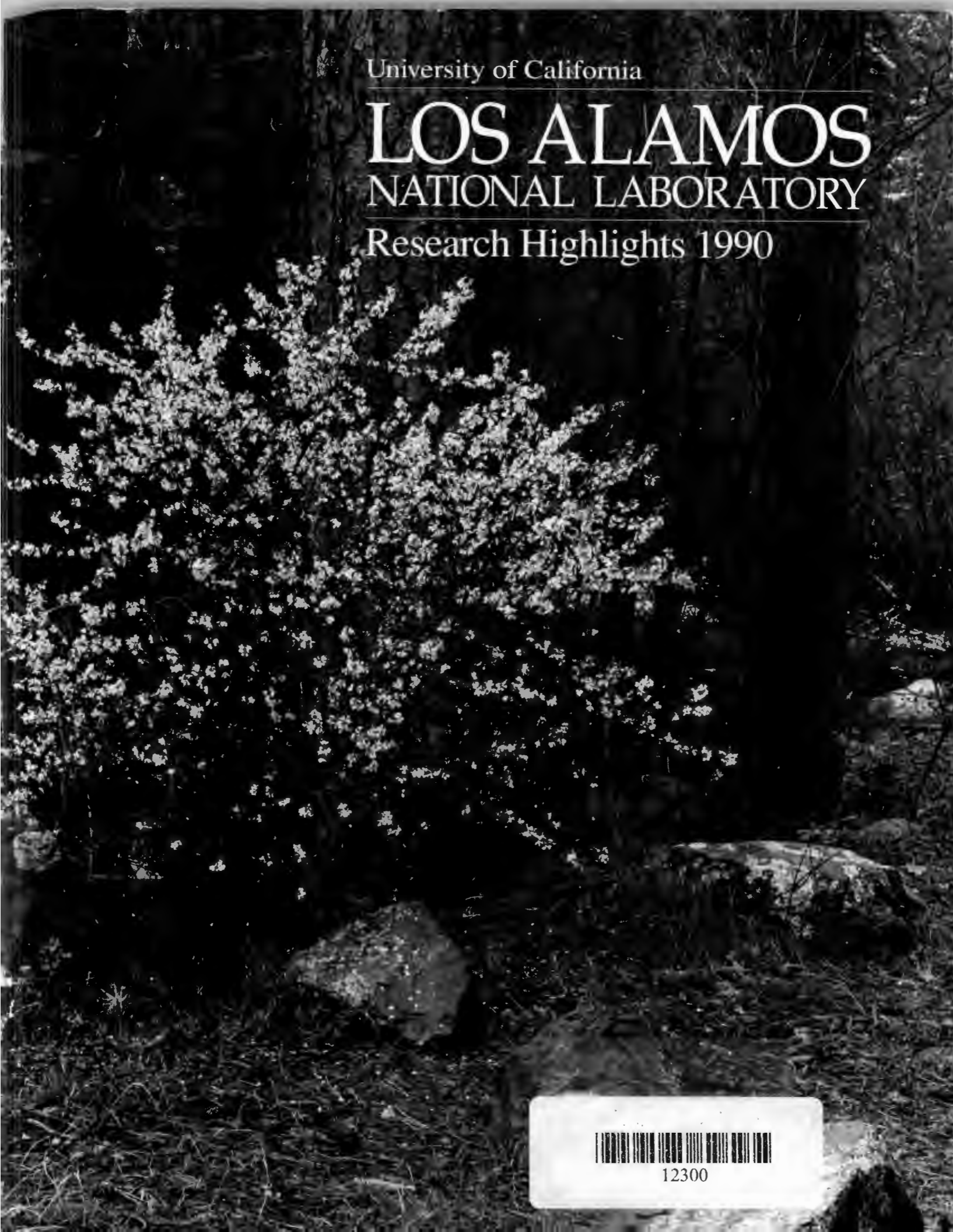
University of California

LOS ALAMOS NATIONAL LABORATORY

Research Highlights 1990



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LALP-90-38
February 1991

This report covers the Laboratory's research for calendar year 1990.

The scenic photographs in this report were taken on or adjacent to the property of Los Alamos National Laboratory.

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Profile

"I decided if I wanted to do science and also enjoy a place to live, I could not do better anywhere in the world."

John Manley

"It crossed my mind once or twice to work someplace else. But I never found another place that matched the breadth of talent, the academic environment, and this physical location."

Robert Thorn

Like John Manley and Bob Thorn, many current employees were attracted to Los Alamos National Laboratory because it offers professional challenges in a serene setting of natural beauty. From valleys of cottonwoods and chamisa, plateaus of piñon and juniper rise to mountains forested by stands of aspen and ponderosa pines—all under bright azure skies. Dotted along the plateaus, spread over an area of more than 40 square miles, lie the sites that compose Los Alamos National Laboratory, one of the world's premier scientific research centers. Here, scientists, engineers, and support staff work together to solve problems of national importance.

The Laboratory's primary mission—ensuring the nation's security through nuclear weapons technology—depends on a strong science and technology base. That base includes nonnuclear defense technology, energy and related technologies, chemistry and materials science, and basic science. To fulfill its mission, the Laboratory attracts scientists and engineers from across the country: 45 percent from the West, 17 percent from the Midwest, 30 percent from the Northeast, and 8 percent from the South. About one-third are physicists, one-third are engineers, and one-third have degrees in chemistry, materials science, mathematics, biology, geoscience, and other disciplines.

The Laboratory continues to benefit from the work environment initiated here by J. Robert Oppenheimer, which nurtures independent, imaginative thinking and encourages communication across scientific disciplines, in basic and applied sciences, and with academia and industry. In institutes, pilot centers, and research centers within the Laboratory, employees collaborate to study nonlinear phenomena, national security, geophysics and planetary physics, flow cytometry, the human genome, superconductivity, parallel computing, materials science, and neutron scattering. Los Alamos offers state-of-the-art laboratories, a world-class computing center, and an excellent technical library to its employees, visiting scientists, and collaborating students so that they may effectively study phenomena from the subatomic to intergalactic levels.

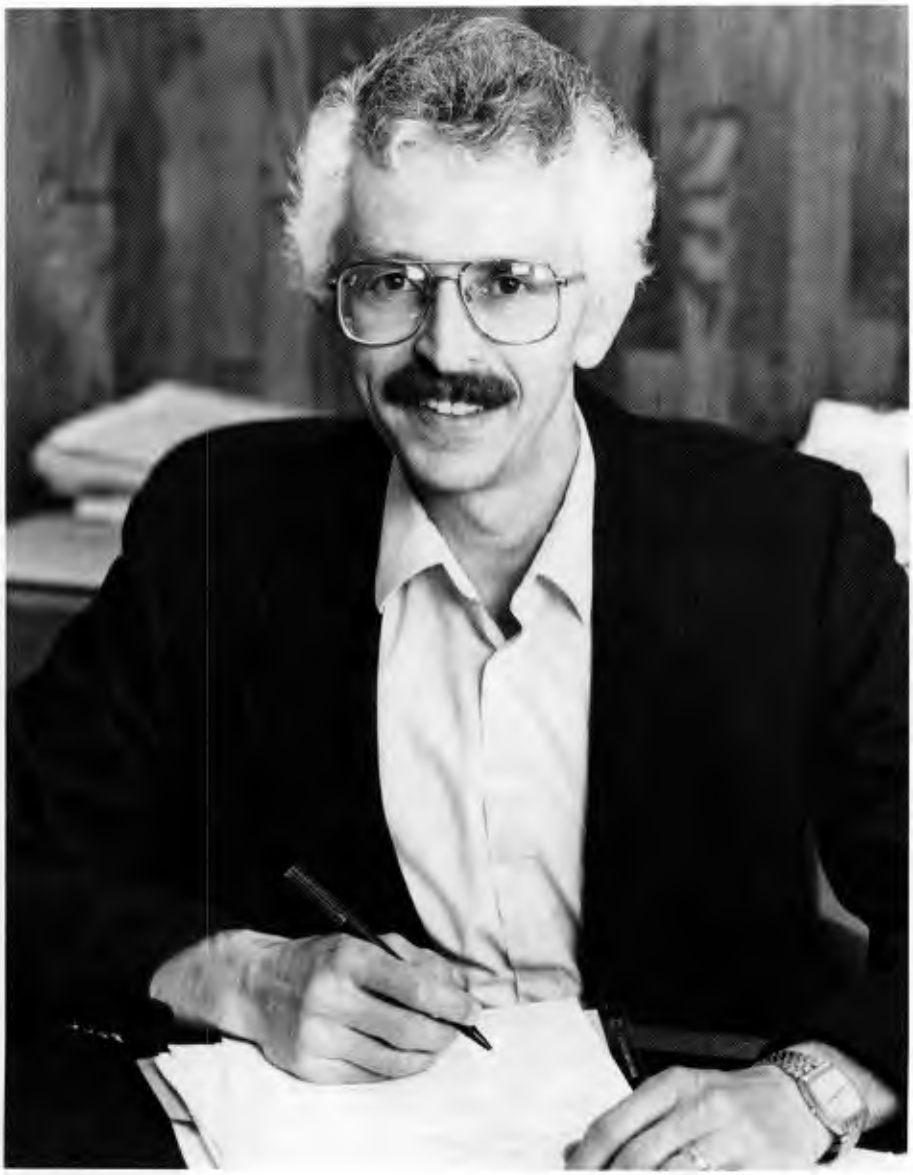
In fiscal year 1990, the Laboratory allocated almost half its operating budget of $950 million to employee salaries and benefits. The remainder went to various materials, services, and support functions needed to fulfill our mission. The Laboratory's construction budget was $49 million; the capital equipment budget was $40 million. With 7750 employees and a total annual budget of more than $1 billion, the Laboratory is the largest employer in the northern half of New Mexico. The impact on the area's economy is estimated at $3 billion. More than 33 percent of the jobs in our three-county area and 5 percent statewide are Laboratory related.

In staff and technical capabilities, Los Alamos is one of the largest multidisciplinary, multiprogram laboratories in the world. It is operated by the University of California for the Department of Energy. Across the United States thirty-three laboratories, nine of which are multiprogram, are operated for the Department of Energy. Collectively, the national laboratories conduct thousands of basic and applied research projects each year. The results of work at Los Alamos and the other national laboratories contribute significantly to fundamental knowledge, national security, and the economic competitiveness of the country.

John Manley was one of the founding fathers of Los Alamos. He was Oppenheimer's right-hand man—the administrative workhorse in charge of coordinating all the experimental work conducted at Los Alamos in the early 1940s. He later became leader of the Physics Division and then technical associate director under Norris Bradbury.

Robert Thorn was one of the foremost nuclear weapons designers and program managers in the nation. He held positions as division leader; associate, deputy, and acting director; and senior adviser. He also masterminded the development of Pajarito Mountain into one of New Mexico's finest ski areas.

Science at Work for the Nation



Siegfried S. Hecker, Director

The political world is changing rapidly, even unpredictably. If a year or two ago, someone had stated that by 1990 the Berlin Wall would crumble, the Cold War would end, and the Soviet Union would cooperate with the United States in a defensive mission in the Middle East, most Americans would have scoffed in disbelief. Yet, these events are now history. The American public, national leaders, and the U.S. defense complex are adapting to these new realities. Strategic planning for national security must be done within a new and constantly changing context.

Americans look forward to a less confrontational world and an economic "peace dividend." Some ask "Is the job of the weapons laboratories finished?" "Can we safely dismantle them to save money?" The same questions were asked at the end of World War II, and the answer then was "no." History has shown the wisdom of that answer: the weapons laboratories helped to maintain a strong nuclear deterrent that bought—and continues to buy—time for political leaders to resolve many of their differences by peaceful means.

I believe the answer to the questions is still "no." The federal government has the responsibility to deliver a lasting peace as the first and foremost peace dividend. We still live in a world with tens of thousands of nuclear weapons. As long as these exist in the hands of other nations, the United States must maintain its own nuclear competence to understand, design, manufacture, safeguard, and eventually retire the weapons. That competence—our insurance policy—has evolved carefully over almost half a century at the Department of Energy's three weapons laboratories. It exists nowhere else in the United States.

But recent world changes have certainly altered our priorities and have broadened the definition of national security. We must now help the nation reduce its nuclear arsenal while preserving national security and global stability. We must provide the nuclear weapons deemed necessary by the U.S. government as we "build down" the stockpile. We must further enhance the safety features of nuclear warheads remaining in the stockpile, and we must minimize negative environmental impacts of their manufacture and retirement.

In addition to nuclear weapons, the scientific work at Los Alamos has many applications to national security. We have strong basic research programs and great strengths in applied research and technology. The knowledge and

technologies developed at the Laboratory can help the nation reach its goals of adequate energy supplies, economic competitiveness in world markets, environmental protection, excellence in science and engineering education, elimination of drugs and terrorism, and improved health care. Several current research projects are good examples.

Exploring new sources of energy has been part of our mission since the 1970s. Our research on fusion energy and on geothermal energy extracted from hot dry rock beneath the Earth's surface is laying the foundation for essentially inexhaustible and environmentally benign sources of energy for the future. We are also working with the petroleum industry on several methods to extract more oil from already-developed fields.

Several strategic partnerships with industry will allow us to transfer the results of our unclassified scientific research into the marketplace in a timely and cost-effective manner. For example, work spun off from our strategic defense laser research could be the key to enabling U.S. producers of computer chips to recapture the world market in the twenty-first century. We envision a chip that holds the computing power of a supercomputer.

To clean up the environment, the United States needs technologies that are cheaper and easier to use than those now available. One new technology is our portable midget mass spectrometer that can reduce the cost and time needed to characterize pollutants in contaminated sites. An important new research idea at Los Alamos, transmutation of waste using an accelerator, promises to reduce the time that radioactive defense wastes must be stored from tens of thousands to a few hundreds of years. We propose using accelerator technology, with which we have many decades of experience, to transmute the radioactive waste into less hazardous and shorter-lived materials.

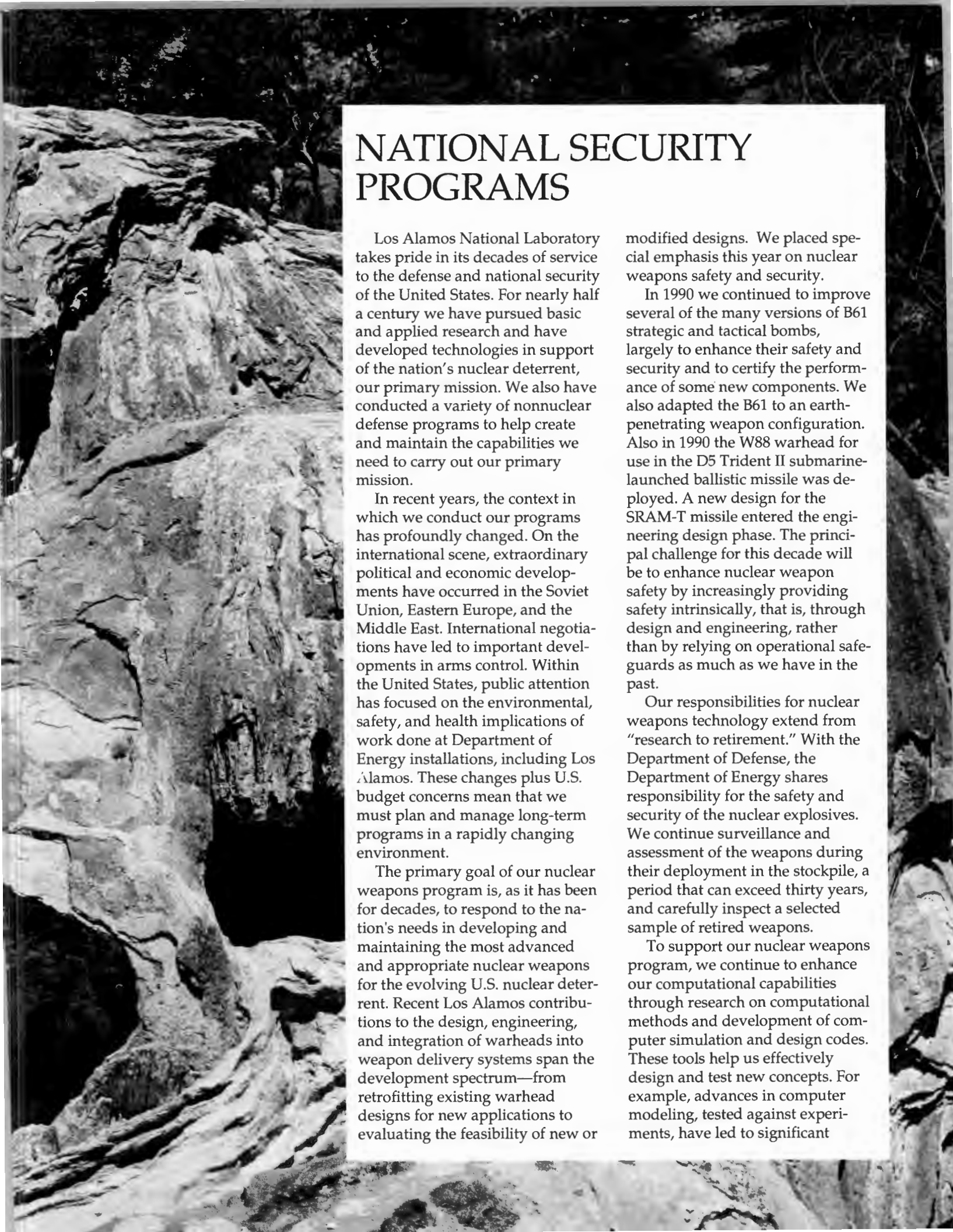
Los Alamos takes seriously its role in inspiring future scientists and engineers. Through a variety of programs we involve more than 10,000 students and teachers in the excitement of science each year. Our newest program, called SWOOPE (Students Watching Over Our Planet Earth), teaches both scientific techniques and environmental monitoring skills. Our hope is to "turn students on to science" and to encourage a new generation of skilled professionals.

Many of our technologies can help in the effort to reduce and eliminate drug traffic and terrorism. A new method of fingerprint detection developed here is already being used by federal officials to catch and convict criminals. Other sensitive instrumentation can detect the types of explosives that terrorists might use to destroy airplanes. Computer models developed at Los Alamos can help the U.S. Treasury Department follow the money trail left by drug dealers.

Our research also offers great potential in the field of medicine and human health care. We are blazing the trail in the use of lasers in noninvasive medical applications that include real-time diagnosis. These applications will improve diagnoses and may help to reduce the cost of medical care. Our studies on the AIDS virus shed new light on its rapid spread and mutations. Our work on the genetic makeup of the human body may someday help prevent and perhaps cure many genetic diseases.

To contribute in all these areas, we draw on the people, the resources, and the can-do attitude that we developed as part of our first wartime mission. Encouraged by the University of California to strive for excellence, we have developed an environment that fosters individual creativity, encourages vigorous debate, and promotes teamwork to achieve program objectives. We know how to conduct large, complex projects and deliver a product.

We will continue to use our technical expertise and resources to address pressing national challenges—both in the 1990s and for the twenty-first century. While maintaining the vigilance in defense that protects the nation from the unexpected, we will apply our skills to meet national needs within the broad concept of national security. Our purpose is to put science to work to make a positive difference in the world.



NATIONAL SECURITY PROGRAMS

Los Alamos National Laboratory takes pride in its decades of service to the defense and national security of the United States. For nearly half a century we have pursued basic and applied research and have developed technologies in support of the nation's nuclear deterrent, our primary mission. We also have conducted a variety of nonnuclear defense programs to help create and maintain the capabilities we need to carry out our primary mission.

In recent years, the context in which we conduct our programs has profoundly changed. On the international scene, extraordinary political and economic developments have occurred in the Soviet Union, Eastern Europe, and the Middle East. International negotiations have led to important developments in arms control. Within the United States, public attention has focused on the environmental, safety, and health implications of work done at Department of Energy installations, including Los Alamos. These changes plus U.S. budget concerns mean that we must plan and manage long-term programs in a rapidly changing environment.

The primary goal of our nuclear weapons program is, as it has been for decades, to respond to the nation's needs in developing and maintaining the most advanced and appropriate nuclear weapons for the evolving U.S. nuclear deterrent. Recent Los Alamos contributions to the design, engineering, and integration of warheads into weapon delivery systems span the development spectrum—from retrofitting existing warhead designs for new applications to evaluating the feasibility of new or modified designs. We placed special emphasis this year on nuclear weapons safety and security.

In 1990 we continued to improve several of the many versions of B61 strategic and tactical bombs, largely to enhance their safety and security and to certify the performance of some new components. We also adapted the B61 to an earth-penetrating weapon configuration. Also in 1990 the W88 warhead for use in the D5 Trident II submarine-launched ballistic missile was deployed. A new design for the SRAM-T missile entered the engineering design phase. The principal challenge for this decade will be to enhance nuclear weapon safety by increasingly providing safety intrinsically, that is, through design and engineering, rather than by relying on operational safeguards as much as we have in the past.

Our responsibilities for nuclear weapons technology extend from "research to retirement." With the Department of Defense, the Department of Energy shares responsibility for the safety and security of the nuclear explosives. We continue surveillance and assessment of the weapons during their deployment in the stockpile, a period that can exceed thirty years, and carefully inspect a selected sample of retired weapons.

To support our nuclear weapons program, we continue to enhance our computational capabilities through research on computational methods and development of computer simulation and design codes. These tools help us effectively design and test new concepts. For example, advances in computer modeling, tested against experiments, have led to significant

improvements in assuring nuclear weapon safety. Advanced modeling techniques can also provide insights into physics phenomena not directly observable through experiments. With the possibility of new international agreements that will further restrict underground testing, computer simulations become increasingly important.

Complementing our underground testing and computer simulation capability is an extensive suite of experimental physics, diagnostics, and simulation resources, which we call above-ground experiments. They provide critical information about specific pieces of physics or performance in a laboratory environment. We gather as much information as possible with laboratory experiments and diagnostics to complement the data gathered from expensive but necessary underground nuclear tests.

As part of our nuclear weapons research, we support the Strategic Defense Initiative by investigating potential concepts for nuclear directed-energy weapons, including lasers and hypervelocity projectiles. Although the nation is committed to systems based on nonnuclear technologies for the initiative, exploring concepts for nuclear directed-energy weapons offers insurance against technological surprise from potential adversaries.

Our inertial confinement fusion program complements our research in weapons physics. The short-term goal is to produce small-scale thermonuclear reactions in the laboratory similar to those that occur on a large scale during the detonation of a thermonuclear weapon. A long-term goal is to investigate the feasibility of using fusion to generate electric power. In 1990 our Aurora krypton fluoride laser system completed its initial operational phase, delivering high-power light pulses to targets. The Aurora system is undergoing extensive characterization.

Nuclear weapons require special materials. Some are expensive; some produce hazardous waste during processing and fabrication. Los Alamos carries out research, development, and demonstration of new technologies used in processing nuclear materials and in manufacturing weapon components. These efforts are supported by programs in nuclear materials measurements; materials management, control, and accountability; safety, radiation protection, waste management, and minimization of waste; and environmental protection and restoration.

Los Alamos is also actively involved in the transfer of new technologies associated with nuclear materials processing and fabrication to the nuclear weapons production complex. For example, the Laboratory maintains a Technology Office at Rocky Flats. Los Alamos is also providing its technical skills to help the Department of Energy design a modernized plant to fabricate and process plutonium.

Our involvement is now being extended to broader areas of the nuclear weapons complex. In 1989 we established a Weapons Complex Modernization Office, which has spearheaded a Department of Energy initiative that places priority on environment, safety, and health and that minimizes wastes through changes in design and processes.

Los Alamos continues to be actively engaged in verification of arms control agreements. Since the early 1960s we have designed and built more than three hundred space sensors, most for monitoring nuclear testing treaties but many specifically for space science research.

At present, we are producing x-ray detectors that are deployed on satellites of the Global Positioning System to detect nuclear detonations in space. In addition, we have under way a number of projects that will extend our knowledge of the harsh space environment and allow us to improve our capability for monitoring nuclear tests. A plasma analyzer developed at Los Alamos was deployed on Ulysses, the satellite launched by the National Aeronautics and Space Administration in 1990. Ulysses will provide vital information about the solar environment.

Our extensive experience in space research focuses most prominently on the development of a satellite system for detecting soft x-rays. We see the first satellite, ALEXIS (Array of Low-Energy Imaging Sensors), as the beginning of an extensive research program in space and verification.

Los Alamos continues to improve the nation's verification capabilities in a host of other areas. For example, we are improving our capability to verify underground nuclear tests on site, and we are conducting considerable research in the areas of radiation detection.

In 1989 we established the Arms Control Office to coordinate all arms control and related activities of the Laboratory. The office directs our programs in verification technology research and development; serves as the Laboratory's liaison with the Department of Energy's Office of Arms Control; coordinates our technical support to various arms control treaty negotiations; contributes to our efforts to safeguard special nuclear materials; and supports the International Atomic Energy Agency in its monitoring of the Nuclear Non-Proliferation Treaty.

To carry out our primary mission of deterrence, we maintain broad capabilities in nonnuclear defense. These capabilities allow us to contribute to national security in such areas as conventional weapons, directed-energy weapons, and defensive lasers. Collaborating with industry to assure that newly developed technologies reach the military quickly is crucial to our successful support of national security.

Much of our work in technologies for conventional defense is based on our expertise in high explosives, materials, and large-

scale computations. We have developed new and safer propellants, better armor and armor-penetrating materials, high-power microwave weapons, and low-cost guidance and control systems. Using new insights we have gained into what makes explosives less likely to explode accidentally, we can synthesize new materials with increased confidence.

We are demonstrating the use of new heavy-metal alloys for improved kinetic-energy penetrators. A major goal is to develop materials that eliminate or substantially reduce the use of uranium so that the environmental burden is reduced. An important part of our research and development effort is the Armor/Anti-Armor Program, a collaborative effort with the Defense Advanced Research Projects Agency, the U.S. Army, the U.S. Marine Corps, and 130 corporations, laboratories, and universities. A key element in this collaboration is the Advanced Technology Assessment Center, created at Los Alamos to take advantage of our science and technology base. The center serves as both a testing center for prototypes and a scientific resource for all participants.

To assist industries interested in designing and manufacturing new armor, we developed the three-dimensional MESA hydrodynamics code. We have transferred this analytical tool to a number of U.S. companies. We developed and operated successfully a new diagnostic system called cineradiography that uses x-rays and electronic cameras to obtain time-lapse photographs of the interaction of penetrators and targets.

Los Alamos research in conventional defense also includes developing computer codes and software for battlefield simulations and for mission planning and rehearsal systems, as well as for command, control, and communications systems. We are helping to develop a quick-running, macro-level computer program for analyzing regional deployment of U.S. forces. We are also developing a distributed network of workstations for the Joint NATO Warrior Preparation Center. This year we continued to work with the U.S. Army to complete the combat simulation called Eagle.

Terrorism, drugs, and regional wars rather than worldwide wars may be the major threats of the 1990s. Los Alamos has strong expertise in technologies to counter low-intensity conflicts. We are developing instruments for detecting explosives and nerve gases. We are refining the broad class of nonlethal weapons, such as microwave and optical munitions, that can disable without loss of life. To assist in the war against drugs, we are working with the U.S. Treasury Department to develop a statistical tool that will identify illegal money-laundering in the banking system.

In our work on directed-energy weapons, we continue to investigate the use of neutral particle beams (NPBs) for space defense. A major next step in the program is to develop NPB technology in an integrated testing system called the Ground Test Accelerator (GTA), a project that successfully pairs the Laboratory with the Grumman Aerospace Corporation. We will use the GTA, scheduled to become operational in 1992, to turn new developments into engineering prototypes and to test both the individual components and the prototype as an integrated system.

In our research program on defensive lasers, we are developing a variety of systems. They range from powerful free-electron lasers (FELs) usable for missile defense, to unique compact lasers capable of penetrating seawater, to advanced short-wavelength lasers that may make possible the large-scale production of integrated circuits.

Los Alamos has operated an FEL since 1981. Among our contributions to FEL technology are the abilities to tune the wavelength of the laser, to scale the power to the needed level, to generate very bright beams, to recover energy from the laser, and to produce and analyze diagnostics for bright electron beams.

Our advances in FEL technology enable us to address the next major advance in large-scale production of integrated circuits. By using an FEL to generate extremely short wavelength light, we expect to develop an efficient way to produce semiconductor chips that will carry one thousand times more information than current chips do. We believe that this extension of FEL technology will give the nation a strong competitive advantage in the global market for chips for both commercial and military products.

Los Alamos is developing laser systems that address tactical military requirements. Novel compact lasers driven by small quantities of explosives—called battlefield optical munitions—fit existing military weapons and are applicable to several potential battlefield problems. We have successfully demonstrated a solid-state laser with blue-green color, which may have applications in submarine communications and underwater radar. We expect to develop compact and efficient light sources that penetrate seawater and can be deployed on surface vessels, submarines, aircraft, satellites, or other unmanned vehicles.

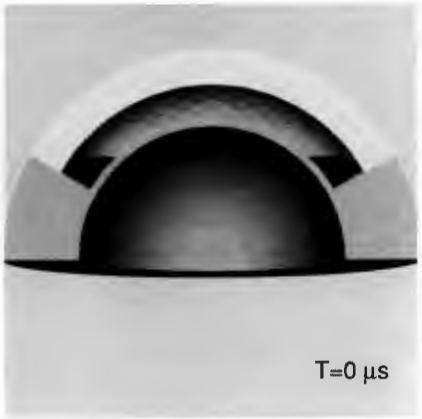
We expect nonnuclear defense programs to grow in importance as the world community turns increasingly toward arms control and further limits nuclear weapons. Current events in Europe and the ongoing problems in the Middle East reinforce this expectation. Through a wide variety of activities, from nuclear weapons design to treaty verification, we continued in 1990 to address national security problems.

Modeling Techniques For Nuclear Weapon Safety

Can a nuclear weapon ever be characterized as safe? Each year, design physicists, detonation experts, materials scientists, and others at Los Alamos work to ensure that nuclear weapons, the foundation of our national defense, are safe, as well as reliable and effective. These two objectives of safety and reliability are satisfied by weapons that produce nuclear yield (explosive energy) only when detonated under the desired circumstances. The safety of all Los Alamos-designed nuclear weapons in the nation's stockpile has been extensively investigated through computer simulations, laboratory experiments, and field tests. All Los Alamos stockpile devices have satisfied a specific objective known as the one-point-safety criterion. The current criterion states that if the chemical explosive of a weapon were detonated at a single point, the chance that a nuclear reaction would ensue to produce energy greater than that produced by 4 pounds of TNT is less than one in a million.

Over the past year, landmark nuclear safety experiments proposed, executed, and analyzed by Los Alamos scientists have had a major impact on the analysis of nuclear weapon safety. A key element in the planning and analysis of such experiments, as well as in the design of safe nuclear weapons, depends heavily on the development and use of large computer programs known as codes. These codes simulate numerically the complex physical processes that occur when a nuclear weapon is detonated. Using insight gained from such simulations and from appropriate experiments, the weapon designer strives to factor into the design process all physical phenomena that might affect nuclear safety.

Code developers at Los Alamos



Design physicist and nuclear safety expert Arthur Lane Dana studies a three-dimensional rendition of a solution to a test problem used to calibrate three-dimensional codes. The corresponding calculational image is shown at left (T=27 μs).

continue to make significant progress toward improving the codes needed by weapon designers to investigate complex nuclear weapon safety issues. New code capabilities in turn lead to more advanced experiments and increased understanding of safety issues—and, therefore, to a safer nuclear weapon stockpile. In particular, the recent development of three-dimensional computer codes has enabled designers to model much more sophisticated scenarios involving the accidental or unauthorized detonation of nuclear weapons than had previously been possible. The resulting modifications in the conventional wisdom concerning safety have stimulated experiments to validate new concepts and confirm stockpile safety. These experiments have in turn stimulated the development and refinement of the computer codes.

Using three-dimensional codes places huge demands on the speed and memory of modern computers. To improve speed, code developers at Los Alamos have refined the efficiency of nuclear weapon design codes running on the large, fast CRAY supercomputers that currently form the backbone of Los Alamos computing power. The latest additions to this inventory, the CRAY YMP 8-128s—machines with 8 parallel processors and 128 megabytes of memory—have made it possible for the first time for designers to use the new three-dimensional codes effectively. Research is also under way to investigate the feasibility of adapting numerical algorithms—computational procedures—to run on the Laboratory's two massively parallel Connection Machine CM-2s, each of which has 65,536 processors and 2 trillion bytes of memory.

In theory, if a computer code could be devised to contain all the physics necessary to describe the processes that occur during the explosion of a nuclear device, along with the numerical algorithms to solve exactly the equations describing that physics, and if a computer large enough and fast enough to solve the equations were available, then design physicists, laboratory experiments, and field tests would be superfluous. However, computers are finite in both memory capacity and execution speed. Thus, any computer code contains inherent limitations as to the size of the problem, the accuracy of the solution, the type of numerical algorithm to be applied, and the complexity of the physics involved. Both design physicists and experiments will be needed for the foreseeable future.

For a new nuclear weapon design, physicists attempt to satisfy performance requirements by modeling different configurations of weapon components in series of numerical simulations to optimize the performance of the device under planned operating conditions. In order to make safety assessments, however, designers must have tools to predict as accurately as possible what would happen if the device were accidentally detonated or detonated by unauthorized means. Relying on their experience, they approximate unknown physical data and compensate for a number of other shortcomings in their knowledge. Ultimately, using such a process complemented by benchmark experiments, they assess the safety performance of a particular nuclear weapon under the wide variety of conditions to which it might be exposed when it is placed in the weapons stockpile.

Frequently, designers discover through experiment that their predictions are not as accurate as necessary to make safety assessments—especially when the designers are developing a totally new type of device or are otherwise operating in areas in which they have limited experience. Careful analysis of experimental results that deviate from predictions often leads to insight into the operation of the device. Sometimes this insight leads to the upgrading of the physics approximations or numerical algorithms already in the code or to the addition of new types of physics to the codes; often it remains as a bit of experience that designers keep in mind when assessing nuclear weapon performance and safety or approximating parameters for a new weapon configuration. Frequently, unexpected results suggest new avenues of investigation that lead to further testing or to new objectives in code development.

Safety is a key factor at each stage in the development of a nuclear weapon and continues through the years the weapon remains in the stockpile. From special insensitive high explosives that control the initiation of the nuclear reaction, to fire-resistant containers that preclude accidental dispersal of nuclear materials, to detonation systems that contain special safety design features, modern nuclear weapons incorporate increasingly effective and reliable safety features. This year's achievements in implementing more complex and detailed numerical models and taking advantage of the new, faster computers with greater memory capacity have led to better ties to experimental data verifying the efficacy of safety features and to greater confidence in our ability to assure the nuclear safety of the stockpile. Continued Los Alamos investment in new code development and advanced computing hardware will lead to designs that provide even greater assurance of nuclear weapon safety in the future.

Best ICF Pulse Shapes to Date

The sun has fusion down to a science: it supplies enormous amounts of heat and pressure to cause hydrogen nuclei to fuse. When the nuclei of two hydrogen atoms fuse, they form a heavier nucleus of less mass than the original two. The excess mass becomes energy, which we see and feel as sunlight and heat.

As U.S. oil and gas reserves gradually diminish, alternative energy sources such as fusion will come to the forefront of basic research. Fusion offers the potential of inexpensive and inexhaustible energy.

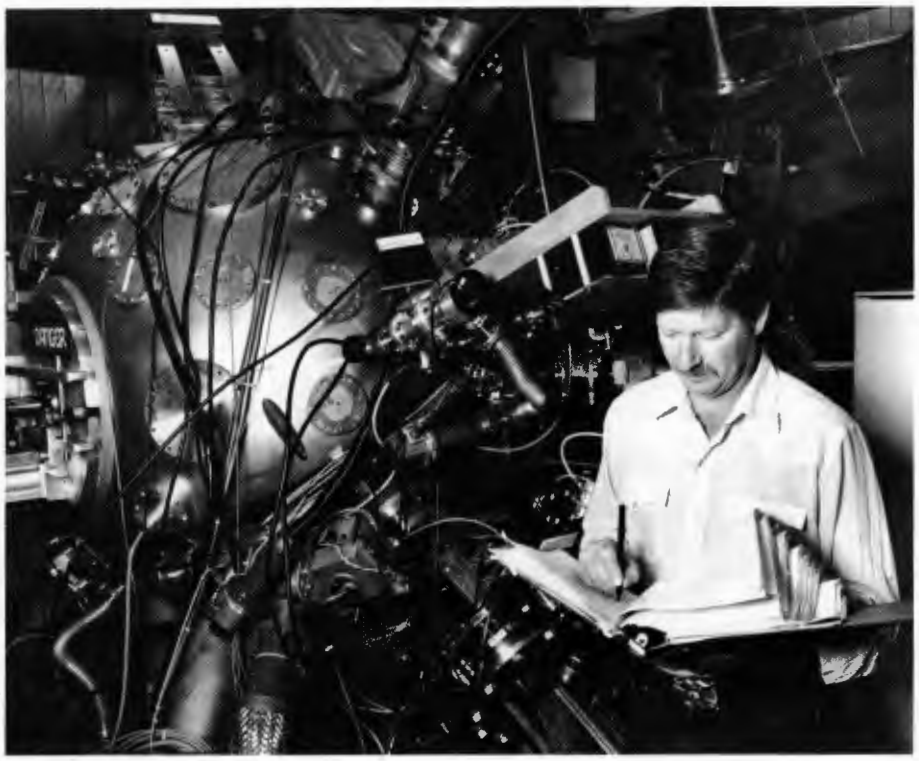
For example, the energy in one-quarter teaspoon of a hydrogen isotope is the same as that provided by 250 gallons of gasoline. A fusion program at Los Alamos, the Inertial Confinement Fusion (ICF) Program, is working toward initiating fusion with the help of lasers. This year the ICF program produced the best-shaped laser pulses ever, a key element in generating a high level of energy.

Because we cannot simulate the sun's great gravitational forces on Earth, we are trying to generate the fusion process with the help of lasers. The U.S. national program primarily utilizes solid-state lasers for this purpose. At Los Alamos, we have been developing and evaluating a krypton fluoride gas laser called Aurora. Like most lasers, this type of laser converts electrical energy to light energy. To do this, a molecule of krypton fluoride must be produced in an excited state. Noble gases, which include krypton, neon, helium, and argon, are very stable and rarely, if ever, combine with other elements. But when an electron beam "excites" the krypton, it enters a new state of energy, a state in which it can combine with the fluorine. The excited krypton fluoride molecule is very unstable. In other words, the two elements would rather be apart than together. When the two elements break away, energy is released in the form of a photon (a photon is a particle of light). A series of mirrors and lenses then transport, amplify, and focus the photon beam onto a fusion target.

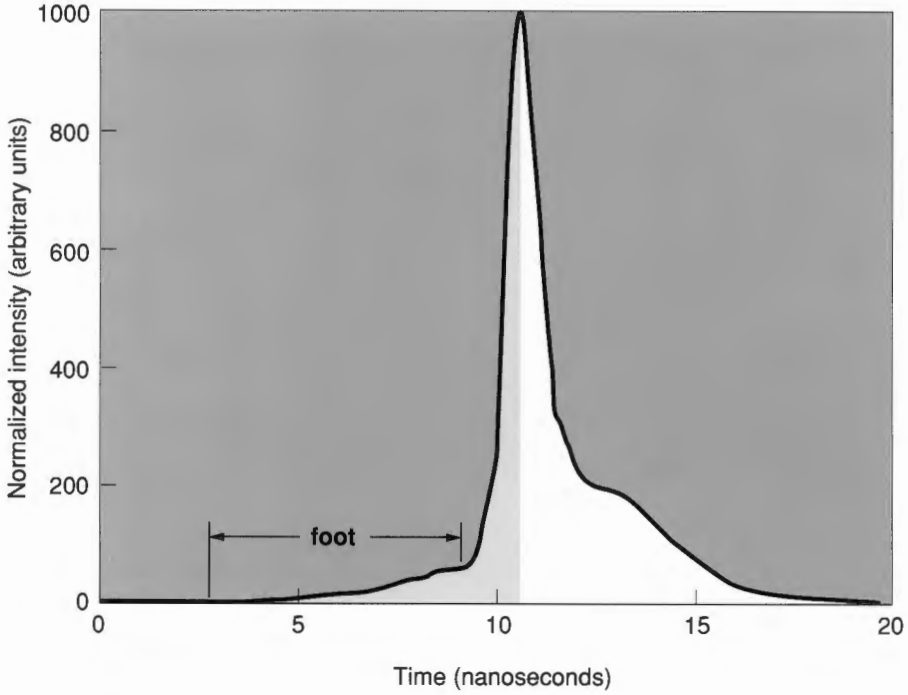
In inertial confinement fusion, the target is a tiny pellet filled with a fuel composed of two isotopes of hydrogen known as deuterium and tritium. The beam hits and heats the pellet, which is most likely made of some type of plastic. The heat begins to compress the fuel within the pellet. In a flash, the plastic shell explodes, which compresses (implodes) the central fuel. This implosion causes the hydrogen nuclei to fuse.

