last few years, the number of licensing agreements has steadily increased. We now have 100.

A selection of these projects follows.

*A new radar-based sensor is shown here in an automobile taillight, where it could be installed to serve as a collision or pedestrian warning system. The small, sophisticated invention has been licensed to California-based Amerigon, Inc., for several automobile safety applications.*



## Catalysts for Reducing Nitrogen Oxide Emissions

We have been working with General Motors (GM), Ford, Chrysler, and Sandia and Los Alamos national laboratories to develop aerogel catalysts and a catalytic converter system that meet current and future mandated Clean Air Act standards for motor vehicle emissions. The project's goal is to reduce nitrogen oxide (NOx) emissions from both diesel and lean-burn gasoline engines.

So far the prototype catalysts—metal oxide aerogels developed at Livermore and hydrous metal oxides developed at Sandia—have been characterized and modeled at Los Alamos and are now being tested at GM, Ford, and Chrysler, on dynamometers and in vehicles, for adherence to emission control standards.

Participation in this project has allowed us to refine our capabilities in aerogel synthesis, processing, and molecular modeling. This, in turn, has improved our understanding of how catalysts behave in amorphous and crystalline inorganic oxides. It has also given us the opportunity to sharpen our modeling capabilities in the kinetics of combined heterogeneous and homogeneous reactions.

## Flywheel Batteries for Hybrid Cars

In July 1994, we entered into a three-year, $2.5 -million CRADA with GM to evaluate the flywheel battery (a battery in which kinetic energy is stored in a flywheel and transferred and processed electronically between the flywheel and the load) as part of a hybrid system to power future passenger vehicles. The agreement, co-sponsored by GM and DOE's Hybrid Vehicle Program, is part of GM's contribution to the broad-based Partnership for a New Generation of Vehicles—a concerted, "precompetitive" effort by Ford, GM, and Chrysler (the Big Three) to investigate ways to produce safer, more energy-efficient passenger cars. The ultimate goals are to reduce petroleum consumption in order to minimize dependence on foreign oil and to decrease carbon dioxide emissions contributing to global warming.

As part of the hybrid fuel system, the flywheel battery would capture and store the energy dissipated during braking, thus harnessing what was once wasted braking power. It would also power the car for quick accelerations uphill or after a stop.

## Flywheel Battery for Regulating Power Supply

In 1994 we began a cooperative research project with Trinity Flywheel Batteries and Westinghouse Electric Corporation to develop a flywheel battery for quality power applications. In such applications, the objective is to mitigate the perturbations and interruptions in electrical power (i.e., common power surges) that can damage computers and process-control equipment. Westinghouse uses an active power line conditioner (APLC) that continuously monitors and controls the power supplied to a critical load—such as a programmable logic controller or a machine tool—to maintain good power quality. Westinghouse requires high-performance energy storage to provide the APLC with the ability to ride through total power outages of up to tens of seconds. The electromechanical battery developed by LLNL and manufactured by Trinity meets this need. It provides almost 10 times as much power in a small package as the best chemical battery does and offers the potential for a long, maintenance-free life.

## Superconducting Materials for Digital Electronics

We are collaborating with Varian Associates to develop a superconducting building block for a variety of electronic devices—from high-speed digital signal processors and central processing units to microwave circuits and detectors. Key to the development of such materials is the fabrication of high-quality wafers and devices with specific characteristics. We have determined that a multilayer structure composed of high-temperature superconducting materials, metallic and insulating barrier materials, and associated substrate and electrode materials can provide devices with characteristics that make them suitable for use as sensors or electronic circuits. We also catalogued the microscopic defects that occur in such structures, investigated their origins, and identified the most critical process variables for tunnel barrier quality.

## Highlights for 1994

- Worked with General Motors, Ford, Chrysler, Sandia National Laboratories (SNL), and Los Alamos National Laboratory (LANL) to develop advanced catalysts and catalytic converter systems to reduce nitrogen oxide emissions.
- Worked with Trinity Flywheel Batteries and Westinghouse Electric Corporation to develop an electromechanical, flywheel battery for power-quality applications.
- Began working with Webster Research Center of Xerox Corporation on atomic-level materials theory and modeling software to extend capabilities in etching, passivation, growth of thin films, and other microelectronic processes.
- Worked with Cincinnati Milacron to improve the accuracy of its machine tool products.
- Signed the three-year, $52-million Industrial Computing Initiative with Cray Research, Inc., Los Alamos National Laboratory, and eight other industrial partners to conduct research in massively parallel computing.
- Worked with BioNumerik Pharmaceuticals, Inc., to develop new anticancer drugs by computer simulation.
- Worked with Varian Associates to investigate methods to provide high-temperature, superconducting multilayer films required for high-speed, low-power signal processors and detectors.
- Made radar detection and cell sorting technologies available to industry for commercialization through two licensing agreements.

## Simulating Molecular Dynamics of Surface Processes

In a cooperative venture with Webster Research Center of Xerox Corporation, we are using our atomic-level materials theory and modeling software to study the surface processes—such as etching, passivation, and thin-film growth—that figure in the development of a microelectronic device. This collaboration enables Xerox to extend its capabilities in microelectronics research and development so that it can improve the quality of its industrial and consumer products.

By extrapolating what we know about the surface interaction of a few atoms to large numbers of atoms, layers of atoms, and eventually to the quantities of material needed to build microchips, we expect to learn how to optimize the processes used to fabricate new materials and devices. With such knowledge, Xerox will be able to improve process control, lower process temperature, and achieve more abrupt multilayer material interfaces for improved electrical performance.

## Improving the Accuracy of Machine Tools

We are working with machine tool manufacturer Cincinnati Milacron to improve the accuracy of competitively priced, general-purpose machine tools. The company anticipates that by combining our expertise in precision engineering and machine tool development with its high-volume production capabilities, it will be able to produce the quality machine tools that the U.S. machine tool industry needs to regain its share of the market from long-time foreign competitors.

The focus of this effort is Cincinnati Milacron's latest horizontal machining center, the Maxim 500 CNC, which was installed at the Laboratory's facility for collaborative research and development earlier this year. Through analysis and testing of the Maxim, engineers from the Laboratory and Cincinnati are developing a capability that can achieve a tenfold increase in machine tool accuracy without degrading productivity or significantly increasing capital equipment costs. The capability derives from the Laboratory's deterministic approach to machine tool development—that every effect has an identifiable cause that one can find if one looks hard enough, and that, therefore, random errors do not exist[5]—and from an array of analytical tools used by Livermore researchers to improve the accuracy, speed, throughput, and reliability of computer-controlled machine tools.[6] The net result will be a system that encourages engineers to assess a machine tool's capabilities during design rather than after prototyping. This will ultimately lower production costs and cut down on the time it takes to bring the machine tool to market.

*Cincinnati Milacron's latest horizontal machining center, the Maxim 500 CNC. Through analysis and testing of this machine tool, engineers from LLNL and Cincinnati Milacron are developing a capability that can achieve a tenfold increase in machine tool accuracy.*

## Medical Laser Systems

We are working with Beckman Laser Institute and Medical Clinic (Irvine, California) to design, build, and test three medical laser systems. We expect these systems to be more compact and less expensive than current medical laser systems and offer greater efficiency, reliability, and flexibility. Beckman is identifying the system specifications, designing the delivery systems, and evaluating the lasers' performance in clinical trials. Our task is to design and build the prototypes.

The new systems are made possible by two of our recent laser technologies: a modular diode package that uses water and silicon-etched microchannels to cool the laser diode for operation at high power levels—much higher than is possible with other cooling techniques—and a 350-µm-diameter optical lens that precisely channels light for delivery to laser crystals.

The first system developed under the three-year, $1.3-million CRADA will be used for photodynamic therapy, a type of cancer treatment in which the photosensitized cells of a malignant tumor are shot through with laser light. The light raises the cells to a higher-than-normal energy level, causing them to interact with and convert oxygen into a lethal form. The second system, which will be used to remove birthmarks, will be a small, notebook-sized flashlamp-pumped laser with a pulse length of 1 to 8 milliseconds. The third system, a thulium:yttrium-aluminum-garnet device that delivers infrared light, will be used to drill tiny holes in the surfaces of human and animal eggs to increase their probability of being fertilized by sperm.

## Industrial Computing Initiative

In 1994, we signed a $52-million, three-year agreement with Cray Research, Inc., Los Alamos National Laboratory, and eight other companies—IT Corporation, Boeing, Halliburton, Alcoa, Hughes Aircraft, Arete Engineering Technologies Corporation, AT&T, and Xerox Corporation—to do research in massively parallel computing. The machine being used for this cooperative venture is the Cray T3D, a 128-processor capable of operating at a speed of 18 billion floating point operations per second.

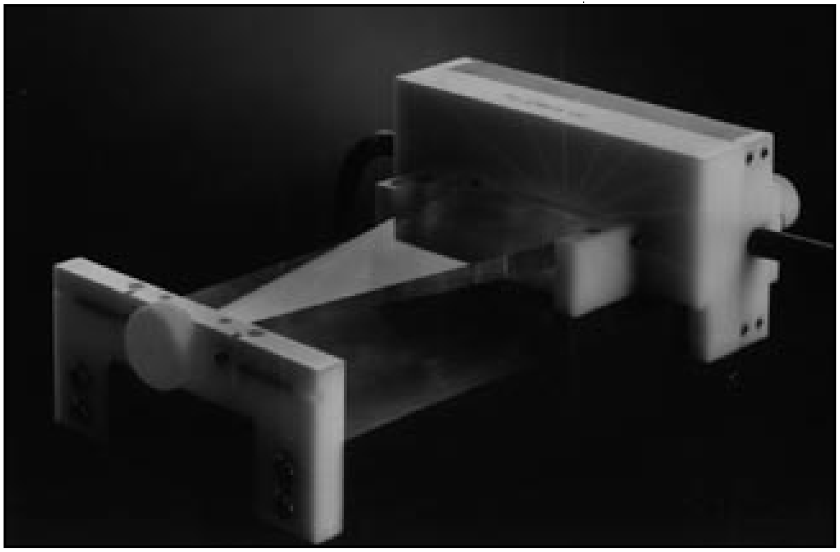
The Laboratory's goal in this project is to work with U.S. industry to develop software that will pave the way for the use of massively parallel computers in all areas of the economy. The specific goals have been defined by each industrial partner's use of the T3D:

- IT Corporation—to develop underground terrain models.
- Boeing—to develop a global atmospheric transport model.
- Halliburton—to develop software for nuclear oil-well logging.
- Alcoa—to simulate the formation of ingots from molten aluminum alloys.
- Hughes Aircraft—to design better components for communications satellites.
- Arete Engineering Technologies Corporation—to model the interaction of underwater acoustic signals and underwater objects.
- AT&T—to develop models that will predict the behavior of materials for the next generation of microelectronics.
- Xerox—to develop atomic-level material simulation codes.

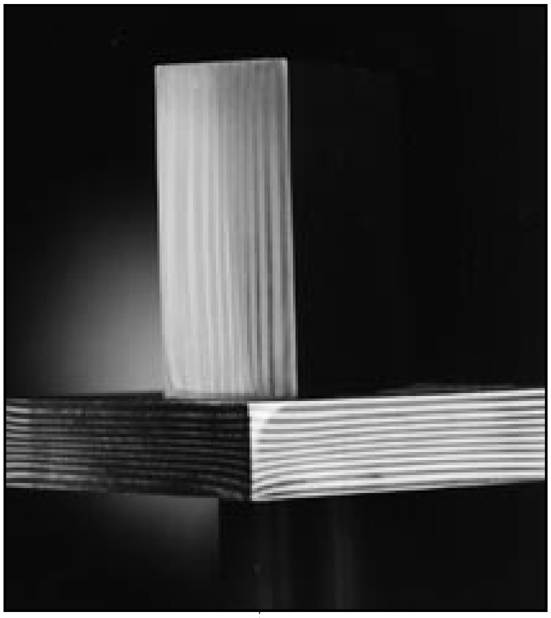
## Small Business Initiative

The Small Business Initiative (SBI) is a national effort to help small companies (those with 500 or fewer employees) overcome technological barriers by giving them access to resources at the national laboratories. In essence, the laboratories provide the companies with the assistance, facilities, or equipment they need to test and develop the products that will enable them to compete successfully in domestic and foreign markets.

