September 2009

Science & Technology REVIEW

National Nuclear
Security Administration's
Lawrence Livermore
National Laboratory

Remembering Herb York (1921–2009)

Also in this issue:

About the Cover

In 1952, Herbert Frank York, who died on May 19, 2009, was appointed as the first director of the new nuclear weapons laboratory in Livermore, beginning a pattern of "firsts" that was to continue for a decade. In 1958, President Dwight D. Eisenhower selected York as the first chief scientist for the new Advanced Research Projects Agency in Washington, DC. Not long afterward, he became the first director of Defense Research and Engineering. Then in 1961, York returned to California as the founding chancellor of the University of California's newly established campus at San Diego. The article beginning on p. 4 pays tribute to York's long career of service. The cover shows York in the mid-1950s, sitting at his desk at Livermore. In the background is an aerial photograph of the Laboratory during that time period.

Cover design: Daniel Moore

About the Review

At Lawrence Livermore National Laboratory, we focus science and technology on ensuring our nation's security. We also apply that expertise to solve other important national problems in energy, bioscience, and the environment. *Science & Technology Review* is published eight times a year to communicate, to a broad audience, the Laboratory's scientific and technological accomplishments in fulfilling its primary missions. The publication's goal is to help readers understand these accomplishments and appreciate their value to the individual citizen, the nation, and the world.

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Science & Technology REVIEW

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Lawrence
Livermore
National
Laboratory

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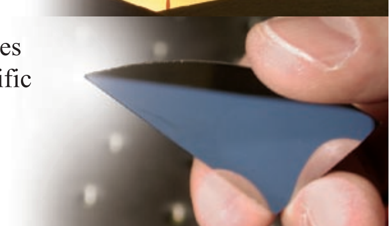

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Livermore Captures Eight R&D 100 Awards

Eight technologies developed by Livermore scientists and engineers have received R&D 100 awards—more awards than the Laboratory has ever won in *R&D Magazine*'s annual competition for the top 100 industrial, high-technology inventions. The winning technologies are as follows:

• Artificial Retina, the first retinal prosthesis that can function for years inside the harsh biological environment of the eye.

• FemtoScope, a fiber-optic-based time microscope that can be attached to the front end of a recording instrument such as an oscilloscope or streak camera.

• GeMini, a portable gamma-ray spectrometer based on germanium technology.

• Land Mine Locator, an aerial detection system that reduces the time and cost of demining operations and improves the safety of personnel and equipment.

• Laser Beam Centering and Pointing System, a compact sensor that combines two critical laser alignment measurements—beam location (centering) and direction (pointing).

• Precision Robotic Assembly Machine, an automated system for manufacturing targets for fusion ignition experiments on the National Ignition Facility.

• ROSE, a computer application that improves access to compiler technologies so users can build tools to, for example, detect defects and optimize codes.

• Spectral Sentry, an advanced technology to protect critical laser systems from pulses with incorrect bandwidth before amplification.

The October/November issue of *S&TR* will feature detailed reports on these award-winning inventions and the researchers who developed them.

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Report Assesses Impact of Climate Change

Researchers representing government science agencies, major universities, and research institutes, including Lawrence Livermore, have produced the most comprehensive report to date detailing how global climate change is likely to affect the nation. The report, *Global Climate Change Impacts in the United States*, provides current information on changes in temperatures, rainfall patterns, and sea level.

Livermore physicist Benjamin Santer was a lead author of the report's first chapter. "This part of the report explains why climate is changing and how we know that we are the ones causing it," says Santer, who works in the Program for Climate Model Diagnosis and Intercomparison. "Climate change is telling us a consistent story: Humans have had a pronounced effect on global climate."

The study, which was commissioned by the U.S. Global Change Research Program and led by the National Oceanic and Atmospheric Administration, finds that Americans are already being influenced by climate change through extreme weather, drought, and wildfire. It also describes how the nation's transportation, agriculture, health, water, and energy sectors will be affected in the future.

The global warming of the past 50 years has been primarily caused by human-induced increases in heat-trapping gases. Scientists have also identified human "fingerprints" in such aspects of the climate system as changes in ocean heat content, precipitation, atmospheric moisture, and Arctic sea ice.

Climate models project that global temperatures will rise during this century. By how much and for how long depend on several factors, including the amount of heat-trapping gas emissions and how sensitive the climate is to them. The emissions responsible for human-induced warming come primarily from burning fossil fuels (coal, oil, and gas) with contributions from forest clearing and agricultural activities.

Since 1900, global average temperature has risen by about 1.5°F. Models predict that by 2100, it will rise another 2°F to 10°F. Increases at the lower end of this range are more likely if global heat-trapping gas emissions are cut substantially. If emissions continue to rise at or near current rates, temperature increases are more likely to be near the upper end of the range. The report notes, however, that the current trend for greenhouse-gas emissions is significantly above the worst-case scenario examined in the study.

In developing the report, researchers drew from a large body of scientific information, including a set of 21 synthesis and assessment reports by the U.S. Global Change Research Program. The government agencies affiliated with this program include the Departments of Agriculture, Commerce, Defense, Energy, Health and Human Services, Interior, State, and Transportation; Environmental Protection Agency; National Aeronautics and Space Administration; National Science Foundation; Smithsonian Institution; and U.S. Agency for International Development.

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Remembering the Laboratory's First Director

"INSTITUTIONS are merely the lengthy shadows of great men." Herb York would surely have given one of his loud and prolonged laughs to hear the Laboratory described as his shadow. But this quotation, adapted from a Thomas Carlyle remark on history, is more than appropriate. In a career notable for the founding role Herb played in several important institutions (including the Defense Advanced Research Projects Agency, Defense Research and Engineering, University of California at San Diego, and Institute for Global Conflict and Cooperation), Livermore was the first. Not only did his six years (1952–1958) as the founding director of the Laboratory set its character and direction for the subsequent decades, but that period also tested and honed Herb's abilities as a thinker and a leader. It began the broadening of his perspective from that of a scientist and technologist to encompass an understanding of the potential of and problems in applying technology for military advantage and, in turn, the utility and limitations of using military capability in support of national security.

In setting up the Laboratory that Ernest Lawrence and Edward Teller had persuaded the Atomic Energy Commission to establish, Herb planned thoughtfully before acting, always considering alternatives carefully. Sometimes he proceeded cautiously, for example, relying heavily at the beginning on the infrastructure at Berkeley. Sometimes he went out on a limb, as in agreeing with Teller that the Laboratory would not only test and diagnose nuclear (and thermonuclear) weapons but also design them.

Herb recruited a team of program leaders almost all of whom were even younger than he was (I guess I was the youngest), seasoned with a few relative graybeards. Lawrence served as his mentor and a significant role model. Teller was something of a challenge (to any manager) as well as an inspiration to many at the Laboratory.

During the first few years, Herb learned to deal effectively with the executive and legislative branches in Washington, DC, which were then infinitely simpler, more straightforward, and results-oriented than they have since become. Relations with Los Alamos were often cooperative, sometimes quite competitive, but always correct. From the beginning, Livermore was "the second laboratory," but Los Alamos was never called "the first."

Those early years produced some "misfires" on our part, but Herb's approach of not promising too much sustained—and perhaps even saved—the new institution. By 1956, we had established the Laboratory's ability to produce major advances in weapons characteristics that would prove vital for the nation's nuclear deterrent, from equipping U.S. ballistic missiles with thermonuclear warheads to designing tactical nuclear weapons light enough to be incorporated into various delivery systems.

At about that time, Herb was tempted by an offer from private industry. He turned it down, however, because Lawrence thought Herb's career and the national interest would be better served by staying at Livermore. That advice proved to be correct. By late 1957, Herb had become deeply involved in the Washington apparatus advising the Eisenhower administration, especially following the Soviet Union's launch of the Sputnik satellite in October of that year. He served on panels of the President's Science Advisory Committee, not only on nuclear issues, such as the test ban and nuclear arms limitation, but also on missile development and space science and exploration.

When the 1958 National Security Act established the Advanced Research Projects Agency, Herb was asked to become the agency's chief scientist. This time, the broader scene was enough to draw him away from the Laboratory. Although Herb was not bored by the remaining challenges at Livermore, I could tell that the wider perspective he found through his Washington work made the attractions of affecting national decisions irresistible. Thus began the next stage of a remarkable record of achievement.

At Livermore and afterward, Herb York's style was open, collegial, and informal, but also reasoned and decisive. Loud expositions, technical disagreements, and raucous laughter were frequently heard coming from the director's office. His intellectual interests were of almost unlimited breadth; his interest in people no less so. I remember him telling me he found it important to realize that a person's defects were often inseparable from his or her virtues, so you had to accept both together and use the latter to best advantage. To a major degree, the entrepreneurial nature of Livermore, to the extent that the impediments in government bureaucracy and the contractor structure allow it to flourish, is a legacy from Herb York.

■ Harold Brown is director emeritus for Lawrence Livermore National Laboratory.

Herbert F. York (1921–2009) A Life of Firsts,

Often finding himself in the right place at the right time, the Laboratory's first director had a remarkable career.

an Ambassador for Peace

WHEN Herbert Frank York, the Laboratory's first director, died on May 19, 2009, he left behind an enduring legacy as a scientific innovator and diplomat for a more peaceful world. In his autobiography, *Making Weapons, Talking Peace: A Physicist's Odyssey from Hiroshima to Geneva*, York remarks about himself and fellow physics graduate students at the University of California (UC) at Berkeley, "We were in exactly the right place at the right time." He was referring to their ability to obtain far more research time on the new giant cyclotron for their own projects than would have been possible a few years later. Yet, that statement appears to apply to many events in the early years of his professional life.

York's appointment as director of the new nuclear weapons laboratory in 1952 established a pattern of "firsts" that was to continue for a decade. In 1958, he was selected as the first chief scientist for the new Advanced Research Projects Agency (ARPA) in Washington, DC, and not long afterward, he became the first director of Defense Research and Engineering. Then in 1961, York returned to California as the founding chancellor of UC's newly established campus at San Diego.

The Laboratory's first director, Herbert Frank York (shown at left in 1984), died on May 19, 2009. In 1956, York (above, second from right) was one of many Laboratory and University of California employees who traveled to the Pacific Proving Grounds for Operation Redwing.

During his tenure in Washington, York experienced a change of heart about the role of nuclear weapons. Specifically, he came to believe that ending war was done most effectively by not starting one in the first place. He turned to arms control, with a nuclear test ban as a first step. Over the course of his long career, York was an advisor on arms control to six U.S. presidents and served on the President's Science Advisory Committee and the scientific advisory boards of the Army and Air Force. A hallmark of his career was his conviction that science and policy making should be above politics. He thus supported or opposed policies based strictly on his scientific judgment and served in both Democratic and Republican administrations.

York's extreme modesty is evident in his autobiography. Sybil York, his wife of 61 years, notes that he would likely be bemused by all the "flap and flurry" in the press that have accompanied his death. In addition to his wife, York leaves three children and four grandchildren.

