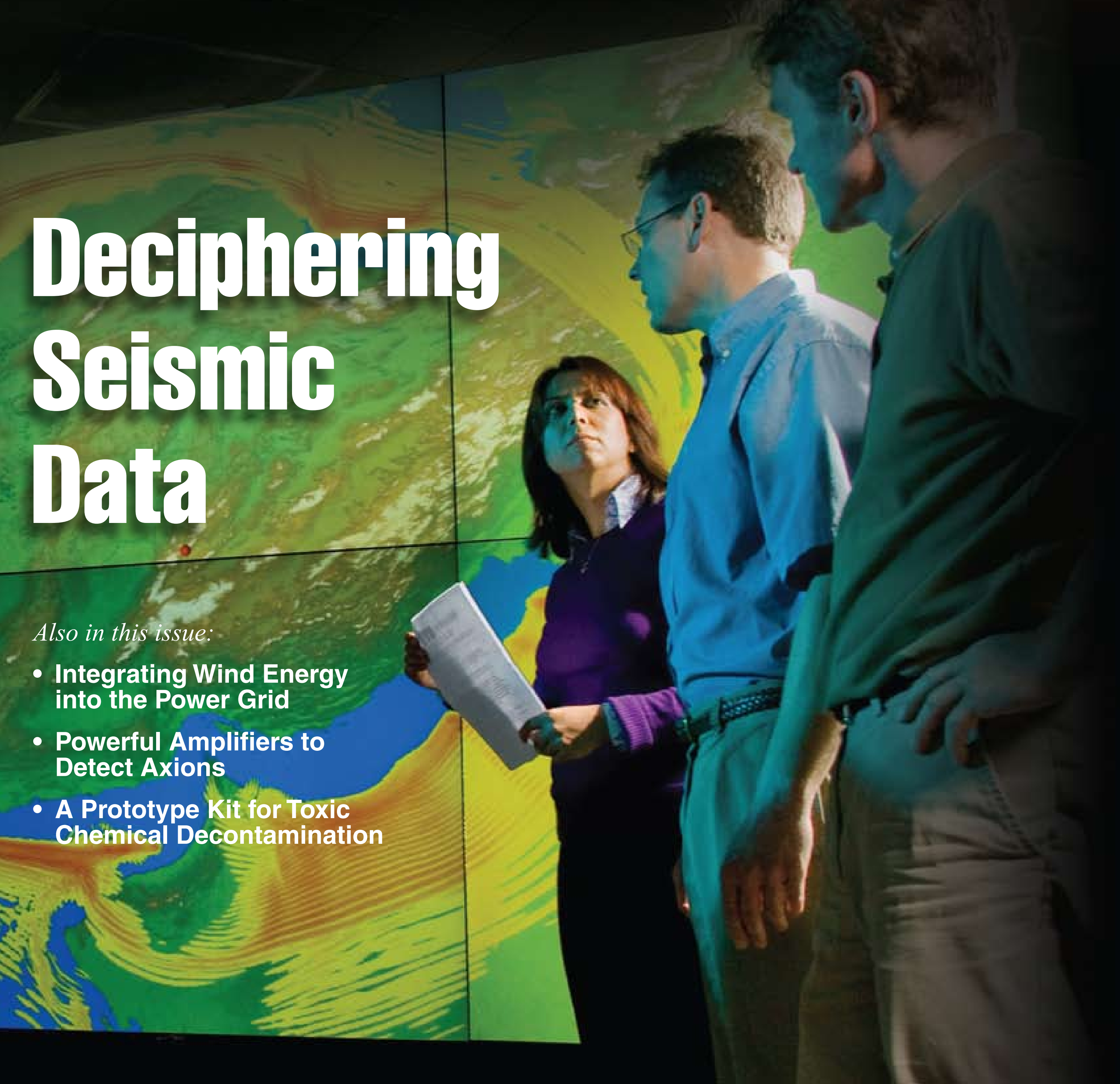
Science & Technology REVIEW

March 2009

National Nuclear Security Administration's
Lawrence Livermore National Laboratory



Deciphering Seismic Data

Also in this issue:

- Integrating Wind Energy into the Power Grid
- Powerful Amplifiers to Detect Axions
- A Prototype Kit for Toxic Chemical Decontamination

About the Cover

Livermore seismologists are developing computational methods that more accurately distinguish nuclear explosions from earthquakes, mine collapses, and the rest of Earth's activity. These new methodologies, some of which are described in the article beginning on p. 4, improve the nation's capabilities for nuclear explosion monitoring. On the front cover, team members (from left) Rengin Gök, Steve Myers, and Anders Petersson examine seismic waves from a simulated event at the location of the 2005 Kerman earthquake in Iran. The back cover shows team members Mike Pasyanos, Bill Walter, and Artie Rodgers. The simulation used Livermore's WPP code with a resolution of nearly 4-billion grid points to propagate long-period waves through a three-dimensional model of Earth.

Cover design: Amy Henke

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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Lawrence
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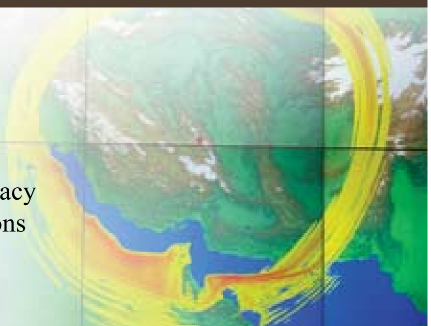

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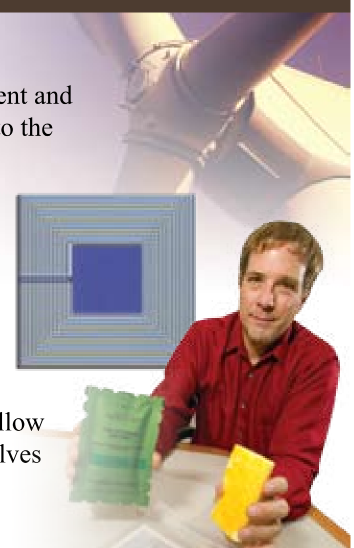

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Billions of Positrons Created for Antimatter Research

A team of Livermore researchers has developed an improved method for creating a large number of positrons in a laboratory, opening the door to new areas of antimatter research. Led by physicist Hui Chen in the Physical and Life Sciences Directorate, the team used a short-pulse, ultraintense laser to irradiate a millimeter-thick gold target. “Previously, we concentrated on making positrons using paper-thin targets,” says physicist Scott Wilks, who designed and modeled the experiment using computer codes. “Recent simulations showed that millimeter-thick gold would produce far more positrons. We were excited to see so many of them.”

In the experiment, the laser ionizes and accelerates electrons, which are driven right through the gold target. The electrons interact with the gold nuclei, which serve as a catalyst to create positrons. Because the laser concentrates energy in space and time, it produces positrons more rapidly and in greater density than ever before in a laboratory.

Particles of antimatter are almost immediately annihilated by contact with normal matter and converted to pure energy (gamma rays). Normal matter and antimatter are thought to have been in balance in the very early universe, but because of an “asymmetry,” the antimatter decayed or was annihilated. Scientists have yet to determine why the observable universe is apparently almost entirely matter, whether other places are almost entirely antimatter, and what might be possible if antimatter could be harnessed.

Laser production of antimatter is not entirely new. Livermore researchers detected about 100 particles in experiments 10 years ago on the since-decommissioned Nova petawatt laser. With a better target and a more sensitive detector, Chen’s team directly detected more than 1 million particles per laser shot. From that sample, the scientists infer that about 100 billion positron particles were produced in total.

Chen presented the team’s results in November 2008 at the American Physical Society’s Division of Plasma Physics meeting.

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Mechanical Response without Heat or Electricity

Laboratory researchers in collaboration with the Institut für Angewandte und Physikalische Chemie of the Universität Bremen and the Institut für Nanotechnologie of the Forschungszentrum Karlsruhe (both in Germany) have found a new method that directly converts chemical energy into a mechanical response without generating heat or electricity first. The team led by chemist Juergen Biener from Livermore’s Nanoscale Synthesis and Characterization Laboratory took a sample of nanoporous gold and alternately exposed it to ozone and carbon monoxide. Using the oxidation of carbon monoxide by ozone as a driver, the team achieved reversible macroscopic strain amplitudes of up to 0.5 percent.

The experiment is based on surface-chemistry-induced changes of the surface stress at a metal–gas interface, which in turn cause the sample to contract and expand. “Like nature’s muscles, our actuator directly converts chemical energy into a mechanical response without generating heat or electricity first,” says Biener.

The team selected nanoporous gold for several reasons. It has remarkable catalytic properties and can sustain high stresses. In addition, its open-cell foam morphology allows for mass transport. The research showed that ozone exposure leads to oxygen absorption, which triggers sample contraction by modifying the surface stress. Exposure to carbon monoxide then restores the original sample dimensions by removing the absorbed oxygen.

Using molecular dynamics simulations, the team independently tested the effect of surface stress on the equilibrium shape of nanoporous gold and its structural building blocks. “These simulations allowed us to understand the stress–strain response of nanoporous gold,” says Biener. He adds that the team’s research, which appeared in the November 30, 2008, issue of *Nature Materials*, could be applied to developing a new generation of chemical-driven sensor and actuation devices.

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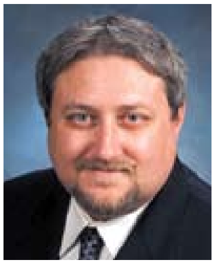


Seismic Science and Nonproliferation

WHEN it comes to the nation's nuclear security, Lawrence Livermore is best known for its responsibilities for the U.S. nuclear arsenal. But since the 1960s, Livermore scientists have also supported the efforts of U.S. policy makers to contain the nuclear arms race and limit nuclear proliferation by developing the means to verify disarmament and nonproliferation treaties. Today, Livermore and other Department of Energy national laboratories continue to press ahead with research on many fronts that enhance U.S. capabilities to monitor and limit proliferation.

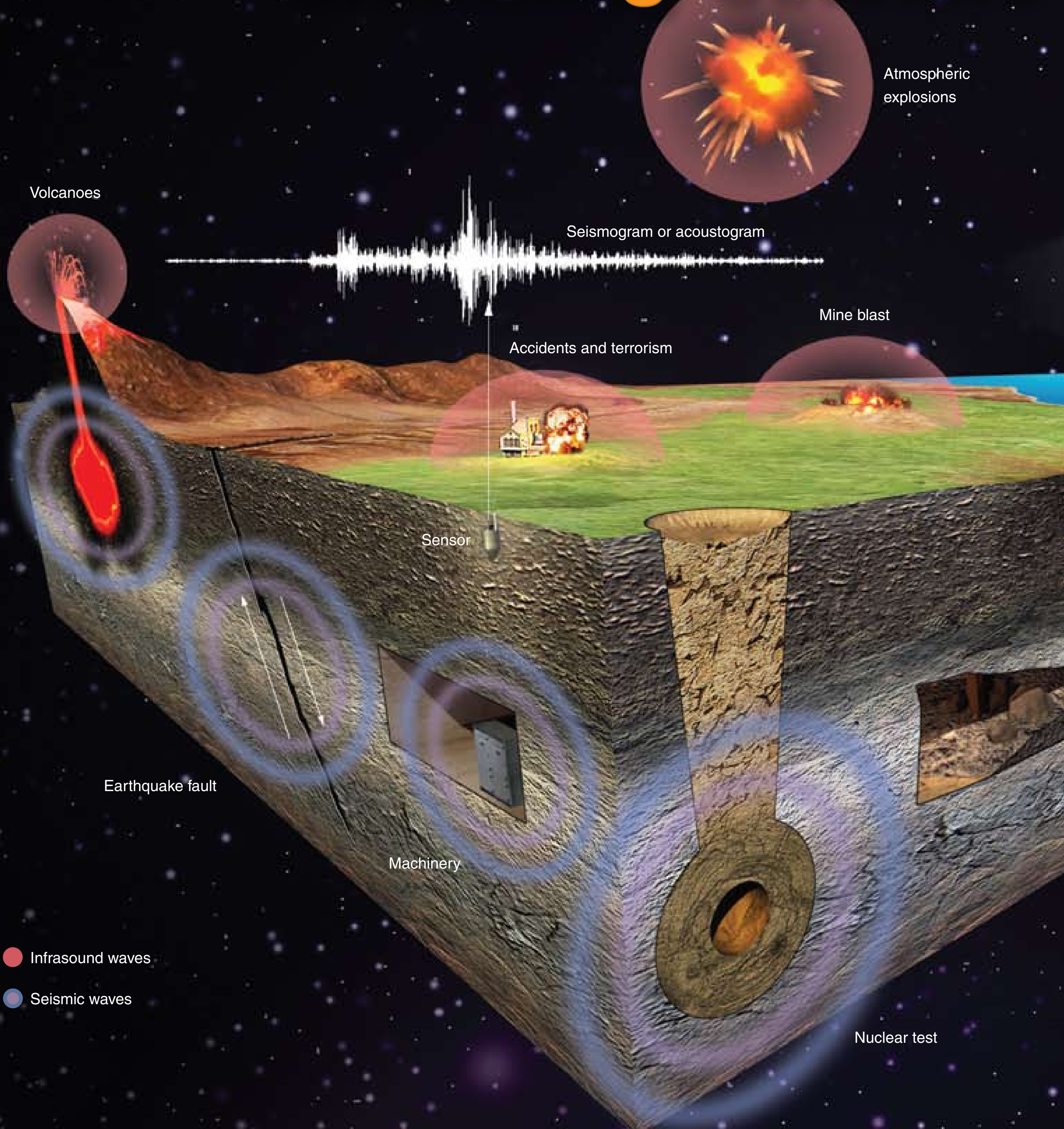
For example, Livermore is addressing the challenge of identifying and locating small nuclear explosions through seismic monitoring. In fact, one Laboratory mission is to better predict seismic signals and improve our ability to distinguish nuclear tests in the continuous stream of signals emitted by Earth's ongoing tectonic activity, such as earthquakes and volcanoes, as well as the occasional man-made event. The seismic signature that results from a nuclear test differs from that of an earthquake or other natural event, but Earth alters the signal in ways that can be challenging to decipher.

