LAWRENCE LIVERMORE NATIONAL LABORATORY

FY 2017 ANNUAL REPORT

SCIENCE AND TECHNOLOGY ON A MISSION

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 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

(front) Sierra, a next-generation supercomputer being delivered to LLNL, provides high-performance computing capabilities that are crucial to sustaining the nation's nuclear weapons stockpile and other national security applications.

(back) Laboratory researchers demonstrate their newly developed process for 3D printing aerospace-grade carbon fiber composites. This achievement is one of LLNL's many breakthrough advances in additive manufacturing.

Lawrence Livermore National Laboratory

Managed and operated by LLNS

A limited liability company comprised of members Bechtel, BWXT, AECOM

And supported by teaming subcontractor Battelle The Business of Innovation

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(left) The 65th anniversary of the Laboratory, founded on September 2, 1952, provided an occasion to hold a Family Day weekend. Visitors of all ages had opportunities to tour facilities, see displays, and discover the wonders of science.

(right) Stories of remarkable accomplishments were added to update LLNL's 50th-anniversary book. See the 65th-anniversary book online at: www.llnl.gov/news/publications.

INSIDE FY 2017

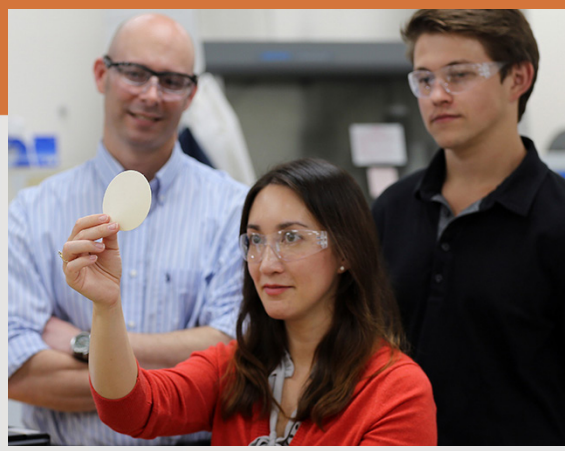
SCIENCE AND TECHNOLOGY ON A MISSION

LAWRENCE Livermore National Laboratory (LLNL) applies world-class science, technology, and engineering (ST&E) to enhance national security in a rapidly changing world. This enduring mission for the Department of Energy (DOE) and its National Nuclear Security Administration (NNSA) requires vigilance, innovative thinking about emerging threats, and productive partnerships with industry, academia, and government. This annual report highlights our many successes this year in making the nation—and the world—safer and more secure.

In fiscal year 2017, LLNL excelled in every respect—mission, ST&E, and operations. In keeping with our "Science and Technology on a Mission" motto, the Laboratory realized one of the most exceptional years in recent memory. Our continuing success depends on people who bring forth new ideas, work with integrity and zeal, and thrive in an inclusive work environment.

Our Laboratory's defining mission is nuclear security. Livermore is a major contributor to DOE/NNSA's Stockpile Stewardship Program. We made important progress during the year in extending the stockpile life of the W80-4 warhead for the U.S. Air Force's Long-Range Standoff missile. In this effort, we are exploring ways to take advantage of 3D printing to make parts with optimized properties at lower costs and with shorter production schedules.

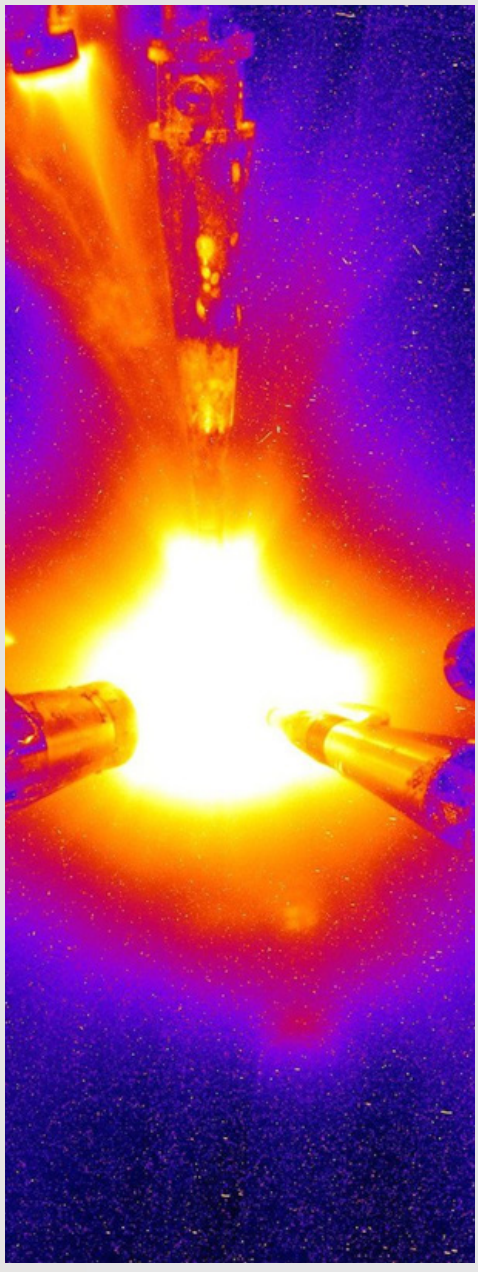
We are also advancing the experimental and computational capabilities needed to assess the condition of weapons in the stockpile and certify changes made to extend their life. High-energy-density physics experiments at the National Ignition Facility (NIF) are providing crucial data for stockpile stewardship.



(far left) LLNL Director William Goldstein answers employee's questions after one of his "Laboratory Update" talks in the main auditorium.

(left) The High-Repetition-Rate Advanced Petawatt Laser System (HAPLS), the world's highest average-power laser, was delivered to the ELI Beamlines Facility in the Czech Republic in June 2017.

(above right) Among their many additive-manufacturing successes, LLNL researchers demonstrated the 3D printing of shape-shifting structures that can fold or unfold to reshape themselves when exposed to heat or electricity.



(below right) Fusion ignition experiments at the National Ignition Facility produced a record-setting number of fusion neutrons, benefiting from research on ways to better control implosion symmetry.

LLNL scientists have also achieved record-setting neutron yields in inertial confinement fusion ignition experiments that continue our progress toward demonstrating ignition and a burning plasma.