A Career of Service

Herb York was born on November 24, 1921, in Rochester, New York, and in 1943, he received an M.S. in physics from the University of Rochester. World War II was well under way by then, and physicists of all stripes were in high demand. UC Berkeley beckoned, and York accepted the offer, arriving in May. At Berkeley, he worked for Ernest O. Lawrence, director of the University of California Radiation Laboratory and inventor of the cyclotron. As part of the Manhattan Project, York helped produce uranium on the calutron

This 1944 photo of York may have been used on his badge for the University of California Radiation Laboratory.

at Berkeley and at the Y-12 Plant in Oak Ridge, Tennessee, where the new process of electromagnetic separation of uranium-235 was being developed in support of the U.S. effort to build the first atomic bomb.

The Manhattan Project launched many careers, York's among them. However, York felt that his own career got off to a rather slow start. In a 1992 lecture at Livermore, he recalled, "When we were running the calutron, manufacturing uranium, I spent a lot of time sweeping up. I also painted racks to hold equipment." Fortunately, his days on the calutron were numbered.

After the war, York began doctoral studies in physics at UC Berkeley. J. Robert Oppenheimer, who had been director of the Manhattan Project, taught York's quantum mechanics class, and Emilio Segrè, a close protégé of physicist Enrico Fermi, became York's thesis advisor. "Fermi could explain anything in a way that seemed immediately understandable . . . but that turned out to be not so easily reproducible when I [thought] about it later." During his doctoral research, York codiscovered the neutral pi meson. He received a Ph.D. in physics in 1949 and in 1950 began what would be a brief career as an assistant professor of physics at UC Berkeley.

Working under Lawrence for eight years at Berkeley, York learned the managerial style that later served him so well at the new laboratory at Livermore. In his autobiography, York says, "Lawrence made it a regular practice to tour all parts of his laboratory. He visited the cyclotron . . . and would briefly take over the controls of the machine himself. Then he would tour the various experimental areas around the machine. . . . He also visited the drafting rooms and the mechanical and electrical shops; there he would ask the workmen to show him the various things they were doing. Later when I became a laboratory director myself, I deliberately and fruitfully copied this practice of his." Lawrence also created the model of how large-scale science should be pursued—through multidisciplinary team efforts.

Lawrence and renowned physicist Edward Teller had been advocating for a second nuclear weapons laboratory to augment the efforts of the laboratory at Los Alamos. One day, Lawrence asked York to draw up plans for the new research center. In his autobiography, York writes, "I began to sketch out my ideas about how to go about it: the first elements of a research program, new facilities, manpower, and

York (right) worked in a concrete bunker on the Enewetak Atoll during Operation Redwing, a series of seven thermonuclear tests conducted by the Laboratory in 1956.

the rest. After a few weeks of such work, Lawrence asked me if I thought I could 'run it.'" York was just 31 years old.

His family moved with him from Berkeley to Livermore, which in 1952 had a population of about 4,500. "We always lived as close as possible to where Herb worked," says Mrs. York. "He was devoted to the Laboratory, but he was a terrific family man, too. He always came home for dinner, read to the children, and put them to bed before returning to the Lab for the evening."

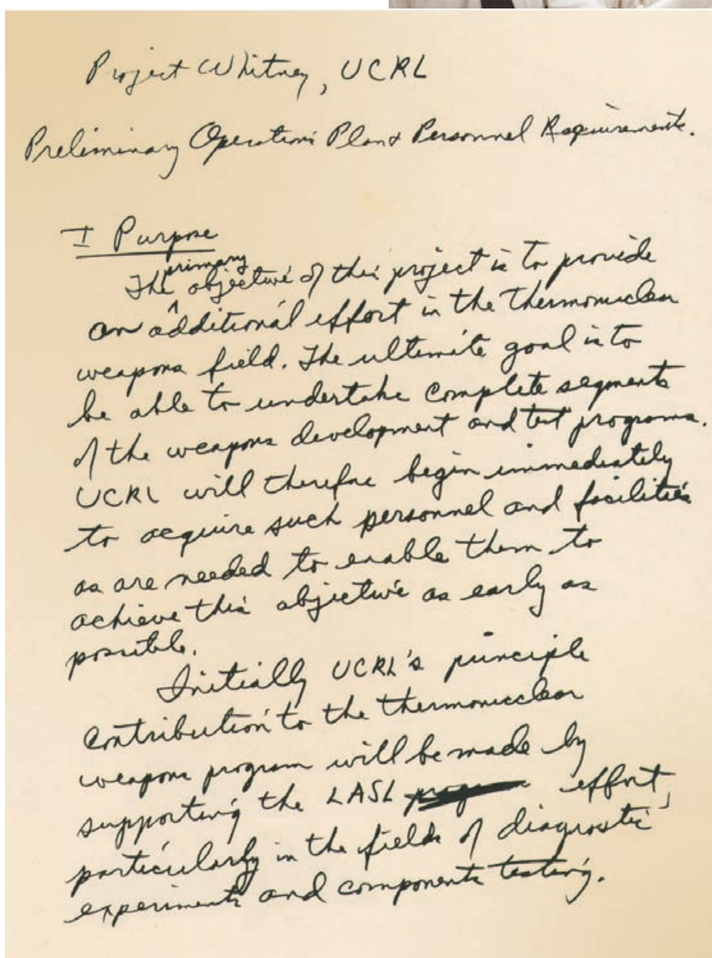
A New Ideas Laboratory

The new laboratory, established in September 1952, was born at the height of the Cold War. The Soviet Union had proved its success with its first atomic weapon, the Sino–Soviet partnership was increasingly menacing, and then China advanced into Korea. A few months later, the U.S. would detonate its first full-scale thermonuclear weapon, known as Mike, in a test over the Pacific.

York followed Lawrence's team-science approach and made Livermore a "new ideas" laboratory. York's philosophy was for the new Lab to always push at the technological extremes. "We did not wait for higher government or military authorities to tell us what they wanted and only then seek to supply it," he says in his autobiography. "Instead, we set out from the start to construct nuclear explosive devices that had the smallest diameter, the lightest weight, the least investment in rare materials, or the highest yield-to-weight ratio or that otherwise carried the state of the art beyond the currently explored frontiers."

At the 1992 Livermore lecture, York noted, "Lawrence had remarkable trust and confidence in people, especially young people. He thought people would grow to fill a responsibility, despite having no track record in the field. Everyone at the new Lab was in their 20s and 30s, except for the 44-year-old Teller. Lawrence and Teller had the credibility to

Livermore's cofounders (from left), Ernest Orlando Lawrence and Edward Teller, selected York as the new Laboratory's first director. (Courtesy of Jon Brenneis.)



Project Whitney, UCRL

Preliminary Operations Plan & Personnel Requirements.

I Purpose

The primary objective of this project is to provide an additional effort in the thermonuclear weapons field. The ultimate goal is to be able to undertake complete segments of the weapons development and test programs. UCRL will therefore begin immediately to acquire such personnel and facilities as are needed to enable them to achieve this objective as early as possible.

Initially UCRL's principle contribution to the thermonuclear weapons program will be made by supporting the LASL ~~program~~ effort, particularly in the fields of diagnostic experiments and component testing.

At Lawrence's request, York outlined plans for a second nuclear weapons laboratory at Livermore.

convince the politicians in Washington, DC, that these youngsters could make the Lab work."

The new managerial team was indeed a young bunch. Harold Brown, 24 years old and one of York's best friends, headed A Division, which was chartered to design light, small thermonuclear weapons. (Just a few years earlier, Brown babysat at the Yorks' home in Berkeley so the couple could make a midnight dash to the hospital for the birth of their second daughter.) John Foster, another good friend and just 29, directed B Division, whose task was to build better fission bombs. "York's managerial style throughout his years as director was highly informal," says Brown. "He was in charge but never authoritarian. He welcomed the exchange of new ideas." Both friends followed in York's footsteps to become Laboratory director, Brown serving from 1960 to 1961 and Foster from 1961 to 1965.

"From the beginning, York's most challenging task was to mediate between Teller and Lawrence and their very different goals for the new laboratory," says Brown. "Teller wanted the Lab to be as big as possible. Lawrence was more cautious, encouraging York to start small and work up, broadening the Lab's goals as successes mounted."

According to Brown, the successes did not come immediately. "We were trying to do a lot, develop new instrumentation for nuclear tests, fundamental physics measurements, and of course, new weapons designs. The first two years were not great, and some programs did not work well. But we learned from our mistakes. After two years, we began to move in radically successful directions."

A major breakthrough was the design of a high-yield warhead small enough to fit on a ballistic missile that could be launched from a submarine. It made possible the Polaris program, and since then, the U.S. has stationed much of its nuclear deterrent safely and securely at sea. The Laboratory went on to develop even smaller strategic warheads—compact enough that a single missile could carry several warheads.

Programs in fusion energy and advanced computations also were part of the Laboratory's initial research portfolio. Livermore acquired the fifth UNIVAC computer in 1953 as well as first editions of the increasingly more powerful and faster computers that followed. Site 300, the remote experimental test facility, opened in 1955. Under York's leadership, the Laboratory grew from a staff of 123 and a first-year budget of $600,000 to a workforce of 3,000 employees and an annual budget of $55 million by March 1958.

Washington, DC, and Change

York's position as Laboratory director brought him into regular contact with movers and shakers in Washington, DC, and he participated in half a dozen high-level scientific advisory organizations.

The Soviet Union launched Sputnik, the world's first Earth-orbiting artificial satellite, in October 1957. In response, President Dwight D. Eisenhower created ARPA as a research and development organization under the Department of

The York family visited the office of the Secretary of Defense when York was sworn in as director of Defense Research and Engineering (from left): Sybil, Cynthia, Herb, Rachel, and David. (Courtesy of the York family.)

Books by Herb York

- *Arms and the Physicist* (American Institute of Physics, 1995)
- *A Shield in Space? Technology, Politics, and the Strategic Defense Initiative* (University of California Press, 1989, with Sanford Lakoff)
- *Making Weapons, Talking Peace: A Physicist's Odyssey from Hiroshima to Geneva* (Basic Books, 1987)
- *Does Strategic Defense Breed Offense?* (University Press of America, 1987)
- *The Comprehensive Nuclear Test Ban* (California Seminar on Arms Control and Foreign Policy, 1979, with G. Allen Greb)
- *The Advisors: Oppenheimer, Teller, and the Superbomb* (W. H. Freeman, 1976)
- *Arms Control: Readings from* Scientific American (W. H. Freeman, 1973)
- *Race to Oblivion: A Participant's View of the Arms Race* (Simon and Schuster, 1970)

Defense and named York as its first chief scientist. A few months later, Eisenhower appointed York the first director of Defense Research and Engineering, serving as the civilian supervisor of missile and space research.

York moved to Washington in March 1958, in the middle of the school year, and rented a studio apartment during his first months there. He flew home to Livermore every other weekend until the school year was over and his family could join him on the East Coast. “He made a date with each of the children for a few hours every weekend that he was home,” says Mrs. York. “One would want to go hiking; another wanted a sundae at the local soda fountain. Herb devoted a few hours exclusively to each child.”

