Science in Support of International Weapon Treaties

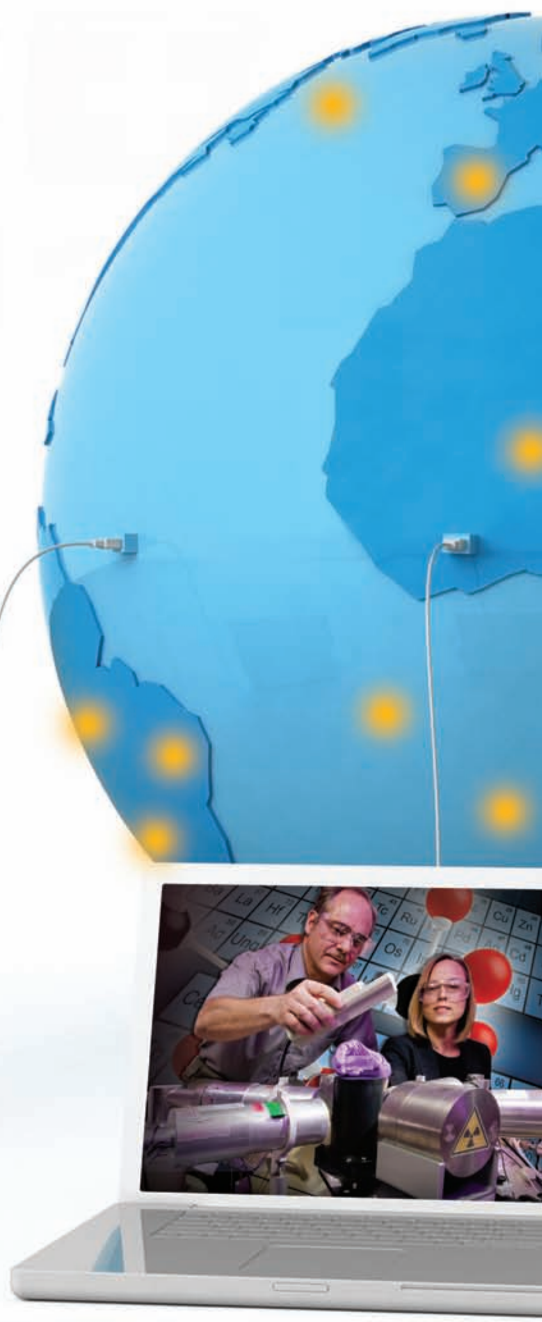
Livermore scientists provide technical expertise for negotiating and verifying treaties that limit or ban weapons of mass destruction.

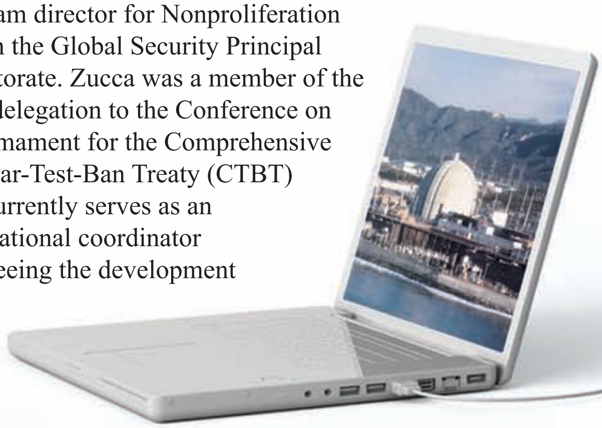
FOUNDED as a nuclear weapons laboratory, Lawrence Livermore has for more than five decades helped support international treaties and agreements that limit or ban weapons of mass destruction. Laboratory experts have provided technical guidance for proposed treaties and have analyzed the possible effects of a treaty's provisions on national security. After a treaty enters into force, Livermore expertise about weapons, nuclear materials, and verification technologies contributes to U.S. and international efforts to ensure worldwide compliance with the treaty's terms and commitments. Indeed, the strength of treaties and arms reduction agreements rests, in large part, on the technical capabilities available for monitoring compliance.

"Laboratory employees have been involved at various levels with many international and bilateral treaties governing weapons of mass destruction," says Laboratory seismologist Jay Zucca, program director for Nonproliferation within the Global Security Principal Directorate. Zucca was a member of the U.S. delegation to the Conference on Disarmament for the Comprehensive Nuclear-Test-Ban Treaty (CTBT) and currently serves as an international coordinator overseeing the development of the International Monitoring System for the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization in Vienna, Austria.

