Energy and Environment
Understanding Our World

THE country's focus on energy—its availability and its costs, both monetary and environmental—has waxed and waned over the half-century of the Laboratory's existence. Similarly, the nation's rate of investment in the environment has fluctuated. When energy and environmental concerns have been at the forefront of national attention, Lawrence Livermore has stepped up its research activities to alleviate those concerns. In quiet times, the Laboratory has continued research in the energy and environmental arenas that are related to its national security mission. Many of these efforts can draw lines of inheritance back to the initial nuclear weapons work that forms the Laboratory's historical foundation.

The first 20 years at Livermore saw the beginnings of efforts to harness fusion as a source of cheap, inexhaustible power by using enormous magnets and, later, powerful lasers. Energy research at the Laboratory burgeoned in the 1970s and early 1980s during the energy crisis, when finding ways to enhance the nation's energy supply became a national priority. At the time, Livermore was already in the energy business through Project Plowshare, which explored the peaceful uses of nuclear explosions for recovering oil and gas and for other applications. In the 1970s, the Laboratory also became active in researching how to safely dispose of radioactive waste from nuclear power plants, an activity that continues to this day. And when the country's attention turned toward alternative energy supplies, Lawrence Livermore's scientists and engineers researched energy sources such as coal, oil shale, geothermal energy, solar power, advanced batteries, flywheels, and more.

Analyzing the environmental effects of nuclear weapons tests led naturally to examining other environmental issues—from the atmospheric to the subterranean. As a result of assessing fallout from atmospheric tests, capabilities such as the National Atmospheric Release Advisory Center and projects such as the Marshall Islands Dose Assessment and Radioecology program were born. Over the years, there was a further branching out of such research into other environmental concerns. Livermore scientists have, for example, analyzed the effects of accidental spills of liquefied natural gas; designed innovative methods for tracking, cleaning up, and modeling contaminants in groundwater; calculated how structures respond to earthquakes; and developed seismic prediction models.

> ***Available energy is the main object at stake in the struggle for existence and the evolution of the world.***
>
> *Ludwig Boltzmann (1844–1906)*
> *Austrian mathematician and physicist*

Harnessing the Power of Stars

The drive to find new ways to produce energy was present from the Laboratory's genesis. Herbert York, who Ernest O. Lawrence put in charge of organizing the Livermore branch of the University of California Radiation Laboratory, viewed work on controlled thermonuclear reactions as a natural adjunct to Livermore's nuclear weapons research. In such reactions, two lightweight nuclei combine and release energy, which is the same process that powers the stars and thermonuclear weapons. The idea of using fusion for power production came to the fore in the early 1950s.

Initial efforts focused on using strong magnetic fields to trap a plasma fuel long enough to achieve fusion. This was the work of the Controlled Thermonuclear Reactions (CTR) program, classified until 1958. The goal of the first CTR group was not

to get a reaction going, but, according to York's prospectus for the Livermore site, ". . . to reach some sort of halfway point, say, setting up a plasma with a temperature of 100 electronvolts and then investigating various points of interest such as particle mobility across and along field lines, heat conductivity, plasma oscillations, etc."

Physicist Dick Post, reminiscing in 1982 about those first efforts, said, "In 1952, hardly anyone understood even the simplest aspects of the confinement of plasma by magnetic mirrors; there just wasn't any prior work to go on." Diagnostics for this kind of work were also in a similar state. "An understanding of the basic physics of magnetic confinement was not the only thing we were lacking back in 1952–1953," Post added. "While we were trying to gain understanding through experiments, we also had to feel our way along by inventing our own diagnostic techniques to measure the plasma properties."