In his autobiography, York notes that he became an advocate for arms control during his time in Washington, DC, when he was exposed to the political arena. He served as a member of the first General Advisory Committee on Arms Control and Disarmament (1962–1969) and as the U.S. ambassador and chief negotiator for the Comprehensive Nuclear Test Ban (1971–1981). He also was part of the U.S. delegation to the 1965 conference on the application of science and technology held by UNESCO, the United Nations Educational, Scientific, and Cultural Organization, and to the 1978–1979 Soviet–American Arms Control Talks.

Teaching Peace

In 1961, UC again beckoned, this time for York to serve as the first chancellor of the newly established UC San Diego, which he did until 1964. In 1983, he founded UC’s Institute on Global Conflict and Cooperation (IGCC), with the goal of directing the resources of the entire UC system, including Lawrence Livermore and Los Alamos national laboratories, toward nonproliferation and ending nuclear war. Today, IGCC is one of the nation’s largest sources of dissertation and fellowship support for international studies students.

Says IGCC Director Susan Shirk, “Herb was the founder of the UC Institute on Global Conflict and Cooperation, our director emeritus, and the inspiration for IGCC’s mission of bringing the knowledge generated by UC faculty and students to bear on policy efforts to prevent nuclear war and other forms of military conflict. Among his many achievements, he initiated the summer nuclear weapons policy training sessions and the track two dialogues, which have become hallmarks of IGCC.”

York remained strongly engaged in the institute’s activities until his death. “In recent years, his talks became the high point of our summer program on public policy and nuclear threats,” says Shirk. “The students in the program could not get enough of his reminiscences about his involvement with the development of nuclear weapons and negotiations to control their spread and use, mixed with his cogent analysis of how to reduce current proliferation threats. And of course, he was a great role model to our students and to us of a scholar-diplomat who made the world a better place.”

On hearing of York’s death, Laboratory Director George Miller noted that York was instrumental in shaping the Laboratory and helped lay the foundation for the institution it is today. “Among Herb’s many contributions is a legacy of team science, a defining characteristic of this Laboratory, and a commitment to applying science to strengthen national policy,” says Miller. “His understanding of science, technology, and global geopolitical issues was the basis of his strong leadership in arms control. Herb contributed his talents and leadership broadly to the Laboratory, the University of California, and the nation. He is one of the true leaders of this Laboratory and a founding father we will never forget. He will be truly missed.”

—*Katie Walter*

Herb York’s Awards

2000	Clark Kerr Award for Distinguished Leadership in Higher Education, the highest honor bestowed by the University of California at Berkeley’s Academic Senate
2000	Enrico Fermi Award, the government’s oldest science and technology award honoring lifetime achievement, presented by President Bill Clinton for York’s efforts and contributions in nuclear deterrence and arms control agreements
2000	Vannevar Bush Award for leadership in the arms control movement and work in nuclear energy, presented by the National Science Board, the policy-making arm of the National Science Foundation
1994	American Physical Society’s Leo Szilard Award
1993	Federation of American Scientists’ Public Service Award
1972–1973	Guggenheim Fellowship
1962	Atomic Energy Commission’s Ernest O. Lawrence Memorial Award

Key Words: Advanced Research Projects Agency (ARPA), arms control, Herbert Frank York, Institute for Global Conflict and Cooperation (IGCC), University of California (UC) at San Diego.

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Searching for Life in Extreme

A compact device will help identify new marine organisms and improve instruments for space exploration.

Livermore engineer Vincent Riot holds the polymerase chain reaction (PCR) module developed for research in extreme environments from the seafloor to other planets. (background) An artist's concept shows a space probe on Europa, one of Jupiter's natural satellites. Such a probe, equipped with a PCR module, would penetrate Europa's icy surface and descend through its liquid ocean to search for life near volcanoes or hydrothermal vents. (Rendering courtesy of the National Aeronautics and Space Administration.)

IN the scientific search for new life forms, nature continues to surprise, revealing marine species below freezing ice floes or next to scalding vents on the ocean floor. The Monterey Bay Aquarium Research Institute (MBARI), a nonprofit organization in Moss Landing, California, is one of several institutions developing instruments to aid the search for aquatic life forms and to further scientific research on microbes' role in mediating the cycling of Earth's elements and energy.

Marine microbes such as archaea, bacteria, and blue-green algae have significant effects on ocean chemistry and larger marine organisms. Studying these organisms is difficult, often because they cannot be cultured in the laboratory and have only recently been discovered. Possibly thousands of additional species have yet to be found.

Livermore scientists and engineers have joined the MBARI search for new life forms by designing an autonomous electro-opto-mechanical device that detects microbial genes of interest and measures their preponderance. The device, a polymerase chain reaction (PCR) module,

Environments

incorporates features from Livermore-designed systems that detect pathogens, but it is much more compact and "intelligent" than previous instruments.

Data produced by the PCR module will help researchers better understand the roles microbes may play in responding to global climate change. Scientists estimate that the world's oceans are absorbing about one-third of the carbon dioxide produced by burning fossil fuels, gradually causing seawater to become more acidic. As part of Earth's carbon cycle, species of microscopic marine algae take up large quantities of carbon dioxide and release oxygen. By studying the genetic makeup of these species, scientists can learn how microbes remove carbon from the atmosphere and cope with the increasing acidity of oceans.

The combination of PCR data with results from other instruments developed to investigate marine environments will also be evaluated as part of a National Aeronautics and Space Administration (NASA) program to determine the instrumentation to deploy in searching for life on other planets. Livermore researchers are developing the PCR module as part of NASA's Astrobiology Science and Technology for Exploring Planets Program.

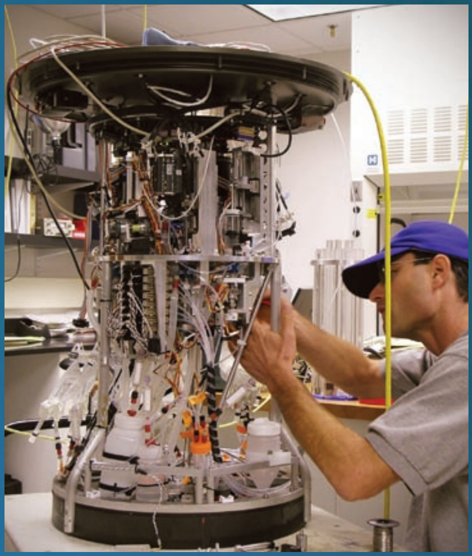
By any measure, one of Earth's extreme environments is the deep sea, where superheated (more than 350°C) fluids mix with near-freezing seawater at several hundred atmospheres of pressure, where 1 atmosphere equals more than 100 kilopascals. Compared to most of the deep sea, the areas immediately around hydrothermal vents typically support complex microbial communities. Deep-sea studies may also contribute to astrophysics research because extreme environments on Earth could be similar to conditions elsewhere in the solar system. For example, the surface of Europa (a Jupiter satellite) appears to be entirely submerged beneath a sea covered with thick ice. Some scientists speculate that primitive life forms resembling Earth's microbes could exist around active volcanoes or hydrothermal vents believed to exist on Europa's seafloor.

Remote Sampling in the Ocean

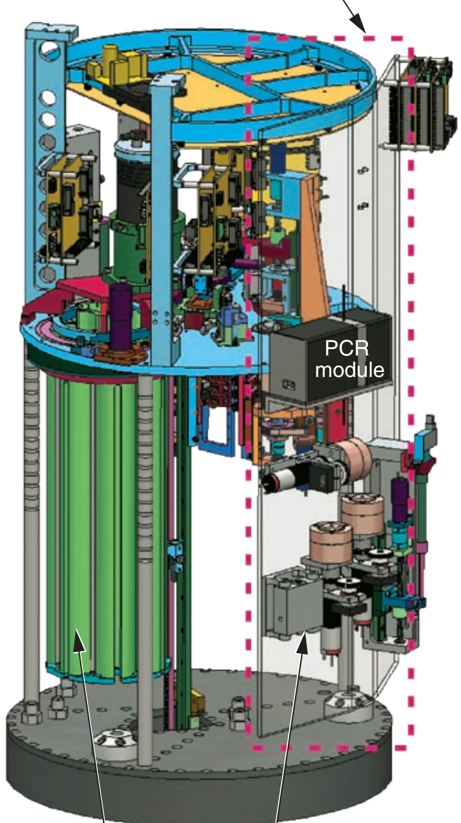
To analyze marine organisms in their native habitats, MBARI scientists developed the Environmental Sample Processor (ESP). This remote instrument system collects water samples and puts them through several stages of filtration to obtain a variety of microbes. The processor lyses, or dissolves, the filtered cells to obtain DNA, RNA, and proteins. It then forwards concentrated extracts to instruments that analyze the genetic material and identify the microbes and their gene products, such as deadly marine toxins. ESP also archives samples for further analysis after the device is recovered and returned to land.

ESP consists of three major components: the core sample processor (or core ESP), a sampling module, and add on analytical modules. The core ESP extracts target molecules from filtered particulate matter and performs DNA and protein array analyses. This component handles sample volumes from a few milliliters to several liters at depths to 50 meters. Below 50 meters, an external sampling module introduces depressurized seawater into the core ESP, which operates internally at about 1 atmosphere regardless of depth.

Analytical modules such as Livermore's PCR module are stand-alone systems that provide enhanced analysis downstream of routine sample-processing operations.



Electrical engineer Scott Jensen of the Monterey Bay Aquarium Research Institute (MBARI) works on the second-generation Environmental Sample Processor (ESP). A self-contained robotic laboratory, ESP collects water samples, concentrates microbes, and automates instruments that identify microbes and their gene products. (Courtesy of Kim Fulton-Bennett, MBARI, © 2005.)



This model shows the core ESP with a PCR module and microfluidic block attached on the right-hand side. (Courtesy of MBARI, © 2008.)

In addition to the three primary components, outside environmental sensors monitor temperature, depth, and salinity and measure the concentrations of chlorophyll, nitrates, dissolved gases, and other substances.

According to MBARI molecular biologist Chris Scholin, the limited number of sampling opportunities has hindered marine life studies. Organic material is often collected in brief surveys conducted by costly research vessels. The resulting data "snapshots" may not reflect the dynamics of fluctuating populations and metabolic changes that microbes undergo in response to changing environmental conditions.

To overcome the problems posed by typical at-sea scientific investigations, MBARI researchers have designed ESP to be a plug-and-play sample-processing device. "ESP is a lab in a can," says Scholin. "It can operate continuously for weeks to a month in the same location." With ESP, researchers can conduct biological analyses remotely, in real time, using the processor's interactive functionality. Its long-term deployment capability allows scientists to determine if certain types of microbes are present at a particular place and time and to archive samples for future analyses.

MBARI currently has six ESPs (including a deep-water version), each measuring about 0.5 meters wide by 1 meter tall. Units weigh 32 to 45 kilograms, depending on the instruments selected for the mission. In the past several years, Scholin and his team have used ESPs in experiments near the sea surface (within the upper 15 meters) in Monterey Bay to study microscopic marine life, such as bacteria, archaea, phytoplankton, toxins produced by algae, and small invertebrates.