A basic problem in generating fusion is how to hold the hydrogen nuclei together long enough at the appropriate temperature for fusion to occur. The fusion must take place in about a billionth of a second, which is shorter than the time it would take for the fuel to fly apart. Because fusion occurs at very high temperatures, molecules become a plasma, which means that the fuel assumes a gaseous and ionized state. Confining this plasma appeared to be almost impossible, but scientists have found several ways to do it. In one approach, they have found that inertia (matter's tendency to resist motion) can confine the nuclei long enough for fusion to occur.

To make sure that the plasma generates fusion, the laser needs to provide precisely shaped pulses of energy to the plastic shell. Such precise control of the photon beams leads to a gradual increase in the fuel's temperature and pressure. If the fuel's temperature and pressure



Keith Hosack stands next to the target-reaction chamber for Aurora, the krypton fluoride laser that this year produced the best ICF pulse shapes to date.



A typical Aurora pulse begins with a long, low foot followed by a dramatic increase in intensity. Producing such pulses allows a fusion implosion to occur in an efficient manner.

increase too abruptly, the fusion process will prove inefficient and wasteful.

To understand this process, think for a moment how the space shuttle escapes the Earth's gravitational force. The space shuttle does not accelerate like a cannon ball because such acceleration would harm the astronauts inside. Instead, the space shuttle gradually increases in speed. At some point, the shuttle reaches sufficient speed to escape Earth's gravity and enters space.

The same principle applies to fusion. The laser pulses must generate precise, gradually increasing pressure and temperature for fusion to occur in an efficient manner. Otherwise, the fuel is "harmed" like the astronauts in the above example. Theoretical predictions indicate that producing and sustaining the fusion process in a laboratory or a power reactor will require a laser system that can deliver 5 to 10 megajoules of light energy (5 to 10 megajoules equals the energy in 2.5 to 5 pounds of high explosive) in a pulse with a duration of a few tens of nanoseconds or a peak power of 10 quadrillion watts. In this ideal laser power curve, power gradually increases throughout the pulse. The first part of this gradual increase is called a "foot" because the graph of such an increase resembles a foothill. To be effective, the shock wave from the foot of the pulse must break though the pellet shell and into the fuel before being overtaken by subsequent shock waves. Krypton fluoride lasers easily produce the required long, low foot, which comes close to the ideal graph.

Producing a pulse that comes close to the ideal is one thing; reproducing such a pulse at different amplifications without distortion is another. Aurora has a chain of four stages designed to amplify pulses. To see if any distortion would occur when amplifying the pulses, we sent tailored pulses through various combinations of these amplifiers. In each case we demonstrated that the amplifiers increased the power in the laser pulse with little distortion. This behavior of krypton fluoride lasers allows the generation of complex pulse shapes easily at low power and their amplification with no distortion.

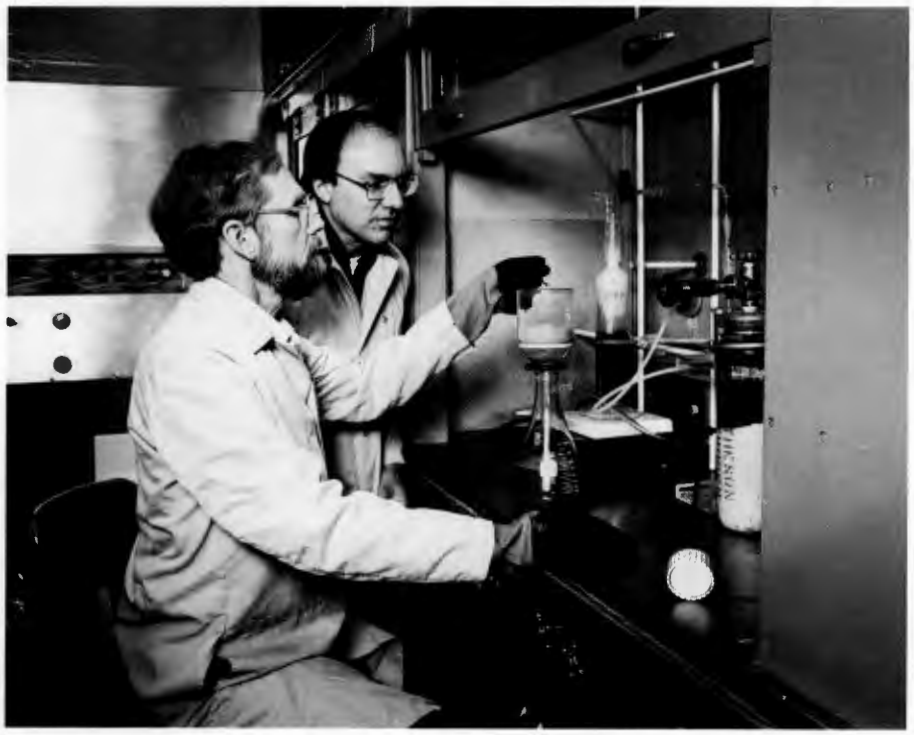
Research accomplishments such as this one contribute to the overall knowledge base of the national ICF research effort. Such contributions continually improve the possibility of using inertial confinement fusion as an energy source.

A New Class of High Explosives

For decades scientists have tried to find the safest possible high-performance explosive—one that is very powerful but that is insensitive, detonating only on demand. Recently, Los Alamos theoreticians and organic chemists made what may well be this century's most exciting discovery in the field of explosives: they discovered a new class of high explosives. The first in this class to be synthesized, called LAX-112, compares favorably with other known explosives in preliminary tests. It rivals the performance of the most powerful and is less sensitive to accidents than most.

Among commonly available explosives, HMX is the most powerful, but it could detonate under severe accident situations. On the other hand, TATB, the insensitive high explosive in nuclear weapons, is very safe—in a series of tests, it did not detonate even when slammed into a wall at 650 meters per second—but unfortunately it is not as powerful as HMX. Our new explosive approaches HMX in performance and is much less sensitive, although it still does not match the insensitivity of TATB.

The high nitrogen content of LAX-112 helps account for its performance. Traditionally, useful explosives are rich in carbon and contain enough oxygen to oxidize sufficient carbon for detonation. Explosives with enough oxygen to oxidize all the carbon are too sensitive for our applications. For that reason, very few explosives contain enough oxygen to balance the carbon. The unburned carbon ends up as soot that degrades the performance of the explosive. Theoreticians calculated that explosive compounds containing a high percentage of nitrogen would give unusually high performance without oxygen. Our high-nitrogen compound LAX-112 has very little carbon or oxygen. Little of the compound goes to waste, and the result is high efficiency and performance.



Organic chemist Michael Coburn (left) and theoretician James Stine examine an intermediate compound after it has been filtered. The compound is necessary for the final production of LAX-112.

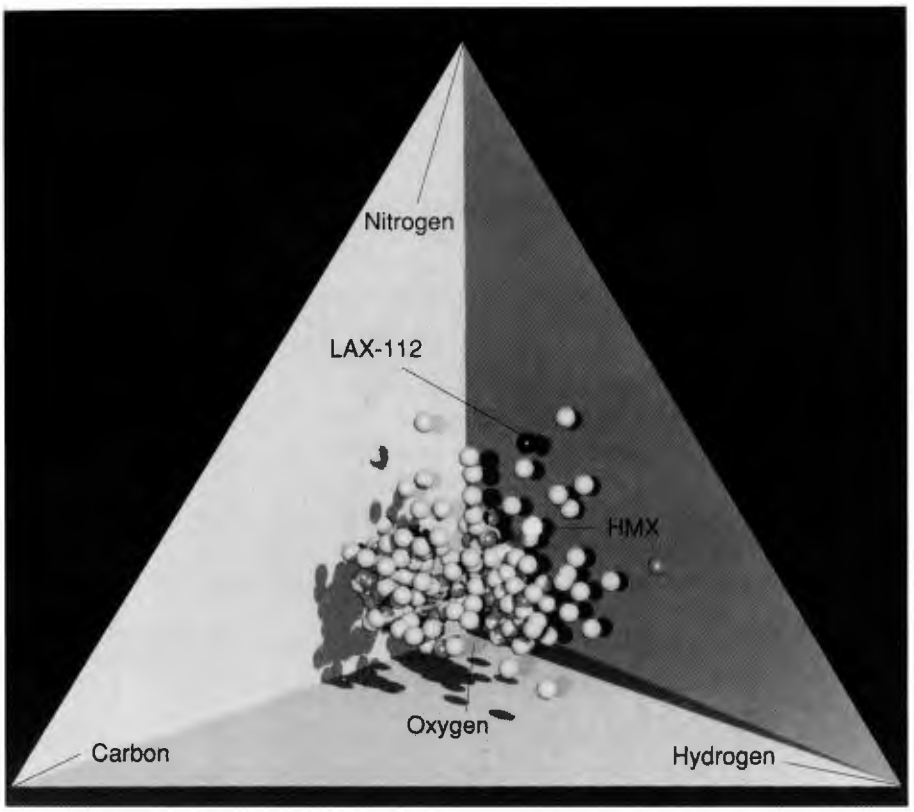
One factor contributing to performance is the large amount of gas released during detonation. The tremendous, rapid change in volume occurring when the explosive changes from a solid to gaseous products causes the shock wave, or the force of the explosion. A molecule of nitrogen gas requires only two atoms of nitrogen, whereas the gaseous products from carbon compounds require three atoms per molecule. Therefore, high-nitrogen explosives should produce more gas more efficiently than do traditional explosives.

The high performance of LAX-112 was indicated in preliminary tests. It has a favorable detonation pressure (how well the explosive can push metal) of 38.7 gigapascals, approaching that of HMX at 39.3 gigapascals and far surpassing that of TATB, which is capable of only 31.5 gigapascals of pressure. We also measured the detonation velocity (how fast a detonation wave traverses an explosive), which indicates how quickly the explosive converts to gaseous products. For LAX-112 the detonation velocity is 9.13 kilometers per second, slightly greater than that for HMX at 9.10 kilometers per second and significantly greater than that for TATB at 7.98 kilometers per second.

We determined impact sensitivity by dropping a 2.5-kilogram weight onto samples of the explosive. The distance the weight must drop to cause LAX-112 to explode 50 percent of the time is 179 centimeters. Therefore, LAX-112 is much less sensitive and safer than HMX, which has a drop-weight distance of only 32 centimeters, but still

more sensitive than TATB, whose impact sensitivity is greater than 320 centimeters. Tests for thermal stability showed that LAX-112 was as stable as HMX although less stable than TATB.

One way to compare the atomic composition of LAX-112 with the compositions of the other known organic explosives is to plot them inside a regular tetrahedron. One property of a tetrahedron is that the sum of the four distances from any interior point to each of the four sides is a constant. Hence, if the corners of the tetrahedron represent carbon, hydrogen, nitrogen, and oxygen, then an interior point represents the relative composition of these four atoms for a particular explosive. Most existing explosives, which are carbon rich and oxygen deficient, form a cluster when plotted in this way. The region above the cluster represents the new class of high-nitrogen explosives, of which LAX-112 is an example. So far, this region of the tetrahedron is largely vacant, waiting to be explored.



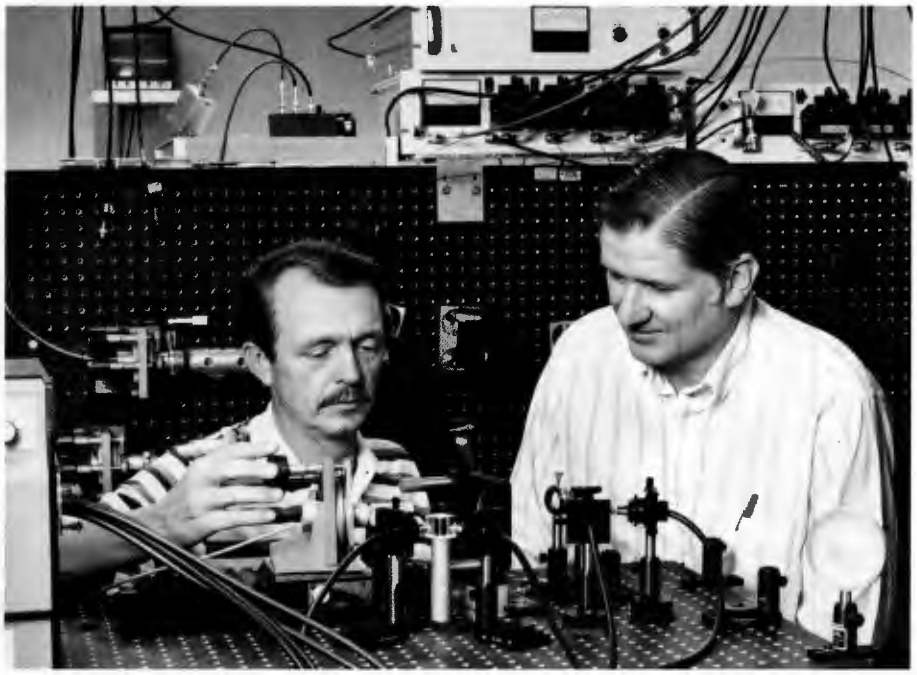
Most known organic explosives contain large amounts of carbon and insufficient oxygen to convert all of the carbon to a gaseous product. High-performing HMX is closer to the point of carbon/oxygen balance than is TATB—one of the gray spheres in the cluster. LAX-112 occupies the relatively unexplored region of high-nitrogen compounds that evince high performance.

Before LAX-112 is considered in any new weapon design, it must prove clearly superior to available explosives by passing many tests. This year, in addition to conducting preliminary performance and sensitivity tests, we also doubled the chemical yield and increased the scale of synthesis so that large amounts of LAX-112 can be made for more extensive testing—no easy task. We had to find solutions to many practical problems, such as dissipating heat, selecting reaction solvents, and recrystallizing the compound to the desired particle size for making it into a plastic-bonded explosive suitable for pressing. Additional performance tests include identifying the failure diameter, that is, finding the smallest-diameter cylinder that will support a detonation. Additional sensitivity tests will show how the compound reacts to different kinds of stimuli. Further considerations include compatibility with other materials and manufacturing processes.

Even if LAX-112 falls short in any of the tests and is not actually used in weapons, it has opened new areas in the synthesis of organic explosives that are qualitatively different from most existing explosives. We believe there is now hope for finding the perfect explosive that has eluded scientists for the past century.

Measuring High Velocities with Line-Imaging VISAR

Imagine trying to measure the speeds of all thirty-three race cars as they accelerate across the starting line at the Indianapolis 500. From past experience, you know that the cars will flash by in a group. You know that you will have only one chance to get the measurements. In a way, your task would be like that of measuring velocities in an explosive or hydrodynamic experiment. In a hydrodynamic test, where extreme pressures easily compress metal and solids flow like liquids, the diagnostic instruments must extract crucial information in far less time than the blink of an eye. As at the start at Indy, the instruments have only one chance. But instead of thirty-three speeding cars, they must measure surface velocities that change from zero to several kilometers per second in less than a millionth of a second.

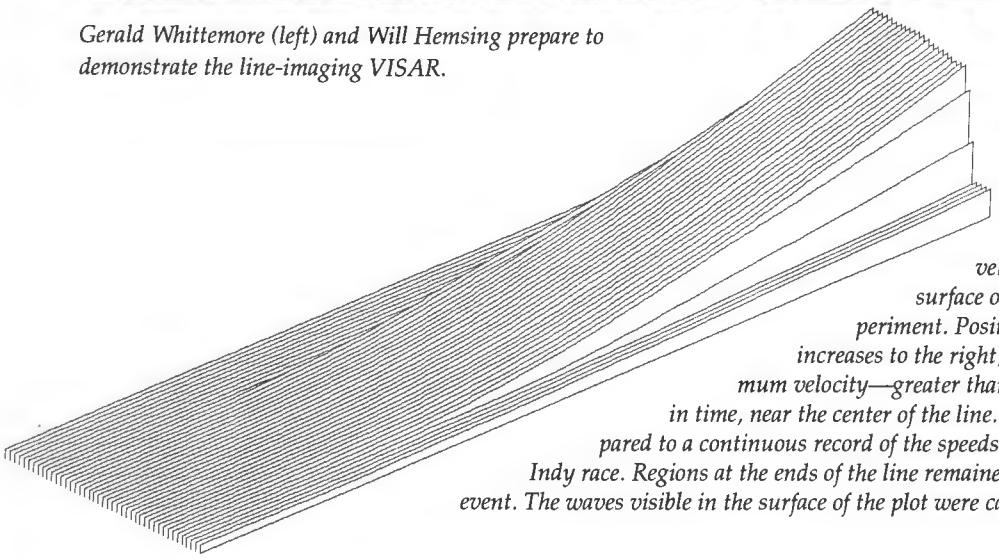


Gerald Whittemore (left) and Will Hemsing prepare to demonstrate the line-imaging VISAR.

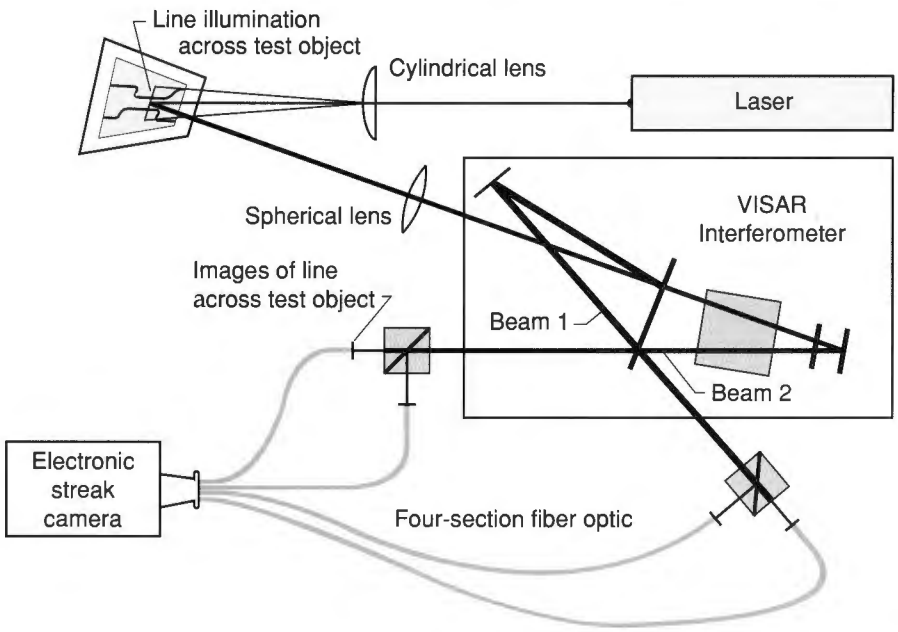
At Los Alamos, we have developed increasingly efficient measurement tools to extract velocity information from hydrodynamic tests. One of these devices is our new line-imaging VISAR (Velocity Interferometer System for Any Reflector), an instrument that can measure many high velocities simultaneously. We expect it to increase dramatically the amount of information we can obtain from a single test.

In an interferometer, light from two beams is combined in such a way that the two electromagnetic fields are superimposed. The increase or decrease in the resulting electrical field as the two input beams either reinforce or cancel each other is called interference. (Interference in water waves, a similar effect, appears where expanding rings of water collide after two stones are thrown into a lake.) In a velocity interferometer, interference is used to sense the Doppler shift, or change in wavelength, of laser light reflected from an accelerating surface. By measuring the changes in the interference caused by the Doppler shift, the velocity interferometer system provides us with measurements of velocity over the duration of an experiment.

Practical interferometers for measuring surface motion were developed shortly after suitable lasers became available in the 1960s. These instruments measured displacement, rather than velocity, by setting up interference between a beam of laser light



This pseudo three-dimensional plot shows velocity at each position along the line on the surface of the test object during the time of the experiment. Positions along the line extend to the left, time increases to the right, and velocity increases vertically. The maximum velocity—greater than 3 kilometers per second—occurred latest in time, near the center of the line. The central portion of the plot could be compared to a continuous record of the speeds, from start to finish, for all the cars in an Indy race. Regions at the ends of the line remained at near zero velocity during the entire event. The waves visible in the surface of the plot were caused by imperfections in data reduction.



Experimental setup for the line-imaging VISAR demonstration.

reflected from a single point on a moving surface and a second, unshifted beam obtained directly from the laser. The extreme sensitivity of these devices, however, caused difficult problems at high velocities and soon led to the development of the velocity interferometer.

The velocity interferometer does not use unshifted light directly from the laser. Instead, the second beam is split off from the Doppler-shifted light reflected from the moving surface and is then reflected between mirrors to produce a delay before this beam is recombined with the first beam. The resulting interference remains fixed for constant velocity but changes when the experimental surface accelerates. Thus, the velocity interferometer avoids problems that occur at high velocities in displacement interferometers by responding only to acceleration.

During the past fifteen years, we have been refining the single-point VISAR, a sophisticated velocity interferometer developed in the early 1970s. The point VISAR can make fast and accurate measurements of a variety of surfaces, and we can adjust the instrument's sensitivity to measure a wide range of acceleration, velocity, or time conditions. In one experiment, we tracked a laser-driven flying plate accelerated, in only 4 billionths of a second, to a velocity of about 1.1 kilometers per second. Acceleration of the plate reached a magnitude thirty billion times that of Earth's gravity, yet the plate traveled a distance of less than 2 micrometers, approximately one twenty-fifth the diameter of a human hair.

This instrument is highly useful for measuring single-point velocities. However, in tests where velocities of multiple points across a surface are to be measured, a separate VISAR is required for the measurement of each point. Our line-imaging VISAR, on the other hand, enables us to measure many velocities simultaneously. The system works by focusing an image—a line of light on the surface of the test object—through a VISAR for recording by an electronic streak camera. On the line image, the interferometer superimposes interference corresponding to the acceleration of the moving object. Before the light reaches the streak camera, beam splitters divide it into four images. The camera makes a continuous, high-speed record, like a special movie, of the images. Unlike an ordinary motion picture, which consists of thousands of pictures taken in sequence, this record contains only four pictures. Time variations in the images are captured during the event as the camera rapidly moves, or streaks, the line images across the film.

In our demonstration, the surface of the test object was unevenly driven to very high velocities during an event that lasted only half a millionth of a second. Analysis of the record yielded sixty velocity histories for points on the line. Obtaining this much information from a conventional VISAR would require either one test with sixty VISARs or sixty separate tests with the attendant problem of the inevitable test-to-test variations. By eliminating that problem, the line-imaging VISAR provides us with a much clearer understanding of the behavior of the test object and, at the same time, saves much time and effort.

Because it uses light as its probe, the line-imaging VISAR can measure many surface velocities without mechanically contacting the experimental object. It is ideal for experiments that occur over short times ranging from thousandths to billionths of a second. By responding only to acceleration, it avoids problems with very high velocities. It can even follow continuously changing surface shapes. We expect our new instrument to benefit nonnuclear tests in which many related velocities must be measured simultaneously. No longer limited to making single-point velocity measurements, we also anticipate applying the line-imaging VISAR in nuclear weapons tests, where obtaining accurate results is crucial to the nation's security.

Safety Analysis of the Savannah River Reactors

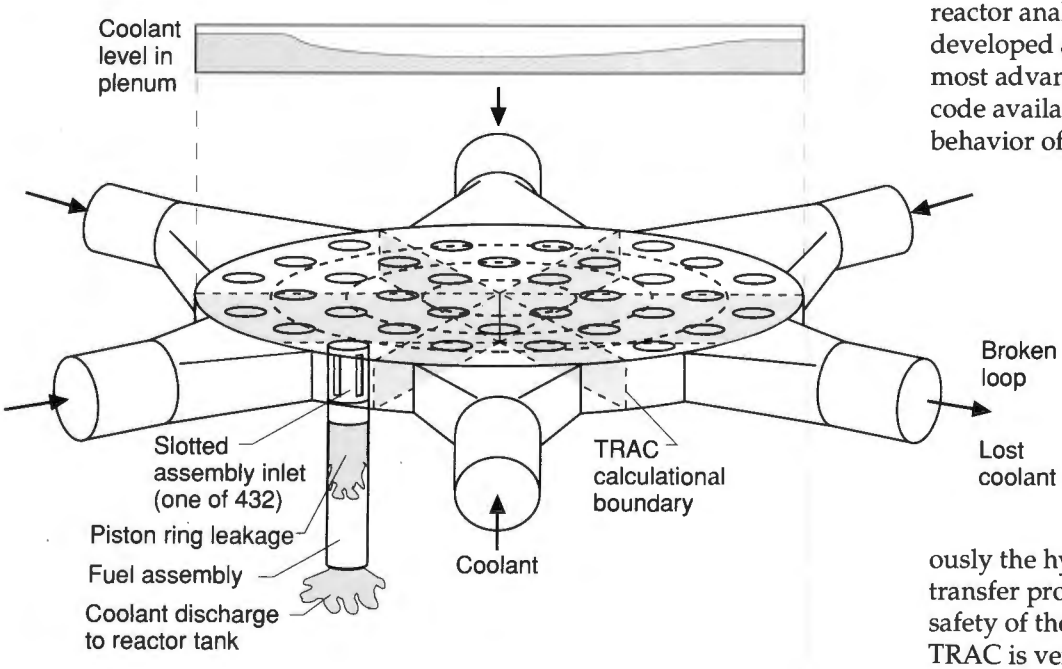
After operational problems at the Savannah River Site in South Carolina, the Department of Energy shut down the reactors in 1988, pending safety reviews and required upgrades to the reactors. The three reactors, which had been in operation since the mid 1950s, produced tritium and plutonium, components important to the nuclear deterrent of the United States. Although plutonium production is of less concern for now because supplies are adequate, tritium must be replenished periodically because of its short half-life. Within the next decade the Department of Energy plans to build one or more new production reactors, but the Savannah River reactors must produce the required tritium until the new reactors are ready. Even then, the current reactors will serve as back-ups and will require an ongoing safety assessment.

Los Alamos is participating in the safety reviews, which encompass many aspects of the plant's operation, including reliability of the safety systems, the structural integrity of the reactors, and operating specifications. The reviews also cover the capability of the reactors to survive accidents, such as loss of reactor coolant or loss of capability to pump coolant through the reactor core. Los Alamos is responsible for performing independent safety checks of three areas: the power limits program, the probabilistic safety assessment, and the reactor physics analysis.

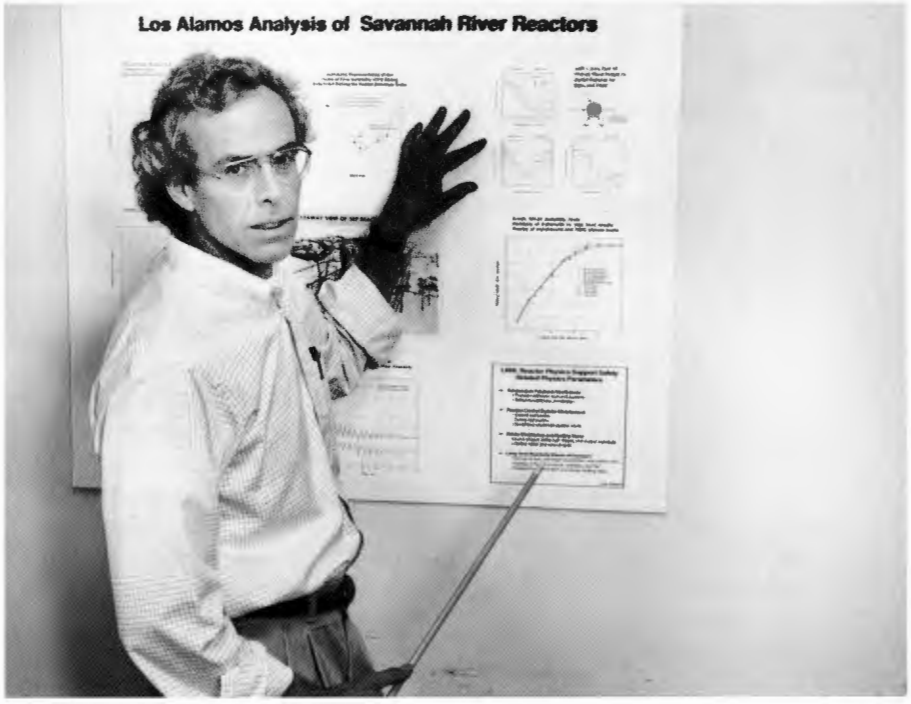
The power limits program determines the maximum safe operating power for the reactors when they restart. We try to find the most severe transient (an event, normal or accidental, that causes change in reactor behavior) and the maximum power at which the reactors can operate and still survive the transient. In trying to support power limits, we have worked for some time on the thermal-hydraulic analysis of the reactors. As a result, we have improved collective understanding of the reactors, their behavior during a variety of transients, the need for upgrades, the consequences of operating specifications, and the impact of operator actions.

Currently, the thermal-hydraulic analysis relies on the transient reactor analysis code (TRAC) developed at Los Alamos. The most advanced thermal-hydraulic code available, it can model the behavior of the hydraulic system in both one and three dimensions while integrating the effects of power generation and heat transfer. Because the generation of power can damage the reactor core during a transient, it is necessary to calculate simultaneously the hydraulic and energy-transfer processes to ensure the safety of the reactor. Analysis by TRAC is verified by comparing computer calculations with actual test and operational data.

We modified TRAC to model details of the reactor systems that are important during an accident. In 1990 we completed modifications to account for geometry that is applicable only to the Savannah River reactors. We ran calculations



The flow geometry in the upper part of a Savannah River reactor during a loss-of-coolant transient reflects a break in one of the piping systems (the broken loop, a break between the reactor tank and the plenum). When the circular plenum collects the coolant flow from the five intact piping systems and distributes it to 432 fuel assemblies, some coolant leaks out through the broken loop. The fuel assemblies discharge the coolant into the reactor tank, and the coolant reenters all piping systems, including the broken loop. If the flow to the reactor core is disrupted as a result of the break, the core may overheat. Using TRAC to calculate the thermal-hydraulic behavior during such hypothetical transients, the Los Alamos team will help to ensure safety.



Jack Edwards, a member of the Los Alamos team studying the thermal-hydraulic systems of the Savannah River reactors, explains results of a TRAC analysis.

to investigate responses of the reactor to potential breaks in various locations; to operation of the main coolant pumps; and to the initial, or operating, power. Calculations continue, but we have already confirmed several facts important to determining restart power limits: (a) we determined the location of the worst potential break; (b) the effect of a loss of electrical power to the alternating-current motors on the pumps, resulting in slower operation by the direct-current motors, is only marginally different from the effect of no loss of power; and (c) the response of the system is basically unaffected by the initial reactor power, provided that it is low enough to preclude boiling, which interferes with fluid flow.

Our review of the probabilistic safety assessment is based on previous Los Alamos reviews of commercial power plants and special sites of the Department of Energy and on independent safety assessments for other Department of Energy installations, such as the reactor at Hanford, Washington. At the Savannah River Site the assessment estimates the frequencies of accidents that cause damage to the reactor core and models the safety systems available for mitigating the accidents. We independently analyzed the safety systems of the reactors and alerted the Department of Energy to potential systems dependencies and interactions that significantly increase the risk posed by operating the reactors. We also identified additional single failures that have severe impact on system safety.

This year we pioneered ways of including in the analysis diverse types of initiating events—events that start a sequence of problems. We also added a more detailed common-cause analysis, in which we examine a group of ordinarily independent failures that can occur simultaneously from a common cause. These changes allowed improved modeling of failures resulting from initiating events. In addition, we developed a method for accurately propagating initiating events that degrade the ability of the system to mitigate failures. Our modeling of the safety systems and required support systems resulted in the integrated schematics now used at Savannah River to train reactor operators.

As part of our involvement in the Savannah River review, we perform analyses of reactor physics. We perform calculations to determine safety-related parameters and compare our results with those of the plant staff. We also review for the Department of Energy the reactor physics methods used at Savannah River in their accident analyses. We use radiation-transport computer codes and methods previously developed at Los Alamos; these computer codes allow us to describe neutron and photon transfer and interaction.

This year we completed a physics review of a Savannah River analysis of a postulated loss-of-coolant accident: we reviewed how the shutdown of the reactor affected the power over time and the distribution of that power throughout the core. Our results confirmed that the approach of the Savannah River staff was conservative in the interest of safety; that is, they had successfully defined the severest response of the system. We also recommended a number of improvements in the analysis methods.

Our work this year with Savannah River and Department of Energy representatives resulted in improvements at the plant and in our methods and increased overall understanding of reactor behavior. Combined efforts in defining criteria for power limits, as well as for analysis and modeling, have further defined the power limits for restarting the Savannah River reactors.

Advances in the Ground Test Accelerator Program

Picture a beam of light shining from a window in a building in Los Angeles and striking a particular window in a New York City high-rise. That accuracy is required of the Ground Test Accelerator (GTA) Program if it is to place particle beams into space for nonnuclear defense.

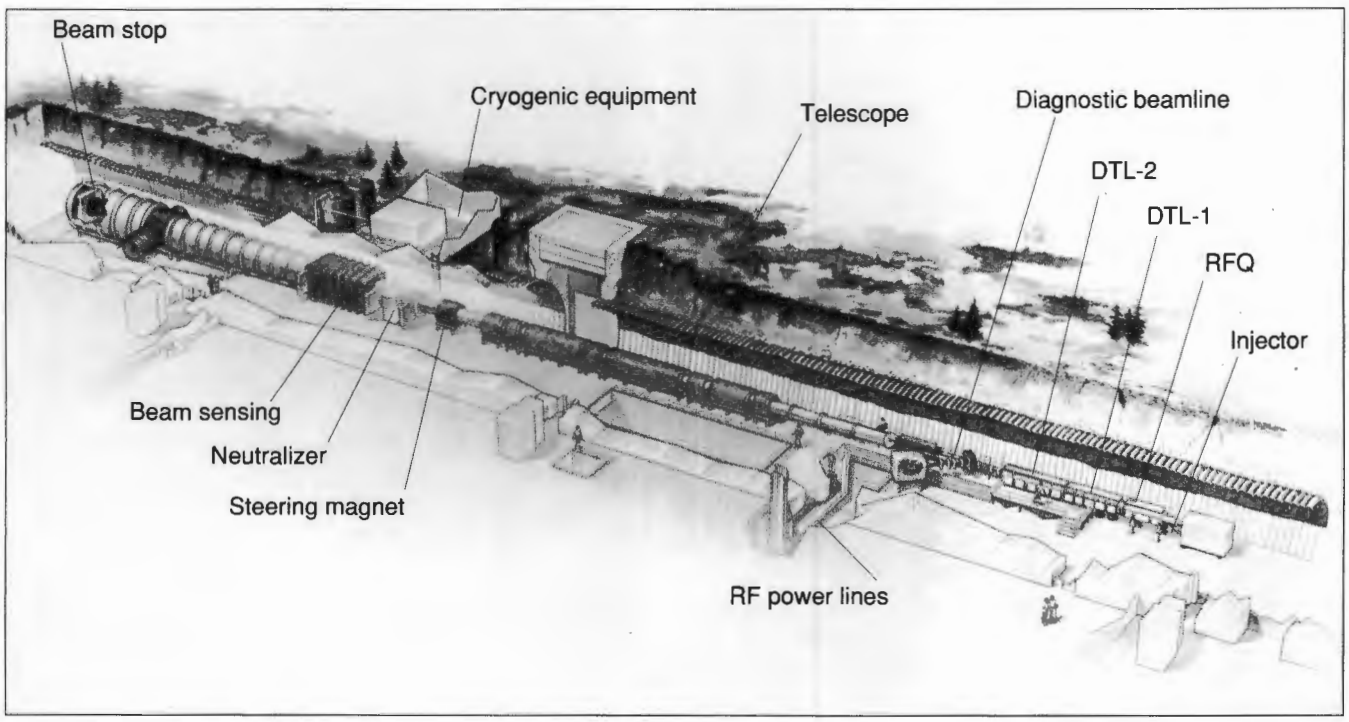
The primary challenge is to create a bright beam. First, the beam must be generated. Then it must be accelerated to energies that would penetrate a missile warhead, and last, the beam must be focused and directed onto a target.

Started in 1986, the first phase of GTA should be operative by 1992, and the second phase is expected to be completed in 1995. The GTA is representative of what will actually be placed in space. The viability of the neutral particle beam concept in space was demonstrated by BEAR, Beam Experiments Aboard a Rocket. Launched by an Aries rocket July 13, 1989, from White Sands Missile Range, BEAR was the first test of an accelerator in space.

This year we made three significant advances in the GTA program. First, we demonstrated that particle-beam brightness can be increased by the process of beam funneling, which is combining two or more beams. Second, we demonstrated that the beam direction can be sensed with extreme precision using a device called the wire and fluorescent fiber offset grid. Third, the bright hydrogen beam produced by the GTA injector was bunched and accelerated by the radio-frequency quadrupole (RFQ) particle accelerator as expected.

GTA is part of the Strategic Defense Initiative, the program formed to investigate the potential of nonnuclear defense systems that detect and destroy ballistic missile warheads. One promising concept under investigation is using neutral particle beams in space as a discriminating and defensive weapon. This use is the only effective method to determine whether an object is a decoy or a real nuclear warhead. When hydrogen atoms are accelerated to velocities that approach the speed of light, they gain enough kinetic energy to blast into a missile warhead and upset its complex electronic circuits. In addition, inside the warhead the particles react with materials to emit reaction products such as neutrons or gamma rays. Sensors in space measure the reaction products to determine the warhead's mass, therefore discriminating between real warheads and much lighter decoys.

To understand GTA we must look at its individual components and examine the way they work. First, the hydrogen-ion injector generates a very bright hydrogen beam and fires it into the RFQ particle accelerator where these low-energy beams are bunched,



Components in the first phase of the Ground Test Accelerator. The beam travels from right to left.

Universal Process for Fingerprint Identification

Fingerprints have been troublesome for the twentieth-century criminal. John Dillinger, among others, even tried to have his obliterated by cauterization. Now, work at Los Alamos has complicated the criminal's life even more. The Universal Process for Fingerprint Detection, developed in only four months, is a simple, inexpensive, and highly sensitive technique that can be used to detect fingerprints on a large variety of surfaces where conventional methods either fail or must be used in cumbersome combinations. The Universal process has been tested successfully on objects such as credit cards, bullet cartridges, and counterfeit currency. Genuine currency, however, is among the few objects on which the method cannot be used because genuine bills contain so much protein-bearing flax and cotton.

The Universal process gives a vivid impression of fingerprints on a plastic credit card.

In our process, fingerprints become visible when gold particles adhere to the proteins in secretions left on an object by the touch of a finger. The object is first washed for about thirty minutes in colloidal gold, a buffer solution of citric acid that contains tiny (20 to 100 billionths of a meter in diameter) particles of gold. Colloidal gold binds to protein, which is present in latent prints. After the incubation with colloidal gold, the object is washed in distilled water to remove unbound gold particles. The object is then bathed in a silver solution for five to fifteen minutes. The silver enhances the image by filling in around the gold and highlighting the fingerprint features, producing a permanent, well-defined print.

Despite the use of gold and silver in the baths, the technique is inexpensive, about $25 per kit. We estimate that we can do up to a hundred tests per kit.

In many instances, the Universal process is a practicable replacement for previous fingerprinting methods such as powders, ninhydrin sprays, cyanoacrylate esters (Super Glue), and the Laserprint 1000 Forensic Argon Laser. Its improvement over other methods is evident in eight significant ways.

