

SCIENCE AND TECHNOLOGY ON A MISSION

FY 2015 ANNUAL REPORT



Lawrence Livermore
National Laboratory



ABOUT THE LABORATORY

Lawrence Livermore National Laboratory (LLNL) was founded in 1952 to enhance the security of the United States by advancing nuclear weapons science and technology and ensuring for a safe, secure, and effective nuclear deterrent. With a talented and dedicated workforce and world-class research capabilities, the Laboratory strengthens national security with a tradition of science and technology innovation—anticipating, developing, and delivering solutions for the nation’s most challenging problems.

The Laboratory is managed by Lawrence Livermore National Security, LLC (LLNS), for the National Nuclear Security Administration (NNSA), a semi-autonomous agency within the U.S. Department of Energy (DOE). LLNS is a limited liability company managed by Bechtel National, Inc.; the University of California; BWXT Government Group, Inc.; and the URS Division of AECOM. Battelle Memorial Institute also participates in LLNS as a teaming subcontractor. Cutting-edge science is enhanced through the expertise of the University of California and its 10 campuses and LLNS’ affiliation with the Texas A&M University system.

ABOUT THE COVER



(right) The cover of LLNL’s fiscal year (FY) 2015 Annual Report features work at the Laboratory’s High Explosives Applications Facility, a Center of Excellence for nuclear weapons stockpile stewardship. (left) The back cover shows students displaying their accomplishments to interested Laboratory staff. LLNL hosted a record number of summer students in FY 2015. The students, who worked as part of research teams, concluded their internships with a day of poster sessions.



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Researcher Anna Belle records biomarkers in living tissues in real time. Biosensors integrated into diagnostic platforms provide insight into the physiology of cellular communication.

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Lawrence Livermore National Security

Lawrence Livermore National Security, LLC (LLNS), Board of Governors Chairman Norman Pattiz (left) and LLNS President and Laboratory Director William Goldstein.

SCIENCE AND TECHNOLOGY ON A MISSION

The Lawrence Livermore National Laboratory (LLNL) FY 2015 Annual Report chronicles our Laboratory's progress in developing and applying frontier science and technology to its national security mission.

From the standpoint of Livermore's goals and performance, FY 2015 was a very good year. We met our responsibilities in stockpile stewardship, achieved remarkable research and development milestones, and provided unique capabilities and results for the Department of Defense, the Department of Homeland Security, the Intelligence Community, and other partners, all while operating safely, effectively, and efficiently.

Of particular note were the opportunities our Laboratory had to celebrate its history. Events marked the 50th anniversary of the establishment of Z Program as a center for intelligence work on weapons of mass destruction, the 60th anniversary of Site 300's opening as an area for high explosives testing, and the 30th anniversary of the world's first x-ray laser, demonstrated at Nova, the precursor to the National Ignition Facility (NIF). Such celebrations, which help us rediscover our distinctive contributions to national security and scientific progress, honor successes that have established a firm foundation for LLNL's coming years.

We also celebrated people, the key to Livermore's enduring success. A great example was the inaugural bestowal of the John S. Foster, Jr. Medal on Johnny himself, at a star-studded event in Washington, D.C. Honoring Johnny's career—rising to Laboratory director and adviser to U.S. presidents—was certainly a reminder of what Livermore is all about; but it also taught us that having a storied past is not just a matter of nostalgia, but can form the basis for considering where we are and guide our future. To quote Johnny from his comments at the ceremony,

"When considering the situation in which we find ourselves, we naturally will look to innovation as part of the solution!"

— Johnny Foster

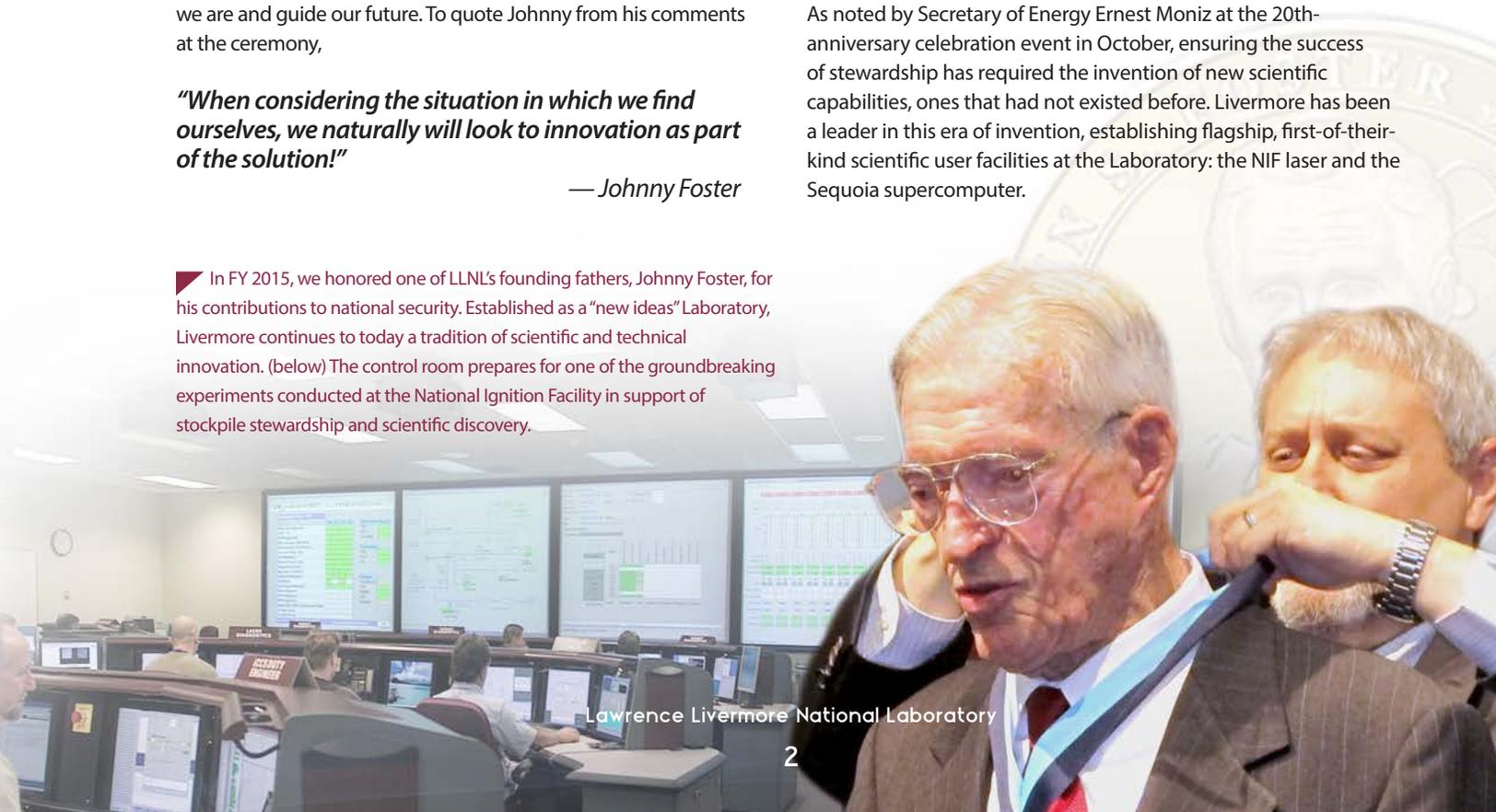
■ In FY 2015, we honored one of LLNL's founding fathers, Johnny Foster, for his contributions to national security. Established as a "new ideas" Laboratory, Livermore continues to today a tradition of scientific and technical innovation. (below) The control room prepares for one of the groundbreaking experiments conducted at the National Ignition Facility in support of stockpile stewardship and scientific discovery.

In addition, we honored the 90th birthday of Berni Alder, Presidential Medal of Science laureate and inventor of computational molecular dynamics, and celebrated the 60-year career of Dan Patterson, who has mentored a generation of nuclear weapons designers.

Livermore's talented staff is inspired by these individuals, shares their dedication to national service, and carries on the Laboratory's tradition of scientific, technological, and engineering (ST&E) excellence. In the past year alone, 10 Livermore scientists were named fellows of the American Physical Society, and 17 scientific journals featured covers highlighting work by LLNL authors. To help sustain our outstanding workforce, we launched an Early- and Mid-Career Recognition Program to identify promising scientists and engineers and provide them with funding to boost their careers. Our activities to attract future staff members, and enhance the diversity of our workforce, are highlighted in this report.

Our core mission at LLNL is to ensure that the nuclear arsenal remains safe, secure, and effective. The year 2015 also marked the 20th anniversary of the Stockpile Stewardship program, which has successfully enabled us to perform this mission without nuclear testing, and to reduce the numbers and types of weapons we rely on for deterrence. LLNL is central to realizing the vision for the nation's future nuclear deterrent, with responsibility for the next two warhead life extension programs (LEPs). The first, the W80-4 LEP, will present the new challenge of adapting an existing warhead for use on a new delivery vehicle, the next-generation cruise missile. The LEP also presents the exciting opportunity to use additively manufactured components to better assure performance and reduce production costs.

As noted by Secretary of Energy Ernest Moniz at the 20th-anniversary celebration event in October, ensuring the success of stewardship has required the invention of new scientific capabilities, ones that had not existed before. Livermore has been a leader in this era of invention, establishing flagship, first-of-their-kind scientific user facilities at the Laboratory: the NIF laser and the Sequoia supercomputer.



High performance computing (HPC) has been essential for stockpile stewardship both as the replacement for full-scale integrated testing and as a means for advancing our understanding of physics under the extreme conditions relevant to nuclear explosions. Advancements in HPC will continue under the Department of Energy's exascale (1,000 quadrillion operations per second) computing program and the President's National Strategic Computing Initiative. As described in our annual report, the next step toward exascale, the Sierra supercomputer, will be delivered to LLNL in the next two years.

NIF surpassed expectations to fire a record-breaking 356 experiments last year, including shots that safely used minute amounts of plutonium to generate data directly relevant to understanding nuclear weapon performance. We are on track to perform 400 experiments this year and will begin using complex new diagnostic capabilities to directly observe the burning hot spot in fusion experiments.

The Laboratory played a critical role in international threat reduction in FY 2015. A Livermore scientist was one of the U.S. government's technical experts at the negotiations of the Joint Comprehensive Plan of Action with Iran over its nuclear program. He utilized his Laboratory team for reach-back technical support and provided extensive, timely, real-time analysis to Secretary of State John Kerry, Secretary Moniz, and the rest of negotiating team during intense discussions. In addition, our scientists and engineers played a leading role in fielding an underground high-explosive test that improved the nation's ability to detect and identify low-yield nuclear tests.

Our researchers also apply our exceptional ST&E to broader issues of national importance, such as energy and environmental security, and to advance fundamental science. For example, readers of this report will also learn about new implants to treat neural disorders, novel, heretofore unrealizable materials created through additive manufacturing, a promising approach to carbon capture based on microcapsules, and a telescope that will map the sky in unprecedented detail every few nights.