Recently, the LAST Factory of Livermore, California, a small manufacturer of liquid preservatives for magnetic media (e.g., compact discs, audiotapes), came to LLNL under the SBI for help in developing a line of products that would comply with the environmental regulation to eliminate freon from all industrial products and processes. With technical assistance from LLNL and its industrial partner Allied Signal (Kansas



*The new medical laser systems we are developing with Beckman Institute and Medical Clinic incorporate two of our most recent laser technologies: a high-power, continuous-wave modular diode package that uses water and silicon-etched microchannels to cool the laser for operation at high power levels and a 350-µm-diameter optical lens that precisely channels light for delivery to laser crystals.*



*An example of the type of superconducting, multilayered, laminated metal composite material that the Laboratory and Varian are developing as building blocks for electronic devices. It is designed for toughness and fatigue behavior as well as high vibration suppression and high damping.*

City, Missouri), LAST achieved a freon-free line of products and spent considerably less than expected on R&D.

## California Manufacturing Technology Center

A memorandum of agreement with the California Manufacturing Technology Center (CMTC) and the California Community College Centers for Applied Competitive Technologies represents another opportunity for us to help small manufacturing firms gain a competitive edge. Under this agreement, CMTC members and other small- and medium-size manufacturing firms throughout the state have access to our expertise, equipment, and facilities (through training, lectures, and technical assistance). This kind of collaboration keeps us informed of the state's manufacturing needs and gives us the opportunity to meet members, introduces small firms to the latest in manufacturing technology, and helps individual firms resolve specific manufacturing problems.

## Applications for New Radar Technology

Recently, we granted a limited exclusive license to two companies for a radar-based technology developed in one of our engineering programs. One company, Amerigon Incorporated (Burbank, California), anticipates using the technology to create an on-board warning device that will alert a driver who is backing up or parking a vehicle to an object in the "blind spot." The other company, Zircon Corporation (Campbell, California) will adapt the technology for use in electronic hand tools. The key to both applications is a patented receiver that can detect echoes of rapid, wide-band radar pulses (about 1 million per second) from objects that are very close or as much as 200 feet away.

## High-Speed Cell Sorter

In 1992, we patented a high-speed cell sorter that can analyze cells and chromosomes at a rate of 20,000 per second and separate them at up to 2,000 per second, which is up to ten times faster than today's standard commercial machines. This year, we granted a limited exclusive license to Cytomation, Inc. (Fort Collins, Colorado), to manufacture and sell this technology. The license covers all research and clinical applications of the technology except for the sorting of human blood-forming cells; we granted a license for that application to SyStemix, Inc. (Palo Alto, California). This technology would also be useful in pharmaceutical research and development and in the study of infectious diseases.

## Drugs by Computer Design

Since June of this year, we have been working with BioNumerik Pharmaceuticals (San Antonio, Texas) to develop "pharmaceutical discovery software" and computer simulation techniques that can help advance research on existing drugs and provide information for developing new drugs. BioNumerik estimates that such technology could save $200 million in development costs per drug and cut the time it takes to get a drug to market by as much as six years.

BioNumerik intends to use this technology to help characterize and identify the molecular interactions of proteins or DNA that are altered by disease so that it can develop "selective" anti-cancer drugs—those that kill cancer cells but spare normal ones. The drugs will target the most common and lethal cancers (solid tumors of the lung, breast, colon, prostate, and pancreas, which do not respond to chemotherapy), and should mean better treatment and fewer side effects for cancer patients. The company also intends to use the technology to study the development of new molecules that may reverse or prevent coronary artery disease.

The software is being written in Sisal, an LLNL-developed language particularly suited to parallel programming yet also inherently portable.

This means that the software will be able to run on a variety of different machines (e.g., the Cray supercomputer family, Convex II, IBM RISC/6000, Silicon Graphics and Sparc workstations, and Encore Multimax) in a variety of environments without sacrificing performance.

## Summary

For several years, we have been working with key industries to help reach major Laboratory program goals most cost-effectively. That cooperation has often simultaneously sped the development of technology to produce better products, improve processing or production methods, and stimulate higher productivity and growth. Our relationships with these industries are thus strategic and vital because they enable us to fulfill LLNL's core missions, and, very significantly, they also provide some of the technical infrastructure necessary for successful competition in the rest of the economy.

**Notes and References**

1. According to various government agencies (Departments of Energy, Defense, and Commerce; the Council on Economic Competitiveness; and the National Critical Technologies Panel), the nation's future economic standing will be determined by industrial development in computing, electronics, machine tool manufacturing, transportation technology, materials development, information and communication technology, and biomedical and environmental technology.

2. A licensing agreement makes the Laboratory's patented or copyrighted products and processes available to industry for commercialization. A company interested in licensing a Laboratory-developed product or process will refine, manufacture, and market it, subject to fees and royalties defined in the negotiated agreement.

3. For a list of technologies available to transfer, see *Opportunities for Partnership*, Lawrence Livermore National Laboratory, Livermore, California, UCRL-TB-110794, 1993.

4. CRADAs, chartered by the National Competitiveness Technology Transfer Act of 1989, encourage the national laboratories to seek out U.S. industries for mutually beneficial research and development projects. Under such agreements, each party contributes personnel, facilities, equipment, and equal funding.

5. At the Laboratory, determinism has figured heavily in developing Laboratory machine tools such as the Large Optics Diamond Turning Machine—which maintains an overall accuracy of 0.02 $\mu$m (about 1/5000 the thickness of a human hair) across a 1.65-m contoured optical surface.

6. Included in this array of analytical tools are the Laboratory's finite-element modeling codes, which predict static, dynamic, structural and thermal behavior and break errors down into separate, identifiable components.

***For further information contact Alan Bennett (510) 423-3330.***

*The Cray T3D is the massively parallel supercomputer that will be used by LLNL and the other eight participants in the Industrial Computing Initiative to carry out research and development projects that make extensive use of massively parallel computing.*

# Education

*The Lawrence Livermore National Laboratory Education Program, as a catalyst for change, facilitates partnerships and collaborations between LLNL and the global community to contribute to systemic improvement in science, math, engineering, and technology education; ensure a highly skilled, diverse workforce; and enhance scientific and technical literacy.*

If the U.S. is to compete successfully in the world marketplace and remain a major economic power, it must have a workforce capable of understanding and applying the scientific and technological innovations that drive such competition. At LLNL, we are helping to shape that workforce through our collaborative efforts in science education. We are expanding the traditional science curricula, introducing new approaches to teaching science and math, enhancing science education through the use of technology, and providing students with opportunities to do research and earn advanced degrees. Our goals are to stimulate greater interest in science among students, teachers, administrators, and the public, and to encourage more students to pursue scientific and technical careers.

## New Science Curricula

Since 1989, we have been working with schools and educators to design relevant science curricula that incorporate technology in teaching and learning. This year, our major accomplishments in curriculum improvement have been at the high school level. We have also succeeded in developing programs and courses at the junior college and elementary school levels. Many of these courses are multidisciplinary and cross over into less traditional areas of science, mathematics, engineering, and technology. All reflect our commitment to improving science education. Among those are the following four program summaries.

*Dozens of LLNL scientists are participating in an LLNL program to become certified to teach grades K–12 in California public schools. Here, Lan T. Nguyen (right) is practice teaching at Granada High School in Livermore.*

### Global Climate Change Program

The Global Climate Change Program is a multidisciplinary curriculum in which elementary and high school teachers and students explore the physical aspects of the earth's climatic variations (for example, drought and atmospheric warming) and their social, political, and environmental effects as well. The entire curricula, developed by LLNL scientists and California teachers, received a thorough formative pedagogical review in 1994 by a group of university science educators from Oregon and Washington. The evaluators praised the creative and innovative ways used to study issues in global climate change; they also identified areas where the materials needed improvement to match "best practices" in education. Consequently, we are working to incorporate strategies for developing inquiry-based learning skills, integrating technology into the curriculum, and implementing strategies to use the curriculum to achieve systemic change in the instruction of science and technology. During FY 1994, over 50 teachers participated in workshops, including teachers from Louisiana and Georgia, and teachers from California, Nevada, and Utah who teach primarily Native American students.

### The Biotechnology Education Program (BEP)

The Biotechnology Education Program is a high-school curriculum that deals with issues in biotechnology, including genetic engineering and ethics in research. Developed and implemented with educators, parents, and representatives from the biotechnology industry, the BEP is designed to impact student learning, teacher proficiency, and school-wide dynamic relationships. The program is a two-week series of multidisciplinary courses that can be integrated with and taught as part of different school subjects such as English, Spanish, and art, or coordinated with other school activities such as school assemblies and "Back to School Night." The program was piloted in five local high schools in 1994, involving several thousand students. In FY 1995 this program will be introduced to eight high schools. In addition, we have proposed expanding this effort by establishing a network of BEP "hubs" across the country. Equipment and supplies would be provided by local partnerships between high schools and private/public institutions. We have established three possible nonlocal hubs: Tacoma, Washington; Richmond, California; and Sacramento, California. We are also entering into an agreement with a private company to develop BEP kits and publish BEP curriculum.

### The Global Security Project

The Global Security Project, our latest addition to the science and math curricula, is a course of study that draws on the Laboratory's expertise in remote sensing and imaging technologies for use in arms control and treaty verification applications. Such technologies are used to track and capture electronic images of just about anything—from a large crater on the moon to a small cell in the human body. Students in this program have the opportunity to view such images on electronic media, such as the Internet or CD-ROM, and study relevant scientific principles such as light, lasers, and digital imaging. Recently they viewed the high-resolution images of the moon's surface taken by cameras on the Clementine satellite.[1] The educational CD-ROM will be available in early 1995.

### Partnerships for Environmental Technology Education

In 1991, in an effort to improve environmental science and technology teaching at the junior college level, we established Partnerships for Environmental Technology Education. This program provides community colleges with the resources they need to develop training programs or college-prep curricula that will increase the number of qualified environmental scientists and technicians and promote environmental technology transfer. Currently, 40 community colleges in five states (Arizona, California, Hawaii, Nevada, and Utah) are participating in the program; however, with six new partnerships in the remaining 45 states, Puerto Rico, and the U.S. Territories, that figure will soon increase.

## New Approaches to Teaching Science

The Laboratory offers a variety of programs and workshops to help teachers evaluate and enhance their approaches to teaching science. In the past, the emphasis was on the use of "prepackaged" kits and materials in the teaching of science. Although such tools are effective for rote teaching and learning, they do not encourage the creative thinking and problem-solving skills necessary to scientific investigation. Therefore, we have modified our programs to emphasize an inquiry-based approach to teaching.

## Highlights for 1994

- Implemented the Global Climate Change Program, a multidisciplinary curriculum in which high school teachers and students explore the environmental, social, and political effects of the earth's climatic variations.
- Implemented the Biotechnology Education Program, a two-week series of high-school-level biotechnology courses that can be taught as part of other subjects or coordinated with other school activities.
- Implemented the Global Security Program, a high school science curriculum that draws on our expertise in remote sensing and imaging technologies.
- Worked with bilingual teachers from the Oakland Unified School District to design a science curriculum for elementary school students whose first language is Spanish or Chinese.
- Sponsored a number of inquiry-based teaching workshops to help teachers evaluate and enhance their approach to teaching science.
- Sponsored several K through 12 programs that enable students to explore science through cooperative research.
- Began developing software for distance learning, desktop video conferencing, and interactive learning.
- Began setting up a server that will enable the Laboratory's partners in education to communicate with the Laboratory directly and access the resources of the Internet.
- Began developing the software and engineering support that will be needed to access the Laboratory's scientific and technical resources.
- Implemented a program in which students are growing crystals to be used for laser research at the Laboratory.