A small, low-yield nuclear test can be particularly difficult to pick out from other seismic activity. North Korea's small nuclear test in 2006 offered data that Livermore experts have since incorporated in new simulation tools with the potential to vastly improve the ability to quickly and accurately distinguish a small nuclear event and pinpoint its location. Three-dimensional models of Earth's interior, tomographic analysis techniques, and applications that run on high-performance computing assets such as BlueGene/L will continue to play key roles in developing improved methodologies to detect and characterize nuclear events.

We are entering a new era in nuclear test monitoring capability, as signs appear that U.S. nonproliferation policy may rely more heavily on the Comprehensive Nuclear Test Ban Treaty. Since the treaty was open for signature in 1996, 180 states have signed it, and 148 states have ratified it. However, it will only go into force after all 44 nuclear-capable states have ratified it. Nine such countries, including the U.S., have yet to do so. President Barack Obama has promised to encourage the U.S. Senate to ratify the treaty and to work through diplomatic efforts to bring other nuclear-capable states on board. A decision about ratification may well depend on the nation's ability to verify compliance through seismic monitoring.

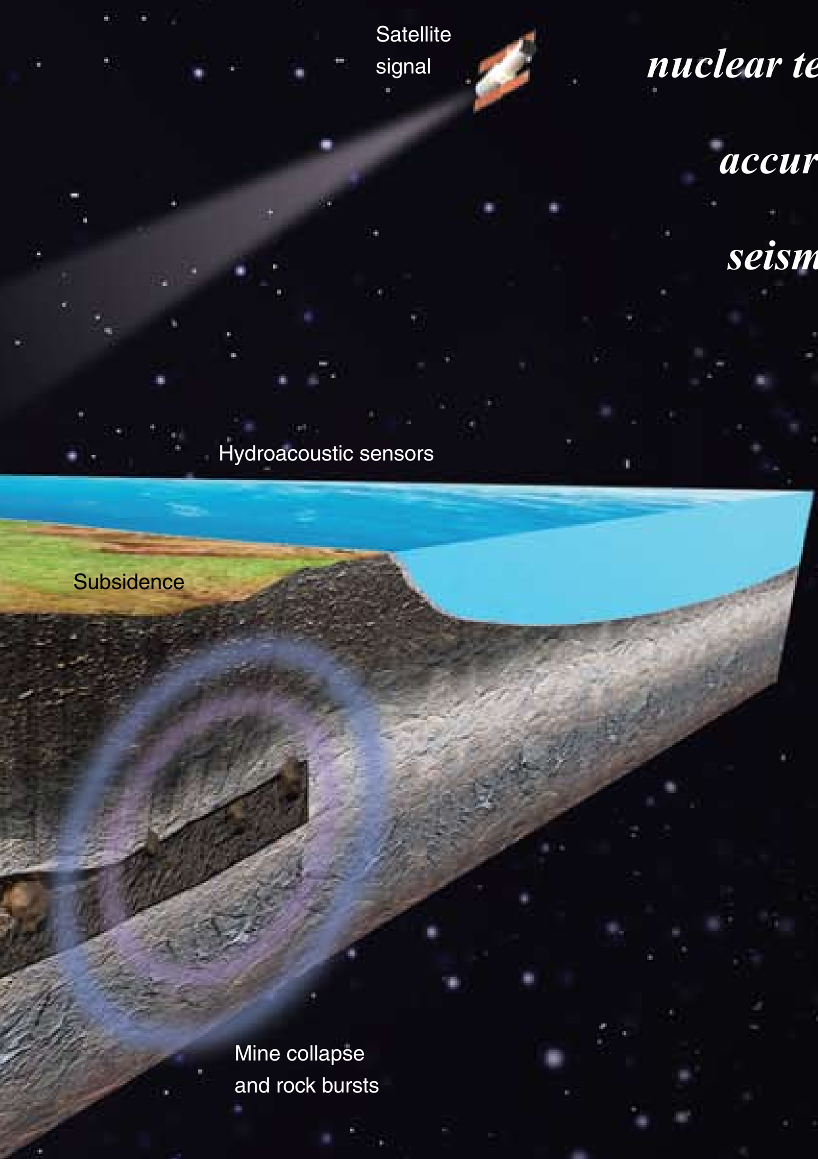
■ William H. Goldstein is associate director for Physical and Life Sciences.

Sleuthing Seismic



Signals

Monitoring the world for clandestine nuclear tests requires accurate forensic seismology tools.

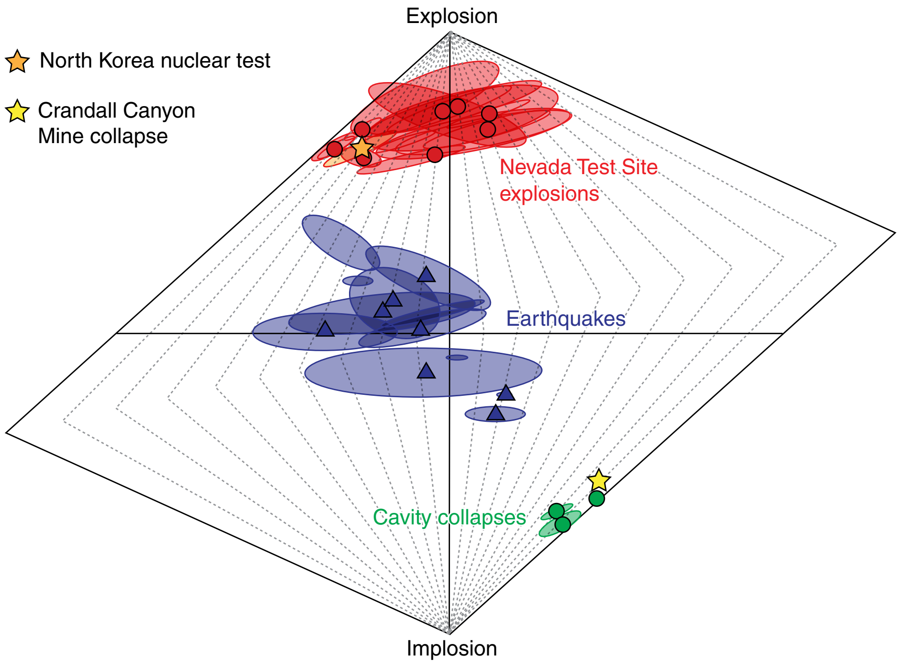


This cutaway view through Earth's subsurface shows many of the disturbances recorded by sensors worldwide.

AN earthquake, a nuclear test, and a mine collapse all cause seismic disturbances that are recorded at monitoring stations around the world. However, these three types of events produce very different ground motions at their source. Earthquakes are caused by sideways slippage on a fault plane, while underground nuclear explosions push outward in all directions. A mine collapse is a massive vertical roof fall.

Lawrence Livermore is at the forefront of research to more accurately distinguish nuclear explosions from the rest of Earth's never-ending seismic activity, including earthquakes large and small, volcanoes, and waves crashing on shore. The Laboratory's work was unexpectedly put to the test following the August 2007 collapse of the Crandall Canyon coal mine in Utah, which killed six miners. Ten days later, another collapse killed three rescue workers. Both events were recorded on the local network of seismic stations operated by the U.S. Geological Survey (USGS) as well as on the USArray stations, which are part of EarthScope, a program funded by the National Science Foundation. There was considerable contention about whether the initial magnitude-3.9 event was caused by an earthquake or a collapse.

At the time, Livermore seismologists were working with colleagues from the University of California at Berkeley on a waveform-matching technique to distinguish among nuclear explosions, earthquakes, and collapse events. This technique compares seismograms produced by computer modeling with recorded data at local to regional distances (from 0 to 1,500 kilometers) for periods of 5 to 50 seconds. Livermore's analysis of the August 2007 seismograms pointed to a collapse rather than an earthquake. The important result for the Laboratory team



Various kinds of seismic events can be grouped on a source-type, or Hudson, plot based on their ground motion. A perfectly symmetric underground explosion would appear at the apex of the plot. By analyzing the seismic waves produced by the disturbance that rocked the Crandall Canyon Mine in Utah in August 2007, Laboratory seismologists determined that the event was an implosive tunnel collapse, not the sideways slippage of an earthquake.

was being able to identify the Crandall Canyon event from its seismic signature despite its small magnitude.

Livermore's seismological research is part of the Department of Energy's support for the U.S. National Data Center in the area of nuclear treaty verification. (See the box below.) The team's experience with the Crandall Canyon Mine has given the Livermore seismologists even greater confidence that they can identify a relatively small nuclear test using the same technique.

Ground-based monitoring of nuclear explosions based on seismic data relies on understanding the fundamentals of ground motion from a high-energy nuclear explosion, the shock waves that propagate near the explosion source, and the subsequent waves traveling away from the source at longer distances. A full understanding is only possible if researchers consider this motion in terms of the geology and topography near the source and surrounding it for many kilometers. For more than 10 years,

Monitoring the Comprehensive Nuclear Test Ban Treaty

The U.S. ceased nuclear testing in 1992 in anticipation of the acceptance of the Comprehensive Nuclear Test Ban Treaty (CTBT). In 1996, President Bill Clinton and many other heads of state signed this multilateral treaty to prohibit all nuclear testing. Although most signatory countries ratified the treaty, the U.S. did not, and several countries required for the treaty to enter into force did not sign it. Expectations are high that the administration of President Barack Obama will reevaluate the CTBT's role in nonproliferation policy.

Although the CTBT is not in force, signatory countries and the U.S. are active participants in the International Monitoring System, which is overseen by the International Data Centre in Vienna, Austria, an organization established specifically to verify the CTBT. Every country supporting the system has a national data center. Livermore provides research and development support to the U.S. National Data Center at Patrick Air Force Base in Florida, which is responsible for U.S. nuclear test monitoring and international treaty verification.

The International Monitoring System comprises a worldwide network of 337 sensitive monitoring stations and laboratories to detect nuclear explosions. Seismic stations anchored to bedrock record underground elastic waves, infrasound stations collect acoustograms from low-frequency sound waves aboveground, hydroacoustic stations in the oceans record underwater sound waves, and radionuclide stations measure airborne radioactive gases or particles. More than 230 of the recording systems now send data to the International Data Centre on a provisional basis. This unique network is designed to detect nuclear explosions anywhere on the planet—in the oceans, underground, or in the atmosphere.

After the treaty enters into force, the signatory countries will have the role of identifying an event as a violation. The treaty also specifies several ways to resolve concerns about suspicious events, from consultation and clarification through a protocol that could lead to on-site inspections.

Laboratory seismologists have used available seismic data to develop and verify their one- and two-dimensional (1D and 2D) regional Earth models and calibrate the dozens of seismic monitoring stations around the world, thereby ensuring that new algorithms properly account for regional geologic characteristics. With expanding supercomputing capabilities at Livermore, 3D seismic models can include more realistic geology for more accurate calibration.

Seismology group leader Artie Rodgers in the Physical and Life Sciences Directorate and others are building on identification techniques first developed during underground nuclear experiments conducted by Lawrence Livermore and Los Alamos national laboratories at the Nevada Test Site. As part of this effort, Rodgers works closely with seismologist Bill Walter, program leader for ground-based nuclear explosion monitoring in the Global Security Principal Directorate.

North Korea Tests

The most recent nuclear test took place on October 9, 2006, when the Democratic People's Republic of Korea—North Korea—detonated a nuclear device. USGS and other organizations worldwide focused on analyzing seismic data from the test. Their aim was to quickly find the location—the epicenter, as it were—of the explosion and measure its size.

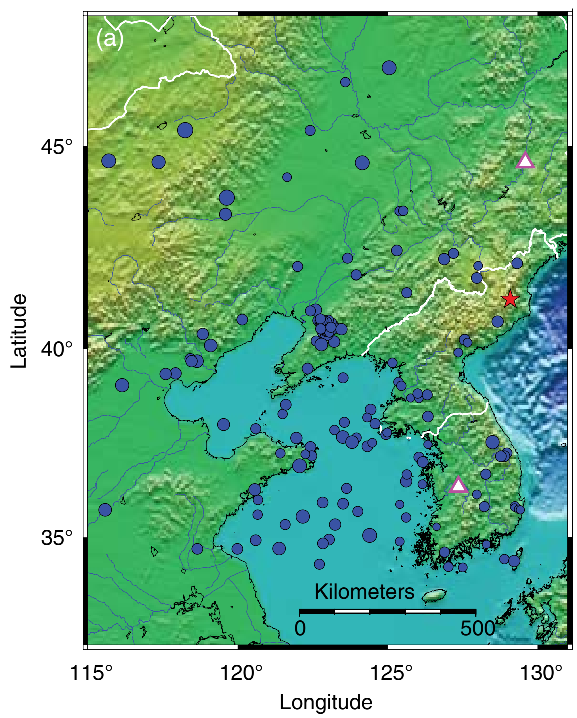
Livermore seismologists also analyzed data shortly after the magnitude-4 event but with a different purpose. The last nuclear experiments had been conducted eight years earlier in India and Pakistan. The North Korea test offered a rare source of valuable new data recorded at the seismic monitoring stations nearest North Korea, which the team could use to test its regional models and various calibration algorithms.