CTBT prohibits all nuclear explosions, including those intended for peaceful purposes. Dozens of Laboratory scientists worked for more than three decades providing technical support to U.S. government efforts to achieve this international agreement, which was signed by President Bill Clinton and other heads of state on September 24, 1996, at the United Nations. In signing the treaty, President Clinton used the same pen President John F. Kennedy had used to sign the Limited Test Ban Treaty in 1963. Clinton described CTBT as the "longest sought, hardest fought prize in the history of arms control negotiations."

Although 153 nations have ratified the pact, the treaty specifies 44 nuclear-capable states that must ratify CTBT before it can take effect. Of the 44,





nine have not ratified: the U.S., China, Indonesia, Egypt, India, Iran, Israel, Democratic People's Republic of Korea (North Korea), and Pakistan. India, Pakistan, and North Korea have conducted nuclear tests since CTBT was signed. Although the Senate has not ratified the treaty, the U.S. has not conducted a nuclear test since 1992. President Barack Obama has said he will "aggressively" push for CTBT ratification. (See the box on p. 7.)

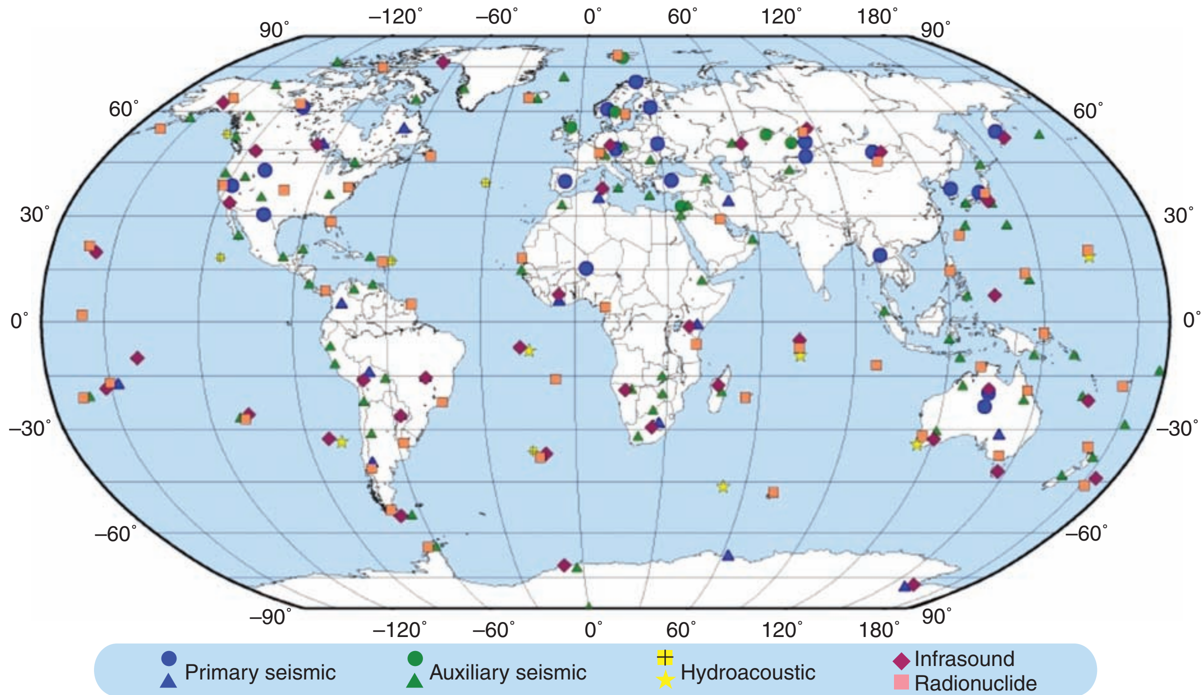
"Listening" to the World

CTBT's International Monitoring System is designed to search for evidence of clandestine nuclear explosions. In Vienna, an International Data Center processes data from hundreds of monitoring stations around the world. Although the network of stations is still in the buildup phase and is operating in testing and evaluation mode, it transmits data daily to the Vienna center. When complete, the International Monitoring System will have 321 stations and 16 laboratories located worldwide, including 50 primary and 120 auxiliary stations to monitor local seismic signals. In addition, hydroacoustic stations "listen" to the oceans, infrasound stations record very-low-frequency atmospheric sound waves, and radionuclide stations collect air samples to detect radioactive debris from atmospheric or underwater nuclear explosions as well as noble gases that could be produced by underground nuclear explosions.