1. The process has increased sensitivity (it can detect less than a trillionth of a gram of protein); it can develop faint prints that other methods fail to detect. The Secret Service and the Federal Bureau of Investigation have already identified several suspects and have obtained at least one conviction by applying the Universal technique to evidence on which other methods had failed to detect prints.

2. The process works well on both porous and nonporous surfaces, including paper; smooth, rough, soft, and hard plastics; smooth and adhesive sides of all tapes; metals; glass; and ceramics.

3. It is equally effective on light and dark surfaces. Prints developed on a dark surface appear

Because full power cannot be immediately introduced into the radio-frequency quadrupole, Ken Lyons is conditioning the cavity slowly before sending the beam.

bunched, focused, and accelerated. The RFQ uses electrical fields to boost the speed of charged particles. From the RFQ, particles are propelled into a series of drift tube linear (DTL) accelerators that further accelerate the hydrogen ions.

Then the very small, intense beam enters a magnetic telescope. The lenses of this telescope are magnetic but function the same as glass lenses in an optical telescope. The magnetic lenses allow the beam to expand in the transverse plane to reduce beam divergence. Next, the beam is collimated, or focused, by a group of lenses and steered by fast-cycling electromagnets that allow the beam to be moved very rapidly. Because this move is electromagnetic rather than physical, the beam can be focused faster and more efficiently than it can with a laser whose mirrors must be moved.

The beam passes through a thin carbon or aluminum foil that removes the electrical charge from the particles, converting them to a neutral particle beam that goes through a beam-direction sensing device, called the wire and fluorescent fiber offset grid. This device is like the strings of a tennis racket. The horizontal and vertical "strings" form a grid that casts shadows onto a downstream fiber grid coated with fluorescent material. The movement of the shadow is a measure of the change in beam direction. A beam characterization system used to verify the grid system employs an array of pinholes that permit beamlets to illuminate dots on a downstream fluorescent plate. The analysis of that image permits us to measure aberrations and divergence and beam focusing. At the very end, a carbon target stops the beam.

The GTA has presented great scientific and engineering challenges. Los Alamos and Grumman Aerospace have met these challenges in a cooperative effort. One of the first big technical challenges was to design and build an RFQ that would be small enough and light enough to go into space and still be able to transmit a very bright beam without decreasing the quality of that beam. The three-foot-long RFQ replaces the three-story, high-voltage generator used in conventional circumstances.

A second challenge was to produce a beam with the brightness required for an effective weapon. Los Alamos developed a source that can produce ion current densities and brightnesses compatible with weapons requirements. However, the maximum current such a source can presently produce is not enough for ultimate weapon performance. To increase brightness, currents are combined in the funnel, a complex device following the RFQ. Combining must be done without compromising the quality of the beam. Finally, the third challenge was steering and focusing the beam and sensing this direction and focus. For this purpose we developed the wire shadow technique. Any method of focusing and directing the beam must be extremely accurate and must allow for very rapid movement.

Technology developed for GTA may have medical and industrial applications. Features of GTA have been extended to designs of an accelerator that can be used for transmuting long-lived nuclear waste to short-lived waste and an injector system for the Superconducting Super Collider used for particle physics research.

Invention and perfection of the RFQ enabled scientists to create a compact accelerator that can be used in a medical environment for such purposes as cancer treatment or medical diagnostics. A compact accelerator may also prove useful in food processing, particularly in sterilizing foodstuffs. As is often the case with technologies developed for national defense, research on the neutral particle beam program may have applications that also improve the environment and public safety and health.

light, and prints developed on a light surface appear dark.

4. The process is the method of choice for adhesive surfaces. The ability to detect fingerprints on adhesive surfaces is especially important in drug detection because drug dealers often wrap their drugs, money, and bombs in adhesive tape.

5. The process can be used on latent prints after other techniques, such as ninhydrin sprays and Super Glue, have been tried.

6. It requires no expensive readout instrumentation (lasers or other light sources).

7. It generates no toxic vapors, as do ninhydrin sprays and Super Glue processes.

8. The process is not hampered by fluorescence emitted by many surfaces. That autofluorescence interferes with detection methods that depend on fluorescent readout for visualizing the fingerprint.

Conventional processes lack the versatility of ours. Some computer disks, for example, have metal, paper, and plastic surfaces. To detect prints on them, two conventional methods would have to be used: the ninhydrin process on the paper; the Super Glue process on the metal and plastic. Our process, however, reveals latent prints on all three components with one application. The Universal process reveals palm prints and footprints as well as fingerprints. In fact, the first arrest of a criminal suspect resulting from the use of the Universal process came after palm prints were developed on a blank government check that had been stolen from a military installation in Pennsylvania.

The Universal process is an invaluable new tool for law enforcement agencies worldwide. Its development means law enforcement officers can be more efficient and thorough in their collection of evidence. This process may allow authorities to solve a number of previously unsolvable criminal cases. A member of the Secret Service, which helped develop the method, has said that the new process is one of the top five developments in the fingerprint field in the past one hundred years. We have applied for a patent for the Universal process. Transfer of this innovative technology to private industry is under way, and we anticipate that the introduction of Universal analytical kits to process evidence will result in worldwide use of this unique method.

In addition to use in crime detection, components of the Universal Process for Fingerprint Detection will be useful in molecular biology. The extreme sensitivity of the process, for example, may facilitate the staining of protein bands that are obtained in a variety of electrophoresis procedures (procedures in which colloidal particles migrate in a solution under the influence of an electric current). In this regard, the process might aid researchers in their efforts to identify the protein gene products responsible for the expression of genetic diseases, such as Huntington's chorea.

George Saunders, developer of the Universal Process for Fingerprint Detection, dips a check into a gold solution in the first step toward finding clear fingerprints.

Enhancing and Transferring the MESA Code

In the fall of 1990, televised sights and sounds of American soldiers, clad in desert camouflage and at work thousands of miles away, caught the attention and concern of U.S. citizens. The large-scale deployment of armed forces to the Middle East reminded the nation of the responsibility that conventional weapons continue to shoulder. Although the possibility of conflict seemed to arise suddenly, the nation's defense was not caught napping—for several years Los Alamos has been working with others in the defense community to strengthen the armor of U.S. tanks and to create warheads that more effectively stop hostile tanks.

To keep ahead of rapid changes in defense technology, our three-dimensional MESA computer code provides designers of armor and anti-armor (warhead) systems with a research tool to understand better the processes and results of armor penetration. MESA is a hydrodynamics code used to study the behavior of solid materials, such as metals, ceramics, and high explosives, that under extremely high pressures act as if they were fluids. In a typical MESA application, the code provides a detailed numerical simulation of a warhead penetrating tank armor at high velocity and high pressure.

One warhead, the TOW missile, has been described by an industry leader as "the principal anti-tank weapon of the free world." We developed MESA specifically to model the performance of this and other weapons and to design improvements to them. As a result of our success, the Laboratory is now a recognized expert in the field of armor and anti-armor modeling.

Organizations Represented at MESA Code Workshops

Aerojet, Electronics Systems Division
Alcoa Laboratories
Battelle Memorial Institute
California Research & Technology, Inc.
Central Intelligence Agency
E.I. du Pont de Nemours and Company
FMC Corporation
General Dynamics Corporation, Land Systems Division
General Research Corporation
Honeywell Inc.
Kaman Sciences Corporation
Kirtland Air Force Base
Lockheed Corporation
Los Alamos Technical Associates Inc.
Martin Marietta Aerospace
McDonnell Douglas Corporation
Naval Surface Weapons Center
Physics International Company
Research and Development Associates
Sandia National Laboratories
Science Applications International Corporation
Shock Transients, Inc.
System Planning Corporation
Textron Defense Systems
U.S. Army Armament Research, Development and Engineering Center
U.S. Army Ballistic Research Laboratory
U.S. Army Foreign Science and Technology Center
U.S. Army Engineer Division, Huntsville
U.S. Army Missile and Space Intelligence Center
U.S. Army Missile Command
U.S. Army Tank Automotive Command
University of California

Pure hydrodynamics codes treat materials as fluids, an approach that does not account for some of the failure pheonomena such as shear, fracture, and spall that reflect the strength of the materials typically used in warheads and armor. To add part of this needed capability, this year we gathered and implemented in MESA a variety of existing models of materials from other institutions, such as Lawrence Livermore National Laboratory and Honeywell Inc., as well as from other researchers at Los Alamos. Some of these models had been developed in other research programs, and some were specifically designed for armor and anti-armor studies.

MESA's newest enhancements in the treatment of material strength feature physical models (those using mathematical descriptions of the laws of physics) rather than empirical models (those using parameters to summarize the results of experiments). This treatment represents a satisfying advance because researchers' confidence in the predictive capability of computer models is greater when the calculations are more directly tied to basic principles of physics.

One improvement in modeling fractures employs a flow-stress model providing a better understanding of the plastic deformation process in ductile materials (those that can be easily molded). Integrated into MESA, the models contributed to the code's improved fidelity in describing what happens to armor and penetrators during and after impact.

Continuing improvements to MESA will include even more advanced fracture models for brittle materials—especially for ceramics, which are increasingly important in modern armor and difficult to model in their interaction with projectiles.

Each time we make substantial changes to the code, we run a set of test problems consisting of eight

Tom Adams, one of a number of speakers from Laboratory groups participating in MESA development, conducts a hands-on session of the October workshop on the MESA computer code. Those attending the workshop were primarily from industry and the Department of Defense.

to ten standard problems run in the past as benchmarks. This process helps find coding errors and allows a direct comparison of results obtained using new models with those calculated using earlier treatments. The test set is designed to run quickly and it exercises all the major features of the code.

Funded by the Armor/Anti-Armor Program of the Defense Advanced Research Project Agency, the U.S. Army, and the U.S. Marine Corps, MESA is currently in use by armor and anti-armor designers for applications such as evaluating advanced armor and designing shaped-charge jet warheads. For these studies, MESA simulates the behavior of shaped-charge jets, which are formed in a warhead by an explosive charge that squeezes a metal liner, compressing it in such a way that it emits a high-velocity jet effective in penetrating metal.

From the beginning, the Los Alamos team responsible for developing and improving MESA had a complementary mission: to transfer this established and useful code to Department of Defense laboratories, their industrial partners, and government laboratories in the North Atlantic Treaty Organization. To this end, Los Alamos has hosted four workshops for individuals from approximately thirty institutions. To supplement these training sessions, we provide user manuals, sample problems, and up-to-date documentation describing the features in the code. The Laboratory also provides support for the code after transfer to a user; members of the MESA team visit institutions to help adapt copies of the code to the users' machines and to troubleshoot problems.

Until this year, MESA has been available to outside organizations for remote use through encrypted (coded) computer lines. To boost our technology transfer, this year we received permission to use MESA on open computer lines, making access much easier for authorized users and helping to place the code in the hands of weapons designers as quickly as possible. Designers from outside the Laboratory can now choose from four methods of accessing MESA: using the open lines to Los Alamos, converting the code and placing it on their own computers, funding calculations to be done at Los Alamos, or coming to the Laboratory themselves to run calculations.

MESA has proved to be useful in a diverse range of studies involving impact and penetration. In addition to the armor and anti-armor research, we are working with industry and the U.S. military to help make threat assessments in such areas as submarine hull penetration and satellite protection from orbiting space debris. British, French, and German researchers are interested in collaborating on further model development. As we continue to refine this versatile code, we are finding new opportunities to help solve technical problems in national and international security.

Neutron Multiplicity Counting

Plutonium is one of the more valuable elements in the world, but also one of the more deadly. It is a key component in the nuclear fuel cycle and is essential to nuclear weapons production. Plutonium, however, is also radioactive and extremely toxic. Consequently, controlling or "safeguarding" the nation's supply of plutonium is important to public health as well as to national security. In 1990 scientists at Los Alamos developed an instrument that more accurately measures plutonium in a wider variety of containers and purities than was possible before.

Accounting for plutonium in the nuclear fuel cycle and in the weapons complex is a difficult but essential job. Plutonium is produced and processed in a variety of chemical forms, purities, and isotopes. It is often combined with other materials and stored or shipped in a variety of containers, which can hold everything from pure plutonium metal to waste material with very little plutonium. While it is vitally important to know the contents of such a container, the very act of opening it to inspect for plutonium presents a health and safety hazard.

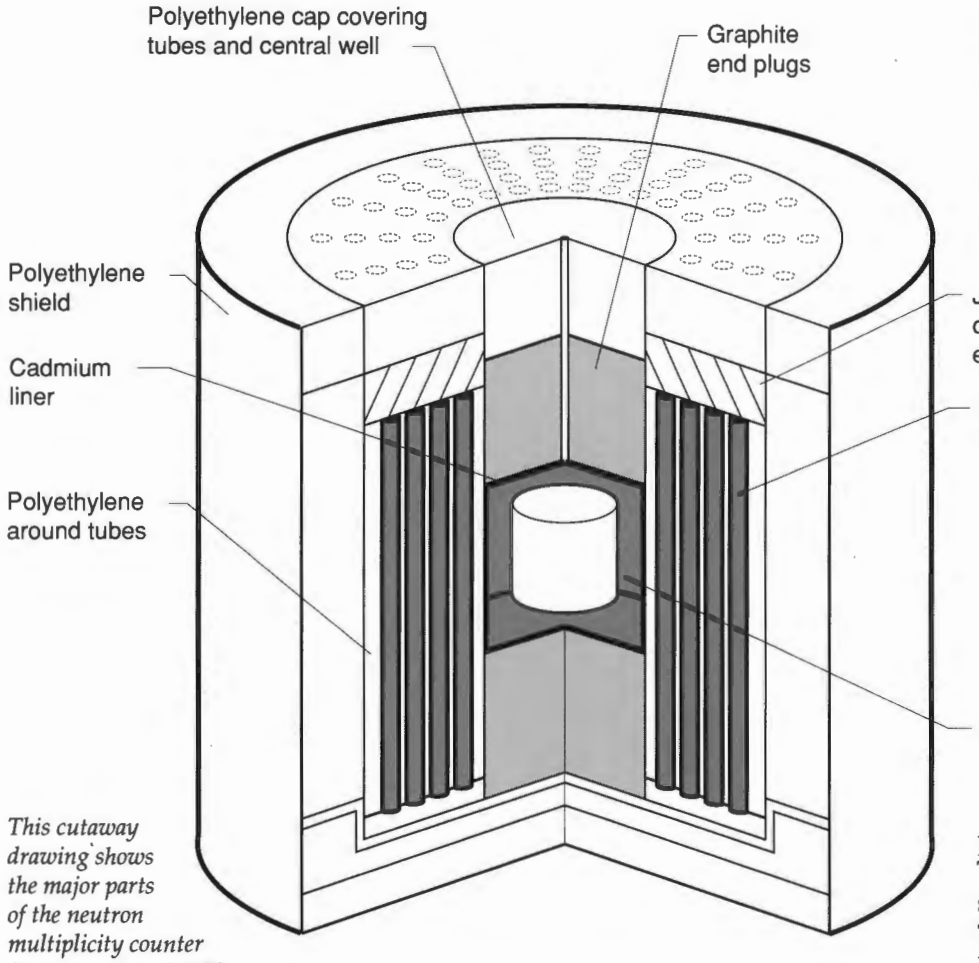
Sophisticated techniques are required to accurately measure plutonium in the many forms in which it is encountered. The most accurate techniques often require taking a small sample from the container and destroying it through chemical analyses. Such testing requires opening the container, a great expense, and a long wait for the results, and then does not accurately test the entire contents. A nondestructive assay that quickly measures all the plutonium in the container without opening or sampling it is obviously preferable.

Diana Langner and Merlyn Krick guide half of the helium-3 tubes into the polyethylene shield of the neutron mulitplicity counter. The counter is designed to split in half to fit around the sample well of a glove box.

Part of the Laboratory's mission for the past twenty-five years has been to develop measurement devices that nondestructively assay plutonium in a container. One class of devices counts the total neutrons emitted from a container. In the simplest case, all the detected neutrons are from the spontaneous fission of plutonium nuclei, which releases neutrons. The mass of the plutonium can then be deduced from the total neutron counts. However, if there are light-element impurities in the container with the plutonium, the assay will not be accurate because additional neutrons are released when alpha particles from the plutonium collide with the impurities. Both these alpha-induced neutrons and the spontaneous fission neutrons induce other fissions that release more neutrons and further complicate the analysis. Now three quantities have to be measured, the numbers of alpha-induced, spontaneous fission, and induced fission neutrons.

We therefore improved the technique by distinguishing the number of neutrons emitted in pairs and triples from the total number of neutrons. The spontaneous fission neutrons are emitted, on the average, in groups of two. Induced fission neutrons are emitted, on the average, in groups of three. However, fission is a statistical process and these neutrons are also emitted singly or in groups of four or more. Statistical methods allow us to separate the fission neutrons from the alpha-induced neutrons and deduce the plutonium content.

Neutron groups are hard to distinguish and count. The primary focus of our research in 1990 has been to design and build a neutron



This cutaway drawing shows the major parts of the neutron multiplicity counter (not to exact scale). The arrangement of the 126 helium-3 tubes is more complicated than it is possible to show clearly in the diagram; they are arranged in four concentric circles with equal amounts of polyethylene on all sides.

measuring device that can detect neutron events with an efficiency high enough to count enough "triples" to obtain a result that is of acceptable statistical precision.

The new counter, called a neutron multiplicity counter because it counts neutrons emitted in groups or multiples, consists of a cylinder of polyethylene with a central hole in which the sample rests during measurement. Neutrons emitted from the container move outward into the counter and collide with the abundant hydrogen in the polyethylene. Collisions slow the neutrons so they can be detected by detector tubes filled with helium-3.

Designing the best counter requires adjusting the number of expensive helium-3 tubes and the amount of polyethylene between the tubes. Too much polyethylene around the helium-3 tubes keeps the neutrons from reaching the outermost tubes. Too little polyethylene and the neutrons will travel too fast to be detected by the innermost tubes. Theoretical calculations, which modeled the movement of neutrons through the counter, revealed the best combination of tubes and polyethylene for the counter.

These calculations suggested that the best design would use 126 helium-3 tubes (71 centimeters long) in four concentric rows around the sample cavity. The tubes are separated by 1.6 centimeters of polyethylene, and a 10.2-centimeter outer ring of polyethylene is placed around the counter to protect the tubes from neutrons coming from outside the cavity as well as to protect any personnel near the counter from neutrons coming from inside. The 71–centimeter length of the tubes ensures a uniform detection efficiency for neutrons originating in different parts of the 17,000-cubic-centimeter sample cavity.

Once the captured neutrons are transformed into an electrical pulse, sophisticated multiplicity electronics, designed and built for this purpose, process the signals. The counts are sorted into singles, pairs, triples, and so on. The electronics package also keeps track of neutrons that might be counted as a group but are more likely to have originated from single neutrons that happened to arrive at the detectors close together in time. Next, a laptop computer analyzes the multiplicity distribution of the counts, corrects for errors due to background or to losses in the electronics, and then reduces the measured information to the three processes that created the neutrons in the first place. From this analysis, the amount of plutonium in the sample can be calculated.

The new multiplicity counter is expected to have a detection efficiency of 57 percent and thus provide enough statistical precision to assay a wide variety of plutonium-bearing samples. This precision will prove an asset as the Department of Energy complex diversifies its plutonium processing to produce less radioactive waste.

TECHNOLOGIES

Los Alamos National Laboratory devotes considerable effort to developing safe, reliable technologies to meet three major national concerns: an adequate supply of energy, stewardship of the environment, and economic competitiveness. Our programs range from biological solutions for environmental cleanup to enhancing the recovery of domestic oil in collaboration with industry. These programs complement our national security mission by supporting our defense work and by contributing technology that helps ensure U.S. energy security.

Dependence on imported oil weakens national energy security and reduces foreign policy options. During the late 1980s the U.S. oil industry suffered some of its worst years and, as profits declined, marginal wells were abandoned. Events of 1990 in the Persian Gulf interrupted the flow of oil from Iraq and Kuwait. As a result, the worldwide supply of crude oil and refined products has diminished.

To enhance domestic oil production, we focused in 1990 on the Oil Recovery Technology Partnership, an alliance of the Department of Energy, Los Alamos and Sandia national laboratories, and the petroleum industry. The Partnership emphasizes commercializing new technology (developed for defense and energy programs) that will allow industry to recover more oil from domestic fields. Our technology for mapping microseismic fractures is being used in experiments with Murphy Operating Corporation, and we participated in crosswell seismic surveys in an experiment with Texaco U.S.A. and Chevron Oil Field Research Company.

As part of the Partnership, Los Alamos is also beginning a

collaborative project with Mobil Research and Development Corporation, Chevron Oil Field Research Company, and the University of Houston. We will use massively parallel computing techniques to improve the simulation of oil flow through porous and fractured rocks. The Oil Recovery Technology Partnership is investigating future collaborative projects with independent oil producers in Kansas, Oklahoma, and Texas. These projects will be designed to improve production and delay the abandonment of oil wells with low productivity.

As one of the Department of Energy's Superconductivity Pilot Centers, we have formed a variety of collaborative relationships with U.S. companies. We are focusing our research on understanding the relationship between materials processing and properties. We also are concentrating on developing a theoretical understanding of high-temperature superconductivity. Our chief collaboration is a three-year, $11-million partnership with DuPont and Hewlett Packard to develop electronic devices. These relationships with U.S. companies, both large and small, are proving the efficacy of integrating Laboratory and industrial research and development.

Technology transfer activities in 1990 included the receipt of seven R&D 100 awards, filing of forty-one patent applications, having forty-four patents issued, and issuing three revenue-producing licenses.

Several research and development activities address the national concern about the effects of nuclear weapons production, energy use, and global change on the environment. Because radioactive wastes must be isolated for up to thousands of years, storage of these by-products is a complex problem. We are investigating the use of high-energy accelerators to transmute long-lived, high-level waste produced by the defense complex into short-lived waste. We also have developed effective techniques for stabilizing contaminated sites before they are cleaned up.

The Laboratory is combining resources from many scientific fields to examine the possible environmental effects of storing hazardous waste in various types of geologic formations. We maintain field tests at shallow-burial sites to assess how well natural barriers isolate low-level contaminants from the ground water. In a major effort, we are studying the geology of Yucca Mountain, Nevada, which is a candidate for a high-level waste depository.

At Los Alamos we are designing processing techniques that can prevent hazardous and toxic substances from entering the environment in the first place. We also research innovative detection techniques and cleanup remedies for use where hazardous and toxic materials have been introduced.

Portable instrumentation for measuring organic compounds and radionuclides that may migrate from a waste site is one of the Laboratory's advances in measurement technology. With remote-sensing technology, we can measure environmental processes over time. We also have instruments for three-dimensional remote measurements of atmospheric constituents. In addition, we are using our computational and measurement resources to contribute to studies of global climate change.

Studies in fusion energy, the process that powers the sun and other stars, have engaged our scientists since early in the Laboratory's history. Our goal is to simplify the production of fusion energy and lower its cost by allowing the currents flowing within a high-temperature plasma to generate a substantial part of the magnetic fields required to confine that plasma. Our experimental program in alternative concepts explored two fusion reactor configurations: the reversed-field pinch and the field-reversed configuration. Both of these experiments were terminated in December 1990 to accommodate major reductions in funding for DOE's Magnetic Fusion Energy Program.

In our field-reversed experiments, we produced a configuration in one apparatus and translate it into an adjoining apparatus, where magnetic compression heated it further. In 1990 we achieved record plasma temperatures before shutdown. This experiment demonstrated the concept of producing plasma in one area and fusion burn in another and has the potential to greatly simplify some aspects of fusion reactor designs.

Following shutdown of our experimental program to develop advanced concepts for fusion reactors, we will continue to study the fuel cycle itself. In the free world, Los Alamos has the only full-scale processing capability for developing and testing a complete and integrated fuel-handling system for fusion reactors, the Tritium Systems Test Assembly. The U.S. Department of Energy and the Japan Atomic Energy Research Institute jointly operate and fund the assembly under a five-year agreement signed in 1987.

To enhance the safety of nuclear reactors using fission energy, we use computer programs to analyze what happens in nuclear reactors during simulated normal operation and accidents. With a better understanding of the relevant processes and effects, we can improve techniques for avoiding accidents or minimizing their results. Our experience in this area is being applied to safety issues involving the Department of Energy's production reactors at Savannah River.

In 1989 the Department of Energy announced it would replace existing production reactors at Savannah River with two new reactors to produce tritium, an

essential component in nuclear devices. Los Alamos was named the lead laboratory to provide independent safety reviews for these new production reactors (NPRs) from design through construction and operation. We created the NPR Safety Project Office to lead, integrate, and coordinate the program; developed top-level safety requirements; drafted a review process; and reviewed proposed conceptual designs with respect to established safety requirements.

The peaceful use of international nuclear resources is enhanced by our safeguards research and development program. Through the Department of State's Program of Technical Assistance, Los Alamos supplies technical support for the U.S. policy of international nonproliferation. All over the world, International Atomic Energy Agency inspectors use nondestructive assay instrumentation developed at Los Alamos to verify compliance with the Nuclear Non-Proliferation Treaty.

For the past sixteen years, Los Alamos has been developing methods to mine the vast store of energy that exists as heat in hot dry rock within the Earth's crust. We have built a large underground "reservoir" consisting of a small amount of water stored within a huge quantity of hot rock. We are now preparing for a long-term flow test in which water will be pumped into the reservoir through an injection well, become heated as it traverses the hot rock of the reservoir, and be withdrawn as superheated fluid through a second well. At the surface, the energy will be extracted by a heat exchanger, and the same water will be recirculated to mine more heat. The energy can be used for generating electricity or for heating or industrial processes. The goal of our long-term flow test is to demonstrate that heat mining can be used to provide a practical and economical source of energy for the world.

The environmental effects of mining heat from hot dry rock are minimal. When the system is operated as a closed-loop, no carbon dioxide or other "greenhouse" gases are released. Our research has shown that only a small amount of water is lost from the circulating system. Land usage is small, and the plant can be decommissioned by simple techniques that have been practiced for many years in the oil industry.

Another energy program focuses on fuel cells for transportation. Fuel cells can operate on alternative fuels (such as methanol) and are more efficient and cleaner burning than internal combustion engines. Impediments to commercial applications have been high cost and performance that is not yet competitive with the performance of combustion engines. We have found that the proton exchange membrane fuel cell using reformed methanol is the best power source for electric vehicles. To transfer this technology, we collaborated with International Fuel Cells, a subsidiary of United Technologies Corporation.

Los Alamos also participates in research on gasoline-fueled internal combusion engines. This year we released an updated version of the KIVA II computer code, used by several major automobile manufacturers for designing internal combusion engines.

The Laboratory has several international energy programs under way. Guatemala, El Salvador, Honduras, and Costa Rica participate in our Central American Energy Resources project. Los Alamos staff members work closely with counterparts in each country to develop existing geothermal fields, locate the most promising new geothermal prospects, and evaluate tradeoffs involved in various options for developing energy. Training focuses on well logging, energy planning, geology, geochemistry, reservoir engineering, and geophysics. A project modeled on the work in Central America is now under way in Melanesia in the South Pacific. Initially, we will evaluate energy alternatives and capabilities for energy planning. Subsequent efforts will focus on identifying the most promising energy alternatives—a crucial factor for an island nation that is dependent on imported oil for more than 90 percent of its supply.

Urban air pollution, a growing environmental problem in many countries, has serious immediate and long-term implications for human health and the environment. Through the Mexico City Air Quality Research Initiative, the Laboratory and the Mexican Petroleum Institute are examining the complex relationship between the impact of air pollution on economic growth and the consequences that air quality policies can have on society. The results of this initiative will be relevant to urban pollution problems around the world.

Los Alamos has been actively engaged in space research and technology since the 1950s. Our long history of space research has produced several notable scientific discoveries and an unparalleled set of data on the space environment. For example, we have designed and built more than three hundred space sensors that have been launched on ballistic rockets and satellites, and our researchers have made important contributions to understanding the interaction of cosmic rays and the solar wind with the Earth's magnetic field.

Our varied and challenging energy and technology programs reflect the Laboratory's clear commitment to ensuring a reliable, safe supply of energy for the nation. Equally important, we channel our capabilities into critical efforts to guard and restore the environment and to enhance U.S. economic competitiveness in world markets.

Modeling Improved Oil Recovery

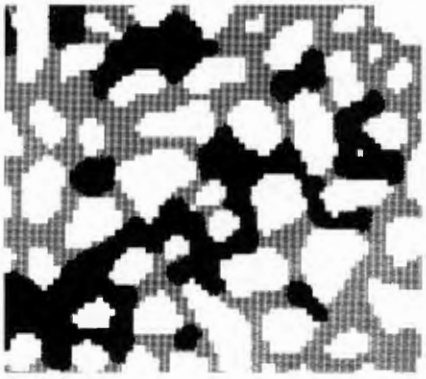
Using a new application of an elegant computer method, Los Alamos researchers can now take a microscopic look into oil-bearing rock to analyze the best ways to recover more oil from developed fields. Typically, oil fields, called reservoirs, are large bodies of porous rock soaked with oil. In the past, oil recovery was straightforward: just drill down to the oil, insert a production pipe, and pump out oil. In most domestic oil fields today, this "easy" primary recovery has been done, but 40 to 60 percent of the oil is still down there, held in small pores in the rock, and other fluids such as water or liquid natural gas have moved in to occupy the pore spaces that previously contained oil. Selectively recovering the remaining oil is the main goal of improved oil recovery processes.

Techniques for extracting this remaining oil often involve pumping a fluid flood down an injection well under pressure to sweep oil from tiny pores in the oil-bearing layer so that it can be pumped out of a production well. (Water under pressure is routinely used during primary recovery: the problem is getting the residual oil out.) Several methods involving various fluids and chemicals are used in improved oil recovery projects. For example, under the elevated pressures and temperatures encountered at several thousand feet beneath the surface of the Earth, carbon dioxide may be injected as a liquid to force the oil out of the rock. Carbon dioxide is relatively inexpensive and is often available. At certain temperatures and pressures, oil and carbon dioxide are nearly immiscible (incapable of mixing). Therefore, capillary and wetting forces dominate the displacement of oil. The wetting forces are caused by the attraction of the molecules of oil for the rock. These forces serve to hold the oil in the pores until the carbon dioxide enters the tiny, oil-rich pores and forces oil into larger, more conductive pores from which it can eventually be recovered in a production well. However, depending on the pore structure and on conditions in the reservoir, the carbon dioxide may not enter the oil-rich pores and may simply bypass the oil. In this case, the oil will remain in the ground, and the production wells will recover mostly carbon dioxide—an expensive and ineffective effort.

Therefore, before beginning such an improved oil recovery project, oil companies need to understand what will happen to the fluids inside the reservoir and under what conditions the proposed carbon dioxide flood would work. Laboratory studies are usually conducted on samples from rock cores drilled from the reservoir and on glass micromodels based on thin sections of rock taken from the reservoir. These micromodels are constructed by using photographic images of microscopic rock pores to form a pattern that is etched into glass. The etching is then sandwiched between two glass plates, and fluids are forced through the micromodel under pressure. Essentially, then, a microscopic carbon dioxide flood may be conducted in the laboratory. These experiments provide data needed for computer models that use the equations of fluid flow to predict oil recovery in production wells as fluids are introduced into injection wells. However, the model predictions are only as good as the understanding of fluid flow processes built into the computer programs.

These microscopic studies allow direct observation of the oil displacement from the rock, thereby providing scientists the opportunity to observe directly the behavior of the fluids in the pores. The problem with these laboratory studies has been that the observed behavior is very complex and in the past could be described only qualitatively. What is needed is a quantitative method for describing the fluid motion that can be used directly or for providing input data to a computer simulation model.

Using a mathematical technique called lattice gas computation, we can now quantitatively model the flow of immiscible fluids in porous



This sequence of computer simulation results, taken from a much larger simulation, shows a microscopic view of the movement of immiscible fluids in pore spaces in rock. Fluid flow is basically from left to right. The grains of rock are shown in white, oil wetting the rock is gray, and black represents a nonmixing, nonwetting fluid, such as liquid carbon dioxide, bubbling through the oil in the pores. A long linked body of black fluid is often called a ganglion. In a typical experiment as observed in a laboratory micromodel, we observe bubbles snapping off of the larger ganglion and proceeding through the pore space. In these frames from a simulation using a massively parallel computer, we see a small bubble snap off from the downstream end of a ganglion on the right side of the frames and then reform and snap off again. This snap-off or bubble formation is important because it helps direct the carbon dioxide into the small pores, thereby displacing some of the trapped oil.

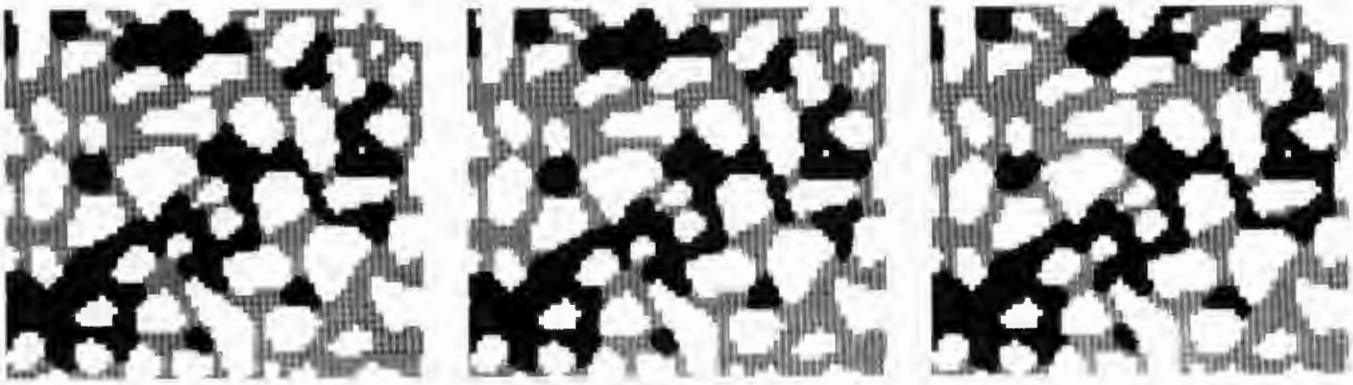
Gary Doolen (left), Bryan Travis, and Ken Eggert compare their computer simulation (on the table) with the corresponding glass micromodel of a small section of an oil reservoir.

media. We are capitalizing on work to characterize pore spaces and to construct statistically justifiable computer models of pore geometries.

To model fluid flow, we visualize moving fluids as consisting of many simple particles, colliding rapidly in simple interactions. A hexagonal grid, called a lattice, defines the locations of millions of these particles at grid intersections. A simple computer program specifies the solid boundaries of each grain of rock and fills the rock pores with the grid. When the program is started to simulate fluid injection, the particles all step from their intersections along grid lines to adjacent intersections and change direction as they collide. Their collective motion simulates fluid flow, and the lattice gas program thereby calculates the movement of immiscible fluids through the pore spaces.

Surface tension and fluid wetting properties are included in the simulation to mimic the dynamics observed in laboratory experiments. Wetting is a particularly important part of the problem because one fluid usually preferentially sticks to the rock grains. This same phenomenon causes the water surface in a glass cup to rise slightly as it nears the cup wall. What the computer program provides is a system of hypothetical immiscible fluids that may be made to behave microscopically like real reservoir fluids. We can numerically sample these fluids in the computer, both in space and in time, to obtain velocity and pressure detail that is not possible in experimental work. Although these lattice gas fluid models have properties that are different from those of the oil, carbon dioxide, and other real fluid systems, we can learn a great deal about porous flow of immiscible fluids by learning how microscopic behavior in the simulations relates to the larger scale behavior that is needed for reservoir simulations.

This work is very exciting because for the first time we have the equivalent of a computational microscope for better understanding porous media flow. The situation in which several immiscible fluids occupy portions of the pore space simultaneously presents a modeling task that has been impossible to address with traditional computational techniques. However, the lattice gas method is capable of modeling this situation and will increase our ability to represent the basic processes of immiscible fluid flow in reservoir models used to predict the effectiveness of improved oil recovery techniques. Finally, this new tool may eventually be applied not only to recovering oil more economically but also to achieving a better understanding of a variety of hazardous waste disposal problems.



New Uses for Thermal Technologies

Living in a less noisy and cleaner world has become important to the quality of life for many people. Thermal technologies can be used in applications meant to improve the comfort and safety of life. For more than twenty years, Los Alamos has been a leader in innovative thermal technologies. Two of our latest developments in this field are the thermoacoustic absorber and a process for cleaning the soil of contaminant vapors.

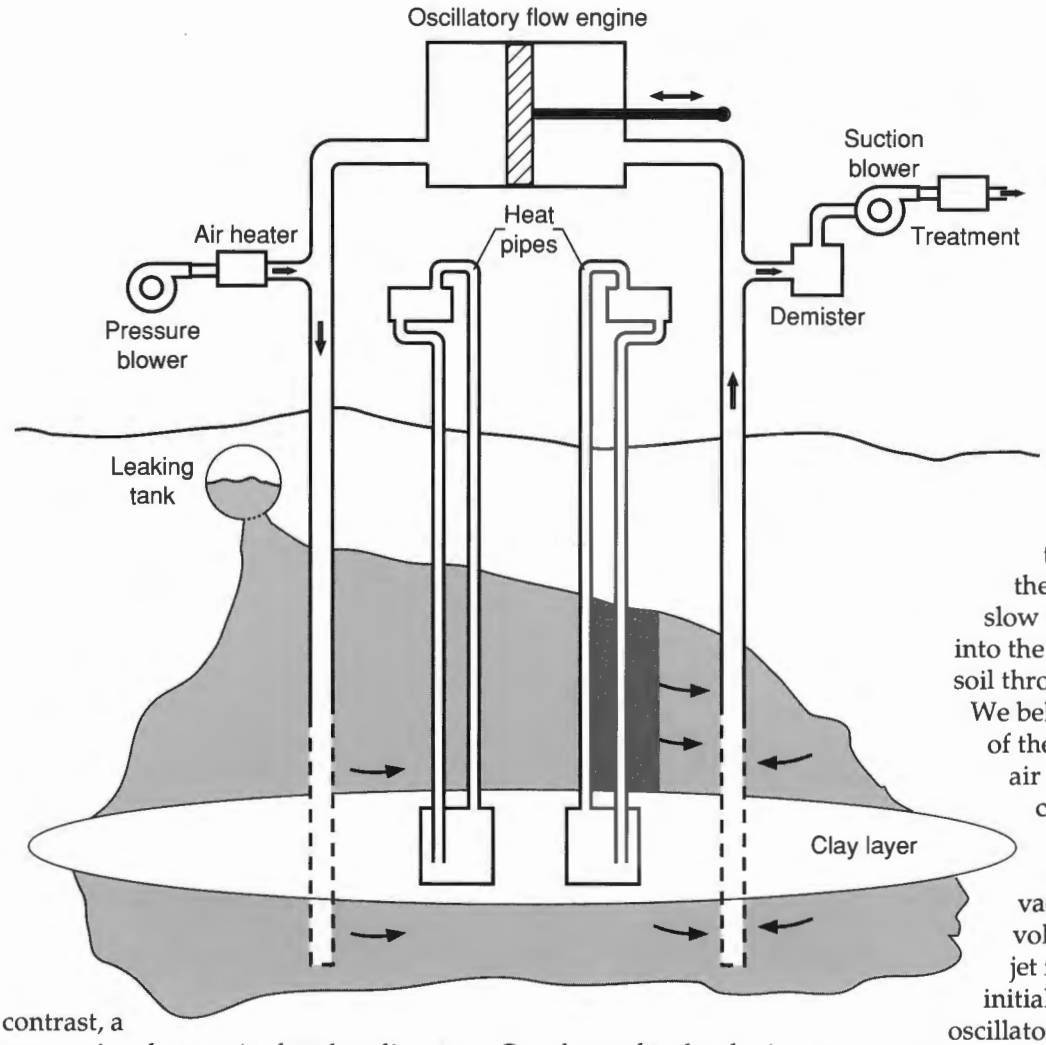
Thermal technologies developed at Los Alamos, such as heat pipes and thermoacoustic engines, offer efficient and reliable solutions to engineering problems of heat conduction, heat exchange, the conversion of heat into other forms of energy, and the conversion of various forms of energy into heat. Heat pipes transfer heat over relatively large distances, and between regions with small temperature differences. Traditionally, heat pipes were pumped by gravity. Now capillary forces, produced in a porous material (or wick) that lines the walls of heat pipes, replace the work of gravity. Like most thermal engines, thermoacoustic engines can convert heat into mechanical energy and mechanical energy into a flow of heat. The mechanical energy produced or consumed is in the form of acoustic vibrations (or sound). Thermoacoustic engines are versatile: they can be run as refrigerators, generators of acoustic vibrations, or power producers.