In one project, they examined archaea, primitive single-celled organisms that contain no cell nucleus and live in hot springs and deep-sea vents. Archaea are important components of Earth's carbon cycle (in which carbon compounds move between air, land, and sea) and its nitrogen cycle (the process that transforms nitrogen and nitrogen-containing compounds in nature). Also of considerable interest is phytoplankton, or planktonic plant life, which encompasses a variety of microalgae that live near the water surface and absorb light for photosynthesis. Phytoplankton are important because they provide a major source of food to aquatic life.

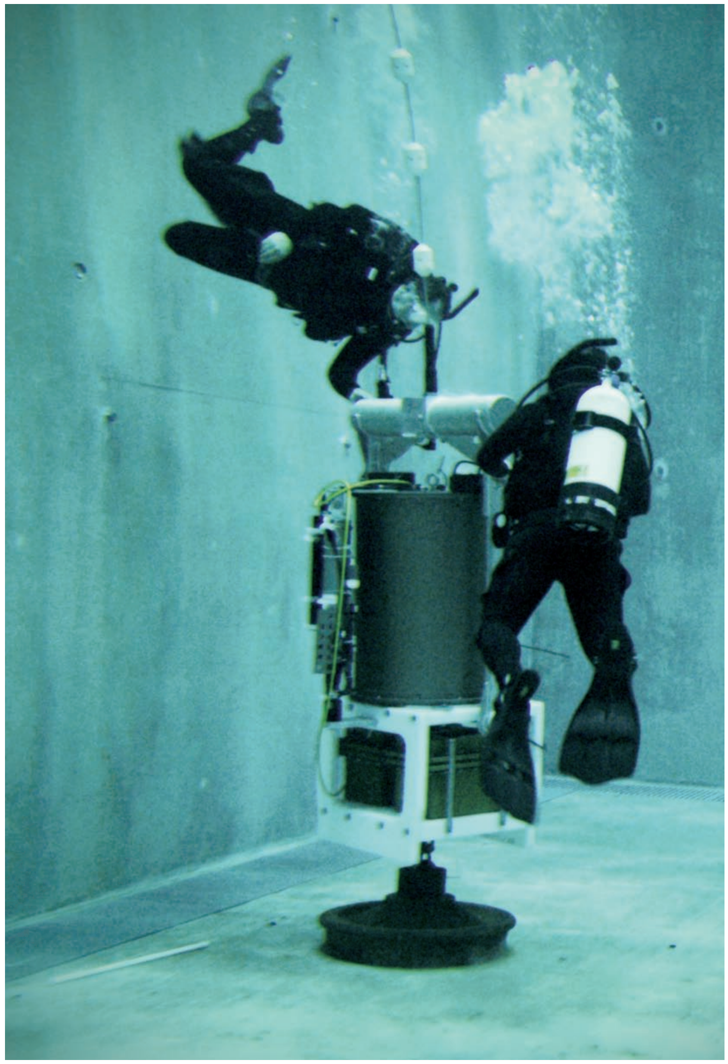
Improving Data Fidelity

The assays deployed onboard every ESP include DNA and protein arrays, which identify selected organisms and metabolites. Although these tests are useful, identifying particular genes with high confidence requires the higher fidelity analyses provided by PCR, a technique widely used in molecular biology. PCR generates millions of copies of a particular DNA sequence for easy identification. The method relies on repeated heating and cooling cycles to quickly replicate the targeted DNA in the large quantities needed for research. However, because PCR does not test for all unknowns, scientists must decide what organisms to look for before processing begins.

The technique features short DNA fragments called primers, which contain sequences of nucleotides (the building blocks of DNA) that complement the DNA region targeted for study. As a sample is heated, its two intertwined strands of DNA unwind. During the cooling process, DNA makes a copy of itself through an enzyme called DNA polymerase, provided the primers find their complementary sequences in the sample. In one heating and cooling cycle, the amount of targeted DNA approximately doubles—a replication process that takes less than 2 minutes. Within 30 cycles, a single molecule of DNA is amplified more than 1 billion times.

A synthesized DNA probe tagged with a fluorescent dye is introduced between the primers. An increase in fluorescence indicates that the targeted DNA sequence has been detected. When more copies of the target are present, the signal is stronger. Each PCR channel is assigned a different color of light to process more than one type of DNA. Because PCR amplifies the regions of DNA that it targets, it can discriminate between slightly different species. For example, it can distinguish pathogenic from nonpathogenic strains of the same species.

PCR is both more sensitive and more specific than the standard probe arrays. "With the DNA probe arrays on ESP, we can look for more targets simultaneously but with less sensitivity than PCR offers," says Scholin. "PCR allows us to search for target molecules that we can't find with other ocean-deployable instruments. We can study genes that regulate the nitrogen cycle, for example, or that are involved in a certain biochemical pathway. We can target a specific species or a general class of species that share the same gene. By combining DNA probe arrays and PCR, we can obtain a community profile and quantify the presence of particular genes."



Divers test an ESP in a deep-water tank prior to ocean deployment. (Courtesy of Todd Walsh, MBARI, © 2006.)

Tapping PCR Experience

MBARI turned to Livermore researchers to design the compact PCR module because of their expertise with this technology. Over the past decade, the Laboratory has developed a number of PCR-based systems that rapidly detect and identify airborne biological agents. Among such systems are the handheld advanced nucleic acid analyzer and the autonomous pathogen detection system (APDS). APDS monitors the air for biological threat agents including bacteria, viruses, and toxins, and units can operate continuously in public areas such as subway stations.

"Our challenge was to develop a compact, low-power, smart system to run PCR reactions and take measurements," says Livermore chemical and mechanical engineer John Dzenitis, who led the PCR module development effort. "Running PCR underwater had never been done before. We were confident we could do it, though, because operating the sample processor is analogous to running an APDS unit underwater. Before we developed APDS, no one had autonomously operated this type of detector in a subway."

The performance goals for the PCR module were similar to those for an APDS unit, but the underwater device had to be self-contained. In addition, the Livermore team wanted to provide fast heating and cooling cycles and at least two optical channels for reading concentrations of different fluorescent-labeled molecules. The team also had to ensure that the device drew minimal power from ESP's marine batteries and interfaced seamlessly with the processor's fluid-shuttling systems. Finally, the module had to be easy to program and able to function without receiving external commands.

To achieve these goals, team members focused on specific aspects of the module design. Bill Benett worked on mechanical design and low-power heater fabrication, while Dean Hadley developed the analog electronics. Former Laboratory engineer Tony Makarewicz was responsible for optics and fluidics integration, and Vincent Riot designed the digital electronics and the related software. "Vincent's electronics and software really set this PCR module apart from previous designs," says Dzenitis. "The controller offers a simple but flexible command set and has proven to be very reliable."

The Livermore team assembles each device, programs the software, and checks out the system before transferring a module to MBARI. A master controller and subsidiary processors allow the module to operate without external commands. Custom software instructs each channel what to do, including the number of heating and cooling cycles to run for different samples.

Module components are enclosed in a black box measuring 13 centimeters long by 7 centimeters high by 5 centimeters wide and weighing about 425 grams. (See the figure below.) One or two units can fit easily inside an ESP. Current designs feature two PCR channels with the capacity for two additional channels, one of which can be used as a control. Module interfaces include 12-volt direct-current power, tubing for samples and reagents, and data transmission.

In operation, the PCR module receives a concentrated extract of DNA taken from marine microbes. The module then amplifies the target DNA molecules, measures their fluorescence, and reports the results. The device requires one to two hours from the time it receives a sample to confirm the presence of a specific gene or section of DNA.

In fall 2008, MBARI deployed a prototype PCR module in an ESP suspended to a depth of 10 meters about 10 kilometers offshore in Monterey Bay. The module was fielded a second time in May 2009, also off the Monterey coast. Both missions lasted about a month. An electromechanical cable connected to a radio modem on a surface float transmitted commands and data. In both field tests, the PCR module successfully identified a series of target genes.

Active and Sleep Modes

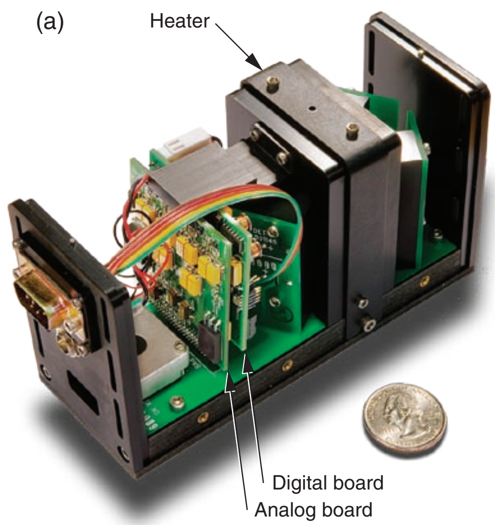
Unlike Livermore's APDS, the underwater ESP does not operate the PCR module continuously. Instead, the module runs intermittently based on a programmed schedule. After sample processing is complete, the module reverts to "sleep" mode to conserve power. MBARI scientists and engineers are developing the capability to autonomously trigger specific PCR analyses in response to an external event, such as a sudden change in seismic activity, temperature, or water chemistry. Says Riot, "If needed, the module could process samples every day at the same time, or if conditions dictate, do many reactions for a few days, or follow any other schedule."

Water samples are processed within the core ESP by metal disks called pucks, measuring 30 millimeters in diameter and 17 millimeters tall. The pucks serve as surrogates for a traditional laboratory bench. Located in a rotating carousel, the pucks collect and homogenize large-volume samples and process probe arrays for nucleic acid and protein analyses. Pucks also can preserve samples for later analysis on shore.

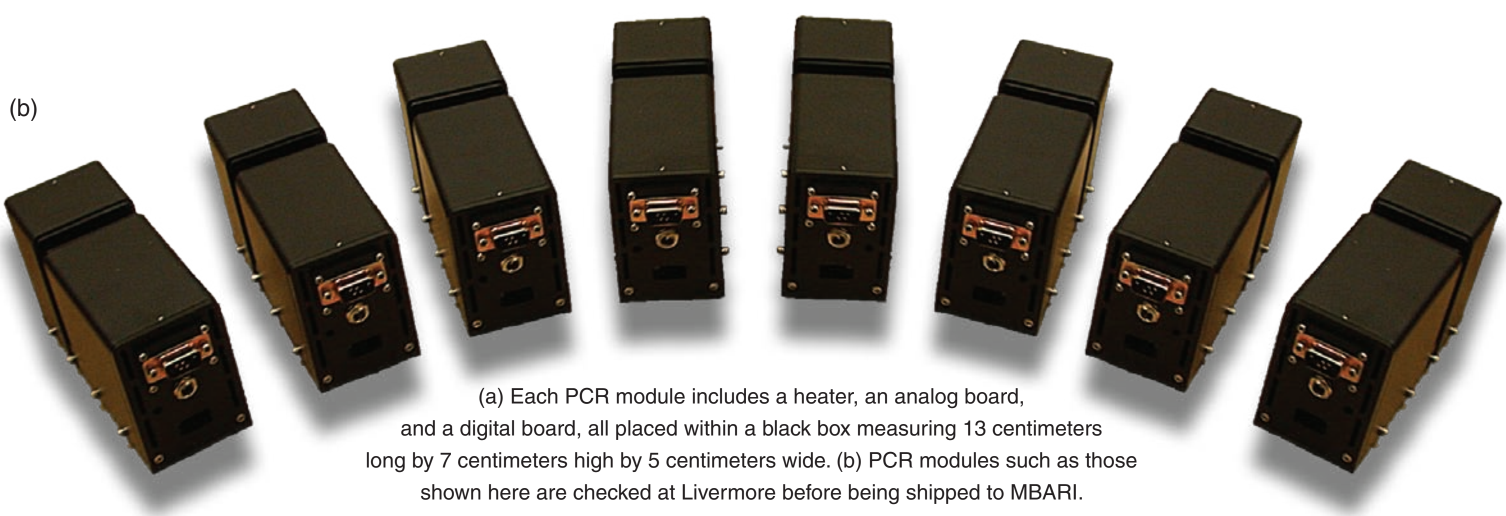
Once microbes are filtered, chemicals break down their cell walls and release their genetic material into solution for testing. Samples then pass over a puck imprinted with an array of tiny dots that contain chemical mixtures and fragments of DNA probes used to identify organisms. In a similar process, protein arrays detect certain proteins such as domoic acid, an algal neurotoxin that can be deadly to marine life and humans.