Laboratory staff provided extensive technical expertise to the team that negotiated the Joint Comprehensive Plan of Action with Iran (with LLNL engineer Roger Miller at the lower right). (right) Engineer Vanessa Tolosa holds up an implantable flexible electrode array. Laboratory-developed neural interfaces—together with efforts in computational biology and biological agent detection—improve human health and strengthen defenses against bioterrorism and outbreaks of pandemic diseases.

The programmatic and scientific accomplishments highlighted in this report, and the many more that have made FY 2015 such a success, would not have been possible without an ongoing focus on safe, secure, sustainable, and effective operations, and the exceptional support provided by our operations staff. Thanks to their dedication, and the unwavering attention of our entire workforce, we achieved or exceeded every operational goal we set for ourselves. We have also seen the start of new facility construction, and set the standard for the entire NNSA complex for innovative approaches to infrastructure management.

The Laboratory's combination of a highly skilled workforce and state-of-the-art facilities serves national security in many complementary ways. It is a vital part of U.S. readiness to any dramatic shift in the nuclear security environment that might require changes to our force structure. We provide the technology and expertise to enable high-confidence implementation of arms control, nonproliferation, and other threat reduction measures. Laboratory programs aim to counter the spread and potential use of weapons of mass destruction across the full spectrum of threats. In addition, LLNL's strong ST&E base is a national asset in ensuring that the U.S. has a competitive advantage in advanced technologies with potential security implications. Finally, we help our leaders to understand new challenges and opportunities in a manner that is technically informed and sound.

In each of these roles, FY 2015 was a standout year for the Lawrence Livermore National Laboratory.

NUCLEAR DETERRENCE

Ensuring the safety, security, reliability, and effectiveness of the enduring stockpile

LLNL's foremost responsibility is to ensure the safety, security, reliability, and effectiveness of the nation's nuclear arsenal. The knowledge gained through experiments, theory, and simulations is applied to assess the condition of stockpile weapons and to develop and certify needed modifications with confidence in the absence of nuclear tests.

Annual Stockpile Assessment

In FY 2015, LLNL completed required activities for Cycle 20 of the annual stockpile assessment. The process included comprehensive peer review by the nuclear design laboratories (LLNL and Los Alamos National Laboratory (LANL)) of each other's weapons in the stockpile. Laboratory scientists continue to improve the baseline weapons-physics simulation codes that support annual assessments and certification of weapons. This year, for example, LLNL conducted highly detailed studies of detonation processes in high explosives. Assessment tools were also applied to close a significant finding investigation and complete requested analyses for LANL and NNSA headquarters.

Life-Extension Program Activities

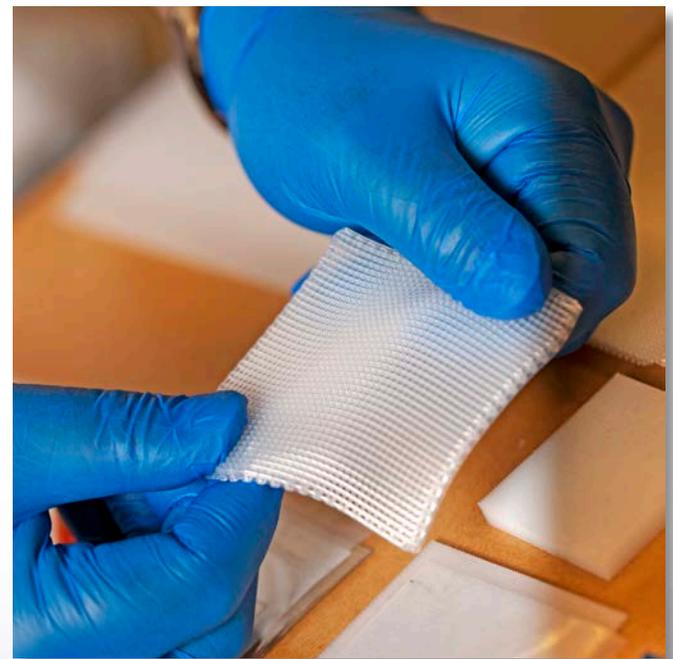
LLNL is partnered with Sandia National Laboratories as the design agencies to extend the life of and certify a warhead for the bomber-delivered Long-Range Standoff (LRSO) missile. In June 2015, NNSA completed a yearlong Phase 6.1 study to prepare conceptual designs for a warhead based on the W80 nuclear explosive package. The proposed cost-conscious design options for the W80-4 improve warhead safety, security, and reliability. The Phase 6.2 study began in July 2015 and will develop over about a two-year span a mature set of requirements and refined design options that meet these requirements. Additional LLNL activities are enabling ongoing and future life-extension programs (LEPs). These efforts include participating in the B61 LEP Interlaboratory Peer Review, strengthening the technical foundation for certification of weapon pit reuse options, and developing new high explosives in support of future systems.

► The LLNL Independent Diagnostics Scoring System collected 100 percent of the data for two intercontinental ballistic missile (ICBM) flight tests. The system was deployed by an LLNL team sent to the South Pacific, where they endured tropical storm Bavi and super-typhoon Maysak in a 330-foot Navy vessel.

Broad Support of the NNSA Complex

Livermore researchers are exploring the use of additive manufacturing (AM) to develop next-generation manufacturing processes and materials tailored for the NNSA complex. The goal is to accelerate development-to-production cycles and create lower cost parts that have more desirable material properties. The Laboratory has applied advances in AM to fabricate tooling for NNSA production facilities and has demonstrated AM techniques for manufacturing parts for weapons applications. Computer simulations and hydrodynamic experiments support these AM development activities by assuring that the fabricated materials will meet demanding performance requirements.

In addition to research on AM for NNSA application, LLNL personnel engaged in a wide range of activities to support other sites across the NNSA complex. Efforts have enhanced technical capabilities at Pantex to nondestructively examine weapon pits, production methods at the Kansas City Plant, and safety processes broadly within NNSA and DOE. LLNL also provided diagnostics support for flight test programs.



► Livermore researchers have demonstrated they can additively manufacture pads and cushions with different tensile or shear properties within the same component, an unprecedented achievement. They are able to control the properties and structure of a part in three dimensions.



► The full Sequoia supercomputer is occasionally tested with challenging calculations to assess the machine's ability to run a diverse range of codes. A Sequoia simulation of Earth's mantle convection won a University of Texas-led team the prestigious Gordon Bell Prize in 2015.

From Sequoia to Sierra

LLNL is preparing for delivery in 2017–2018 of Sierra, a next-generation supercomputer built by IBM. The procurement, which was announced in November 2014, is part of the DOE-sponsored CORAL (Collaboration of Oak Ridge, Argonne, and Lawrence Livermore national laboratories) program to accelerate the development of high-performance computing (HPC) to meet mission needs. Livermore is working with IBM, NVIDIA, and Mellanox to design, develop, and deploy a system providing 120-150 petaflops (quadrillion floating-point operations per second) peak performance. Sustained performance will be four to six times greater than that of the Sequoia supercomputer at LLNL, which is a shared resource for the NNSA laboratories to assess the condition of the stockpile. An NNSA Center of Excellence for supercomputing established at Livermore will facilitate collaborative research on large-scale scientific and engineering applications for use on Sierra. A precursor system will arrive in 2016 to start testing some early software and applications.

Sierra is a technically challenging but vital next step in extreme-scale computing. On behalf of NNSA and the DOE Office of Science, LLNL also manages the FastForward 2 project, which targeted \$100 million to leading HPC companies to develop exascale (10^{18} flops) computing technologies. In addition, Livermore is actively assisting DOE in planning its Exascale Computing Initiative.

Stockpile Stewardship Experiments

Researchers made great strides to better understand the properties of plutonium under extreme conditions. Four groundbreaking plutonium shots at the National Ignition Facility (NIF) were safely executed and produced exceptionally high-quality data. LLNL researchers also completed an important series of experiments studying high-pressure shock compression of



Honoring 20 Years of Stockpile Stewardship

President Bill Clinton formally committed the nation to the science-based Stockpile Stewardship Program (SSP) on August 11, 1995, when he announced that the United States would seek a comprehensive nuclear-test-ban treaty. In October of 2015, NNSA hosted a celebration of the 20th anniversary of SSP as one of the nation's greatest achievements in science and security. The event featured remarks by Secretary of Energy Ernest Moniz, Secretary of State John Kerry, and Under Secretary for Nuclear Security and NNSA Administrator Lieutenant General Frank G. Klotz, USAF (Ret.). General C. Robert Kehler (left), USAF (Ret.) and former commander of U.S. Strategic Command, led a panel discussion with the three NNSA national laboratory directors (left to right, Charles McMillan, Jill Hruby, and William Goldstein).

plutonium at LLNL's Joint Actinide Shock Physics Experimental Research (JASPER) Facility, located at the Nevada National Security Site. In addition, new diagnostic techniques tested for use at JASPER and successful tests of PHOENIX (see figure below) prepare the way for future experiments that will help deepen our understanding of materials at extreme conditions.

LLNL completed all planned work in FY 2015 in support of the national hydrotest program including technically challenging integrated weapons experiments at hydrodynamic testing facilities at Los Alamos and the Contained Firing Facility at LLNL's Site 300. These experiments supported pit reuse options, studied new materials produced using AM technologies, tested technical options for use in the W80-4 LEP, and developed diagnostics techniques. The many additional experiments conducted at NIF in support of stockpile stewardship are described on pp. 6–7.

► (right) LLNL conducted a full-power test of a large PHOENIX explosive pulse-power generator at the Los Alamos National Laboratory's Ancho Canyon bunker. The generator is designed to be used for stockpile stewardship equation-of-state experiments. (far right) A mini-generator was tested first, after the two laboratories had jointly completed an upgrade to the bunker facility.

NATIONAL IGNITION FACILITY

Supporting stockpile stewardship through high-energy-density science experiments and pursuit of fusion ignition, and operating as a national user facility for scientific discovery and other applications

During FY 2015, the National Ignition Facility (NIF) conducted a total of 356 target shots—an 86 percent increase compared to FY 2014 and surpassing the stretch goal of 300. These shots included 266 for stockpile stewardship and 44 for the Discovery Science program. NIF continues to be a highly productive cornerstone of stockpile stewardship, supports diverse national-security applications, provides valuable insights into the nature of the universe, and advances the prospect of laser fusion ignition and energy gain.

Stockpile Stewardship HED Science Experiments

In FY 2015, campaigns of high-energy-density (HED) science experiments at NIF explored wide-ranging physical phenomena central to stockpile stewardship. The shots gathered information about the properties of materials at extreme conditions, the interaction of matter with intense radiation, and hydrodynamic turbulence and mixing. The results are critical to understanding nuclear weapons performance and improving the predictability and results of fusion ignition experiments. In FY 2015, researchers conducted the first experiments studying the behavior of plutonium at extreme pressures. Shots using tantalum foils tested an experimental method to characterize the strength of high-atomic-number materials at high pressures and low temperatures via x-ray radiographic measurements of the growth of hydrodynamic instabilities. In addition, the Pleiades campaign, a series of 26 radiation flow experiments at NIF fielded by scientists from Los Alamos and the United Kingdom's Atomic Weapons Establishment, concluded with its final shot in 2015.