*Our Global Climate Change Program is one of LLNL's workshops that provides opportunities for local teachers to spend the summer at LLNL developing up-to-the-minute curricula for their science classes using inquiry-based learning skills.*

In addition, we provide opportunities for educators to participate in summer-long internships as researchers in Laboratory programs and to experience first hand the scientific process and Laboratory research. Teachers return for multiple summers to continue their experiences and are encouraged to transfer their experience and new-found knowledge to the classroom, enrich curricula, and excite students with real-life applications and problems.

### Science and Technology Inquiry Partnerships

A series of workshops prepares teachers to be partners in the systemic change process and allows them to develop and implement inquiry-based curricula for science and technology. In this approach, teams of teachers work with Laboratory scientists to apply the scientific method to a problem. First, teachers examine a problem, design their own theories to explain it, and suggest ways that they might go about solving it. Second, all participants work in groups to refine their theories and develop ways to test them. They then test their theories, revise them according to the test results, and retest them. Finally, they present their results, and use the knowledge gained through the process to explore other problems.

The goal is to have teachers use the process as a model for developing inquiry-based activities in the classroom. It also serves to move teachers who have little or no science background into a realm where they can teach science with confidence and finesse. This effort is implemented in two phases. The first, Introduction to Inquiry-Based Science and Technology, brings teachers from entry level to where they can use an inquiry-based curriculum in their classrooms. The second, Inquiry-Based Study of Science and Technology, brings teachers from the adoption level through the independent/adaptation level—where they can adapt curriculum to fit the individual needs of their departments—to a level of interdependence with other schools in their district so that they can implement innovative education reform.

Most of our inquiry-based teaching workshops are offered to teachers in California; however, this coming year we will be working with teachers in Louisiana, Georgia, Arizona, and New Mexico.

### Fun with Science

In Fun with Science, LLNL scientists visit kindergarten through eighth grade classrooms and work with students' to present scientific experiments or demonstrations. Our goal with this program, as with others for this level, is to stimulate students' interest in science and heighten their curiosity about the physical world and the way it works. In keeping with our approach to promote systemic reform, this program is coordinated with our Science and Technology Inquiry Partnership workshops, so that teachers who have participated in it present the Fun With Science demonstrations to their students in tandem with LLNL scientific and technical staff. The teachers then continue promoting science and technology with their students, and the impact is sustained in the classroom. This year, more than 20,000 students have experienced Fun With Science activities.

### Student Science Research Associates (SSRA)

We sponsor programs in which kindergarten through 12th grade students explore science through cooperative research teams and develop problem-solving skills necessary to succeed in the changing workplace. The goal is for students to form research teams and use computers and data recording and analysis tools to study complex global issues. They also use electronic communication networks to share ideas and discoveries with their research mentors at LLNL and with students who are doing similar research at other schools. For example, this school year students from several northern California school districts are conducting water-quality research in their communities and sharing their results via electronic mail. Teachers will guide student work in research teams to ask questions; gather background knowledge; develop a research plan; use technology to collect, analyze, and interpret data; communicate results and findings; and develop community action plans. The current topic of study is water quality; partners include Adopt a Watershed and Global Rivers Environmental Education Network and its affiliated EcoNet, an environmental network and bulletin board.

An outgrowth of this effort is the International Science Partners project, a collaborative effort among LLNL, Los Alamos National Laboratory, and Oak Ridge Institute for Science Education. The program joins students and teachers from schools in North America with those from schools overseas in collaborative teams. Teachers and students have come from California, New Mexico, Texas, Tennessee, Mexico, and Obninsk, Russia. During summer 1995 we will be adding teachers (and their students) from Chelyabinsk-70 and Arzamas-16, Russia; Dresden, Germany; and the Hopi and Navajo Nations.

## Improving Education through Technology

As a center for research and development, the Laboratory has always been committed to advancing technology and demonstrating its applications in science. Now we are extending this commitment to education. We are developing software for learning at a distance, desktop video conferencing, and interactive learning so that we can bring scientists and technical specialists “into the classroom.” We established a server (on the Internet) so that our partners in education are able to communicate with us directly.[2] And, through our association with the Science Education Academy of the Bay Area[3]—a cooperative effort between the DOE and various Bay Area organizations to improve education through technology—we are developing the software and engineering support needed to access the Laboratory’s scientific and technical resources.

In addition to developing educational technology, we are teaching students and teachers how to use it. For example, we run LLNL’s Science Education Center, where students and teachers learn to use computers and telecommunications equipment by participating in a class or working on a special project. Since 1984, more than 2500 students and 500 teachers have taken advantage of this resource. We also offer summer workshops in which teachers can learn how to use the National Education Supercomputer (NES)[4] and how to apply supercomputing to the classroom. In the NES user workshops, the object is to turn out master teachers who train their peers and thereby extend access to the NES. In the application workshops, participants develop curricula that they can use for the next school year. At the end of the school year, each participant reports on his or her new curriculum, telling how it was used, whether it benefited the students or enhanced teaching methods, and how it can be improved for the following year.

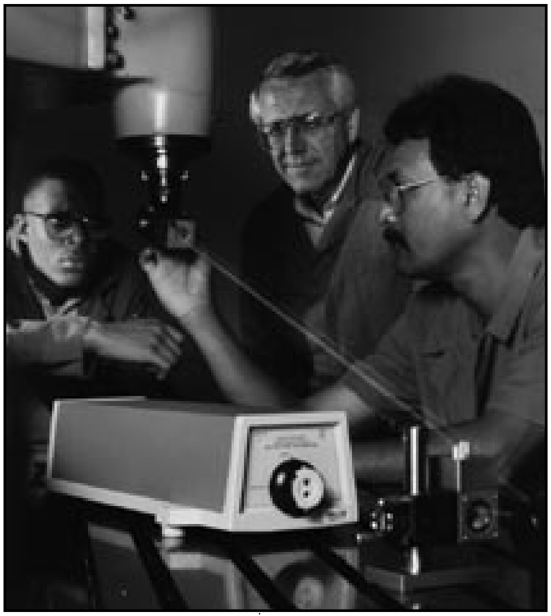

*Students from Fort Valley State College, Fort Valley, Georgia, toured LLNL’s National Energy Research Supercomputer Center and learned about our Cray computers. The visit was a part of our collaboration in the HBCU Cooperative Developmental Energy Program sponsored by the Department of Energy.*

## Opportunities for Research and Advanced Degrees

In the late 1950s, Dr. Edward Teller observed that government-supported basic science and industry cherished engineering, but no one laid claim to applied science—a body of knowledge that fell somewhere between the two and that depended on researchers who were well educated in several disciplines rather than one. Although by this time applied science had become the norm in research and product development, it still posed a problem: how to assure a continuous flow of R&D research talent when there were no institutions that “taught” applied science. Recognizing the need for such institutions, Teller and Roy Bainer, Dean of the College of Engineering at UC Davis, proposed having a graduate center in applied science at the Laboratory. In the fall of 1963, with the opening of the UC Davis Department of Applied Science, their idea became a reality.

### The Department of Applied Science

The Department of Applied Science, now in its 31st year, combines traditional training in science with very progressive training in application. Students find the program attractive



College-level students reap collaborative research opportunities in our laser program as part of our work to shape the future scientific work force.

because it offers them a great deal of latitude: they may pick a thesis advisor from among several hundred researchers at the Laboratory, take all of their courses at the Laboratory from faculty or senior researchers, and, with the guidance of seasoned Laboratory professionals, perform their research using the Laboratory's unique facilities and equipment. Since 1963, 189 students have earned Ph.D. degrees. Of these, 57 work at LLNL, and another 26 worked at other national laboratories upon receiving their degrees.

### Internships and Institutes

In addition to the graduate program in applied science, the Education Program offers a variety of internships and institutes. For example, through our association with the Associated Western Universities—a consortium of universities devoted to preparing students for scientific and technical careers in government, business, and industry—we provide an on-site program in which students choose their own projects and perform research under the supervision of Laboratory scientists. Approximately 50 students enter the program each year. They usually complete their internships over several summers and then seek employment. We are working with DOE to find out where these students ultimately are employed and what career paths they have chosen.

Every summer we offer a two-week institute to students in their junior year of college. The program is structured so that the students spend their mornings at lectures and their afternoons working with researchers on projects in applied physics, chemistry, mathematics, or engineering. At the end of the two weeks, the students present the results of these projects at a poster session. Since 1983, approximately 700 students from colleges and universities throughout the country have attended this institute.

We host the DOE Science and Engineering Research Semester, a program in which undergraduate students (women and minorities in particular) spend a semester as professional researchers at a national laboratory. At LLNL, these students spend 80% of their time on a Laboratory project and 20% of their time in seminars, technical communication workshops, and supercomputing courses. The intent of the program is to encourage the students to pursue advanced degrees and, ultimately, careers in science and engineering. Since the program was implemented, we have sponsored over 60 students from all over the U.S. The students receive a stipend for their work and credit for the supercomputer course. Many of the students also are able to receive credit for their research through their undergraduate institutions.

### Targeting Diversity

Many of our college-level programs are specifically designed to encourage a wider and more diverse segment of the student population to pursue careers in science and engineering. For example, since the early 1970s, we have been helping historically black colleges and universities[5] enhance their science and engineering programs through the loan or donation of equipment and the presentation of workshops, seminars, or conferences. Over the last few years, the focus of our relationship with these institutions has been on collaborative research. This year, we implemented a program at Fisk University in which students are growing crystals to be used in laser research at the Laboratory. We also facilitated a collaboration between Spelman College and Morehouse College (both of Atlanta, Georgia) that has resulted in a new physics project. The experimental work for the project will be done at Spelman, the theoretical research at Morehouse.

Through our collaboration with the American Indian Science and Engineering Society, which began formally in 1982, we are helping the Navajo Community College revamp its science program, and we are offering teaching enhancement courses for elementary school teachers on the Navajo Reservation.

As a member of the National Physics Education Collaboration, which encourages minority college students to pursue advanced degrees in physics, we sponsor nearly 20 minority physics students, selected nationwide, in an eight-week summer research project. This program, in collaboration with California State University, Hayward, is to increase the pool of physics researchers by increasing the number of students pursuing advanced degrees in physics.

As a member of the National Physical Science Consortium, a collaborative effort among academia, business, and industry to prepare women and minorities for careers in the physical sciences, we support women and minority students earning advanced degrees in chemistry and physics. This year 15 students from institutions throughout the country came to the Laboratory to do research for their doctoral degrees. The first such student from LLNL to achieve a Ph.D. will be graduating during the coming year.

### Teacher Certification Program

Two years ago, in collaboration with representatives from San Jose State University, LLNL's Employee Development organization initiated a program in which Laboratory employees with advanced degrees in science or math could earn a single-subject secondary teaching credential. The first class consisted of 24 students with specialties in physics, chemistry, geology, engineering, and math. We currently have students practice teaching at several junior and senior high schools in the area; our first students will receive their credentials in January 1995.

## Summary

We are developing new science curricula, changing the way science is taught, providing enrichment opportunities for teachers, bringing technology to the classroom, and providing more opportunities for students to do research and earn advanced degrees. We hope to stimulate greater interest in science among teachers, students, and administrators; encourage more students to pursue careers in science; and foster a technically and scientifically literate generation. Our ultimate goal is to help shape a work force that can produce the scientific and technological innovations needed to sustain a strong national economy and a competitive edge in the world marketplace.

*Figure 5. Students from Hart-Ransom School in Modesto, California, conduct water-monitoring research in the field with LLNL "mentors" as part of the Student Science Research Associates (SSRA) Water Quality Project.*

**Notes and References**

1. For more information on the Laboratory-developed sensors for the Clementine satellite cameras, see the June 1994 issue of *Energy and Technology Review* (UCRL-52000-94-6).