Livermore scientists provide technical expertise in support of international efforts to limit or ban nuclear weapons. Many Laboratory technologies are used to monitor compliance with a treaty's provisions. Examples (shown in the computer screens from left) include detectors for monitoring nuclear power plants, new materials for detecting radiation, and forensic seismology tools for distinguishing earthquakes and other seismic disturbances from underground nuclear explosions.

During the 1990s, Livermore experts contributed to the CTBT negotiations in Geneva, Switzerland, by helping to select sites for monitoring stations, define procedures for onsite inspections, and adopt concepts for national monitoring. Since the treaty signing, Livermore researchers have worked on several Department of Energy projects that support the U.S. National Data Center at Patrick Air Force Base in Florida, the U.S. facility responsible for treaty monitoring. Bill Walter leads a team of about a dozen seismologists and other scientists in this effort. (See *S&TR*, March 2009, pp. 4–12.) The Laboratory is also working closely with the International Data Center to ensure an effective monitoring capability.

In a National Geographic Explorer documentary, "Inside the Nuclear Threat," which first aired in April 2010, Zucca discusses how seismology can detect underground nuclear tests. "Many events, such as a small earthquake, can produce a seismic signature similar to a small clandestine nuclear detonation," he says. Every year, more than 200,000 earthquakes occurring around the world have a similar seismic magnitude to that of a small underground nuclear explosion. Laboratory researchers are pioneering methods to more accurately distinguish a nuclear explosion from other seismic events, including earthquakes, volcanoes, and mining activity, and to pinpoint



The International Monitoring System for the Comprehensive Nuclear-Test-Ban Treaty searches for evidence of clandestine nuclear explosions. When complete, the system will comprise 321 seismic, hydroacoustic, infrasound, and radionuclide stations and 16 laboratories worldwide. (Courtesy of Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization.)

The Vienna International Centre in Vienna, Austria, houses the International Atomic Energy Agency (IAEA) and the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization. (Courtesy of IAEA; photographer: Dean Calma.)

an event's location. They are also working with scientists throughout the Middle East and Asia to determine how regional geology affects seismic signals, which travel underground before being recorded.

When India and Pakistan conducted underground nuclear tests in 1999, Livermore scientists used seismic data recorded from the blasts to successfully differentiate the nuclear tests from typical regional earthquakes. In the process, they characterized the test yields and noted inconsistencies between the announced yields and the inferred results. The signals from the nuclear tests also provided important data for calibrating seismic stations in this geologically complex region.

When North Korea declared it had conducted a small nuclear test in October 2006, only two-thirds of the 321 seismic stations for the International Monitoring System had been installed. Nevertheless, the system performed extremely well, with 22 stations detecting the low-yield explosion. On May 25, 2009, North Korea announced another nuclear test. At that time, about 85 percent of the monitoring system had been installed, and 61 stations recorded the event. The extensive data set permitted a more precise assessment of the event's location and magnitude. The following month, Laboratory personnel were among the 500 verification technology experts from 86 countries who gathered in Vienna for the International Scientific Studies Conference to discuss the treaty's capabilities to detect nuclear explosions in light of the two North Korean tests.

An important element of CTBT is the provision for an onsite inspection, which may be requested when remote systems cannot resolve the nature of a suspicious event. A group of inspectors will then search the area identified as the possible nuclear-test location. Livermore experts have led the development of onsite inspection technologies and procedures, such as looking for underground explosion cavities or rubble. Laboratory-developed tools also can detect small amounts of the rare radioactive gases that would be generated by an underground nuclear detonation and then would migrate to the surface. In addition, three Laboratory scientists serve on the five-member inspection team for the U.S.

Safeguards to Prevent Proliferation

Preventing the spread of nuclear weapons requires efforts on many fronts. Monitoring activities provide evidence to verify that no nuclear experiments are conducted and that no nuclear materials are stolen, diverted, or clandestinely produced. In addition, controls are needed to prevent the export of nuclear facilities, equipment, and sensitive technology.