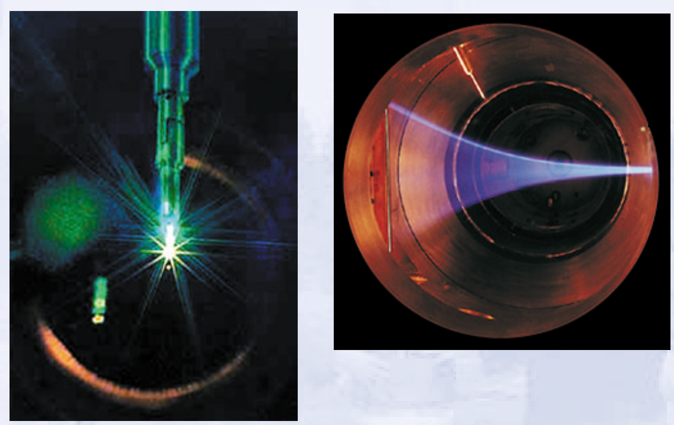
By summer 1954, the Table Top Reactor was completed and tested. It provided a clear demonstration of the magnitude of the magnetic forces involved when the magnet's coil windings were crushed by the sheer strength of the magnetic fields. In 1961, Livermore achieved the first definite fusion reactions. In 1977, Livermore began the Tandem Mirror Experiment, exploring an approach in which the reactor vessel holds a long solenoid magnet in its middle, where the plasma fuel is held. Large quantities of electric current traveling through huge magnet coils surrounding the solenoid magnet produce the immensely strong magnetic fields needed to confine the plasma. Magnetic mirrors at the ends of the reactor vessel keep the plasma from leaking out.

The Tandem Mirror Experiment and its upgrade, completed in 1981, demonstrated a marked improvement over the Laboratory's previous systems in terms of plasma confinement. These magnetic confinement machines used large electric current traveling through huge magnet coils to produce the immensely strong magnetic fields needed. The magnetic system for the Magnetic Fusion Test Facility-B, initiated in 1981, was the largest superconducting system ever built in the world.

In 1986, the Department of Energy decided to focus its magnetic fusion energy research on a different technology, the tokamak. The Laboratory contributed to the International Thermonuclear Experimental Reactor project for designing and building the world's first full-scale magnetic fusion reactor based on the tokamak design. In a tokamak, magnetic fields are generated by large, external magnetic coils surrounding a doughnut-shaped reactor. Livermore continues to provide leadership in computational fusion energy science and to explore alternative approaches to fusion energy.

Recently, Livermore began to revisit the spheromak concept. (A spheromak takes the hole out of the doughnut-shaped reactor.) In the spheromak configuration, the plasma fuel produces some of its own confining magnetic fields, requiring only an external set of coils and making for a much more compact machine capable of producing a higher-temperature and higher-density plasma. (See *S&TR*, December 1999, pp. 18–20.)

The Laboratoy also has explored using laser light as a method of creating fusion energy and providing a virtually inexhaustible, low-cost, safe, and environmentally attractive energy source. Laboratory researchers envisioned doing this through inertial confinement fusion (ICF), in which small targets of fuel are imploded by laser beams until the fuel



Since its inception, the Laboratory has explored the prospects of creating fusion as an energy source through (a) using the energy of laser light to generate laboratory fusion and (b) using enormous superconducting magnets to confine plasmas.

reaches temperatures that induce fusion. Beginning in 1972, the Laboratory pursued this vision in a series of increasingly powerful laser systems. (See *S&TR*, September 2002 pp. 20–29.) The latest—the National Ignition Facility—will be a key component of the National Nuclear Security Administration's Stockpile Stewardship Program and will, in addition, provide the most powerful system yet for exploring the ICF energy production process.

Plowshare's Energy Legacy

In 1957, the Atomic Energy Commission (the predecessor to DOE) officially established Project Plowshare to explore the use of nuclear explosives for peaceful purposes, including using these explosives to stimulate natural gas reservoirs and process underground oil shale into oil. Even though Plowshare was terminated in 1977, its legacy lived on through these and other energy projects.