Progress in Studying Fusion Ignition

Achieving fusion ignition and energy gain at NIF is a grand scientific challenge, and scientists are making progress on several fronts where impediments preventing success have been identified. The research aligns with physics issues important to stockpile stewardship—success would provide the Stockpile Stewardship Program with significant new experimental capabilities to study the physics of ignition and thermonuclear burn. One impediment to ignition is associated with poor control of the overall symmetry of the x-ray pulse created by the laser beam impinging on the walls of the hohlraum, the open-ended cylinder containing the target capsule. Drive symmetry is needed to implode the target uniformly, create a central hot spot, and ignite the fuel. To identify workable options, experimenters are investigating a complex set of tradeoffs among hohlraum designs and gas fills, laser pulse shapes, and target capsule ablator materials.

Hydrodynamic instabilities in the imploding capsule present another set of issues—they contaminate the hot spot through the mixing of materials into the fuel. Experiments demonstrated that the “tent”—an ultrathin membrane that supports the target capsule inside the hohlraum—is a significant source of hydrodynamic instabilities that reduce implosion symmetry and neutron yield. Researchers are considering tent design alternatives and other options.

Discovery Science at NIF

In FY 2015, NIF conducted 44 shots as part of the Discovery Science program, which provides academic users with access to the unique density, temperature, and velocity regimes that NIF can create. By

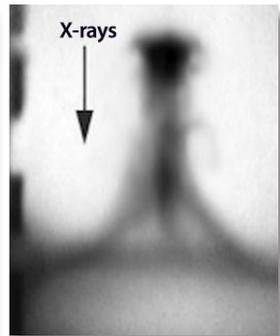


Preparing for the fiscal year's 300th laser target shot in the National Ignition Facility Control Room are (from left) Shot Director Dean Latray, Operations Manager Bruno Van Wonterghem, and Lead Operator Rod Rinnert. The stretch goal for FY 2015 was met on August 13, 2015, more than six weeks early. The final total for the year was 356 shots.

Livermore researcher Hye-Sook Park holds a hohlraum used in National Ignition Facility laser experiments to test the strength of tantalum at a previously unobtainable combination of pressure and strain rate.



▶ (left) A target struck by laser light created in sequence three separate x-ray sources, producing a long-duration radiation field to mimic the cluster of bright massive stars illuminating the Eagle Nebula. (below, left) Radiation is key to the formation and stability of the pillars, the largest being about 19 trillion miles high. (below, right) NIF experiments replicated the result. (Credit: NASA/ESA/Hubble/Hubble Heritage Team [2015].)



comparison, just eight shots were fired in FY 2014. With the recent efficiency improvements, NIF was able to support eight different experimental campaigns this year, greatly enhancing collaboration between academia and LLNL scientists. One notable success addressed the mystery of the Eagle Nebula's Pillars of Creation, where stars are born. A team of LLNL physicists, in collaboration with the French Alternative Energies and Atomic Energy Commission and the University of Maryland, replicated the phenomenon and created "pillar" structures in the laboratory.

Other Discovery Science program experiments studied material properties (equations of state) of hydrogen under conditions similar to those in giant planets, iron at pressures comparable to the interiors of Earth-like and super-Earth exoplanets, and plasma conditions relevant to the interior of white dwarf and brown dwarf stars. The hydrogen campaign, for example, characterized the phase transition as warm hydrogen (1,000 to 2,500 Kelvin) is compressed at megabar pressures and changes from a molecular insulating fluid to an atomic metallic conducting fluid. The data will help resolve the differing predictions of current hydrogen models in this regime.

Effective Operations as a User Facility

The 86-percent increase in the number of target shots compared to the FY 2014 total is the result of teamwork—coupled with innovations in operational efficiency, new technologies, and carefully planned task execution. Many of the adopted ideas for improved operational efficiency have been based on the recommendations of a 120-day study, mandated by Congress, to find ways of increasing the NIF shot rate at constant annual funding. The study's recommendations included steps to improve scheduling efficiency, such as the use of "mini-campaigns" that group similarly configured



Advanced Radiographic Capability

NIF's Advanced Radiographic Capability (ARC) is poised to provide experimentalists with unprecedented diagnostic capabilities. This petawatt-class (10^{15} watts) laser system is designed to produce brighter, more penetrating, higher energy x rays than achievable with current radiographic techniques. The x rays will backlight and illuminate NIF targets as they implode, producing a radiographic "movie" with tens-of-picoseconds (10^{-12} seconds) temporal resolution during the critical phases of an inertial confinement fusion experiment. Designed and developed this year, a technology upgrade—a new high-contrast ARC front-end system (shown being installed)—eliminates target-damaging "prepulses" that would arrive before the main x-ray pulse.

experiments to minimize facility reconfigurations. In addition, the NIF User Office is working on improved interfaces with researchers.

New technologies, software controls, and equipment are also improving the shot rate. The target fabrication team is turning to robotics to automate time-consuming processes such as installing the ultrathin tents that suspend target capsules inside NIF hohlraums, and mounting the hohlraums in the cryogenic target positioners. New target positioning equipment (currently being fabricated), software tools, and a high-speed laser-tracker alignment system will enhance experimental capabilities and further reduce experimental setup time.

▶ Mechanical and robotics engineer Matthew Bauer completes the assembly and programming of new versions of the universal robotic target assembly robots.

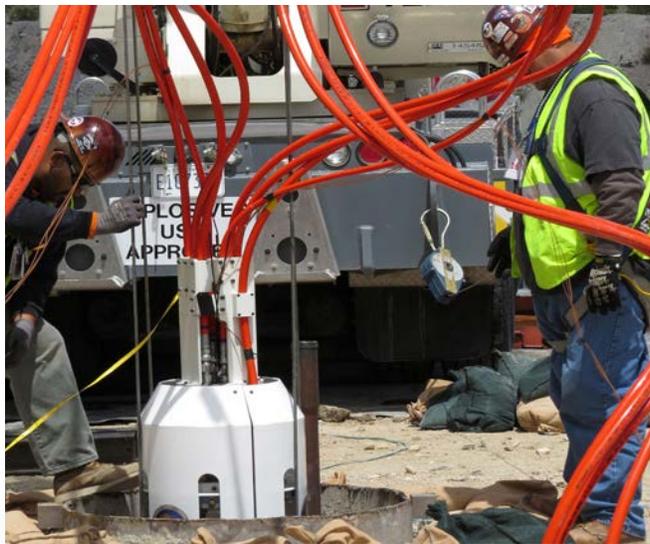


Reducing the threat from terrorism and weapons of mass destruction and enhancing global stability

LLNL develops innovative, advanced technologies to help the government anticipate, identify, and address global security threats. By applying scientific and engineering expertise in chemical, biological, radiological, nuclear, and explosive weapons, our experts support threat preparedness, prevention, protection, and response and recovery. Innovations in space situational awareness and cyberdefense help strengthen national security in an interconnected world.

Source Physics Experiment

LLNL played a leading role in fielding Source Physics Experiment-4 Prime (SPE-4 Prime), detonated at the Nevada National Security Site (NNSS). The test, conducted in May 2015, is the fourth in a series of underground, high-explosive field tests in hard rock. The SPEs provide data to improve capabilities to detect and identify low-yield nuclear explosions amid the clutter of conventional explosions and small earthquakes. LLNL engineers and technicians designed the canister that contained the explosive charge, emplaced the canister downhole, and fired the shot. The instrumentation yielded extensive information, including high-resolution accelerometer, infrasound, seismic, explosive performance, ground-based light detection and ranging (LIDAR), ground-based hyperspectral imagery, and satellite data. Results will enable researchers to advance ground motion and seismic wave propagation models and algorithms toward a predictive capability. The SPE tests partner NNSS and the Los Alamos,



Two workers oversee the emplacement of the canister that contained the chemical explosive charge for Source Physics Experiment-4 Prime at the Nevada National Security Site. A chemical explosive equivalent to 196 pounds of TNT was detonated in the contained environment 286 feet below ground.

Lawrence Livermore, and Sandia national laboratories with the Department of Defense's Defense Threat Reduction Agency and the University of Nevada at Reno.

Detecting Covert Nuclear Explosive Tests

Livermore staff participated in the planning and execution of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) Integrated Field Exercise (IFE), which took place on the eastern shore of the Dead Sea in Jordan in late 2014. The purpose of the exercise was to test the current state of on-site inspection capability to detect signatures related to a possible underground nuclear test explosion within a 1,000 square-kilometer area. Supported by staff from LLNL and other national laboratories, the Preparatory Commission for the CTBT Organization worked for several years to develop the exercise scenario and plan its execution. The five-week exercise involved more than 200 participants, including seven scientists from LLNL who served as subject matter experts and role players. Several Livermore technologies were used to identify radioactive isotopes, including an in situ gamma-ray measurement instrument, and the LLNL-developed backpack and car-borne radiation detectors. In addition, the Laboratory's Smart Sampler system provided an effective means for collecting samples to test for subsurface noble gas emissions that would be indicative of a nuclear test.

Preparing for the Worst

LLNL is helping the Federal Emergency Management Agency (FEMA) and other Department of Homeland Security agencies understand what to expect in a disaster such as detonation of an improvised nuclear device (IND) or dispersal of a toxic chemical. While the probability of such events are low, they are high-consequence situations in which many lives could be saved with appropriate planning. Detailed simulations of potential events show officials—and the public—what to prepare for in the first critical minutes and hours after a disaster. A valuable lesson learned from the research is the importance of sheltering in place after an IND detonation with later evacuation once fallout is reduced.

The analyses build on the capabilities of Livermore's National Atmospheric Release Advisory Center (NARAC), which provides



▶ A Laboratory team mounted its ground-penetrating radar system, iRADAR, onto an autonomous military cargo truck. The system received high marks in a field test of its ability to detect buried improvised explosive devices.

real-time assessments of dispersion and deposition of radioactive and other toxic materials based on state-of-the-art computer simulations coupled with actual meteorological, geographical, and material property data. Researchers have developed and validated simulation models that include complex urban landscape features, as detailed as individual buildings, which affect wind patterns. NARAC provided indispensable support to FEMA's Southern Exposure 2015 exercise in July. It was the first full-scale field exercise of response to a nuclear power plant accident in more than a decade.

Countering Improvised Explosive Devices

The Laboratory's iRADAR system, which is able to detect underground improvised explosive devices (IEDs) in real time, was evaluated in a counter-IED demonstration at Fort A. P. Hill, Virginia, where it received high marks in all assessment areas. The LLNL team mounted the iRADAR unit onto an autonomous version of a Marine Medium Tactical Vehicle Replacement seven-ton truck. The radar system provides a highly reliable autonomous decision to stop the vehicle and any trailing convoy on detection of an IED. The work was funded by the Office of Naval Research/Naval Surface Warfare Center (ONR/NSWC), which is pursuing technology to support operations of Marine Expeditionary Units.