Leading-edge high-performance computing (HPC) is essential to success in stockpile stewardship and breakthroughs in many other mission areas. Delivery of Sierra promises a four- to six-fold performance improvement over Livermore's most capable supercomputer, Sequoia. Laboratory scientists are also providing leadership in DOE's Exascale Computing Project and working to prepare the Livermore site for an exaflop computer in 2023. In addition, we are supporting efforts by national security sponsors to extract information from enormous amounts of data.

Our annual report also highlights experiments and modeling aimed at improving capabilities to detect low-yield nuclear events and to better prevent and respond to terrorism involving weapons of mass destruction. LLNL completed development and delivery of HAPLS, the world's most advanced and highest average-power laser system. We launched a partnership with academia and industry, the ATOM consortium, that applies the Laboratory's HPC capabilities to dramatically accelerate the drug discovery process. Our researchers are achieving a deeper understanding of 3D printing, which they are applying to new types of materials. In addition, seven R&D 100 awards and prize-winning work under the aegis of DOE's HPC for Manufacturing Program testify to LLNL's continuing success in technology transfer.

As our annual report highlights, Livermore is also strengthening safety and security, investing in infrastructure to upgrade and enhance the quality of our workplace, and taking innovative approaches to modernize the nation's nuclear weapons complex.

LLNL celebrated its 65th anniversary in 2017. Our founders began operations on September 2, 1952, with the goal of serving the nation as a "new ideas" laboratory. Our many accomplishments this year show that we continue to deliver innovative, world-class science and technology to meet the difficult security challenges our nation and the world face.

NUCLEAR DETERRENCE

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

LLNL's foremost responsibility is to ensure the performance 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 additional nuclear tests.

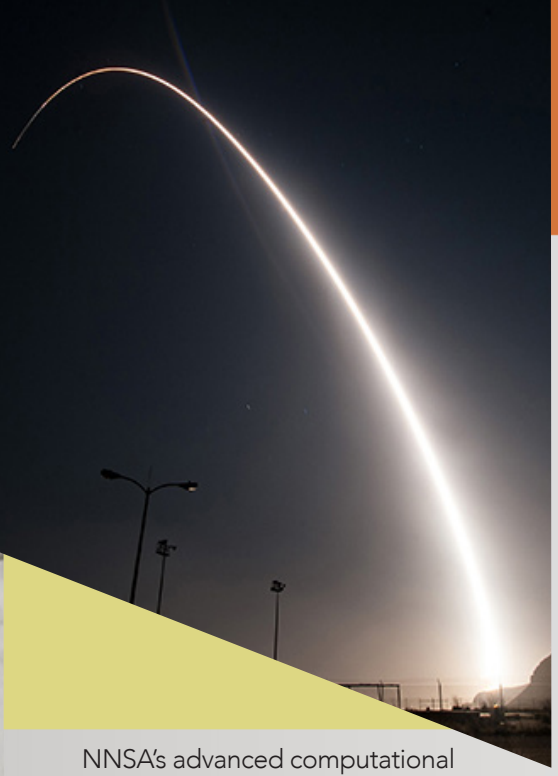
Annual Stockpile Assessment

In FY 2017, LLNL completed Cycle 22 of the annual stockpile assessment. As part of this extensive process, the nuclear design laboratories (Livermore and Los Alamos) conduct peer review of each other's weapon systems. Laboratory scientists continue to improve the physics and engineering simulation codes that support the annual assessments and weapon certifications. Emphasis is on improving predictability and quantification of uncertainties. Stockpile surveillance activities, weapon subsystem tests, and flight tests supplied critically needed data. For example, the LLNL Independent Diagnostic Scoring System team provided vital support to joint DOE–Department of Defense flight tests. They developed and fielded a one-of-a-kind diagnostic suite to collect in-flight, real-time measurements of system accuracy and performance.

Life-Extension Program Activities

LLNL is partnered with Sandia National Laboratories as the design agencies to develop and certify the W80-4 warhead for the bomber-delivered Long-Range Standoff missile. The Laboratory is making excellent progress in the life-extension program (LEP). The ongoing Phase 6.2 study to extend the stockpile lifetime of the W80 will result in a mature set of requirements and refined cost-conscious design options. One critical need is to qualify and remanufacture additional insensitive high explosives to be used in the refurbished W80-4 warheads. Investments to upgrade aging high-explosives facilities and infrastructure at LLNL's Site 300 will support this work and a wide range of national security activities.

The design and certification process will require innovations and proficient use of



(far left) Senior mechanical technician Rich Moore and mechanical designer Kevin Morris (right) prepare a confinement vessel for an experiment with explosives and mock parts. Such vessel tests assure that debris will be fully contained during underground explosive tests to be performed in Nevada with subcritical quantities of plutonium.

(left) A Minuteman III intercontinental ballistic missile streaks through the night sky from Vandenberg Air Force Base in California to waters off the Kwajalein Atoll in the Marshall Islands carrying a mock W87 warhead in a highly instrumented flight test.

NNSA's advanced computational and experimental resources. An area of significant innovation is additive manufacturing (AM) to improve the quality and reduce the cost of materials and parts for weapons undergoing LEPs. Hydrodynamic tests fielded in FY 2017 provided confidence in the performance of W80-4 LEP design options that include additively manufactured components.

Preparing for Sierra and Beyond

Sierra, a next-generation supercomputer built by IBM, is being delivered to LLNL in 2017-2018. The machine is expected to provide greater than 120 petaflops (10^{15} floating-point operations per second) peak performance—four to six times that of Sequoia, currently LLNL's most capable supercomputer. Sierra's procurement for NNSA's Advanced Simulation and Computing (ASC) Program is part of the DOE-sponsored CORAL (Collaboration of Oak Ridge, Argonne, and Lawrence Livermore national laboratories) initiative to accelerate the development of high-performance computing (HPC). CORAL is also providing a strong foundation for NNSA and the DOE Office of Science to pursue DOE's Exascale Computing Project, in which Livermore researchers lead several key efforts (see pp. 12-13).