The International Atomic Energy Agency (IAEA) is responsible for verifying peaceful uses of nuclear energy under the Nuclear Non-Proliferation Treaty. Established in 1957 as the world's "Atoms for Peace" organization, IAEA implements various verification measures (safeguards) to ensure that nuclear facilities and materials are not misused for military purposes. The Nuclear Non-Proliferation Treaty, which limits the spread of nuclear weapons, came into force in 1970 and has been ratified by 189 states. (India, Pakistan, and Israel have not signed or ratified the treaty. North Korea ratified it in 1985 but withdrew from participation in 2003.)

The treaty requires a participating nonnuclear weapon state to sign a comprehensive safeguards agreement with IAEA and to place all of the state's nuclear material and activities under IAEA safeguards. The agency regularly inspects nuclear facilities in 57 nonnuclear weapon countries. Inspectors confirm nuclear material inventories, review surveillance camera footage, analyze environmental samples, and look for evidence of undeclared activities.

The Laboratory supports IAEA's nuclear safeguards mission by developing new technologies and providing expert advice to the agency and to U.S. policy makers. Livermore personnel not only work with international partners to strengthen safeguards implementation but also take leaves of absence to serve as IAEA staff members. Laboratory scientists Tony Lavietes and Cynthia Annese are currently working at the IAEA Department of Safeguards in Vienna. Researchers Young Ham, Jonathan Essner, and George Anzelon have also worked there in years past.

Livermore scientists have developed both portable and stationary tools to detect and characterize materials produced as part of the nuclear fuel cycle. One example is GeMini, a handheld high-resolution gamma spectrometer developed by a team led by physicist Morgan Burks. (See

Nuclear Arms Treaties Nearly as Old as Nuclear Weapons

Since the first experiment with a nuclear explosive was conducted in 1945, a succession of treaties has narrowed the lawful environment for nuclear testing. Public concern over atmospheric testing led the U.S. and the Soviet Union to establish a Conference of Experts to examine the technical issues associated with a comprehensive ban on nuclear weapons testing in all environments, including the atmosphere, outer space, underwater, and underground. Ernest O. Lawrence, the Laboratory's cofounder, served as one of three U.S. representatives to this conference. Harold Brown, who became Laboratory director in 1960, was a member of the delegation's technical advisory group.

At the end of the conference in 1958, the U.S. and the Soviet Union entered into a nuclear testing moratorium, and negotiations began on a test-ban treaty. Livermore scientists participated in technical working groups complementing the negotiations on a comprehensive nuclear test ban. Measuring seismic signals was considered a viable technique for detecting underground explosions, and a worldwide network of seismic stations was built as part of this effort. The Soviet Union's resumption of nuclear testing in September 1961 broke the bilateral moratorium and ended the negotiations at that time.

In the ensuing decades, the Laboratory contributed to arms-control negotiations on strategic force levels and nuclear testing. These negotiations led to a number of successful international treaties. The Limited Test Ban Treaty, ratified in 1963, banned nuclear explosions in the air, oceans, and space. President Richard Nixon and Soviet Secretary Leonid Brezhnev signed the Threshold Test Ban Treaty in 1974, although the U.S. Senate did not ratify it until 1990. That treaty limited underground nuclear tests to 150 kilotons. By comparison, the bomb dropped on Hiroshima had a yield of 15 kilotons.

The Comprehensive Nuclear-Test-Ban Treaty was signed in 1996, following many years of negotiations. It prohibits all nuclear explosions but has yet to be ratified by the U.S. Senate.

The Strategic Arms Reduction Treaty (START), a bilateral treaty between the U.S. and the Soviet Union, was signed in 1991. It succeeded the Strategic Arms Limitation Treaty I and II, agreed to in the 1970s. Shortly after signing START, the Soviet Union dissolved. Negotiations continued with the former Soviet republics, allowing START to enter into force in 1994. START barred its signatories from deploying more than 6,000 nuclear warheads atop a total of 1,600 intercontinental ballistic missiles, submarine-launched ballistic missiles, and bombers. The treaty expired in December 2009.

New START, signed in 2010 by U.S. President Barack Obama and Russian President Dmitry Medvedev, reduces strategic delivery vehicles by more than half and deployed warheads by three-quarters compared with the START limits. This agreement will enter into force after the two countries' legislatures ratify it.