From 1974 through 1988, the Laboratory developed an underground coal gasification process that converted coal beds into gas without mining. This method had two benefits. First, it reached coal that was not economically feasible to mine with the usual techniques. Second, the method produced a combustible gas that was easy to clean—easier, in fact, than removing the pollutants from stack gas at coal-fired power plants.

This project and others included large-scale demonstrations to prove or disprove the commercial viability of a given technology. "Large-scale demonstrations were the Laboratory's forte because of our experience in nuclear testing," notes retired physicist Bob Schock, who spent more than two decades managing one aspect or another of the Laboratory's energy efforts beginning in the 1970s. "The Laboratory did some large experiments in Wyoming in the late 1970s to early 1980s to gasify coal seams in place. We started by using high explosives—we'd foregone nuclear explosives by then—and came up with a technique that gasified the coal without explosives." The technique used the natural fractures in coal and controlled the burn zone through a movable oxygen injector.

"In situ coal gasification is still a good idea," says Schock. "If the technology is ever implemented, it could double or triple the accessible U.S. coal reserves and has the advantage that the carbon dioxide produced by the process can be separated out and captured."

In another Plowshare offshoot, the Laboratory investigated the feasibility of using nuclear explosives—and later, high explosives—to fracture oil shale. Oil shale can be converted to

On December 10, 1967, a 29-kiloton nuclear device was exploded in a sandstone formation 1,200 meters deep in the San Juan basin of New Mexico. The experiment, called Gasbuggy, was the first of three Project Plowshare experiments exploring the use of nuclear explosives to stimulate natural gas production in rock too impermeable for production by conventional means.

In the 1980s and early 1990s, Livermore developed an oil-shale retort technology to help unlock the vast oil-shale reserves in the western U.S. Such reserves could provide an important alternative source of liquid fuel.

oil by subjecting it to high temperatures and high pressures—in other words, by speeding up the geologic clock. Laboratory researchers envisioned using explosives to fracture the vast oil-shale reserves in the western U.S. so that the oil could be processed in place, thus providing an important alternative to imported oil. That effort evolved in the early 1980s into a surface oil-shale retorting process that used hot oil-shale particles as the heat carrier. The research also produced a model of how oil is formed. Today, this model aids the exploration efforts of every major oil company in the world.

Work supporting fossil fuel research and exploration still continues at Livermore. For instance, in 1997, Laboratory researchers developed a much-improved version of a tiltmeter to help oil explorers determine the orientation of fractures in deep oil wells. (See *S&TR*, October 1997, pp. 14–15.) Livermore is also part of the DeepLook consortium, an oil industry collaboration formed to find breakthrough technologies for detecting, predicting, and monitoring hydrocarbons, particularly in reservoirs deep below the surface. Livermore is developing computational modeling techniques to produce three-dimensional images of such reservoirs, computational neural networks to evaluate strategies that will help maximize gas and oil production, and nuclear magnetic resonance techniques to look for oil. (See *S&TR*, November 2001, pp. 12–19.)

Closing the Nuclear Fuel Cycle

With nuclear fission power still an important source of energy in the United States and throughout the world, a way must be found to satisfactorily close the fuel cycle—that is, to safely dispose of the radioactive waste produced by nuclear power plants. Beginning in 1977, the Laboratory participated in studies of candidate sites for a U.S. high-level waste repository that culminated in the recent choice of the Yucca Mountain site in Nevada.

In 1987, Congress directed DOE to study the Yucca Mountain site for its feasibility as a permanent repository for high-level nuclear waste. The Laboratory was given responsibility for designing the waste package and barrier system for the proposed repository. As part of this work, Livermore scientists designed a computer code that would run on the world's most powerful computers and show how buried nuclear wastes would affect the Yucca Mountain geology. (See *S&TR*, March 2000, pp. 13–20.)