In September 2016, LLNL took delivery of Sierra "early-access" systems. Researchers have been using these systems to prepare nuclear-weapons simulation codes so that they take advantage of the performance improvement offered by graphics processing units (GPUs), a prominent feature of the Sierra machine. Originally developed for video games and graphics design, GPUs present significant challenges to existing ASC simulation codes, which were developed to run on central processor units. For selected codes, LLNL computer scientists are now achieving substantial performance speedups—10 times faster on a per-node basis. Initial results were about a factor of 100 slower.

Stockpile Stewardship Experiments

Livermore successfully executed its work in the FY 2017 National Hydrodynamic Test Plan, carrying out experiments to mature technologies with potential use in LEPs and improve predictive capabilities that underpin all facets of stockpile stewardship. The Flash X-Ray (FXR) radiography machine, used in hydrodynamic experiments at Livermore's Site 300, successfully conducted its first double-pulse imaging experiments. This enhanced capability enables researchers to follow the time evolution of the implosion process. Laboratory researchers also conducted hydrodynamic tests to prepare for fielding a series of subcritical experiments at the Nevada Nuclear Security Site that will provide important data about how a plutonium bomb core implodes. The preparatory tests are providing absolute assurance that the plutonium will remain subcritical and that materials will be safely contained.

Experiments at the Joint Actinide Shock Physics Experimental Research (JASPER) Facility and the National Ignition Facility (see p. 6) provide essential data about plutonium. Work at JASPER included developing new capabilities to gather data in unexplored lower pressure regimes. In addition, LLNL researchers and NNSA collaborators have for the first time taken 3D snapshots of operating high-explosive detonators. The experiments, performed at Argonne National Laboratory's Advanced Photon Source, are important for assessing aging effects on detonator safety and performance and for developing new and improved designs.

The Rescue of Atmospheric Nuclear Test Films

Rare-film expert Jim Moye examines a nuclear test film before scanning it. A team of weapons physicists, film experts, archivists, and software developers hunted down some 6,500 decomposing films of the nation's 210 atmospheric nuclear tests. The films are being scanned to preserve content and reanalyzed to extract more precise data for assessing nuclear weapons performance. In FY 2017, the first set of 63 Livermore test films was declassified and published in an LLNL YouTube playlist.

NATIONAL IGNITION FACILITY

Supporting stockpile stewardship through a wide range of nonignition experiments and pursuit of laser fusion ignition, and operating as a national user facility for high-energy-density science

The National Ignition Facility (NIF) team conducted 408 shots in FY 2017. Of these, 165 shots explored stockpile stewardship high-energy-density (HED) science and 135 advanced the prospect of demonstrating inertial confinement fusion (ICF) ignition and energy gain. Other shots supported diverse national-security applications, pursued discovery science, and helped scientists develop new experimental capabilities.

Stockpile Stewardship HED Science Experiments

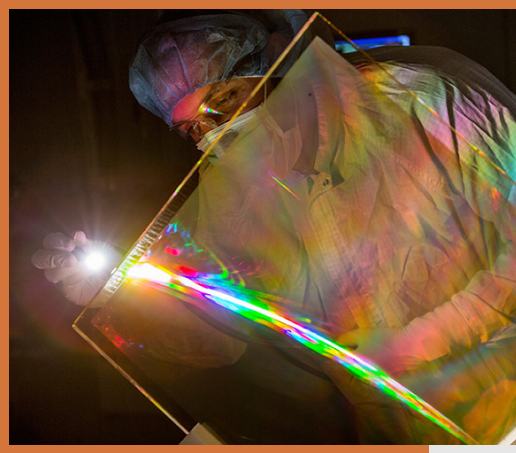
Campaigns of HED science experiments at NIF explored wide-ranging physical phenomena central to stockpile stewardship. Researchers gathered information about the properties of materials at extreme conditions, radiation hydrodynamics and transport, and material mixing. These issues are critical to understanding nuclear weapons performance and improving the predictability and results of fusion ignition experiments. Researchers achieved excellent results in the second material dynamics experiment examining the strength of plutonium at extreme conditions, and they continued a series of high-*Z* (high-atomic-number) diffraction shots to study plutonium's equation of state at extreme pressures. A team of NNSA researchers has also launched an experimental campaign to study radiative opacity—how opaque a hot, dense material is to transporting photons. Their first experiment was NIF's 2,000th shot since becoming operational in March 2009.

Progress Toward Fusion Ignition

Achieving fusion ignition and energy gain at NIF is a grand scientific challenge. Scientists are making progress on several fronts. In a two-shot series, experimenters at NIF nearly doubled the previous record for number of fusion neutrons generated. The first shot on June 2, 2017, produced 1.7×10^{16} neutrons (48 kilojoules of energy). Fired on August 28, 2017, the second, with higher laser energy, reached 2.0×10^{16} neutrons (57 kilojoules of energy), the highest yield to date. Full

((far left) Target area operators prepare a TANDM for a NIF shot. The 9,000-kilogram mechanism is about 8.5 meters long with a boom that can extend nearly 6.8 meters. TANDMs enhance NIF operational efficiency. They allow a special target positioner to be dedicated to growing cryogenically cooled target layers, while TANDMs and other manipulators position targets for other scheduled experiments.

(left) Cryogenic systems operator Sean Brum installs an opacity target in the NIF target positioner. The target consists of a shielded hohlraum (top), a collimator to produce parallel laser beams, and a plastic shell as a backlighter for producing x rays. The experiment used a spectrometer to measure opacity through the hohlraum.



Damage-Resistant Technologies for NIF Optics

Laboratory chemical engineer Marcus Monticelli inspects the anti-reflective coating on a NIF grating debris shield. The coating reduces NIF-energy loss and damage to the laser and the shield. LLNL researchers have also developed a patented chemical process that makes the surface of optics more damage resistant by removing impurities and absorbing microfractures. These important breakthroughs cut the cost of repairing or replacing damaged optics and present opportunities to boost the energy of NIF.

data recovery and analysis is ongoing. Results are approaching the "burning plasma regime," in which the hot spot in the deuterium–tritium (DT) fuel is heated more by fusion-created alpha particles than by energy from fuel compression.