Directors from the National Nuclear Security Administration's three weapons laboratories testified in July 2010 before the Senate Armed Services and Foreign Relations committees on the prospects for sustaining the nation's nuclear stockpile under New START. Lawrence Livermore Director George Miller noted that the Stockpile Stewardship Program is "a cornerstone of the nation's strategic deterrent for the future" and emphasized the continued need for a stewardship program that is "balanced, integrated, and sustained over time."

Laboratory researcher Young Ham (center) and two South Korean scientists prepare to test a prototype of a Livermore-developed spent-fuel verification instrument at the Kori-2 nuclear power station in Gori, Republic of Korea.

In July 1991, Livermore physicist Jay Davis, who later served as an associate director, worked on an IAEA inspection team in Iraq. This photo shows Davis examining the bombed remains of Iraq's clandestine uranium enrichment facility at Al Tarmiyah. (Courtesy of IAEA.)

S&TR, October/November 2009, pp. 8–9.) An R&D 100 Award–winning technology, GeMini does not need liquid nitrogen for cooling and thus can be used in the field to accurately identify nuclear materials. A version is being built for the international safeguards community to evaluate for use in IAEA inspections at nuclear facilities and other locations.

Another promising technology for safeguarding nuclear facilities is the liquid scintillator multiplicity counter being designed by researchers from Lawrence Livermore and Sandia national laboratories. (See *S&TR*, July/August 2008, pp. 23–25, and the highlight beginning on p. 20.) In addition, Ham leads a team developing innovative methods to verify spent fuel stored at reactor sites, in cooperation with the Republic of Korea and other nations. Another team, led by researcher Faranak Nekoogar, is developing ultrawideband radio-frequency identification tags for tracking nuclear material containers.

Lawrence Livermore is also a member of IAEA's Network of Analytical Laboratories. In this role, Ross Williams and his team of chemists analyze a portion of the environmental samples collected by IAEA during its inspection activities and report results back to IAEA. The Laboratory also conducts research to develop analytical techniques and methods for interpreting safeguards-relevant signatures present in these samples.

Expertise for Inspections

In a few special cases—notably Iraq, Libya, and North Korea—countries have agreed, either voluntarily or under the threat of action from the United Nations' Security Council, to disclose and eliminate previously clandestine nuclear capabilities. To support this effort, several DOE laboratories, including Lawrence Livermore, have provided experts to work with or in parallel to IAEA's expert teams. For example, following the 1991 Gulf War, Livermore's Anzelon, Bill Nelson, Jay Davis, Lee McLean, Ron Kerst, Bill Domke, Bill Conaway, Frank Pabian, Jackie Kenneally, Cal Woods, and Bill Quirk participated in IAEA inspection teams that uncovered and dismantled Iraq's secret nuclear weapons program. In early 2003, Domke and Rob Schmidt served on IAEA teams inspecting Iraq in the weeks before the second Gulf War. Heather Harvey and Jennifer Swenson joined Domke and Kerst as participants in the U.S. inspection following that war.

Libya agreed to disclose its formerly secret nuclear program in 2004 and allowed the U.S. and the United Kingdom to remove sensitive nuclear equipment and materials. Mark Franks, an engineer at the National Ignition Facility, contributed to plans for the removal operation. Other Livermore staff traveled to Libya to help inspect facilities, remove equipment, and verify activities. More recently, as part of the now-moribund denuclearization efforts in North Korea, the Department of Energy and several of its laboratories sent personnel to monitor disablement activities at the Yongbyon nuclear center. Livermore's Lisa Szytel, now with the National Nuclear Security Administration, led several monitoring teams in North Korea. Another Laboratory scientist led the nuclear monitoring team that was expelled, along with IAEA monitors, in April 2009 when North Korea abrogated its denuclearization agreement.

To help strengthen IAEA verification technologies and scientific resources, DOE launched the Next Generation Safeguards

In 2004, Livermore scientists assisted a U.S.—United Kingdom effort to remove large quantities of sensitive nuclear materials and nuclear material processing equipment from Libya. In this photograph, U.S. personnel are positioning a container of uranium hexafluoride in a cargo aircraft prior to departure from Libya. (Courtesy of U.S. Department of Energy.)

U.S. President Barack Obama (left) and Russian President Dmitry Medvedev signed the New Strategic Arms Reduction Treaty (New START) on April 8, 2010, in Prague, Czech Republic. (Courtesy of U.S. Department of State and White House; photographer: Chuck Kennedy.)