By coupling thermoacoustic technologies with a configuration of heat pipes, we are exploring new approaches to the absorption of sound. Consider a solid sheet of backing material covered on one side by a thin membrane to form a closed space in which liquid is contained. In this space, a wick is saturated with the liquid whose pressure is just over atmospheric pressure. Vapor fills the remaining space in such a way that the two phases—liquid and vapor—are in equilibrium. If a sound wave impinges on the membrane, it disturbs that equilibrium by changing the pressure in the enclosed space. When the pressure increases, some of the vapor condenses. The heat released by condensation of the vapor is deposited in the liquid. The backing material absorbs the heat from the liquid and keeps its temperature nearly constant. When the pressure of the sound wave on the membrane decreases, more liquid evaporates and the vapor pushes back on the sound wave. To complete the cycle, the backing material absorbs energy from the sound wave as heat and then releases the heat into the environment.

Michael Merrigan (right) and Robert Ortega prepare a feasibility demonstration of the thermoacoustic absorber.

The amount of heat generated is small; the reduction in sound levels is large. To grasp this concept, look up in the sky at the visible trail of water droplets forming in the wake of an aircraft. The trail forms upon the condensation of water vapor produced by the combustion of fuel in the airplane engines and can stay in the sky for hours after the airplane has flown out of sight. This trail is also an instance of the equilibrium between liquid and vapor being disturbed and not restored instantly. In our experiment, it is precisely the failure of the liquid and vapor phases to return immediately to their original equilibrium that allows the heat released through condensation to be stored and transported away.

Our acoustic absorber, the first new one in decades, dissipates the pressure rather than the velocity of a sound wave. In practical terms, this means that the absorber performs best when it is placed directly against a hard wall. In



Extraction of contaminant vapors from the soil is enhanced by heat pipes, hot air injection, and oscillatory flow. We can use these techniques separately or in combination.

contrast, a conventional acoustic absorber dissipates the velocity of sound; it must therefore be placed about one-quarter wavelength away from the wall. Because that space has to be filled with absorbing material, the conventional absorber is thicker and heavier than ours. In applications that involve low frequencies—produced by long acoustic waves—and require light weight, our new acoustic absorber should perform better than conventional technologies. Imagine traveling in one of the back seats of a Boeing 727. Our sound absorber could considerably eliminate the noise of the engines. Submarines might be less visible to sonar if they were coated with thin layers of our absorber. And, finally, our technology could reduce high acoustic levels in the cargo bay of the space shuttle.

Our thermal technologies can also contribute to a cleaner environment. A national survey estimated that 189,000 underground tanks are leaking at retail gasoline stations. Remediation of fuel-contaminated soils is expensive and can take years. To speed the removal of spilled fuels and solvents from the ground, we are using thermal technologies.

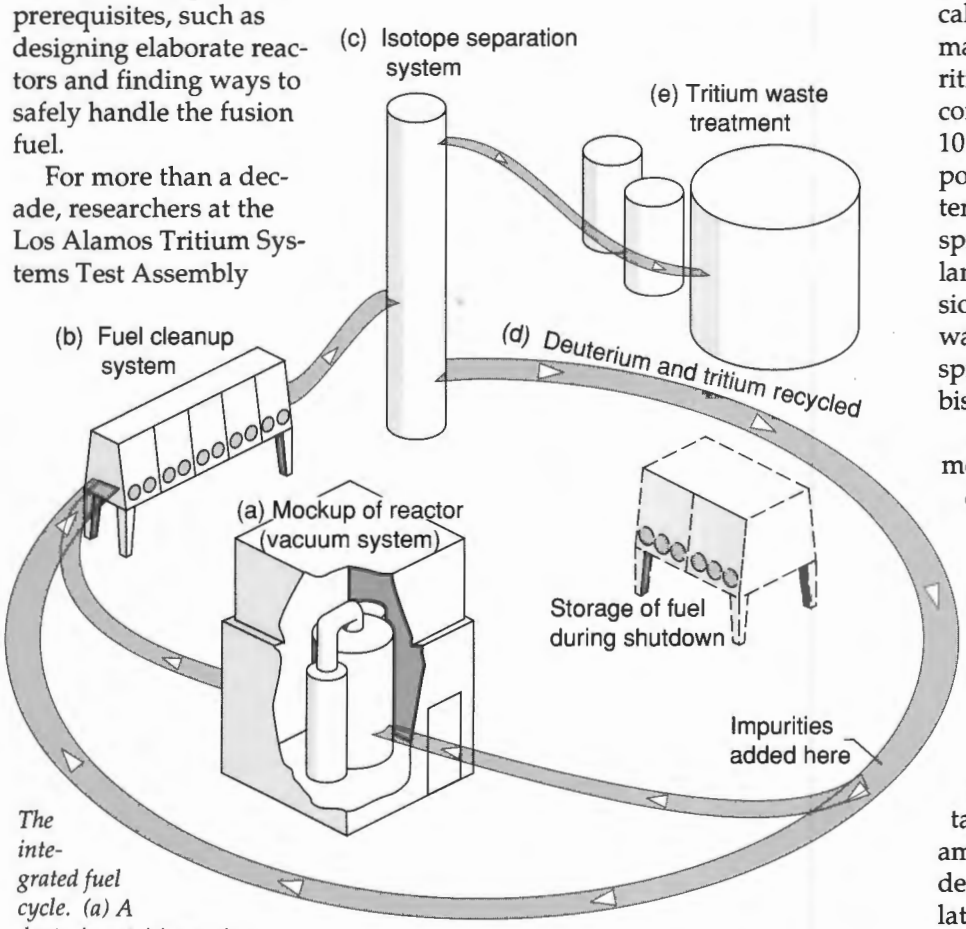
Vapor extraction is the most convenient way of removing a volatile contaminant from the soil. In this process, wells are drilled into the contaminated ground. If a vacuum is applied to one or more wells, the resulting airflow in the ground sweeps the contaminated vapors to the wells. Subsequently, the extracted air is treated to remove or destroy the vapors. However, the rate of extraction of a volatile contaminant is limited by the low concentration of the contaminant and by the slow diffusion of the vapors into the small channels in the soil through which the air flows. We believe that *in situ* heating of the vapors by injecting hot air or by using heat pipes can increase the concentration of the contaminant vapors and allow vacuum extraction of less volatile substances, such as jet fuel. Moreover, our initial experiments show that oscillatory flow techniques—the direction of flow is reversed many times per minute—may circumvent diffusion limitations. We expect that the combination of heating and flow techniques will reduce the high costs of remediation.

A cleaner environment and a less noisy world are only two possible results of innovative applications of thermal technologies. Think also about the possibility of using a heat pipe system to generate cooling from solar energy. This and many other useful applications of thermal technologies stimulate the imagination of our scientists and engineers.

A New Fuel Cleanup System for TSTA

Fusion reactions that power the sun are also the ultimate source of nearly all energy on Earth. If scientists could duplicate these reactions, the world would inherit a windfall of affordable, limitless energy. Although the fusion recipe sounds simple—fuse two isotopes of hydrogen (one deuterium and one tritium) to get a huge amount of energy—Earthly fusion depends on several complicated prerequisites, such as designing elaborate reactors and finding ways to safely handle the fusion fuel.

For more than a decade, researchers at the Los Alamos Tritium Systems Test Assembly (TSTA) have concentrated on testing and developing the entire life cycle of the deuterium-tritium fuel—from its injection into the mockup test reactor to its purification and recovery for recirculation. TSTA, the only full-scale integrated system for fuel reprocessing in the world, was designed to eventually function as it would in a full-sized commercial power plant.



The integrated fuel cycle. (a) A deuterium-tritium mixture, plus the impurities likely to result from a fusion reaction, is injected into the mockup of a reactor, called the vacuum system. (b) The deuterium-tritium gas and impurities are transferred to the fuel cleanup system, which removes all impurities (except helium) from the fuel. (c) The purified fuel stream and the helium-containing waste stream are then sent to the isotope separation system. Here the hydrogen isotopes are separated into four streams: deuterium, tritium, a deuterium-tritium mixture, and a waste of hydrogen and helium. (d) The deuterium and tritium are recombined for recycling into the vacuum system. (e) The waste stream is sent to the tritium waste treatment system where it is cleaned for release to the stack. This final system plays a key role in tritium safety at TSTA.

TSTA's goals have long emphasized both safe operations and cooperative efforts with other laboratories. The largest of TSTA's cooperative efforts is a five-year agreement with the Japan Atomic Energy Research Institute (JAERI) that calls for joint funding and joint operation of TSTA from 1987 to 1992. Each year four Japanese scientists come to Los Alamos to work at TSTA.

The Los Alamos/JAERI/Mitsubishi team recently completed delivery and installation of a new fuel cleanup system—designed by JAERI and built by Mitsubishi Heavy Industries. The fuel cleanup system is the most complex chemical processing unit at TSTA. Its two main functions are to remove impurities from the fuel stream until the concentration of impurities is below 10 parts per million and to decompose the impurities to recover deuterium and tritium for reuse. Despite minor interruptions caused by language barriers—and an occasional softball game—the system was installed on schedule this past spring by Los Alamos and Mitsubishi workers.

In the new system, a palladium membrane diffuser separates hydrogen isotopes from the impurities. A unique property of palladium is that when it is heated to about 350 degrees Celsius, hydrogen can easily flow through it. Thus, as the deuterium-tritium fuel flows through the diffuser, one clean stream emerges as pure hydrogen, while another stream contains all the impurities plus a small amount of hydrogen. Eventually the deuterium and tritium are recirculated through the system, and the waste stream is cleaned of most tritium and released to the stack.

A second important feature of the new system is its use of a ceramic electrolysis cell to decompose by-product water in the waste stream. (In electrolysis, an electric current is passed through water to separate hydrogen from oxygen.)

We selected a ceramic material because tritium-containing water, which reacts adversely with many materials, does not react with ceramic. In ordinary room-temperature electrolysis, water remains in its liquid state. But at the high temperatures used in our electrolysis cell, water becomes a gas—and in this state, tritium-containing water can be more efficiently purified by the system. Over the next few years, we will carefully test the new cleanup system in integrated fuel cycle operations. The new system's advances hold promise of contributing to longer, cleaner operations with less solid waste.

The existing thirty-five trillion tons of deuterium in the ocean, enough to supply the world's energy needs for an infinite number of years, can be inexpensively and easily extracted from water. But tritium is both rare and costly—one gram costs about $20,000. Because tritium is radioactive, our goal from the beginning was to develop advanced technology and to ensure that it would operate safely and efficiently in the real world. We realized that regulators and the public would rightly insist on hard evidence showing that commercial-level quantities of tritium could be handled and recycled with minimal tritium releases to the environment and minimal exposure to workers.

This insistence on safety and accountability led TSTA to establish a self-imposed limit of 200 curies per year, which can be safely emitted into the atmosphere (a curie is a measure of radioactivity). This amount is much lower than the more than 1,000 curies allowed by regulatory standards. When the fuel recycling process is highly efficient, a very small amount of unrecovered tritium is released. During the last six years, TSTA has released a total of 110 curies, equal to 0.01 gram of tritium. In contrast, cosmic rays naturally produce 2 million curies of tritium per year. Because tritium has a short half-life of twelve years, it relatively quickly decays into harmless components. (Uranium 238, for instance, has a half-life of 4.5 billion years; carbon 14 has a half-life of about 5,700 years.)

Jim Barnes (standing in white shirt) and (clockwise from Barnes) Satoshi Konishi, Masahiko Inoue, and Tetsuo Watanabe of JAERI are conducting initial check-out procedures on the newly installed fuel cleanup system at TSTA.

TSTA's several safety systems have been fully computer controlled since tritium operations started, and the process systems are operated through the computer by manual instructions from operators. TSTA has considerable back-up capability for the computer and its power supply: two main computers are available at all times. One computer controls the fuel cycle process and one acts as standby, ready to take over if the control computer fails. An uninterruptible power supply (battery bank) is available as well as a diesel-fired emergency generator.

Other experiments are an ongoing part of TSTA's research program. Six glove boxes are available for studies on new components such as palladium diffusers, on the tritium contamination of remote handling tools, and on testing the compatibility of new components with tritium. The Experimental Contamination Studies Laboratory at TSTA, which focuses on the contamination of materials, provides valuable information for system design, routine maintenance, and emergency cleanup. Many of these experiments have been conducted with other laboratories such as Oak Ridge National Laboratory, the Princeton Plasma Physics Laboratory, Kernforschungszentrum Karlsruhe in Germany, the Canadian Fusion Fuel Technology Project, and the Joint European Torus Undertaking.

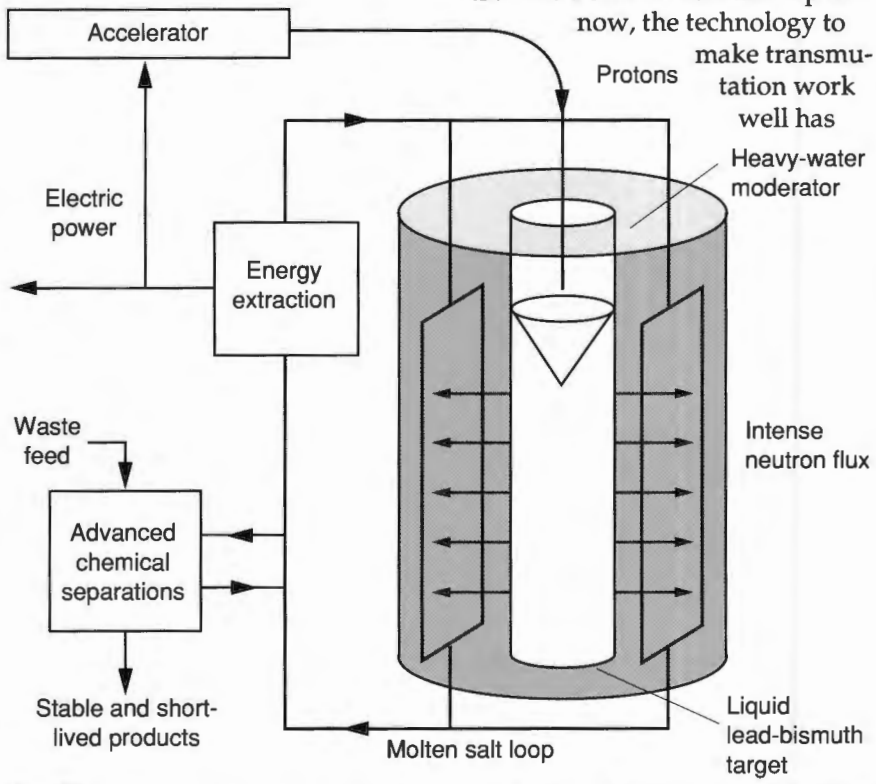
As further improvements are made in the fuel cycle, TSTA will move toward longer, more routine operations and a complete transfer of operations to a larger staff of full-time operators. So far, TSTA's many contributions to the national fusion program include advanced fuel cycle technologies, capabilities for testing the complete fuel cycle, extensive operating experience, and an exceptional record of safe operations.

A New Concept for Transmuting Nuclear Waste

Los Alamos researchers have proposed an innovative concept that may help alleviate public concerns about storing radioactive defense waste in geologic repositories. Although the Laboratory believes the nation could safely isolate the waste in certain geologic formations for thousands of years, our concept of accelerator transmutation of waste (ATW) has the potential to drastically cut the storage time needed. We may even be able to safely produce energy with ATW while we transmute nuclear waste.

This year, we realized that combining several Laboratory technologies into an integrated system offers an option to help safely and permanently dispose of radiotoxic waste. We propose using neutrons produced by an advanced accelerator to transmute long-lived radioactive waste—accumulated at Department of Energy defense production sites—into short-lived radioactive or stable (nonradioactive) substances. This transformed refuse would in many cases still require isolation from human contact, but demands upon storage would be reduced from tens of thousands of years to only hundreds of years, or less.

The notion of transmutation is not new. For more than two decades, scientists have contemplated using neutrons to transform long-lived radioactive substances. When a radioactive atom absorbs the neutrons, the resulting reaction would convert the atom into a different isotope that is stable or that has a shorter half-life. Up to now, the technology to make transmutation work well has been primitive. Major independent advances serve as the technical framework for our concept—an integrated system comprising a high-current particle accelerator, an intense neutron source, and advanced chemical processing methods.

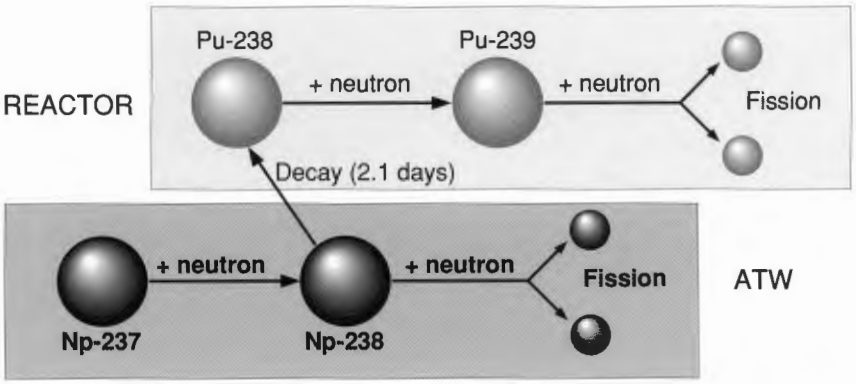


The ATW system would combine a high-current accelerator, an intense neutron source, and advanced chemistry to offer safe and efficient transmutation of nuclear waste. We envision that the system also could generate fission energy free from high-level radioactive waste.

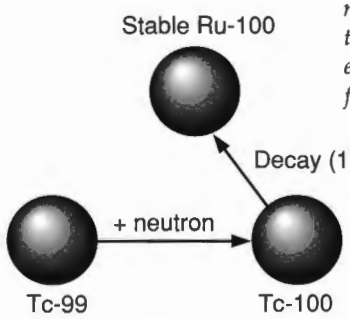
Our technological achievements with high-energy, high-current accelerators (a spin-off from the Strategic Defense Initiative) enable us to design an accelerator with hundreds of times the beam power of the Clinton P. Anderson Meson Physics Facility (LAMPF), the most powerful medium-energy accelerator in the world. This advance, combined with the design of an intense neutron source, makes it possible to produce neutron intensities up to one hundred times greater than levels in standard nuclear reactors.

In our ATW concept, the accelerator generates a high flux (the number of particles moving through a given space at a given time) of neutrons by directing a beam of subatomic particles (protons) into a lead-bismuth target. The interaction of beam and target releases neutrons from the target; these neutrons then enter a surrounding heavy-water moderator, which slows them down. Our system is designed so that the neutrons then interact with radioactive waste circulating through the moderator.

In this system, an intense flux of slow neutrons is more likely to interact with and transmute both types of nuclear waste components: fission products and actinides (elements with atomic numbers above that of uranium). These actinide components would be transmuted, through fission, to smaller amounts of fission products, which would then reenter the system to continue transmutation to less harmful materials. ATW's intense concentration of slow neutrons would be much more efficient than other methods in transmuting defense waste. Our



As an example of actinide transmutation, a neptunium isotope absorbs a neutron and is converted to a different neptunium isotope. In ATW's intense neutron flux, this isotope absorbs another neutron and is efficiently converted to fission products, rather than following the longer decay path, typical in reactors, to a plutonium isotope.



After absorbing a neutron, an isotope of technetium—a fission product—is converted into another isotope that then decays into ruthenium, a stable product.

ultimate goal is to achieve a final radiotoxicity less than that of uranium ore as it occurs in nature. In particular, we would transmute specific components that dominate long-term hazards associated with nuclear waste.

One of the advanced technologies featured in ATW is its chemical system. Our concept uses a continuous flow of a molten fluoride salt to move the waste quickly through the heavy water and out into a purifier that separates the transmuted materials for safe disposal. Recent advances in fluoride chemistry, along with proven separation techniques developed at Los Alamos, provide the basis for effective decontamination. We are also investigating use of other carrier media (slurries for example) to transport aqueous nuclear waste through the system.

Our concept's intense level of neutrons, its ability to transmute actinide waste, and its advanced chemistry design mean that ATW can operate efficiently with uniquely dilute concentrations of radioactive waste. ATW requires less than 100 kilograms of resident waste to produce high transmutation rates—earlier concepts required more than 10,000 kilograms to achieve the same performance. Avoiding the need to handle such large amounts of radiotoxic refuse at one time is important for safety.

ATW offers a second safety advantage. In earlier transmutation concepts, reactors produced the required neutrons. ATW is accelerator-driven and, unlike reactors, does not involve criticality; that is, it cannot sustain a nuclear chain reaction. There is no possibility of a runaway event, which could be the case in a critical system.

In addition to its potential applications in dealing with national defense waste, ATW has significant possibilities for application to radiotoxic waste from commercial nuclear power plants. Commercial nuclear waste is about ten times more abundant than defense waste is. We are considering systems that might handle all of the long-lived nuclear waste discharged from up to ten power reactors.

Another exciting, longer-range application for ATW is to potentially help meet the nation's energy needs by supplying fission energy free from long-lived nuclear waste. In our accelerator-driven system, plentiful natural fuels such as thorium or uranium would undergo fission, producing heat that would be converted, through an efficient molten salt process, into electrical energy. Concurrently, a high level of excess neutrons would be available to transmute the nuclear waste produced. The net effect would be that ATW would generate its own power, contribute electricity to a public power grid, and burn its own refuse—without leaving a large legacy of long-lived waste.

Our ATW effort will need to draw on Laboratory achievements in varied scientific domains. At LAMPF, we have two neutron sources—the Manuel Lujan, Jr. Neutron Scattering Center and the Weapons Neutron Research Facility. Researchers working there and those working in basic physics research, accelerator technology, fission product and actinide chemistry, and materials science (including studies in radiation damage) have demonstrated most of the individual components of ATW technology. Now we face the demanding challenge of developing and demonstrating an integrated system.

Much difficult work remains, but the foundation for our concept is in place. We believe ATW's potential is great—for cutting the storage time of radioactive defense waste from millennia to only a century or two, and for producing fission energy with little long-lived waste.

Supercritical Water Oxidation

Solvents, paint thinner, machine oil, motor oil, contaminated water—all these and more specialized wastes are produced by industrial, commercial, and defense-related processes every day. The proper disposal of these hazardous wastes is one of the most pressing challenges our nation faces. These wastes often pollute ground water, soil, and the air—or pile up in temporary storage, awaiting the day when safe disposal technologies are available. To speed the arrival of that day, scientists at Los Alamos have been evaluating and adapting a promising technology originated at the Massachusetts Institute of Technology that may be able to destroy, rapidly and completely, many of the industrial and propellant wastes generated by the defense complex.

Called supercritical water oxidation, the process takes place in an enclosed system, releasing no harmful by-products to the atmosphere. The destiny of its end products (gases, clean water, and solids) can be completely controlled. Supercritical water oxidation lends itself to remote or automatic control and can be adapted to either large- or small-scale disposal of chemicals. Ultimately, the technique may provide both federal and industrial plants with the capability to solve disposal problems associated with contaminated ground water, process waste water, mixed radioactive wastes, and remediation of waste sites.

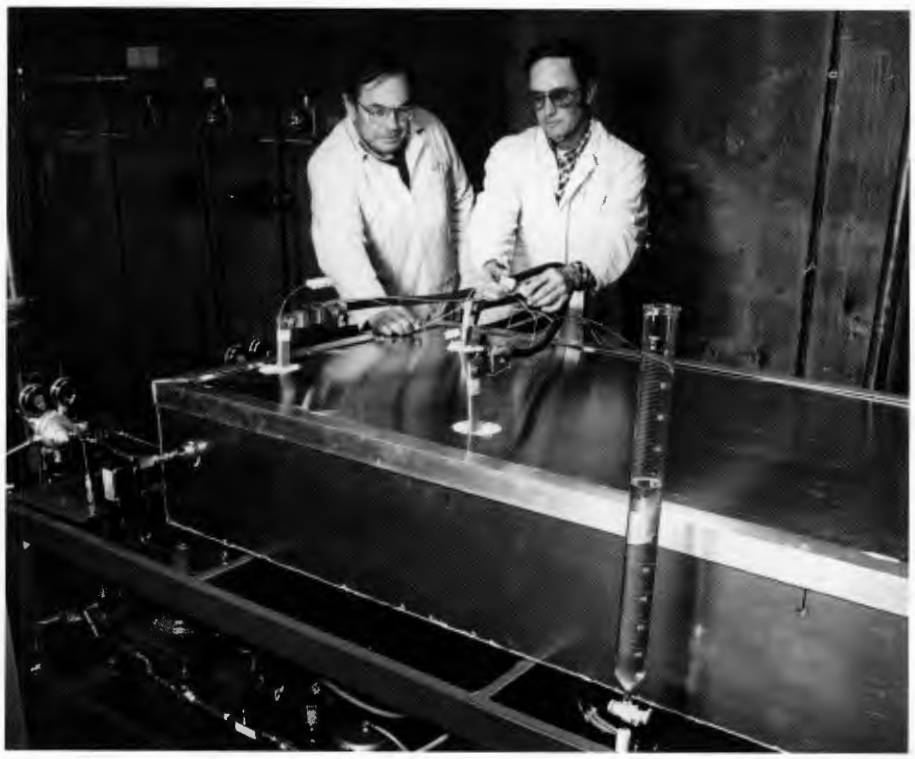
This waste-destroying technique is based on oxidation. Oxidation is a process in which oxygen reacts with other materials, such as food in the human body or wood in a fire, to release energy. It may take place slowly at low temperatures, as in the rusting of iron, or rapidly at high temperatures, as in an incinerator fire. Supercritical water oxidation takes place between these two extremes, in an enclosed vessel that works on the same principle as a pressure cooker. As the temperature of the water inside the vessel increases, so does the pressure. When the temperature and the pressure of the water rise above what is called the critical point—374 degrees Celsius and 3209 pounds per square inch—the liquid and gaseous forms (steam) become indistinguishable. Supercritical water can be thought of as a type of dense steam. It behaves like a gas in many ways, but it is dense for a gas, one-tenth the density of liquid water.

In this state, the ancient truth that oil and water cannot be mixed collapses, for oil becomes soluble in supercritical water, as does oxygen. This property is an important one for waste destruction because many hazardous wastes are oily. The oily wastes, oxygen, and water can mix uniformly to allow the oxidation chain reaction to progress swiftly and systematically to destroy contaminants completely.

Both the Office of Technology Development of the Department of Energy and the U.S. Air Force Engineering and Services Center are funding work in supercritical water oxidation at Los Alamos. Sandia National Laboratories' Combustion Research Facility is participating with us in the projects. Together, we are evaluating the basic feasibility of the process for Department of Energy and Department of Defense wastes and moving toward practical demonstrations.

We are developing an understanding of the chemical reactions that occur and the rates at which they occur. When we fully

Cheryl Rofer (right), coordinator of the Laboratory's supercritical water oxidation program, and Steven Buelow discuss the diamond window cell through which supercritical water oxidation reactions are observed.



Robert McFarland (left) and G. Ray Brewer examine the transportable unit that will test supercritical water oxidation at Department of Energy sites.

understand these reactions, we will be able to use the extensive and growing literature on elementary chemical reactions (the atom-by-atom steps in the overall oxidation reaction) to predict the behavior of a wide variety of wastes. In this effort, we have shown that oxidation in supercritical water is substantially similar to processes that occur in combustion and in the atmosphere, although the operating pressures and water densities of supercritical water oxidation are different.

This similarity, once it is further validated for a selection of representative compounds, is important for two reasons. It means we can use information from the existing literature on combustion to extrapolate the behavior of a wide variety of wastes during supercritical water oxidation. It will also help us understand the limits of the supercritical water oxidation technique, answering questions concerning the ways in which different kinds of wastes should be processed. These answers will help us evaluate a projected industrial demonstration and develop processes for treating variable and complex waste streams.

This year, we built a transportable processing unit for testing supercritical water oxidation at Los Alamos and at other Department of Energy sites. Information from these tests and from other experiments and computer modeling will help us to develop engineering criteria with which to evaluate a planned major industrial demonstration of the supercritical water oxidation process at a Department of Energy site. Our goals are to identify potential limitations of the process and to discover if there are technical roadblocks to large-scale use of this technique. If we find no roadblocks, we will adapt the technology to specialized Department of Energy and Department of Defense wastes, including mixed radioactive wastes and propellant wastes.

Our research has generated a body of information on the chemistry of oxidation in supercritical water in the public domain and serves as a resource for industry as well as the defense complex.

Because supercritical water oxidation destroys not only wastes that can be burned in an incinerator but also those mixed with large amounts of water, it offers a new and attractive solution to treating a wide range of contaminants. Over 90 percent of the wastes produced in the chemical processing industry, for instance, are water based. Currently, much of this waste water is injected into deep wells.

Supercritical water oxidation may be able to destroy many of the wastes produced by the defense complex, thus eliminating the difficulties associated with their storage and handling. The Laboratory's efforts to apply this technique to waste-management problems within the defense complex are part of our ongoing efforts to help clean up the environment—and to do so in a timely, cost-effective manner.

Innovative Technologies for Environmental Cleanup

From the beginning of the Industrial Revolution, humanity has used many types of chemical processes designed to improve the quality of life and ensure the defense of nations. Unfortunately, most of the processes have also produced residues and other unwanted materials, some of them hazardous to human health. Such substances in many cases have proven difficult to clean up.

This year Los Alamos continued to investigate safe and innovative ways of cleaning up the environment. Methods currently under development include soil bacteria and sophisticated chemical processes.

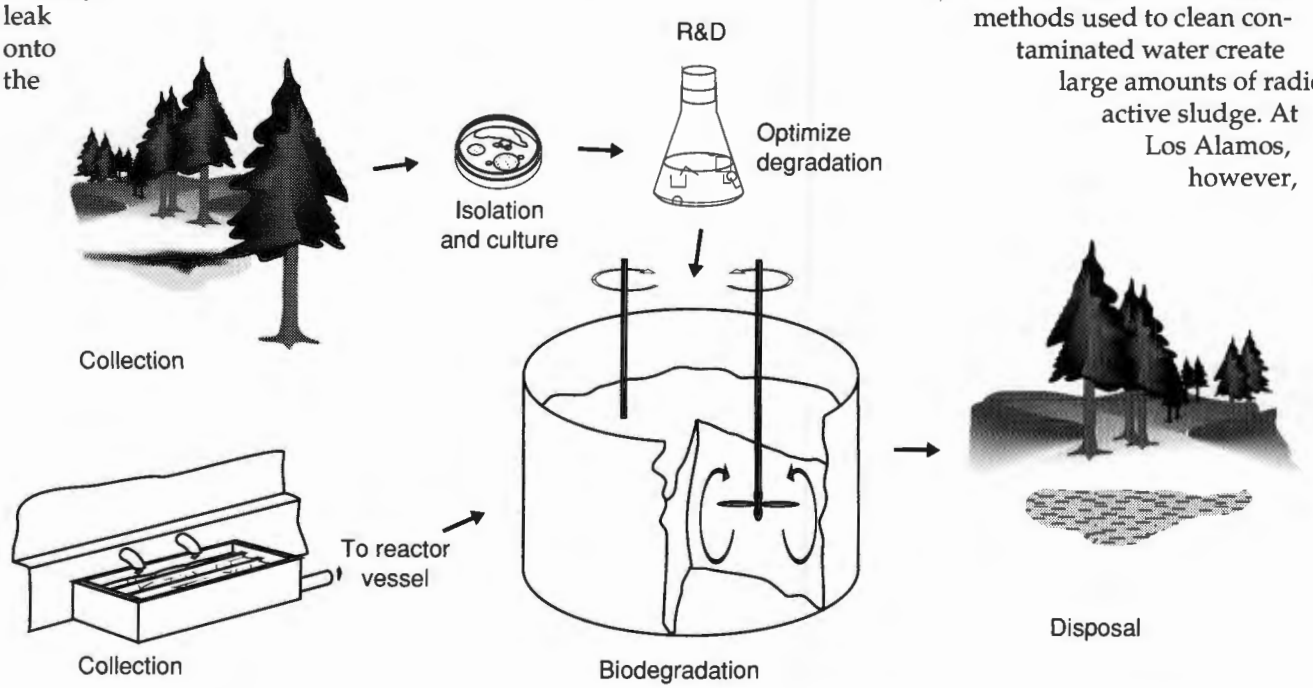
Picture for a moment a warehouse filled with trinitrotoluene (TNT) and nitroglycerin. Now imagine that some of these explosive and unstable substances accidently leak onto the warehouse floor, eventually seeping into the soil. In years past the contaminated soil would have been hauled to an incinerator to be burned, but a new technology may make this method obsolete.

After examining a variety of sites with soils contaminated by explosives, we discovered that certain bacteria have adapted to be able to live in these conditions. We collected such bacteria, identified them, optimized conditions for their growth, and determined how they functioned. We found that some soil bacteria eat and digest nitroglycerine and TNT, rendering the explosives harmless in less than twelve hours. The bacteria break down the explosives into harmless products such as carbon dioxide and useable forms of nitrogen. Although these products are harmless, we intend to verify that all the products produced during biodegradation of explosives are in fact not toxic and that any intermediate materials involved are also not toxic.

Future studies in biodegradation will determine ways to adapt microorganisms to different climates or conditions such as high salt concentration. We also plan to study other bacteria that may be capable of eating other hazardous wastes.

Presently, biodegradation can be used to eliminate many dangerous explosives from contaminated sites at military installations. Biodegradation may prove especially useful when the military needs to clean up a base it intends to close down. In the future, commercial firms may use this technology to clean up soils at factories, warehouses, and other industrial sites.

Chemical contamination is not limited to soil. Nuclear power plants, chemical production plants, and electronics manufacturers produce water streams contaminated with radioactive elements known as transuranics. Present methods used to clean contaminated water create large amounts of radioactive sludge. At Los Alamos, however,



Certain soil bacteria can actually eat and digest nitroglycerine and TNT. We collected these bacteria, identified them, optimized conditions for their growth, and determined how they functioned. We then placed these bacteria in a variety of disposal sites. The bacteria managed to render the explosives at these sites harmless in less than twelve hours.

scientists have developed a technology known as ferrate precipitation, which will dramatically reduce the amount of such sludge. Los Alamos licensed this technology to Analytical Development Corporation, who will further develop, evaluate, and market the process as Tru/Clear for the industrial sector.

The ferrate precipitation process effectively extracts all traces of transuranics from waste water by coagulating them into a solid state. The process begins with an innovative chemical formulation consisting of potassium ferrate and other additives. The iron in the potassium ferrate salt undergoes a chemical change called degradation, which yields an insoluble material. The insoluble material becomes solid at a microcrystalline level, and as the crystal forms and grows, it binds both soluble and insoluble transuranics to its surface. This slow, controllable precipitation allows the chemical formulation to sweep over every molecule in the waste water.

Early cost estimates indicate that the ferrate precipitation process may save waste management installations tens of millions of dollars. In addition, the process is completely compatible with existing water treatment technology. In other words, the process requires no special equipment or buildings to operate.

Another set of contemporary processes, which convert plutonium oxide (a binary compound of oxygen and a metal) to a metal, have generated significant amounts of salt and crucible waste. A new process developed at Los Alamos known by the imposing title of multiple cycle direct oxide reduction (MCDOR) reduces the salt and crucible wastes by a factor of four, saving thousands of dollars in waste management packaging and storage. This technique may also help process and recover nuclear fuels.

Technician Vonda Dole checks equipment as she unloads the stainless steel secondary containment can that holds the ceramic crucible, salt slag, and plutonium metal product.

The MCDOR process directly converts plutonium dioxide to metal. To remove the oxygen from the plutonium, a calcium metal reductant (a material that removes oxygen from ores or concentrates) and a calcium chloride-based solvent salt react with the plutonium dioxide under high temperatures. The reaction forms plutonium metal and calcium oxide. To "recycle" the calcium oxide, scientists combine the compound with chlorine to recreate a calcium chloride-based solvent salt. This substance can again be used to generate more plutonium metal.

The MCDOR process doubles the plutonium recovery rate, reduces plutonium in the contaminated waste by twofold, and dramatically lowers doses of radiation exposure. In addition, the MCDOR process can be used in any installation that intends to convert oxide compounds to metals.

In past decades the direct conversion of the oxide to metal was the single largest solid-waste-producing step in the recovery process. The MCDOR process has significantly reduced the amount of waste from the reaction, making this process not only safe and efficient but affordable as well.

The Industrial Revolution offered humanity the potential to improve its quality of life. New technologies developed now and in the decades to come can help the world clean up past wastes and prevent the generation of significant amounts of new wastes. In this way, humanity may continue to enjoy the benefits of technology without adversely affecting the environment.

Superconducting Tapes and Films

Superconductivity, the ability to transmit electricity without resistance, holds the tantalizing promise of efficient energy production and transmission, and therefore a promise of more abundant and perhaps cheaper supplies of energy. For decades after the discovery of the phenomenon of superconductivity in 1911, it was observed only in materials cooled to close to absolute zero, a temperature too cold for practical applications. In the past few years, however, scientists have discovered new materials that become superconducting at higher temperatures. These materials are called high-temperature superconductors.

Los Alamos scientists are investigating why materials become superconducting under certain conditions. We are also synthesizing new materials that can be fabricated in forms usable in power transmission lines, motors, generators, microwave devices, and many other commercial applications. We fabricate superconducting tapes and thin films, and we are transferring this technology to industry. Major advances in superconducting theory are being achieved through a new program that integrates leading academic theorists into Los Alamos theoretical and experimental work.

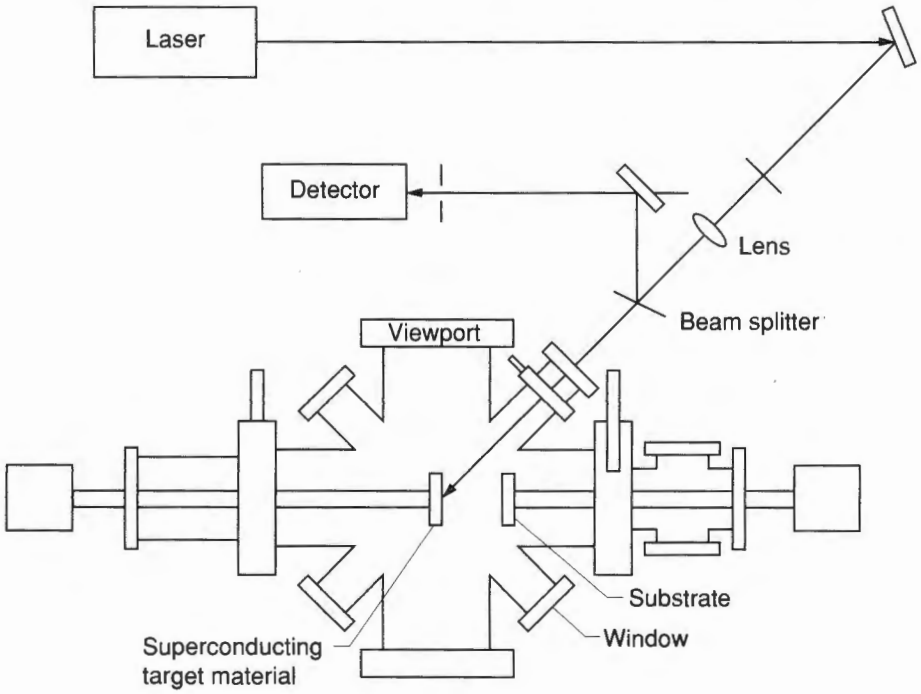
Since the discovery of superconductivity, scientists have pursued the goal of fabricating superconducting wires that carry large electrical currents. A superconducting wire can be ten times smaller in cross section than a copper wire that carries the same current. Dramatic applications for such conductors range from more efficient motors and power transmission lines to large, powerful magnets for such uses as levitating monorail trains and building room-size magnetic resonance imaging machines that the patient could simply walk into.