The PCR module requires more extensive sample preparation than that needed by the DNA and protein arrays. To meet that need, the Livermore team helped MBARI design a separate fluid-handling system for the core ESP. Called a microfluidic block, this device distributes samples and reagents via a series of valves and pumps. It also takes

(a)



(b)



(a) Each PCR module includes a heater, an analog board, and a digital board, all placed within a black box measuring 13 centimeters long by 7 centimeters high by 5 centimeters wide. (b) PCR modules such as those shown here are checked at Livermore before being shipped to MBARI.

crude sample homogenates from the core ESP and processes them, for example, purifying the DNA. It then combines purified DNA with chemicals and shuttles microliter quantities of the mixture into the PCR module. “Like the fluidics module in APDS, the microfluidics block is an automated platform,” says Dzenitis. “It follows the same steps a biologist performs with pipettes in preparing samples for a benchtop PCR instrument.”

Designed for Deep Water

Although the PCR module can be used on all ESPs, it was designed with Deep ESP in mind. This version of the processor, which can operate in waters as deep as 4,000 meters, includes an original ESP surrounded by a 1-centimeter-thick titanium pressure housing. The Deep ESP sampling module can take in up to 10 liters of water at pressures of up to 400 atmospheres. It then decompresses the water to about 1 atmosphere and pumps it into the core ESP. Together with its sampling module and support frame, Deep ESP weighs several thousand kilograms. Underwater, however, it is only about 45 kilograms because of buoyancy provided by air in the pressure housing and in blocks of special flotation foam bolted to the top of the processor’s frame.

Deep ESP can be placed on the sea bottom and hooked to a cable carrying power and data from shore or a buoy and linked by satellite to researchers on shore. MBARI researchers ran the first samples through a Deep ESP in May.

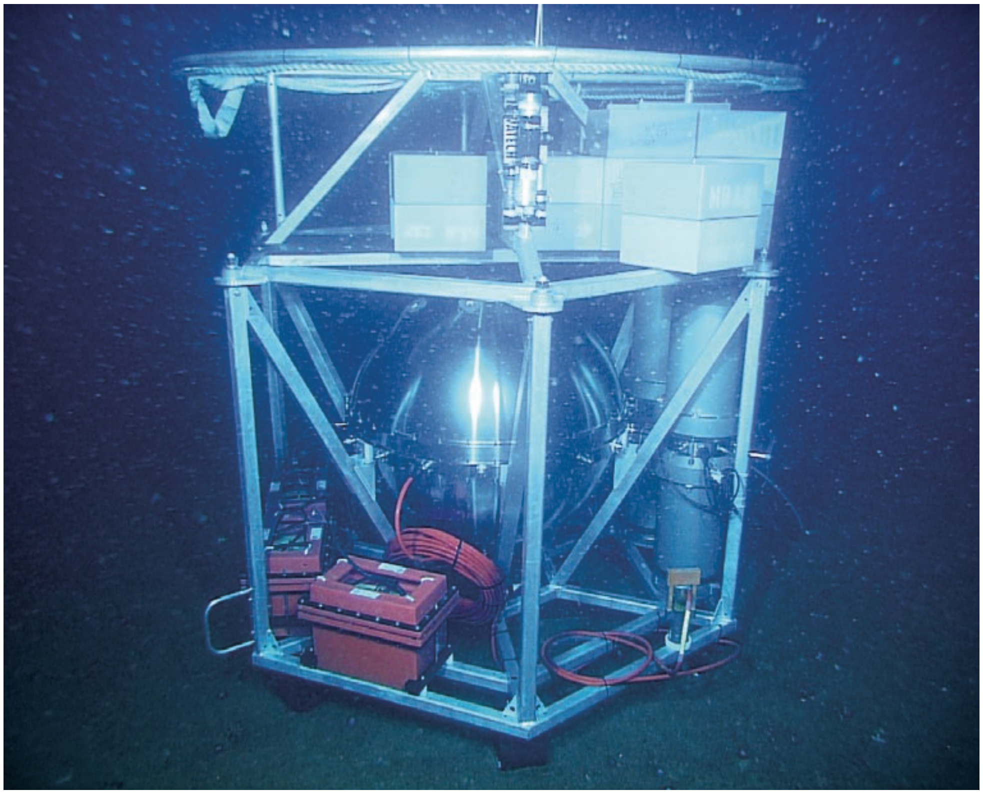
In its first sea trial, Deep ESP is lowered into Monterey Bay from the research vessel Point Lobos. Designed for depths to 4,000 meters, the instrument is enclosed in a titanium pressure vessel and protected by a strong support frame. Several blocks of flotation foam are secured to the top of the frame. (Courtesy of MBARI, © 2009.)

Scientists are especially interested in using Deep ESP to study organisms that have evolved over millions of years to survive in such extreme environments as the methane seeps in the Santa Barbara Basin or the hot, deep-sea vents found at the Axial Seamount submarine volcano off the Oregon coast. The MBARI team has planned a Deep ESP expedition near the Axial Seamount for 2009 to study the interaction between volcanic events and thriving microbial populations. Another potential study environment is adjacent to methane hydrate (“fire ice”) outcroppings off California, Oregon, and Washington. These outcroppings, which consist of methane trapped within ice, support large microbial populations.

The Livermore team delivered three PCR modules to MBARI in early 2009, and another eight units are in assembly. Later this year, a Deep ESP containing the PCR module will be connected to the Monterey Accelerated Research System. This undersea observatory includes a 52-kilometer cable that carries data and power to an electronics package called a science node located 890 meters below the surface of Monterey Bay. With this system, researchers can remain onshore while they run experiments and gather data.

Growing Interest

MBARI scientists report increasing interest worldwide in using ESPs. Researchers have proposed applying the processors to study ecologic relationships among the thousands of marine microbe species, to detect harmful or toxic microbes for monitoring water quality and managing water resources, and to explore other areas of extreme environments. Data gained from ESP research will likely help scientists improve their understanding of Earth’s oceanic processes, many



In initial tests, Deep ESP operated on the seafloor about 640 meters below the surface. (Courtesy of MBARI, © 2009.)

of which are strongly influenced by microbial communities.

The Laboratory, meanwhile, has received interest in licensing its compact PCR technology. Livermore's Industrial Partnerships Office is currently in license negotiations with Spyglass Biosecurity, Inc., a small San Francisco startup company.

The advances incorporated in the PCR module may soon be added to other Livermore devices. For example, in current APDS units, interactions between the master controller and the components it regulates can be troublesome. On the next version of APDS, Livermore designers plan to offload the control for most functions to smart electronic cards. Such a change, says Riot, would simplify APDS operation and make the instruments more robust.

Scholin notes that the development of ESP and its deep-water version, along with PCR and other analytical modules, provides NASA with a model for developing a compact, low-power device to search the solar system for signs of life. "NASA faces many of the same problems ocean scientists do in terms of sample acquisition, preparation, autonomous operation, and data transmission," he says.

Dzenitis adds that the Livermore researchers are proud that they could tap national security expertise to contribute to efforts for monitoring the health of the oceans, discovering life on Earth—and perhaps exploring other worlds, as well.

—Arnie Heller

Key Words: archaea, Astrobiology Science and Technology for Exploring Planets Program, autonomous pathogen detection system (APDS), Environmental Sample Processor (ESP), Europa, Monterey Bay Aquarium Research Institute (MBARI), polymerase chain reaction (PCR) module.

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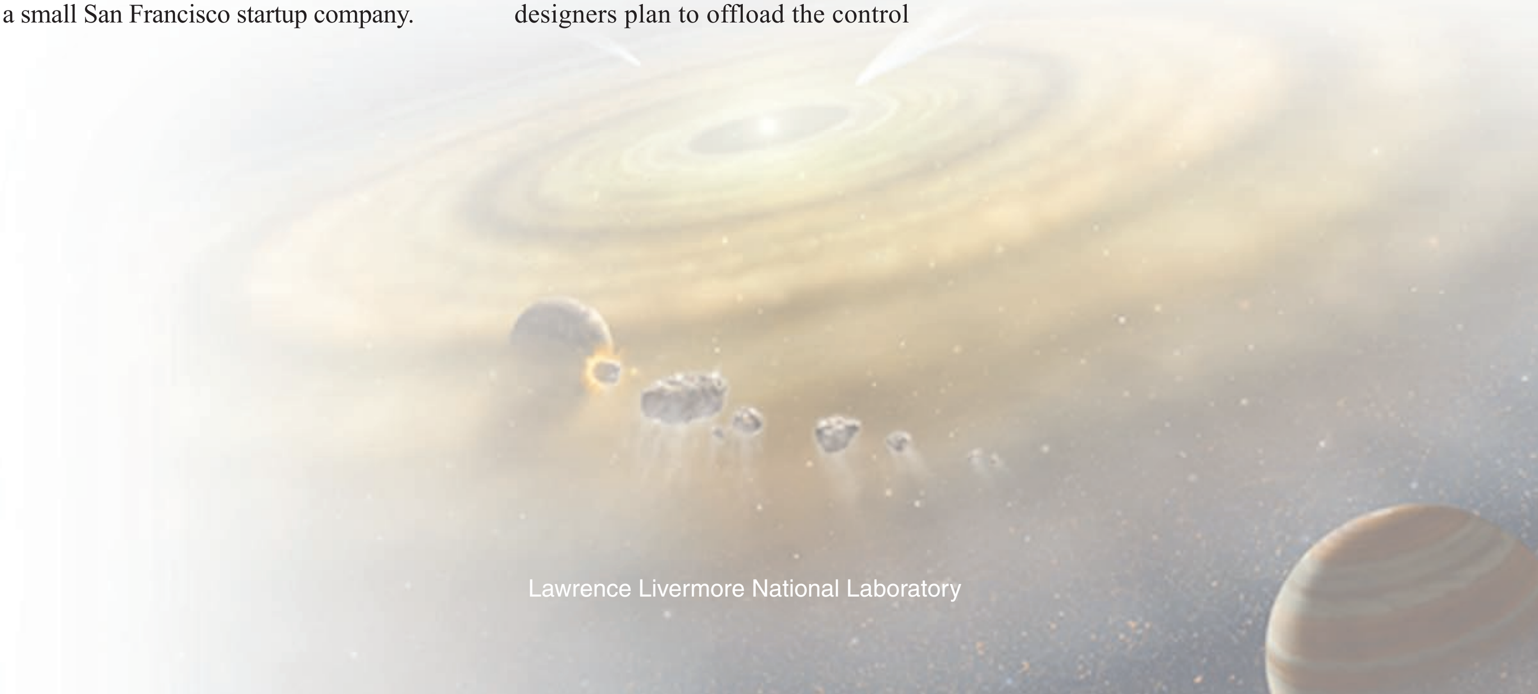


Energy Goes with the Flow

LAWRENCE Livermore produced the first diagrams illustrating U.S. energy use in the mid-1970s. Portraying U.S. energy resources and their ultimate use, these diagrams, called energy flow charts, help scientists, analysts, and other decision makers to visualize the complex interrelationships involved in powering the nation. The charts continue to provide value, drawing widespread attention and praise from such organizations as the National Academy of Sciences and the President's Council of Advisors on Science and Technology.