An Expedition to Antarctica

Global threat reduction efforts took an LLNL team to Antarctica, where they supported recovery of four Russian radioisotope thermoelectric generators (RTGs) containing special nuclear materials. The complex undertaking was managed for NNSA by the Laboratory and conducted in partnership with the Russians. One of the RTGs was located far in the interior of the continent and had become deeply buried in the ice pack. Recovery by Russian and American experts necessitated a specially equipped, technically challenging expedition. Altogether, LLNL has helped in the successful removal of 486 RTGs throughout Russia and Antarctica, enabling the permanent securing of more than 20 million curies of radioactive material.

Hands-On Training for Cyber Defenders

For the sixth year, LLNL brought a diverse group of 38 paid summer interns to the Laboratory as part of the Cyber Defenders Program. Participants—ranging from high-school students to faculty members—received frontline training in cyberdefense and developed skills in intrusion detection and prevention, network monitoring and analysis algorithms, anomaly detection, and machine learning. The experience opened up exciting career opportunities for the interns to contribute to our nation's security. Nearly a dozen former interns are currently Laboratory staff members working on cyberdefense projects.



▶ LLNL geophysicist Charles Carrigan (left), portraying a representative of the inspected state party during the Integrated Field Exercise in Jordan, evaluates background radiation levels in a storage bag containing subsurface gases captured by the Livermore-developed Smart Sampler.



▶ Summer interns participate in the Cyber Defenders Program at Lawrence Livermore National Laboratory.

Using science and technology to provide clean, abundant energy, protect the environment, and understand and mitigate climate change

Laboratory researchers apply leading-edge capabilities to develop efficient and environmentally benign energy technologies and to investigate the processes behind climate change.

Microcapsules for Efficient Carbon Capture

LLNL scientists, together with academic colleagues, have developed a new, capsule-based technology to capture carbon dioxide (CO₂) using the same baking soda found in most grocery stores. Fossil fuel power generation and other industries could use these microcapsules to capture large quantities of CO₂—a greenhouse gas—before it is released into the atmosphere. The microcapsules consist of a highly permeable polymer shell and a fluid (made up of sodium carbonate solution) that reacts with and absorbs CO₂. Sodium carbonate only reacts with the gas of interest, unlike more caustic sorbents currently used in capturing CO₂. The encapsulation approach dramatically increases absorption compared to traditional carbon capture techniques. Immobilized within the tiny high-surface-area droplets, the absorbent has much more contact with the CO₂. After saturation, the capsules are removed from a power plant's flue gas and heated to remove the now-pure CO₂ gas, which can be stored or used in industrial applications.

Microcapsules containing sodium carbonate solution are suspended on a mesh during carbon dioxide absorption testing. The mesh allows many capsules to be tested at one time while keeping them separated, exposing more of their surface area.

Assisting the State of California on Water Issues

LLNL is assisting the State of California in designing a groundwater-monitoring program for oil- and gas-well stimulation (i.e., hydrofracturing) operations in California. Recent legislation requires the State Water Resources Control Board to develop programs to monitor protected groundwater for impact from well stimulation at both the individual well scale and at the oil- and gas-field scale. The Laboratory provided expert advice on program design. LLNL experts collaborated with colleagues from Lawrence Berkeley National Laboratory and academia to prepare a set of recommendations on groundwater monitoring of well stimulation in California. The team delivered their final report to State Water Board staff in June 2015 and presented their findings at a State Water Board meeting in July.

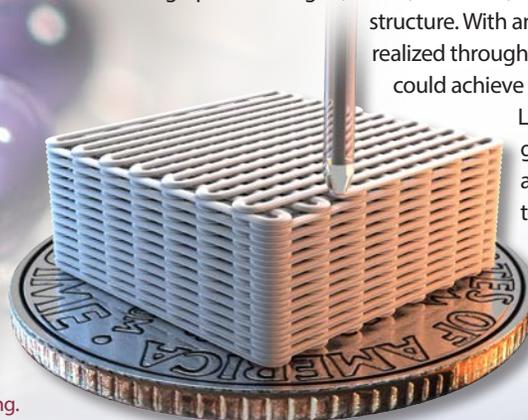
Carbon Aerogels for Energy Applications

Laboratory researchers are pursuing innovative approaches to combine the best features of two remarkable materials: carbon and aerogels. The marriage of carbon and aerogels—networks of sturdy, low-density nanoparticles—produces three-dimensional (3D) materials suitable for battery electrodes, catalyst supports, and other applications in the energy realm. LLNL's focus is on two forms of carbon: (1) graphene, a single sheet of carbon atoms, and (2) carbon nanotubes, made of one or more graphene sheets rolled into a tube. With its long history in aerogel science, Livermore has adapted its aerogel synthesis techniques for new approaches to organize multiple nanotubes or sheets of graphene into functional 3D structures that have superior properties for energy applications.

Additive manufacturing offers ways to build even better aerogels. The research aims to improve the quality of pore networks of graphene aerogels, which, until now, have had a fairly random structure. With an engineered structure, realized through 3D printing, these aerogels could achieve even better performance.

LLNL has developed a printable graphene-based ink and adapted 3D printing methods to accommodate aerogel processing. Preliminary results are promising.

Livermore researchers have made graphene aerogel microlattices with an engineered architecture via a 3D printing technique known as direct ink writing. With 3D printing, one can intelligently design the pore structure of the aerogel and optimize physical properties, such as stiffness.





► This computer simulation of aerodynamic drag on a tractor-trailer rig was conducted as part of a DOE study to reduce the fuel consumption of trucks.

Designing the SuperTruck

Efforts at LLNL to improve highway fuel efficiency have evolved, from a focus on adding devices that reduce drag, to a completely redesigned highly aerodynamic tractor-trailer rig. Livermore's second-generation supertruck model, the Generic Speedform Two (GSF2), reduces the aerodynamic drag compared to existing road vehicles by more than 80 percent. It was designed using the Laboratory's exceptional high-performance computing (HPC) capabilities combined with extensive testing of a one-eighth reduced-scale clay model in the NASA Ames Research Center's wind tunnel. A full-scale wind-tunnel test is planned for 2016. This supertruck research builds on nearly two decades of work for DOE's Heavy Vehicle Aerodynamic Drag Consortium, which has developed many drag-reducing technologies to make heavy trucks more aerodynamic.

High-Performance Computing for Manufacturing

A new DOE initiative enables industry to leverage the HPC capabilities of Lawrence Livermore, Oak Ridge, and Lawrence Berkeley national laboratories to advance clean energy manufacturing technologies. The High Performance Computing for Manufacturing Program (HPC4Mfg) will make up to \$5 million available to national laboratories to work with qualified U.S. industry partners. HPC4Mfg will couple U.S. manufacturers with the national laboratory experts in advanced modeling, simulation, and data analysis to address key manufacturing challenges.

Small Volcanoes and Global Warming

A large interdisciplinary LLNL-led team concluded that the warming hiatus that occurred over the last 15 years has been caused in part by small volcanic eruptions. During this warming hiatus, global temperatures appeared to level off after the steep climb in global surface temperatures observed over the 20th century. Scientists have long known that volcanoes cool the atmosphere but have focused on large eruptions. Following publication of a paper that concluded that smaller eruptions contributed to the hiatus, Livermore led a study that substantiated this work and found that the eruptions deflected more solar radiation than originally estimated. Signs of



Better Fluorescent Lighting

Researchers at LLNL, Oak Ridge National Laboratory, and General Electric have teamed up to create new kinds of fluorescent lighting phosphors that use far less rare-earth elements than current technology. The U.S. has access to a limited amount of rare-earth elements and relies on imports. The team identified new, low-cost phosphors that appear to be close to meeting stringent requirements of long lamp survivability, high efficiency, and precise color rendition. The team worked with the Critical Materials Institute at Ames Laboratory, and the work was funded by the DOE's Office of Energy Efficiency and Renewable Energy.

late 20th- and early 21st-century eruptions were positively identified through atmospheric temperature, moisture content, and the reflected solar radiation at the top of the atmosphere.

► Computer scientist (and project principal investigator) Dean Williams displays the Ultrascale Visualization Climate Data Analysis Tools software, which earned an Interagency Partnership Award from the Federal Laboratory Consortium for Technology Transfer in 2015. The novel system was developed by LLNL and nine partnering institutions.

SCIENCE AND TECHNOLOGY

Expanding the boundaries of scientific knowledge and advancing the technological state of the art to solve problems of national and global importance

Science and technology are central to addressing many of the most difficult problems of the 21st century and to understanding the world around us. Research using LLNL's multidisciplinary scientific expertise and its world-class experimental and computational resources have led to exciting discoveries and innovative solutions.

Advances and Partnerships in Additive Manufacturing

A 3D-printing device garnered LLNL a 2015 Federal Laboratory Consortium Far West Region Award for outstanding technology development. The Large-Area Projection Microstereolithography system rapidly produces very small features over large areas using optical techniques to write images in parallel, in contrast with conventional serial techniques. Many applications, such as medical devices, would benefit from the new instrument's capability to quickly make complex, detailed parts.

Collaborations with industry are rapidly advancing additive manufacturing (AM). Researchers from LLNL and a San Francisco Bay Area company, Autodesk, Inc., are exploring how design software can accelerate innovation for the 3D printing of advanced materials. Under a cooperative research and development agreement, LLNL is using Autodesk's state-of-the-art software for generative design to study large sets of "potentially printable" material microstructures. The goal is to design materials with previously unachievable properties to produce products such as lightweight, impact-absorbing helmets. In work funded by America Makes (a public-private partnership for AM research), LLNL and General Electric are developing open-source algorithms for additively manufacturing metal parts layer-by-layer using the selective laser melting process, in which a focused, high-energy laser beam fuses metal powder particles.

LLNL researchers (left to right) Manyalibo (Ibo) Matthews, Wayne King, and Gabe Guss examine a 3D-printed part made using the selective laser melting process. General Electric and LLNL are developing open-source algorithms that will improve additive manufacturing of metal parts using the process.

Three R&D 100 Award Winners

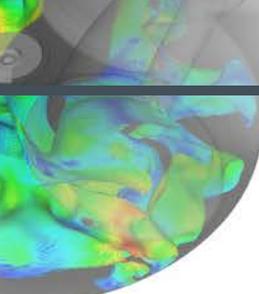
Lawrence Livermore received three awards in this year's R&D 100 competition, bringing the total number of awards LLNL has won since 1978 to 155. The winning technologies are: the Large-Area Projection Microstereolithography (see previous story), a 3D printing device; Zero-order Reaction Kinetics (Zero-RK), a computing code; and the High-power Intelligent Laser Diode System (see p. 14). Zero-RK has significantly advanced predictive science for designing next-generation car and truck engines by speeding up simulations of chemical reactions a thousandfold over methods traditionally used for internal combustion engine research.