Ralph R. Trujillo uses a micrometer to measure the diameter of drawn superconducting wire that will be rolled to produce superconducting tape.

Central to any understanding of superconductors are the concepts of current density and critical current. Current density is how much current a conductor can carry: that is, it is the electrical current per unit cross section of a conductor, usually measured in amperes per square centimeter. Critical current marks the transition to superconductivity. Above that current the material acts as a normal conductor, and below that current the material can be superconducting at a specified temperature and in the absence of magnetic fields.

The use of the new high-temperature superconductors in wires has been limited by low current densities under operational conditions. And when the temperature is increased or when the tapes are placed in a strong magnetic field, this current density decreases further. Recently, however, scientists at Los Alamos have successfully produced metal-oxide superconducting tapes (flattened wires) that have critical current densities in excess of 50,000 amperes per square centimeter when cooled to –452 degrees Fahrenheit. The processing approach has considerable potential for ultimately producing high-temperature superconductors that will be useful in commercial applications.

When we fabricate these superconducting tapes, we first synthesize powders of a particular superconductor and fully characterize their composition and electronic properties. Silver tubes are packed with the selected superconducting powder, and the ends of the tubes are sealed. A typical tube has a



Apparatus for producing superconducting thin films. Laser output is relayed with lenses to a superconducting target material. The resulting plume of material is collected on the substrate to form the thin film. A beam splitter sends a fraction of the beam to a detector to provide monitoring of laser beam characteristics. Scientists monitor the experiment through a viewport. A video camera records the experiment through one of the windows.

length of about 6 inches and an outside diameter of 0.3 inches—about the size of a 6-inch piece of automobile radio aerial.

The next step in fabrication is a conventional drawing operation. One end of a tube is tapered and is inserted into the first of many chucks, each with a slightly smaller hole through its center than the previous one. By pulling the tube through these holes, we can fabricate superconducting wires over 15 feet in length that have silver outside and superconductor inside.

The wire is rolled multiple times to produce a flat silver tape containing a superconducting core in which the crystal planes are lined up. Alignment of crystal planes enhances superconductivity: if the crystals are randomly oriented, the material will be a poor superconductor. The assembly is then heat treated, actually melting the superconductor but not the silver, followed by slow cooling for fifty to one hundred hours. This "texturing" increases the size of the crystals to increase current density in the superconductor. We then fully characterize the tapes with regard to their microstructure and current densities (as a function of temperature and magnetic field). The last stage of fabrication involves bundling the tapes to obtain multiple-filament superconductors that support even higher total currents.

Our most successful approach thus far in achieving high critical currents in tapes involved use of a bismuth-strontium-calcium-copper oxide superconducting material. Los Alamos has also used this powder-in-the-tube method to produce similar tapes involving thallium-barium-calcium-copper oxide superconducting compounds. In addition, we are exploring vaporizing thallium compounds to deposit thick films of thallium superconductors on metal substrates to fabricate superconducting wires. These thallium-based wires and tapes have the potential advantage of becoming superconducting at a significantly higher temperature than do the bismuth or rare-earth compounds, and these wires and tapes could be used in higher magnetic fields.

Development of these new superconductors has required a broad range of experts—chemists, physicists, metallurgists, engineers, ceramists, and others. Furthermore, the work has involved collaborations with the University of Wisconsin, Du Pont, Hewlett-Packard, and Sandia National Laboratories.

In addition to fabricating superconducting tapes, we can now produce high-temperature superconducting thin films faster and with higher quality than before by using a process involving lasers.

A number of conventional approaches to depositing films, including evaporation (direct heating of a solid to produce vapor), sputtering (bombarding a target with heavy ions to produce a small plume), and chemical vapor deposition (treating a gaseous chemical to produce solid material on a substrate), have been tried in an effort to produce high-quality thin films. Laser deposition offers an attractive alternative to these techniques.

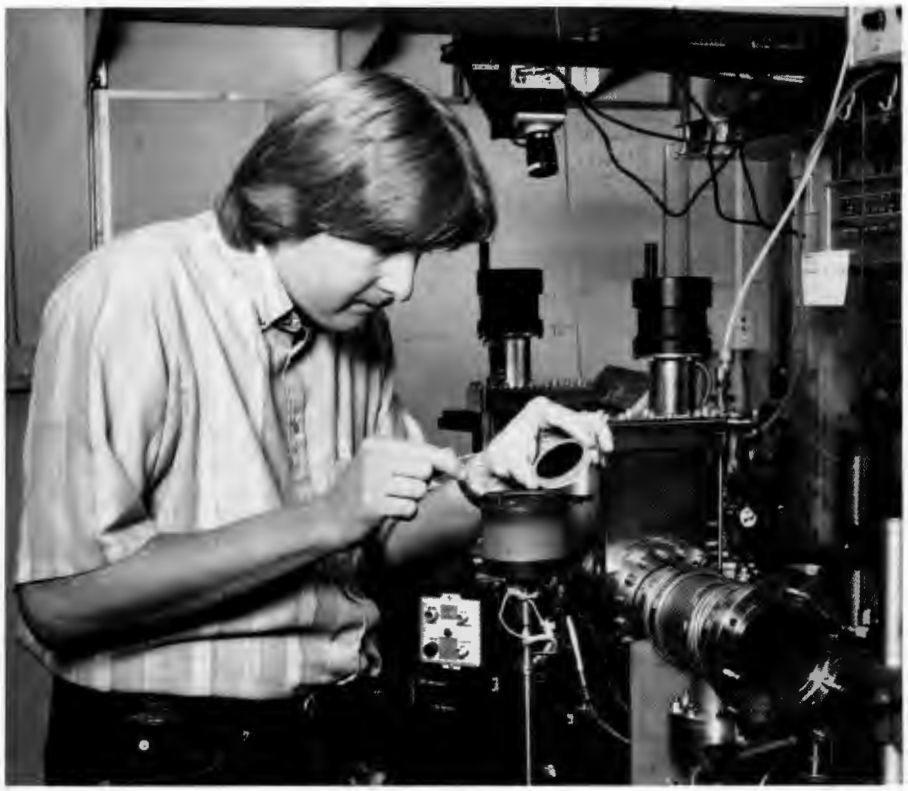
Researchers have studied laser ablation (to create plumes) and deposition for more than twenty years, and these processes have become useful tools for producing conventional thin films. We apply this technique to fabricating superconducting thin films. In this process, a high-energy pulsed laser beam is directed upon a superconducting target material in the experiment chamber. The beam vaporizes a plume of material, and the plume is directed onto a crystalline substrate (the physical material on which a microcircuit is fabricated or a film is deposited).

The ablation and deposition processes are controlled by a

variety of techniques. We can vary precisely the power and focus of the laser, and the target can be rotated or wobbled to produce the optimum plume. During deposition, we can rotate the substrate to ensure that an even film is laid down. The pressure, temperature, and gases in the chamber can be monitored and controlled. A video camera looking through a window into the apparatus permits observation of the process as it occurs and provides a permanent record of that process.

Laser ablation and deposition of thin films offer a number of advantages. (1) The laser deposits energy on the target very quickly. As a result, the temperature of the target's surface rises so rapidly that we achieve congruent evaporation; that is, the solid material and the resulting vapor are identical in composition. Thus the superconducting material laid down on the substrate is the same as the material in the target. (2) The film growth rate is rapid: about 150 angstroms per second to the desired thickness of about 1,000 to 2,000 angstroms (about a tenth of the thickness of a sheet of paper). So it takes only seconds to deposit a particular film. (3) Because this process occurs *in situ*, the product needs no further processing before it is ready to use. (4) The film quality is very high because the superconducting material was not contaminated during processing, it has good critical currents, and it has low surface resistance.

Laser evaporation and deposition can be used under a variety of processing conditions. With laser evaporation, pressure may vary from ultrahigh vacuum to a pressure equal to several Earth atmospheres of inert or reactive gases, and the operating temperatures of both targets and substrates are restricted only by the physical properties of those materials. Under appropriate conditions we can grow an epitaxial thin film in which the superconducting layer



Ross Muenchausen examines a large-area superconducting coating fabricated by the laser ablation process.

Alexander Balatsky (left), Dermot Coffey, and Kevin Bedell discuss new theoretical results describing the normal state of superconducting materials.

has the same crystal orientation as the substrate layer on which it is deposited. This type of thin film makes a more efficient superconductor.

The goals for the initial phases of this laser ablation and deposition study were twofold: we wanted to develop an understanding of the basic physics and chemistry associated with laser ablation, plume expansion, and condensation and crystallization, and we wanted to develop the technology to produce high-quality superconducting thin films. We are now making material suitable for working devices, and we are doing the engineering to make multiple target holders so that we can evaporate and deposit several materials.

These developments in experiments with and fabrication of high-temperature superconductors are effectively complemented by the Advanced Study Program on High-Temperature Superconductivity Theory, a new program designed to bring leading academic theorists to Los Alamos.

The community of academic and laboratory scientists created by the program is significantly influencing Los Alamos research as well as enriching the research activities of the academics. The program, directed at Los Alamos, involves academic fellows from the University of California at Santa Barbara, the University of Illinois, Rutgers, Stanford, and Eidgenössische Technischne Hochschule, Zurich. These academic fellows spend considerable time at Los Alamos interacting with the local experimentalists and theorists and supervising postdoctoral appointees. The program brings thirty to forty academic visitors per year to Los Alamos to participate in collaborations and in publications that result from the visits. The academic theorists and Los Alamos scientists meet to discuss theories of superconductivity and test them against experimental results.

This program is probably unique in the United States because seed money was provided by the Public Service Company of New Mexico, a public utility. In forming the program, both the utility company and Los Alamos committed themselves to a program focused on basic science with a principal objective of advancing knowledge on a broad front. Los Alamos assumed full responsibility for the program in April 1989.

Participants look at scientific data from experiments and at theories of superconductivity. The focus is on the interaction between theory and experiment, emphasizing the properties and nature of the normal state of the materials. The program's goal is to develop an understanding of the underlying microscopic reaction that results in the transition of a material from the normal state to superconductivity. Once we gain a better understanding of the phenomenon of superconductivity, we can turn to industry for commercial applications.

Global Positioning System: Eyes and Ears in Space

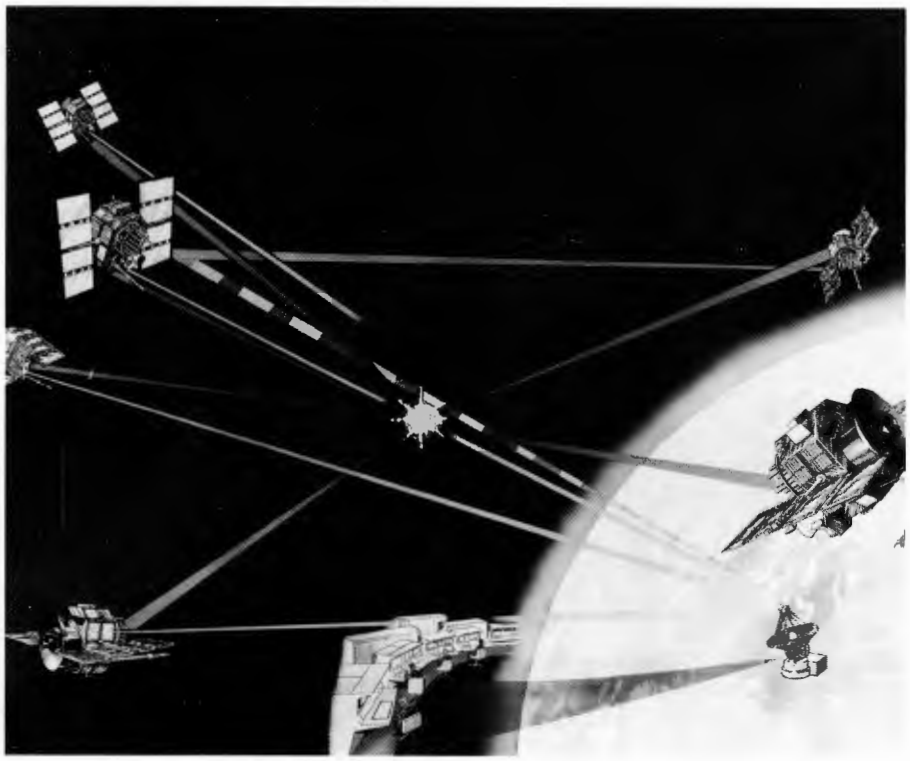
When a Delta 2 rocket roared off the launch pad at Cape Canaveral on November 26, 1990, it carried into orbit the eleventh of what will eventually be an operational constellation of twenty-four satellites continuously monitoring space and every point on Earth. That constellation will be the Global Positioning System (GPS), a radio navigation and nuclear detonation detection system that the U.S. Air Force began deploying in 1989. On board each satellite are sensors designed at Los Alamos to detect and measure radiation in space.

The primary purposes of the system, which should be fully in place in 1993, are to detect nuclear bursts in or above the atmosphere and to help navigators around the globe accurately determine their own positions. As a detection system, GPS will provide nearly instantaneous information on the size and location of a nuclear blast anywhere on or above Earth. Thus, it offers improved monitoring of international adherence to the Limited Test Ban Treaty, which bars explosive testing of nuclear weapons either in the atmosphere or in space. As a navigational system, the GPS will be invaluable to both military and civilian users.

Since 1963, Los Alamos has been involved in developing technologies for verifying compliance with the Limited Test Ban Treaty. Our responsibility in the GPS program is for two instruments that, as part of the nuclear detonation detection system, monitor space radiation. The first, the BDX, is designed to detect x-rays from nuclear detonations outside the atmosphere. These detectors are positioned so that eventually the constellation as a whole will view space in all directions. The second instrument, the BDD, measures background charged-particle radiation in space. Twice a day each BDD travels through the Van Allen radiation belt, one of the Earth-circling belts of intense ionizing radiation formed by high-energy charged particles trapped in the Earth's magnetic field. Primarily a research tool, the BDD measures protons and electrons, in part to determine how well electronic parts stand up to high-intensity radiation. One or the other of our detectors is mounted on each spacecraft, five satellites carrying BDXs for every one carrying a BDD.

At Los Alamos, we design, fabricate, and calibrate the exo-atmospheric sensors in a specially equipped laboratory. To meet strict mission requirements, these small instruments, each weighing only a few pounds, must be flight-qualified and able to withstand large doses of radiation. They are

Darrell Drake places a BDD in the "oven" for a thermal cycle test of the instrument's resistance to temperature extremes in space. The test will subject the BDD to a temperature range of 50 to –30 degrees Celsius, a little higher and lower than actual space temperatures. The two domes on top of the BDD are beryllium windows that shield the sensor from radiation. Electrons enter the device through tiny holes pierced in the windows. In the photograph on the right, Paul Higbie (left) and Kenneth Spencer prepare to calibrate a BDX (held by Spencer). This sensor is designed to detect x-rays signaling a nuclear explosion outside the Earth's atmosphere. The four small domes on the BDX are x-ray filters that define the range of incoming x-ray energies for each of the instrument's four measurement channels.



The BDXs aboard orbiting satellites receive x-radiation emitted by a nuclear explosion in space (center). Satellites above the horizon transmit measurements of the radiation (solid beams) directly to the control station in the base of the receiving site (lower right). A network of ultrahigh-frequency crosslinks between spacecraft enables satellites below the horizon, like the one at upper right, to relay their data to one of the satellites positioned to send the measurements (variegated beam) on to the control station.

tested here and again at Sandia National Laboratories before they are delivered to the spacecraft contractor for mounting on the satellites. After some twenty days in orbit, they are subjected to about five days of further testing and calibration before they are finally placed in operation.

Also mounted on the satellites are sensors designed and built at Sandia. Shielded from space radiation and constantly scanning the Earth, these instruments watch for the revealing flash of light from a fireball signaling that a nuclear explosion may have occurred within the atmosphere. On board each spacecraft is a processor, also a Sandia design, that handles the data collected by all the sensors on that satellite.

At any given time after the full GPS constellation is in place, four or more satellites will be monitoring every point on the globe and thus all possible terrestrial locations for a nuclear blast. Should such a detonation occur, Los Alamos-developed mathematical algorithms and the different times at which various satellites detect the blast can be used to calculate its location. Because the detonation detection system will enable military observers to detect and understand the characteristics of nuclear detonations anywhere on the Earth at any time, the GPS can be used to check the progress of emerging nuclear powers and to provide information, should that become necessary, on the progress of a nuclear war. It can also be used by military navigators and for space operations or battle management.

Observers on the ground have several means of crosschecking data received from the sensors to be certain that no mistakes are made about the true source of any radiation recorded. The Los Alamos exoatmospheric sensors can distinguish radiation generated by a nuclear blast from background radiation or bursts coming from stars and other celestial sources. Sandia's atmospheric detectors can distinguish nuclear fireballs from natural sources of light such as lightning flashes.

For navigation and location, the constellation will provide worldwide position information in three dimensions (longitude, latitude, and altitude) together with time and velocity information. Radio signals exchanged between satellites and Earth-based receivers combined with a sophisticated computer triangulation system will enable the receivers to determine the distance from the source to each spacecraft by measuring the transit time of the received signals. Because the satellites occupy known positions, users on Earth can determine their own positions by obtaining a fix on the constellation.

Time signals between source and sensor that are accurate within 100 millionths of a second are crucial to GPS-based navigation and to locating nuclear bursts as well. Consequently, a key feature of the GPS is the synchronization of satellite-mounted atomic clocks with similar clocks in the Earth-based receivers.

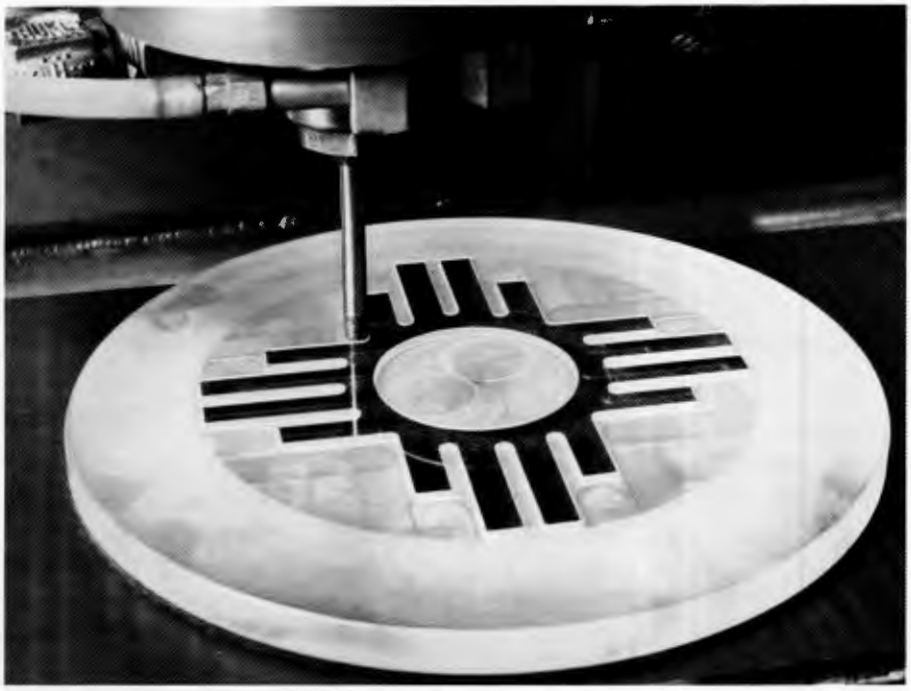
The most precise location measurements, accurate to about 50 feet, will be encrypted so that only the military will have access to them. Civilian users, nevertheless, will be able to pinpoint their own locations within 300 feet. Civilian applications for the GPS include navigation, air traffic control, search and rescue operations, and land mapping. And individual receivers now available are small enough to be mounted on the dashboard of a boat, a motor vehicle, or an airplane—or to hold in the hand. Thus, the eyes and ears in space that will help enforce the test ban treaty and perhaps prevent a nuclear war could even save the life of a lone hiker lost in wilderness country.

Machining Ceramics

In the summer twilight of the twelfth century, an Anasazi Indian crouches in the dusty courtyard of a cliff dwelling, shaping a clay pot to hold the water she will carefully collect from a seep. In a modern factory, a worker shapes porcelain whiteware into a washbasin. From the first pots and bricks to the plethora of modern artifacts that range from table lamps to teapots to transducers, ceramics pervade human life. Ceramics are nonmetallic, inorganic substances largely composed of silicon, silicon oxide, and silicates. Because they are both hard and brittle, ceramics are difficult to machine. In a spin-off from weapons-related technology, engineers at Los Alamos have developed two devices that allow ultrasonic core drills to penetrate very hard materials like ceramics more quickly, more easily, and more efficiently.

Ultrasonic core drills are commonly used on very hard materials—for example, ceramics, glass, and cermets (composites of ceramics and metals)—that resist precise machining with ordinary equipment. The vibrations from an ultrasonic core drill—typically 20,000 cycles per second—enhance the cutting action of the industrial diamonds in the drill's tip. However, if the vibrations cause the drill shaft to wobble, the drill does not penetrate the material as well as it should nor can the machine contour the material to the desired shape.

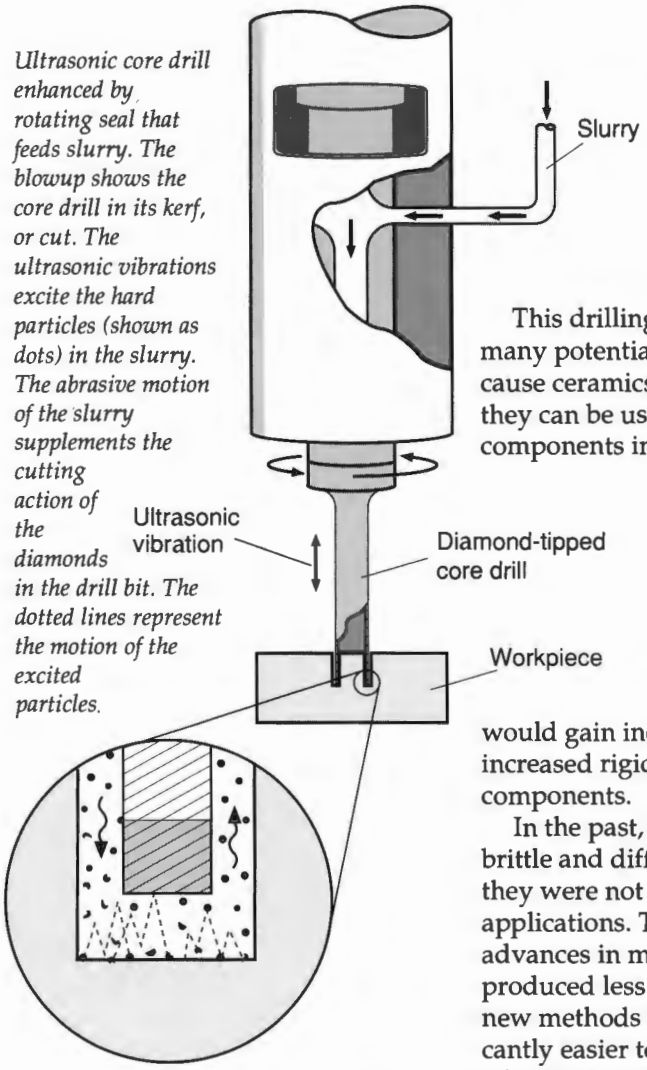
To eliminate wobbling and increase precision and efficiency, we added an air bearing to an ultrasonic core drill. Through the holes in a bushing around the shaft, we pump compressed air that "stiffens" the shaft by supporting it from the sides. We chose an air bearing rather than an oil bearing because air is frictionless, whereas the friction created by the oil can damp the ultrasonic vibrations. But we had to accommodate the increased stress of a machine shop—stress created, for example, when an operator chooses to increase the cutting speed beyond the level the air bearing can tolerate. If the air bearing's tolerance is exceeded, the drill shaft may rub against the bushing, destroying both the bearing and the ultrasonic vibrations. To avoid this problem, we bonded a Vespel liner impregnated with molybdenum disulfide to the bushing. The molybdenum disulfide acts as a lubricant just as the oil would have. The air bearing increases drilling capabilities, but even more important, the added stiffness allows the cutter to go sideways: for the first time we are able to contour difficult-to-machine materials.



We contoured this quartz workpiece to demonstrate our unique ultrasonic machining capabilities.

Our second new device, a rotating seal, enhances drilling effectiveness by delivering a continuous, easily renewed supply of slurry as a cutting agent. We are now able to cut several inches into a very hard material. Previously, ultrasonic core drills could penetrate only one-third of an inch.The slurry, a thick liquid containing abrasive boron carbide particles, offers a third way to penetrate the material in addition to the ultrasonic vibrations and the cutting edge created by the industrial diamonds. Thus, drilling is faster and deeper. The slurry is delivered through the rotating seal to the bottom of the cut, the place where it can enhance the cutting power most dramatically. Placing the slurry precisely at the bottom of the cut offers other benefits: the slurry protects the cutting edge by creating a buffer zone between the edge and the material, and it cools the area and carries away debris as it spurts back from the bottom of the cut.

Adding the rotating seal to the ultrasonic core drill was a tricky



Ultrasonic core drill enhanced by rotating seal that feeds slurry. The blowup shows the core drill in its kerf, or cut. The ultrasonic vibrations excite the hard particles (shown as dots) in the slurry. The abrasive motion of the slurry supplements the cutting action of the diamonds in the drill bit. The dotted lines represent the motion of the excited particles.

maneuver. The entire drill column vibrates at a particular frequency just as an individual bar in a xylophone does. If you touch the bar, you damp the oscillations and kill the tone. Thus, incorrectly adding a component—the rotating seal in this case—would have changed the frequency, making the drill ineffective in penetrating the material. We built three models before we developed one that would retain the correct ultrasonic frequency while feeding the slurry.

The applications for our enhanced core drill are intimately connected to the development of advanced ceramics and composites. A new material may be an exciting discovery, but it does not offer many practical advantages unless it can be machined to the appropriate tolerances without being damaged. Our enhanced drill provides U.S. industry with the technology to successfully shape today's and tomorrow's difficult-to-machine materials.

This drilling technology has many potential applications. Because ceramics are extremely stiff, they can be used effectively as components in ultraprecision tools. For example, the operator of a diamond-turning lathe or the tool used to create the microscopic shapes and features of computer chips would gain increased control from increased rigidity of the ceramic components.

In the past, ceramics were so brittle and difficult to machine that they were not used in engineering applications. Tremendous advances in materials science have produced less brittle ceramics; our new methods make them significantly easier to machine. These advanced ceramics, which retain their ability to withstand temperatures up to thousands of degrees Celsius, are ideal candidates for engineering applications in which temperature resistance and toughness are both required. For example, advanced ceramics could be used in turbine blades for more efficient jet engines. Current jet engines do not operate at maximum efficiency because the metal turbine blades would get too hot and bend. Given the nation's current dependence on imported oil and the long-term nature of research to increase oil recovery in the United States, a more efficient jet engine is a highly desirable goal for U.S. industry.

One interesting spin-off of our research involves a proposed Mars landing. We were asked to determine whether our enhanced drill could remove cores from rocks whose composition simulates that of the rocks on Mars. The 1976 Viking landings analyzed only samples of dust because the equipment could not penetrate the extremely hard Martian rock. We were able to remove cores from the simulated Martian rocks. Perhaps a future Mars mission will bring back rock cores collected with our enhanced drill.

Ralph Lundin (left) watches Eddie Duran prepare a ceramic workpiece for machining by our enhanced ultrasonic core drill.

BASIC RESEARCH

Los Alamos National Laboratory continues to expand the horizon of scientific knowledge. Underpinning our defense programs, our basic research ranges from nuclear and particle physics to the biosciences. Researchers draw ideas and techniques from defense programs, and knowledge gained in nondefense areas feeds back into our defense programs. This interdisciplinary sharing of ideas, resources, and knowledge strengthens both our defense work and our programs in other areas.

A primary concern of the Department of Energy weapons complex and of the nation is to protect and clean up the environment. At Los Alamos, we study the interactions of materials and processing that may cause harm, and we lay the scientific foundations for environmental control and cleanup strategies. We study diagnostics and sensors that can be developed into instruments for identifying contaminants. We have identified microbes that can turn nitroglycerine and TNT into harmless products, and we are studying the fundamental chemical processes involved in the oxidation of organic wastes in supercritical water to destroy hazardous organic materials.

Since the 1940s much basic research at Los Alamos has been in physics. At the heart of our physics research is the Clinton P. Anderson Meson Physics Facility (LAMPF), which houses the world's most powerful medium-energy accelerator. With its unique beams of subnuclear particles—protons, pions, muons, neutrons, and neutrinos—scientists study basic nuclear physics, fundamental laws and interactions of particles, condensed-matter and atomic physics, and even some aspects of chemistry. Today, the LAMPF user group consists of approximately a thousand scientists representing some three hundred external organizations from the United States and abroad. A Department of Energy review panel established to assess major U.S. nuclear science institutions several years ago called LAMPF "the flagship of American nuclear science" because of its size, the diversity and quality of its science programs, and its large user community.

LAMPF also produces pulsed neutron beams for experiments at both the Manuel Lujan, Jr. Neutron Scattering Center (LANSCE) and the Weapons Neutron Resource (WNR). LANSCE provides the highest peak flux of thermal and epithermal neutrons in the world. Its capability in pulsed neutron scattering is used for research in atomic and magnetic structure, condensed-matter structure and dynamics, structural biology, and nuclear physics. The WNR uses the LAMPF beam for both applied and basic research, primarily in nuclear physics. Scientists from all over the world use both facilities, which contribute to a variety of Laboratory programs.

Our "bright source" experimental program illuminates a new direction in physics: we are examining atomic states and processes in a precise way no other method has rivaled. Researchers use low-energy, ultrahigh-intensity lasers to achieve electric fields stronger than those binding atoms, thereby forcing atoms into conditions never before observed. Our Bright Source II laser focuses its intense beam on a tiny spot smaller than the width of a human hair and can heat a target to temperatures near those of the sun's core.

Researchers at Los Alamos are part of an international team that is currently searching the heavens for a ghostlike particle—the neutrino—that fills the universe in profuse numbers but has, so far, largely eluded detection on Earth. Two Los Alamos scientists confirmed the existence of neutrinos in 1956. Startling new evidence, which indicates a deficit in the predicted number of neutrinos that should reach the Earth from the sun, threatens to upset long-standing theories of particle physics and revise accepted views of the structure of the universe. Through complementary laboratory experiments on the beta decay of tritium, researchers at Los Alamos recently confirmed that a particular type or "flavor" of neutrino—the electron antineutrino—has very little mass, a key step toward confirming physics theories.

Computational science is one cornerstone of science and engineering at Los Alamos. The Advanced Computing Laboratory (ACL) provides an experimental environment that encourages interdisciplinary, applications-driven research in high-performance computing. In addition to ongoing relationships, we began major new collaborations this year with International Business Machines on the RISC System/6000 workstation, with Convex Computer Corporation on software technology, with Silicon Graphics Incorporated on visualization, and with Cray Research, Inc., on future systems.

Research teams can use the Laboratory's new 65,536-processor Connection Machine, a new generation, massively parallel computer built by Thinking Machines. Already it is being used to develop hydrodynamics codes for armor/anti-armor studies. We can achieve problem execution speeds superior to speeds of current mainframe computers. We can also achieve large increases in resolution capabilities needed for solving problems in three dimensions.

With the Connection Machine in the ACL and a twin machine in a secure area, we have developed computational simulations for modeling ocean and atmospheric changes as part of our global climate studies. We have also developed simulations for multimaterial fluid dynamics, molecular studies of hydrodynamics properties, condensed-matter theory, flow through porous media, neutron transport, plasma physics, and diffusion in viscoelastic polymers. This year, in applied mathematics and computational science, we made fundamental advances in the design and modeling of communications networks and advanced architectures, in algorithms for color compression and signal processing, in algebraic solution techniques for sparse systems of equations, in mimetic discretizations for partial differential equations, and in understanding nonlinear phenomena described by integral equations and partial differential equations.

This year the Laboratory formed the High-Performance Parallel Interface testbed consisting of hardware located in the Central Computing Facility, the Laboratory Data Communications Center, the ACL, and the Numerical Laboratory. This testbed provides researchers with the most advanced networking resources. Los Alamos, the California Institute of Technology, the San Diego Supercomputing Center, and the Jet Propulsion Laboratory form the CASA Gigabit Testbed, jointly funded by the Defense Advanced Research Projects Agency and the National Science Foundation through the Corporation for National Research

Initiatives. The goal of this project is to develop prototype computer applications that can effectively use resources connected by very high speed networks over hundreds or thousands of kilometers.

The Laboratory's scientific expertise and technological resources in both computational science and the biosciences have made it the home of many unique capabilities. Four examples of such national assets located at Los Alamos are the National Flow Cytometry and Sorting Research Resource, the National Stable Isotopes Resources, GenBank, and the National Research Resource for AIDS Sequences (all jointly sponsored by the Laboratory and the National Institutes of Health).

As one of three national Centers for Human Genome Studies, Los Alamos works to help determine the genetic bases of many human diseases and to clarify some of the factors associated with individual susceptibility to disease-causing agents. The goal of analyzing all human genetic material requires first the development of a new science and technology base. We draw expertise from many scientific disciplines to develop new DNA sequencing methods and map chromosomes, and we use computer techniques to analyze the immense volume of genetic information. Collaboration with private industry to develop commercial applications for this technology is an important objective of the centers.

In reponse to worldwide requests for DNA from specific human chromosomes for research, Los Alamos helps to build recombinant DNA libraries. Besides providing a service to the scientific community, this project has catalyzed the development of important concepts and new applications in medicine and biology. The gene library project, together with GenBank, provides a sound experimental and theoretical basis for associated work by the Center for Human Genome Studies.

In life sciences, we have pioneered in applying several unique resources to advance current knowledge and techniques. For example, magnetoencephalography provides noninvasive monitoring of human brain activity. To develop better biomedical techniques, instruments, and calculations, we apply our background in accelerators and associated technology. Collaboration with universities and private companies is a vital component in these studies.

In our materials science program, we conduct research in metallurgy and ceramics, high-temperature superconductivity, materials chemistry, and condensed-matter physics. To predict failure limits and to develop materials to better withstand extreme conditions, we study the properties of materials under extreme conditions such as high pressure, high electric or magnetic fields, and high radiation. New technologies are often limited by the materials available to do the job. Thus new substances tailored for specific applications are increasingly important to defense, energy, communications, and environmental control.

The Laboratory's research in Earth and space sciences covers a broad spectrum. Earth sciences research focuses on basic problems of energy discovery and production and waste disposal. In geophysics, we examine nonlinear acoustics, heat transport and electrical conductivity properties, and computational techniques. Our geochemical research includes isotopic studies, rock-water interactions, and the migration of elements in aqueous systems. In our study of thermal regimes, we analyze results from the Valles Caldera as part of the Continental Scientific Drilling Program.

In space plasma physics, we examine, among other topics, the structure and flow of plasma energy in the solar wind, the magnetosphere, and the ionosphere and aspects of the interaction between the solar wind and the magnetosphere. In our atmospheric sciences program, we investigate—both theoretically and experimentally—the influence of terrain on the transport and diffusion of gases. To make our regional environmental assessments more reliable, we apply principles and models developed from a combination of scientific disciplines.

The Laboratory is a principal in the Department of Energy's research on global climate change. The goal is to understand natural and human-induced changes in the global environment and their regional impacts on human society. During 1990 we initiated major research pertinent to the Global Change Initiative. One example is the development of new scientific models and computational capabilities for large-scale global change simulations. We use the capabilities of both our Cray and Connection Machine computers to develop new levels of scientific detail and computational speed. These advances are applicable to calculations of the "greenhouse effect," which involve modeling global pollutant flows, physics of cloud formation, ocean effects, and long-term temperature variations.

A major strength of Los Alamos is the interdisciplinary nature of much of our research. Scientists in one field may draw on research and techniques developed for quite a different, seemingly unrelated, area. For example, this year bioscientists investigating the structure of bile salts used neutron scattering techniques developed by physicists to obtain their data, and then used the theory of maximum entropy to interpret their data. By combining diverse and unique resources from many scientific fields, the Laboratory can respond with expertise and flexibility to help safeguard the nation while providing other much-needed benefits to society.

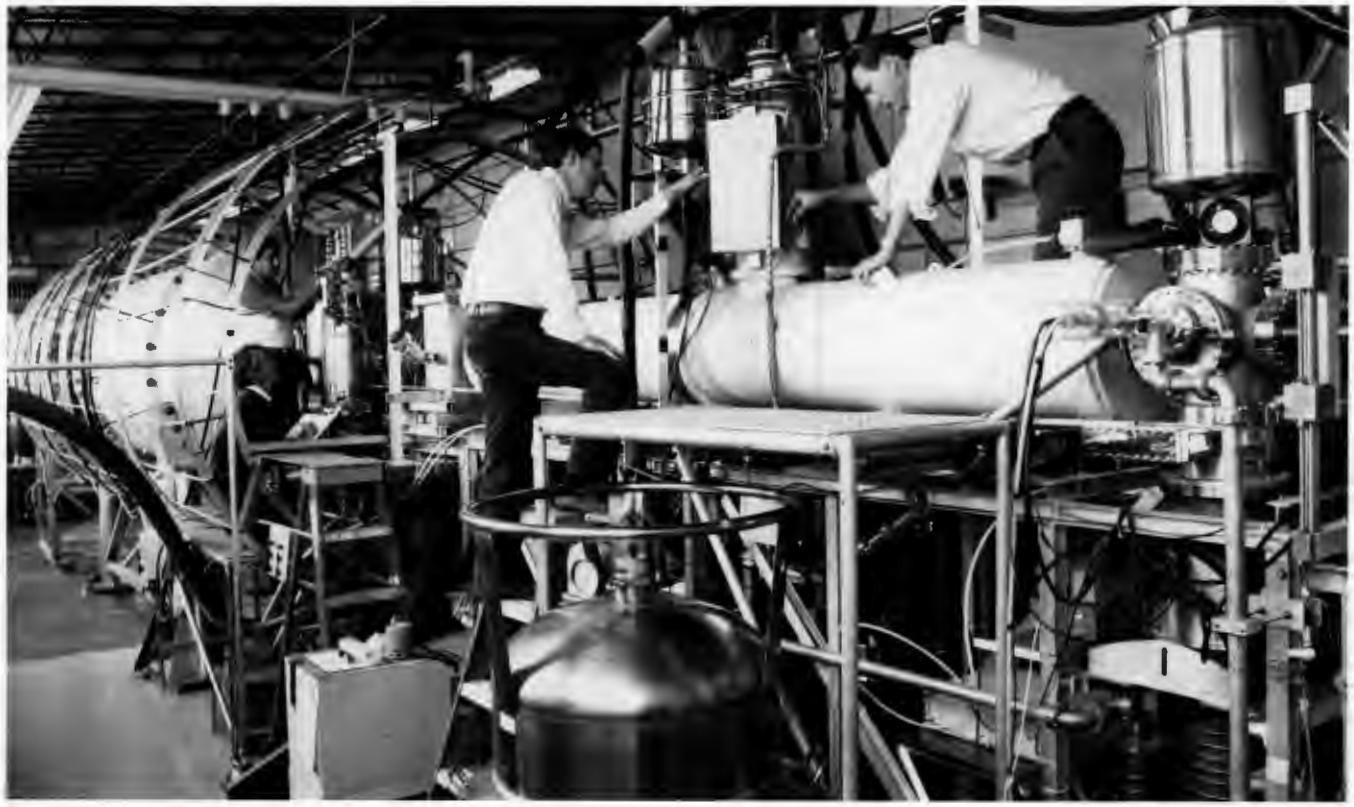
The Elusive Neutrino: Enticing Signs of New Particle Physics

The universe was born in a fraction of a second as a powerful explosion filled all of space with a multitude of elementary particles and antiparticles (for every type of elementary particle there exists a mirror-image antiparticle). Of these early particles, photons and neutrinos, which escaped annihilation because they did not combine with their antiparticles, fill the universe today in vastly more abundant numbers than the few remaining protons and neutrons that compose ordinary matter. Neutrinos have recently become the focus of intense research worldwide because startling new evidence concerning these elusive particles, including research findings at Los Alamos, threatens to upset long-standing theories of particle physics and revise accepted views of the structure of the universe.