2. This server will also be available to other national laboratories for the same purposes.

3. At last count, SEABA included four national laboratories; several offices of education; the California state universities; the U.S. Geological Survey; Marine World Africa USA, Vallejo, California; the Monterey Bay Aquarium; the San Francisco Exploratorium; the Corporation for Public Broadcasting, KQED, San Francisco; the California Academy of Sciences; NASA Ames Research Center; and the San Francisco Zoological Society.

4. In 1990, Cray Research, Inc., donated one of its supercomputers to the DOE for the sole purpose of education. Today this computer, known as the National Education Supercomputer is housed in the National Energy Research Supercomputing Center at LLNL.

5. The schools associated with this program include Howard University, North Carolina A&T State University, Southern University and A&M College, Spelman College, Morehouse College, Fisk University, Fort Valley College, Clark Atlanta University, Alabama A&M University, Jackson State University, and Prairie View A&M University.

***For further information contact Eileen Vergino 424-0567.***

# Operations and Administration

*We are enhancing the operations and management of the Laboratory to ensure the continued viability of our scientific and technical programs and to respond to a changing set of expectations and requirements.*

A critical factor in maintaining a world-class scientific research organization is the ability to embed that research in a working environment conducive to and supportive of the unique demands of specialized work. In addition to fostering research, the Laboratory's environment must provide for the safety and health of its employees and the public, serve the business and personnel needs of programs, protect the natural environment, and, in the case of national defense research, protect the security needs of the nation. The Laboratory conducts a vast array of operational and administrative functions to achieve a successful working environment.

LLNL is intimately involved in the changes that are sweeping through the business practices of U.S. industry and government. We are seeking to enhance our management and operational functions at every level. In addition, we are operating under a new, performance- and incentive-based contract to which the University of California (UC) and the DOE agreed in 1992. This contract provides a framework to assist our efforts toward enhanced management. We report here on several major operational functions in the context of the past year's progress toward improvement.

*LLNL's Mike Holda (left) received a DOE Individual Achievement Award from Bill White, Deputy Secretary of Energy, for his contributions to energy efficiency.*

## Plant Operations

Plant Operations provides the Laboratory and its programs with quality services and support in the areas of environment, safety, and health (ES&H); physical plant services; information services; and quality assurance. With an operating budget of more than $150 million and 1600 employees, the directorate is composed of the Environmental Protection Department, the Hazards Control Department, the Health Services Department, Plant Engineering, Information Systems, and the Laboratory Assurance Office.

Our commitment is to meet our customers' needs with responsive, cost-effective, and innovative services. We ensure a work place that runs smoothly and is environmentally safe. We also pursue research and development challenges of importance to both the institution and the nation.

Plant Operations has taken the lead in implementing Continuous Quality Improvement (CQI) at the Laboratory. CQI is an important tool to achieve the dual goals of improved services and lower costs. Activities during the past year included cosponsoring the Quality Tools Forum with Sandia National Laboratories, providing briefings by outside industry leaders on R&D Quality for the Senior Management Council, and continuing the implementation of CQI within each organization.

All Plant Operations departments have established CQI councils and identified Process Action Teams, which recommend changes in work systems and monitor their implementation. We have made notable achievements in several areas this year.

**Maintenance Windowing.** Plant Engineering is using maintenance windows to schedule routine, preventive, and corrective maintenance. All work in a given facility is scheduled in a window or time frame of three to four consecutive days every three to six months. Maintenance windowing better utilizes maintenance funds for real property and installed equipment, reduces the impact of maintenance on daily operations, and facilitates the most effective deployment of workers and material. Our approach to preventive maintenance resulted in an average facility productivity improvement of 27% and a projected cost avoidance for FY 1994 of $300,000.

**Graded Approach Maintenance.** Plant Engineering developed and is now implementing a graded approach for both institutional and programmatic systems and equipment. The graded approach allows us to tailor our maintenance resources by analyzing the relative importance of each facility in terms of safety and security requirements, environmental compliance, programmatic needs, and other requirements. This approach to maintenance has been adopted as a DOE standard.

**Condition Assessment Survey (CAS).** In 1993, the DOE developed the CAS concept as a standard methodology for assessing the physical condition of its facilities. LLNL was selected as the site for testing and implementing the CAS system. Representatives from DOE and the leading CAS contractor visited LLNL in May 1994 to observe our implementation. After a week of intensive review, the DOE declared LLNL a model for all its contractors and asked us to develop presentations at DOE meetings and conferences.

Working with the business departments and new technologies, the Administrative Information Systems department has contributed to a more efficient business environment. The new technologies include document imaging applications, use of digital signature to allow electronic transactions, and broader use of electronic commerce. The objective is to allow users easier access to business data and to improve productivity by reducing time on administrative tasks.

The Library of the Future project in the Technical Information Department is quickly moving toward electronic access to information. Laboratory administrative and personnel policy information is now available on-line, IEEE journals

## Highlights for 1994

### Plant Operations

- Developed a cleanable steel HEPA filter that could save the DOE $42 million annually.
- Created a simulated highbay for fire-testing drums of hazardous waste.
- Received our second consecutive “100 Best Employers for Bay Area Commuters” award.
- Helped the Center to Protect Workers’ Rights evaluate worker exposure to lead paint.
- Established a fiber-channel testbed for independent testing of vendor products.
- Evaluated keyboard designs for their ability to prevent cumulative trauma disorders.
- Connected LLNL to the Bay Area Gigabit Network to develop and deploy a computer multimedia network infrastructure.
- Developed and tested interconnections from our local high-speed networks to the UC network, XUNET, which connects nine research laboratories and universities.

### Controller

- Implemented a new financial methodology for distributed and indirect costs.
- Implemented new or improved electronic cost transfers, electronic time entry, automated field budget submission, reimbursable work system, and signature responsibility system.
- Implemented a financial management training program.

### Business Operations

- Received a “Best Practice” designation from the DOE for LLNL’s property program.
- Received an “Exceeds Expectations” designation from the DOE and UC for our property and procurement programs.
- Reduced the cost of operations by $4 million, and reduced the stores inventory by $3.2 million.

### Safeguards and Security

- Implemented major cost-effective initiatives, including automated pedestrian portals between security areas and a reduction of classified workstations.
- Developed and activated the DOE Automated Visitor Access Control System (DAVACS), which eliminates time-consuming, labor-intensive forms and reduces delays.
- Helped develop the DOE Safeguards and Security Systems/Electronic Transfer (DISSS/ET), which automates the security-clearance process throughout the DOE complex.

### Human Resources

- Implemented the Resumix system to streamline the employment process.
- Modified the “Term Employment” policy to allow five-year appointments and to attract a well-qualified, flexible work force.
- Opened a Career Center that provides career counseling, skills assessment, and training.
- Documented position responsibilities and duties for 95% of LLNL employees.
- Provided a Management Certificate Program covering team building, financial analysis, and TQM.

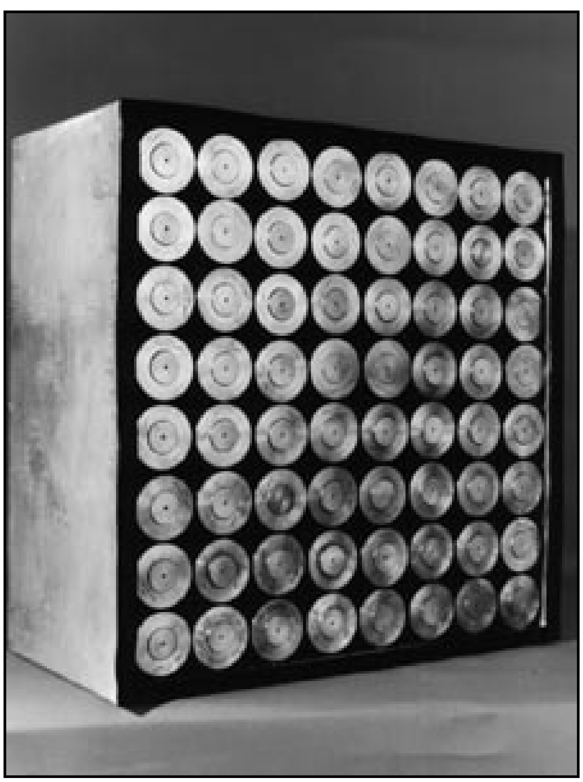
are available via CD-ROM, and unclassified Laboratory reports with unlimited distribution are being made available electronically.

The Telecommunications Systems Department now provides full-service operation around the clock and processed 44.5 million calls in 1994. Among its cost-saving measures were the implementation of a new external network connection that reduces connection costs by $110,000 and reconfiguration of the emergency telephone system for an annual savings of $60,000.

We place high importance on meeting the Laboratory's commitment to ES&H. Several key developments occurred in this area in FY 1994.

**CHemical Exchange Warehouse (CHEW).** As part of our overall recycling effort, the Environmental Protection Department implemented a process by which unused, excess chemicals could be stored for future use (also see p. 38). This process reduces both the cost of purchasing new chemicals and the Laboratory's waste stream.

**Case Management.** Improved case management by the Health Services staff has reduced the time lost due to injury. Improved on-site treatment, follow-up, and a managed-care approach have resulted in earlier return to work by employees and reduced long-term disability. The outcome was a reduction in the workers compensation rate with a savings of about $200,000 in FY 1994.



*A prototype HEPA filter contains 64 cartridges of stainless-steel fiber media, making it more reliable and environmentally safe than previous paper filters. It can be cleaned in place, saving workers from exposure and eliminating the need for and cost of processing radioactive particulate waste.*

**Energy Management.** The Laboratory's Energy Management Program received five energy-efficiency awards in FY 1994. From the Federal Interagency Energy Policy Committee, we received one Organization Award for energy efficiency and alternative fuels, one Small Group award for water conservation, and one Individual Achievement award. We also received two In-House Energy Management awards from the DOE for water conservation. For the second consecutive year, the Transportation System Management Program received the "100 Best Employers for Bay Area Commuters" award from Rides for Bay Area Commuters for its outstanding contributions in promoting alternatives to driving.

**Filter Development.** Hazards Control is developing a cleanable, steel, high-efficiency particulate-air (HEPA) filter. This filter could save the DOE $42 million each year in HEPA maintenance and waste disposal costs, and the steel media will improve reliability. The latest prototype exceeded the required 99.97% efficiency for 0.3-mm dioctyl phthalate aerosols. Tests also showed the filter was readily cleanable by reverse air pulses. We are now focusing our efforts on reducing the pressure drop to meet DOE requirements and standard industry practices.

**Liquid-Filtration Model.** We have developed a theoretical liquid-filtration model that simulates particle removal in realistic liquid filters. The computer code uses rigorous three-dimensional hydrodynamics flow through complex fiber matrices and particle-capture mechanisms due to Brownian motion, inertia, and electrical forces. The model will be used to develop improved liquid filters at a fraction of the cost of the current empirical method.

Plant Operations is striving for additional improvements. Our objectives for the coming year include moving the CQI program to the next level and developing an improved, risk-based budget prioritization system with broad applicability and good correlation with subjective management judgment. We will also help develop an institutional awareness and understanding of the ES&H performance measures and a system for their timely monitoring and management.

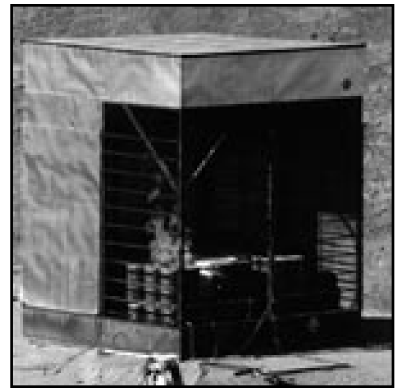
## Controller's Organization

With annual budgets of about $1 billion, were the Laboratory a "for-profit" company, we would be in Fortune magazine's list of the top 500 companies. Instead of reporting to stockholders, however, we are charged with the responsible stewardship of taxpayers' money.