Building the World's Largest Camera

Starting in 2022, the 8.4-meter Large Synoptic Survey Telescope (LSST) will take digital images of the entire visible southern sky every few nights, revealing unprecedented details of the universe. The images will help researchers study the formation of galaxies, track potentially hazardous asteroids, observe exploding stars and better understand dark matter and dark energy. In September 2015, DOE approved the start of construction for LSST's 3.2-gigapixel digital camera, which is the size of a small car. DOE is funding the camera, while financial support for the rest of the enormous undertaking comes primarily from the National Science Foundation. LLNL has leadership responsibilities for two of the major camera subsystems, and a Laboratory researcher is a key manager for the camera system effort. Livermore has played a pivotal role in the LSST project for more than a decade, drawing on expertise in large optics development for NIF.



The camera on the Large Synoptic Survey Telescope (LSST) will capture full-sky images at such high resolution that it would take 1,500 high-definition television screens to display just one picture. Over a 10-year period, LSST will detect tens of billions of objects.

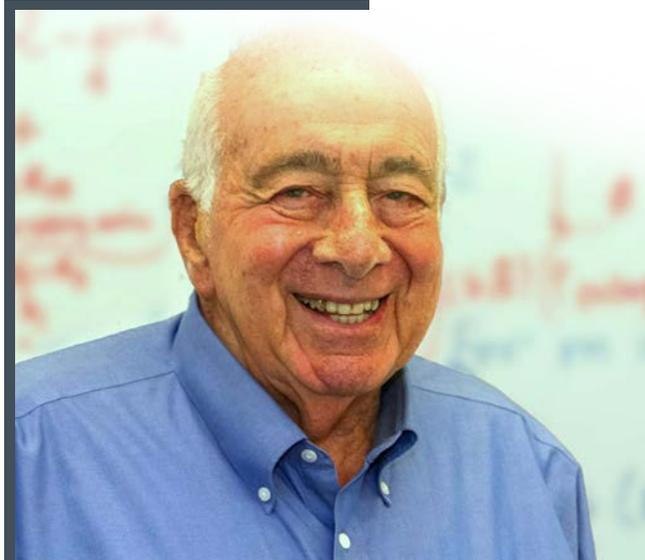


► The local flame propagation speed in a gasoline combustion engine was simulated using the Zero-order Reaction Kinetics code as a plug-in to computational fluid dynamics software.

Implantable Neural Interfaces

The Laboratory is finding wide application for its innovative biocompatible neural interface technologies that are implantable and capable of recording and stimulating neurons in the brain. This year, the National Institutes of Health (NIH) awarded LLNL and research partners several grants to develop neural interface systems that will enable scientists to better understand how the brain and sensory organs function at unprecedented resolution. The team is to design and build neural interfaces that can record and stimulate hundreds to thousands of neurons simultaneously. Their goal is to produce an interface with 1,000-plus sensors that can eventually be expanded to 10,000 sensors.

In addition, LLNL is leading the development of implantable neural interface technologies for the first three projects in President Barack Obama's Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative. These projects are sponsored by the Defense Advanced Research Projects Agency (DARPA). LLNL is teaming with the University of California at San Francisco to develop the world's first closed loop neuromodulation system to treat neuropsychiatric disorders. For this effort, Livermore developed the world's first high-spatial-resolution recordings of electrical signals in living human brains. In a second project, researchers from LLNL, the University of California at Los Angeles and the University of Pennsylvania are developing the world's first neuromodulation system to treat memory disorders. Finally, as part of DARPA's Hand Proprioception and Touch Interfaces program, an LLNL-Case Western Reserve University team is building the world's first neural system to enable naturalistic feeling and movements in prosthetic hands for wounded service members.



The Berni Alder Symposium

In August 2015, the Laboratory honored Dr. Berni Alder at a special symposium to celebrate his 90th birthday and his illustrious 60-year research career at Livermore. The day's agenda featured invited speakers who reflected on the contributions of Alder, the creator of the discipline of computational molecular dynamics using the Monte Carlo technique. In 2009, Alder received the National Medal of Science, the highest honor bestowed by the U.S. government on scientists, engineers, and inventors. Driven by mission needs, LLNL remains a world leader in predictive simulation science at the atomic and molecular scale.



► Director for Livermore's Center for Bioengineering Sat Pannu and his research team are developing wireless neural interface technologies. The objective is to measure and decode motor signals recorded in peripheral nerves to control movement and sensation in a patient's prosthetic hand.

Boosting the Nation's Space-Launch Capabilities

Lawrence Livermore demonstrated the value of HPC in transforming the design and testing of new rocket engines and launch vehicles in work for the Defense Advanced Research Projects Agency (DARPA) and two ambitious small American companies. For the first project, the Livermore team simulated the performance of a novel liquid-propellant rocket engine intended for DARPA's Next-Generation Rocket program. Using LLNL's supercomputers, researchers performed 3D simulations using up to a 60-million-cell mesh to take a detailed look at the safety and efficiency of engine operation. The second effort used simulations to study the thermal and structural response of a design for DARPA's reusable launch vehicle called the XS-1. The team examined the flightworthiness of the system at various points along a simulated flight trajectory from liftoff to Mach 10 and back to vertical landing.

Record-Setting Laser Diode Arrays

An innovative diode-pumped solid-state laser system, the High-power Intelligent Laser Diode System (HILADS), has been commissioned for use as a key component in the High-Repetition-Rate Advanced Petawatt Laser System (HAPLS). LLNL is designing and building HAPLS for the European Union's Extreme Light Infrastructure Beamlines high-intensity laser science facility, under construction in the Czech Republic. HAPLS will be the world's highest-average-power petawatt (quadrillion-watt) laser system, producing 10 ultrashort 30-joule pulses per second. To achieve this high repetition rate—and to increase overall laser system energy efficiency—the Livermore team had to look beyond flashlamps, which are used in NIF, and turn to HILADS as the energy source to pump HAPLS. Diode lasers, produced by Tucson, Arizona-based Lasertel, are configured in arrays to repetitively produce short energy pulses that total a record-setting 3.2 megawatts in peak power. HILADS, which was an R&D 100 Award winner this year, draws power from the grid and incorporates novel technologies to drive the diode arrays with the required precision and to keep them cool.

► The High-power Intelligent Laser Diode System can produce 3.2 megawatts of peak optical power. It achieves two-to-threefold improvements in peak output power and intensity over existing technology in a 10-times more compact form.

► LLNL researchers are pursuing experiments to re-create the physics of extreme astronomical phenomena, such as the gargantuan x-ray burst emanating from a supermassive black hole in the Centaurus A galaxy, about 12 million light years from Earth. The high-energy x rays (shown in blue) were detected by NASA's Nuclear Spectroscopic Telescope Array, for which LLNL designed and tested key optics.

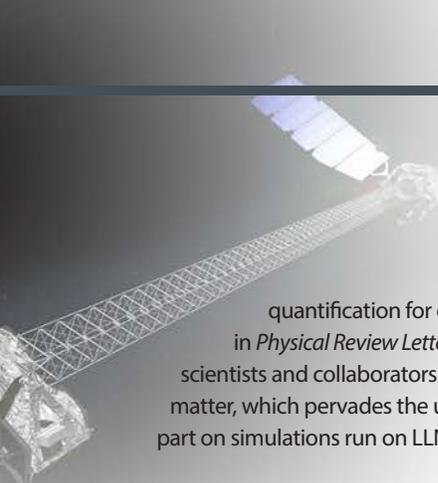
Probing the Wonders of the Universe

In FY 2015, Laboratory researchers participated in many exciting astronomical discoveries. The most Jupiter-like planet ever seen in a young star system was found by the Gemini Planet Imager at the Gemini South Telescope in Chile, which employs advanced adaptive optics developed at LLNL. This young cousin of Jupiter, only 20 million years old, is still hot and further study of the planet will provide clues about Jupiter's formation and history. Another team found compelling observational evidence that supernova explosions are not symmetric. The Nuclear Spectroscopic Telescope Array (NuSTAR), launched into orbit in 2012 and operating with Livermore-developed x-ray optics, gathered the data. In addition, an LLNL astronomer contributed to the discovery of new stars being created by shockwaves resulting from the collision of two nearby dead galaxies.

Laser experiments conducted this year by LLNL scientists using facilities at Livermore, the University of Rochester's Laboratory for Laser Energetics, and the United Kingdom's Atomic Weapons Establishment are also helping to better understand astrophysical phenomena. Researchers reproduced the conditions that exist deep inside giant planet cores; created record numbers of electron-positron pairs, which are likely responsible for extreme astronomical events such as gamma-ray bursts; and studied an instability phenomenon thought to be the source of cosmic magnetic fields. (See pp. 6–7 for additional scientific accomplishments performed at NIF.) In other work, an international team led by an LLNL researcher used an accelerator to measure a carbon fusion reaction at star-like energies. These data identify a unique chemical signature indicating the formation of the earliest stars in the universe.

Predictive Simulations and Scientific Discovery

The Computing Grand Challenge Program at LLNL, now in its 10th year, nurtures the Laboratory's enduring strength in predictive science through HPC simulations. The program provides participants ample time on Livermore's exceptional unclassified HPC resources to perform groundbreaking science. Projects have ranged from the study of laser-plasma interactions to quantum Monte Carlo simulations of hydrogen at extreme conditions, and uncertainty



quantification for climate modeling. Published in *Physical Review Letters* in May 2015, Livermore scientists and collaborators devised a new model of dark matter, which pervades the universe. The model is based in part on simulations run on LLNL's Vulcan supercomputer.

Eight Livermore scientists are also pursuing scientific discovery as part of DOE's Innovative and Novel Computational Impact on Theory and Experiment (INCITE) program. In FY 2015, they were awarded nearly 800 million core hours on supercomputers at Argonne and Oak Ridge national laboratories for various projects, including the DOE Office of Science's Accelerated Climate Modeling for Energy (ACME) effort.

Detection of Infectious Disease Outbreaks

A study by LLNL and Kansas State University scientists found that the Lawrence Livermore Microbial Detection Array (LLMDA) could help identify diseases in the commercial swine industry because of the array's ability to detect within 24 hours any bacteria or virus that has been previously sequenced. Using 180,000 probes, the current version of LLMDA can spot approximately 8,100 microorganisms. The research team was able to detect infectious swine diseases by identifying the multiple viruses and bacteria in the blood, tonsils, and oral fluid of swine and their farm environment.