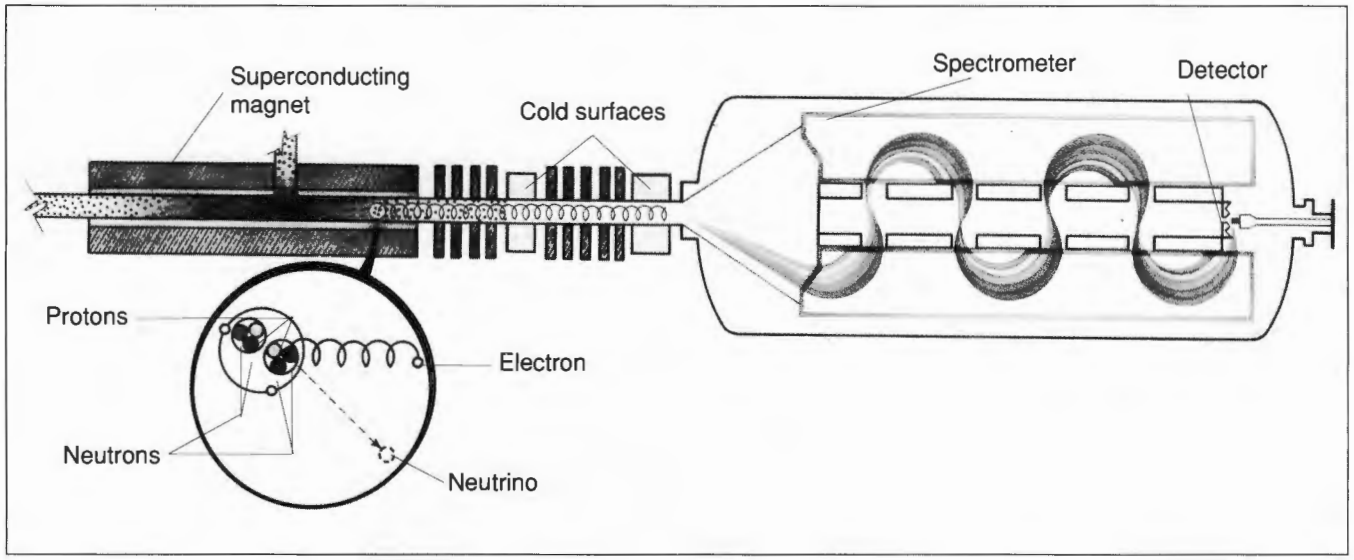
The neutrino's existence was postulated more than fifty years ago when an Austrian physicist, Wolfgang Pauli, came up with a "desperate remedy" to save the principle of conservation of energy in decays involving beta particles (high-energy electrons emitted from radioactive atoms). Early experiments determined that beta particles did not carry away all the kinetic energy available in the decay process. Pauli speculated that perhaps a second particle produced at the same time carried off the remaining energy. This second ghostlike particle was dubbed the neutrino, or "little neutral one." Neutrinos interact weakly with other particles; thus very little is known about them except that they are always produced in pairs with either an antineutrino or a charged particle such as the electron.

Pauli's neutrino, the electron neutrino, is one of three types or "flavors" of neutrinos. Like the electron neutrino, the other two flavors, the muon and tau neutrinos, are named after their associated charged particles.

These three neutrinos seem to fit neatly into a modern theory of particle physics, known as the Standard Model, which accommodates every known fact about particles and forces (other than gravity). According to the Standard Model, neutrinos are massless and move at the speed of light. Many particle physicists believe,



Mel Anaya (standing at left), Hamish Robertson, Tom Bowles, and John Wilkerson check the tritium-beta-decay apparatus before an experimental run. Electrons emitted from the beta decay of tritium are guided through a long tube by a superconducting magnet (foreground) to the spectrometer (background) in its "cage" of wires that cancels the Earth's magnetic field.



The tritium-beta-decay apparatus. A steady pressure of tritium gas is maintained in the source tube on the left. The inset shows a tritium molecule in which a neutron in one of the two atoms is decaying into a proton, an electron, and a neutrino. The neutrino escapes, but the superconducting magnet forces the electron to spiral along the axis to the right. Tritium gas moving to the right is frozen on very cold surfaces, and only the electrons can enter the spectrometer where they are sorted according to their energies (schematically indicated by the grey shading). Only a selected band of energies can reach the detector at the end.

however, that the Standard Model is only an approximation of some grander theory that seeks to unify all of the particles and the four forces of nature—gravity, electromagnetism, the strong nuclear force, and the weak nuclear force. If neutrinos and antineutrinos do have mass, flaws in the Standard Model will be confirmed.

Moreover, neutrinos are so abundant that they could account for much of the "dark matter" believed to make up 90 percent of the universe. If so, then a neutrino mass of 22 electron volts (less than one ten-thousandth the mass of an electron) could cause our universe to contract and eventually collapse—like a giant deflating balloon—from gravitational forces.

Physicists at Los Alamos recently confirmed, through experiments conducted on the beta decay of tritium, that electron antineutrinos have very little mass (and may, indeed, have no mass as predicted by the Standard Model). Our finding refutes an earlier claim of a massive neutrino—a claim that ignited worldwide research on the beta decay of tritium. In 1980, we began an exhaustive search for the electron-antineutrino mass with innovative methods, which freed us of the uncertainties that cast doubt on earlier work. We used pure, gaseous, molecular tritium, which required a rather complex experimental setup but led to a clear-cut result.

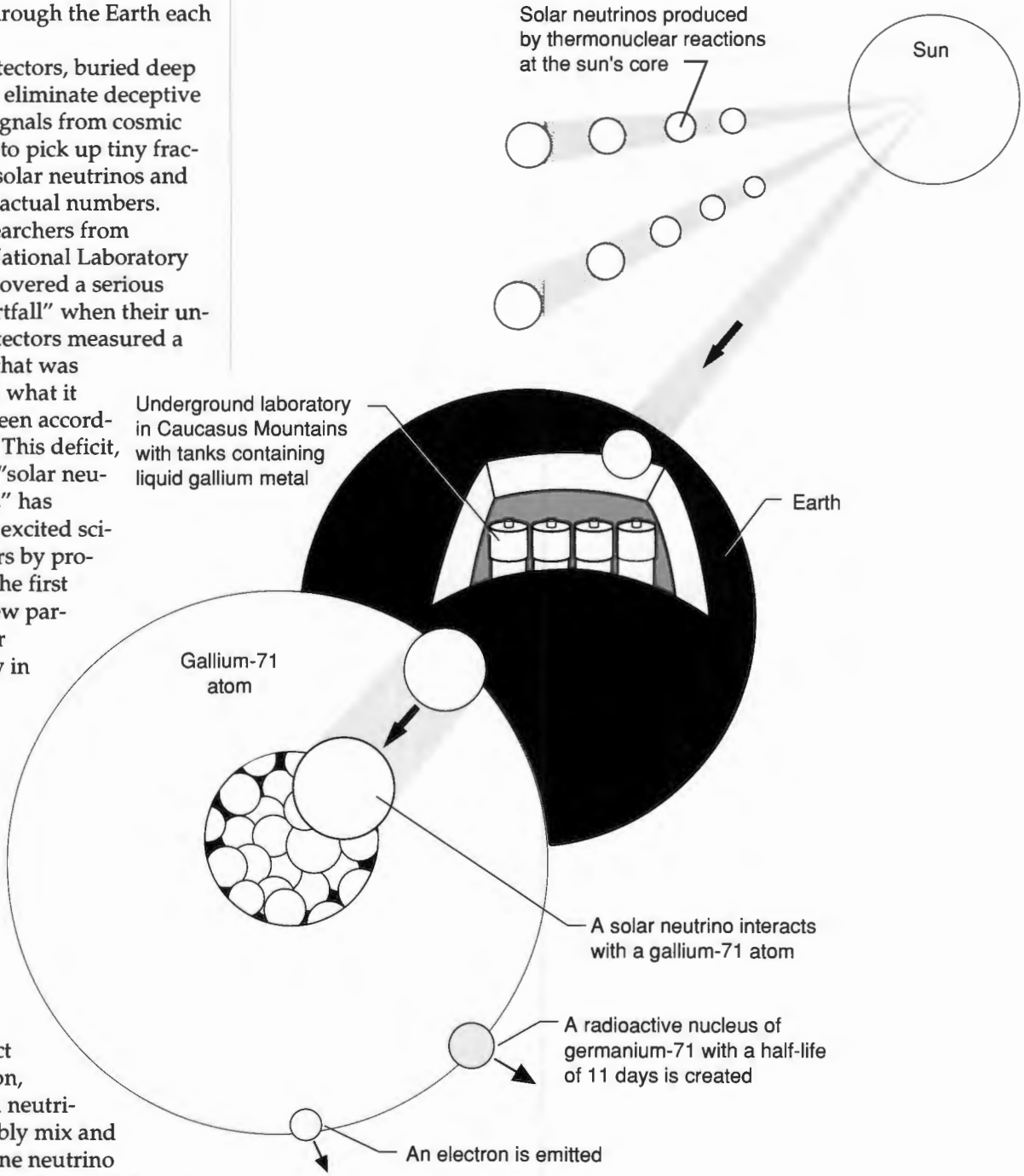
Our experiments were consistent with an electron-antineutrino mass of zero. We recorded the relative number of electrons emitted by the beta decay of the tritium gas at various energies up to the maximum allowed by energy conservation. The decays of interest were those rare cases in which the electron carried away almost all of the available energy. The shape of the beta-decay spectrum close to the maximum energy revealed whether some of the energy released in the decay process was "locked up" in the rest mass of the neutrino and thus unavailable to the electron. Although a very tiny mass might have escaped detection, it could not have been larger than 9.4 electron volts—an upper limit far smaller than the 22 electron volts needed to cause the universe to contract. Therefore, electron neutrinos and antineutrinos cannot, by themselves, "close" our universe and cause it to collapse in the distant future. Furthermore, if neutrinos constitute much of the gravitating dark matter in the universe, their pervasive presence must surely consist of the other two flavors—the muon and tau neutrinos.

Another approach to the neutrino-mass question involves the heavens. All stars, including the sun, produce energy by thermonuclear processes. More than 90 percent of the energy generated by the sun comes from the fusion of pairs of protons at the sun's core. Large numbers of low-energy neutrinos are created as byproducts of these processes. Unlike light, which loses its original identity on its ten-thousand-year trek to the surface of the sun and beyond, neutrinos can pass through the sun with little interference or loss of identity because they interact weakly with solar matter. Thus, by knowing how much energy the sun makes, physicists can calculate, with great certainty, how many neutrinos

should pass through the Earth each second.

Massive detectors, buried deep in the Earth to eliminate deceptive background signals from cosmic rays, are used to pick up tiny fractions of these solar neutrinos and measure their actual numbers. However, researchers from Brookhaven National Laboratory and Japan uncovered a serious neutrino "shortfall" when their underground detectors measured a neutrino flux that was only one-third what it should have been according to theory. This deficit, known as the "solar neutrino problem," has mystified and excited scientists for years by providing either the first evidence of new particle physics or perhaps a flaw in astrophysics theory.

Whereas the Standard Model predicts that the three flavors of neutrinos are completely distinct, grand unified field theories predict that the electron, muon, and tau neutrinos may possibly mix and change from one neutrino flavor to the other through a process known as neutrino oscillations. This mixing process could explain the apparent neutrino deficit seen in the Brookhaven and Japanese experiments because the solar-neutrino detectors used were sensitive only to electron neutrinos, not the other two flavors. Yet, neutrino oscillations are explicitly forbidden by the Standard Model. Moreover, to oscillate, neutrinos must possess an inherent property negated by the Standard Model—mass!



Tracking a solar neutrino.

In 1985, we teamed with an international group of physicists, led by Soviet scientists, to search for low-energy electron neutrinos using gallium atoms as our target. This Soviet-American Gallium Experiment (SAGE) was the first attempt to observe low-energy neutrinos produced in the sun's core. The Brookhaven and Japanese experiments recorded high-energy neutrinos whose predicted numbers are sensitive not only to neutrino properties but also to details of solar theory. We recognized the importance of studying low-energy neutrinos because their numbers are simply related to the

John Wilkerson (left) and Tom Bowles examine data from the detectors used for SAGE.

sun's total energy output; therefore, a deficit seen in their predicted numbers would indicate new particle physics involving the properties of neutrinos themselves.

Working with our Soviet colleagues, we began initial operations by purifying 30 tons of gallium, a liquid metal placed in tanks a mile underground in the Baksan Valley of the Soviet Caucasus mountains. As solar neutrinos interacted with the nuclei of the gallium-71 atoms, electrons were emitted and radioactive nuclei of germanium-71 with half-lives of 11 days were created. The team chemically extracted these radioactive nuclei as they accumulated each month and then counted the radioactive decay of the germanium atoms using a very sensitive detector. We expected to count about four neutrino events each month after eliminating all sources of radioactive contamination, but after five months not a single neutrino event was recorded! This astonishing result, if confirmed, may provide the first solid evidence of neutrino oscillations and a neutrino mass of about one-thousandth of an electron volt, thereby contradicting the Standard Model and pointing toward a unified theory of nature.

We are taking part in a new collaboration that will compare the flux of electron neutrinos with that of the other flavors to show whether neutrino oscillations actually do occur. The Canadian and U.S. governments funded a Solar Neutrino Observatory designed to measure all neutrino flavors using a heavy-water detector that will be located 7,000 feet underground in a nickel mine in Sudbury, Canada. This experiment, slated to begin operations in 1995, will push state-of-the-art technology in achieving optimum purification of both equipment and material (even a few grains of dust from the mine settling into the tank of heavy water can have a profound effect on the results). Thus, if SAGE indicates new particle physics, experiments at the Solar Neutrino Observatory will possibly go beyond measurements and offer a more definitive explanation. Meanwhile, a new gallium experiment, located in the Italian Gran Sasso underground laboratory, is attacking the solar neutrino problem in an effort to verify the SAGE result. With these and other resolute experiments under way, the 1990s may well become the "decade of the neutrino," revolutionizing theories of physics and revising long-held views of the structure of the universe.

A Field Spectrometer for Environmental Cleanup

One of the nation's major environmental concerns is cleaning up contaminated waste sites. The presence of volatile organic compounds in the soil is a threat because of the possibility that they can get into the ground water, move to agricultural products, and be ingested by livestock and humans. This year Los Alamos developed a transportable ion trap mass spectrometer for analysis of these volatile organic compounds in the field. With our mass spectrometer we can identify the boundaries of a waste site, characterize chemical contaminants, and monitor and document the progress of site restoration.

Current procedures for characterizing a waste site and monitoring the effectiveness of the cleanup require an extensive number of samples (soil, water, and core), careful quality control and chain-of-custody documentation of the samples while they are being transported to a certified laboratory, and comprehensive analysis in the laboratory. Collecting and analyzing a typical sample could cost a few thousand dollars and take five to six weeks. Obviously, we need technology that will reduce both the cost and the time required for these analyses if we are to restore contaminated areas within the next few decades.

To answer this need, we built and tested an instrument that can be used in the field and can generate analytical results with the reliability and reproducibility required by the Environmental Protection Agency (EPA). Our mass spectrometer is simple to build, maintain, and operate.

Mary Cisper tests a soil sample in the field on the transportable ion trap instrument.

Although the mass spectrometer we developed is only one-fourth the size of a conventional instrument, it is very sensitive and demonstrates detection limits that meet or exceed those required by the EPA for purgeable organic compounds in water. The spectrometer currently can detect up to sixty compounds, which makes it unique for field-transportable instruments. These sixty compounds are only a fraction of those that can be classed as volatile organics, but the technique could be demonstrated for an even larger collection of organics.

The transportable mass spectrometer has a modular design with three parts: (1) a purge and trap device for extracting the hazardous chemicals from the environmental matrix, e.g., soil or water, (2) a gas chromatograph for separating individual constituents from the mixture of hazardous chemicals, and (3) an ion trap mass spectrometer that detects, measures the quantity, and identifies the chemicals. A computer connected to the instrument automatically calibrates the spectrometer and documents the findings. Where possible, these components are modified commercial components.

Sample analysis is required in three phases of site restoration: site evaluation, restoration monitoring, and long-term postrestoration monitoring. We can compare the relative merits of field and laboratory methods for analysis during these phases.

With this instrument, a sample can be analyzed in twenty minutes, and because the analysis is done at the site, the cost is dramatically less than with conventional methods that require transporting the sample to a laboratory for analysis. Also very little documentation of chain of custody and of analytical results is required

	Field Screening	Laboratory Screening
Site Preparation	No advantage/disadvantage	No advantage/disadvantage
Instrumentation Costs	Potential advantage once instruments commercialized	Can be cheaper, commercially available now
Sample Transportation Cost	Advantage No removal	Disadvantage Removal and documentation
Sample Analysis Costs	Advantage Specific analyses most likely directed toward a single group (type) of contaminants.	Disadvantage Can address more types of contaminants but subject to general overhead costs (building maintenance, etc.).
Sample Disposal (postanalysis)	Advantage No removal, no disposal	Disadvantage
Personnel Safety	Advantage Samples not removed. No transit, no disposal. Can be used to monitor for unexpected hazardous chemicals during restoration.	Disadvantage
Personnel Training	No advantage/disadvantage	No advantage/disadvantage
Equipment Installation	Disadvantage Transportation of equipment to and set up at site	No advantage/disadvantage Included as overhead analysis costs
Instrumentation Decontamination	No advantage/disadvantage	No advantage/disadvantage

Qualitative comparison of field and laboratory methods for screening hazardous waste sites.

(documentation represents a substantial percentage of the cost). Use of this instrument can reduce the number of samples that are sent to an EPA-certified laboratory by screening out those samples that contain insignificant amounts of chemical contamination. Also the immediate feedback identifying the chemicals present at the site will reduce potential hazard to workers.

Even though the Department of Energy uses only a few volatile organic solvents, the characterization of volatile organic chemicals at waste sites is a significant environmental problem within the Department of Energy complex. Such chemicals are common industrial solvents used for cleaning machinery. The detection and analysis of these chemicals were the focus of our work. Another example for the use of the instrument is the analysis of fuel spills, such as those involving aviation fuels. If the location of the spill is known, the transportable mass spectrometer could be used to trace the distribution of the spill to see if it endangers a water supply.

As useful as this mass spectrometer seems, it is not the total solution for site characterization. Some classes of organic compounds, such as PCBs (polychlorinated biphenyls), pesticides, and herbicides, will require new technology, but with appropriate modification, this instrument can analyze these classes of compounds. Los Alamos is also developing new technology for analyzing inorganic compounds, heavy metals, and radioactive elements.

Before any new technology can be used, however, it must be demonstrated and approved by the EPA; to date the EPA has approved very few field techniques. The Idaho National Engineering Laboratory has submitted a proposal to do a side-by-side comparison of field-screening techniques and laboratory methods under EPA protocols. We plan to submit our field spectrometer for this independent evaluation.

After the evaluation, Los Alamos plans to transfer the design and technology to industry and government agencies so they can clean up waste sites in a more timely and cost-effective manner.

Maximum Entropy: A Useful Tool for Data Analysis

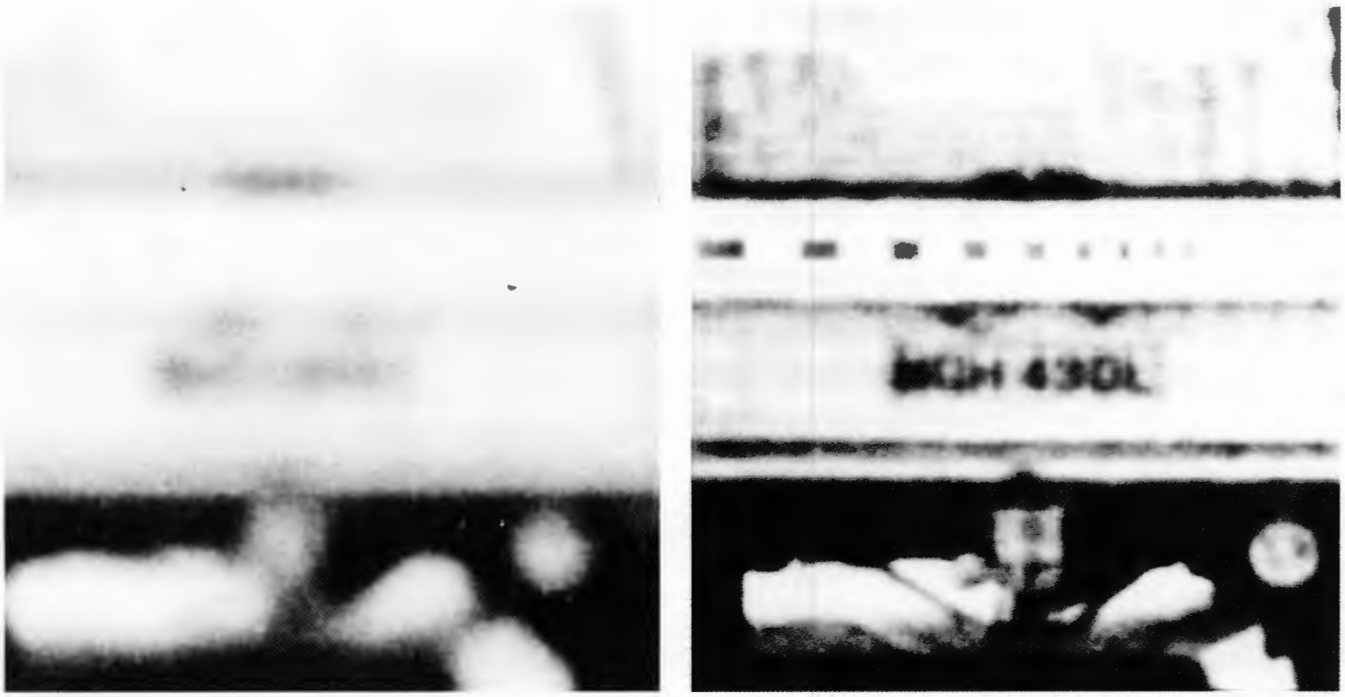
Suppose a telephone book listed names randomly, without regard to alphabetical order. Locating a friend's number would involve a large uncertainty, or lack of information, about where to look. Scientists interested in analyzing experimental data refer to such uncertainty as entropy. If names in the telephone book are alphabetized completely, the book has no entropy. If the names are alphabetized, but only by the first letter of each name, the book's entropy has increased. And if names are listed completely at random, the book has maximum entropy.

As a quantitative measure of uncertainty and information, entropy has become a powerful concept in data analysis. This year Los Alamos scientists used maximum-entropy methods to shed light on the behavior of atoms in condensed matter such as metals.

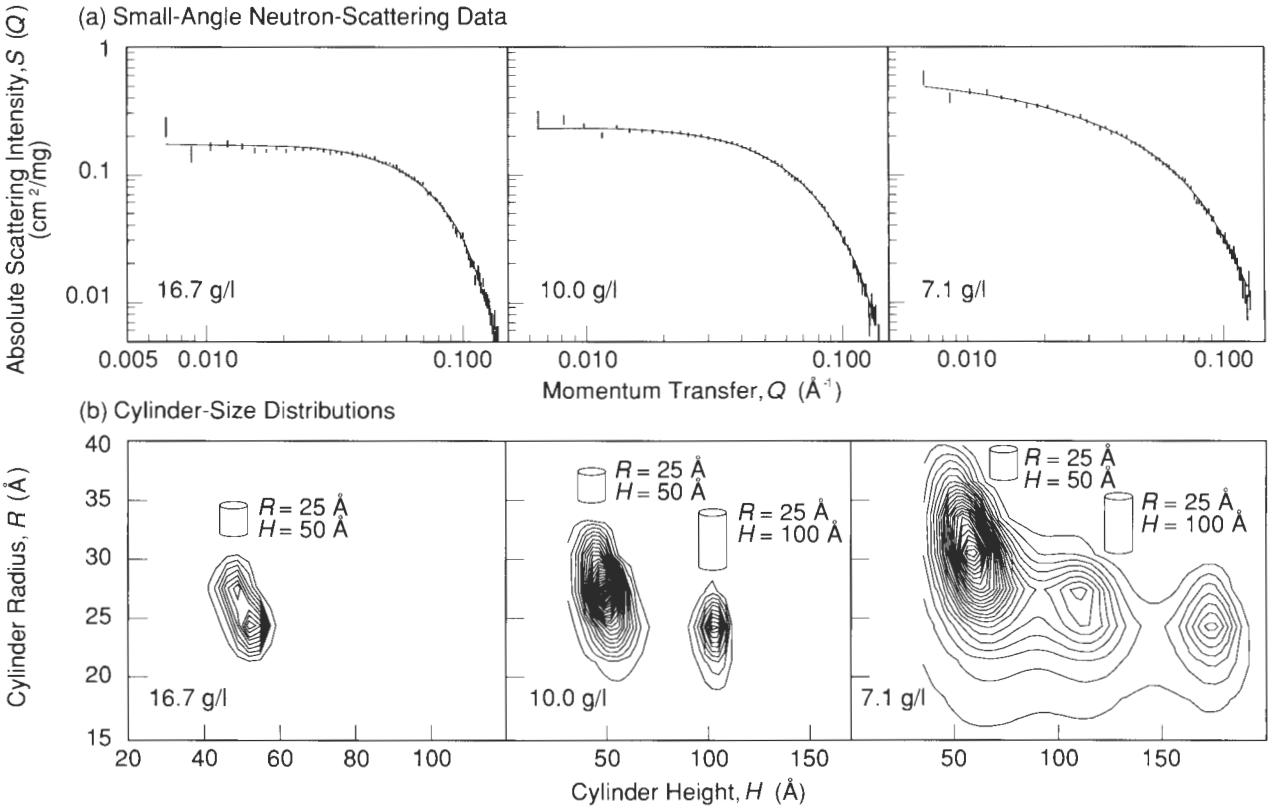
As an example of data analysis using the maximum-entropy method, consider a roulette player who wants to know the probability that the ball will land on a certain number. If she has never played the game, she might guess that any number is equally probable. However, her prior knowledge of the game permits her to restrict this estimate to only those numbers actually on the roulette wheel, and to assign zero probability to any number not on the wheel. By assigning equal probability to all numbers on the wheel, the player has made a maximum-entropy prediction subject to her prior knowledge. That is, she has used her prior knowledge to limit the range of uncertainties, and then has assigned equal probability to the remaining uncertainty.

The dealer now begins the game. If the ball lands on certain numbers much more frequently than others, the player may conclude that the dealer is cheating. That is, she will alter the probabilities she derived before the game began for where the ball will land. The player's best choices for new probabilities are ones that maximize entropy subject to the results, or data, obtained from the game.

The roulette player's problem reflects a general truth that applies to all data analysis: the best estimate for the range of probabilities associated with an experiment (the probability distribution) is the one that maximizes entropy while taking into account both the data obtained and any knowledge acquired beforehand. This maximum-entropy method has been successfully applied to data analysis problems in experiments ranging from radio astronomy and magnetic resonance imaging to DNA sequencing. Recently, we



The photographs above show an example of forensic deblurring. The prior knowledge used in data analysis is the improper focus of the camera and knowledge that the image is a positive (that is, not a negative). The image obtained by the maximum-entropy method is sufficiently clear to allow identification of the license plate number.



The top graph in the example shows small-angle neutron scattering measurements obtained from solutions of lecithins and bile salts that are important to liver function and digestion. The raw data reveal little information about the atomic structures scattering the neutrons. A maximum-entropy analysis of these data, using prior knowledge that the particles scattering the neutrons are cylindrical and further using the known distortion of the measuring device, provided the distribution of the particle sizes shown in the bottom graph—important information for analyzing the data.

used the method to extract information about condensed matter from data obtained by neutron scattering experiments and from Monte Carlo computer simulations of strongly interacting electrons in metals.

Neutron scattering is a powerful technique for investigating the structure of matter at an atomic level. At the Manuel Lujan, Jr. Neutron Scattering Center (LANSCE), neutrons scatter from material samples in a pattern known as the neutron scattering law. The instrumentation at LANSCE measures the neutron scattering laws for a wide variety of materials. However, the view of the scattering law provided by such data is distorted by measurement error, called the instrument response function, that is analogous to the blurring of a photograph. Applying maximum-entropy methods to such data can remove this distortion to reveal the atomic structure responsible for the scattering pattern.

The maximum-entropy method has the potential to dramatically enhance the power of LANSCE. In addition, the method is extremely cost-effective because it reduces the amount of time the equipment must operate to obtain useful measurements. Our past successes at LANSCE have led us to begin development of new instruments that are designed to make optimal use of the maximum-entropy method.

We have also applied the maximum-entropy method to problems in theoretical physics. Characterization of strongly interacting electrons in metals, such as those occurring in the phenomenon of superconductivity, or zero resistance at low temperatures, is an area of intense research and practical importance. Methods used in Monte Carlo computer simulations can provide information about the static properties of such systems, but reliable simulation methods for calculating dynamic properties such as resistance have eluded scientists for years. Recently we combined Monte Carlo and maximum-entropy methods to develop an accurate simulation method for dynamic properties.

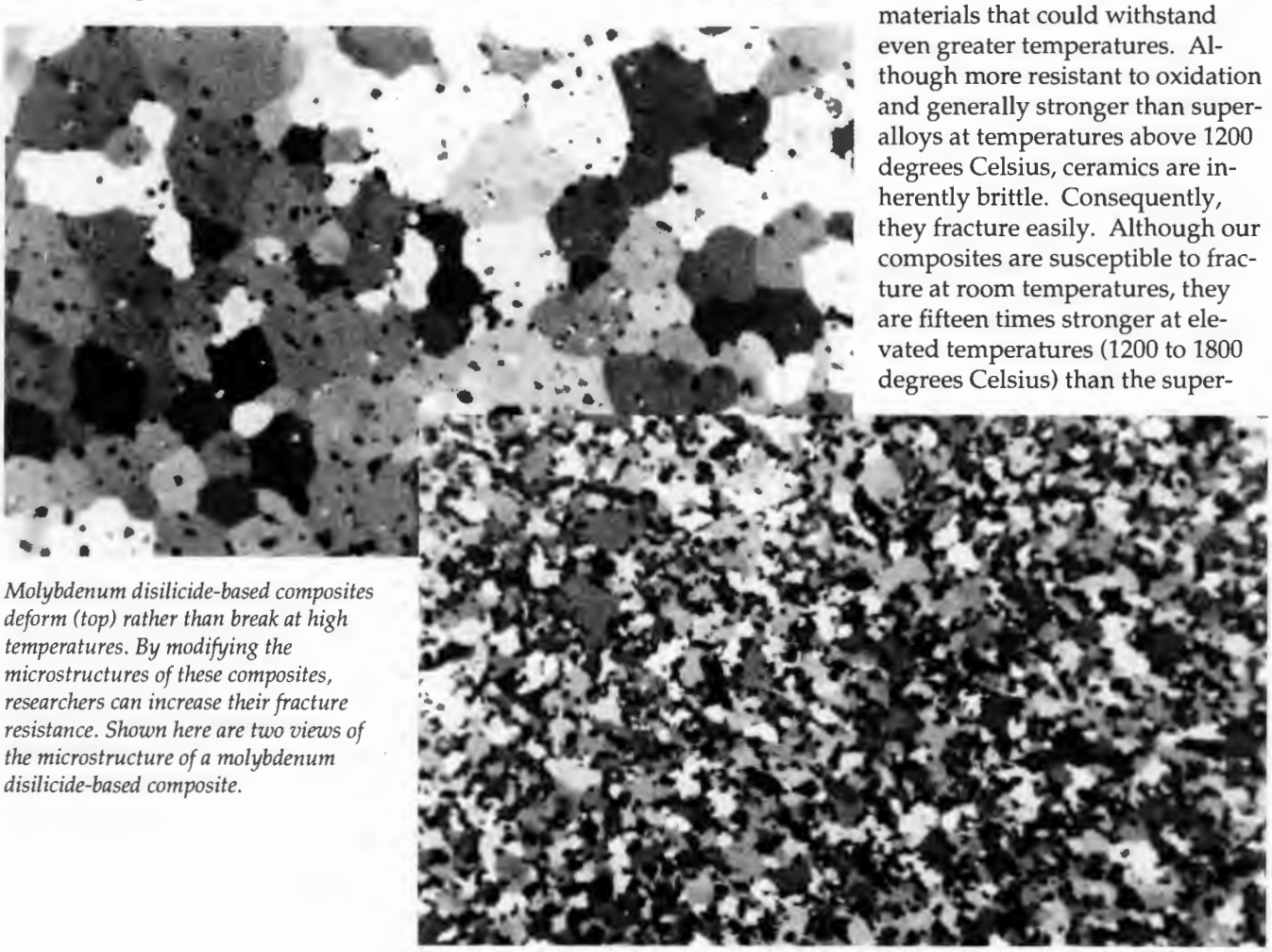
The maximum-entropy method, as a general approach that incorporates prior knowledge into the analysis of experimental data, can help researchers confronted with data that are noisy, incomplete, or subject to distortions inherent to the measurement process. Because almost all scientific research has these problems, maximum-entropy methods will be a valuable research tool to scientists at the Laboratory and around the world.

A Totally New Class of High-Temperature Materials

Imagine advanced, high-powered automobile engines with parts that perform reliably for fifteen, twenty, or even thirty years; parts made from materials that are stronger, more resistant to oxidation, and far more resistant to breaking at extreme temperatures than any structural material available on the commercial market today. Now imagine using these materials to produce equipment designed for generating power or controlling pollution, or to manufacture aircraft components. No doubt, the equipment would be more reliable and have a longer service life; the aircraft would be safer, more powerful, and much more efficient than those currently in use.

At Los Alamos, we envisioned such superior materials, and our research efforts resulted in the most significant breakthrough in high-temperature structural materials since structural ceramics were introduced in the early 1970s. By combining an intermetallic (two-metal) compound whose atoms are arranged in an ordered structure with a ceramic reinforcement, we developed molybdenum disilicide/silicon carbide composites, a new class of high-temperature materials, for which we received two patents this year.

Traditionally, high-temperature materials have been either metal-based materials, such as superalloys and aluminide intermetallic compounds, or structural ceramics. The first high-temperature structural materials were superalloys, nickel- and cobalt-based metals, developed in the 1950s for use in military aircraft engines. These heat-tolerant materials were an important development at the time because they allowed for the production of high-powered, fuel-efficient engines. Over the next two decades, a desire for hotter running, more powerful engines led to the development of structural ceramics—nonmetallic materials that could withstand even greater temperatures. Although more resistant to oxidation and generally stronger than superalloys at temperatures above 1200 degrees Celsius, ceramics are inherently brittle. Consequently, they fracture easily. Although our composites are susceptible to fracture at room temperatures, they are fifteen times stronger at elevated temperatures (1200 to 1800 degrees Celsius) than the super-



Molybdenum disilicide-based composites deform (top) rather than break at high temperatures. By modifying the microstructures of these composites, researchers can increase their fracture resistance. Shown here are two views of the microstructure of a molybdenum disilicide-based composite.

alloys currently used and forty times more fracture resistant than structural ceramics.

Why do our composites outperform other high-temperature structural materials at elevated temperatures? Primarily because molybdenum disilicide is the principal component. This remarkable intermetallic compound forms a protective silica layer on the surface of our composites, which makes them extremely resistant to high-temperature oxidation; molybdenum disilicide also remains ductile, or capable of changing shape without breaking, at very high temperatures. Ductility is especially important because the ability to move under stress prevents a metal from fracturing or breaking easily. To produce a high-temperature material that is strong enough for engineering applications, however, ductility must be accompanied by reinforcement. That is, the principal component must be strengthened by another high-temperature material that partially stops or "pins" the motion. We selected silicon carbide as our reinforcement because it remains strong at high temperatures, is resistant to oxidation, and most important, will not react with molybdenum disilicide. Such a reaction would weaken the composite.

Using a scanning electron microscope, John Petrovic (seated), David Carter, and Richard Honnell examine the microstructure of a molybdenum disilicide-based composite.

Although our composites are in their developmental infancy—currently at the same level of development that structural ceramics were in the early 1970s—the transfer of this technology can be a boon to private industry. Those industries that are involved with the generation of electric power, waste heat regeneration, pollution control, aircraft engine components, and automotive parts will especially benefit. For example, our materials are ideal for making heating elements intended for use in industrial furnaces under extreme temperatures, for manufacturing parts that will be used to build incinerators to dispose of society's waste products more efficiently, and for producing recycling systems that are designed to recover waste heat. These new composites are also excellent materials for the engine parts that will be used in advanced aircraft (improved components in these turbine engines will allow for an increase in engine temperatures, which ultimately will improve the engine's performance and fuel efficiency).

Intrigued by our composites, Pratt & Whitney, a major U.S. manufacturer of turbine engines, plans to conduct simulated engine-environment tests on an aircraft engine component made from materials based on molybdenum disilicide. However, the automotive industry may be the first to benefit from our new technology. Even at this early stage of development, composites based on molybdenum disilicide may outperform the structural ceramics (silicon nitride, silicon carbide) currently used to produce glow plugs, piston faces, valves, turbocharger rotors, and other automotive components.

As our research continues, we foresee notable improvements in both the high- and the low-temperature mechanical properties of molybdenum disilicide materials. Without significantly lowering the resistance of our composites to oxidation, we hope to make them more resistant to fracture at room temperature and even stronger at temperatures above 1200 degrees Celsius. The future indeed looks bright for this new class of high-temperature materials.

Medical Applications for Neutron Scattering

Sometimes the use of a single research technique offers too narrow a window on a problem. Trying a different technique can expand the view and produce new insights. That happened recently when a team of researchers from Los Alamos, Argonne National Laboratory, and the University of Illinois at Chicago applied neutron scattering to a question in structural biology that many believed had already been answered by other means—and obtained surprising results.

The subject of our collaborative research effort was bile, a complex substance that is not well understood even though it is essential to the digestive process and has been studied extensively for some thirty years. Research interest in the multipurpose bile system stems in part from a basic desire to understand the system better, but the work has more immediate applications in the medical arena, especially in developing therapies for various digestive disorders. It could, for example, throw light on the conditions that lead to the formation of certain kinds of gallstones and could lead to the development of improved drug therapies for dissolving the stones. Further, a special characteristic of the principal components of bile might be exploited in the formulation of novel drug-delivery systems that could be useful in fighting a variety of diseases.

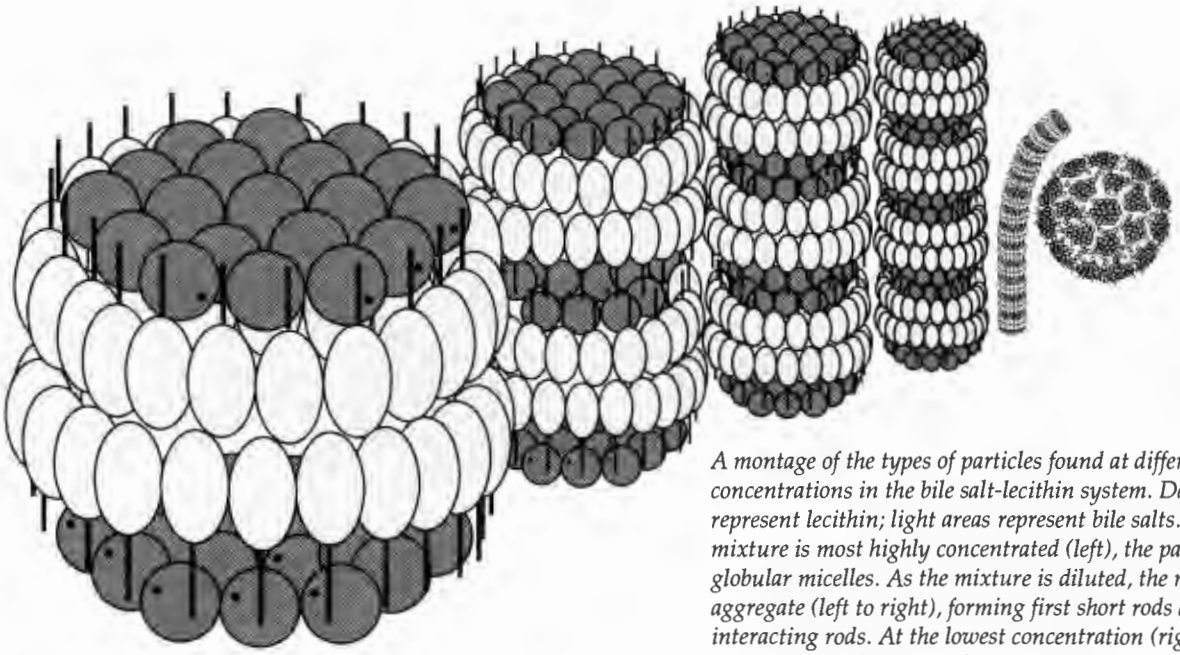
Bile, which is formed in the liver, transports fatty materials through the watery environment of the bile duct to the gallbladder, where it is concentrated and stored. Upon a hormonal signal from the stomach, the concentrated substance is released into the small intestine, where the bile becomes diluted. Once in the intestine, bile serves another major function by emulsifying ingested fats. The bile particles formed in the intestine are also required for the action of digestive enzymes and for the adsorption of the digestive products of fats through the walls of the small intestine.