These experiments benefited from lessons learned in many supportive NIF campaigns over the last two years, which studied options to produce much "rounder" implosions. Assessments of the pros and cons led to the choice of a high-density carbon (HDC) capsule to contain the DT fusion fuel. HDC matches well with use of a depleted uranium hohlraum (the case enclosing the fuel capsule) and a low-density helium gas fill. For these shots, the target fabrication team was able to shrink the capsule fill tube diameter from 10 to 5 micrometers (a human hair is 100 micrometers thick) to reduce perturbations in the implosion. Symmetry control is vital for ignition and remains an important focus area for the research team.

Discovery Science at NIF

The Discovery Science program enables a broad user community to perform HED experiments under conditions that only NIF can generate. These experiments include studies of material properties, hydrodynamics, and the interactions of intense radiation fields with matter. The focus of one campaign has been iron, the core material of Earth and Earth-like exoplanets. A team of researchers is investigating whether a giant rocky planet could have an Earth-like magnetic field, which is needed to harbor life. The experiments are measuring iron's melting at pressures from 5 to 20 megabars (1 megabar equals 1 million atmospheres). An initial shock melts the iron (at about 2.5 megabars); then the material is slowly compressed to determine at what pressure iron re-solidifies. Data will indicate whether the core of a giant planet has enough liquid iron in its outer regions to generate an Earth-like magnetic field.

Improving Operations and Experimental Capabilities

New technologies and equipment are increasing operational efficiency and experimental capabilities. In December 2016, the NIF team fielded an experiment utilizing the Advanced Radiographic Capability (ARC). A high-energy, high-intensity laser, ARC produces brighter, more penetrating x rays than standard NIF backlighting techniques. The ARC-generated radiograph showed, in never before seen clarity at such extreme conditions, an imploding shock driven by x rays in a NIF hohlraum interacting with a deliberately machined groove in a copper foam ball. The experiment was an important step toward applying this new capability to generate high-quality radiographs in support of the Stockpile Stewardship Program.

The target for the ARC experiment was held by NIF's first of two new Target and Diagnostic Manipulators (TANDMs), which was installed in June 2016. Use of TANDM to insert targets for experiments has become routine. In February 2017, the second TANDM was moved to the NIF target bay and is being used for manipulating diagnostics. The TANDM positioners were designed to enhance NIF's capabilities and operational efficiency. Now, NIF has two cryogenic target positioners, three dedicated diagnostic positioners, and the two TANDMs, which can insert either non-cryogenic targets or diagnostics.

GLOBAL SECURITY

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

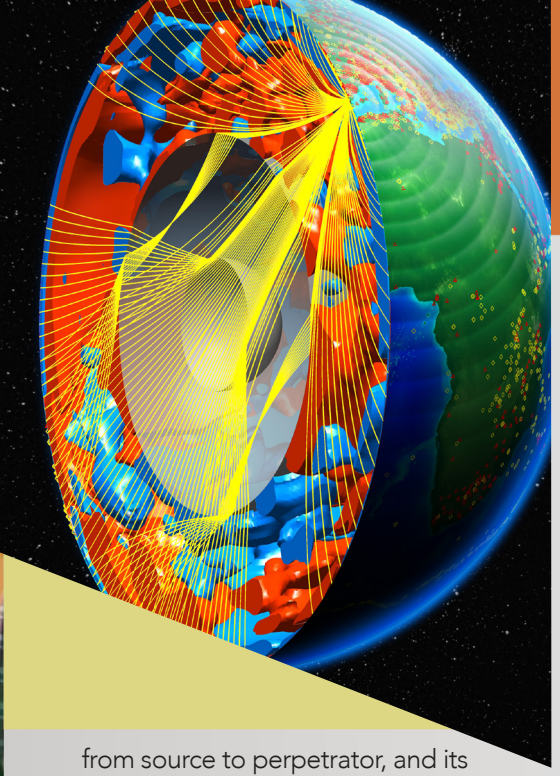
LLNL develops advanced technologies to help the government anticipate, identify, and address global security threats and prevent surprise. Our researchers apply expertise in chemical, biological, radiological, nuclear, and explosive weapons to support threat identification, preparedness, prevention, protection, and response and recovery. In addition, Livermore innovations in space situational awareness and cyber defense help strengthen national security in an increasingly complex world.

Identifying Underground Explosions

A Laboratory team played a key role in fielding the sixth and last in a series of underground, high-explosives tests conducted down a borehole in hard granite rock. The Source Physics Experiment (SPE) series, fielded at the Nevada National Security Site (NNSS), was designed to improve the nation's ability to detect and identify low-yield nuclear explosions amid the seismic clutter of conventional explosions and small earthquakes. SPE-6 was a 2.2-ton (TNT-equivalent yield) underground chemical explosion. By comparing the data obtained from SPE-6 to the previous deeper SPE tests as well as data from nearby underground nuclear tests conducted before the testing cessation in 1992, scientists better understand the effects of depth and explosion size on the generated seismic signals. The test series improves the capability to monitor the globe for clandestine nuclear testing by a state or nonstate group. A second phase of SPE, scheduled to begin in 2018 at NNSS, will focus on tests conducted in alluvium soil. LLNL researchers also provide leadership in developing computational tools to analyze seismic events and identify their source.

LION Hunts for Nuclear Clues

The laser ionization of neutrals (LION) laboratory is the latest tool developed by Livermore experts in nuclear forensics, a science that LLNL helped pioneer. The tool quickly analyzes nuclear material and provides critical information on a material's source, the pathway it took



(far left) Nuclear engineer Brett Isselhardt works on the resonance ionization mass spectrometry (RIMS) system inside the LION laboratory. Researchers use RIMS in nuclear forensics analyses to rapidly extract critical information from small samples of material.

(left) To improve capabilities for locating seismic events, LLNL developed LLNL-G3D. The model uses millions of event-produced, seismic-wave travel time records to construct a map of density variations in Earth's crust and mantle at regional-scale detail.

from source to perpetrator, and its possible use. LION, first used to perform nuclear forensics on spent fuel samples in 2017, employs a technology called resonance ionization mass spectrometry (RIMS) to measure isotopic ratios of elements such as uranium and plutonium. Lasers tuned to unique resonant frequencies ionize only atoms of elements of particular interest. RIMS requires only small samples and can distinguish between elements with isotopes having the same atomic weight, such as uranium-238 and plutonium-238.