U.S. and Russian delegations sat opposite one another at the New START negotiating table in Geneva, Switzerland. (Courtesy of U.S. Department of State; photographer: Eric Bridiers.)

Initiative in 2009. Mona Dreicer, the deputy program director for Nonproliferation, supported colleagues at the National Nuclear Security Administration's Office of Nonproliferation and International Security to develop the initiative's implementation plan. To help train the next generation of safeguards professionals, the Laboratory and the Monterey Institute of International Studies prepared a short course on safeguards policy and information analysis. Many Livermore researchers also mentor graduate students assigned to safeguards-related projects.

New START for Disarmament

Because they have first-hand knowledge of nuclear weapons, radiation detection capabilities, and verification technologies, Livermore researchers have worked on many nuclear treaty negotiations. Dreicer supported DOE as part of the U.S. delegation at negotiations for the follow-on agreement to the Strategic Arms Reduction Treaty (or New START) between the U.S. and Russia. The original START agreement, which was signed in 1991 and expired in 2009, dramatically reduced the number of strategic delivery systems and deployable warheads for both countries.

U.S. President Obama and Russian President Dmitry Medvedev signed New START on April 8, 2010. The agreement will cut American and Russian deployed strategic nuclear warheads to 1,550 over seven years, about a third less than the 2,200 warhead limit established in 2002 under the Moscow Treaty. In comparison, the U.S. deployed about 19,000 warheads at the end of the Cold War. Within the next seven years, both nations will reduce their total land-, sea-, and air-based launchers to 800, with no more than 700 deployed intercontinental and sea-launched ballistic missiles and heavy bombers. New START is awaiting ratification by the U.S. Senate and the Russian Duma.

Dreicer's background includes modeling radionuclides and determining their effects on people and the environment. Her work, which has involved evaluating health and environmental impacts of the 1986 accident at the Chernobyl nuclear power plant, brought her to the U.S. Arms Control and Disarmament Agency as a technical expert on the radionuclide monitoring network for CTBT. When the agency became part of the State Department, her role expanded to leading the office that worked on verifying compliance with nuclear arms-control and nonproliferation agreements.

During the past year, in support of DOE, Dreicer participated in the Treaty Text Working Group of the New START Delegation in Geneva. This group was responsible for ensuring that the treaty articles accurately conveyed the terms agreed to by the Russian and American delegations. She also participated with the team responsible for developing the treaty's terms and definitions, a protocol

Negotiators present the details of New START to international arms-control diplomats at a plenary session of the 2010 Conference on Disarmament in Geneva, Switzerland. (Courtesy of U.S. Department of State; photographer: Eric Bridiers.)

section that applies to the treaty articles, protocol sections, and related documents.

Livermore radiochemist John Luke spent many months at DOE headquarters helping to develop negotiating positions for the U.S. government. Engineer Carolyn Pura from Sandia National Laboratories, California, supported DOE by contributing expertise to develop the treaty's inspection and telemetry components.

Dreicer notes that New START required less than a year of preparation—an extraordinarily short time. "For START I, we saw higher levels of mistrust on both sides," she says. "New START reflects the current state of improved relations between the U.S. and Russia."

A Ban on All Chemical Weapons

Unlike nuclear treaties that limit the numbers and types of permitted weapons, the Chemical Weapons Convention (CWC) bans an entire class of weapons of mass destruction. It outlaws the development, production, acquisition, stockpiling, and use of chemical weapons. Signatory nations must destroy any chemical weapon stockpiles and production facilities. The treaty also bans the transfer of chemical weapon–related technologies to other countries or groups. CWC is the first arms-control treaty to widely affect the private sector because many chemicals of concern have legitimate civilian uses. As a result, industrial facilities as well as government sites are subject to inspections.

CWC opened for signing in 1993 and has been ratified by 188 countries, including the U.S. The Organisation for the Prohibition of Chemical Weapons (OPCW), headquartered in The Hague, Netherlands, implements the treaty.

A unique feature of CWC is its incorporation of the "challenge inspection," whereby any signatory in doubt about another signatory's compliance can request that the OPCW Director-General send an inspection team. By agreeing to this procedure, signatories have committed to the principle of "anytime, anywhere" inspections with no right of refusal.