The Controller's Organization helps to ensure that program accomplishments are achieved within the boundaries of good financial business practices. The Lab has a good record in this area, and, in the spirit of CQI, we are trying to reach beyond that achievement. Good financial business practices will always be the top priority for us, and this includes seeking ways for improving the Lab's cost effectiveness and enhancing our customer focus.

We have changed the way we budget and account for distributed and indirect costs. The basis for the new financial system is the separation of distributed personnel management, program management, and facility costs, and the distribution of these costs to the program that receives the benefit. The intent is to provide additional consistency in the distribution of costs across activities, to make costs more visible, and to closely tie the distributed/indirect costs back to all programs on a causal-beneficial basis. The new approach will help managers make more informed business decisions based on true costs, thereby allowing appropriate sizing of activities.

An achievement that has drawn favorable attention outside the Lab is our implementation of automated financial systems. Developed by the Controller's Organization, these systems benefit LLNL programs and operations by providing timely, accurate, and accessible financial information. Recent examples include the electronic cost-transfer system and the electronic time-entry system. The Finance Department, Budget Office, and Resource Information and Analysis Office are involved in systems projects that have gained considerable visibility. As a result, the DOE and other laboratories refer to some of our systems as models to be followed. For example, the DOE is exploring the possibility of adapting LLNL's automated field-budget process for use on a department-wide basis. Future financial requirements are expected to put greater demands on our systems. Thus, we have initiated actions to be ready with appropriate Lab-wide financial systems.

*Fire testing of flammable liquid waste drums at Site 300. Without controls (left), fire caused a drum of volatile liquid to fail, producing a 4-inch split in the top of a drum and a much larger fire. In a facility with closed sides and no wind (right), we were able to control the fire.*

As our financial operations become more complex, it is important that Lab employees who use the system understand it. We continue to expand a curriculum of courses that enables individuals to acquire and maintain the financial skills they need. We are also teaching an overview course on the financial management system for managers, researchers, and others who do not need specialized knowledge in financial management.

## Business Operations

The past year has been one of dramatic change for the Business Operations organization. The process of providing business support to Laboratory programs is increasingly subjected to federal rules as a result of the new UC/DOE contract. We also see greater federal involvement in our operations, most notably in procurement. In response, we rebuilt many administrative systems to more closely model federal practices. Performance measures in Appendix F of the new contract lent a sense of urgency to these changes.

In FY 1994, we received DOE ratings of "exceeds expectations" in both the property and procurement areas. Now that we are in compliance with DOE expectations, we are operating with a new theme: "1995—The year of the internal customer." Our focus is to modernize and streamline operations so we can minimize the time and cost implications of a more detailed administrative system.

Property became a pressing issue within the DOE due to problems encountered at other sites. In contrast, LLNL's property program—particularly its PRISM information system—was identified as a "best practice" by the DOE. The DOE also highlighted socioeconomic contracting as a primary goal for FY 1994. After receiving ratings of "marginal" in 1991 and 1992, we met and exceeded much higher goals in all categories during the last two years.

Business Operations has embraced the DOE and LLNL quality initiative. This year, we enhanced our operations through the activities of Quality Councils and 17 different Quality Action Teams. To further improve operations and limit management layering, we initiated a re-engineering project to change the ways we perform our work. This, along with reducing our organization from three departments to two, enabled us to reduce our budget request for FY 1995 by $4 million.

Our Stores project represents another major contributor to reduced costs. The Lab's large, antiquated warehouse and store, with an inventory level of over $6 million and an exceptionally high cost of operation, had no automated inventory management system. In less than one year, we reduced the inventory by more than $3 million, eliminated millions of dollars of slow-moving or obsolete items, and reduced the cost of operation by more than $2.5 million.

*Our ergonomics lab uses three-dimensional motion-analysis instruments. This sensor-based hand-tracking system can evaluate the use of alternative keyboards and the risks of repetitive-motion problems.*

To modernize our low-value commodity-acquisition process, we will put into place a new inventory-management system. The system will take full advantage of Electronic Commerce, Electronic Data Interchange, and common commercial practices such as "just-in-time" inventory methodology. At the same time, we will take full advantage of the recently signed Federal Acquisition Streamlining Act. Finally, by expanding the Laboratory's credit card program, we can empower our employees to make purchasing decisions in the low-dollar arena.

## Safeguards and Security

The Safeguards and Security Department is charged with protecting national security information and providing physical security at the Laboratory. Among our efforts, the SAFE Program (which stands for Security Awareness For Employees) identifies and counters foreign intelligence threats against Lab personnel, information, and technologies. Operations Security (OPSEC) is designed to delay or deny an adversary's ability to exploit pathways to our critical and sensitive information.

We continue to address changing Laboratory needs by implementing strategic planning initiatives and pursuing quality improvements. Our managers empower their staff members to continually assess areas of responsibility and to identify alternative approaches that can increase effectiveness and customer satisfaction while meeting the intent of DOE directives. During FY l994, we completed more than 80 self-assessments and reviewed the resulting issues monthly.

The cost-effectiveness initiatives we implemented in FY 1994 resulted in savings of more than $3.5 million. These initiatives included installing automated pedestrian portals between security areas, consolidating badge operations into the new Westgate badge office, and reducing classified workstations throughout the Lab. Among the initiatives planned for l995 is the risk-based manner in which services are provided to support a high-security area. We anticipate annual savings of nearly $2 million for Defense Programs.

Unique among DOE labs is an ongoing process to share resources with Sandia National Laboratories, Livermore. Assets and capabilities in excess of $400,000 have been identified to date. Similarly, we focused on redesigning the entire DOE contractor personnel security processing system to achieve end-to-end automation, improve customer service, and reduce costs.

Our department was assigned a rating of "Exceeds Expectations" by both the University and the DOE in FY 1994. The rating was a direct result of management support, dedication, and teamwork across all components of the department.

## Human Resources

The Laboratory's most important resource is its people. Human Resources is working to create an environment that encourages individuals to reach their maximum potential for the benefit of both individual workers and the programs that employ them. In seeking to recognize and better understand human differences, our ultimate objective is a diverse, highly talented, and productive Laboratory work force.

The functions of Human Resources include work force planning, education and training, career counseling, and many other activities. Work force planning, for example, involves identifying and recruiting qualified candidates, and retraining and reassigning employees when the objectives of certain programs change. We help to ensure consistent policies, compensation, and benefits. We also make important contributions in the areas of facilitated planning, team building, and quality management.

This year, as requested by the Council on National Security, we facilitated interdirectorate planning groups that will enhance collaboration among LLNL directorates with common program interests, such as High Energy Density Physics and the Primary Program. We worked extensively with associate directors in areas such as business planning, reorganization, and re-engineering. We provided high-level management consultation and process facilitation services to the DOE and UC.

We also responded to the DOE's call for exposure of LLNL leadership and staff to Stephen Covey's writings and to the principles of Total Quality Management (TQM). Several of our staff members are certified to deliver workshops on Covey's Seven Habits of Highly Effective People. Over the last two years, 442 Lab people have graduated, including 87 supervisors and managers.

We have implemented the Resumix system, which allows resumes to be optically scanned, screened, and transmitted electronically. Resumix streamlines the employment process, reduces recruitment costs, and enhances our ability to find qualified candidates, including women and minorities. A new Career Center opened this year to provide employees with skills assessment, training, and information about job opportunities both inside and outside the Laboratory.

Among many other improvements this year, we have put in place an automated benefits enrollment process, an institutional repository of completed courses, and an integrated Human Resources payroll system for FY 1995. Our new documentation on the duties and responsibilities of practically all LLNL career positions will support the Lab's compensation, performance management, and career development objectives.

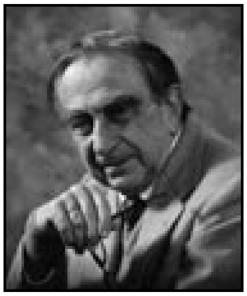
## Summary

The Laboratory's Administration and the Plant Operations Directorate supply the essential services the Laboratory and its programs need to function efficiently. They also ensure that the Laboratory complies with applicable business practices, regulatory requirements, ES&H, and facility maintenance, and that it deals effectively with issues related to work force diversity. In response to the new era in which we operate, including our new UC/DOE contract, TQM, and many other issues, we have made substantial progress in enhancing the management of the Laboratory.

***For further information, contact***
***Robert W. Kuckuck (510) 422-2371.***

# Awards

*LLNL's long-standing reputation for excellence has been earned in part through the efforts of its scientists, researchers, engineers, and supporting staff. In 1994, many of the Laboratory's people were honored with awards and fellowships to professional societies.*



**Edward Teller**
*Middle Cross with the Star of the Order of Merit*

## Middle Cross with the Star of the Order of Merit

Dr. Edward Teller, one of Hungary's most famous native sons, has been awarded the Middle Cross with the Star of the Order of Merit. The republic's highest civilian decoration has been awarded only a handful of times in the past. Teller, who was born in Budapest in 1908, was recommended for the decoration by Hungarian President Arpad Goncz for Teller's role in ending the Cold War, thereby helping to free Hungary, and in his continuing contributions to the nation.

Pal Tar, Ambassador to the U.S., presented the medal, noting that Teller had been declared *persona non grata* in Hungary for many years, but "as soon as Hungary opened up and started on the road to democracy, Professor Teller never hesitated to go back to his homeland and to think about the problem of his fellow Hungarians . . . full of ideas and projects which I am sure will contribute greatly to the well being of Hungarians and Hungary." Tar also quoted Eugene Wigner, the Nobel prize winner and Teller colleague who also knew Einstein: "Teller is the most original thinker among those I have ever met."

This is the second award Teller has received from Hungary in the last four years. In 1990 he was awarded the Order of Banner with Rubies of the Republic of Hungary for his achievements in science and for "serving the universal welfare of humanity."

**James Wilson**
*Marcel Grossmann Award*

## Marcel Grossmann Award

James Wilson, a physicist in his fifth decade at the Lab, received a prestigious Marcel Grossmann Award in July 1994, at the Seventh Marcel Grossmann Meeting on General Relativity, at Stanford University. The award honored Wilson "for having built on his experience in nuclear physics, thermonuclear reactions, and extensive numerical simulation to create a new testing ground for the novel concepts of relativistic astrophysics."

Marcel Grossmann (1878–1936) helped Einstein develop the mathematics of general relativity. This year marks the fourth distribution of the Grossmann Awards. Previous recipients include such notable physicists as Stephen Hawking and Nobel prize winner Abdus Salam. The other individual Grossmann Award in 1994 was given to Nobel laureate Subrahmanyan Chandrasekhar of the Enrico Fermi Institute, the University of Chicago. An institutional award was given to the Space Telescope Science Institute at Johns Hopkins University.

With a bachelor's degree in chemistry from UC Berkeley, Wilson went to Los Alamos, New Mexico, in 1943 to work on the Manhattan Project. Deciding that physics was his true calling, he earned a Ph.D. in physics in 1952 (also from UC Berkeley). He has been at LLNL since 1953, having begun in nuclear physics and weapons design but turning to astrophysics in the late 1960s. He addressed such fundamental areas as black holes, supernovas, gravitational waves, and relativity. As computer speeds accelerated over the years, Wilson increased the sophistication of the physics in his models, studying rotating magnetized supermassive stars, the accumulation of matter into black holes, and the role of hydrodynamic instability in astrophysical processes. These and other studies established Wilson as one of the world's pioneers in applying computational techniques to hard-to-measure natural events.

Some of Wilson's recent research has been an investigation of gravity radiation given off by colliding neutron stars. He hopes that observations from LIGO, the gravity wave detector now under construction at Hanford, Washington, and Livingston, Louisiana, will corroborate his numerical experiments. Wilson is also well known for his research on supernovas. He has also modeled heavy ion collisions, identifying the role played by subnuclear particles, called pions, in events involving matter packed into incredibly high densities, such as supernovas.