A Vaccine Breakthrough

In research sponsored by the National Institutes of Health, Livermore scientists made significant progress in developing a vaccine for chlamydia using synthetic biology. Chlamydia, caused by the bacterium *Chlamydia trachomatis*, is the most common bacterial sexually transmitted disease and is difficult to treat. The team used a patent-pending technique pioneered in partnership with Synthetic Genomics, Inc., that uses telodendrimer nanolipoprotein particles to produce high yields of so-called major outer membrane proteins in a cell-free environment. Because these proteins are specific to *C. trachomatis*, they can be used as antigens in a vaccine to protect the patient from real-world infection. The project carries important implications for developing vaccines for other bacteria and diseases that also require difficult-to-produce antigens for vaccination—including cancer.

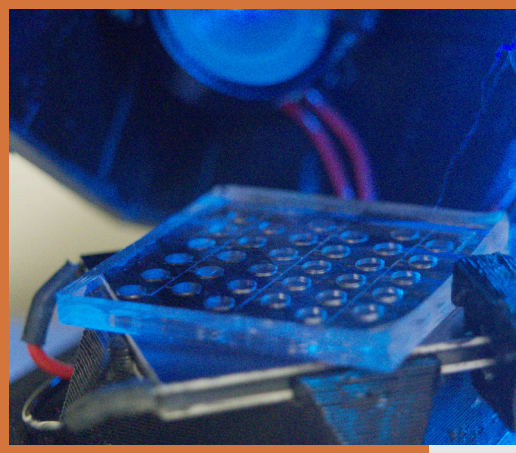
Another "A" in Forensic Science

The Organisation for the Prohibition of Chemical Weapons (OPCW) awarded LLNL's Forensic Science Center (FSC) its seventh consecutive "A" grade. Despite a worldwide ban, chemical weapons remain a threat to global security. Since 2003, FSC has been one of only two U.S. laboratories accredited by OPCW—and one of only twenty worldwide. To maintain accreditation, FSC must achieve high scores on OPCW's increasingly difficult annual proficiency test. It requires accurate detection and identification of chemical warfare agents, precursor compounds, and their decomposition products. Also in 2017, FSC received an "A" for its second biomedical proficiency test given by OPCW. Created in 1991, FSC is home to nationally recognized experts who support chemical, nuclear, and biological counterterrorism activities.

Predicting Atmospheric Plumes and Hazard Zones

In the event of an atmospheric release of radioactive or other hazardous materials, LLNL's National Atmospheric Release Advisory Center (NARAC) provides timely and accurate plume predictions to aid emergency preparedness and response efforts in protecting the public and the environment. Predictions must be probabilistic because of uncertainties in weather and release conditions (e.g., location, time frame, and quantity). To test and improve their predictive capabilities, researchers at NARAC used data from an atmospheric tracer experiment conducted three decades ago at California's Diablo Canyon Nuclear Power Plant. With tens of thousands of computer simulations and their best weather and statistical models, they accurately determined release conditions and provided an estimated margin of error.

In a related development, NARAC researchers completed a working prototype of a software tool that can help federal, state, and local emergency responders rapidly identify hazard zones following a nuclear detonation. This tool can quickly assess the areas damaged and impacted by a nuclear detonation and subsequent fallout, for example, caused by a terrorist attack.



A New Kit for Rapid Bacterial Detection

Researchers from LLNL and the University of Wisconsin, Madison, developed a low-cost, portable diagnostic kit that provides timely, accurate pathogen identification for an infection. The shoebox-sized kit is easy to use and runs on 9-volt batteries. A soft plastic reader called a bacteria-detection chip performs a recombinase polymerase amplification assay in about 1 hour and can simultaneously assess up to 16 different diseases. Pathogen identification is the critical first step in effective patient care.

ENERGY AND ENVIRONMENT

Using science and technology to improve national energy security and surety, 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.

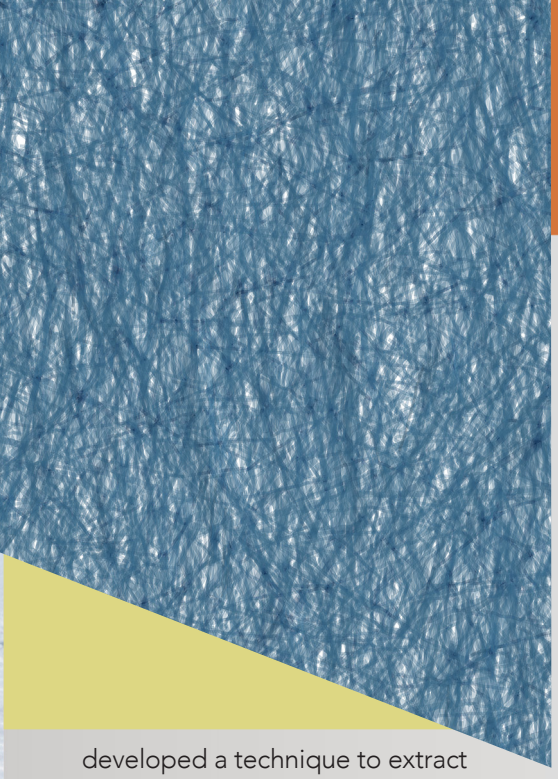
Helping the Paper Industry Save Energy and Reduce Costs

The U.S. paper-making industry ranks third among the nation's largest energy users, behind only petroleum-refining and chemical production. Researchers from Lawrence Livermore and Lawrence Berkeley national laboratories are using their supercomputing capabilities to make paper production more energy efficient. The scientists are targeting "wet pressing," the stage where water is removed by mechanical pressure from wood pulp. The effort leverages advanced simulation, high-performance computing (HPC), experimental measurements, and industry data to develop computer models that accurately simulate the wet-pressing process and thereby identify opportunities to save energy.

The paper-industry study, part of DOE's High Performance Computing for Manufacturing (HPC4Mfg) Program, earned an HPC Innovation Excellence Award at SC17 in Denver, Colorado. HPC4Mfg provides opportunities for industry partners to access the HPC capabilities and expertise at DOE's national laboratories for optimizing production processes to decrease energy consumption, enhancing product quality, and speeding design and testing cycles. LLNL has been the lead laboratory for the program, and with its success, DOE has launched the High Performance Computing for Materials (HPC4Mtls) Program, also led by Livermore.