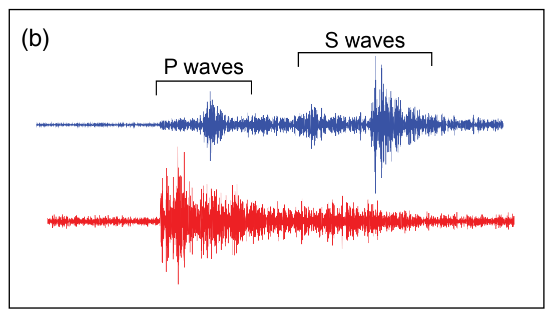
Detecting and Locating

Distinguishing an earthquake from a nuclear event requires a close examination of the seismic waves. Such waves fall into two major categories: surface waves, which move along Earth's surface, and body waves, which move through Earth and bounce off structures inside. Body waves may be primary (P) or secondary (S). Seismic P waves are compressional waves, similar to sound waves in the air. S waves are shear, or transverse, waves, similar to those that propagate along a rope when one end is shaken. Underground explosions radiate P waves in a relatively symmetric spherical shape. Earthquakes, which result from plates sliding along a buried fault, strongly excite the transverse motions of S waves, producing a distinct radiation pattern. Explosions thus show strong P waves and weak S waves. Earthquakes, in contrast, typically show weak P waves and strong S waves.

But this information alone is not foolproof because the structure of Earth imparts an imprint on the signal. One way to quantify the difference between these seismic disturbances is to determine the ratio of P-wave to S-wave energy measured from the seismograms. Explosions should have higher P:S ratios than earthquakes.

Recent Livermore work led by Walter sought to clarify the characteristics of





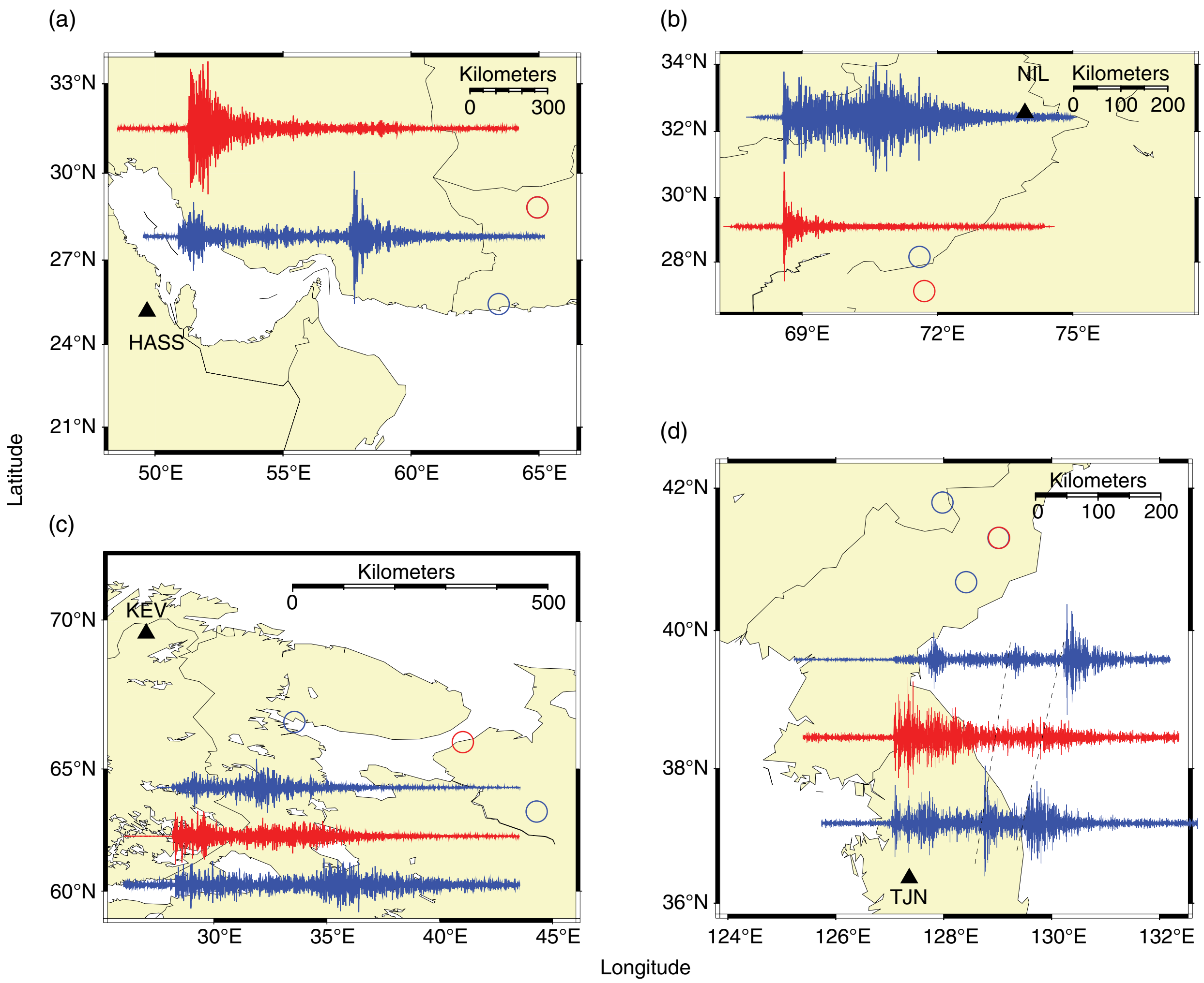
North Korea detonated a nuclear device on October 9, 2006. (a) A map of the region shows the location of the test (red star), nearby earthquakes (blue dots), and seismic monitoring stations (white triangles) at Mudanjiang in northeast China and Taejon, South Korea. (b) Seismograms recorded during the explosion (red wave) and a recent earthquake (blue wave) near that experiment show the different seismic patterns produced by these geologic disturbances.

the P:S ratios that distinguish nuclear weapons tests from other tectonic activity. By examining regional amplitude ratios of ground motion in a variety of frequencies, his team empirically demonstrated that such ratios indeed separate explosions from earthquakes. The researchers used closely located pairs of earthquakes and nuclear explosions recorded at monitoring stations at or near the Nevada Test Site; Novaya Zemlya and Semipalatinsk, former Soviet Union test sites; Lop Nor, China; India; Pakistan; and the North Korea test.

"At high frequencies, above 6 hertz, the P:S ratio method appears to work everywhere we looked," says Walter. "Explosions have larger P:S amplitude values." For example, a test in India on May 11, 1998, compares well with the October 9, 2006, North Korea test.

However, west of Pakistan, in the tectonically complex Middle East, seismogram analysis becomes more complicated. S waves attenuate, or lose energy, more rapidly in regions that are geologically complicated and seismically active. Seismograms from these areas tend to have larger P-wave amplitude relative to their S-wave amplitude. As a result, earthquake signals may look like those from an explosion. Because of these wave propagation effects, Walter's team applied a tomographic technique to measure the highly variable attenuation of S waves in the Middle East.

Tomography is a mathematical operation that uses variations in the waves passing through a material to construct an image of the material's structure. For



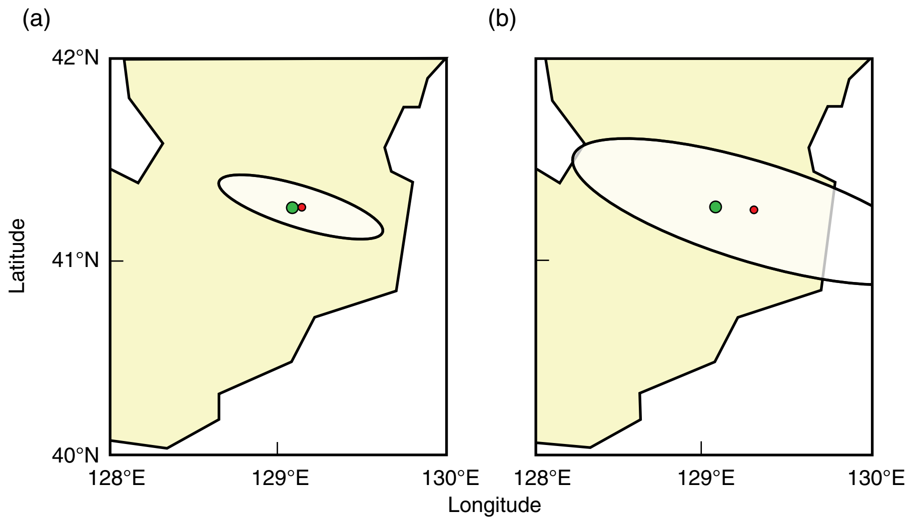
At frequencies of 6 to 8 hertz, nuclear explosions (red waves) consistently have larger ratios of primary- to secondary-wave amplitude than earthquakes (blue waves). Data sources are (a) Pakistan, (b) India, (c) Agate test in the former Soviet Union, and (d) North Korea. Circles indicate event epicenters. Triangles are seismic recording stations.

example, a medical tomography scan uses variations in the waves of x radiation transmitted through the body to produce an image that a radiologist can analyze. Tomography of Earth uses seismic waves to generate comparable images of Earth's inner structure.

The tomographic technique developed by Walter's team models structural deformation based on the attenuation occurring as S waves propagate through different geologic media. Even with the precise algorithms in this tomographic attenuation method, however, some known earthquakes have P:S ratios that look like those of explosions. "We expect that analysis of ground motion at higher frequencies will help us better understand and use this method," says Walter. "But we have only recently had the computational power we need to model high frequencies in 2D and 3D Earth models."

Pinpointing the location of a test is as challenging as distinguishing it from an earthquake. The site of a seismic event is determined by measuring how long seismic waves take to get from the event to the various monitoring stations. Earth's crust and mantle are not homogeneous, however, so velocities through them vary. "Travel-time calculations over long distances can be accurate because the variations tend to average out," says Walter. "But over shorter distances—less than 2,200 kilometers—the 1D, radially symmetric models commonly used in monitoring systems today are prone to error."

At the time of the North Korea nuclear test, a collaborative team led by deputy program leader Steve Myers was working on a new velocity model. The Seismic Location Baseline Model—developed by researchers from Lawrence Livermore, Sandia, and Los Alamos national laboratories; the U.S. National Data Center; and Quantum Technology Sciences,



(a) Livermore's Seismic Location Baseline Model predicts the location of the 2006 North Korea nuclear explosion much more accurately than (b) global, one-dimensional models, which until recently were the standard for determining explosion location. Red dots show the event location predicted by each model, and green dots indicate the actual epicenter. Ellipse area: (a) 1,552 and (b) 8,343 square kilometers.

In 2002, Livermore seismologist Artie Rodgers (center) and colleague Cindy Lersten (right foreground) from the Department of Energy worked with a team in the United Arab Emirates to install the country's first seismic monitoring station.

Inc.—has the potential to become the standard for regional travel-time prediction. Not only does the model capture the effects of the 3D Earth, but it also can be used in a real-time monitoring system because it is so efficient computationally. "We expect the National Earthquake Information Center, which is part of the USGS Earthquake Hazards Program, to begin evaluating our model sometime this spring," says Myers.

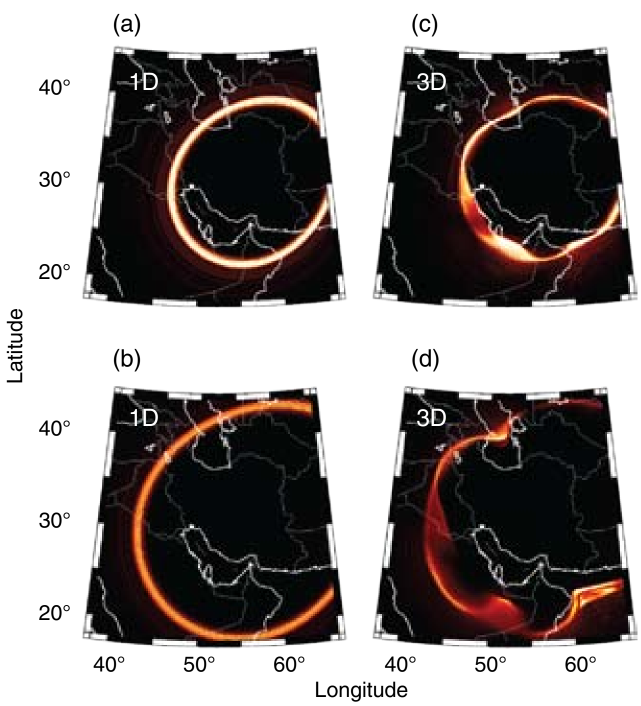
One reason the Seismic Location Baseline Model can so accurately predict the travel time of seismic waves is that its tomographic imaging techniques better capture the structure of Earth in 3D. These techniques use travel-time data to predict geologic structure based on variations in seismic-wave velocity. "We combed through large databases of seismic measurements for high-quality data," says Myers, "and applied tomographic methodology to modify the model to better predict measurements." The Seismic Location Baseline Model can currently resolve Earth structure with a lateral dimension of 100 kilometers. Ongoing efforts include increasing the model's resolution in areas where data are available and extending the model's capabilities to predict all seismic phases.