Wilson officially retired in 1988, but continues to work full time at the Laboratory. He is designing a supernova burst observatory to detect particles called tau neutrinos given off by supernova explosions in our galaxy. Wilson and collaborators are seeking funding to build this facility near Carlsbad, New Mexico.

Wilson is a fellow of the American Physical Society. He has been awarded visiting scientist positions at the University of Rome, Vatican Observatory, and Hebrew University.

## Awards for Excellence in Technology Transfer

LLNL has aggressively pursued opportunities to sustain U.S. national security interests through technology transfer, the dissemination of Laboratory discoveries, and inventions into civil industrial and commercial applications to enhance U.S. economic competitiveness. In 1994 the Federal Laboratory Consortium gave Laboratory researchers four awards for excellence in technology transfer. These are more awards than were won by any of the other more than 650 government laboratories and research centers that make up the consortium. The consortium was formed in 1974 to help the public and private sectors exploit technologies developed by federal research laboratories. Awards were given to

- Precision engineer Dan Thompson, who has directed four Cooperative Research and Development Agreements (CRADAs) in machining and engineering with U.S. companies. Thompson has also directed the development of a series of machine-tool metrology workshops with the Society of Manufacturing Engineers.

In early 1992, Dan Thompson helped establish the Livermore Center for Advanced Manufacturing and Productivity, or LCAMP, which helps bridge the gap between the Lab's technological capabilities and the needs of U.S. manufacturing companies. To date, LCAMP has assisted in developing about 25 CRADAs at the Lab.

- Chemist Dan Makowiecki, who designed a new type of magnetron sputtering source that has been licensed to a California-based firm. (Sputtering is a vacuum coating process used to protect compact disks and integrated circuits.) The new magnetron sputtering source is a revolutionary, simple design that uses ceramics to remove process heat and eliminate the problems associated with direct water cooling.
- Metallurgists Alfred Goldberg, Don Lesuer, Mike Strum, Stephen Root, Dick Landingham, and technician Paul Curtis, who have transferred a superplastic steel technology to two companies. Since late 1988, this team of Livermore scientists has been working with Stanford University, a steel company, and a heavy equipment manufacturer to move superplastic steel technology from initial research to production-scale demonstrations. (Superplastic steel can flow like molasses under pressure and high temperature into complex shapes or dies, substantially reducing the need for welding, machining, and joining processes, which typically represent at least 25% of the cost of parts.)
- Mechanical engineers Robert Whirley and Bruce Engelmann, who helped transfer the computer program DYNA3D, used in analyzing impacts upon structures, to private industry. For the past several years, engineers Whirley and Engelmann have helped transfer the Lab's computer program to outside users; it is now used by some 750 companies, research laboratories, and universities. One of LLNL's most successful technology transfers ever, DYNA-like programs annually save U.S. industry $350 million.

**Dan Thompson**

**Dan Makowiecki**

*Back row from left to right:* **Paul Curtis, Alfred Goldberg, Don Lesuer, and Dick Landingham,** *Front row from left to right:* **Stephen Root and Mike Strum.**

## The R&D 100 Awards

Each year *R&D Magazine* selects the 100 most technologically significant products and processes submitted for consideration and honors them with an R&D 100 award. Winners are chosen by the editors of the magazine and a panel of 75 experts in a variety of disciplines. Corporations, government laboratories, private research institutes, and universities throughout the world vie for this “Oscar” of applied research. The R&D 100 judges look for products or processes that promise to change people’s lives, such as by significantly improving the environment, health care, or security. Since the competition began in 1963, the Laboratory has won over 55 R&D 100 awards.

In 1994, Laboratory researchers received six R&D 100 awards. Michael D. Perry, Robert D. Boyd, Jerald A. Britten, Derek E. Decker, Bruce W. Shore, and Howard T. Powell shared an award for developing multilayer dielectric gratings for use with high-power lasers. The far superior resistance of these gratings to optical damage compared to conventional metallic gratings allows the use of much greater effective laser intensities.

James J. DeYoreo, Natalia P. Zaitseva, Russell L. Vital, and Kenneth E. Montgomery received an award for developing a method of growing high-quality KDP crystals some 10 to 40 times more quickly than conventional methods, thus promising great savings in laser technology and all other fields requiring high-quality crystals.

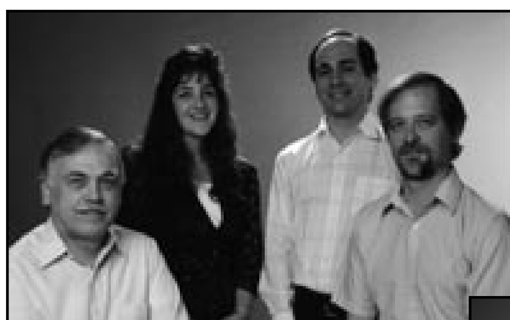
Stephen A. Payne, Laura Deloach, Larry K. Smith, and William F. Krupke received their award for developing ytterbium-doped apatite laser crystals, which have 2.5 to 5 times the energy storage of other crystals and can therefore fully exploit the advantages of diode-pumped lasers.

David J. Hopkins received an award for developing a high-precision, low-noise amplifier that increases the resolution of sensors called linear variable differential transformers, used for measuring surface irregularities in precision engineering and manufacturing.

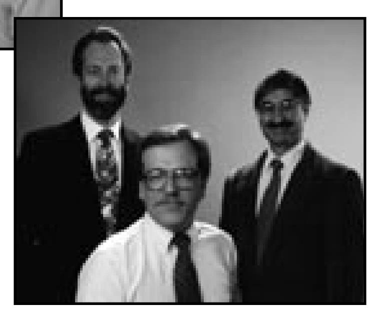
Michael D. Pocha, Oliver T. (Ted) Strand, and Daniel C. Nelson shared an award for developing a process and hardware for aligning single-mode opto-electronic fibers and components at submicron tolerances in very short times. The enormous potential savings in cost makes new communications standards economically possible for operation well above 1 Gb/s.

James D. Tucker received an award for developing DNA probes that color or “paint” chromosomes of the common laboratory mouse to

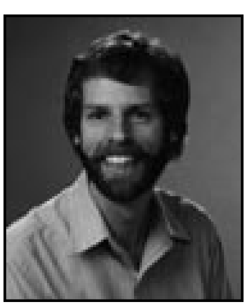
*This page:*
**R&D 100 award winners.**
*From left to right:*
**Bruce W. Shore, Jerald A. Britten, Robert D. Boyd, and Michael D. Perry. Derek E. Decker and Howard T. Powell are not pictured.**



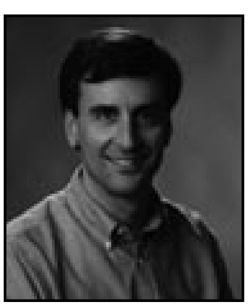
*From left to right:*
**William F. Krupke, Laura Deloach, Stephen A. Payne, and Larry K. Smith.**



*From left to right:*
**Oliver T. (Ted) Strand, Daniel C. Nelson, and Michael D. Pocha.**



**David J. Hopkins**



**James D. Tucker**

*From left to right:*
**Russell L. Vital, Natalia P. Zaitseva, Kenneth E. Montgomery, and James J. DeYoreo.**

make them instantly identifiable, even by a novice investigator. Identifying chromosomes by the old method is difficult, even for someone highly trained. Painting is up to 200 times more efficient than banding, making it attractive for drug safety testing by pharmaceutical companies.

These awards signify that the Lab's work has been valuable not only for maintaining national security in the past, when defense research was necessarily the largest single component, but for advancing it now, when the mandates of economic competitiveness—speed, efficiency, and quality—give urgency to our work.

## Intelligence Community Seal Medallion


A Laboratory research team, known as the Woodpecker Project, has been awarded the Intelligence Community Seal Medallion for its work on a classified project to improve information-gathering techniques. The award was presented at Central Intelligence Agency headquarters in Langley, Va., by the Deputy Director of the CIA and the Director of the National Security Agency.

The award cited the team's success "on a series of technical problems of enormous complexity, resulting in an extremely powerful operational capability that can be used to gather intelligence from unique sources not exploitable by any other means."

It went on to state that "many members of the Laboratory team, combining advanced concepts of physics and engineering, applied continuing determination to the solution of many practical problems that arose during this period. The Woodpecker Project team's brilliant insights and sustained efforts reflect credit upon themselves, the Lawrence Livermore National Laboratory, the National Security Agency, and the Intelligence Community."

The Seal Medallion is an intelligence community award bestowed upon groups or individuals that are not members of the intelligence community. The 21-member Woodpecker team started work on the project in 1985 with initial feasibility studies. The team's final product was delivered to the project sponsor in 1992.

The Woodpecker team, part of the Nonproliferation/Arms Control/ International Security directorate, included individuals from the Laboratory's Mechanical Engineering, Electronics Engineering, and Chemistry and Materials Science departments.

Lab employee Frank Pabian received an individual Intelligence Community Award. Pabian was commended for his work in verification of South African denuclearization.

The Intelligence Community Award was established by the Director of the Central Intelligence Agency to honor those who provide exceptional service on behalf of the U.S. Intelligence Community. It recognizes sustained superior performance of duty of high value that distinctly benefits the interests of the U.S. and is related to the mission of the Intelligence Community.

**Frank Pabian**
***Intelligence Community Seal Medallion recipient***

## NASA Medals for Exceptional Achievement

Lyn Pleasance was awarded the NASA Medal for Exceptional Engineering Achievement for technical leadership of the Livermore team in the design, fabrication, and testing of the Clementine sensor suite. The team used advanced technologies to provide state-of-the art, wideband imaging and tracking capabilities with a lightweight instrument package.

Isabella T. Lewis received the NASA medal for Exceptional Scientific Achievement for her "skill and dedication in performing and adjusting the settings of the cameras and LIDAR system to obtain high-quality data of the moon."

## Fellowships

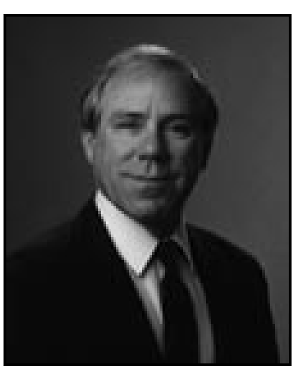
Laboratory scientist Carl Henning has been elected a fellow of the American Nuclear Society. He has been associated with the society for more than a decade, has served as chairman of several conferences, and will chair the 1996 Topical Conference on Fusion Energy. Henning was elected a fellow, which is the society's highest membership grade, in recognition of the contributions he has made to the advancement of nuclear science and technology through the years, according to a letter from society President Alan Waltar.

He has recently served in Washington, D.C., as coordinator of the National Ignition Facility (NIF) for Defense Programs, coordinating the work on Key Decision One between the Department of Energy's Defense Programs, the Laboratory, and DOE's Oakland office, and serving as conceptual design review deputy manager for NIF.

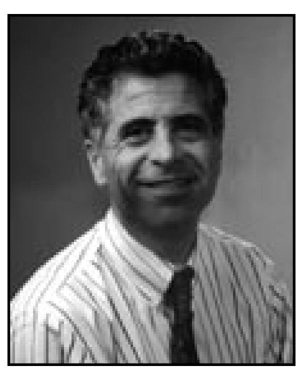
Henning started at the Laboratory in 1965, leaving in 1973 to serve as vice president of Intermagnetics General and later as branch chief of the DOE, and returned to the Lab in 1978. He served as deputy project manager for the Mirror Fusion Test Facility from 1978 to 1981, headed the Lab's Mirror Fusion Program Office from 1982 to 1986, served as U.S. deputy managing director for the International Thermonuclear Experimental Reactor from 1987 to 1990, and was deputy program leader in charge of Laser Science and Technology from 1990 to 1993.