Extracting Hydrogen from Water

Because it generates no carbon emissions, hydrogen is an attractive fuel source for many applications, including fuel cells. Laboratory scientists, working with colleagues from Rice University and San Diego State University, have



(far left) Sediments collected in Greenland by polar scientists (from left) Alice Nelson (University of Vermont), Dylan Rood (Imperial College) and Jeremy Shakun (Boston College) were analyzed at LLNL's Center for Accelerator Mass Spectrometry. (Photo courtesy of Joshua Brown/University of Vermont.)

(left) The fibers in one square centimeter of a paper towel are modeled in a simulation with 20 million finite elements. The fibers are shown partially transparent. The blue color indicates pressure, which is higher in places where many fibers overlap.

developed a technique to extract hydrogen from water efficiently and cheaply by using a new class of catalysts based on inexpensive transition metals such as molybdenum and tungsten. Quantum mechanics simulations revealed particular material properties that could make catalysts far more efficient, and the research team computationally screened for candidate compounds. Experiments validated the effectiveness of two proposed catalysts, which performed better than expected. Today, splitting molecules to extract hydrogen from water using electricity is fairly straightforward but energy intensive, or requires expensive precious-metals catalysts.

Capturing Carbon Dioxide

Carbon dioxide (CO_2) constitutes about 82 percent of total greenhouse gas emissions in the United States. Although CO_2 is released through a variety of human activities, the biggest concern is CO_2 emitted from large-scale sources such as power plants and industrial sites. Ideally, CO_2 would be separated from power plant flue gas before leaving the smokestack and entering the atmosphere; but this process, known as carbon capture, is prohibitively expensive. A new Livermore separation technology relies on the recently discovered phenomenon of a reversible CO_2 reaction in molten hydroxide. The technology involves a gas separation membrane containing molten hydroxide solution held in a porous material that selectively turns CO_2 into carbonates.

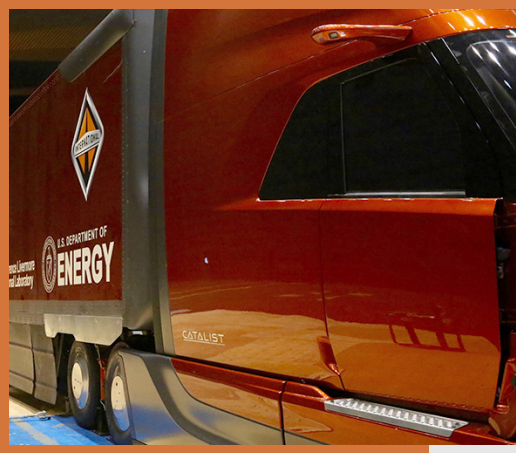
Climate's Impact on Snowpack

Laboratory researchers are deeply involved in studying climate change. An international team, including an LLNL scientist, found that human influence is responsible for up to 20 percent loss in the annual maximum amount of water contained in the Western United States' mountain snowpack in the last three decades. Peak runoff in streams and rivers is strongly affected by melting of this snowpack. A significant decline in water has serious implications for hydropower, municipal, and agricultural sectors in the region. The team showed that the observed snowpack loss is consistent with results from climate simulations that included changes from natural factors and human influences.

In a separate study, an international team analyzed sediments eroded from the East Greenland ice sheet. They showed that over the past 7.5 million years the ice sheet has been dynamic and consistently responded to climate change. The team used LLNL's Center for Accelerator Mass Spectrometry to analyze the sediments.

Bioengineered Bacteria Increase Rare Earth Supply

The rare earths comprise 17 elements in the periodic table, and many are essential to national security and U.S. industries. However, rare earths require extensive chemical processing to isolate individual elements. What's more, greater than 90 percent of rare-earth elements come from China. To alleviate supply vulnerability and diversify the global supply chain, a Livermore-led team has developed a way to recover rare-earth elements using bioengineered bacteria. The outer cell walls of these bacteria feature binding tags containing molecules called ligands that exhibit 1,000 times greater affinity for rare earths than other metals. The new process makes mining for rare earths practical in nontraditional and low-value resources such as mine tailings, geothermal brines, and coal byproducts.



Improved Fuel Efficiency for Tractor Trailers

In FY 2017, final wind tunnel tests of the new SuperTruck were conducted at the NASA Ames Research Center. Together with Navistar engineers, Laboratory scientists helped design a new type of tractor-trailer truck with significantly improved fuel economy. The new SuperTruck vehicle achieved 13 miles per gallon and 104 percent improvement in freight efficiency. Forty-eight percent of this improvement comes from aerodynamic enhancements, which could potentially equate to 21 billion gallons of diesel fuel saved annually. The effort combined experiments, computer simulations, and wind-tunnel tests.

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

Livermore's scientific and technological research provides benefits to society that range from better materials for advanced products to innovative biomedical solutions for human health and a better understanding of the universe we live in.

Record-Setting Petawatt Laser

Livermore researchers delivered to the European scientific community the High-Repetition-Rate Advanced Petawatt Laser System (HAPLS), designed to deliver 10 pulses per second, each 30 quadrillionths of a second long with greater than 1 petawatt peak power. As the world's highest average-power laser, HAPLS is a major advancement over today's petawatt lasers, which cannot fire more often than once per second. The system incorporates many breakthrough technologies, including the use of laser diodes as flashlamps to reduce system size and power requirements. HAPLS will be a key component of the European Union's new Extreme Light Infrastructure (ELI) Beamlines facility, where the international scientific user community will study laser–matter interactions. The laser pulses are of such intensity (up to 10^{23} watts per square centimeter) that HAPLS makes possible new investigations into atomic physics, time-resolved proton and x-ray radiography, nuclear physics, high-energy-density physics, plasma physics, chemistry, biochemistry, and medicine.

Advancing Applications for Exascale Computing

Livermore is taking delivery of the Sierra supercomputer (see p. 5). Laboratory researchers have been preparing for it and looking ahead to exascale computing (10^{18} floating-point operations per second). In FY 2017, DOE's Exascale Computing Project (ECP) awarded funding for 35 software development projects. LLNL computer scientists lead six of the projects and are collaborators on another seven. Livermore was also one of four national laboratories selected to lead an ECP co-design center. These co-design centers focus on selected exascale hardware–software issues. LLNL's Center for Efficient Exascale

(far left) HAPLS, the world's most advanced and highest average-power, diode-pumped petawatt laser system, was designed, developed, and constructed in only three years by LLNL researchers and delivered to the ELI Beamlines facility in the Czech Republic in June 2017.