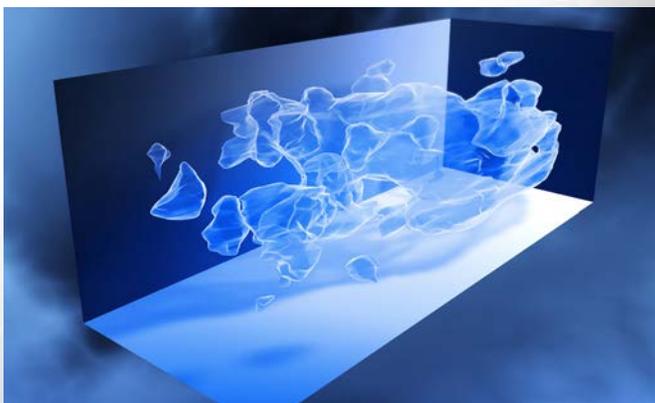
Other researchers from LLNL and three other institutions assisted Cepheid, a San Francisco Bay Area biomedical company, in gaining an emergency-use authorization from the U.S. Food and Drug Administration (FDA) for its Ebola virus assay test. Under a work-for-others contract, Livermore scientists—experts in multiplex polymerase-chain-reaction-based assaying—tested Cepheid's

system against non-Ebola bacterial and viral targets to show that the assay would only detect Ebola. No live virus material was used in these research studies.

Expanding Industrial Partnerships

Technologies developed at Livermore are increasingly impacting the U.S. economy. The top four companies started by LLNL scientists now have a market value of \$11 billion. In FY 2015, Livermore obtained 97 new patents, asserted 77 new copyrights, and licensed 37 new technologies. Licensing income for the year totaled approximately \$10 million. Through the Livermore Valley Open Campus, a partnership with Sandia National Laboratories/California, and other outreach efforts, LLNL is seeking greater engagement with U.S. industry and helping the local Tri-Valley area grow into a technology innovation center. The two laboratories were selected by DOE to participate in LabCorps, a pilot program to facilitate commercialization of technologies that have the potential to rapidly benefit society. In addition, the Laboratory is a corporate partner to i-GATE, a new-startup incubator located in downtown Livermore. The incubator's first six companies have raised more than \$8 million to turn game-changing technologies produced by LLNL and others into successful businesses.

LLNL biomedical scientist Celena Carrillo conducts benchtop experiments in a collaboration between the Laboratory and three other institutions that assisted Sunnyvale-based Cepheid in advancing an Ebola virus detection test for emergency use.



Simulations using LLNL's Vulcan supercomputer contributed to the development of a new theory of dark matter by Laboratory scientists and collaborators. A 3D map illustrates the estimated large-scale distribution of dark matter, which has an observable effect on light from distant galaxies.



SAFE, SECURE, AND SUSTAINABLE OPERATIONS AND INFRASTRUCTURE

Conducting safe, secure, and environmentally sound operations and modernizing the Laboratory's infrastructure to meet evolving mission needs

LLNL is committed to the highest level of operational performance. The Laboratory implements best practices in environment, safety, and health (ES&H), and security. Management systems support continuous improvement in work practices and target investments to modernize the Laboratory's infrastructure. Prudent risk management, coupled with active measures to prevent accidents, ensures the safety of employees and the public.

Effective ES&H and Work Planning

The Laboratory's injury and illness statistics continue their long-term downward trend. FY 2015's total recordable case (TRC) rate of 0.95 continues the prior year's excellent performance and represents about a 60-percent decrease since the contract transition in 2008. Similarly, the days away, restricted, or transferred (DART) rate, which is a measure of the severity of injuries, is down by about 60 percent over the same time period. To prevent injuries, the Laboratory continually emphasizes attention to safety and undertakes concerted efforts to improve performance in high-risk areas, including facilities and infrastructure (F&I) operations and protective services.

Continual improvement is a key facet of LLNL's Integrated Safety Management System, which is certified with Occupational Health and Safety Series (OHSAS) 18001 accreditation. One major effort nearing completion is the Laboratory's project to revamp work planning and control (WP&C) in response to incident assessment recommendations and worker feedback. Designing the new WP&C processes, controls, and implementation concepts was an extensive effort that included gathering best practices from around the Laboratory and across the NNSA complex. A beta pilot of the new WP&C process, tested in selected areas of the Laboratory, has been judged successful. The Laboratory has extended the WP&C pilot process through FY 2016 before institution-wide implementation.

Work safety is paramount to all Laboratory operational and research activities. LLNL postdoctoral fellow Jianchao Ye is shown working on a lithium-ion battery, while colleague Yinmin "Morris" Wang looks on. They are part of a team studying the use of hydrogen for longer-lasting batteries.

Progress Toward Site Sustainability Goals

Ecologically responsible work practices are ensured by LLNL's Environmental Management System, which has International Organization for Standardization (ISO) 14001 accreditation. These practices provide a systematic approach to identifying and reducing the impact of Laboratory activities. The 2014 Site Annual Environmental Report (issued in October 2015) records LLNL's compliance with environmental standards, describes protection and remediation programs, and presents the results of environmental monitoring. A notable success in 2015 was achieving cleanup standards for tritium in contaminated areas of Site 300.

LLNL exceeded several of its FY 2015 sustainability goals and is making progress toward meeting ambitious FY 2020 goals. The Laboratory has already achieved its FY 2020 greenhouse-gas-reduction goal of 28 percent and is on target to meet the water intensity reduction goal. A 3.3-megawatt solar photovoltaic system at the Livermore site, which began construction in late 2015, will contribute to meeting the renewable energy use goal.

Livermore earned an NNSA Sustainability Award for its novel water conservation plans. The multifaceted approach to cutting water usage in drought-stricken California ranges from replacing turf with water-wise landscaping and fixing leaky pipes, to using treated water—cleaned with a reverse osmosis unit—rather than potable water in cooling towers. LLNL also received a DOE Sustainability Award for a multiyear effort to consolidate 26 data centers into one Enterprise Data Center, which conserves energy and reduces costs. The center houses more than 2,500 mission-critical science, engineering, computational research, and business computing systems.

LLNL won an NNSA Sustainability Award in FY 2015 for its water conservation plan. The plan includes reducing patches of turf and re-landscaping with water-wise plants to maintain an aesthetically pleasing appearance while using less water.



Altogether 13 teams (166 employees) received 2015 Director's Institutional Operational Excellence Awards. The awards recognize extraordinary team efforts that have an institutional impact, demonstrate cost savings, and improve Laboratory programs and operations.

Effective Operations

In FY 2015, operations at LLNL were effectively and efficiently managed in all principal areas: ES&H, security, business operations and systems, and legal management. Of particular note is an initiative to improve F&I maintenance by deploying dedicated F&I teams. The teams' in-place workers are gaining greater familiarity with program operations and specialized equipment and can resolve more difficult problems. They receive direct feedback from the programs on how their efforts are helping mission success. LLNL also received better-than-goal Facility Condition Index scores; was recognized as the one NNSA site with "excellent performance" in the DOE 2014 Annual Criticality Safety Report to the Defense Nuclear Facilities Safety Board; and made improvements that enhance and bring substantial cost-benefit to security operations.

Revolutionizing Infrastructure Management

LLNL is working with NNSA headquarters as an innovative partner to help revolutionize F&I management across the NNSA complex. NNSA is working toward a comprehensive approach that considers investments in capital equipment, facilities maintenance, and new construction, and weighs risks to successful mission execution. Currently, the Laboratory is benefiting from flagship projects funded by the NNSA Capability-Based Infrastructure Program—targeted at crucially needed capital equipment. Broader future Laboratory needs are detailed in the LLNL Ten-Year Site Plan, identified as "best in the complex" in 2015. NNSA will pilot an improved, more comprehensive site planning process with LLNL next year.

NNSA enterprise risk management entails effectively targeting investments by weighing facility condition against consequence to mission resulting from potential failure. Livermore is serving as NNSA's Center of Excellence for implementing BUILDER, a knowledge-based condition-assessment infrastructure modeling system. LLNL is also the pilot site for implementing the Mission Dependency Index (MDI), a tool for assessing the mission consequences of F&I failure.



Celebrating 60 Years of Site 300 Stewardship

Sixty years ago, the University of California Radiation Laboratory began testing high explosives at what would become known as Site 300. It is home to the Contained Firing Facility, the largest indoor explosive-testing facility in the world, the newly refurbished Engineering and Environmental Test facility, and other mission-supporting facilities. Activities at Site 300—crucial for the success of stockpile stewardship—are performed safely with attention to protecting the remote, rugged area's fragile ecosystem. Designated as a critical habitat, the area is home to coyotes, deer, bobcats, golden eagles, red-tailed hawks, and many threatened or endangered species.

With support from NNSA's Capability-Based Infrastructure Program, LLNL refurbished existing and procured new equipment to address current and future Stockpile Stewardship Program needs. Technician Greg Ciraulo is inspecting a band saw, which underwent extensive modifications so that it could be used for safely sawing radiological materials.



MANAGING FOR THE FUTURE

Positioning the Laboratory for continuing science and technology excellence directed at important national missions

In FY 2015, Laboratory managers focused on engaging stakeholders, contributing to NNSA enterprise-wide efforts and new initiatives, and building for future successes.

A Year of Strategic Engagements

With the vision of Livermore continuing to serve the nation as “A New Ideas Laboratory,” the LLNL management team engaged wide-ranging audiences in FY 2015 to listen to stakeholders’ needs. The Laboratory welcomed visitors from DOE and NNSA headquarters, Congress, and the executive branch, as well as work sponsors. LLNL also hosted conferences and workshops on wide-ranging topics such as modernization of nuclear forces, the future of deterrence, additive manufacturing, and workforce diversity. These strategic discussions serve to strengthen relationships and ensure that LLNL’s “Science and Technology on a Mission” is aligned with work sponsors’ priorities and long-term national needs. They have also provided a foundation for strategic planning activities launched at the end of FY 2015.

Technical Leadership in the NNSA Complex

Livermore is actively participating in—and providing leadership for—many NNSA/DOE initiatives to solve complex-wide issues. For example, LLNL researchers are pursuing innovative approaches such as pit reuse and additive manufacturing to help transform the complex and make it more cost effective. Livermore is also assisting other sites to improve weapons surveillance technologies and safety processes. In addition, LLNL has provided leadership in acquiring next-generation supercomputers, and is spearheading initiatives to improve infrastructure management across the complex. In the area of workforce management, Livermore hosted a conference on diversity and inclusion convened under the auspices of the DOE National Laboratory Directors’ Council (see the box on p. 19).

DOE Secretary Ernest Moniz and LLNL Director William Goldstein converse with visitors at the National Security Lab Day on Capitol Hill, held at the Dirksen Senate Office Building in October 2015. LLNL served as the lead laboratory in preparing the displays.

Sustaining Workforce Excellence

The Laboratory’s principal strength is its outstanding workforce. Accomplishments, activities, and initiatives highlight the quality of our staff and the importance of recruiting and nurturing future technical and programmatic leaders. In FY 2015, 10 Laboratory scientists were named fellows of the American Physical Society (see p. 22 for individual awards), and 17 scientific journal covers featured papers with LLNL authors. Livermore’s newly launched Early and Mid-Career Recognition Program honored 15 scientists and engineers for their exceptional accomplishments on the path toward technical leadership at LLNL. Selected from 99 outstanding nominees, the first-year winners of this annual program received a cash award and part-time institutional funding to pursue research activities in their area of interest.