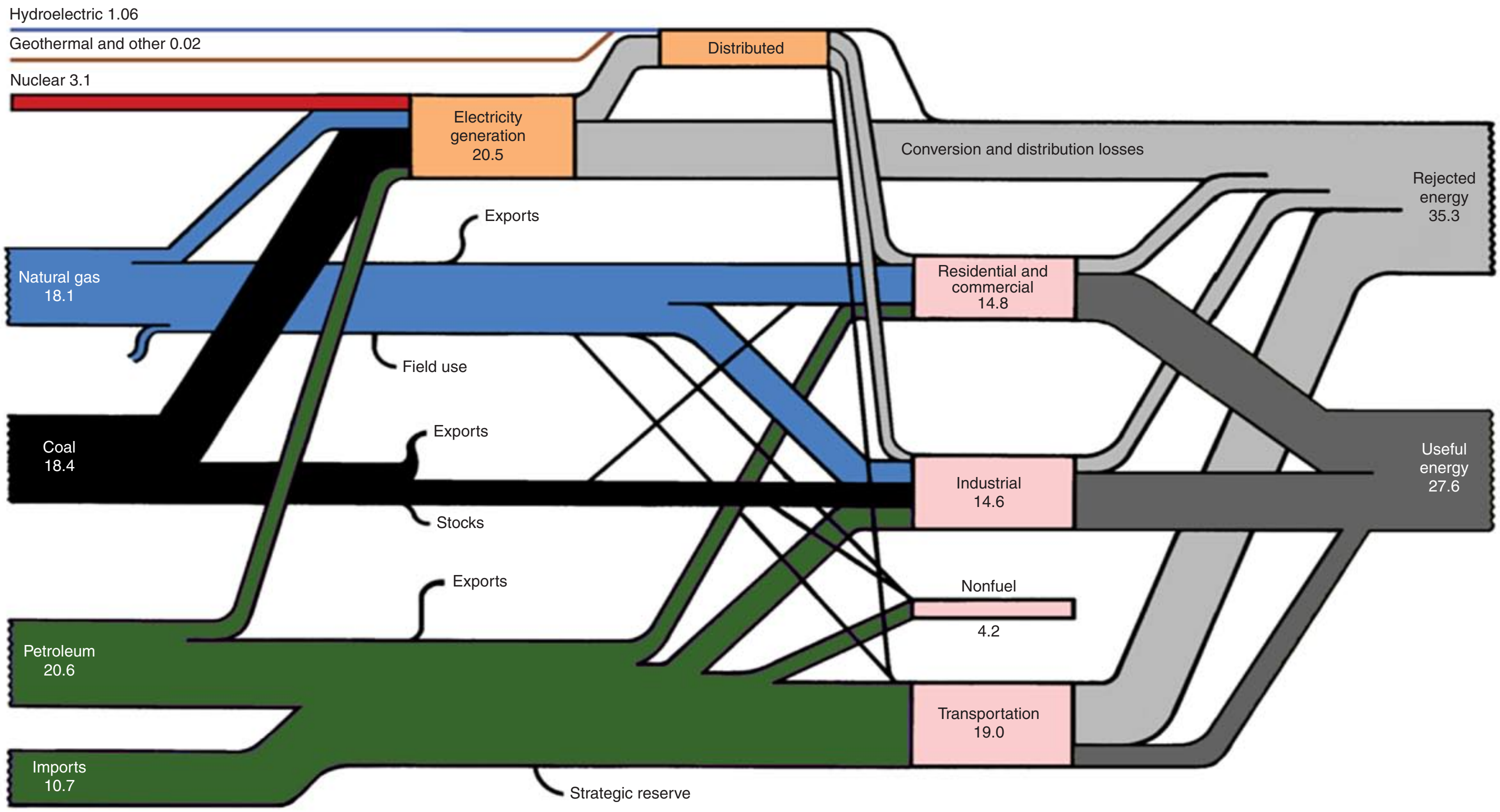
Nalu Kaahaaina, deputy project director for Energy and Environmental Security in the Global Security Principal Directorate, has overall responsibility for Livermore's development of the energy flow charts, and engineer A. J. Simon leads the analysis. The researchers, both previously lecturers at Stanford University, note that the Laboratory's work on the energy diagrams is one reason they chose to come to Livermore. "A huge community of experts is performing energy systems analysis," says Simon, "but Livermore is one of the few organizations that distills 'the big picture' into a concise visual representation." Because the Laboratory's staff includes a variety of experts working across disciplines, it is uniquely qualified to develop the charts.

A single energy flow chart for U.S. resources and their use represents vast quantities of data from the Department of Energy's Energy Information Administration (EIA). In 2007, for example, energy resources included solar, nuclear, hydroelectric, wind, geothermal, natural gas, coal, biomass, and petroleum. Fully 40 percent of the total resources expended produced electricity—to power hair dryers and coffee makers, run factory lines and agricultural irrigation systems, and keep the lights on. All nuclear energy and virtually all coal resources went toward electricity generation as well. The uses for natural gas, another major resource, were more varied. Petroleum, the largest single resource, representing almost 40 percent of total energy inputs, continued to be used primarily to fuel cars, planes, and other forms of transportation.

A Snapshot of Changing Technologies

Energy flow diagrams change over time as new technologies are developed and as priorities change. (See the figures on pp. 18–19.) Twenty-five years ago, the U.S. consumed 70 quadrillion British thermal units (or quads) of energy compared with 101.5 quads in 2007, an almost 50-percent increase. In 1982, a primary concern was whether energy sources were domestic or imported.

"Alternative" energy resources such as wind and solar did not figure into the 1982 diagram at all. Solar energy appears on the 2007 chart, but it is used almost exclusively by private homeowners. This detail reflects the expense of the technologies that collect solar radiation and transform it into electricity relative to the cost of systems that deliver other forms of energy. As a result, choosing solar energy as a power source is usually an individual decision.



The first energy flow diagrams such as this one from 1982 required a technical specialist to review data from the Department of Energy's Energy Information Administration and a graphics designer to produce the image.

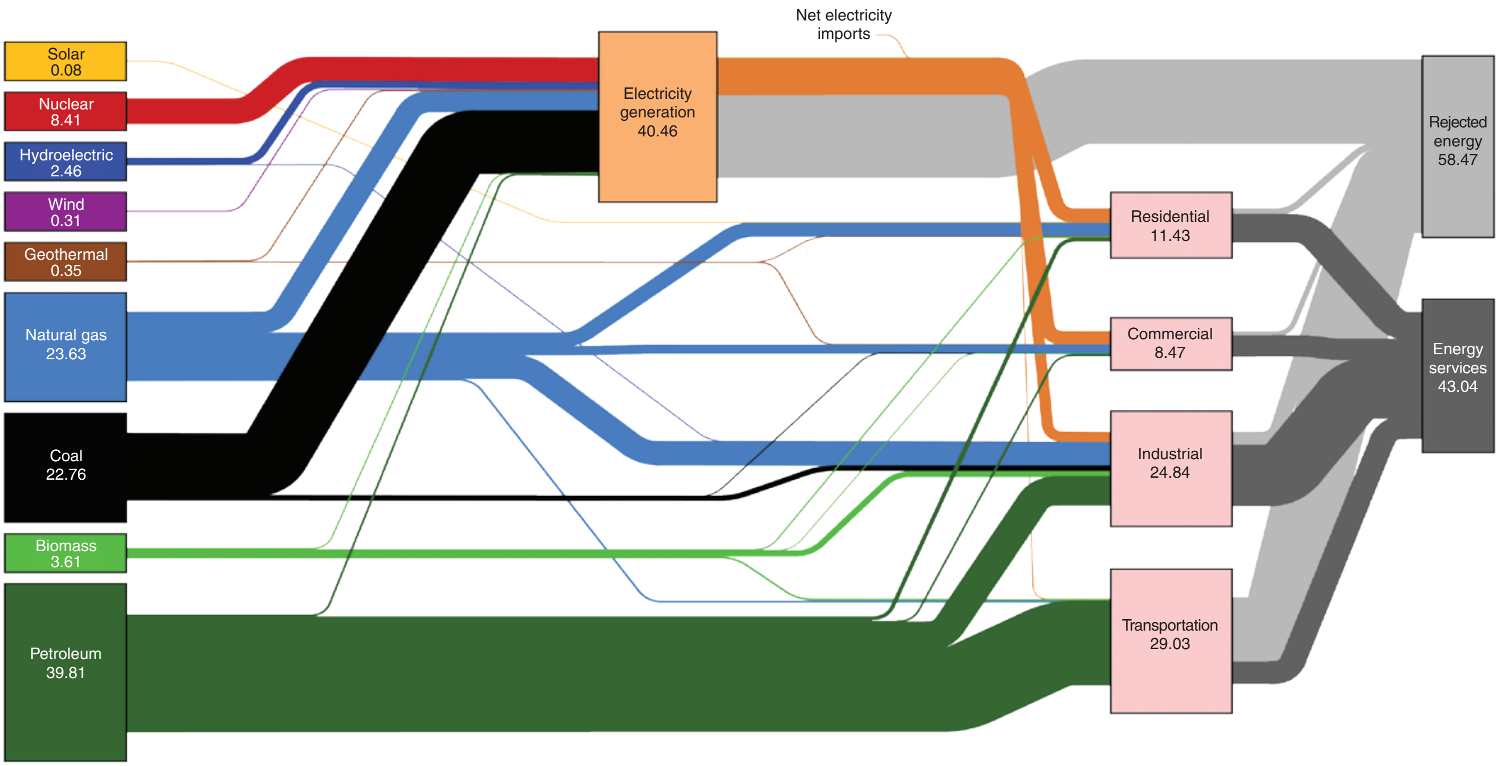
Considerable research and development is under way to make solar and other forms of energy less expensive and more available to the public. In fact, the newest charts, which are available online at publicaffairs.llnl.gov/news/energy/energy.html, show that this effort is producing results. Not only did Americans reduce their energy usage from 101.5 quads in 2007 to 99.2 quads in 2008, but also more of that energy came from renewable resources. Nuclear power continues to make small gains through increased reliability. Thus, if current clean energy policies are successful, the flow chart for U.S. energy sources and their use will look very different by 2032.