(left) Astronomers discovered a cosmic event unlike any ever seen in a pair of colliding galaxy clusters called Abell 3411 and Abell 3412. LLNL researcher William Dawson performed optical observations and analysis of the collision. (Composite spectral image courtesy of NASA/CXC/SAO/van Weeren et al; NAOJ/Subaru; and NCRA/TIFR/GMRT.)

Discretizations addresses a key challenge in developing next-generation algorithms for large-scale applications so that they run efficiently on exascale platforms.

A team of LLNL computer scientists successfully met the challenge of dramatically enhancing the performance of first-principles molecular dynamics computer simulations. With the improvement, computing time scales linearly with the number of molecules (N) rather than a higher power of N. The team's "Computing More than a Million Atoms with over a Million Cores" project was a finalist for the 2016 Gordon Bell Prize. The technique, which opens the door to simulating systems of a size and complexity previously impossible, has broad application in chemistry, physics, materials science, biology, and medicine.

High-Performance Computing Applied to Life Sciences

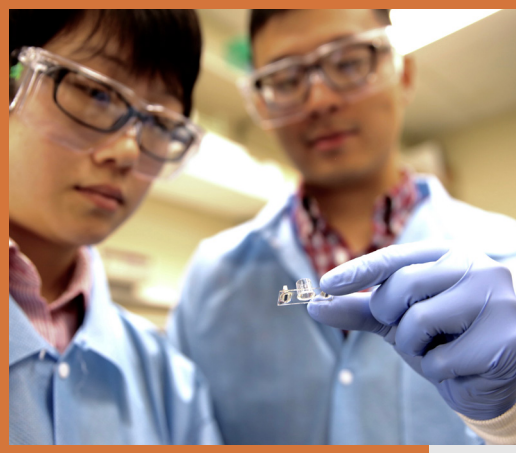
The Accelerating Therapeutics for Opportunities in Medicine (ATOM) Consortium unites Livermore, the Frederick National Laboratory for Cancer Research, pharmaceutical manufacturer GSK, and the University of California at San Francisco in a new discovery process for cancer medicines. ATOM's goal is to reduce the time from identifying a drug target to developing a clinical candidate. The typical time is 6 years, but ATOM is working to shrink this cycle to 12 months. ATOM will integrate high-performance computing (HPC), data science, and artificial intelligence into a single drug discovery platform.

Scientists are increasingly using HPC to improve not just drug discovery, but healthcare in general. Laboratory and Norwegian researchers are cooperating to analyze Norway's database of 1.8 million cervical cancer screening results covering 25 years from the Cancer Registry of Norway. The country's screening program is a linchpin of its efforts to reduce cancer incidence. Using pattern recognition, machine learning, and statistical analysis, the research team will focus initially on improving risk assessment and the screening recommendations for individual women, moving healthcare toward an era of personalized medicine.

Experimental and Computational Astronomy

Through experiments, simulations, and observations, Laboratory researchers take part in astonishing discoveries about objects and events in our universe. In addition to the Discovery Science experiments at the National Ignition Facility (see p. 7), LLNL scientists probe high-energy-density astrophysical phenomena at other facilities, such as the Linac Coherent Light Source (LCLS) at the SLAC National Accelerator Laboratory. As part of an international team, they used LCLS to generate a "diamond rain," which is theorized to exist within slushy high-pressure interiors of planets such as Uranus and Neptune. They watched carbon forming into nanodiamonds in real time under extreme pressures, a phenomenon they theorize is an everyday occurrence on the gas giant planets, where diamonds within the rain may grow to visible size. Another team, led by a researcher from Colorado State University, used compact lasers at LLNL's Jupiter Laser Facility to re-create conditions that exist inside stars. The ultra-high-density matter was formed by irradiating arrays of aligned nanowires with intense ultra-short laser pulses.

Livermore scientists and colleagues also apply HPC to astronomical discovery. To assist in the search for moons around planets of other star systems, one Livermore-led team has simulated the



LLNL Unveils a "Heart-on-a-Chip"

Researchers Fang Qian (left) and Chao Huang hold LLNL's "heart-on-a-chip." They successfully recorded both electrical signals and cellular beating from normal human heart cells grown on the multi-electrode array. The goal is to decrease the time needed for new drug trials and ensure that potentially lifesaving drugs are safe and effective. The research is part of the Laboratory's iCHIP (in-vitro chip-based human investigational platform) project.

(left) A new 3D printing technique, developed at the Laboratory, could allow scientists to print glass that incorporates different refractive indices in a single flat optic, making finishing cheaper and easier.

(far right) LLNL researcher David Trombino tests a prototype of the Radiation Field Training Simulator. The device provides more realistic training of first responders protecting against radiological or nuclear terrorism. The simulator's two enclosures (in white) are attached to a commercial radiation detector.

formation of moons from collisions of planetary bodies to determine what factors affect exomoon formation. They found that a collision between like-sized objects, each two to seven Earth masses, could launch enough mass into orbit to form a moon that could be detected by the Kepler spacecraft. LLNL scientists have also simulated the formation of the giant crater on the surface of Phobos, one of Mars' moons, and estimated the impacting body's size and speed.

Fiber Optics Breakthrough

With 3.4 billion people connected to the Internet and that number growing, telecom companies are searching for ways to increase Internet bandwidth as rapidly and inexpensively as possible. A Livermore team has developed a fiber-optic amplifier that could potentially double the information-carrying capacity of existing fiber-optic cables.

Most of the bytes moving over fiber-optic cables travel on lasers operating at a wavelength of 1,550 nanometers (nm), amplified by inline optical amplifiers. The Livermore team discovered a new fiber capable of amplifying at the 1,330-nm laser wavelength, while suppressing interfering signals at other wavelengths. At 1,330 nm, the new fiber shows significant optical gain with good efficiency—possibly allowing telecoms to double the transmission rate on their existing installed base of fiber-optic lines. Use of the new fiber could eliminate the huge cost of digging new tunnels and laying more cable.