From 1980 to 1984, Livermore scientists and engineers also designed, built, and operated at the Climax Mine in Nevada an

Livermore's involvement in the Yucca Mountain project dates from 1977. The current focus for Laboratory researchers is on developing a system of engineered barriers surrounded by natural barriers to contain highly radioactive waste. Little is known about how modern materials, placed in a geologic site and subjected to initially high temperatures and radiation, will behave during time periods of thousands of years. So, much of Livermore's development work is based on predictive models and accelerated age testing of materials and systems.

In the 1970s, the Laboratory explored the feasibility of using shallow ponds to store solar energy to produce domestic heat and run chemical processes.

underground repository to test the storage and retrieval of commercial spent-fuel and to monitor the environment. At the time, Climax was the first place in the world where high-level radioactive waste from fission reactors was stored underground for any lengthy period. The successful demonstration of this concept paved the way for future work on repositories.

Small Projects, Innovative Ideas

Although the Laboratory had many large demonstration projects during the energy heyday of the 1970s and 1980s, small innovative energy projects also flourished, such as research into solar energy. Some of these projects continue to this day.

For instance, battery research at the Laboratory, which started with aluminum–air batteries in the 1970s, has transformed into today's fuel cell research. Fuel cells, which convert the chemical energy of a fuel directly to usable energy without combustion, are widely viewed as the technology of the future for replacing internal combustion engines in vehicles.

Livermore scientists are working on several fuel cell approaches. The refuelable zinc–air fuel cell—an alternative to the standard lead–acid batteries now powering most electric cars and other vehicles—promises trouble-free, nearly 24-hour-a-day operation for numerous kinds of electric vehicles, from forklifts to delivery vans and maybe even personal automobiles. (See *S&TR*, October 1995, pp. 6–13.) Other possibilities include a fuel cell based on a proton exchange membrane and the solid-oxide fuel cell that uses hydrogen or other combustible gas as fuel. (See *S&TR*, September 2002, pp. 17–19; December 1998, pp. 4–12.) Another concept, the carbon-conversion fuel cell, uses an electrochemical process to convert carbon particles from fossil fuels directly into electricity. (See *S&TR*, June 2001, pp. 4–12.)

Interest in developing high-technology flywheels—rotating wheels to store kinetic energy, as in a potter's wheel—also grew in the 1970s. The Laboratory's flywheel research started when Dick Post envisioned flywheels made of composite materials for storing energy in electric vehicles and improving power quality. When the energy crisis hit in the mid-1970s, the Laboratory began serious research into flywheels and the necessary composite materials. Funding disappeared in the mid-1980s when the nation's focus shifted away from energy research. Flywheel research resumed in the 1990s when affordable graphite composite materials of very high strength became widely available and the U.S. Council for Automotive Research—a consortium of the Big Three U.S. automakers—developed hybrid vehicle components. (See *S&TR*, April 1996, pp. 12–19.) Livermore's flywheel technology was licensed to a commercial company in 1994. Today, flywheel researchers are working on using better carbon-composite materials and developing passive magnetic bearings to replace present-day mechanical bearings.

Environment: The Air Above

From the Laboratory's earliest days, large computers were used to simulate three classes of fluid dynamics problems: weapons explosions, the plasmas contained in magnetic fusion energy machines, and stellar physics. A natural extension was another area of fluid dynamics—the weather. In the late 1950s, with the encouragement of Livermore cofounder Edward Teller, Chuck Leith constructed the first global general circulation model. It simulated the growth, movement, and decay of large weather systems from the fundamental laws of physics. This model was the first in a series in which the Laboratory's computational capabilities were used to study atmospheric processes. (See box on p. 19.)