Livermore’s educational outreach programs range from activities designed to interest young students in scientific careers (see p. 20) to those that bring prospective future scientists and engineers to LLNL to participate in research. In FY 2015, a record-breaking number of students—more than 700—participated in LLNL’s research and intern programs. Nearly 100 postdoctoral fellows were hired; more than half of those who completed their terms as fellows stayed on to work at the Laboratory. A new outreach initiative is LLNL’s participation in DOE/NNSA’s Cybersecurity Workforce Pipeline Consortium. The Laboratory will help develop curricula at 13 historically black colleges and universities (and a South Carolina school district), and bring students to LLNL to participate in the Cyber Defenders Program (see p. 9).



New Facilities for the Laboratory

Ground was broken in FY 2015 for two new facilities: a new armory for the Protective Force Division and a modular supercomputing facility. Construction of the much-needed armory began in April and was completed in November. To be completed in FY 2016, the supercomputing facility will provide computer room space to accommodate a variety of high-performance computing architectures, including water-cooled machines. NNSA's Advanced Simulation and Computing Program is spearheading development of next-generation supercomputers for stockpile stewardship. The unclassified facility will promote collaborations with U.S. industry and academia to advance hardware and software solutions.

Expanded partnerships and collaborative research will benefit further from constructing a new, much-expanded High Performance Computing Innovation Center (HPCIC) at the Livermore Valley Open Campus (LVOC). In October 2015, NNSA gave approval to LLNS to seek partners to finance construction of the facility, which will house 350 to 400 people. Collaborative activities at HPCIC bring top-notch scientists and engineers to Livermore to conduct cutting-edge research at world-class facilities and capabilities. The work supports LLNL mission needs and benefits industry and university partners.

LLNS Board of Governors Activities

The LLNS Board of Governors and its committees provided oversight to the Laboratory. The committees delved into issues crucial to mission and mission-support activities. The Board participated in external review committees (ERCs), panels of independent experts, to critically assess the quality of LLNL's technical workforce and research efforts, and how effectively these efforts advance Livermore's missions and meet future national needs. Advice and counsel provided by the ERCs, which held seven meetings in FY 2015, led to substantive actions by the Laboratory. The ERC reports provided DOE/NNSA with an independent validation of quality, and consistently affirmed the mission relevance and high impact of LLNL research. The Board also charts Functional Management Reviews (FMRs) to examine issues on an as-needed basis. Seven FMRs were completed in FY 2015 in topical areas ranging from safety basis guidance to safeguards and security compliance.



Flanked by Director William Goldstein (far right) and Deputy Director for Science and Technology Patricia Falcone (far left) are the FY 2015 Early and Mid-Career Recognition Program winners: (left to right) Manyalibo (Ibo) Matthews, John Heebner, Félicie Albert, Nathan Barton, Vanessa Tolosa, Miguel Morales-Silva, Dawn Shaughnessy, Stefan Hau-Riege, Felice Lightstone, Brian Pudliner (obscured), Carol Woodward, and Sergei Kucheyev. (Not shown: Stephan MacLaren, Jennifer Pett-Ridge, and Kumar Raman.)



Workforce Diversity and Inclusion

Fourteen laboratory directors and more than 60 participants representing each of the 17 DOE national laboratories met in Livermore to share best practices and explore new ways to attract, retain, and develop a more diverse workforce. Moderated by Patricia Falcone, LLNL deputy director for science and technology, the workshop was held under the auspices of the National Laboratory Directors' Council. Participants—representing a cross section of experts from the laboratories—identified steps that the laboratories might take both individually and as a network. Sandia National Laboratories' Sandra Begay-Campbell is shown speaking in one of the panel discussions.



Currently under construction, the new modular, sustainable supercomputing facility will include a 6,000-square-foot machine floor and support space. The main computer structure is flexible in design to allow for expansion and accommodation of future computer architectures.

COMMUNITY CONNECTIONS

Supporting local communities through science education and charitable giving

Each year, the Laboratory supports a wide range of activities within the community, demonstrating its commitment to being an integral, involved, and valued neighbor. LLNL participates in myriad science, technology, engineering, and math (STEM) education programs; volunteer efforts with local social service agencies; and charitable giving. In addition, LLNS' gift program provides a direct investment in community education, arts, and services.

Saturday is Science Day

LLNL's Science on Saturday (SOS) lecture series for middle- and high-school students continued to play to sold-out crowds. This year, more than 5,000 people attended 10 lectures held in the cities of Livermore and Tracy. SOS events featured themed discussions on earth, wind, water, and fire—pairing Laboratory researchers with local science educators to discuss earthquakes, electricity, shale gas, and hydrology. As always, the presentations are free of charge and recorded for the University of California's TV website and YouTube.

In FY 2015, the Laboratory added a new twist to its popular lecture series in Modesto, California, with Science on Screen. This three-week series for middle-, high-school, and college students combines popular feature-length movies with prominent researchers from the Laboratory who discuss the scientific viability of what is seen in these classic, cult, science fiction, and documentary films.

More than 30,000 students of all ages visit the Bay Area Science Festival at AT&T Park in San Francisco, California, each year, where they get a lesson in hands-on science from Laboratory volunteers.

Fair Share

LLNL continued to invigorate interest in science through various fairs and festivals. In November, the Laboratory participated in the Bay Area Science Festival, which attracted more than 30,000 young scientists and their families to AT&T Park in San Francisco, California. In addition to day long presentations of Fun With Science, attendees were challenged to show off their scientific know-how or put their pedal power to the test through an energy bike connected to various household items.

Closer to home, LLNL sponsored the annual Alameda County Science and Engineering Fair held in March. Approximately 650 middle- and high-school students and more than 175 teachers from 18 school districts participated in the 2015 fair. More than 170 awards and scholarships were distributed for first, second, and third place, and about 60 special awards were given by national and local government agencies as well as industry sponsors.

Lawrence Livermore also sponsored an Expanding Your Horizons event. Such events are held several times a year throughout the San Francisco Bay Area to introduce science and technology careers to middle- and high-school girls. The free events pair women scientists and engineers with students in hands-on demonstrations of science.

Fun With Science

In FY 2015, more than 12,500 children at the fourth- and fifth-grade levels, along with their chaperones, were introduced to scientific concepts through hands-on experiments in the Laboratory's popular Fun With Science program. Presented by Laboratory employees and retirees, the program provides an entertaining introduction to scientific phenomena and helps prepare students as they embark on their science education.



As its name implies, Fun With Science provides an entertaining introduction of scientific phenomena to elementary school children. On Halloween, the students are treated to a visit by a not-so-mad scientist.



► The Laboratory is a major participant in Expanding Your Horizons, a program that introduces girls grades 6 through 9 to careers in science, technology, and engineering.

Using the Force to Socialize

Social media helped the Laboratory to expand its reach in education. In June, Livermore scientists and their counterparts at Los Alamos and Idaho national laboratories staged a Google+ Hangout to discuss the science of “Star Wars,” postulate just what it would take to build a light saber or land speeder, and speculate on how much energy would be required to power up a “Death Star.” (Hint: Don’t count on one in any century soon.)

The Laboratory continued to stage successful chats through Reddit’s Ask Me Anything, showcasing staff members who, to cite two examples, discussed how LLNL assists veterans in their post-military careers, and its development of a carbon capture and storage technology based on common baking soda (see p. 10). During these chats, participants speak directly with Laboratory researchers.

At the Core of California’s Curriculum

With San Francisco Bay Area K–12 science teachers continuing to implement Common Core State Standards in literacy and math, many educators have turned to LLNL’s professional development academies to gain key skills they need to meet this challenge in two high-demand topics. In computer modeling, Laboratory technical staff teamed with local high-school department heads to offer a two-week, classroom-ready introduction to basic simulation software. In technical writing, LLNL’s practical treatment of ways to meet requirements filled a pair of two-day workshops attended by Northern California science teachers from all grade levels.

HOME Campaign and Community Gifts

Employees and the Laboratory’s managing contractor, Lawrence Livermore National Security, LLC (LLNS), raised more than \$3.4 million in December 2014 in the annual HOME (Helping Others More Effectively) Campaign. The annual charitable drive benefits community and nonprofit agencies in the Tri-Valley, San

► Thirty-two local organizations were thanked and presented monetary awards on behalf of LLNS by Director William Goldstein in October at the annual LLNS Community Gift Event. The gifts, totaling \$100,000, reflect LLNS’ commitment to local communities.



My Brother’s Keeper

More than 60 disadvantaged youth from Oakland, San Francisco, and Tracy, California, came to Livermore in June for a special “Day at the Lab,” as part of the White House initiative, “My Brother’s Keeper” (MBK). LLNL served as the kickoff to a series of MBK events being held at the national laboratories. Throughout the day students were treated to hands-on presentations in science and engineering, as well as tours of the National Ignition Facility and the Discovery Center. President Barack Obama applauded the Laboratory for its efforts. “You are working to curb juvenile arrests, reduce absenteeism, and help these kids to imagine a bigger future for themselves.”

Joaquin Valley, and greater San Francisco Bay Area. Employees pledged almost \$2.4 million, while LLNS contributed \$1 million in matching funds.

At an October ceremony at the LLNS office in the city of Livermore, LLNL Director William Goldstein presented checks totaling \$100,000 to the recipients of the 2015 LLNS Community Gift Program. LLNS received 78 applications totaling almost \$700,000 in requests. Thirty-two applications were selected for awards through a committee review process. The majority of these awards serve children in the Tri-Valley and San Joaquin County, with an emphasis on science, mathematics, education, and cultural arts.

WORKFORCE RECOGNITION

Acknowledging exceptional performance and expertise

The challenges of LLNL's mission require a workforce of exceptionally talented and dedicated employees. The many awards and honors received by Laboratory personnel are testament to their expertise and the impact of their work.



DOE Secretarial Honor Award

Energy Secretary Ernest Moniz awarded LLNL climate scientist David Bader (and two co-winners) a DOE Secretarial Honor Award for his leadership of the Accelerated Climate Modeling for Energy (ACME) project. The Secretarial Honor Awards are the department's highest form of nonmonetary employee recognition.



NNSA Excellence Medal

LLNL scientist Leon Berzins received the NNSA Excellence Medal from Anne Harrington, the NNSA deputy administrator for Defense Nuclear Nonproliferation, for his management of the successful Source Physics Experiment-4 Prime campaign (see p. 8).

NNSA STI Award

Engineer Mark Hart received the 2015 NNSA Surety Transformation Initiative (STI) Award. He will receive \$2 million in funding over three years to develop his proposal for Intrinsic Use Control, a concept for protecting a nuclear weapon and its components from unauthorized use with an uncrackable code.

Office of Science Early Career Award

Climate scientist Yunyan Zhang earned a prestigious Early Career Research Program award from DOE's Office of Science. She will receive \$500,000 for five years for research to improve the understanding of how soil moisture and surface diversity affect cloud formation and precipitation.