Rex Hjelm prepares samples to be measured in the Low-Q Diffractometer at LANSCE.

Bile is made up primarily of bile salts, which are derivatives of cholesterol, and lecithin, the principal component of cell membranes. Mixtures of these two substances, called aqueous mixed colloids, are studied as models of bile. The mixed colloids form submicroscopic particles called mixed micelles, whose size is sensitive to the concentration of the colloid components. Dilution of the mixture causes significant changes in these particles, for the mixed micelles—which are solid—spontaneously transform into vesicles—which are hollow spheres—when the concentration of components is forced below a certain critical value.

This transformation may model what happens when bile enters the intestine. It is also a characteristic that could be employed in a drug-delivery system. A mixture of lecithin, bile salt, and a drug—sufficiently diluted to form vesicles—would be injected into the blood stream. As the vesicles formed, the drug would be bound within them, to be released when the vesicles fused with the cells of the target organ. Such a delivery system would protect parts of the body other than the target organ from the drug's toxicity and prevent the drug from becoming degraded before it reached its target.

But understanding the action of bile or designing a successful drug-delivery system requires accurate structural models that explain the physical and chemical principles determining the changes in particle structure. Until now,



A montage of the types of particles found at different total lipid concentrations in the bile salt-lecithin system. Dark areas represent lecithin; light areas represent bile salts. When the mixture is most highly concentrated (left), the particles are globular micelles. As the mixture is diluted, the micelles aggregate (left to right), forming first short rods and then long, interacting rods. At the lowest concentration (right), the particles are transformed into vesicles.

models of the bile system have been based on measurements of the bile particles made by indirect methods. For our series of experiments we tried neutron scattering, a direct-measurement technique that had not been employed in earlier studies of bile. The instruments we used were the Small-Angle Neutron Diffractometer at Argonne National Laboratory and the Low-Q Diffractometer at the Manuel Lujan, Jr. Neutron Scattering Center (LANSCE). LANSCE is one of several Los Alamos research centers available to scientists from throughout the world.

We used neutron scattering to analyze the particles formed when mixed colloids composed of various bile salts and lecithin from egg yolk were diluted. Because neutrons are uncharged, they can penetrate samples of materials, either passing through the sample, stopping inside it, or changing direction (scattering) and emerging at some angle to the original beam path. Measurements of the angle and time of flight of the scattered neutrons gave us information about the shapes of the particles in our samples.

Our work confirmed some of the conclusions of previous researchers. However, earlier work had indicated that the mixed micelles were disk-like in shape and that growth occurred as an increase in the radius of the disk. To our surprise, our measurements showed that mixed micelles are actually rod-like and that growth occurs as an increase in the length of the rods. The implication of our discovery is that the earlier models of the bile system are incorrect. Thus, all previous work based on those models—in pharmacology, medicine, biology, and physical chemistry—must be reinterpreted.

What we have now is a broad outline. We will continue using neutron scattering, in combination with other techniques, to fill in the details and reconstruct the models of the remarkable bile system. Among the long-range objectives is use of the improved models for solving pharmaceutical problems. A drug manufacturer may know, for example, that a given medication effectively dissolves gallstones without knowing why it does so. Relating macroscopic observations to the information we are gathering on the molecular level will help researchers to understand how the drug works and to improve its effectiveness. Also, the importance of the mixed colloids to intestinal absorption could be used as a means of ensuring that drugs administered orally are properly absorbed in the body.

The research might be extended to insoluble drugs: perhaps an insoluble cancer drug that is currently difficult for patients to tolerate could be reformulated for more satisfactory oral or intravenous use. And some of the lessons we have learned may open new windows on the structures of biological membranes, on discovering the rules of various membrane components, and on many other related biological and technical issues that cannot be readily addressed with the methods currently available.

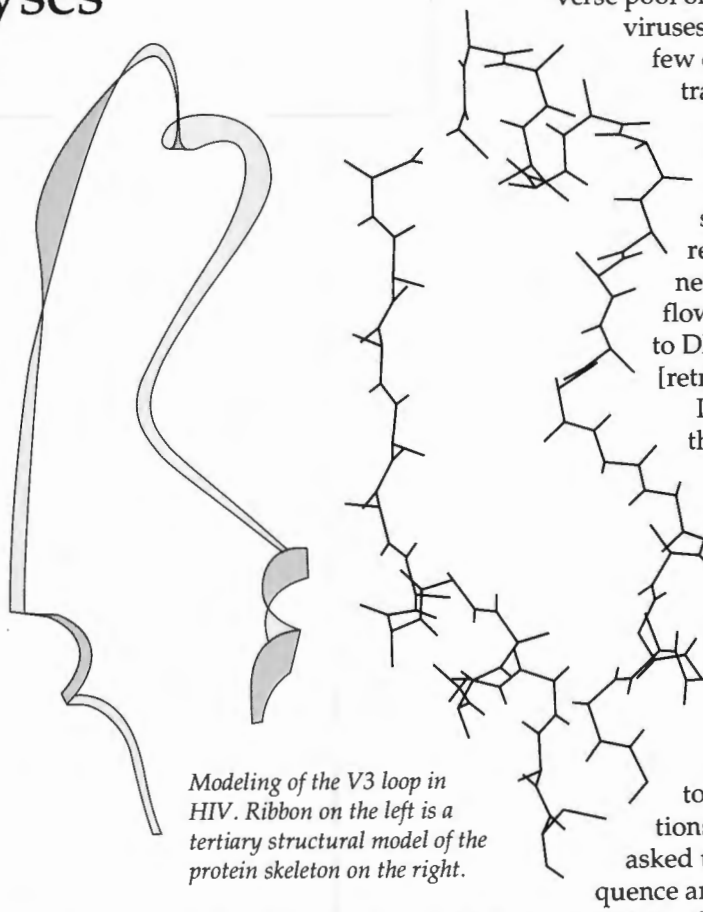
Molecular Analyses of AIDS Viruses

The acquired immune deficiency syndrome, or AIDS, poses a growing threat to human life. A disease caused by a virus that attacks the body's immune system, AIDS is always fatal. One of the first steps toward treating and eventually controlling AIDS is to understand the genetic makeup of the human immunodeficiency virus (HIV) that is the causative agent of AIDS.

Los Alamos has been involved in AIDS research since 1986. The HIV Sequence Database and Analysis Project provides a "second-generation data base" to remove a formidable data compilation/analysis load from AIDS researchers and from the "first-generation" U.S. and European nucleic acid sequence data bases: GenBank and the European Molecular Biology Laboratory. Our data base, in which compilation and analysis are inseparable, comprises molecular information about the DNA, RNA, and protein makeup of HIV samples collected by researchers worldwide.

Sponsored by the National Institute of Allergy and Infectious Diseases, our project originally served 350 researchers; it now serves 1,200 researchers and institutions in more than fifty countries, with information on-line at the National Library of Medicine. We have now studied more than a hundred distinct samples (isolates) representing more than a thousand sequences of nucleic acids and amino acids.

An additional facet of the work is to support a program of molecular epidemiology in which an international committee oversees a unique worldwide sampling and sequencing effort having as its primary purpose the tracking of HIV and SIV (simian immunodeficiency virus) variants. Contractors at Stanford University and the Centers for Disease Control (CDC) provide sequence information to the project for analysis and worldwide publication in cooperation with the Medical Research Council in Great Britain, the World Health Organization in Geneva, and the Pasteur Institute in France. As time and resources permit, we conduct sequence analyses for researchers at large.



Modeling of the V3 loop in HIV. Ribbon on the left is a tertiary structural model of the protein skeleton on the right.

Genetic sequence analysis of HIV and its relatives is playing an incisive role in determining how AIDS evolved and what we can expect. We have shown that HIV-1, the type responsible for the vast majority of AIDS cases worldwide, probably emerged from its ancestor as recently as fifty to one hundred years ago. We are just beginning to understand the origins of the AIDS virus family; there is growing evidence that these viruses originated from a large, diverse pool of simian retroviruses, perhaps a few of which were transmitted to humans through animal bites and scratches. (In a retrovirus, genetic information flows from RNA to DNA, a reversed [retro] direction.)

In July 1990, the CDC reported an unusual case of possible transmission of HIV from a dentist to a patient during tooth extractions. The CDC asked us to do sequence analyses of viruses isolated from the two infected individuals. Our analyses, together with conventional epidemiologic studies, strongly supported the interpretation of viral transmission from the dentist to the patient. In particular, the dentist's and patient's viruses shared a rare form of a crucial stretch of DNA encoding an important viral protein structure called V3. As a result of our analysis, the CDC is now formulating new guidelines and recommendations about AIDS and health care.

In its encapsulated form, HIV consists of a single strand of RNA. When HIV enters an immune system cell, it uses an enzyme called reverse transcriptase to make a complementary strand of DNA. The DNA strand then replicates to form a DNA double helix, one strand of which matches that of the original viral RNA. This viral

DNA can insert itself into human chromosomal DNA, leading to lifelong infection. The viral process of reverse transcription is so error-prone that each HIV-infected individual typically carries many variants of the original infecting virus.

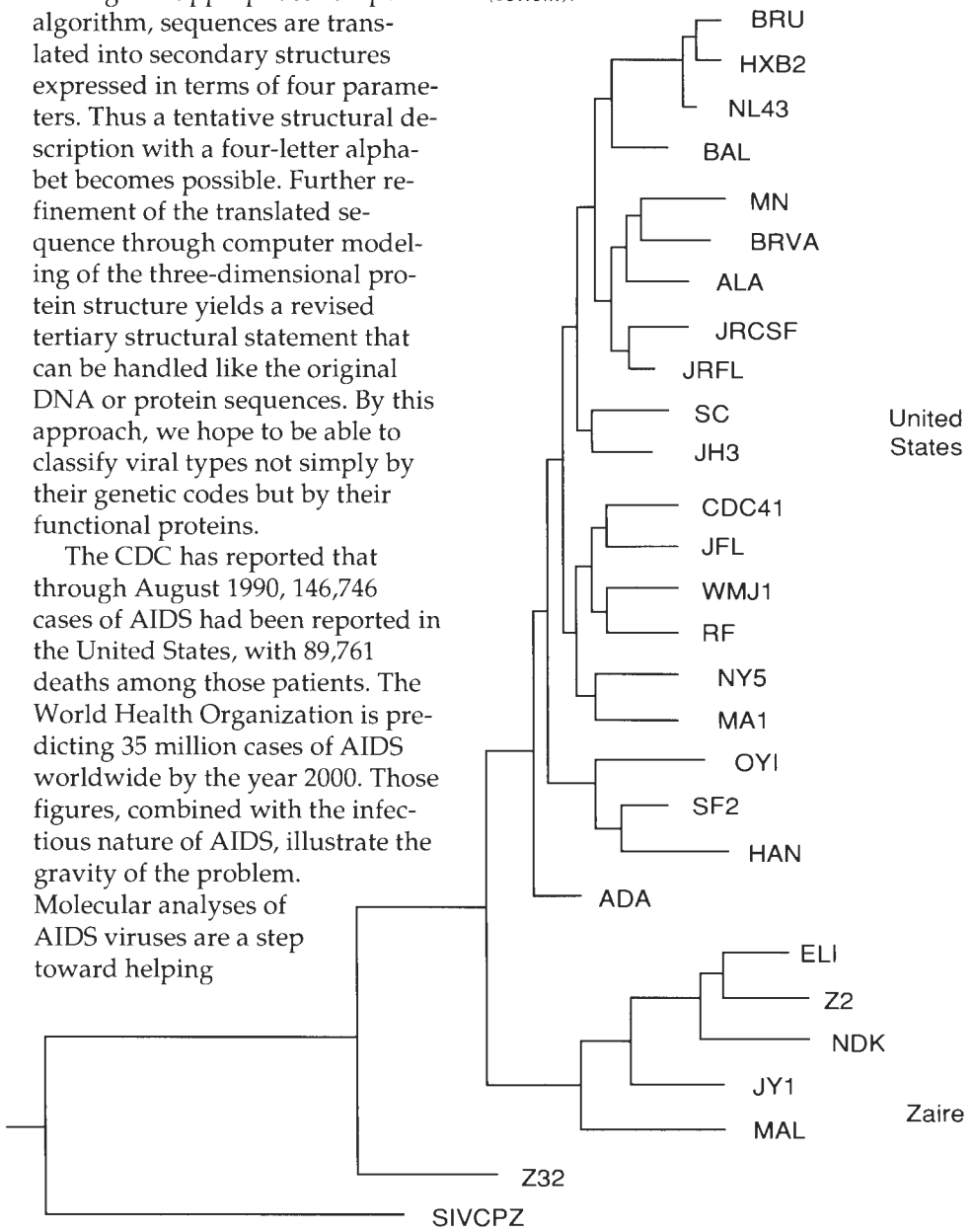
A major concern about HIVs is the rapid mutation rate, which is millions of times faster than that of human chromosomal DNA. For instance, samples of HIV-1 from North American patients can vary genetically by as much as 30 percent. The influenza virus is well known for its high rate of genetic change; however, variants of flu virus compete vigorously with one another, whereas HIV variants do not. Thus new vaccines can be developed to keep pace with the perennially changing but essentially steady-state evolution of the flu virus. The lack of strong selection pressure among HIVs, coupled with the high rate of mutation, raises a disturbing possibility: not only may a single antibody test fail to detect a certain AIDS virus, but also more than one vaccine may be needed.

Is HIV variation intractable? Will vaccines and antiviral drugs be forever out of reach? Accumulating diverse HIV nucleotide and amino acid sequences over the past five years has provided a valuable catalogue of invariant viral structures. Thus from a scientific point of view, the rapid mutation of the AIDS viruses has been instructive: we know much more about the genetic and protein structures of HIV than about those of the polio virus, for example, although polio has been under study for a much longer time. We might say that HIV has revealed itself all the more quickly as a consequence of its mutational properties.

Recently, we have been studying variable genetic sequences of HIV thought to encode protein structures of immunological and pathogenic significance, such as the V3 protein structure mentioned earlier. We are asking whether a heterogeneous set of genetic sequences (primary structures), despite the diversity, might nevertheless encode only a limited number of three-dimensional protein products (tertiary structures). Through an appropriate computer algorithm, sequences are translated into secondary structures expressed in terms of four parameters. Thus a tentative structural description with a four-letter alphabet becomes possible. Further refinement of the translated sequence through computer modeling of the three-dimensional protein structure yields a revised tertiary structural statement that can be handled like the original DNA or protein sequences. By this approach, we hope to be able to classify viral types not simply by their genetic codes but by their functional proteins.

The CDC has reported that through August 1990, 146,746 cases of AIDS had been reported in the United States, with 89,761 deaths among those patients. The World Health Organization is predicting 35 million cases of AIDS worldwide by the year 2000. Those figures, combined with the infectious nature of AIDS, illustrate the gravity of the problem. Molecular analyses of AIDS viruses are a step toward helping researchers understand AIDS and how it might be controlled in the future.

"Bushy" evolution of HIV (top) in contrast to the "slender" evolution of flu virus (bottom).



Listening to the Ear

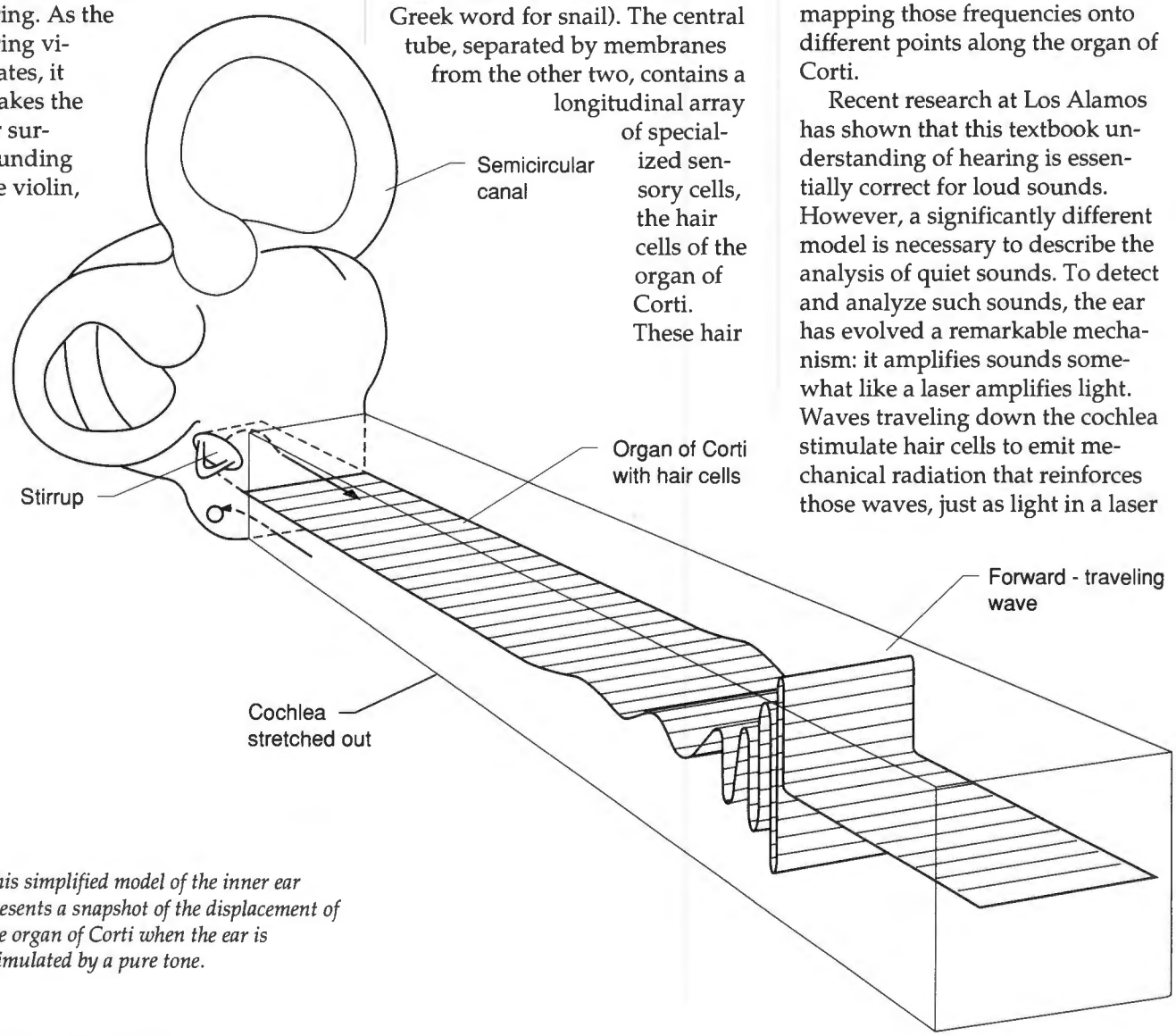
The mammalian ear has evolved a remarkable mechanism for detecting and analyzing sound. The ear, far from being an objective, passive recorder of sense impressions, is an energy-producing mechanical system that creates sound in response to sound. This year at Los Alamos our research was directed toward measuring sounds created by the ear, thereby testing predictions of our theory of the mechanics of hearing.

Pluck a violin string. As the string vibrates, it shakes the air surrounding the violin, creating sound waves that travel outward to the listening ear. Upon entering the ear canal, those waves vibrate the eardrum, whose oscillations are transmitted by the bones of the middle ear—the three smallest of the human body (the hammer, the anvil, and the stirrup)—to the inner ear.

There the oscillations create waves in the cochlea, which consists of three fluid-filled tubes coiled into a spiral like a snail's shell ("cochlea" comes from the Greek word for snail). The central tube, separated by membranes from the other two, contains a longitudinal array of specialized sensory cells, the hair cells of the organ of Corti. These hair cells respond to motion of the fluids and membranes in the cochlea by generating patterns of electrical impulses that are interpreted by the brain as sensations of tone.

Periodic motion of the stirrup sets the cochlear fluids into motion and generates a wave, which travels along the tubes until it reaches a point where its energy is transduced by hair cells into electrical potentials that stimulate the nervous system. The location of the point of transduction varies with the frequency of the stimulus—tones of low frequency excite hair cells further from the stirrup than do tones of higher frequency. The cochlea thus acts as an acoustic prism, separating sounds into their component frequencies and mapping those frequencies onto different points along the organ of Corti.

Recent research at Los Alamos has shown that this textbook understanding of hearing is essentially correct for loud sounds. However, a significantly different model is necessary to describe the analysis of quiet sounds. To detect and analyze such sounds, the ear has evolved a remarkable mechanism: it amplifies sounds somewhat like a laser amplifies light. Waves traveling down the cochlea stimulate hair cells to emit mechanical radiation that reinforces those waves, just as light in a laser



This simplified model of the inner ear presents a snapshot of the displacement of the organ of Corti when the ear is stimulated by a pure tone.

Christopher Shera (left), Jennifer McDowell, and George Zweig analyze sounds made by the ear.

stimulates molecules to create a stronger light beam. Unlike a laser, the mechanical waves eventually transfer their energy back to the hair cells in a small region where transduction and detection occur.

The presence of energy-producing hair cells implies that the ear creates sound while listening to sound. Incoming or forward-traveling waves are reflected by mechanical irregularities in the organ of Corti and produce small backward-traveling waves. These waves are amplified by the hair cells as they travel back to the stirrup. Upon reaching the stirrup, the backward-traveling waves vibrate the middle-ear bones, creating sound in the ear canal that can be recorded with tiny microphones. The model thus predicts the production of sound by the ear, so-called evoked otoacoustic emissions. The existence of such emissions has been confirmed by experiment.

Wave energy that is not transmitted to the ear canal by the stirrup is reflected back into the cochlea, setting up another forward-traveling wave that combines with the wave created by the original stimulus. That secondary traveling wave is itself amplified and is itself reflected by mechanical irregularities, producing yet another backward-traveling wave that is, in turn, partially reflected by the stirrup. The process of backward and then forward wave creation and amplification can build up a large standing wave or resonance within the cochlea.

Occasionally, that process runs away with itself and the ear begins to whistle spontaneously. Once initiated, those spontaneous emissions, corresponding to certain mild cases of tinnitus or "ringing in the ears," require no external sound for their maintenance. Spontaneous emissions can be recorded from the ears of most adults, whose ears, usually without the conscious awareness of their owners, are whistling while they work.

Our current research focuses on listening to the ear's emissions. We are measuring otoacoustic emissions to determine noninvasively whether there is any pattern to the spatial irregularities that generate the reflections. Once those spatial irregularities are characterized, a full test of our theory of the mechanics of hearing will be possible.

The extensive innervation of hair cells by neurons from the brain suggests that the brain may, according to its expectations, purposefully alter the mechanical state of the ear to facilitate the extraction of signal from noise. The ear, far from being an objective, passive recorder of sense impressions, may actively modify and control its own experience. We contemplate additional experiments to explore these ideas.

Studies to uncover the mechanisms of hearing and concomitant attempts to abstract from those mechanisms novel principles of signal processing may result in the improvement of hearing aids and the development of other devices (such as speech-recognition machines) that may help to alleviate the isolation from human society so often imposed on the hearing impaired.

Three-Dimensional Fluid Flow on the Connection Machine

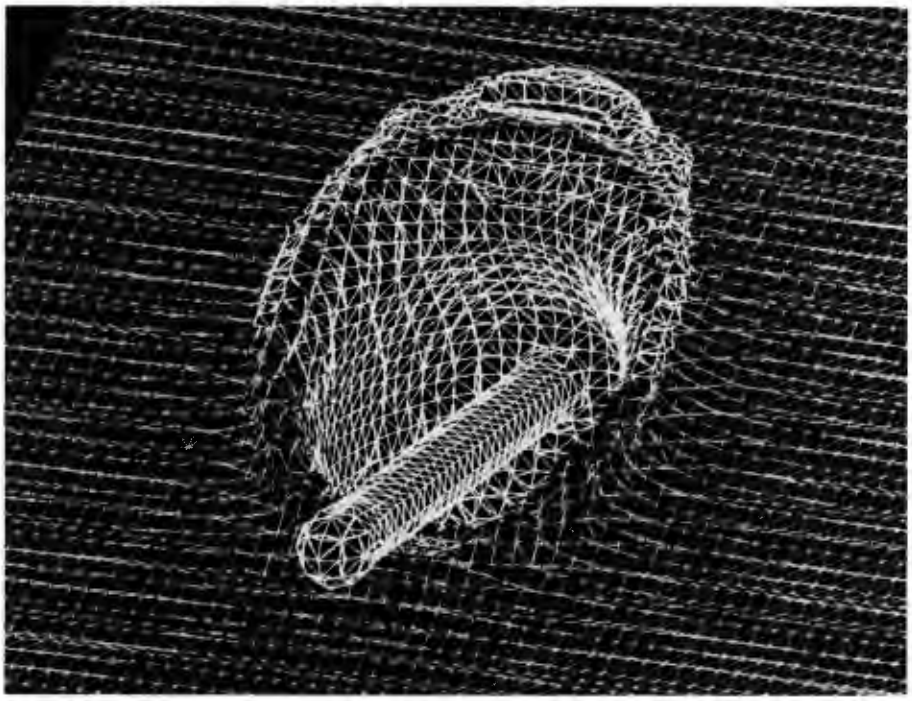
Who would know by looking that the sleek, black cube with red flashing lights is a supercomputer that might revolutionize scientific computing? Not only does it look different on the outside from any other computer in the computing center at Los Alamos, it differs dramatically on the inside in that it is massively parallel—that is, its network of 65,536 processors can operate on data all at once, solving complex equations that challenge even the Laboratory's largest supercomputers, at a fraction of the cost. Called the Connection Machine, or CM-2, it is one of the most powerful computers ever built, and there is little question that this type of machine is the supercomputer of the future for many applications.

Over the years Los Alamos has played the role of a demanding, sophisticated user, driving the requirements of successive generations of powerful computers. We have a history of influencing the development of supercomputers by working closely with vendors such as International Business Machines, Control Data Corporation, and Cray Research, Inc., to develop the next-generation computer. These interactions have benefitted the vendors and the Laboratory. At any given time during the last three decades, the computing center at Los Alamos has housed the biggest, most powerful supercomputer of that era. Los Alamos currently owns two CM-2 computers, manufactured by Thinking Machines Corporation, and, once again, we are helping to unveil the next era in large-scale computing.

The CM-2s at Los Alamos are among the largest in the world, and they are being used to solve larger problems than ever before. The performance of today's CM-2 is comparable to the performance of a CRAY Y-MP computer, but the next-generation Connection Machine may be one hundred to one thousand times faster. Such a machine could open up unprecedented possibilities for solving large, complex problems. For example, when modeling an airplane wing, we can take a slice, or cross section, of the wing and model the air flow over the wing in two dimensions. Computers with more processors and more memory allow us to model not just a slice across the wing but the entire wing itself. In fact, the whole airplane and air flow around the plane can be modeled. However, to understand the dynamics of air flow around the plane requires high resolution. This requirement means the grid (the horizontal and vertical lines that form cells of uniform size) must be fine enough that details of the physics are not lost. Naturally, a fine grid and the ability to model accurately in three dimensions require many, many data points. The massively parallel machine is well suited for such problems because identical calculations are normally performed for each of the cells, and these calculations are readily done in a simultaneous or parallel fashion.

We expect many areas of scientific computing in the future to be dominated by massively parallel machines. Some of the Laboratory's most challenging problems—nuclear weapons, energy, biophysics, global modeling—depend upon the application of leading-edge, high-performance computing. One area of research that has already benefited from

Scientists John Baumgardner and Rick Smith study fluid flow and solid mechanics—applications that are fully three dimensional and cannot be reduced or simplified to two dimensions. The CM-2 computer is an example of a modern architecture that promises to offer the ability to perform highly resolved three-dimensional simulations of complex physical phenomena.



A copper rod traveling at 1.2 kilometers per second penetrates a steel plate inclined at 60 degrees. This calculation was performed on the Connection Machine using the high-speed, multimaterial fluid dynamics code PAGOSA.

parallel processing is three-dimensional fluid flow. We have developed two three-dimensional codes: a multimaterial code for high-speed flow called PAGOSA and a code that models global ocean circulation.

PAGOSA is a powerful fluid dynamics code written specifically for a parallel computer that is being used for armor/anti-armor studies. Modeling plays a critical role in armor evaluation, as well as in the design of shaped charges, explosively formed projectiles, fragmenting charges, and multiple-warhead missiles and in the understanding of blast effects. Physics models describing such phenomena involve nonlinear processes, and realistic simulations commonly require very fine (0.1-millimeter cell dimension) grids for sufficient accuracy.

PAGOSA can model realistic armor/anti-armor problems. One example is a copper rod traveling at more than 1 kilometer per second that penetrates an inclined steel plate. Another example is an explosively driven projectile problem, in which a high explosive burns and collapses a thin, hemispherical copper shell into a high-velocity projectile.

Performance improves ten times when we run PAGOSA on the CM-2 as compared with a similar code running on a single processor of a CRAY Y-MP computer. Furthermore, we can solve more complex problems with finer resolution because of the larger memory available on the Connection Machine. With the current CM-2, we can run problems with many materials and up to four million cells in the grid.

The state-of-the-art ocean model currently running on the CM-2 is the first realistic general circulation model to be implemented on a massively parallel machine. Ocean modeling is important for studying global climate changes, such as the greenhouse effect, because oceans absorb and redistribute both heat and carbon dioxide. To resolve fully the complicated currents and circulation in the ocean requires grids with spacing substantially less than 50 kilometers. The largest calculations that have been run to date use grids with a 55-kilometer resolution. With the current CM-2, we can solve problems with a 28-kilometer resolution. In addition to taking advantage of the parallelism and large memory of the CM-2, we have developed new numerical algorithms for simulating the behavior of ocean currents. The net result of all these enhancements is to decrease the running time of large problems by a factor of 4 compared with a single-processor CRAY Y-MP.

Our ultimate aim in global climate studies is to develop an advanced climate model capable of describing the fully coupled ocean/atmospheric system. Such a model will be required for understanding the effects of greenhouse gases on global warming, and because of the tremendous computational requirements, it will be possible to develop such a model only on a massively parallel machine.

Although the performance of today's CM-2 is impressive, what is particularly exciting is the prospect of using future machines. In two or three years, we expect parallel machines one hundred times more powerful than today's machine and, within the decade, one thousand times more powerful. When these machines become available, we expect to exploit their enhanced capability using the codes that we are now developing for the CM-2. With our commitment to staying at the forefront in scientific computing research, we hope to apply such machines to problems scientists have not dreamed of solving until now.

Conferences

Since the Laboratory's inception in 1943, Los Alamos employees have recognized the importance of interacting with others who share their zeal for scientific discovery. J. Robert Oppenheimer, the first Director of the Laboratory, insisted on weekly colloquia to encourage free exchange of ideas among the staff. Continuing in that tradition, Los Alamos sponsors many colloquia, workshops, and conferences every year. Two conferences in 1990 brought together people from many disciplines and professions interested in supercomputer developments and in nonlinear science.

FRONTIERS OF SUPERCOMPUTING

Seven years ago, Los Alamos cosponsored the first Frontiers of Supercomputing Conference. In August 1990 Los Alamos cosponsored "Frontiers of Supercomputing II: A National Reassessment." Other sponsors of the meeting included the National Security Agency, the Defense Advanced Research Projects Agency, the Department of Energy, the National Aeronautics and Space Administration, the National Science Foundation, and the Supercomputing Research Center.

The challenges in 1983 were to develop computer hardware and software based on parallel processing, to build a massively parallel computer, and to write new schemes and algorithms to use with such machines. (Parallel processing computers are able to address many different parts of a calculation simultaneously.) Today, the earlier dream of computers with parallel processors is beginning to be realized. Some computers, such as the Connection Machine, have more than 65,000 parallel processors and are considered massively parallel. Thus, algorithms and associated technology to handle massively parallel computing are becoming a reality.

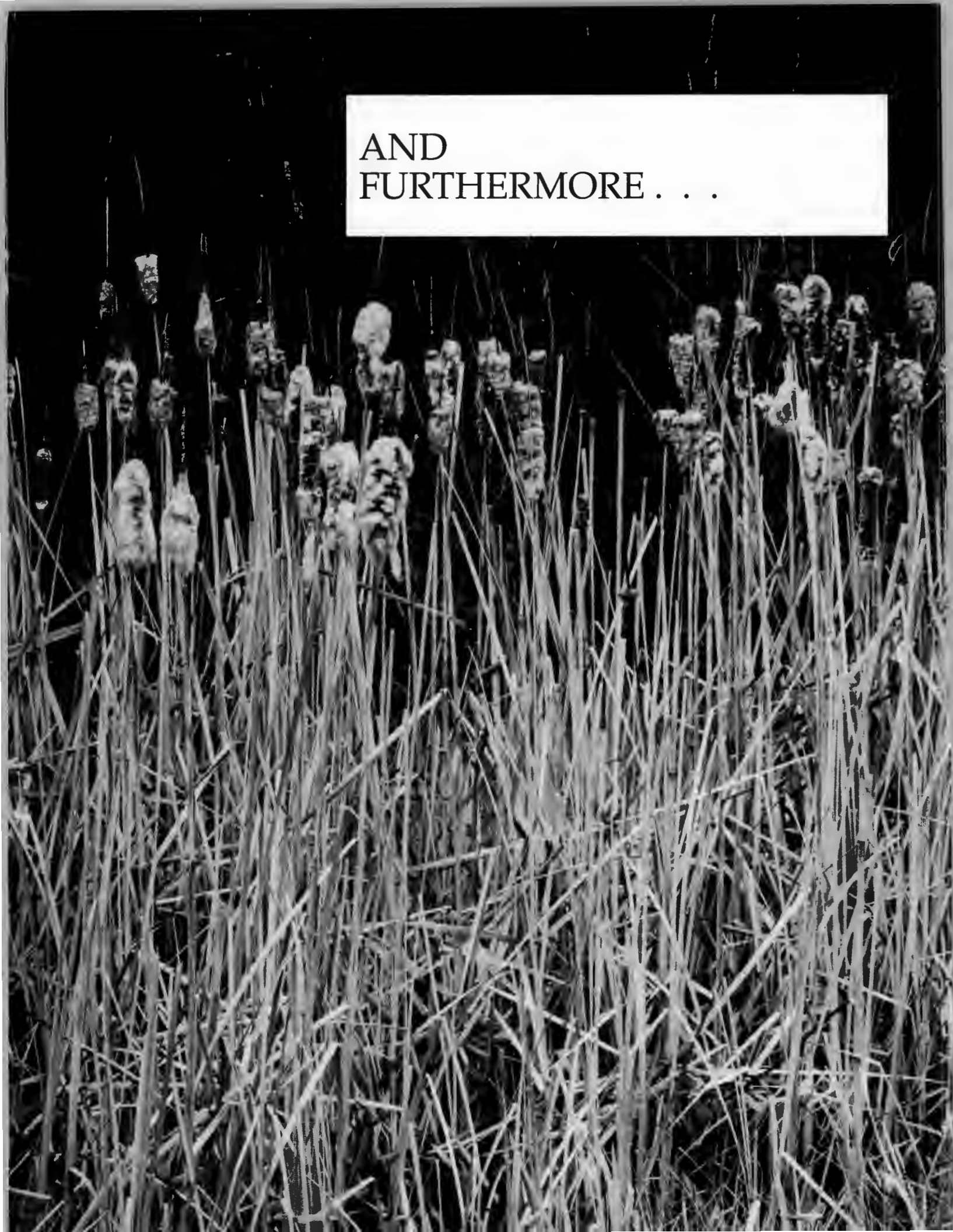
The infrequently held "frontier" conferences are unique. Although about computers, the gatherings are not technical conferences attended only by computer scientists. Speakers at the 1990 conference addressed broad issues such as policy, economics, and the future computing environment rather than detailed computing technology. The small group of invited participants included high-ranking managers and policy makers, chief executive officers and presidents of companies, important computer vendors and industrial users, U.S. senators, high-level federal officials, laboratory directors, and renowned academics.

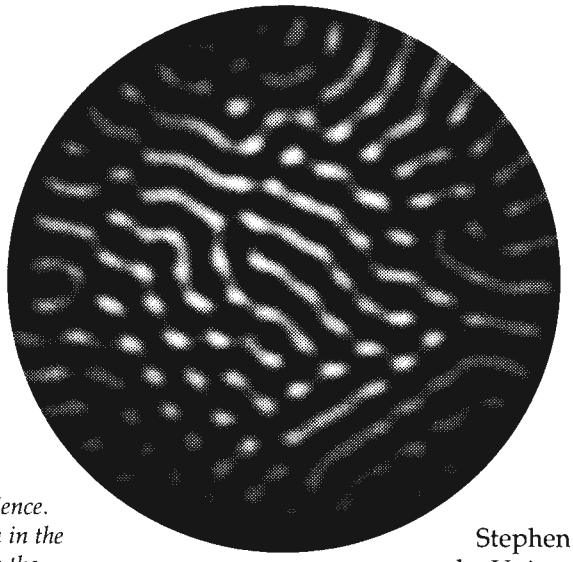
Conferees faced a new challenge: a dichotomy exists in the computing world. The supercomputers of today are huge, centrally located, expensive mainframes that "crunch numbers." These computers are very good at solving intensive calculations such as those associated with nuclear weapons design, global climate change, and materials science. Some computer scientists consider these mainframes to be dinosaurs, and they look to the powerful new microcomputers, scientific workstations, and minicomputers now available. Today's desktop computers can be as powerful as early versions of the Cray supercomputer and are much cheaper than mainframes are.

Participants at this second supercomputing conference were convinced that the mainframes and the powerful new microcomputers have complementary roles. The challenge is to develop an environment in which the ease and usefulness of desktop computers are tied to the enormous capacity and performance of mainframes.

Eric Bloch, Director of the National Science Foundation, gives the keynote address at the computing conference. The Laboratory's Director, Sig Hecker, and U.S. Senator Jeff Bingaman, seated to Bloch's right, participated in this opening session. Senator Pete Domenici (not pictured) presented closing remarks.

AND FURTHERMORE . . .





Complex patterns formed in thermal-convection experiments are good examples of nonlinear pattern formation, a major topic at the conference on nonlinear science. The effects of rotation, an important element of circulation in the atmosphere and oceans, are seen in the differences between the nonrotating case on the left and the rotating one on the right.

Developments must include new user interfaces, high-speed networking, graphics, and visualization. Future computer users may sit at their desktop computers and, without knowing it, their work may be parceled out to mainframes, or they may access data bases around the globe.

When the third "frontier" conference convenes in a few years, the vision of a seamless, comprehensive computing environment may be a reality. The challenge now is to focus the energies of government, industry, national laboratories, and universities to accomplish this task.