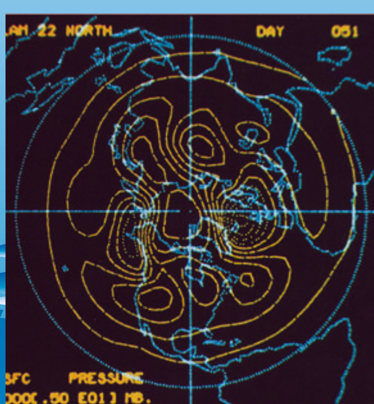
At about the same time, activities for Project Plowshare required assurance that radioactive fallout would not reach harmful levels in populated areas. A small group of scientists began developing computational models of the atmospheric transport and diffusion of radionuclides. They quickly became involved in forecasting the weather when they needed to factor wind speeds into their estimates of the amount of material released, how far the material would disperse, and what the radionuclide dose would be along the trajectory of the nuclear cloud.

Global Climate Modeling

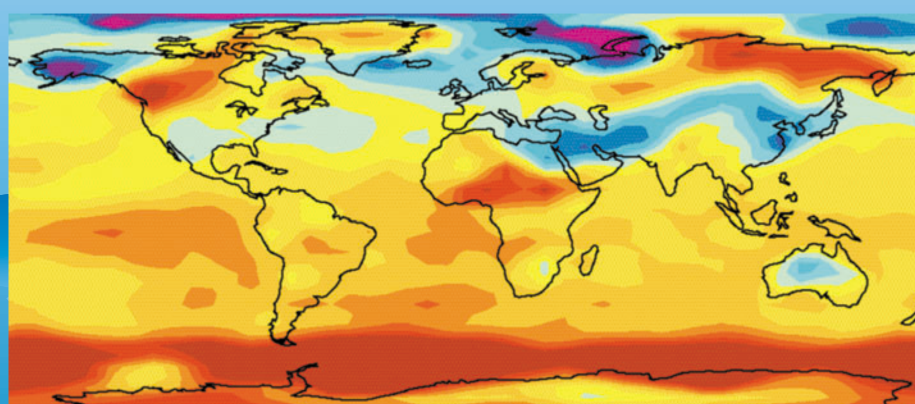
Global climate research—which has been a part of Livermore's work for nearly 35 years—had its origins in the Laboratory's nuclear weapons development and testing programs. Livermore's climate modeling researchers applied computation expertise originally developed to simulate nuclear explosions to the task of modeling the climate. The atmospheric science expertise they drew upon originated from efforts to model fallout from nuclear explosion testing.

Early on, researchers focused on global warming and its possible causes, including increased levels of atmospheric carbon dioxide, introduction of trace gases as a result of industrial and agricultural practices, aerosols from volcanic eruptions, and even variations in solar radiation. (See *S&TR*, October 1996, pp. 6–13.) This research into global warming and its causes continues. Livermore scientists have used sophisticated climate models to separate the effects of recent major volcanic eruptions and El Niños from other causes of climate change. Results indicate that cooling caused by major eruptions in 1982 and 1991 has masked some of the warming brought about by human activities, such as the conversion of forests to farm land. (See *S&TR*, July/August 2002, pp. 4–12.)

As more complex global climate models were developed, the disagreements among models and between models and observations remained significant and poorly understood. So Livermore established the Program for Climate Model Diagnosis and Intercomparison (PCMDI) in 1989 to develop improved methods and tools for evaluating global climate models. The program does not make new models but, rather, sets a standard to which all climate models can adhere and thus gain validity. The ultimate goals are to develop improved methods and tools for the diagnosis, validation, and intercomparison of global climate models and to conduct research into problems in climate modeling and analysis. In one project, for instance, some 30 international modeling groups simulated the climate of the decade 1979 to 1988, and PCMDI evaluated the results.



In the late 1950s, researchers applied numerical methods used for weapon physics to develop the first global general circulation model, which was able to simulate the behavior of large weather systems.



Temperature variability for an ensemble of 20 different simulations, showing mean surface temperatures for December through February. This comparison was conducted in the mid-1990s by Livermore's Program for Climate Model Diagnosis and Intercomparison on behalf of the International World Climate Research Programme.