Focus on the Middle East

In 2002, Rodgers led the team that installed the first seismic monitoring stations in the United Arab Emirates, around the epicenter of an earthquake that occurred in a normally aseismic area. New seismic stations in the Emirates and other Middle Eastern countries allow local seismologists to prepare for future earthquakes by indicating where small earthquakes occur and helping define seismically active faults. In return, Laboratory researchers use data from these and other stations to learn about earthquakes and Earth's structure. Lawrence Livermore is the National Nuclear Security Administration laboratory responsible for seismic calibration of the Middle East for nuclear treaty verification. Livermore researchers work with scientists in many Middle Eastern countries to gather and evaluate ground-motion data.

Rodgers serves as the Laboratory's representative to an organization called the Reduction of Earthquake Losses in the Extended Mediterranean Region, which was established by USGS and the United Nations Educational, Scientific, and Cultural Organization. He and Livermore's Rengin Gök and Michael Pasyanos attended the most recent meeting in Istanbul, Turkey, in May 2008, which included scientists from Cyprus, Egypt, Iran, Israel, Jordan, Kuwait, Lebanon, Libya, Oman, the Palestinian Authority, Saudi Arabia, Turkey, the U.S., and Yemen.

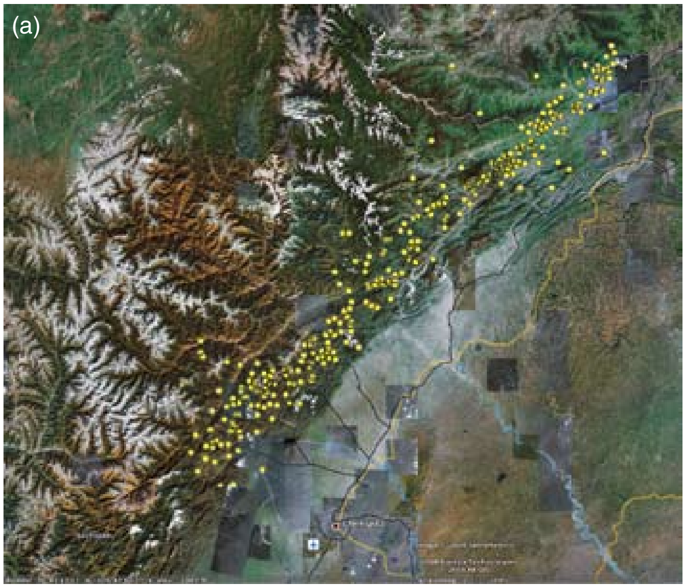
Gök represents the Laboratory in a multinational data exchange agreement with Turkey, Azerbaijan, and Georgia, countries in an area with a high potential for earthquakes and concerns about nuclear proliferation. As part of this agreement, seismologists in the three countries share their ground-motion data with Livermore researchers, who then analyze the data and add them to the store of information for calibrating monitoring stations in the Caucasus region. Gök notes that this particular agreement will end in late 2009, but she is already at work on proposals for similar international scientific exchanges in the region.

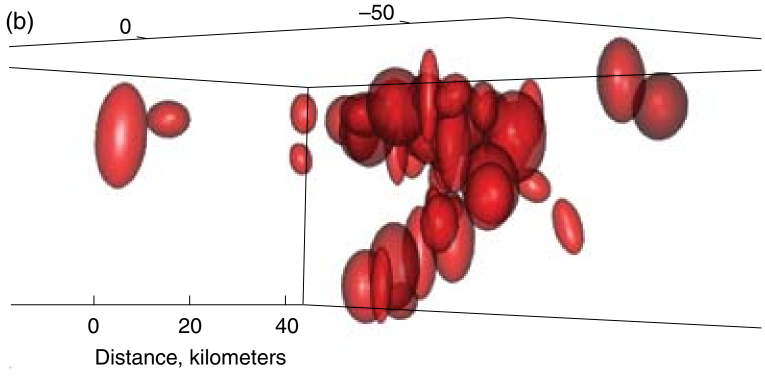


The latest three-dimensional models capture vertical ground displacement far more accurately than one-dimensional models. These images show the ground motions for (a, b) one- and (c, d) three-dimensional models at different times after an event. Comparison with recorded ground motions indicates that the three-dimensional model better predicts the observed behavior.

Seismic Simulations Go Parallel

With BlueGene/L, one of the world's most powerful supercomputers, Livermore's seismologists are developing much improved 3D simulations for detecting nuclear detonations. Says Walter, "Much 3D seismic modeling requires





(a) Seismic data on the aftershocks (yellow dots) of the May 2008 magnitude-7.9 earthquake in Sichuan, China, were used in Livermore's Bayesloc method to produce (b) a cross section of the fault plane viewed from the southwest, revealing its structure.

the high-performance, massively parallel computing capability that we have here at Livermore." Advanced computational power allows for greater numerical resolution of simulations at higher frequencies and covering larger regions. These simulations are especially important for evaluating seismic activity that occurs in parts of the world where earthquakes and other natural ground motion are rare.

Rodgers leads a team of Livermore seismologists, mathematicians, and computational experts who have set the stage for simulating wave propagation in realistic 3D geology. To date, they have focused on three areas: wave propagation within less than 1,500 kilometers of an explosion source, geology and topography of Earth, and nonlinear hydrodynamics of shock waves. For regional-distance simulations, the team compared observed waveforms at various monitoring stations with simulated ones and compared 1D models with 3D models.

Livermore applied mathematician Anders Petersson led the development of an open-source code called WPP for simulating the propagation and anelastic attenuation of seismic waves. The WPP team is extending the code to handle realistic topography, which is important to accurately simulate the propagation of shorter waves associated with higher frequencies. Petersson's team has developed a hybrid numerical technique that combines the complex calculations necessary to capture the effects of topography with an efficient scheme for subsurface geology.

The team is also coupling WPP to GEODYNE, a code that handles nonlinear hydrodynamic wave propagation. Nonlinear hydrodynamic behavior results from the high energy density of chemical and nuclear explosions, which causes vaporization, cavity creation, and other phenomena before stimulating elastic seismic waves. Modeling the near-source phenomena is key to improving amplitude and yield estimates and understanding the generation of S waves.

Yet another team, led by Myers, has developed a Markov Chain Monte Carlo probability method called Bayesloc for locating seismic events. According to Myers, "Bayesloc simultaneously locates a selection of events, evaluates data quality, and assesses the transit time of seismic waves from the source to each monitoring station."

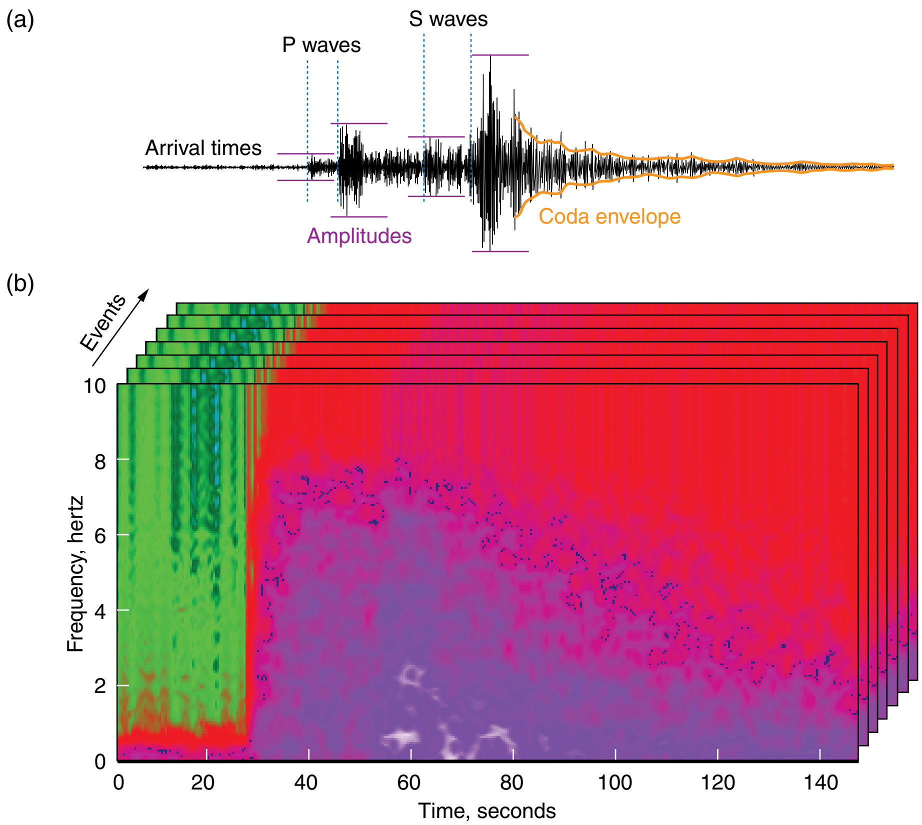
Myers and his team used Bayesloc to pinpoint the aftershocks following the May 12, 2008, magnitude-7.9 earthquake in Sichuan, China. "Locating the aftershocks allowed us to identify the fault plane, which is almost as long as the distance between Los Angeles and San Francisco," says Myers. "The initial quake and its aftershocks thrust the mountainous shelf over the Sichuan Basin." That project did not require massively parallel supercomputers, but the team's next project will. "We plan to simultaneously locate all earthquakes for which we have data," says Myers. "Then when a new quake happens, it can be located in the context of all previous events."

Walter leads the effort to further develop the technique that worked so well in identifying the source of the Utah mine collapse. "We are expanding to a broader range of frequencies and to a different kind of matching," he says. In current seismological practice, the seismogram is deconstructed manually into a series of arrival times, or "picks," for locating the event. Manually selected amplitude measurements also provide information about the event type and its size or yield. However, this method uses only part of the waveform.

A proposed future practice is to convert the entire seismogram to a template, eliminating manual picking and making full use of time–bandwidth data. The template for an event could then be compared with those of previous events or, if no prior event has occurred in a region, to model-based templates. "This new process will allow us to immediately locate, identify, and characterize events relative to all prior events or our models," says Walter. "In addition, we can more easily automate the processing."

This is an exciting time for Livermore seismologists. With the advent of a fully 3D simulation capability, greater automation for analyzing seismic events, and renewed interest in the Comprehensive Nuclear Test Ban Treaty, ground-based nuclear test monitoring research is entering a new era.

—*Katie Walter*



Livermore seismologists are exploring ways to replace (a) the current practice of manually analyzing discrete parts of a seismogram, such as times, amplitudes, and envelopes of specific waves, with (b) conversion of the entire seismogram into a template that can be compared with other event templates.

Key Words: Comprehensive Nuclear Test Ban Treaty (CTBT), Crandall Canyon Mine, explosion monitoring, International Monitoring System, nuclear testing, nuclear treaty verification, seismology.

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Wind and the Grid

As the wind turbines spin on the Altamont Pass near Livermore, residents of the area and travelers passing through get a first-hand look at technology that turns wind power into usable energy. In California, wind generates about 2 percent of the electricity produced by renewable resources, which account for 11 percent of the state's annual energy production. By 2020, the state government wants to increase production from these cleaner, "greener" energy sources to 33 percent of the total power supply. In doing so, the annual production from wind sources would increase from 2,300 megawatts to between 12,000 and 15,000 megawatts. To meet this aggressive goal, the power industry must overcome the challenges associated with integrating wind into the nation's electrical infrastructure, known as the grid.

Wind is intermittent, and changes in the weather affect it on a seasonal, daily, and minute-to-minute basis. Even when winds are strong, the amount of electricity produced by turbine farms varies as conditions change. Because of this variability, electrical grid operators have difficulty establishing schedules to harness wind energy in the amounts needed to meet demand. In addition, sites for large, tall wind turbines must be carefully selected to minimize environmental effects, for example, to protect avian species.

Research engineer Dora Yen-Nakafuji in Livermore's Engineering Directorate is working with utility companies, the power industry, state and federal agencies, and other organizations to address these wind-related energy issues. As part of this effort, she is characterizing the complex interactions that affect wind resources and helping industries develop new technologies for integrating wind energy into the grid.

For the last several years, Yen-Nakafuji and colleagues in the Engineering, Physical and Life Sciences, and Computation directorates have focused on using the Laboratory's modeling and computational expertise to refine wind-forecasting tools. In particular, they want to identify sources in the various models that lead to forecasting error—the difference between predicted wind conditions and those that actually occur. Reducing such errors will provide grid operators with the data they need to reliably determine the output of wind generators and more effectively manage the electrical grid.