APS Fellows

The American Physical Society (APS) named 10 Lawrence Livermore researchers as fellows: (top row, from left) Michael Armstrong, Chris Barty, Ray Beach, Debbie Callahan, Tony Gonis, and Frederic Hartmann; (bottom row, from left) Yinmin "Morris" Wang, James Tobin, Robert Rudd, and Nobuhiko Izumi.

Defense Programs Awards of Excellence

Eleven teams of Laboratory scientists and engineers received an NNSA Defense Programs Award of Excellence in recognition of work performed in 2014 in support of Defense Programs missions. The teams were presented with their awards by NNSA (Acting) Deputy Administrator for Defense Programs Brigadier General Stephen L. Davis.



Newton International Fellowship

Lawrence Scholar Matthew Levy was awarded the prestigious Newton International Fellowship by the Royal Society of the United Kingdom (UK). The program makes 40 awards available per year to postdoctoral researchers to work at UK research institutions for a period of two years. Levy is the first American physicist to become a Newton Fellow.



Outstanding Journal Referees

APS cited experimental physicist Félicie Albert as an Outstanding Referee for 2015. Climate scientist Ken Sperber was awarded the 2014

Editor's Citation for Refereeing for the *Journal of Geophysical Research Atmospheres*. Both were honored for their exceptional assistance in assessing manuscripts for publication.

Senior Fellows

LLNL researchers Tiziana Bond and Jean-Michel Di Nicola were named senior members of the Optical Society for more than 10 years of significant experience and professional accomplishments. Livermore scientists Nerine Cherepy and Edgar Leon were selected to be senior members of the Institute of Electrical and Electronics Engineers, a prestigious status held by only seven percent of the 431,000 members. Cherepy and LLNL researcher Michael Pivovarov are among the 171 new senior members of SPIE, the international society for optics and photonics.

American Chemical Society Medal

Laboratory geochemist Annie Kersting was selected to receive the 2016 American Chemical Society's Francis P. Garvan-John M. Olin Medal. The medal recognizes outstanding scientific achievement, leadership, and service to chemistry by women chemists who are U.S. citizens. She is widely recognized for her work in actinide environmental chemistry.

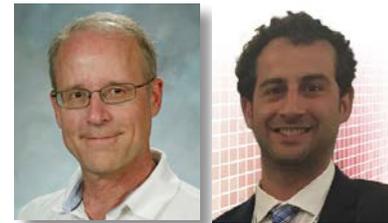


HR Rising Star

Renée Breyer, deputy associate director for Strategic Human Resources Management at LLNL, was named an HR Rising Star for 2015 by Human Resources Executive Magazine. She was selected as one of five rising stars for 2015 out of more than 100 candidates.

Geothermal Energy Award

Engineers Thomas Edmunds and Pedro Sotorrio received a special recognition award from the Geothermal Energy Association for their work advancing the industry's understanding of geothermal energy as both a baseload and a flexible resource in future electrical grids.



IUPAP President

Physicist Kennedy Reed has been elected president-designate of the International Union of Pure and Applied Physics (IUPAP). IUPAP assists in the worldwide development of physics, fosters international cooperation in physics, and helps in the application of physics toward solving problems of concern to humanity.

FPA Awards

The Fusion Power Associates (FPA) Board of Directors selected LLNL nuclear engineer Susana Reyes as the recipient of its 2015 Excellence in Fusion Engineering Award. Reyes was cited for her leadership in magnetic and inertial fusion projects in many areas, including safety and licensing, tritium systems, and power plant designs. The FPA also presented a Special Award to fusion scientist Wayne Meier for his numerous contributions to fusion power development.



TMS President

Materials scientist Patrice Turchi is serving as the 2015 president of The Minerals, Metals & Materials Society (TMS). He has been an active member of TMS for more than 25 years and was the society's vice president in 2014.

Alameda County Women's Hall of Fame

Physicist Natalia Zaitseva was inducted into the Alameda County Women's Hall of Fame. One of 12 inductees, she developed a way to rapidly grow the large crystals used in the National Ignition Facility and more recently led a team that developed plastic scintillator materials for neutron detectors.

Millennial Leader Award

Biomedical engineer Monica Moya was recognized with a Millennial Leader Award at the EmpowHer Institute's Rising Stars Awards event. The award acknowledges women under 40 who are accomplished professionals working for the advancement of girls and women in the arts, business, public service, and STEM (science, technology, engineering, and math) fields.

The Dr. Ian Hutcheon Postdoctoral Fellowship

The Department of Homeland Security's Domestic Nuclear Detection Office established the Dr. Ian Hutcheon Postdoctoral Fellowship award to support research in nuclear forensics. The fellowship honors the late Hutcheon, who significantly advanced America's nuclear forensics capability during his 22-year tenure at the Laboratory.



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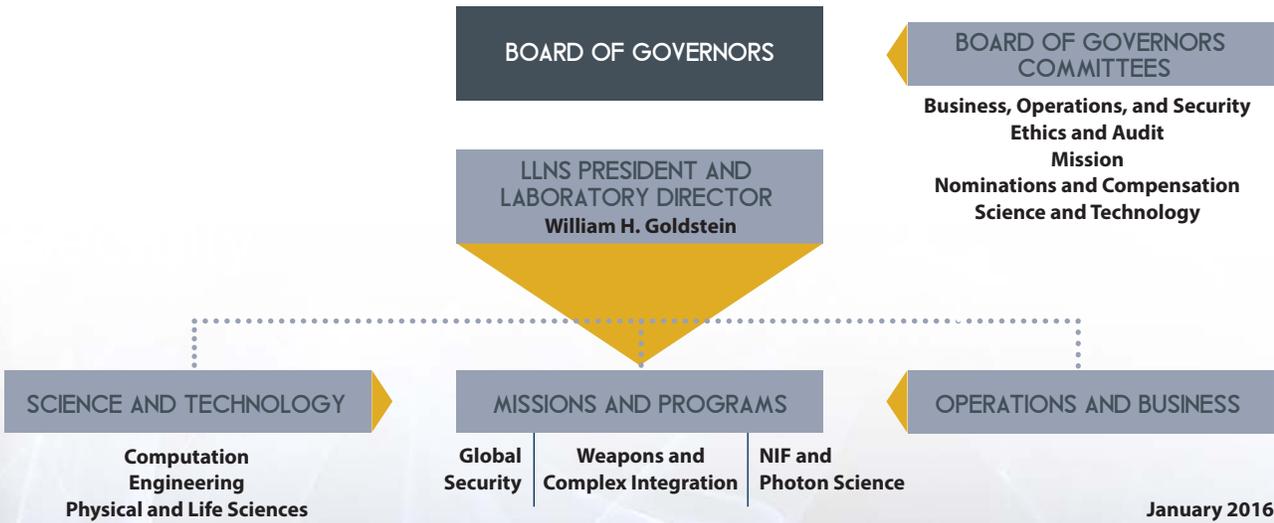
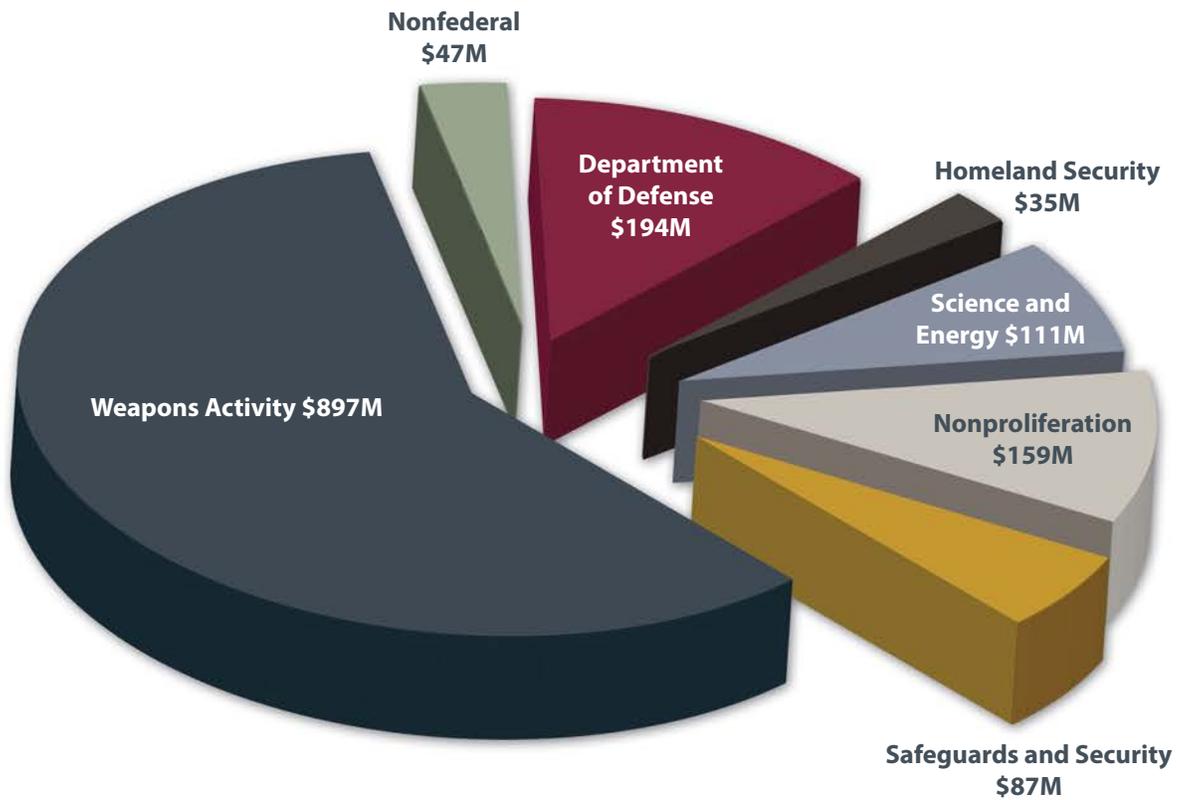
Robert DeGrasse

Vice President and Manager Government Affairs, Bechtel Nuclear, Security & Environmental, Inc.; Chair of the Business, Operations, and Security Committee

LLNS Board of Governors Chairman Norman Pattiz (left) and Vice Chairman Craig Albert (right) join Laboratory Director William Goldstein at a joint meeting of the LLNS and Los Alamos National Security, LLC boards. The two boards work to better integrate activities and make both laboratories and the NNSA enterprise more effective and efficient.



LLNL FY 2015 Actual Costs: \$1.53 billion



January 2016

LLNS is a limited liability company managed by members Bechtel National, Inc.; the University of California; BWXT Government Group, Inc.; and the URS Division of AECOM. Battelle Memorial Institute also participates with LLNS as a teaming subcontractor. Cutting-edge science is enhanced through the expertise of the University of California and its 10 campuses and LLNS' affiliation with the Texas A&M University system.



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