In the late 1960s and early 1970s, the Laboratory became more involved in the study of the regional and global effects of pollutants. At the same time, researchers came up with a plan for estimating in real time the consequences of an accidental radionuclide release. This idea evolved into the Atmospheric Release Advisory Capability (ARAC). The original intent was to establish an emergency response service for the federal government. With the accident at the Three Mile Island nuclear power plant in March 1979, ARAC, which had just begun a limited pilot service to three Atomic Energy Commission facilities, opened ahead of schedule and operated around the clock for a month, providing information to on-scene emergency response managers and others.

Since that time, ARAC has become the National Atmospheric Release Advisory Center (NARAC), which has responded to more than 70 alerts, accidents, and disasters and has supported more than 800 exercises. Besides accidental radiological releases, NARAC has assessed volcanic ash clouds, earthquake-induced hazardous spills, the Kuwaiti oil fires, several toxic chemical accidents, and more. (See *S&TR*, June 1999, pp. 4–11.) In the aftermath of September 11, NARAC has been called upon to help local communities better plan for and respond to releases of chemical or biological agents. The program, called the Local Integration of NARAC with Cities (LINC), will provide local agencies with capabilities to predict the dispersion of chemical and biological agents, which is useful—indeed necessary—for emergency planning and response.

At Bikini Atoll, Livermore scientists experimented with a two-part remediation technique for cleaning up coral islands for resettlement. First, they used potassium fertilizer in agricultural areas to reduce the uptake of radionuclides into locally grown foods. They found that the fertilizer reduced this uptake by nearly 90 percent and also increased plant productivity. Second, they replaced contaminated soil with crushed coral in housing and village areas. This eliminated most of the radionuclide dose resulting from ingestion and inhalation of soil particles.

The Ground beneath Our Feet

Environmental research at the ground level also began at Livermore in the late 1950s and early 1960s. Some of the first research concerned fallout from atmospheric tests at the Nevada Test Site to better understand the dynamics of radionuclides and human and animal metabolism. The Plowshare tests, which created radionuclides that nobody had worked with before, such as isotopes of tungsten, raised further questions. To address them, the Laboratory acquired a small dairy herd to study the metabolism of radionuclides in cattle, a project that lasted into the 1970s.

This research into the interaction of radionuclides in the environment broadened in the 1970s, when the Laboratory became involved in environmental evaluations in the Pacific and in California. One effort, which continues to this day, concerns the effect of the radionuclides released to the environment by the nuclear tests conducted at the Bikini and Enewetak atolls in the Marshall Islands. The islanders were relocated from Bikini Atoll in 1946 and from Enewetak in 1947 before U.S. nuclear testing began. In 1962, both groups of islanders began asking to return to their ancestral homes. U.S. officials decided that more knowledge of the conditions at the atolls was needed before resettlement could begin. Laboratory scientists conducted large-scale environmental surveys of the radionuclide distribution on the islands to determine what long-term radioactive exposures would result, for instance, from eating locally grown crops, drinking the water, or eating fish caught in the lagoons.

They performed 30 years of scientific investigations on the levels and distributions of fallout radionuclides at the atolls and developed remediation techniques for cleaning up the coral islands for resettlement. One technique, developed in large-scale field experiments conducted on Bikini by Livermore environmental scientist Bill Robison (now retired) and others involves using common plant fertilizer to reduce the uptake of radionuclides into locally grown foods and replacing contaminated soil in the housing and village areas. Portions of Enewetak were resettled in 1980, and a cleanup and rehabilitation program on neighboring Rongelap Atoll is under way.

Livermore supports the Marshall Islands resettlement in many ways, including monitoring the health of resettlers by using advanced accelerator-based measurement technologies to analyze urine samples at Livermore's Center for Accelerator Mass Spectrometry. (See the box on p. 22.) Researchers also continue the work started in the 1950s—characterizing the radiological conditions at the various atolls;

determining the transport, uptake, and cycling of radionuclides in the ecosystem; and estimating the potential radiological doses and risk.