Don Correll has been elected a fellow of the American Physical Society (APS). Correll, Deputy Program Leader for Laser Fusion, was recognized for his contributions to science education. The APS awarded Correll a fellowship "for being actively involved in science education with public audiences, pre-college and college students, and teachers, as well as an effective and committed spokesman for science education." Correll has been a lecturer at UC Davis/Livermore, has been involved in science education with a wide range of audiences, has co-authored fusion instructional material for high school science teachers, and is an advisor on fusion energy to the Chicago Museum of Science and Industry. Although several Lab scientists have been elected fellows to the APS over the past few years, Correll is believed to be the first to be so honored for educational achievements, a newly identified Laboratory priority. "Because scientists through their research activities are continuously teaching themselves and their colleagues, physicists are ideally suited for not only teaching recently acquired knowledge, but for helping teachers and students learn to teach themselves," said Correll. "I believe it is the professional responsibility of physicists—indeed all Lab scientists and engineers—to pass along their knowledge."

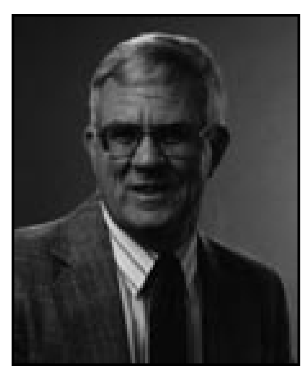
Dennis Hewett, a plasma physicist in the Laser Program, has been elected a fellow of the American Physical Society. He was honored for his work in plasma simulation and modeling. Hewett's fellowship certificate reads: "For significant contributions to the formulation of implicit plasma simulation methods, to the solution of linear systems, and for many advances



**Carl Henning**
***Fellow of the American Nuclear Society***



**Don Correll**
***Fellow of the American Physical Society***



**Dennis Hewett**
***Fellow of the American Physical Society***

in successfully modeling experiments." Hewett uses computational tools that he has developed in order to design sophisticated low-emittance ion sources for heavy ion fusion accelerators.

Jay C. Davis, recently named Acting Associate Director for Environmental Programs, has been elected a Fellow of the American Physical Society. The honor comes in recognition of his contributions in a number of physics disciplines. Davis's Fellowship Certificate reads: "For his substantial contributions to fields varying from nuclear physics, fusion, material science, arms control, and biomedical dosimetry through creative and original design of accelerator and research facilities."

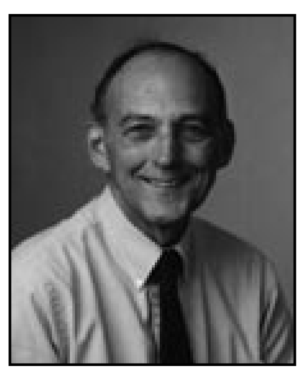
Davis joined the Lab in 1971 and in 1988 was appointed director of the Center for Accelerator Mass Spectrometry. The multidisciplinary, multi-organizational group applies accelerator analytical techniques to problems in biomedicine, geochemistry, materials science, and arms control. In 1993 Davis became program leader for Geoscience and Environmental Research at LLNL, overseeing the Lab's efforts in studying global climate change, environmental sciences, earth sciences, and the emergency response to airborne release of toxic radioactive materials. Davis was one of several Lab scientists who participated in the inspections of suspected Iraqi nuclear facilities after the Gulf War.

Steve Haan, a physicist in X Division, was recently named a Fellow of the American Physical Society. Haan, who has been a member of APS for his entire career, was awarded his fellowship "for pioneering work in the theory and modeling of hydrodynamic instabilities and mix in Inertial Confinement Fusion (ICF) targets and for leadership in the design and analysis of ignition and gain in ICF targets." Haan studies the ripples, or perturbations, on the surface of imploding inertial confinement fusion fuel targets. Much of Haan's modeling work has been tested on the Nova laser and will have a major impact on the National Ignition Facility.

Marvin Ross, a division leader for condensed matter physics at the Laboratory until 1993 and now a senior scientist emeritus, has been elected a Fellow of the American Physical Society. The honor comes in recognition of Ross's accomplishments in the area of high-pressure physics. Ross received his fellowship "in recognition of important and broad ranging scientific advancements toward understanding of the behavior of matter at high pressures, and for his leadership role in the field of high pressure physics." Ross joined the Lab in 1963 as a research scientist in the Physics Department before assuming division leadership in 1987. In the Condensed Matter Division, about 30 Ph.D. physicists carry out a broad research program in theoretical physics, equations of state, materials physics, shockwave, and diamond anvil research.

**Jay Davis**
***Fellow of the American Physical Society***

**Steve Haan**
***Fellow of the American Physical Society***



**Marvin Ross**
***Fellow of the American Physical Society***

# Patents Issued in 1994

| Patent Issued | Patent Number | Title | Inventors | Assignee |
|---|---|---|---|---|
| 1/4/94 | 5275796 | Method for Producing Metal Oxide Aerogels Having Densities Less Than 0.02 $g/cm^3$ | T. M. Tillotson, J. F. Poco, L. W. Hrubesh, I. M. Thomas | UC/TT |
| 1/4/94 | 5275083 | Skirted Projectiles for Railguns | R. S. Hawke, A. R. Susoeff | DOE |
| 1/4/94 | 5275106 | Insensitive Fuse Train for High Explosives | J. L. Cutting, R. S. Lee, W. G. Vonholle | DOE |
| 1/18/94 | 5279723 | Filtered Cathodic Arc Source | S. Falabella, D. M. Sanders | UC/TT |
| 2/1/94 | 5282944 | Ion Source Based on the Cathodic Arc | D. M. Sanders, S. Falabella | UC/TT |
| 2/1/94 | 5283336 | Method for Preparation of 7-Hydroxy-1,2,3,4-Tetrahydroquinoline from 1,2,3,4-Tetrahydroquinoline | P. R. Hammond, G. F. Field | DOE |
| 2/8/94 | 5284539 | Method of Making Segmented Pyrolytic Graphite Sputtering Targets | M. A. McKernan, C. S. Alford, D. M. Makowiecki, C.-W. Chen | UC/TT |
| 2/8/94 | 5285310 | High Power Regenerative Laser Amplifier | J. L. Miller, L. A. Hackel, C. B. Dane, L. E. Zapata | UC/TT |
| 2/15/94 | 5287369 | Laser Beam Generating Apparatus | B. E. Warner, D. B. Duncan | DOE |
| 2/15/94 | 5286361 | Magnetically Attached Sputter Targets | D. M. Makowiecki, M. A. McKernan | UC/TT |
| 2/15/94 | 5286343 | Method for Protecting Chip Corners in Wet Chemical Etching of Wafers | W. C. Hui | UC/TT |
| 2/15/94 | 5286113 | Centrifugally Activated Bearing for High-Speed Rotating Machinery | R. F. Post | UC/TT |
| 3/15/94 | 5294789 | Gamma-Insensitive Optical Sensor | H. W. Kruger | DOE |
| 3/22/94 | 5296125 | Electrochemical Sensor/Detector System and Method | R. S. Glass, S. P. Perone, D. R. Ciarlo, J. F. Kimmons | UC/TT |
| 3/29/94 | 5298755 | Optical Ionization Detector | C. R. Wuest, M. E. Lowry | DOE |
| 4/19/94 | 5305152 | Evacuated Optical Structure Comprising Optical Bench Mounted to Sidewall of Vacuum Chamber in a Manner Which Inhibits Deflection and Rotation of the Optical Bench | J. M. Bowers | DOE |
| 4/19/94 | 5305346 | A Transverse-Type Laser Assembly Using Induced Electrical Discharge Excitation and Method | E. R. Ault | DOE |
| 4/19/94 | 5305074 | Achromatic Self-Referencing Interferometer | M. Feldman | DOE |

| Patent Issued | Patent Number | Title | Inventors | Assignee |
|---|---|---|---|---|
| 4/19/94 | 5305345 | Zigzag Laser with Reduced Optical Distortion | G. F. Albrecht, B. J. Comaskey, S. B. Sutton | DOE |
| 4/26/94 | 5307430 | Lensing Duct | R. J. Beach, W. J. Benett | DOE |
| 4/26/94 | 5306414 | Corrosion Sensor | R. S. Glass, W. L. Clarke, D. R. Ciarlo | UC/TT |
| 5/3/94 | 5308987 | Microgap X-Ray Detector | C. R. Wuest, R. M. Bionta, E. Ables | DOE |
| 5/3/94 | 5307718 | Apparatus and Process for Removing A Predetermined Portion of Reflective Material from a Mirror | S. J. Perry, L. L. Steinmetz | DOE |
| 5/3/94 | 5309282 | High Stability Wavefront Reference Source | M. Feldman, D. J. Mackler | DOE |
| 5/3/94 | 5309456 | Pulse Stretcher | J. A. Horton | DOE |
| 5/10/94 | 5311163 | Electrically Operated Magnetic Switch Designed to Display Reduced Leakage Inductance | E. G. Cook | DOE |
| 5/10/94 | 5310366 | Easily Disassembled Electrical Connector for High-Voltage, High-Frequency Connections | J. R. Milner | DOE |
| 5/10/94 | 5311010 | Buffer for Gamma-Insensitive Optical Sensor with Gas and a Buffer Assembly | H. W. Kruger | DOE |
| 5/10/94 | 5310705 | High Field Magnets Using High-Critical-Temperature Superconducting Thin Films | F. Mitlitsky, R. W. Hoard | DOE |
| 5/10/94 | 5311485 | Fiber Optic Hydrophone | P. J. Kuzmenko, D. T. Davis | DOE |
| 5/17/94 | 5312186 | High Temperature Probe | R. A. Swan | DOE |
| 5/17/94 | 5312232 | Pump for Molten Metal or Other Fluid | J. A. Horton, D. L. Brown | DOE |
| 5/17/94 | 5313481 | Copper Laser Modulator Driving Assembly Including a Magnetic Compression Laser | E. G. Cook, D. L. Birx, D. G. Ball | DOE |
| 5/24/94 | 5315610 | System for Controlling the Flow of Gas into and out of a Gas Laser | T. Alger, D. M. Uhlich, W. J. Bennett, E. R. Ault | DOE |
| 5/24/94 | 5315611 | High Average Power Magnetic Modulator for Metal Vapor Lasers | D. G. Ball, D. L. Birx, E. G. Cook, J. L. Miller | DOE |
| 6/7/94 | 5319662 | Longitudinal Discharge Laser Baffles | B. E. Warner, E. R. Ault | DOE |