Capturing the Big Picture

An integrated approach to energy resources and how they are consumed must consider all scales across all disciplines. "For example," says Kaahaaina, "energy processes for a vehicle can be examined from the individual chemical reactions in a combustion engine to the mechanics of the drive train to the national demand for fuel. These problems affect engineers, physicists, and economists, all of whom speak different technical languages. By better representing energy networks, the Laboratory can help bridge these technical communities."

Simon has already harnessed Laboratory expertise in algorithm design, physics-based modeling, and system analysis to produce increasingly refined assessments of U.S. energy resources and consumption. "Originally, producing these charts required a member of our technical staff to review an EIA report and a graphics designer to produce the image," says Simon. "Now, we automate the routine data synthesis with a software engine that renders the image." Instead of having a person read through a 400-page report, the analysis tool calculates a set of intermediates, ultimately generating approximately 30 energy statistics. This greatly speeds the process—which once took a week—enabling the analyst to now spend a few hours interpreting the results after only a few seconds of processing.

"The relative simplicity of the diagrams sometimes belies the initial effort to build them," says Simon. "Ultimately, this effort is about taking complex systems and sharing them with broader audiences. The less daunting the information is, the more impact it can have. Simplicity is a compliment."



Comparing this 2007 energy flow chart with the 1982 diagram on p. 18 highlights the massive increase in energy consumption during that 25-year period, the new resources in use today, and the changing concerns about the origin of energy resources. The 2008 chart (available online at publicaffairs.llnl.gov/news/energy/energy.html) shows that U.S. energy usage dropped from 101.5 quadrillion British thermal units, or quads, in 2007 to 99.2 quads in 2008.

The next logical step for Kaahaaina and Simon is to apply the science of informatics to the less structured data, particularly data gathered from otherwise distinct technical fields. Such a step would reduce the barriers to optimizing large systems. Energy informatics would combine Livermore's substantial computational capability with expertise in energy technology to organize and process data in ways that make it more accessible.

"Examining information across scales and disciplines requires quick access to the data at many levels," says Kaahaaina. "Our national figures offer a high-level view of what energy means. In reality, the national energy network comprises many layers of technology, from microscale chemical mechanisms to mesoscale devices and macroscale infrastructure. Addressing all of these scales comprehensively requires both dexterity of information and the array of technical disciplines needed to process that data sensibly."

Energy informatics will improve the methods available for visualizing these types of data. As a result, says Simon, "We will be better able to answer the questions we receive from other researchers, and we can develop more useful products for a variety of users." The team is currently searching for a sponsor to support an energy informatics program at the Laboratory.

For Livermore's mission-related work on energy and environmental security, the flow charts are an ideal tool to analyze not only energy but also carbon, water, and other relevant "networks." One chart portrays the estimated carbon dioxide emissions associated with all energy resources. Such analyses provide insights that simultaneously enable system optimization, for example, identifying underused resources or the need for better technology, and reveal cross-system couplings, such as carbon embedded in energy or water demand for electricity generation.

"I think of the energy flow charts as yet another example of 'thought leadership' at the Laboratory," says Kaahaaina. "The diagrams contain so much data, they can be used in many different ways by a variety of groups."

—Katie Walter

Key Words: carbon dioxide emissions, energy consumption, energy flow charts, energy flow diagrams, energy resources.

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The Radiant Side of Sound

Samples for each experiment are taken from 10-centimeter-diameter silicon wafers layered with gallium nitride. Each wafer is sputter-coated with an aluminum layer (reflective surface) only a few hundred nanometers thick.

SOUND is an integral part of the human existence. It propagates through the environment at various frequencies, allowing us to hear music from our radios and voices through our cell phones. But not all sound is audible to the human ear. Some acoustic waves have terahertz frequencies—that is, they oscillate at 10^{12} cycles per second. Sound in this range is too high for humans to hear, but researchers are finding that these high-frequency waves are exceedingly useful for scientific research.

In collaboration with Los Alamos National Laboratory and Nitronex Corporation, Livermore physicists Evan Reed and Michael Armstrong have discovered that by propagating acoustic waves through materials with different piezoelectric coefficients, they can transform waves at terahertz frequency into electromagnetic radiation of the same frequency. "We have developed a fundamentally new technological pathway to get into terahertz regimes," says Reed. "We first predicted this phenomenon using molecular dynamics simulations." With the help of an ultrafast laser and piezoelectric micrometer-thick heterostructures, they have become the first to observe the predicted behavior.

Reed and Armstrong, both of whom work in the Laboratory's Science and Technology Principal Directorate, want to measure acoustic waves up to approximately 10 terahertz—the frequencies predicted to occur at the front of shock waves. Funded by Livermore's Laboratory Directed Research and Development Program, their research is primarily geared toward developing high-resolution diagnostics for examining the shock and strain that materials undergo during laser experiments. Their new terahertz radiation generation and detection method is sparking interest outside the Laboratory as well. Within the semiconductor industry, it could serve as an improved, more direct approach for investigating the structural properties of thin films used to make computer chips.

Blazing a New Trail

Research over the last several years has shown that intense optical pulses from lasers can generate acoustic waves and radiation at frequencies of about 2 terahertz. Optical probes detect the acoustic wave by measuring the reflection of a laser beam from the material that has been modified by the acoustic front. As an example, the Livermore-developed diagnostic called VISAR (Velocity Interferometer System for Any Reflector) combines an external probe and sophisticated electronics to measure strain in materials during high-energy-density laser experiments. Optical probe techniques have time resolutions from 0.1 to 1 nanosecond (where 1 nanosecond is one-billionth of second). “This range is too slow to accurately measure the time history of strain waves at the highest acoustic frequencies,” says Armstrong. “Our new detection method allows us to probe the actual wave.”

For the experiments, Nitronex Corporation in Durham, North Carolina, supplied the Livermore team with silicon substrates coated with a layer of gallium nitride (GaN). The team sputter-coated each substrate with a 260- to 700-nanometer-thick layer of aluminum. An ultrafast laser then generates a 100-femtosecond-long pump pulse (where a femtosecond is one-quadrillionth of a second) with an 800-nanometer wavelength and approximately 1 millijoule of power and fires it at each substrate. The aluminum absorbed the energy from each pulse, causing that layer to heat and expand. This surface expansion created strain in the material, and the resulting acoustic wave propagated through the aluminum to the interface between the aluminum and GaN layers. At that boundary, material compression from the acoustic wave generated polarization currents through the piezoelectric effect, producing terahertz radiation, or light, which was then emitted from the material.

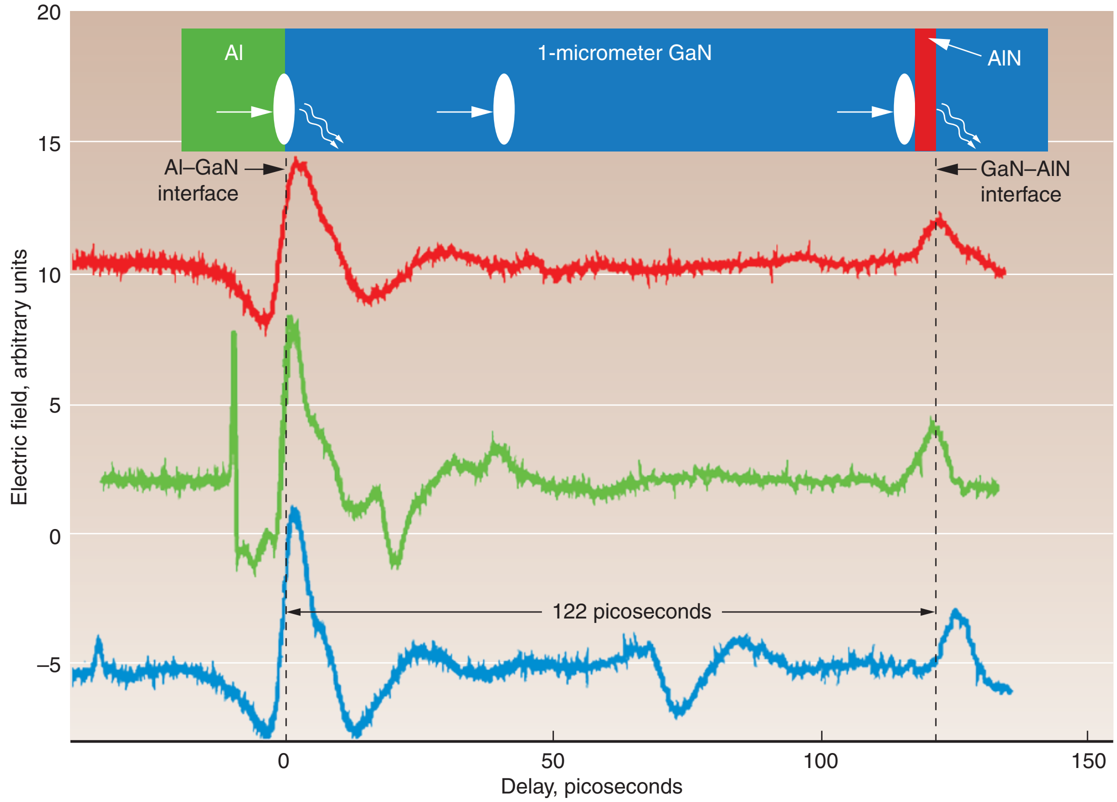
The team applied a standard technique known as electro-optic sampling to detect the radiation from a distance of a few millimeters. “Basically, we use a nonlinear optical process in which we write the terahertz radiation onto an optical pulse and then read the wave off the pulse,” says Reed. A brief terahertz signal produced by fast, nonlinear processes that occur when the laser pulse hits the aluminum layer denotes the time the acoustic wave was generated. After this wave transits the aluminum layer, it travels through the interface, generating terahertz radiation that provides the wave’s time history.

The laser pulse power is set low enough to be nondestructive to the material. Thus, to obtain an accurate estimate of time history, Reed and Armstrong had to average the signals produced by many pulses hitting one substrate. “Ultimately, we want the same results using a single shot,” says Armstrong.

Applications Abound

Terahertz signals have wavelengths approaching the atomic scale—about 0.5 nanometers—allowing them to form and propagate through extremely small material thicknesses. As a result, the semiconductor industry is interested in adapting the Livermore technique to measure the thickness of substrate layers in computer chips. To test the feasibility of this application, Reed and Armstrong experimented with substrates containing a layer of aluminum nitride (AlN) beneath the GaN layer. They then analyzed three samples, measuring the time it took the acoustic wave to travel through the GaN layer to the GaN–AlN interface. The slight time delay between the first and second terahertz signal produced by one substrate indicated that its GaN layer was thicker than those layers in the other samples.

A subpicosecond laser pulse fired onto a piezoelectric sample produced a compressive shock wave that propagated through the material, generating terahertz radiation. Light was measured on the other side of the sample.