NONLINEAR SCIENCE

For the past decade, the Center for Nonlinear Studies at Los Alamos National Laboratory has hosted an annual international conference on some aspect of nonlinear phenomena. Typically attended by more than two hundred researchers, these meetings have proved to be watersheds in the rapid development of the interdisciplinary area of nonlinear science. Topics covered in early conferences included order in chaos, and evolution, games, and learning. The published proceedings of these conferences have been influential in determining new directions for research.

Under the forward-pointing title of "Nonlinear Science: The Next Decade," the tenth annual conference was convened at Los Alamos in May 1990. The Applied Mathematical Science Program at the Department of Energy sponsored the conference. The aim of the meeting was to survey the remarkable progress of the past decade in understanding nonlinear phenomena and to chart the course for research for the coming decade. Discussions focused on four general areas of nonlinear science: nonlinear dynamics; coherent structures; pattern formation, selection, and competition; and, finally, adaptation, evolution, and complexity. Two outstanding presentations were those of Stephen Smale, professor at the University of California, Berkeley, and recipient of the Fields Medal, on the most challenging open problems in nonlinear dynamics and of Professor Vladimir Zakharov, senior member of the Landau Institute in Moscow, on the seemingly contradictory concept of "integrable turbulence."

Beyond the formal presentations, the active individual discussions and interactions reflected the excitement surrounding the prospects for nonlinear science. All the participants agreed that the coming decade holds the promise for even greater insights into inherently nonlinear phenomena, some of which will be reflected in the eleventh annual conference on the topic of "Computational Issues in Nonlinear Science."

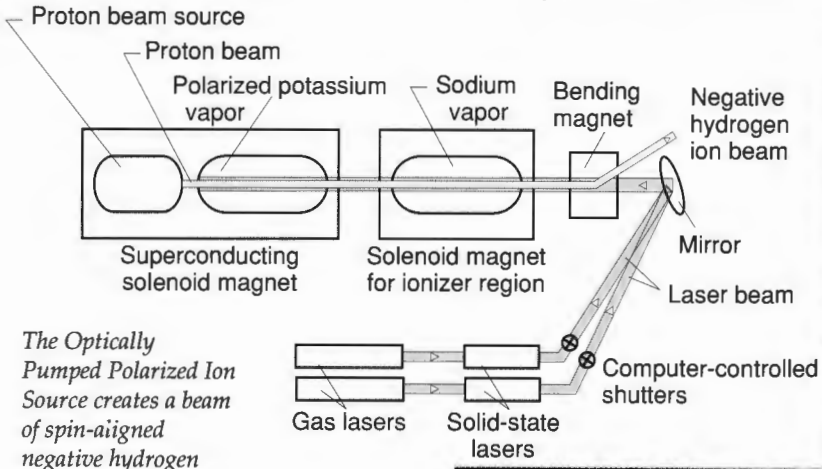
New Resources

This year two projects at the Los Alamos Clinton P. Anderson Meson Physics Facility (LAMPF) allowed scientists to probe the dynamic forces that affect the interactions between atomic particles. One, the Optically Pumped Polarized Ion Source, provides an intense source of spin-aligned (polarized) hydrogen ions to the LAMPF accelerator. The other, the Spallation Radiation Effects Facility, allows us to study the effects of doses of high-energy particles on materials.

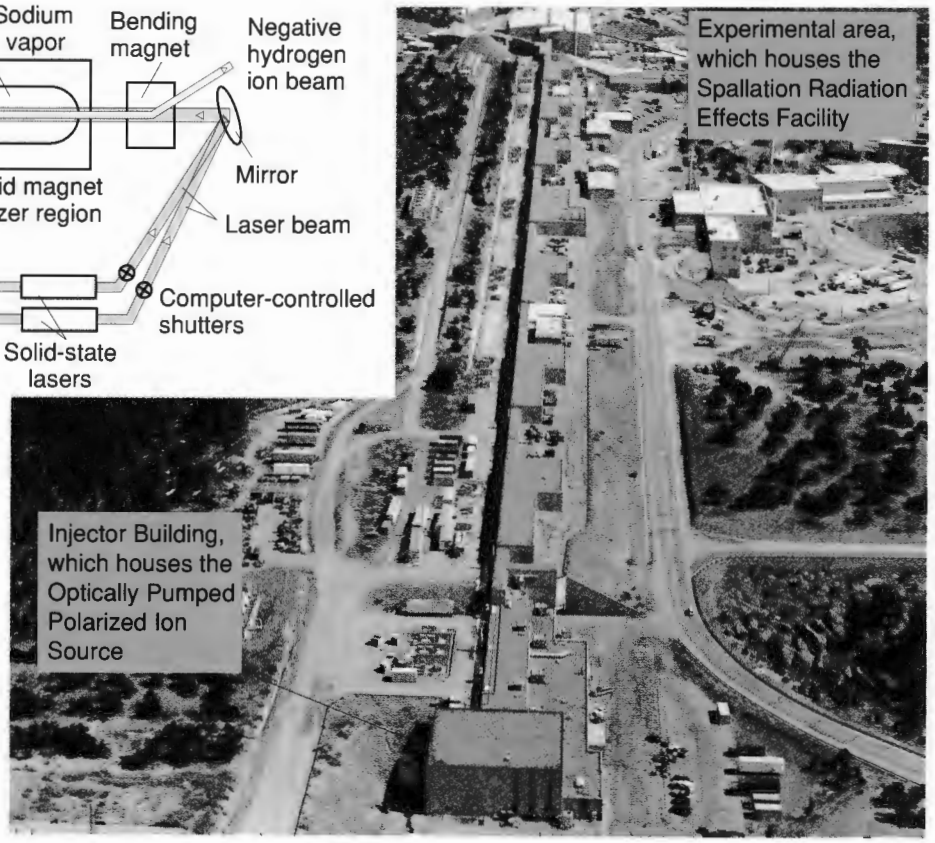
Accelerators increase the kinetic energy of electrically charged atomic or subatomic particles. These high-velocity particles can be aimed at other atoms, or targets, and the resulting collisions break atomic nuclei into smaller pieces. The forces that govern the interaction between atomic particles depend on the direction and magnitude of their spins. Ions whose spins can be aligned provide a superior research tool for physicists. Think of a spin-aligned ion as a spinning top, aligned in a particular direction.

By the mid-1980s, particle physicists had designed experiments that required a source of spin-aligned ions with intensities higher than those then available. A few years later, LAMPF researchers had completed the configuration of the Optically Pumped Polarized Ion Source (OPPIS) and had received Department of Energy support from Accelerator Improvement Project funds. Innovative features in the original design included a superconducting magnet in the polarizer region to provide high magnetic fields for more efficient spin alignment. More recently, the polarization transfer medium was changed from sodium to potassium to allow the use of new solid-state lasers. The OPPIS injector has given LAMPF a polarized hydrogen ion current ten to twenty times higher than previously available.

Since its first test run, OPPIS has outpaced projected goals. During the summer of 1990, the ion source more than doubled its design projections by producing a peak current of 25 microamperes with 55-percent spin alignment. The ion source can also be tuned to improve



The Optically Pumped Polarized Ion Source creates a beam of spin-aligned negative hydrogen ions. The beam starts as protons. Each proton picks up one polarized electron in the potassium vapor cell and another electron in the sodium vapor cell. In the 1990 configuration, the electrons picked up in the potassium vapor cell are spin-aligned by a polarized laser beam from a solid-state laser. The ion beam leaving the ion source is deflected away from the path of the incoming laser beam by a bending magnet. The spin-aligned negative hydrogen ions are then accelerated to high energies for research.



The Optically Pumped Polarized Ion Source and the Spallation Radiation Effects Facility are part of the mile-long LAMPF accelerator complex.

polarization to about 60 percent at a current of 15 microamperes.

This intense polarized ion beam gives LAMPF a polarized neutron beam research capability in many respects unparalleled in the world. This new injector technology represents a $2.5-million commitment of Department of Energy funds and is part of a $10-million upgrade for polarized beams, including new beam lines and spectrometers. Los Alamos researchers continue to improve polarization and beam current so that the two high-current beam channels in the nucleon area at LAMPF can be efficiently served.

The Spallation Radiation Effects Facility is located at the LAMPF beam-stop region, where particles that traverse a number of experiment stations are finally stopped by interactions in metal targets. This part of the accelerator provides an excellent opportunity to study the effects of radiation because the materials that stop the particle beam or experiments designed for the beam-stop environment are heavily irradiated.

This year the Spallation Radiation Effects Facility became recognized as the first and only neutron source in the world where bulk samples (up to 30 liters) can be irradiated and studied on location at varying flux levels. *In situ* radiation experiments allow researchers to actually see microstructural changes in materials while they are being exposed to radiation. Previously, samples were irradiated, removed to another site, and then tested. Because some materials can "heal" themselves during and after irradiation, some changes to their properties went undetected.

Particles from spallation reactions produce more energetic atomic motions than neutrons from fission reactions and cause atomic transmutations that also lead to changes in the physical and mechanical properties of materials. In the past, these energetic reactions could be deduced only by using data from fission reaction neutrons. Spallation reactions can now be studied directly and in their proper environment.

A material's tensile and rupture strength, ductility, and dimensional stability often are degraded after exposure to high doses of radiation. Its volume and dimensions may swell and change because of the atomic rearrangements induced by radiation. Its ability to carry or stop an electrical current may also change. Knowledge about radiation effects on the mechanical and physical properties of materials is essential in designing radiation-hardened electronic and structural components for devices like the Superconducting Super Collider.

Other accelerator technologies may also benefit from our radiation effects experiments: improved components for electric current monitors may be designed; new materials, such as high-nickel alloys, may improve the reliability of beam exit windows at vacuum-to-atmosphere interfaces; radiation-hardened transistors may be developed; and development of aluminum alloys may reduce exposure to workers from radiation when the alloys are used in the design of vacuum chambers used in accelerators.

Recent reviews by the Department of Energy's Office of Fusion Energy and a complementary group in Europe have determined a role for the Spallation Radiation Effects Facility in developing materials for advanced energy sources, such as fusion reactors.

These two world-class research instruments—the Optically Pumped Polarized Ion Source and the Spallation Radiation Effects Facility—allow particle physicists and materials scientists to watch in real time the changes in properties of materials bombarded by high doses of radiation.

Researchers at the Spallation Radiation Effects Facility prepare to install an experiment in the accelerator. The large metal block hanging from the crane provides a biological shield to contain radiation. The material to be irradiated rests at the bottom of the shield in a specially designed capsule. The shield and samples will be placed in the accelerator's beam-stop region.

Finances

Funds to operate Los Alamos National Laboratory come from the U.S. Department of Energy, from other federal agencies, and from other public and private organizations. These funds support a broad range of scientific and engineering research that reflects current national policies. As national priorities change, the Laboratory and research sponsors adjust the budgetary allocations for specific programs. Changes in funding for Laboratory programs in fiscal years 1989 to 1991 reflect our continuing response to these changing priorities.

The Department of Energy, directly and through its contractors, provided 68 percent of our operating funds in fiscal year 1990, financing a variety of Laboratory programs in defense, energy research, nuclear technology, and related areas. This year, the Department of Energy contractors we supported included Argonne National Laboratory, Hanford Engineering Development Laboratory, Idaho National Engineering Laboratory, Oak Ridge National Laboratory, and Rocky Flats Plant.

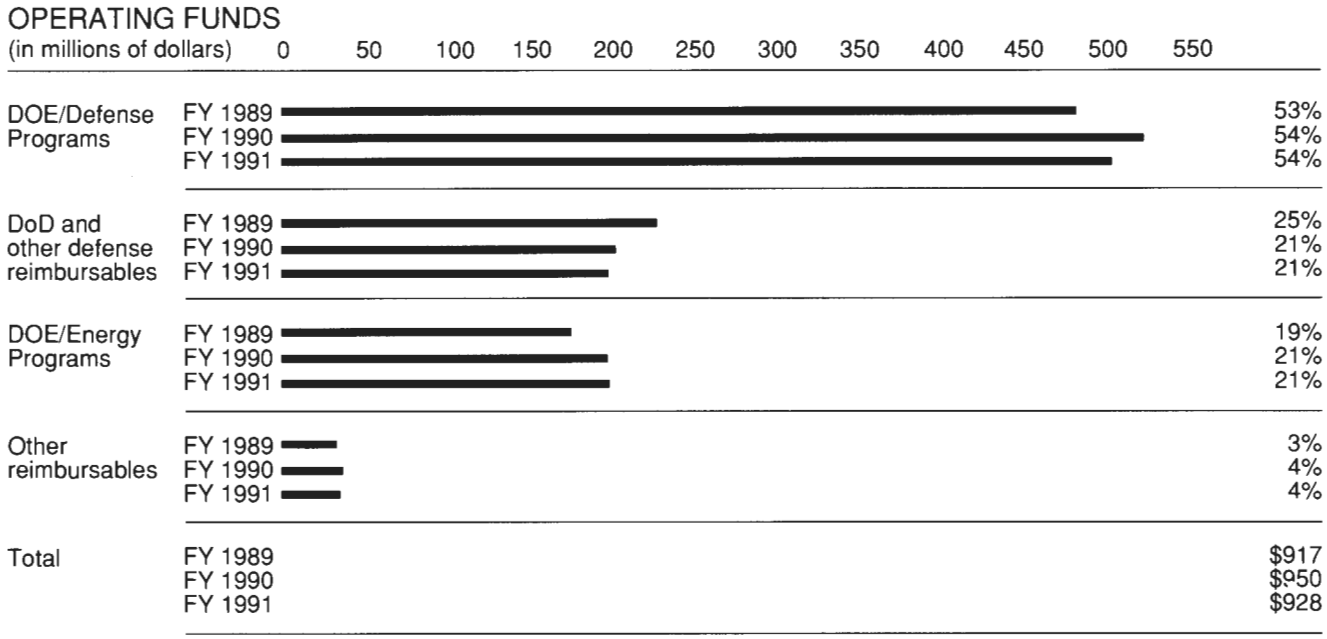
Other federal agencies, including the Department of Defense, the Nuclear Regulatory Commission, the National Institutes of Health, and the National Aeronautics and Space Administration, provided 23 percent of our operating funds in fiscal year 1990. They financed a number of specific research projects related to their areas of responsibility.

In addition to operating funds, the Department of Energy provided funds for capital equipment and construction. We used funds allocated for capital equipment to purchase instruments, computers, and other major research tools. Construction funds were earmarked for research laboratories and other major resources.

The operating budget for 1990 increased less than 4 percent over that for 1989. The percentages of major categories remained fairly constant. The portion of the Laboratory's budget represented by Department of Energy defense programs increased slightly. Department of Defense reimbursables declined from $227 million in 1989 to $202 million in 1990.

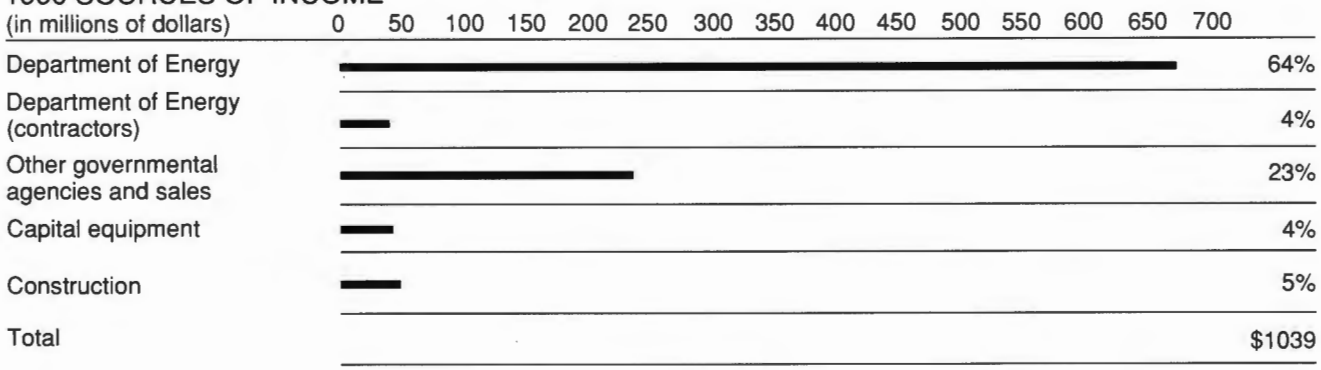
During the same period, Department of Energy support for energy programs increased from $175 million to $196 million, but the percentage of the Laboratory budget represented by these programs rose only slightly. The portion of the funding from other reimbursables also rose slightly.

As might be expected in a research institution such as Los Alamos, the Laboratory's major expense is salaries and fringe benefits. In fiscal year 1990 we paid nearly 45 percent of our total

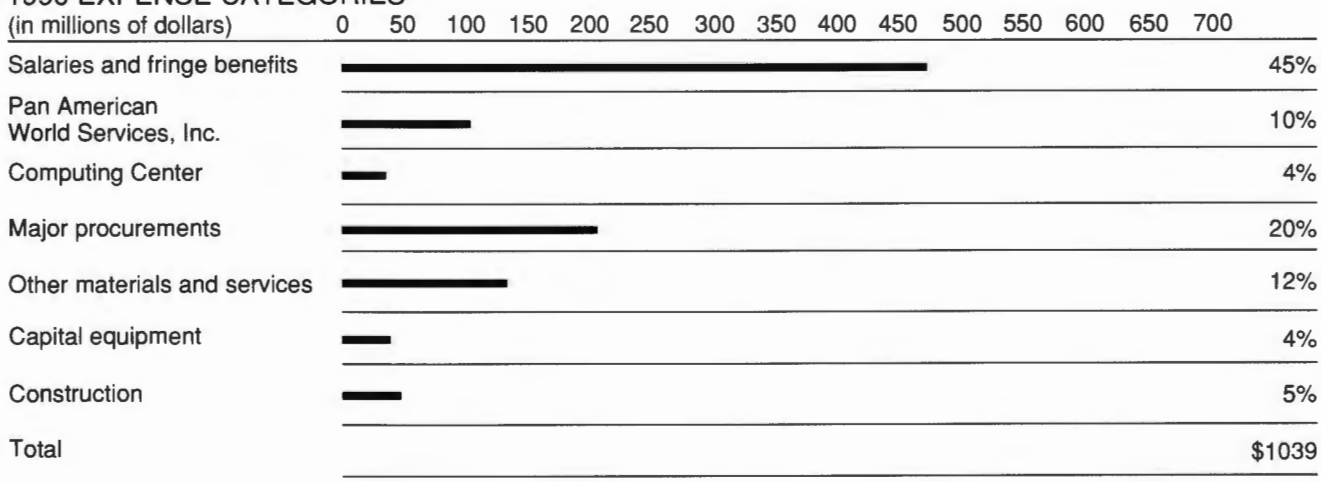


Dollars shown for FY 1989 and FY 1990 are actual costs. Those shown for FY 1991 are estimates prepared in November 1990 and are subject to national budgetary concerns. The percentages refer to percentage of total Laboratory budget.

1990 SOURCES OF INCOME



1990 EXPENSE CATEGORIES



Income and expenses for capital equipment and construction are not considered part of our operating funds.

expenditures—$467 million—for employee salaries and benefits. Excluding Laboratory salaries, Pan Am services, and major procurements of the Central Computing Facility, our computing center required $39 million, or almost 4 percent of expenses. We spent 12 percent of total expenditures on other materials and services. Pan Am, which provides support services including utilities to the Laboratory, accounted for $104 million in expenses, or 10 percent of the total. Capital outlays and construction costs totaled $89 million, less than 9 percent of expenses.

The Laboratory's broad range of research and its technological capabilities are committed to fulfilling national security needs; its financial resources support these commitments.

Laurels

This year, as in the past, Los Alamos employees and others closely associated with us received prestigious national honors and awards. Some became officers in prominent scientific and professional societies. The Laboratory itself recognized employees for outstanding achievement, for patents, and for distinguished job performance. We bestowed the title of Fellow or Senior Fellow upon a select few as a hallmark of their technical excellence. Unfortunately, we cannot list all employees who received honors and awards in 1990, but we congratulate each one and take pride in them all.

Robert N. Thorn

DISTINGUISHED ASSOCIATE AWARD

The Department of Energy awarded the late Robert N. Thorn its Distinguished Associate Award for his contributions to the nation during the past forty years in the areas of nuclear weapons design and engineering and for his work as a Laboratory manager. The award recognizes his contributions to world peace through "imagination, skill, and dedication."

ENRICO FERMI AWARD

George A. Cowan, Senior Fellow Emeritus, was awarded the Department of Energy's Enrico Fermi Award for his work in radiochemistry, nuclear weapons diagnostics, and assessment of nuclear weapons capabilities in other nations. Cowan is currently the president of the Santa Fe Institute.

RECOGNITION OF EXCELLENCE FOR NUCLEAR WEAPONS WORK

The Department of Energy awarded its Recognition of Excellence to sixty-seven Laboratory employees and associates for their significant contributions to weapons-related activities:

Development of New Capabilities for Device Performance Diagnostics: Stephen A. Becker, Charles D. Bowman, William P. Gula, Gerald M. Hale, Kenneth R. Koch, Paul E. Koehler, David C. Moody III, Rodney B. Schultz, Robert E. Seamon, Michael P. Sohn, and Fred J. Steinkruger.

Development of New Capabilities for Provision of Atomic Physics Data Required for Weapons Design: Joseph Abdallah and Robert E. H. Clark.

Development of a Booster Explosive, X-0407: Loren A. Carlson; B. Pruit Ginsberg; Michael Haertling; Raymond J. Juzaitis, WT-DOE; Wilbert H. Meyers; Robert M. Montoya; Lee E. Naranjo; Ronald L. Rabie; Wendell L. Seitz; Lawrence A. Stretz; Pamela Ulibarri; Manuel J. Urizar; Gerald D. Vasilik; Edward Velarde; Jerry D. Wackerle; and Donald L. Wilson.

Highly Filled Polymer Technology: Theodore M. Benziger, Earle Marie Hanson, Stephen B. Kemic, Barbara A. Stine, Gene W. Taylor, Jennings Cline, David Robinson, H. Michael Smith, and Edward Churnetski, all of Y-12 (Oak Ridge); and David Althaus and Robert Sanders, Bendix Kansas City.

Three-Dimensional Code Team: Sumner H. Dean, John D. Fowler, Jr., Daniel Fraser, Robert S. Hotchkiss, James W. Painter, Manjit S. Sahota, and Harold E. Trease.

Development and Demonstration of an Enhanced Predictive Capability for Nuclear Weapons Hydrodynamics: Judith Binstock, Neel W. Glass, and Fred N. Mortensen.

John L. Langford

Analysis of Weapon Engineering Designs: John L. Langford.

The Panchulla Non-LTE Experiment Team: Richard L. Blake, Jack C. Comly, Jr., Melissa Cray, Mary Y. Hockaday, Gordon L. Olson, Joe Vaninetti, and Mark D. Wilke.

Weapons Radiochemical Diagnostics: Roland A. Bibeau, E. Phil Chamberlin, Joseph Cortez, Gregory M. Kelley, and Frank O. Valdez.

Development of Methods to Predict and Analyze the Performance of Nuclear Devices at Low Yields: Donald R. McCoy, Stewart J. Mosso, William L. Mudd, and Donald L. Wade.

R&D 100 AWARDS

Research and Development Magazine recognizes the one hundred most important technical products developed each year. This year, Los Alamos scientists garnered seven of those awards.

Irving J. Bigio, Timothy R. Gosnell, and Pritish Mukherjee developed a new type of spectrometer that measures microwave absorption of molecules in liquid, a common state for biological materials. The spectrometer yields results up to one hundred times faster than conventional methods, is more reliable, and is much less expensive.

David H. Carter, John J. Petrovic, and Richard E. Honnell developed molybdenum disilicide/silicon carbide composites that hold up in very aggressive oxidizing environments. The composites are fifteen times stronger than superalloys currently used at elevated temperatures and forty times more fracture resistant at high temperatures than current structural ceramics. The new composites will be used to create longer-lasting components for machines that operate in high temperatures, such as those used in electric power generators and aircraft.

Frederic R. Fairfield

Frederic R. Fairfield developed the Fast Agarose Gel Electrophoresis (FAGE) Model 100, a method for separating 200- to 400,000-base-long DNA in one-tenth to one-twentieth the time required by existing methods. The method will assist in biological research associated with disease, the human genome mapping project, and forensic investigations.

Dinh Cong Nguyen, George Faulkner, and Nigel Cockroft developed the blue-green solid-state laser, which has military, space, medical, and industrial applications. An important initial use is to improve undersea communications for the U.S. Navy. The laser could also be used for retina welding, cancer treatments, angioplasty, and photochemical processing.

George C. Saunders developed a relatively simple process that will reveal fingerprints on a variety of surfaces from which they could not previously be obtained, such as paper, adhesive tape, and ceramics.

Dipen N. Sinha (left) and Stephen F. Agnew.

Dipen N. Sinha, Stephen F. Agnew, and William Christensen developed a solid-state nitrogen dioxide sensor, which provides a quick, inexpensive, simple, and reusable means of monitoring nitrogen dioxide. The sensor detects gas in a matter of seconds, can be battery operated, and is ideal for remote monitoring of toxic gases emitted from industrial operations.

Gregory W. Swift, Richard Martin, and Ray Radebaugh (National Institute of Standards and Technology, Boulder, Colorado) developed the Coolahoop, a cryogenic refrigerator that has no moving parts to limit its lifetime. The Coolahoop can be used to cool satellite-based infrared, x-ray, and other types of detectors, such as those used for climate monitoring and Earth-resource surveying.

SCHARDIN GOLD MEDAL

Physicist Gary Stradling won the 1990 Hubert Schardin Gold Medal for his contributions to the field of high-speed physics. The German Physical Society presents the award every two years as a means of fostering international cooperation among scientists working in high-speed physics and diagnostics. Stradling is the second American to win the award.

JAMES DOUGLAS GOLD MEDAL

The American Institute of Mining, Metallurgical and Petroleum Engineers awarded the James Douglas Gold Medal to Siegfried S. Hecker for his contributions to the knowledge of the mechanical behavior of nonferrous metals, including plutonium and aluminum alloys, and for his leadership in the materials field.

ROSSI PRIZE

The High Energy Astrophysics Division of the American Astronomical Society awarded the Rossi Prize to Stirling A. Colgate for his contributions toward understanding cosmic rays, neutrino energy, and the radioactive nature of supernova light curves.

AWARDS FROM THE SMALL BUSINESS ADMINISTRATION

The Small Business Administration recognized Los Alamos for its role in supporting small businesses and those owned by women and minorities. Also, Donald N. Bryson was honored as minority advocate of the year in the district and region

because of his role in fostering business relationships between minority vendors and the Laboratory.

Maurice W. Collins (left), Norman R. Morse, and Raymond L. Elliott

FEDERAL LABORATORY CONSORTIUM AWARD

The Federal Laboratory Consortium, an association of seven hundred federally funded laboratories, recognized Maurice W. Collins, Raymond L. Elliott, and Norman R. Morse for transferring the Common File System to private industry.

NUCLEAR MATERIALS SAFETY

Darryl Smith, program manager for safeguards and security research and development, became chairman of the Institute of Nuclear Materials Management. The institute is an international organization of scientists, engineers, and managers dedicated to ensuring that nuclear materials are properly protected and used.

PROFESSIONAL ASSOCIATION FELLOWS

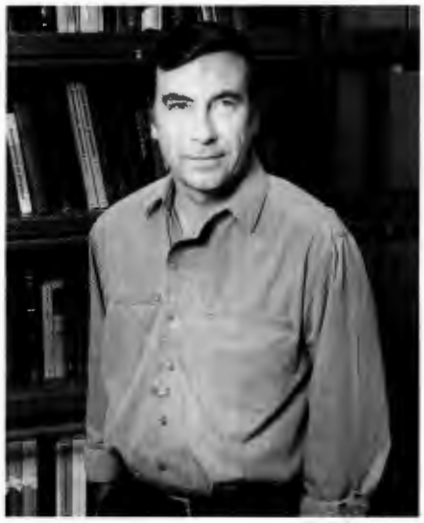
The American Society of Metals elected two Laboratory scientists as fellows: James R. Cost for his contributions to understanding the effects of radiation on several materials and for the development of methods of analyzing kinetics; and Paul S. Follansbee for contributions to understanding the behavior of copper and related materials.

Ronald E. Barks was named a fellow of the American Ceramic Society for contributions in ceramic science and technology and to the society.

The American Physical Society elected John C. Browne a fellow for his contributions in analog states, nuclear astrophysics, and nuclear fission.

David H. Sharp was elected fellow of the American Association for the Advancement of Science for contributions in neural networks, Rayleigh-Taylor fluid dynamic instability, and related areas.

Paul S. Follansbee



David H. Sharp

PHOTOMICROGRAPHY AWARD

JoAnn Herrera-Montoya, a materials science technician, won first prize in the black-and-white category of Polaroid Corporation's annual Photomicrography Competition. Her entry was a photomicrograph of a specimen she had prepared, a copper screen plated with copper.

LABORATORY FELLOWS

Five researchers received the title of Laboratory Fellow:

Darlene Hoffman for her contributions to nuclear physics, including the discovery of plutonium-244 and the development of separation processes for heavy elements.

O'Dean P. Judd for his contributions in shaping the country's strategic defense initiative programs.

Lester E. Thode for his contributions to the field of theoretical physics of charged particle beams, including the concept for the anomalous intense driver and for work on the Integrated Numerical Experiment.

William H. Woodruff for his contributions in the fields of inorganic photochemistry and biophysics, including the development of a pulsed laser technique for analyzing the structure of short-lived molecules in chemical reactions and development of probes for detecting and monitoring environmental contaminants.

Mitchell Feigenbaum for his contributions to the study of chaos, including his mathematical description of the way regular motion becomes chaotic.

SENIOR FELLOW EMERITUS

Louis Rosen was honored as a Senior Fellow Emeritus for his contributions to the Laboratory over forty years. He participated in the Manhattan Project during World War II and later contributed to the understanding of fission, fusion, light nuclei, and neutron/nucleus interactions and nuclear properties.

Judith Binstock

LABORATORY FELLOWS PRIZE

The Laboratory Fellows established a prize in 1988 to recognize significant accomplishments made by scientists at the Laboratory. This year's winners were Judith Binstock for contributions in weapons physics, J. Doyne Farmer for research in nonlinear science, Paul S. Follansbee for studies in the strength of metals, and Ralph Menikoff for contributions to a theoretical framework for understanding the behavior of gases and fluids.

DISTINGUISHED PERFORMANCE AWARDS

For the past ten years the Laboratory has honored individuals and groups for outstanding achievements or for exceptional ability and dedication to their jobs. This year a total of 157 employees received Distinguished Performance Awards.

Individuals receiving awards in 1990 were

A. P. Sattelberger for leading and building a world-class research program in actinide organometallic chemistry;

Phillip Chamberlin for contributing to the Laboratory's commitment to producing medical isotopes for hospitals, universities, industry, and other laboratories;

Richard D. Bolton for innovations on the central proportional chambers for the MEGA experiment at LAMPF;

Caroline F. V. "Cas" Mason for becoming the Laboratory's leading expert on Chinese science and technology as part of her reports on growth of laser crystals;

Caroline F. V. "Cas" Mason

Donald Weber Brown

Donald Weber Brown for showing that hot dry rock systems can be an environmentally acceptable means of power production;

Rick Gutierrez for contributions to the Bowie and Ledoux nuclear tests and for developing a container for improved and less expensive handling of high-explosive test assemblies;

William M. Boedeker for solving design problems and fabricating parts to keep LAMPF operating around the clock during proton beam production;

Carolann Rodriguez for fashioning the *Newsbulletin* into a prize-winning publication that serves as the chief means of employee communications;

Yolanda May Garcia

Yolanda May Garcia for managing an office that handles a large volume of classified work and for serving as a role model to her staff for excellent work habits and organizational skills;

Marcia A. Jones for playing a vital role in the successful outcome of two in-depth audits of documents related to the Yucca Mountain Project by the Department of Energy;

Louie R. Padilla for designing and leading a three-month training program on safe, secure transports.

Louie R. Padilla

Six small teams won awards:

Jane E. Nordholt and David J. McComas for developing the linear electric field device for determining the mass/charge composition of space plasmas with very high spectral resolution;

Joseph L. Parkinson, Michael J. Barr, and Leandro T. Gonzales for developing a new explosive, calcitol, for the fabrication of plane wave lenses of superior quality;

David L. Tubbs (left), Britton A. Girard, Robert G. Hockaday, and Anthony J. Scannapieco

David L. Tubbs, Anthony J. Scannapieco, Britton A. Girard, and Robert G. Hockaday for designing an add-on experiment for the Bowie nuclear test, which addressed the feasibility of developing new sources for weapons physics research for a specific class of nuclear devices;

Donald E. Tolmie, Michael McGowen, Arlo Gene Dornhoff, R. L. Hoebelheinrich, and Richard G. Thomsen for developing specifications for a new high-performance parallel interface that will be the standard for the communications interface that operates at 800 megabytes per second;

David Cooke and James Daniel Doss for their contributions to characterizing conductivity and for the transfer of superconducting technology to industry;

Joel M. Williams, Jr., and Alice M. Nyitray for developing unique low-density foams for several applications.

Four large teams won awards:

WAFFOG team for developing the wire and fluorescent fiber offset grid that accurately determines the direction of a high-energy neutral particle beam. Team leaders were J. Al Sullivan, J. David Schneider, William H. McCulla, and Paul W. Keaton. Team members were Graydon K. Anderson, Marvin J. Barney, Ralph H. Castain, Jim Deal, Mike Gamble, Ross E. Graves, Clifford J. Hewitt, Hiroshi W. Hoida, Charles S. Johnson, Paul Johnson, Mary E. Lujan, Debbie I. Montoya, Don Parker, David A. Romero, Robert K. Sander, John D. Seagrave, Michael A. Sedillo, Roger L. Smith, Timothy C. Thompson, Tom Tucker, and Edward J. Yavornik.

MESA hydrocode team for helping resolve serious deficiencies in U.S. armor/anti-armor capabilities through the development of the high-resolution, three-dimensional computation code called MESA. Team leader was David A. Mandell. Team members were Thomas F. Adams, John R. Baumgardner, S. Tom Bennion, John W. Bolstad, Rudolph Henninger, Kathleen S. Holian, Stewart J. Mosso, and Timothy L. Wilson.

ACORN team for developments that are being incorporated into several new nuclear weapons. Team leader was Charles B. Banks, Jr. Team members were Lee E. Anderson, James M. Baca, Alfred C. Batemen, Paul R. Borrego, Clint D. Bowyer, George H. Brooks, James J. Burns, George H. Carlson, Dean H. W. Carstens, J. R. Conn, Walter R. David, Burt K. Davis, Warren R. Doty, William L. Earl, Walton P. Ellis, Walter E. Ely, Jim B. Finley, Helen J. Fuller, Rosina V. Gray, Earle Marie Hanson, Bobbie J. Harlow, Charles F. Huff, Joyce T. Hunter, Richard C. Keyser, Richard E. Larson, Ivar E. Lindstrom, Jr., Merced M. Lopez, Patrick M. Lynch, Herman R. Maltrud, Antonio A. Martinez, Phil T. Martinez, Leo C. Michels, Johnna L. Montoya, James D. Moss, John M. Newmyer, Robert K. Okagawa, Richard H. Robertson, Yvonne C. Rogers, Robert K. Rohwer, Frank M. Smith, John B. Straw, Carol L. Talcott, Dale G. Tuggle, Dale R. Worlton, and Kyral F. Wylie.

GenBank team for designing and producing a data base of nucleotide sequences that is accessible, complete, accurate, and up-to-date. Team leader was Christian Burks. Team members were Edwin Atencio, Kathy G. Baca, George I. Bell, Michael J. Cinkosky, Deborah A. Cucchiara, Karen Cumella, Alden M. Doyle, Margarita S. Duran, Carol E. England, James W. Fickett, William Fischer, Paul Gilna, Walter B. Goad, Jamie E. D. Hayden, Kathleen S. Kelley, Thomas A. Kelley, Cindy S. Kent, Melinda A. King, Rick Kirk, Nora E. Lari-Castrillon, David G. Lewis, Thomas G. Marr, Annette V. Martinez, Denise A. Martinez, Frances A. Martinez, Maria J. McLeod, Patricia Medvick, Laura Moats, Socorro M. Mondragon, Patrice A. Morgan, Debra A. Nelson, Denise S. Pope, SaraLee M. Rodarte, Scott H. Shattuck, Lawrence J. Smith, Doug M. Sorensen, Steven R. Stelts, Robert D. Sutherland, Laurie J. Tomlinson, Brian L. Trujillo, Felicia K. Trujillo, Chang-Shung Tung, Jeannette C. Vigil, Frank J. Welch, Adele E. Zimmermann, and Larry B. Zins.

Produced by Information Services Division

Managing Editor: J.E. Baker
Writers: J.E. Baker, I.G. Buican, M.A. Burgess, R.L. Byers, N.B. Haines, F.J. Harp, P.W. Henriksen, P.A. Hinnebusch, G.Y. Hollen, J. Machen, M.J. Mann, L.C. McFarland, M.K. Moore, J.J. Mortensen, D.D. Norton, J. Paris-Chitanvis, C.L. Pearcy, O. Ramos, M.K. Ruminer, H.M. Sinoradzki, H. Sowerwine, C.R. Wade, K.T. Wheeler
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Production: V.L. Hartford, A.L. Flores, G.E. Sharp, W.M. Burditt, D.C. Sessions
Illustrations/Computer Graphics: A.L. Flores; J.D. Fowler (page 8, left); M.L. Prueitt (page 13); J.E. Lewis, Jr. (page 15); R.L. Furan (pages 18 and 55); J.M. Mahan (page 36); P.A. Sandford (page 40); J.E. Tubb (page 47); Adaptation of illustration, "How to Track an Elusive Particle," by Nancy Sterngold and Bob Conrad. Copyright © 1990 by The New York Times Company. Reprinted by permission. (page 56); Smith & Associates, Inc. (page 61); Adaptation of illustration, "The Cochlear Compromise," by G. Zweig, R. Lipes, and J.R. Pierce, Journal of the Acoustical Society of America 59 (4), 975–983 (1976). Copyright © 1976 by the Acoustical Society of America. Reprinted by permission. (page 68)
Photo Editor: J.A. Flower
Photographers: J.A. Flower; E.F. Ortega (page 20); F.H. Rick (pages 82, Follansbee; 83, all portraits; and 84, Tubbs et al.)
Systems Support: K.R. Serna
Printing Coordination: G.D. Archuleta

Contributors: E.D. Arthur, L.R. Austin, J.R. Bartlit, J.R. Baumgardner, K.S. Bedell, G.D. Bird, T.J. Bowles, C.D. Bowman, D.K. Campbell, M.D. Coburn, D. Coffey, A.L. Dana, J.W. Davidson, D.M. Drake, E.L. Duran, G.W. Eccleston, R.E. Ecke, J.N. Edwards, K.G. Eggert, N. Ensslin, J.F. Figueira, F.T. Finch, Jr., L.A. Gritzo, P.D. Goldstone, B.C. Hargis, P.H. Hemberger, W.F. Hemsing, P.R. Higbie, R.P. Hjelm, Jr., N.M. Hoffman, J.W. Hopson, Jr., H. Jansen, R.J. Jensen, T.D. Knight, D.A. Korzekwa, M.S. Krick, D.C. Langner, D. Littlefield, R.L. Lundin, R. Malenfant, D. Mandell, A.R. Mathews, R.O. McMaster, P.W. Mendius, M.A. Merrigan, W.F. Miller, Jr., G. Myers, D.A. Neeper, N.S. Nogar, R.B. Perkins, D.E. Peterson, J.J. Petrovic, R.G.H. Robertson, C.K. Rofer, H.M. Ruppel, J.L. Sapir, G.C. Saunders, R.J. Shaw, C. Shera, R.N. Silver, D. Sivia, R.D. Smith, W.F. Sommer, Jr., K.M. Spencer, J.R. Stine, L.H. Sullivan, W.L. Thompson, P.J. Unkefer, O.B. van Dyck, W.J. Verzino, R.A. Waller, P.C. White, G. Whittemore, J.D. Williams, G. Zweig

For more information about work described in this report or for information about other Los Alamos research, contact the Public Affairs Division Office, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, telephone (505) 667-5679, FTS 843-5679, FAX (505) 665-3910.

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