Livermore's work supporting OPCW is performed by the Forensic Science Center (FSC) as part of Global Security's Nonproliferation Program. FSC is one of 19 laboratories around the world certified by OPCW to support challenge inspections. The other certified U.S. laboratory is at the Army's Forensic Analytical Center at Edgewood Chemical Biological Center in Maryland. OPCW requires that samples from sites under challenge be analyzed by two OPCW-certified laboratories. U.S. legislation, however, requires that all samples collected in the U.S. be analyzed within the country. Thus, the U.S. needs two OPCW-certified laboratories to comply with the treaty.

Livermore was selected to be the nation's second OPCW-designated laboratory because its capabilities include chemical analysis and forensic

Livermore chemist Saphon Hok synthesizes a compound as part of the Forensic Science Center's annual recertification exercise for the Organisation for the Prohibition of Chemical Weapons.

characterization of unknown samples and detection of trace levels of unknown compounds. In addition, the Laboratory operates under strict environmental controls and tight physical security.

An OPCW-designated laboratory must be able to detect traces of tens of thousands of possible compounds, including chemical warfare agents, precursor chemicals, and decomposition products, often in the presence of other compounds that complicate the analysis. The laboratory must then synthesize the identified chemicals to verify the analysis and report the results—all within 15 days. "OPCW can call us any time to perform an analysis," says analytical chemist Armando Alcaraz.

All OPCW laboratories must be recertified every year, which requires passing a stringent proficiency test. Test samples typically contain mixtures of many compounds, some of which are added to deliberately mask an incriminating species. For example, facility operators who are clandestinely producing chemical weapons might dump chemicals on the ground near the production facility and then bleach the soil minutes before OPCW inspectors arrive. To ensure that certified laboratories can distinguish chemical warfare agents in those types of samples, OPCW might spike a test sample with bleach. Samples can be in many forms, from soil and decontamination products to aqueous solutions, organic reaction mixtures, and compounds that seem to be chemical agents but are not. Pesticides and their degradation products, in particular, can appear similar to chemical weapons.

FSC chemists use an array of analysis techniques, including mass spectrometry, gas chromatography, nuclear magnetic resonance, and Fourier transform infrared spectroscopy. However, successfully passing the annual recertification test requires far more than having sophisticated equipment. Critical tasks include carefully preparing the sample so its constituents can be identified, completing the analysis, interpreting data correctly, and reporting results to the proper authorities.

Obtaining certification in 2003 brought national recognition to the center and work from the Department of Homeland Security, Environmental Protection Agency (EPA), Food and Drug Administration, and Federal Bureau of Investigation. FSC scientists have led training workshops at various EPA laboratories, showing staff members how to analyze materials containing chemical weapon agents. In the event of a chemical attack at a busy public facility, such as an airport, EPA would then call on these laboratories to determine the extent of chemical agents in building materials such as drywall, floor tiles, and carpeting. Materials would be tested again, after decontamination efforts, to ensure that the facility could be safely reopened to the public. (See *S&TR*, March 2010, pp. 4–10.)

FSC is also certified to store and handle small quantities of nerve agents, so it routinely evaluates new detection instruments for the Department of Homeland Security and law-enforcement agencies. "Surrogates to the main chemical weapons exist, and we might use them in the initial development and testing phases," says Alcaraz. "But until we've tested a device on the real thing, we can't say with 100-percent confidence that it can detect a chemical agent."

National Security in Full Context

Throughout its history, the Laboratory has played a major role in ensuring the safety, security, and performance of the nation's nuclear deterrent, first through its historical work in designing and testing nuclear weapons and, since the early 1990s, through the nation's Stockpile Stewardship Program. Efforts in support of treaty negotiations and verification activities may be less well known. History may show, however, that this work has made an equally important contribution toward ensuring the nation's security.

—Arnie Heller

Key Words: Chemical Weapons Convention (CWC), Comprehensive Nuclear-Test-Ban Treaty (CTBT), Forensic Science Center (FSC), GeMini, International Atomic Energy Agency (IAEA), International Monitoring System, Limited Test Ban Treaty, New Strategic Arms Reduction Treaty (New START), Next Generation Safeguards Initiative, Nuclear Non-Proliferation Treaty, Organisation for the Prohibition of Chemical Weapons (OPCW), Threshold Test Ban Treaty.

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