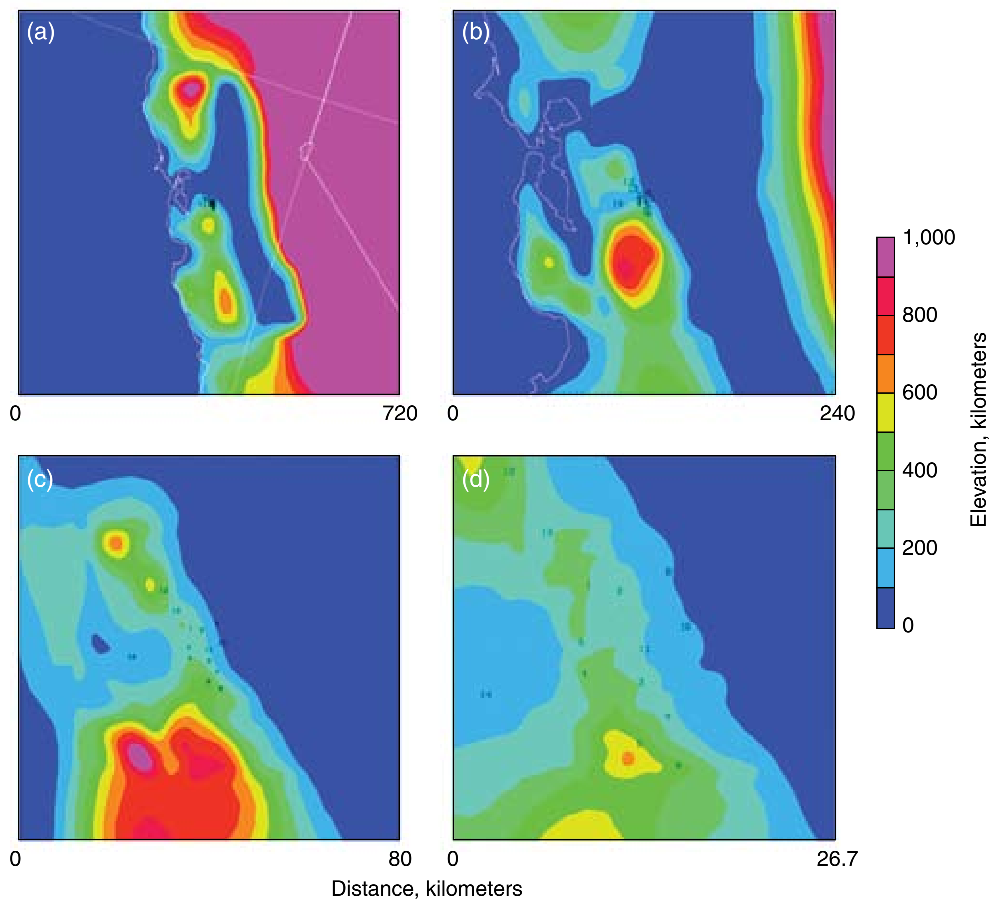
California's Impetus

Approximately half of the states in the U.S., including California, have established standards requiring electrical companies to increase renewable energy production by a certain percentage within a specified period. The California standard, originally passed by the state Senate in 2002, mandates a 20-percent increase in renewable energy production by 2010 with an accelerated target of 33 percent by 2020. In addition, state Assembly Bill 32, passed in 2006, requires a 25-percent reduction in greenhouse-gas emissions in the same time frame. Together, these two bills are a major impetus for California's move toward alternative and renewable energy resources.

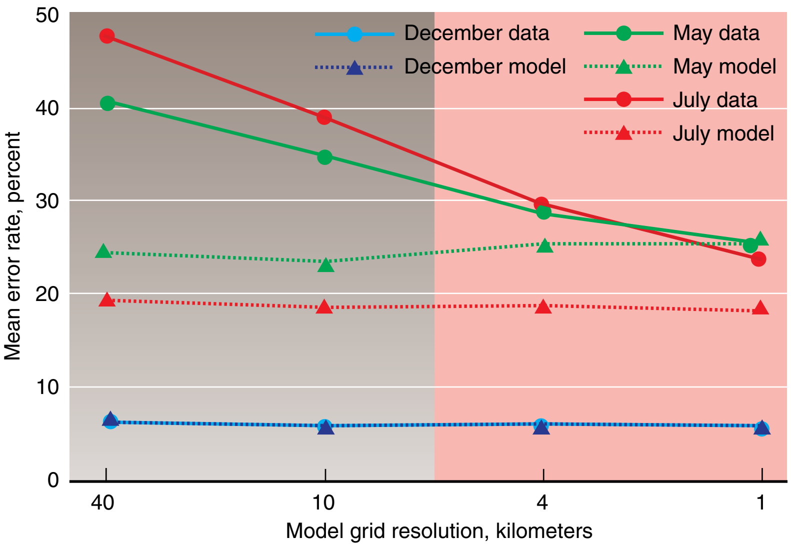
From 2001 through April 2007, Yen-Nakafuji worked with the California Energy Commission (CEC) to meet the goals outlined in the state mandates. During that time, she helped improve wind forecasting by more accurately characterizing the meteorology in California wind corridors, which feature hilly topography and a mix of marine and inland climates. As part of CEC's California Regional Wind Energy Forecasting System Development initiative, Yen-Nakafuji and other Laboratory experts used higher-resolution weather prediction models to better simulate wind characteristics, such as speed and direction.

To create wind-energy forecasts for utility schedulers and operators, industry forecasters input regional and site-specific data gathered from ground sensors and newer remote-sensing devices, such as sonic detection and ranging systems and Doppler radars, to augment standard weather models. Standard forecasts provided by the National Weather Service and other organizations typically cover large land areas tens to hundreds of kilometers wide. Livermore researchers at the National Atmospheric Release Advisory Center have developed higher-resolution models that simulate airflow over smaller areas. Improved grid resolution would likewise improve the accuracy of wind-energy forecasting models. Such changes, however, increase the computing time required for simulations to run and, thus, the associated costs.

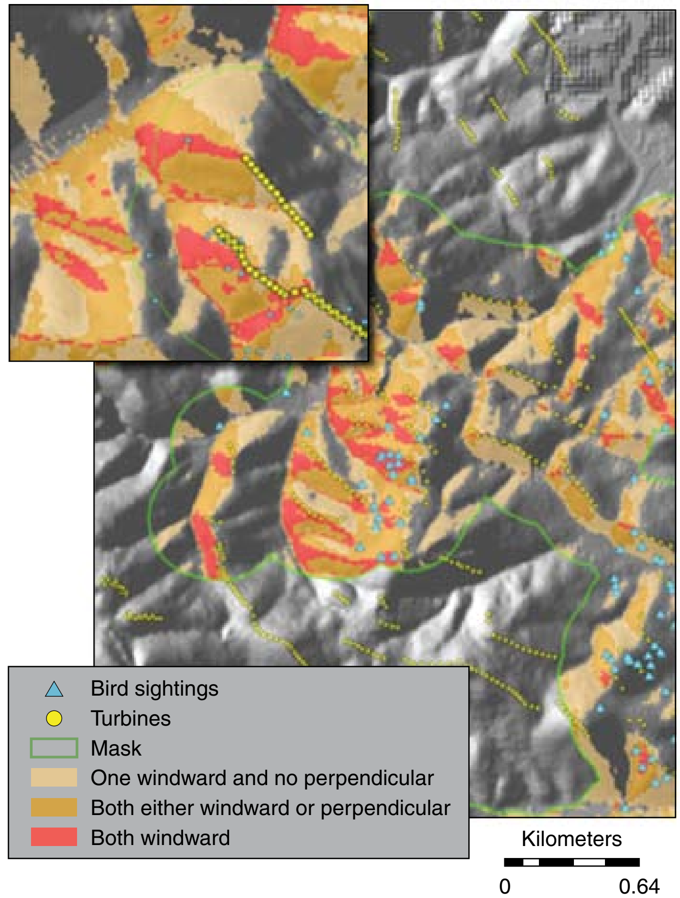
To balance the error rate and computational efficiency, Yen-Nakafuji and her colleague Steve Chin compared simulations with resolutions from 40 to 0.44 kilometers and determined the optimal threshold for grid resolution. Their study also indicated that during summer, variations in meteorological conditions increase the forecasting error rate. Thus, using an improved grid resolution in the summer is especially important for forecasting accuracy.



These computational models, developed by the Laboratory's National Atmospheric Release Advisory Center, have grid resolutions ranging from (a) 12, (b) 4, (c) 1.33, and (d) 0.44 kilometers. As resolution improves, more information becomes available on the wind density in an area, as indicated by the color-coded resolved terrain.



A comparison of modeling results with observational data shows how grid resolution affects the error rate in wind-energy forecasts. The forecasting error is higher in the summer months when meteorological conditions are more variable. Improving grid resolution will significantly increase the accuracy of forecasts during those months.



Data on wind conditions superimposed on topographic data of the Altamont Pass near Livermore show where wind turbines are located in relation to bird sightings. Terrain highlighted in red indicates high-usage areas, where birds are active year-round.

Yen-Nakafuji also worked with the Laboratory's geographical information system (GIS) experts to evaluate sites for wind turbines and mitigate environmental effects of new wind facilities. Using observational data compiled by CEC and the National Renewable Energy Laboratory, the research team showed how placement of wind turbines on the Altamont Pass could reduce harm to birds in the area. Research conducted by CEC linked statistical data on bird activities and behavior to the regional terrain. "That observational study took six years to cover only one-third of the Altamont," says Yen-Nakafuji. "We needed to find a quicker method for evaluating the rest of the area."

Using GIS analysis and rendering tools, the team linked the avian behavioral data from the CEC study to the terrain that various species fly over. The GIS analysis provided details such as flight patterns and timing, terrain gradients, and wind direction. The overall visual representation showed where turbines are located relative to bird sightings. The Livermore team's research indicated that moving turbines away from the high-usage areas would reduce the risk to avian species in the area. This analysis capability is now part of a CEC-sponsored Web-based Renewable Energy Portal, which was developed to aid industry and the public in tracking, trending, and monitoring wind-energy resources.

Inspiring Confidence

In 2008, with funding through the Business Development Counsel in Livermore's Global Security Principal Directorate, Yen-Nakafuji began the National Transmission and Energy Resilience Response Analysis (N-TERRA) initiative to respond to national and regional needs for grid transformation and renewable integration. Under N-TERRA, Yen-Nakafuji assessed not only the reliability and sustainability of wind-energy resources but also the potential vulnerabilities associated with integrating intermittent renewables into the electrical infrastructure.

Out of this initiative grew Wind SENSE, a program funded by the Department of Energy's Office of Energy Efficiency and Renewable Energy. Wind SENSE combines the Laboratory's advanced computing capabilities with field data from meteorological towers and other sensors as well as performance data from turbine farms to develop an integrated wind-forecasting tool for grid operators. "The goal of Wind SENSE is to provide control room operators with an awareness, or 'sense,' of the wind conditions and energy forecasts in their native operating environments," says Yen-Nakafuji. A reliable forecasting tool will increase operator confidence in the availability of wind resources when managing the electrical infrastructure.

Through this program, Yen-Nakafuji and her team are working with industries to selectively input data from wind turbine sites into mesoscale models and develop more accurate wind forecasts. "With the information we collect, we can optimize the placement of sensors upwind and downwind of a resource area," says Yen-Nakafuji. The team can then work with utility operators to generate forecasts 48, 24, and 1 to 3 hours ahead of scheduling times. The team's next step is to develop a mechanism for integrating this tool into control rooms.

The team is also applying the Laboratory's expertise in analyzing large-volume data sets to improve wind forecasts. "So much information is available, no one person could possibly make sense of all the data," says Yen-Nakafuji. Overall, the Laboratory's contributions are providing industry with the tools needed to ensure that the current infrastructure can reliably accommodate intermittent wind resources.

Climate Change and Future Needs

Global changes in climate could have an enormous effect on the output of all renewable energy sources. For example, increases in atmospheric pressure could alter regional wind patterns, or greenhouse-gas emissions may impede production of solar-generated power. According to Yen-Nakafuji, "Livermore is working with utility partners and leading the initial effort to gauge potential climate impacts on electricity generation by weather-dependent renewable resources."

Global-scale climate models can simulate temperature, pressure, and precipitation changes in addition to other environmental parameters. Typically, these models examine potential changes over the next 50 to 100 years. However, utilities are planning infrastructure to support renewables in the next 3 to 5 years. Using data from climate studies, such as the work performed by the Intergovernmental Panel on Climate Change, the Laboratory is developing computational models to forecast environmental conditions within a shorter time frame. These assessments may provide better insight into how climate change could affect renewable energy sources over the long term and thus future investments in renewables. As an example, if models predict significant decreases in rainfall over the next 20 years, hydroelectric dams may generate less energy than they do today. Plans for the future infrastructure must accommodate these changes to ensure that the electrical grid continues to meet demand.

Hydro, solar, and wind resources could play a vital role in the nation's future energy production. Working together, the Laboratory, utilities, and the power sector are improving capabilities to integrate these cleaner sources of energy into the grid. As a result, the Laboratory is helping California serve as an example to other states, moving the nation one step closer to reliable, renewable energy and a healthier environment.

—Caryn Meissner

Key Words: climate change, electrical grid, electrical infrastructure, intermittent renewables, National Transmission and Energy Resilience Response Analysis (N-TERRA), renewable energy, wind forecasting, Wind SENSE.