Other ground-level research started with looking at the environmental effects of different energy sources and evolved from there. For instance, in 1984, DOE was looking into the pros and cons of liquefied natural gas (LNG) as a possible energy source. Through 1988, DOE and Livermore conducted a series of large-scale spill tests at the Nevada Test Site to obtain more information about various aspects of LNG safety and about chemical spills in general. The spill test site now holds the Remote Sensor Test Range, which is the proving ground for nascent remote-sensing technologies developed by DOE's national laboratories. At the range, sensor developers can submit their technologies to full-scale testing consisting of releases of chemicals and mixtures. (See *S&TR*, April 2000, pp. 19–21.)

Joy Hirabayashi (left) and Tina Carlsen collect surface water samples as part of the Laboratory's ongoing environmental monitoring program.

Into the Underground

Another environmental realm extends far below the ground—a world of groundwater, fractures, and tectonic plates. Livermore environmental scientists and geologist have spent many years seeking to shed light on this underworld.

In the late 1970s and early 1980s, people became aware that the contaminants put into the ground—either deliberately or as accidental spills—didn't necessarily stay in one place, but could migrate. In 1983, in conjunction with a seismic evaluation at the Livermore site, groundwater samples were analyzed for natural mineral content and for solvents. The Laboratory found that the groundwater beneath the Livermore site was contaminated by volatile organic chemicals.

Extensive record checking revealed that many—if not most—of the solvents causing the groundwater contamination resulted from the operations of the Livermore Naval Air Station, which was located at the Lawrence Livermore site during World War II. Tests on the nearest domestic well revealed 400 parts per billion of perchlorethylene (PCE), a volatile organic compound once used extensively for cleaning metal airplane parts—far exceeding the drinking water standard of 5 parts per billion.

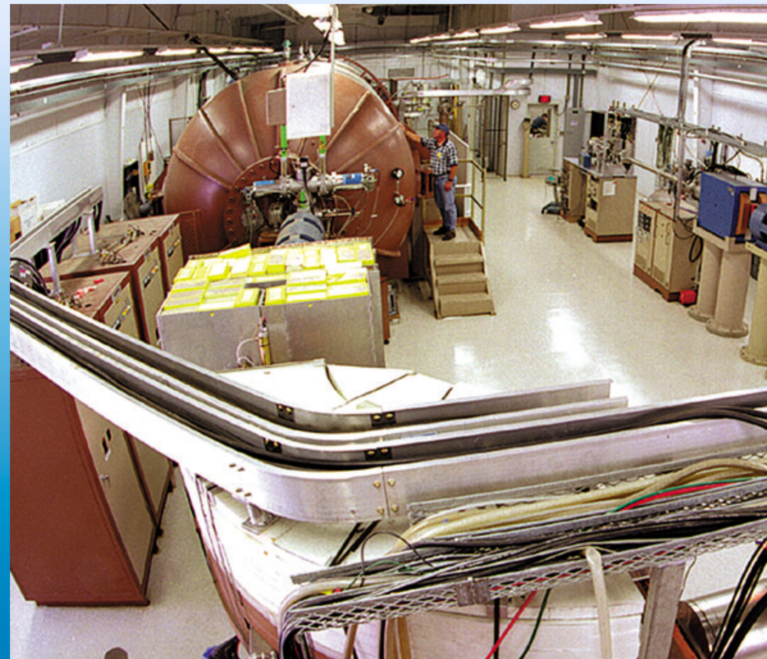
Since the discovery of the contaminated groundwater plumes, Livermore has drilled hundreds of wells for sampling groundwater, measured the extent and concentration of PCE and other chemicals, and evaluated the complex geology of the affected subsurface. Cleanup of the groundwater by the pump-and-treat method started in 1989 at the Livermore site and in the early 1990s at Site 300, Livermore's remote experimental test facility. Livermore researchers continue to develop innovative technologies for cleaning up groundwater and soil. Examples include soil-vapor extraction, in which solvents are sucked out of the soil above the groundwater; dynamic underground stripping, in which the subsurface is heated and the solvents extracted; and microbial treatments, in which bacteria are injected into the subsurface to break the contaminants in situ. (See *S&TR*, May 1994, pp. 11–21; July/August 1997, pp. 21–22).