## Patents Issued in 1994

| Patent Issued | Patent Number | Title | Inventors | Assignee |
|---|---|---|---|---|
| 6/7/94 | 5319211 | Toxic Remediation | S. M. Matthews, R. G. Schonberg, D. R. Fadness | DOE |
| 6/14/94 | 5321753 | Secure Communication of Static Information by Electronic Means | D. G. Gritton | DOE |
| 6/28/94 | 5325391 | Recirculating Wedges for Metal-Vapor Plasma Tubes | J. P. Hall, R. M. Sawvel, V. G. Draggoo | DOE |
| 7/5/94 | 5325918 | Optimal Joule Heating of the Subsurface | W. D. Daily, J. G. Berryman | UC/S |
| 7/19/94 | 5331234 | Solid State Switch | G. R. Dreifuerst, B. T. Merritt | DOE |
| 7/26/94 | 5332938 | High Voltage MOSFET Switching Circuit | T. E. McEwan | UC/TT |
| 8/2/94 | 5334528 | Monoclonal Antibodies to Cyclodiene Insecticides and Method for Detecting the Same | L. H. Stanker, M. Vanderlaan, B. E. Watkins | UC/S |
| 8/2/94 | 5335237 | Parasitic Oscillation Suppression in Solid State Lasers Using Absorbing Thin Films | L. E. Zapata | DOE |
| 8/2/94 | 5333726 | Magnetron Sputtering Source | D. M. Makowiecki, M. A. McKernan, R. F. Grabner, P. B. Ramsey | UC/TT |
| 8/2/94 | 5335236 | Long Pulse Production from Short Pulses | J. S. Toeppen | DOE |
| 8/9/94 | 5336520 | High Density-High Purity Graphite Prepared by Hot Isostatic Pressing in Refractory Metal Containers | C. L. Hoenig | DOE |
| 8/9/94 | 5335548 | Non-Linear Optical Crystal Vibration Sensing Device | R. Kalibjian | DOE |
| 8/9/94 | 5337333 | Laser Beam Pulse Formatting Method | T. P. Daly, E. I. Moses, R. W. Patterson, R. H. Sawicki | DOE |
| 8/9/94 | 5336274 | Method for Forming a Cell Separator for Use in Bipolar-Stack Energy Storage Devices | S. T. Mayer, J. H. Feikert, J. L. Kaschmitter, R. W. Pekala | UC/TT |
| 8/16/94 | 5338115 | Mixing Device for Materials with Large Density Differences | D. W. Gregg | DOE |
| 8/23/94 | 5341392 | Improved Longitudinal Discharge Laser Electrodes | B. E. Warner, E. R. Ault | DOE |
| 8/23/94 | 5341017 | Semiconductor Switch Geometry with Electric Field Shaping | R. Booth, M. D. Pocha | DOE |
| 8/23/94 | 5341389 | Ytterbium- and Neodymium-Doped Vanadate Laser Host Crystals Having the Apatite Crystal Structure | S. A. Payne, W. L. Kway, L. D. Deloach, W. F. Krupke, B. H. Chai | DOE |

| Patent Issued | Patent Number | Title | Inventors | Assignee |
|---|---|---|---|---|
| 9/6/94 | 5345458 | Multiple Density Layered Insulator | T. W. Alger | DOE |
| 9/6/94 | 5345471 | Ultra-Wideband Receiver | T. E. McEwan | UC/TT |
| 9/13/94 | 5347209 | Voltage Control in Pulsed System by Predict-Ahead Control | J. A. Watson, A. N. Payne, S. Esquejo Samapayan | DOE |
| 9/13/94 | 5346850 | Crystallization and Doping of Amorphous Silicon on Low Temperature Plastic | J. L. Kaschmitter, T. W. Sigmon, J. B. Truher, K. H. Weiner | UC/TT |
| 9/13/94 | 5346307 | Using Electrical Resistance Tomography to Map Subsurface Temperatures | A. L. Ramirez, D. A. Chesnut, W. D. Daily | UC/TT |
| 9/20/94 | 5349594 | Insulative Laser Shell Coupler | P. A. Arnold, A. T. Anderson, T. W. Alger | DOE |
| 9/20/94 | 5349194 | Microgap Ultra-Violet Detector | C. R. Wuest, R. M. Bionta | DOE |
| 9/27/94 | 5351032 | Power Line Detection System | V. R. Latorre, D. B. Watwood | UC/TT |
| 10/4/94 | 5353167 | Mirror Mount | T. C. Kuklo, D. A. Bender | DOE |
| 10/4/94 | 5352627 | Monolithic, High Voltage Nonlinear Transmission Line Fabrication Process | G. A. Cooper | UC/TT |
| 10/11/94 | 5355387 | Interface Module for Transverse Energy Input to Dye Laser Modules | R. E. English | DOE |
| 10/18/94 | 5357342 | Process and Apparatus for Measuring Degree of Polarization and Angle of Major Access of Polarized Beam of Light | D. E. Decker, J. S. Toeppen | DOE |
| 10/25/94 | 5359614 | Variable Emissivity Laser Thermal Control System | J. R. Milner | DOE |
| 10/25/94 | 5359497 | Planar Triode Pulser Socket | R. Booth | UC/TT |
| 10/25/94 | 5358802 | Doping of Carbon Foams for Use in Energy Storage Devices | S. T. Mayer, R. W. Pekala, R. L. Morrison, J. L. Kaschmitter | UC/TT |
| 10/25/94 | 5359252 | Lead Magnesium Niobate Actuator for Micropositioning | C. D. Swift, J. W. Bergum | DOE |
| 10/25/94 | 5359246 | Low Backlash Direct Drive Actuator | T. C. Kuklo | DOE |
| 11/1/94 | 5359936 | Non-Detonable Explosive Simulators | R. L. Simpson, C. O. Pruneda | UC |
| 11/1/94 | 5361070 | Ultra Wideband Radar Motion Sensor | T. E. McEwan | UC/TT |
| 11/1/94 | 5360491 | B-Silicon Carbide Protective Coating and Method for Fabricating Same | P. G. Carey, J. B. Thompson | DOE |

## Patents Issued in 1994

| Patent Issued | Patent Number | Title | Inventors | Assignee |
|---|---|---|---|---|
| 11/1/94 | 5360828 | Biofoam II | R. L. Morrison | UC/TT |
| 11/8/94 | 5363244 | High Bandwidth with Optical Mount | D. B. Bender, T. Kuklo | DOE |
| 11/15/94 | 5365379 | Laser Correcting Mirror | R. H. Sawicki | DOE |
| 11/22/94 | 5366721 | Method for Detection of Long-Lived Radioisotopes in Small Biochemical Samples | K. W. Turteltaub, J. S. Vogel, J. S. Felton, B. L. Gledhill, J. C. Davis | UC/TT |
| 11/29/94 | 5368792 | Method for Molding Threads in Graphite Panels | W. W. Short, C. Spencer | DOE |
| 12/13/94 | 5373215 | Ionization Tube Simmer Current Circuit | R. F. Steinkraus | DOE |
| 12/13/94 | 5372391 | Internal Pipe Attachment Mechanism | R. M. Bast, D. A. Chesnut, C. D. Henning, J. P. Lennon, J. A. Smith, J. W. Pastrnak | DOE |
| 12/13/94 | 5373486 | Seismic Event Classification System | F. U. Dowla, S. P. Jarpe, W. J. Maurer | DOE |
| 12/20/94 | 5375158 | X-Ray Source for Mammography | C. M. Logan | UC/TT |
| 12/27/94 | 5376355 | Method of Measurement in Biological Systems | K. W. Turteltaub, J. S. Vogel, J. S. Felton, B. L. Gledhill, J. C. Davis | UC/TT |
| 12/27/94 | 5375321 | Method for Fabricating Fan-Fold Shielded Electrical Leads | R. R. Rohatgi, T. E. Cowan | DOE |
| 12/27/94 | 5376246 | Efficient, Mass-Selective Three-Photon Ionization of Zirconium Atoms | R. H. Page | DOE |

# Acronyms

| | |
|---|---|
| AAICF | Ann Arbor Initial Confinement Fusion (Facility) |
| AMP | Advanced Microtechnology Program |
| AMS | accelerator mass spectrometer |
| ANN | artificial neural network |
| APLC | active power line conditioner |
| APS | American Physical Society |
| ARAC | Atmospheric Release Advisory Capability |
| ASCI | Accelerated Super Computing Initiative |
| AVLIS | atomic vapor laser isotope separation |
| AWE | Atomic Weapons Establishment (U.K.) |
| BEEF | Big Explosives Engineering Facility |
| BEP | Biotechnology Education Program |
| BNL | Brookhaven National Laboratory |
| CAD/CAM | computer-aided design/computer-aided manufacturing |
| CAS | Condition Assessment Survey |
| CCSE | Center for Computational Sciences and Engineering |
| CD-ROM | compact disc/read-only memory |
| CFC | chlorofluorocarbon |
| CHEW | CHemical Exchange Warehouse |
| CIAC | Computer Incident Advisory Capability |
| C&MS | Chemistry and Materials Science (directorate) |
| CMTC | California Manufacturing Technology Center |
| CQI | continuous quality improvement |
| CRADA | Cooperative Research and Development Agreement |
| CRT | cathode-ray tube |
| CSTC | Computer Security Technology Center |
| CT | computed tomography |
| CTB | Comprehensive Test Ban |
| DAVACS | DOE Automated Visitor Access Control System |
| DBIR | dual-band infrared |
| DISSS/ET | DOE Safeguards and Security Systems/Electronic Transfer |
| DNA | Defense Nuclear Agency |
| DNA | deoxyribonucleic acid |
| DOD | Department of Defense |
| DOE | Department of Energy |
| EBIT | electron beam ion trap |
| EMITS | emissions measurement and information tracking system |
| EOS | equation of state |
| ER | DOE’s Energy Research Office |
| ES&H | environment, safety, and health |
| ESnet | Energy Sciences Network |
| EXAFS | extended x-ray atomic fine structure |
| FENIX | Fusion Engineering International Experiment |
| FSTC | Financial Services Technology Consortium |
| FXR | Flash X-Ray (facility) |
| FY | fiscal year |
| GRATIS | Gamma Ray Arcminute Telescope Imaging System |
| HBCU | Historically Black Colleges and Universities |
| HEPA | high-efficiency particulate air (filter) |
| HPSS | High Performance Storage System |
| ICF | inertial confinement fusion |
| ICP | inductively coupled plasma-source |
| IDP | Imaging and Detection Program |
| IFE | inertial fusion energy |
| INSENS | Immigration and Naturalization Service Sensor System |
| ISAM | Isotope Separation and Advanced Manufacturing |
| ITER | International Thermonuclear Experimental Reactor |
| KDP | potassium dihydrogen phosphate |
| LANL | Los Alamos National Laboratory |
| LCAMP | Livermore Center for Advanced Manufacturing and Production |
| LED | light-emitting diode |
| LIFTIRS | Livermore Fourier-transform infrared spectrometer |
| LLNL | Lawrence Livermore National Laboratory |
| LMC | Large Magellanic Cloud |
| LVDT | linear variable differential transformer |
| MACHO | massive compact halo object |
| MIT | Massachusetts Institute of Technology |
| MOLE | Miniature Optic Lair Explorer |
| MOSFET | metal-oxide semiconductor field-effect transistor |
| MPP | massively parallel processor/processing |
| MS | mass spectroscopy |

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| NAI | Nonproliferation, Arms Control, and International Security (directorate) |
| NERSC | National Energy Research Superconducting Center (formerly NMFECC) |
| NES | National Education Supercomputer |
| NEST | Nuclear Emergency Search Team |
| NIF | National Ignition Facility |
| NIH | National Institutes of Health |
| NMR | nuclear magnetic resonance |
| NOx | nitrogen oxide |
| NPR | National Performance Review |
| NRC | Nuclear Regulatory Commission |
| NSL | National Storage Laboratory |
| NTES | Nuclear Test and Experimental Science (former directorate) |
| NTS | Nevada Test Site |
| OES | Office of Emergency Services (State of California) |
| OPSEC | Operations Security |
| OSHA | Occupational Safety and Health Act |
| OSL | Open Systems Laboratory |
| PCE | perchloroethane |
| PDDP | parallel data distribution preprocessor |
| PDLS | Plant-Scale Dye Laser System |
| PINS | Proliferation Information Networked System |
| PPOA | pollution-prevention opportunity assessment |
| R&D | research and development |
| RCRA | Resource Conservation and Recovery Act |
| RHIC | Relativistic Heavy Ion Collider |
| SAFE | Security Awareness for Employees |
| SARA | Superfund Ammendments and Reauthorization Act |
| SBI | Small Business Initiative |
| SCRAMJET | supersonic combustion ramjet |
| SEABA | Science Education Academy of the Bay Area |
| SERS | Science and Engineering Research Seminar |
| SHARP | Super-High-Altitude Research Project |
| SLAC | Stanford Linear Accelerator Center |
| SNL | Sandia National Laboratories |
| SNM | special nuclear material |
| SSRA | Student Science Research Associates |
| START | Strategic Arms Reduction Talks |
| TAISIR | temperature and imaging system infrared |
| TCE | trichloroethylene |
| TPX | Tokamak Physics Experiment |
| TQM | total quality management |
| U-AVLIS | Uranium Atomic Vapor Laser Isotope Separation |
| UC | University of California |
| USEC | U.S. Enrichment Corporation |
| USGS | U.S. Geological Survey |
| UV | ultraviolet |
| VOC | volatile organic compound |
| WIT | waste-inspection tomography |
| XP | xeroderma pigmentosum |