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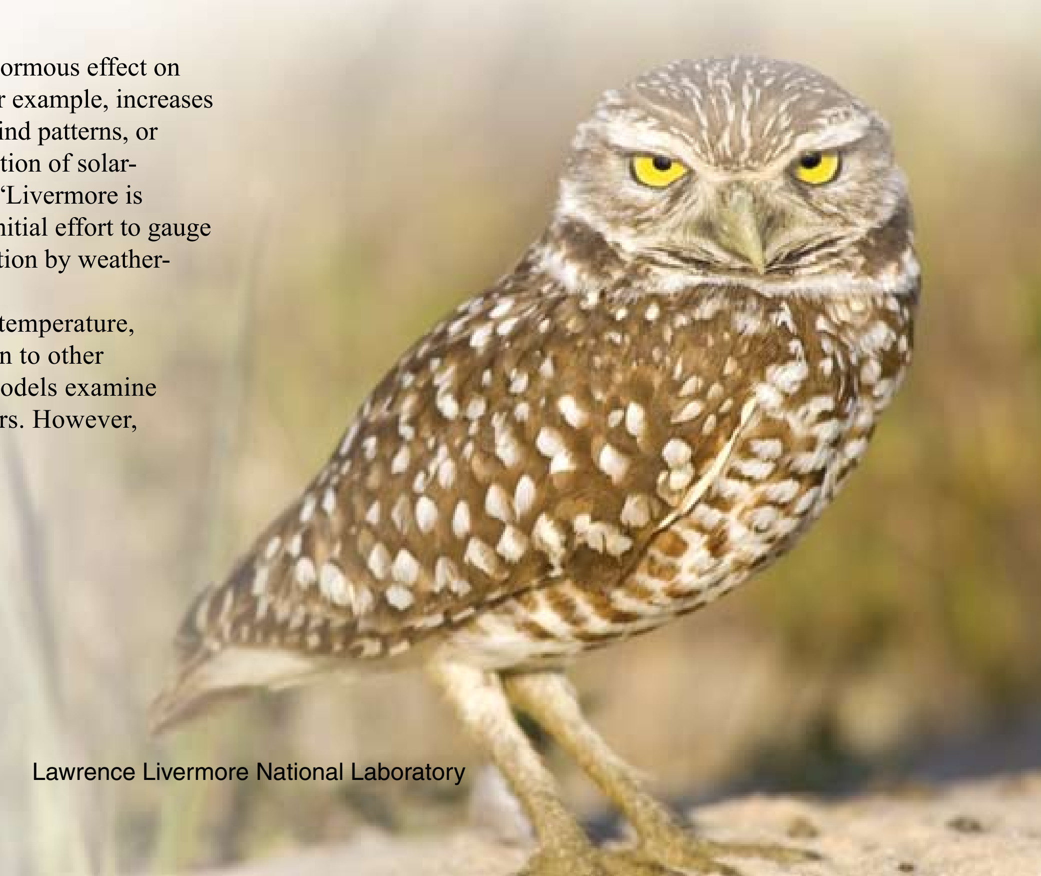


Searching for Tiny Signals from Dark Matter

FOR decades, physicists have struggled to unravel the mysteries of so-called dark matter, a postulated invisible form of matter that constitutes more than 20 percent of the universe and is key to understanding the formation—and fate—of the universe. Many scientists hypothesize that a subatomic particle, called an axion, constitutes dark matter. These scientists calculate that every cubic centimeter of space could contain about 100 trillion axions, all produced during the big bang some 12 billion years ago.

Axions have no electric charge or spin, extremely small mass (a trillion times less than that of an electron), and little interaction with ordinary matter. As a result, detecting these invisible particles requires extremely sensitive equipment. A Livermore experiment, known as the Axion Dark Matter Experiment (ADMX), is designed to find the elusive particle by measuring its decay into a microwave photon in the presence of a strong magnetic field. (See *S&TR*, January/February 2004, pp. 4–11.)

The microwave photon's faint signal must be amplified to an extreme degree to be detected. The capacity to distinguish weak photons during axion decay was significantly enhanced in 2008 when the ADMX team added sensitive amplifiers about the size of computer chips to the experimental apparatus. Together with a new cooling system awaiting installation, these amplifiers should allow the team to detect even the weakest axions.

The high-gain, ultralow-noise amplifiers are based on superconducting quantum interference devices (SQUIDs), which may also have applications in quantum computing. (See the box on p. 18.) Livermore physicist Darin Kinion fabricated the units in cooperation with a group of University of California (UC) at Berkeley researchers headed by John Clarke, a professor in the Physics Department.

The ADMX effort began in 1995 with support from the Department of Energy Office of Science and Livermore's Laboratory Directed Research and Development Program. Physicists Karl van Bibber at the Naval Postgraduate School in Monterey, California, and Leslie Rosenberg from the University of Washington lead the experiment. Other researchers include Kinion and postdoctoral researcher Gianpaolo Carosi, who work in the Laboratory's Physical and Life Sciences Directorate; postdoctoral researcher Gray Rybka and graduate student Michael Hotz, both from the University of Washington; and Pierre Sikivie and David Tanner from the University of Florida. The amplifier development effort received funding from the Laboratory Directed Research and Development Program and, for work at UC Berkeley, from the National Science Foundation.

Livermore physicist Darin Kinion guides the experimental apparatus containing the microwave cavity and superconducting quantum interference device (SQUID) amplifiers into the cavity of a superconducting electromagnet for the Axion Dark Matter Experiment (ADMX). The disks on top of the ADMX device are thermal shields.

Tuning a Microwave Cavity

ADMX features a "tunable" microwave cavity, a copper-plated, stainless-steel cylinder similar in size to an oil drum (1 meter tall and 0.5 meters in diameter). A 1-meter-long superconducting electromagnet weighing 6 tons is wound around the outside of the cavity and generates 8 tesla, making it about 200,000 times more powerful than Earth's magnetic field. Presumably, some axions passing through the ADMX detection cavity will interact with the magnetic field generated by the superconducting magnet and decay into microwave photons. The SQUIDs will then amplify these signals to detectable levels.

When Zeros and Ones Intermingle

The same superconducting quantum interference devices (SQUIDs) that boost weak signals in Livermore's Axion Dark Matter Experiment (ADMX) may one day become an essential component of a radically different type of computer. The machine is called a quantum computer because it is based on the strange properties of atoms and subatomic particles.

In traditional computing, the basic unit of information—a bit—has a value of either 0 or 1. In contrast, quantum computers use a "qubit," in which the 0 and 1 states mix together. That is, qubits can take on both values simultaneously, a property known as quantum superposition. "We are trying to perform new types of computing using the properties of quantum mechanics, which are counterintuitive to our common sense," says Livermore physicist Darin Kinion.

Qubits can be represented by the spins of individual electrons confined in semiconductor nanostructures (often called quantum dots), by nuclear spins associated with single-atom impurities in a semiconductor, or in the proposed Livermore design, by the quantized (discrete) energy levels of a Josephson junction. The Livermore SQUIDs will be used to detect fleeting changes in the quantum state of qubits comprising a prototype computer.

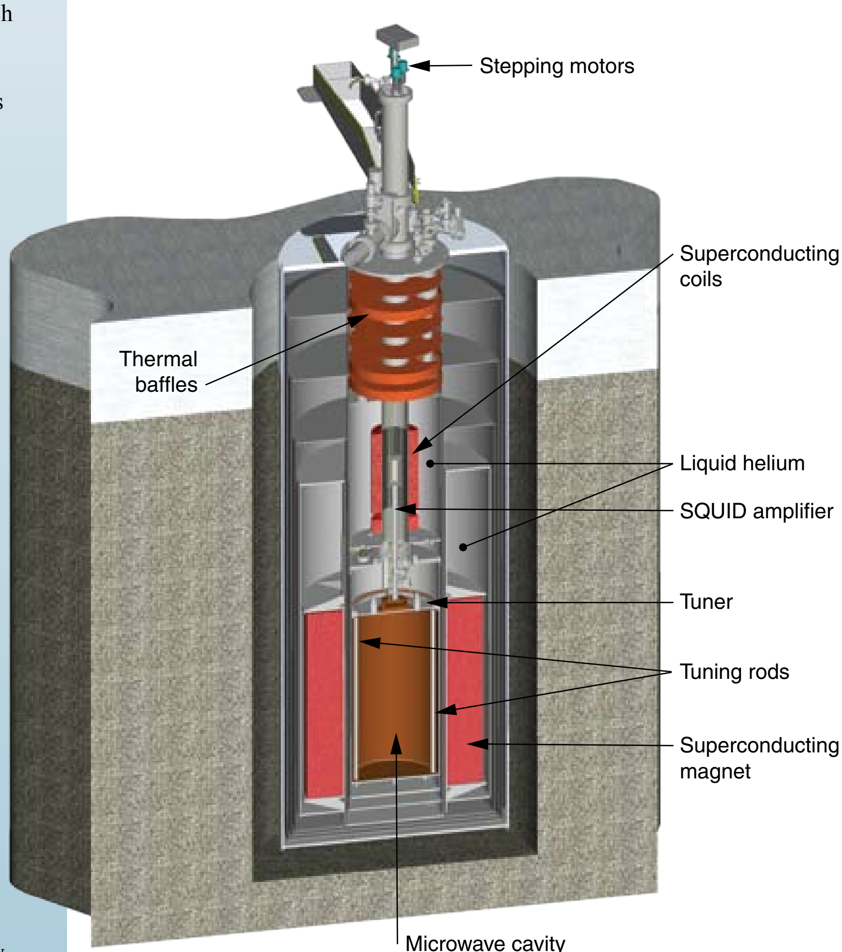
The SQUID development effort is part of a four-year-long Livermore project funded by the Intelligence Advanced Research Projects Activity. Part of the Office of the Director of National Intelligence, this organization invests in high-risk, high-payoff research with the goal of strengthening U.S. intelligence capabilities. The Livermore effort is aimed at building individual qubits, coupling a small number of them, and using a SQUID-based readout technique to record their states significantly faster than current methods.

Corporations such as IBM and Microsoft have been working on simple prototype quantum computers. However, constructing a full-scale quantum computer is a difficult task because quantum states are extremely fragile and difficult to detect and manipulate. "We have only a very short window of opportunity, less than one-tenth of a microsecond, to get information out," says Kinion. A longer readout process would collapse the fragile quantum state of the qubits. Because external disturbances would cause the machine to stop working, qubits must be shielded with layers of extremely cold superconducting fluids. "Even 1 kelvin is too hot," says Kinion.

Scientists believe quantum computers could easily solve problems that are too complex for even the most powerful supercomputers. For example, quantum computers could quickly find factors, prime numbers that are multiplied together to give the original number. Factoring a large number is so difficult for conventional computers that it is used by many cryptographic methods to protect data. Potential applications also include solving other difficult math problems, modeling quantum systems, and mining large databases for particular pieces of information.

To locate the axions, the team must slowly scan the range of possible cavity frequencies—from 300 megahertz to 30 gigahertz. For this operation, stepper motors move a set of tuning rods a few hundred nanometers per minute through the cavity.

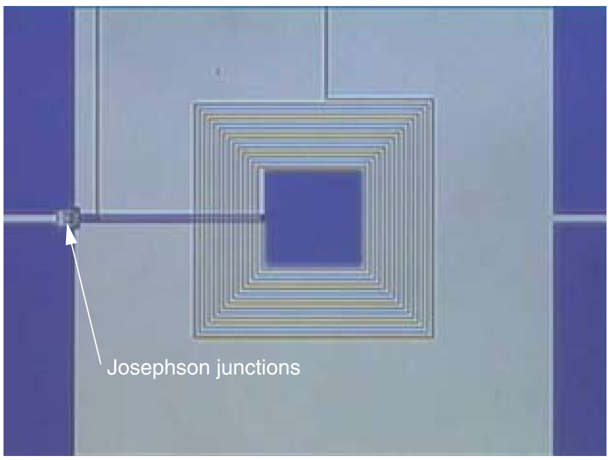
The original amplifiers, built by the National Radio Astronomy Observatory, were based on the heterostructure field-effect transistor, a semiconductor device developed for military communications and used by astronomers to boost weak radio signals. However, investigators decided the transistors were not sensitive enough for the weakest possible signals, so Kinion began a collaboration with Clarke's research group to develop amplifiers based on SQUID technology.



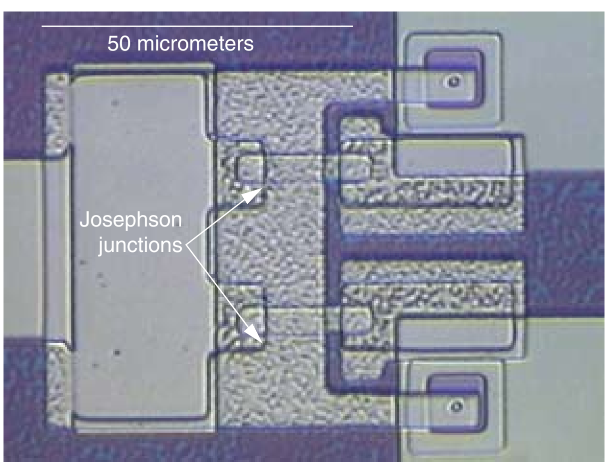
A cross section of the ADMX device shows an 8-tesla, 6-ton superconducting magnet coil wound around the outside of a cylinder the size of an oil drum. Stepper motors move a set of tuning rods in the cylinder's cavity to adjust the cavity's frequency. Helium cools the cavity, reducing the background noise so the ultrasensitive SQUID amplifiers can boost the faint axion signal.

A SQUID is composed of a superconducting loop containing two parallel Josephson junctions, which are made of a thin layer of insulating material sandwiched between two layers of superconducting metals. Josephson junctions are named for British physicist and Nobel Prize recipient Brian Josephson, who in 1962 predicted that pairs of superconducting electrons could "tunnel" through nonsuperconducting material from one superconductor to another.