Research to understand the complex underground environment has broadened to include other studies as well. For instance, some scientists are looking at how groundwater moves through rock fractures underground, studying in particular the relationship between the rate of fluid flow and the rate of mineral dissolution in a fracture. Underground fluid flow is of particular interest to nuclear waste isolation research at the Laboratory. Advances in numerical methods and computational power is helping researchers to gain a better understanding of cracks and fractures, which play a major role in the mechanical behavior of rock at all scales. Accurate predictions of the strength and mechanical behavior of large rock masses are important in many applications in civil, environmental, and mining engineering. Seismic codes developed by Livermore researchers, such as computer scientist–geophysicist Shawn Larsen, simulate the rupturing of an earthquake fault. Researchers such as engineer David McCallen then feed predictions of ground motion into a code that he codeveloped to simulate how bridges and buildings respond to earthquakes. (See *S&TR*, December 1998, pp. 18–20.) Livermore seismologists also have developed ways to use seismic

One Part in a Quadrillion

Established in 1989, Livermore's Center for Accelerator Mass Spectrometry (CAMS) was created to help Laboratory researchers diagnose the fission products of atomic tests and track the spread of nuclear weapons to other countries by detecting radioisotopes in air, water, and soil samples. In addition, the technique is now used to study environmental quality, climate change, seismology, archaeology, and biomedical science.

Accelerator mass spectrometry is a sensitive technique for measuring concentrations of specific isotopes in very small samples. It can be used, for example, to seek out one carbon-14 isotope out of a quadrillion other carbon atoms. Today, the center's scientists participate in about 70 collaborative research projects with universities worldwide. Examples of research using CAMS capabilities are described in *S&TR*, June 2001, "Environmental Research in California and Beyond," pp. 13–21; July/August 2000, "Biomedical Research Benefits from Counting Small," pp. 12–19; January/February 1997, "The B-Factory and the Big Bang," pp. 4–13, and "Assessing Exposure to Radiation," pp. 14–21.



measurements to detect clandestine underground explosions, and they have built a worldwide network of seismic stations to help in this effort. (See *S&TR*, July/August 2002, pp. 24–30.)

A Linked World

Coal, fusion energy, nuclear power, solar energy, rock mechanics, metabolism of radionuclides, global warming—these are only a sample of the dizzying spectrum of energy and environmental topics Livermore's researchers have explored over the past half-century. In many instances, notes Associate Director for Energy and Environment C. K. Chou, these efforts have overlapped, revealing how inexorably connected our world is. "Now that these efforts are in a single organization at the Laboratory," he says, "researchers can more easily link environmental factors to technologies related to energy production and use." As an example, he points to research in three interrelated issues: energy technologies (which may release carbon dioxide), management of human-caused carbon dioxide (which may reduce carbon dioxide's effects on climate), and global climate–carbon cycle modeling. Understanding the complex interactions between the earth system and human activities in the biosphere requires that all three issues be considered as an integrated package.

The Laboratory has always risen to the occasion when addressing environmental and energy issues of national concern. Chou stresses that Lawrence Livermore does not make policy. Rather, the Laboratory provides the scientific understanding that enables policy makers to make informed decisions. It is through this integrated approach that the Laboratory can help those who do make policy to address the complex interrelated energy and environmental challenges that face the nation and the world today.

—*Ann Parker*

Key Words: atmospheric transport and dispersion, coal gasification, fossil fuel, fuel cells, global climate modeling, groundwater contamination, inertial confinement fusion, magnetic fusion, Marshall Islands, nuclear fuel cycle, nuclear waste repository, Project Plowshare, rock mechanics, Yucca Mountain.

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