The Livermore team conducted experiments with substrates containing multiple layers of piezoelectric materials: aluminum (Al), gallium nitride (GaN), and aluminum nitride (AlN). Results showed a slight time delay in the terahertz signal generated at the GaN–AlN interface of the 260-nanometer film (blue curve) compared with the signals for the 70- (green curve) and 560-nanometer (red curve) films. This delay indicates that the GaN layer is thicker in the 260-nanometer substrate.

X-ray ellipsometry, a technique that measures the polarization of light reflected from a surface, is a prominent method in the semiconductor industry for characterizing thin films. According to Armstrong, ellipsometry is an indirect method that models a thin film's optical properties and then compares the results to actual data. Reed and Armstrong's approach is a more direct way to determine layer thickness. "Characterizing thin films is just one application for this type of acoustic wave measurement," says Armstrong.

Although the characterization method has promise for the semiconductor industry, it is first and foremost applicable to mission-related research at the Laboratory. It may enable scientists to better understand how materials act under extremely high pressures and how much pressure can be applied before a material is damaged. It may also provide a better way to evaluate strain and stress in materials used in shock and ramp-compression laser experiments, where pressure is applied incrementally to a sample. (See *S&TR*, June 2009, pp. 22–23.)

Beefing Up Security

The recent work performed by Reed and Armstrong is a testament to how breakthroughs in scientific research can have a broad range of applications. In addition to serving as the basis for new diagnostic and characterization tools, terahertz generation and detection technologies may help improve security applications, such as airport scanners and handheld, high-power devices for detecting explosives in the field. "High-power terahertz sources have the potential to be very compact," says Armstrong. "Our current experiment fits on a small table. With further development, it could eventually fit in the palm of a hand."

Reed and Armstrong already have future experiments planned. "We tested this process using piezoelectric materials," says Reed, "but we want to evaluate it with other materials as well." By further exploring their technique, the researchers may find other applications for their research, demonstrating that "probing" into basic science can sometimes yield unexpected and fruitful results.

—Caryn Meissner

Key Words: acoustic wave, piezoelectric material, ramp compression, shock wave, semiconductor, sound wave, strain, terahertz frequency, ultrafast laser.

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In this section, we list recent patents issued to and awards received by Laboratory employees. Our goal is to showcase the distinguished scientific and technical achievements of our employees as well as to indicate the scale and scope of the work done at the Laboratory.

Patents

Nanolaminate Deformable Mirrors

Alexandros P. Papavasiliou, Scot S. Olivier
U.S. Patent 7,518,780 B2
April 14, 2009
This deformable mirror is made of two layers of a nanolaminate foil attached to a stiff substrate. An electrostatic force between two of the layers causes deformation. The structure's internal stiffness allows for high-spatial-frequency shapes, and the foil provides a high-quality mirror surface. The device achieves high precision in the vertical direction because foil thickness is accurately controlled. However, the device does not require high precision in the lateral dimensions. As a result, those mirrors can be fabricated up to about the meter scale using crude lithographic techniques.

Signal Processing Method and System for Noise Removal and Signal Extraction

Chi Yung Fu, Loren Petrich
U.S. Patent 7,519,488 B2
April 14, 2009
A signal-processing system designed for signal denoising and extraction combines smooth-level wavelet preprocessing with artificial neural networks in the wavelet domain. When the system receives a signal corrupted with noise, it performs an *n*-level decomposition of the signal using a discrete wavelet transform that produces a smooth component and a rough component for each decomposition level. The smooth component is then added to a corresponding neural network that filters out noise by applying pattern recognition in the wavelet domain. Rough components, beginning at the highest level, may also be filtered by corresponding neural networks. The system performs an inverse discrete wavelet transform on the combined output from all the networks to recover a clean signal in the time domain.

Method for Forming a Chemical Microreactor

Jeffrey D. Morse, Alan Jankowski
U.S. Patent 7,534,402 B2
May 19, 2009
A chemical microreactor provides a method to generate hydrogen fuel from liquid sources such as ammonia, methanol, and butane through steam-reforming processes when mixed with an appropriate amount of water. The microreactor contains capillary microchannels with integrated resistive heaters to induce catalytic steam-reforming reactions. One design uses a packed catalyst capillary microchannel and at least one porous membrane. Another design has a porous membrane with a large surface area or a porous membrane support structure containing several porous membranes that have a large surface area in the aggregate (greater than about 1 square meter per cubic centimeter). Various methods can be used to form packed catalyst capillary microchannels, porous membranes, and porous membrane support structures area.

Material System for Tailorable White Light Emission and Method for Making Thereof

Christine A. Smith, Howard W. H. Lee
U.S. Patent 7,535,029 B2
May 19, 2009
This method for processing a composite material tailors white light emission of the resulting composite during excitation. The composite material is irradiated with a predetermined power and for a specified time to reduce the size of nanocrystals and the number of traps in the composite material. This irradiation process intensifies the blue light contribution from the nanocrystals to the white light emission and decreases the red and green light contributions from the traps.

Lipid Nanotube or Nanowire Sensor

Aleksandr Noy, Olgica Bakajin, Sonia Létant, Michael Stadermann, Alexander B. Artyukhin
U.S. Patent 7,544,978 B2
June 9, 2009
A sensor apparatus includes a nanotube or nanowire, a lipid bilayer around the nanotube or nanowire, and a sensing element connected to the lipid bilayer. The biosensor apparatus comprises a gate electrode; a source electrode; a drain electrode; a nanotube or nanowire operatively connected to the gate, source, and drain electrodes; a lipid bilayer around the nanotube or nanowire, and a sensing element connected to the lipid bilayer.

Cellular Telephone-Based Wide-Area Radiation Detection Network

William W. Craig, Simon E. Labov
U.S. Patent 7,545,269 B2
June 9, 2009
A network of radiation detection instruments, each with a small, solid-state radiation sensor module integrated into a cellular phone, provides radiation detection data and analysis directly to a user. The sensor module has a solid-state crystal bonded to an ASIC readout providing a low-cost, low-power, lightweight compact instrument to detect and measure radiation energies in the local ambient radiation field. In particular, the photon energy, time of event, and location of the detection instrument at the time of detection are recorded for real-time transmission to a central data collection and analysis system. The collected data from the entire network are combined by correlation and analysis algorithms, which map the background radiation and detect, identify, and track radiation anomalies in the region.

Flexible Feature Interface for Multimedia Sources

Douglas R. Coffland
U.S. Patent 7,546,603 B2
June 9, 2009
This flexible feature interface can be used to add features and functions to multimedia sources and to access those features and functions from remote hosts. The interface uses the following export statement or its binary equivalent: export "C" D11Export void FunctionName (int argc, char ** argv,char * result, SecureSession *ctrl).

Self Organization of Wireless Sensor Networks Using Ultra-Wideband Radios

Farid U. Dowla, Faranak Nekoogar, Alex Spiridon
U.S. Patent 7,548,576 B2
June 16, 2009
An ultrawideband (UWB) communications system provides self-organization for wireless sensor networks. The self-organization is in terms of scalability, power conservation, channel estimation, and node synchronization. The UWB receiver adds two new units to conventional transmitted reference receivers, one for signal-to-noise ratio enhancement and one for timing acquisition and tracking.

Awards

President Barack Obama has named Livermore physicist **Kennedy Reed** in the Science and Technology Principal Directorate as a recipient of the **Presidential Award for Excellence in Science, Mathematics, and Engineering Mentoring**. The award is given to individuals or organizations to recognize the crucial role that mentoring plays in the academic and personal development of students studying science or engineering and who belong to minorities that are underrepresented in those fields.

Reed has been a leader in national efforts to increase opportunities for minority students and professionals in the sciences. He initiated and directed the Laboratory's Research Collaborations Program for Historically Black Colleges and Universities and Minority Institutions—an innovative program that links Livermore scientists with professors and students in forefront research that benefits the Laboratory and the universities. He also helped establish the National Physical Science Consortium, a coalition of corporations, national laboratories, and universities that provide graduate fellowships for women and minorities in the physical sciences.

The **Department of Energy** (DOE) honored nine scientists in the Laboratory's Science and Technology Principal Directorate with its **Outstanding Mentor Award**. The recipients, **Nerine Cherepy**, **Richard Johnson**, **Sergei Kucheyev**, **Joshua Kuntz**, **Stephan Letts**, **Matthew Myrick**, **Brent Segelke**, **Michael Stadermann**, and **Ross Williams**, were all nominated by the students they mentored during the summer of 2008.

DOE established the Outstanding Mentor Award in 2002 to encourage a culture that values mentorship within the DOE national laboratories. According to DOE, outstanding mentors provide well-defined research projects that match the student's research interests, and they support the student's involvement in enrichment activities beyond the research project. They also provide background material to the student before he or she arrives at the Laboratory, support development of a student's research deliverables, and include the student as part of the research team. In particular, outstanding mentors demonstrate practices that go above and beyond the normal responsibilities to students in the mentoring relationship.

Herbert F. York (1921–2009): A Life of Firsts, an Ambassador for Peace

In 1952, Herbert Frank York, who died on May 19, 2009, was appointed as the first director of the new nuclear weapons laboratory established in Livermore, beginning a pattern of "firsts" that was to continue for a decade. In 1958, York was named the first chief scientist for the new Advanced Research Projects Agency in Washington, DC. Not long afterward, he became the first director of Defense Research and Engineering. Then in 1961, York returned to California as the founding chancellor of the University of California's newly established campus at San Diego. While in Washington, York became convinced that arms control, including a nuclear test ban, would be the most effective route to peace. During his long career, he worked as an arms-control advisor to six U.S. presidents. He also served on the President's Science Advisory Committee and the scientific advisory boards of the Army and Air Force.

Contact: Maxine Trost (925) 422-6539 (trost5@llnl.gov).

Searching for Life in Extreme Environments

Livermore researchers have developed an autonomous module using the well-established polymerase chain reaction (PCR) process for use in underwater Environmental Sample Processors (ESPs) operated by the Monterey Bay Aquarium Research Institute (MBARI). The Livermore-designed device detects and quantifies microbial genes of interest. The device will help MBARI researchers search for new marine life forms and augment their understanding of microbes' roles in responding to global climate change. In operation, the PCR module receives a concentrated DNA extract taken from marine microbes. It then amplifies DNA molecules of interest, measures their fluorescence, and reports the results. Data provided by the PCR module, combined with those from other ESP instruments, should also help the National Aeronautics and Space Administration understand the instrumentation needed for the Astrobiology Science and Technology for Exploring Planets Program, which will search for life on other planets.

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U.S. Government Printing Office: 2009/570-075-71014

Livermore Wins Eight R&D 100 Awards

In *R&D Magazine*'s annual competition for the top industrial inventions, Laboratory researchers won awards for the following technologies:

- Artificial Retina
- FemtoScope: A Time Microscope
- GeMini Spectrometer
- Land Mine Locator
- Laser Beam Centering and Pointing System
- Precision Robotic Assembly Machine
- ROSE: Compiler Software
- Spectral Sentry

Also in October/November

Keeping nuclear materials safe and secure is the business of the Global Threat Reduction Initiative funded by the National Nuclear Security Administration.

Coming Next Issue

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