SQUIDs are sensitive to the magnetic field penetrating the superconducting loop area. That is, the voltage measured across the device is a function of the total magnetic field inside the loop. The device is often configured as a magnetometer to detect extremely small magnetic fields, such as those generated by living organisms. For example, SQUIDs are commonly used as detectors in medical magnetoencephalography imaging. Other applications include oil and mineral exploration, geothermal energy surveys, and gravitational wave detection.



Each 1-millimeter-square, 200-nanometer-thick SQUID is composed of a superconducting loop containing two parallel Josephson junctions, which consist of a thin layer of insulating material sandwiched between two layers of superconducting metals.



This photomicrograph shows the two Josephson junctions used in SQUID amplifiers.

World's Most Sensitive Detector

Kinion produced the 1-millimeter-square, 200-nanometer-thick SQUIDs using UC Berkeley's photolithography facilities and techniques similar to those found in the semiconductor industry. The devices, made in part from superconducting niobium, are the most sensitive magnetic-field detector in the world, capable of picking up signals well below 1 yoctowatt (or 10^{-24} watts). ADMX will require 20 SQUIDs, each assigned to a different set of frequencies, to scan the entire frequency range.

"The biggest challenge we faced was designing a SQUID that could pick up trace differences in magnetic signals in close proximity to the 8-tesla superconducting magnet," says Kinion. He notes that during experiments at UC Berkeley, an unshielded SQUID routinely detected the magnetic field generated by a passing subterranean Bay Area Rapid Transit train about 1 kilometer away. To isolate SQUIDs from outside magnetic fields, the ADMX team enclosed them in a lead-plated box surrounded by concentric layers of materials.

Despite the extreme sensitivity of the SQUIDs and the shielding surrounding them, signals from axion decays could be overwhelmed by thermal and electronic noise emitted from electronic instruments. Therefore, the entire experiment is cooled with liquid helium to below 4.2 kelvins to provide a quiet sensing environment. When a more powerful cooling system is installed later this year, the amplifier will operate at less than 0.1 kelvins. It will then be able to detect even the most elusive axion as well as scan the microwave cavity four times faster than the current system.

The research team is confident that if axions exist, ADMX will detect them. Discovery of an axion would help scientists better understand the mysterious dark matter that permeates the universe, the force that binds atomic nuclei, and the nature of quantum physics.

—Arnie Heller

Key Words: Axion Dark Matter Experiment (ADMX), Josephson junction, quantum computing, qubit, superconducting quantum interference device (SQUID).

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A Better Method for Self-Decontamination

WHEN a person is exposed to dangerous chemicals, time is of the essence. Once hazardous substances make contact with skin, they may cause severe burns or even death. In the event of a chemical attack, people need immediate treatment to prevent further harm. Decontamination showers are effective at removing chemicals but are not feasible when treating large numbers of people. Easy-to-use, personal decontamination kits could be the solution in these emergency situations.

Decontamination kits used by the military allow personnel to treat themselves or their equipment when exposed to chemical agents. In the U.S., these kits contain an extremely porous carbon material, usually in powdered or granular form. The carbon has been activated—that is, it has a large surface area—and a high affinity for a range of chemicals. In powdered form, it is effective at adsorbing and eventually neutralizing chemical agents. However, particulates from the powder can create additional health risks if they are inhaled or spread to other parts of the body.

Another method is a liquid decontaminant called Reactive Skin Decontamination Lotion® (RSDL), which was invented at the Ottawa Laboratory of Defence Research and Development Canada and developed at that institution's Suffield Laboratory with support from the Department of Defense for licensing the product in the U.S. Manufactured by Bracco Diagnostics, Inc., RSDL is free of particulates and effective for a broad spectrum of chemical warfare agents. However, it has not been tested on a wide range of toxic industrial chemicals, nor is it ideal for use on water-sensitive equipment.

Laboratory researchers in the Engineering Directorate, in collaboration with research institutions and manufacturers, are developing an improved system. In a project funded by the Department of Homeland Security and overseen by the U.S. Technical Support Working Group, they have designed a prototype kit that physically removes most of a chemical and neutralizes any residuals on a surface without leaving behind particulate matter. This approach has the potential for use on numerous industrial chemicals and would ensure that treatment is effective, even when an individual cannot identify the specific agent or industrial chemical to which he or she has been exposed.

The Livermore team's prototype design, called the low-cost personal decontamination system (LPDS), is a portable kit that civilians and military personnel could use in the event of a chemical attack. The LPDS concept integrates two separate products—a dry fabric wipe and RSDL—into one kit that can treat a broad range of chemical agents, including toxic industrial compounds such as sulfuric acid. According to William Smith, a chemical engineer who led the LPDS development team, "By combining the existing military decontamination system with the wipe, there is promise for treating nearly every chemical. In some cases, individuals may be in much better shape with both technologies than with either one alone."

Serving a Dual Purpose

Each LPDS prototype kit includes a dry wipe, an RSDL-saturated sponge, and a step-by-step instruction card. All three items are contained in a sealable quart-size bag, and the entire prototype weighs less than 2 ounces. A final approved kit as compact and lightweight as the prototype would be easy to store and readily accessible in an emergency.

The dry wipe, developed by Seshadri Ramkumar at Texas Tech University and manufactured by Hobbs Bonded Fibers, Inc., is a layered, composite fabric that serves two main functions: absorption and adsorption. The top and bottom layers are made from porous and absorbent fabrics that work to remove the bulk of the chemical on a contaminated surface. Sandwiched between the two layers is a nonparticulate fabric form of activated carbon that adsorbs toxic vapors from the absorbed liquid. The activated carbon layer is bound to the absorbent fabrics by a technique called needle punching.

In the needle-punching process, barbed needles pull and loop the fibers, resulting in a tightly interlocked fabric structure. Because this process does not involve thermal or resin bonding, it creates a flexible pad and keeps the pores open in the fabric and carbon layers. The composite fabric can effectively wick away liquid chemicals and draw in toxic vapors. In addition, the multilayer pad could potentially be applied to mucous membranes such as on wounds or the eyes. Unlike older decontamination kits that use powdered carbon materials, the wipe will not leave behind particulate matter on these sensitive areas because the activated carbon is contained between the fabric layers.

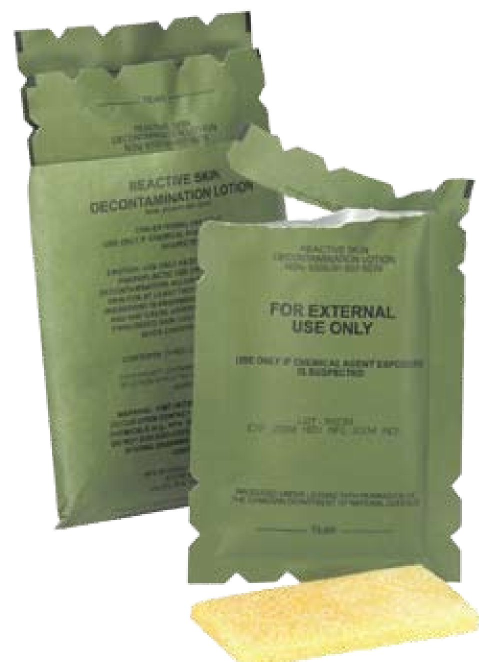
Using LPDS is a simple process that takes just minutes. First, a victim or first responder presses the dry wipe onto the contaminated surface, whether skin or equipment, to remove the bulk of the chemical. The person then scrubs the affected surface with the RSDL-saturated sponge. The lotion neutralizes the chemical agents and can decontaminate hard-to-reach areas, such as cracks in the surface of skin. The used wipe and sponge are resealed inside the original bag, keeping the toxins contained until they can be disposed of properly.

Do No Harm

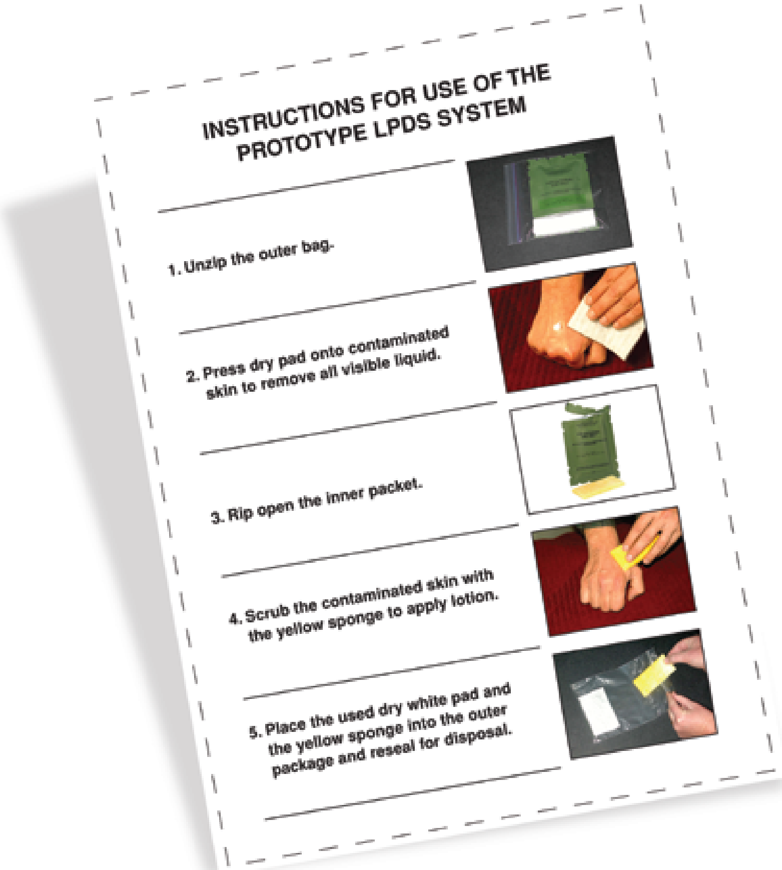
Because treatment after a chemical attack must be performed quickly, individuals cannot always identify which agents they have been exposed to before they apply decontaminants. Therefore, they must know that the decontamination product will react safely if at all with whatever chemical they may have on their body. Livermore scientist Adam Love, who tested the system components, says, "Our goal was to create a treatment system that provides a physical chemical removal process regardless of the actual chemical a person is exposed to."

Livermore researchers tested an LPDS prototype at the Laboratory's Forensic Science Center. The team first evaluated several liquid decontaminants to determine which one was most effective at neutralizing chemicals. For the initial tests, drops of the decontaminants were added to vials containing methyl parathion, sulfuric acid, and sulfur mustard. The most effective liquids from the first round of tests were then applied to samples of human skin. Results showed that RSDL was the most effective liquid formulation. When applied to a highly reactive industrial chemical such as sulfuric acid, RSDL has the potential to prevent acid burns on skin. However, when RSDL was applied to sulfuric acid in the laboratory tests, the mixture increased surface temperature to levels that may pose a burn hazard if used on skin. To mitigate this effect, the team searched for methods to remove most of the industrial chemical before RSDL is applied.

The team evaluated the absorption and adsorption properties of various dry decontaminants using the same toxic chemicals from



The low-cost personal decontamination system (LPDS) is an easy-to-use prototype kit for treating people or equipment after a chemical attack. A dry wipe (top image) removes the bulk of chemicals from the contaminated surface of skin or equipment. The yellow sponge is saturated with Reactive Skin Decontamination Lotion® to neutralize any residual chemicals.



Each LPDS prototype kit includes a step-by-step instruction card so victims of a chemical attack can quickly treat themselves even without training.

the liquid decontaminant experiments. The dry composite fabric wipe developed by Ramkumar performed better than the powdered carbon treatments tested by the team—including the proprietary carbon material in the military's older decontamination kit, which is now being replaced by the liquid RSDL.

Researchers also measured the wipe's reactivity and its ability to remain intact as it absorbs other chemicals. The wipe did not disintegrate even when bleach was added to a pad saturated with sulfur mustard. In addition, the saturated wipe did not exude vapors, which would have indicated chemical reactivity. The team also soaked clean, unsaturated pads in acids and solvents other than bleach. Results demonstrated that the pad remained intact and was not reactive when it came in contact with these chemicals.

The final stage of the Laboratory's testing evaluated how the dry wipe and RSDL worked together on skin samples exposed to sulfur mustard. The two-step process—using the pad first to remove the bulk of the liquid chemical followed by the RSDL sponge to neutralize the rest—was more effective than existing decontamination systems in treating an array of chemicals.

Taking the First Step

Smith notes that LPDS must undergo further testing for safety and with more chemical agents and toxic industrial compounds before the Food and Drug Administration will approve it for use. However, the technology's effectiveness with sulfur mustard—one of the most difficult chemical agents to remove—holds promise for future success.

As designed, LPDS would cost less than $30 per kit. The compact design would allow kits to be available at large outdoor public facilities and in emergency vehicles for first responders to use and distribute to civilians in the event of a chemical attack. "Such kits could prevent panic by providing people the confidence they need to help themselves until more extensive decontamination methods can be set up," says Smith. As a result of the work performed by the Livermore researchers and their collaborators, LPDS could offer military personnel and civilians an effective first step in self-decontamination when time is of the essence.

—Caryn Meissner

Key Words: activated carbon, chemical agents, low-cost personal decontamination system (LPDS), Reactive Skin Decontamination Lotion® (RSDL), toxic industrial compounds.

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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

Method for the Detection of *Salmonella enterica* serovar *Enteritidis*

Peter G. Agron, Gary L. Andersen, Richard L. Walker
U.S. Patent 7,442,517 B2
October 28, 2008
A novel *Salmonella enterica* serovar *Enteritidis* locus serves as a marker for DNA-based identification of this bacterium. Three primer pairs derived from this locus may be used in a nucleotide detection method to detect the presence of the bacterium.

Superconducting Gamma and Fast-Neutron Spectrometers with High Energy Resolution

Stephan Friedrich, Thomas R. Niedermayr, Simon E. Labov
U.S. Patent 7,446,314 B2
November 4, 2008
These superconducting gamma-ray and fast-neutron spectrometers with very high energy resolution can be operated at very low temperatures. A sensor with a bulk absorber and a superconducting thermometer weakly coupled to a cold reservoir determines the energy of the incident particle from the increase in temperature that occurs with absorption. A superconducting film operated at the transition between its superconducting and normal states is used as the thermometer. Sensor operation at reservoir temperatures of about 0.1 kelvins reduces thermal fluctuations and thus enables very high energy resolution. The spectrometer can be configured as either a gamma-ray or a fast-neutron spectrometer, depending on the absorber material used.

Synthesis of DNA

Raymond P. Mariella, Jr.
U.S. Patent 7,452,666 B2
November 18, 2008
This method synthesizes a specific length of double-stranded DNA in a specified sequence. The segments that will complete the sequence are selected and assembled to produce the desired double-stranded DNA.

Time Reversal Communication System

James V. Candy, Alan W. Meyer
U.S. Patent 7,460,605 B2
December 2, 2008
This system digitizes a signal and then time-reverses it, so it can be transmitted through a channel medium. The channel medium may be air, earth, water, tissue, metal, or a nonmetal material.

Material for Electrodes of Low Temperature Plasma Generators

Malcolm Caplan, Sergel Evgeévich Vinogradov, Valeri Vasilévich Ribin, Valentin Ivanovich Shekalov, Philip Grigorévich Rutberg, Alexi Anatolévich Safronov
U.S. Patent 7,462,089 B2
December 9, 2008
A material for electrodes of low-temperature plasma generators contains a porous metal matrix impregnated with a material that emits electrons. A mixture of copper and iron powders used as a porous metal matrix is combined with a Group IIIB metal component such as yttrium oxide (Y_2O_3), with components in various proportions, such as iron from 3 to 30 percent by mass, Y_2O_3 from 0.05 to 1 percent, and copper the remainder. Copper provides a high level of heat conduction and electric conductance. Iron decreases the intensity of copper evaporation during plasma creation, which increases the material's strength and lifetime. Yttrium oxide decreases the electronic work function and stabilizes arc burning. The material will produce electrodes in low-temperature, alternating-current plasma generators, which are used to dispose of liquid organic, medical, and municipal wastes; to decontaminate low-level radioactive waste; and to destroy chemical weapons and toxic warfare agents.

Silicone Metalization

Mariam N. Maghribi, Peter Krulevitch, Julie Hamilton
U.S. Patent 7,462,518 B2
December 9, 2008
This system provides a silicone layer on a matrix and a metal layer on the silicone layer to produce an electronic apparatus. The apparatus has metal features on the silicone body to provide an electronic device.

Gain Media Edge Treatment to Suppress Amplified Spontaneous Emission in a High Power Laser

Lloyd A. Hackel, Thomas E. Soules, Scott N. Fochs, Mark D. Rotter, Stephan A. Letts
U.S. Patent 7,463,660 B2
December 9, 2008
This apparatus suppresses amplified spontaneous emission and parasitic oscillation modes in a high-average-power laser. One or more peripheral edges of a solid-state crystal or ceramic laser gain media are roughened. A high-index bonding elastomer or epoxy is then used to bond the edges to an electromagnetic-absorbing material adjacent to the outer surface of the roughened media.

Multi-Channel Time-Reversal Receivers for Multi and 1-Bit Implementations

James V. Candy, David H. Chambers, Brian L. Guidry, Andrew J. Poggio, Christopher L. Robbins
U.S. Patent 7,463,690 B2
December 9, 2008
A communication system for transmitting a signal through a channel medium digitizes and time-reverses a signal. One arrangement uses a transmitter, multiple receivers, a digitizer, and a time-reversal signal processor. Other setups have one- or multi-bit implementations. Multiple receivers can also be used to transmit the signal through the channel medium.

Liquid Class Predictor for Liquid Handling of Complex Mixtures

Brent W. Segelke, Timothy P. Lekin
U.S. Patent 7,463,982 B2
December 9, 2008
This method establishes liquid classes of complex mixtures for liquid-handling equipment. A response curve for the mixture components is used to prepare a response indicator for the mixtures. A model is then derived to relate the components and mixtures and establish the liquid classes.

Awards

Research conducted by Livermore astrophysicist **Bruce Macintosh** and colleagues from the National Research Council's **Herzberg Institute of Astrophysics** in Canada, **Lowell Observatory**, and the **University of California at Los Angeles** was recognized as the first runner-up on the 2008 list of top 10 science breakthroughs, which is published by *Science*. Using telescopes at the Keck and Gemini observatories in Hawaii, the research team took the first snapshots of the multiplanet solar system that orbits a dusty young star named HR8799. The star, which is 140 light years away, is about 1.5 times the size of our Sun.

Livermore physicists **Don Correll** and **Edward Moses** were awarded the distinction of **Fellow** of the **American Association for the Advancement of Science** (AAAS), an honor bestowed on AAAS members by their peers.

Correll joined the Laboratory in 1976 and has held positions in both the Magnetic Fusion Energy and the Laser Fusion programs. From 1998 to 2003, he served as director of Livermore's Science and Technology Education Program, and in 2004, he became the director for the Institute for Laser Science Applications. In naming him as a fellow, AAAS honored Correll for his "long-standing recognition and distinguished contributions to science education, including communications and materials targeted toward students, teachers and the general public."

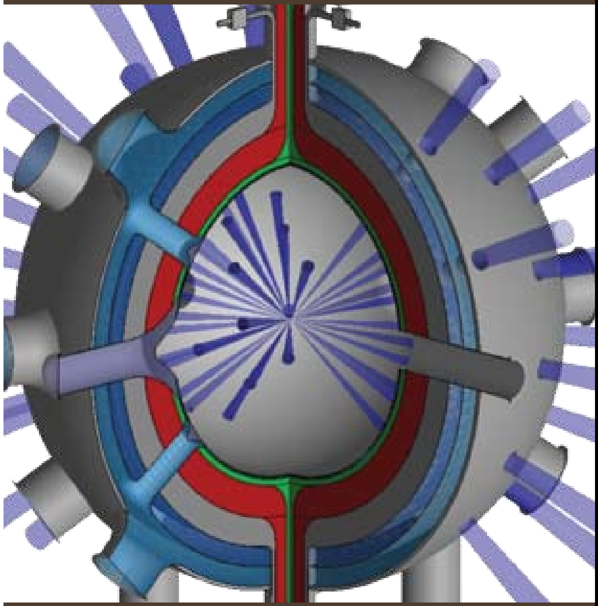
Moses joined Lawrence Livermore in 1980, becoming program leader for Isotope Separation and Material Processing and deputy associate director for Lasers. In 1990, he left the Laboratory and was a founding partner of Advanced Technology Applications, which advised clients on high-technology projects. He returned to Livermore in 1995 as assistant associate director for program development in Physics and Space Technology and today serves as principal associate director for the National Ignition Facility and Photon Science. AAAS recognized Moses for "distinguished scientific and engineering contributions leading to development and construction of the world's largest and most energetic laser system, the National Ignition Facility."

Founded in 1848, AAAS is the world's largest general scientific society, with more than 10 million members, and publishes the journal *Science*. This year, 486 members were named as fellows.

Sleuthing Seismic Signals

Lawrence Livermore is at the forefront of research to more accurately distinguish nuclear explosions from the rest of Earth's never-ending seismic activity. For more than a decade, Laboratory seismologists have been using available seismic data to develop and verify one- and two-dimensional regional Earth models. They also help calibrate the worldwide array of seismic monitoring stations maintained by the Preparatory Commission for the Comprehensive Nuclear Test Ban Treaty Organization in Vienna. Calibration ensures that new algorithms accurately account for regional geologic characteristics. With the expanded capabilities offered by Livermore's supercomputers, they are adding more realistic geology and seismic wave propagation effects to their three-dimensional seismic models to improve the models' precision at detecting and locating events. For example, a hybrid numerical technique combines the complex calculations necessary to capture the effects of topography with an efficient scheme for simulating subsurface geology. Another application is a probability method dubbed Bayesloc, which quickly pinpoints the location of seismic events. Laboratory seismologists are also working on a computational approach that will automatically analyze seismograms. These new methodologies not only improve the nation's capabilities for nuclear explosion monitoring but also allow researchers to better define seismically active faults where small earthquakes may occur.
Contact: Bill Walter (925) 423-8777 (bwalter@llnl.gov).

Clean Energy from a Fusion–Fission Hybrid



A new concept in nuclear energy, based on the National Ignition Facility, could provide safe energy while significantly reducing long-lived waste and proliferation concerns.

Also in April/May

• Livermore's Joint Conflict and Tactical Simulation is the most widely used tactical model in the world.

• By infusing carbon aerogels with platinum, researchers have produced an affordable, efficient catalytic material.

• A robust time-projection chamber provides directional detection of fast neutrons and could improve search methods for nuclear materials.

Coming Next Issue

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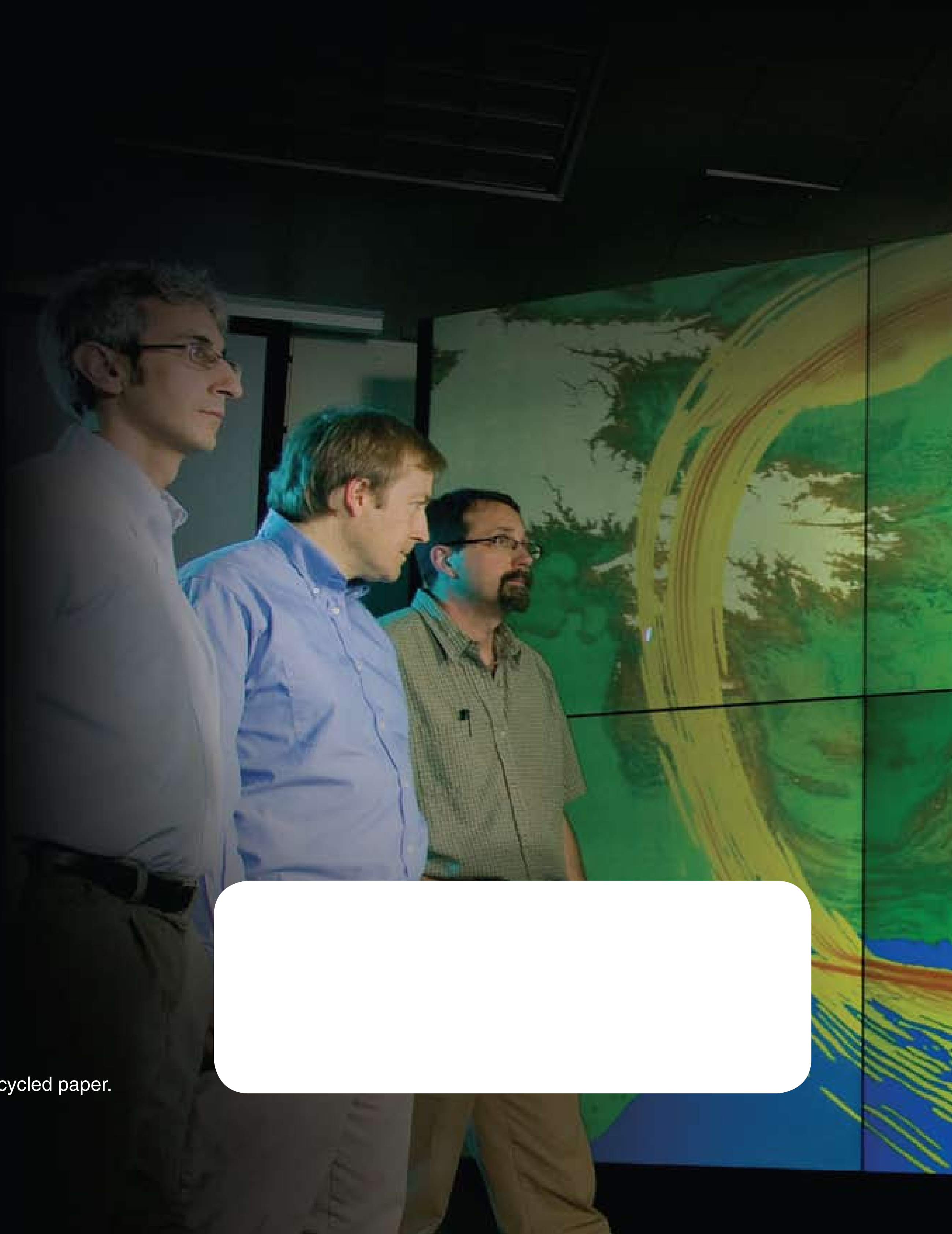

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