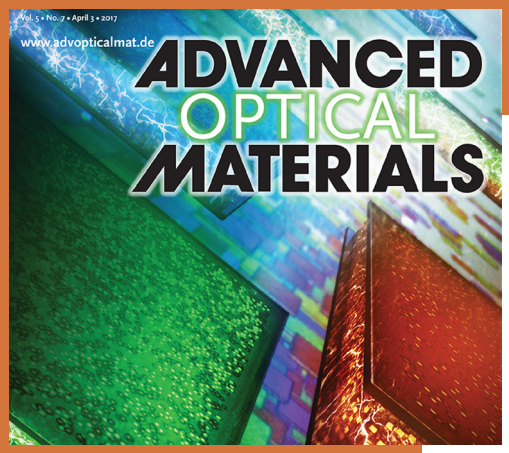
Additive-Manufacturing Advances

Livermore scientists are at the forefront of developing additive manufacturing (AM) technologies. Manufacturing parts by 3D printing means components can be designed, prototyped, and manufactured more rapidly and at lower cost than by conventional manufacturing. In FY 2017, LLNL researchers showed they could produce transparent glass by 3D printing aroom temperature a "slurry" of silica particles and treating it. Since high-resolution features can be printed with the new process, high-quality optics and lenses could also be created by varying the composition of the glass.
In addition, a Laboratory team demonstrated that 3D printing can be used to manufacture parts made of aerospace-grade carbon fiber composites, a material used in the aerospace, defense, and automotive industries, as well as in vehicles for sports and outdoor pursuits. Another team created a composite silicone material with "shape memory"—a 4D material that can be manufactured to assume an alternate shape when heated.

Livermore is also reinventing metal 3D printing processes. Metal 3D printing has enormous potential to revolutionize modern manufacturing. However, the most popular process, which uses lasers to fuse together fine metal particles, has limitations. LLNL scientists have combined ultrafast imaging of the melting process with high-resolution simulations to reveal an important cause of the defects in printed parts and are studying ways to improve it based on an understanding of the underlying physics. Another team is exploring the use of high-powered laser diodes to speed up the metal printing process. Yet another team is taking a new approach to 3D metal printing: direct metal writing, in which semisolid metal is directly extruded from a nozzle.

A Focus on Carbon Nanotubes

Carbon nanotubes (CNTs)—nanoscale hollow tubes formed from cylindrical sheets of carbon—are of great interest to Laboratory scientists. They have unusual strength, stiffness, thermal and electrical conductivity, and other



Creating Nanoparticles in Dynamic Color

As illustrated on the cover of the April 3, 2017, issue of *Advanced Optical Materials*, Livermore researchers created a technique to change the color of assemblies of "core/shell nanoparticles" using electrical stimulation. These assemblies can be useful in colored photonic displays for mobile phones, electronic billboards, and instrument panel displays. The reversibility and angle-independence of the observed colors from the assemblies make the technology ideal for such applications.

properties that are applicable to many LLNL mission areas—from advanced materials for energy and environmental security to biosecurity and biomedicine. Work published by Livermore scientists in FY 2017 showed that a type of nanomolecular channel, the carbon nanotube porin (CNTP), can mimic the behavior of lipid membranes in cells. They demonstrated that CNTPs can act as pores by inserting themselves across sheets of lipid membranes, providing an artificial channel through which water molecules, ions, and protons—all important to various living processes—can pass. Using high-speed atomic force microscopy, they were able to image the motion of CNTPs in real time.

To better understand how to synthesize CNTs that are customized for special applications, LLNL scientists also conducted experiments to directly visualize the structure, growth, and self-organization of CNT sheets. Using an environmental transmission electron microscope, they made a movie of CNTs growing and aligning themselves. Another team used synchrotron x-ray scattering to map the hierarchical structure of CNTs across four orders of magnitude in length. The work has direct application to ongoing efforts developing carbon nanotube membranes as a material for breathable garments that protect against biological agents.

Seven R&D 100 Award Winners

Three technologies developed under LLNL leadership, and four others that Livermore researchers contributed to, won 2017 R&D 100 awards, bringing the Laboratory's total to 165 since 1978. The R&D 100 awards recognize the year's best technological innovations. Livermore-led teams developed the Applied Biosystems Axiom Microbiome Array and the Radiation Field Training Simulator. An LLNL researcher led development of the Earth System Grid Federation (ESGF).

The Applied Biosystems Axiom Microbiome Array is the commercially licensed version of the Lawrence Livermore Microbial Detection Array, which is capable of detecting 3,000 bacteria and viruses within 24 hours for diagnosing diseases, as well as 26,000 other microorganisms, some of which are pathogenic. The Radiation Field Training Simulator is an instrument that provides realistic training for first responders protecting against radiological or nuclear attacks by replicating the physics of radiation hazards. The ESGF system has transformed Earth data into community resources available within a virtual, collaborative environment. ESGF links climate centers and users around the world to models and data via a computing grid powered by the world's high-performance computers.

Livermore staff were recognized as co-developers on four technologies: a new family of aluminum alloys that offers superior mechanical properties at high temperatures, the Geometrically Enhanced Photocathode (which improves the efficiency of x-ray detectors), the National Risk Assessment Partnership Toolset (a computer software package for assessing the environmental risk of geologic carbon dioxide storage sites), and Zirconia Electrochemical Hydrogen Safety Sensors for hydrogen fueling stations in transportation applications.

Expanding Industrial Partnerships

LLNL is benefiting the U.S. economy with innovative technology and methods. In FY 2017, the Laboratory filed 99 new patent applications, received 105 new copyrights, licensed 35 unique inventions, and 10 authored works. Licensing income for the year totaled about $6.2 million. Entrepreneurial Livermore researchers are benefiting from the DOE's Technology Commercialization Fund (TCF). Six awards to LLNL were among the selections announced by DOE Secretary Rick Perry in September 2017. The grants ranged in size from $150,000 to $750,000, with matching funds coming from nonfederal money. For the largest grant, LLNL will be integrating the ParGrid platform with a leading power management company's commercial distribution simulator and LLNL's open-source GridDyn transmission simulator. Developed by Livermore researchers, ParGrid is used to perform coupled transmission and distribution analyses. The study will focus on the electrical grid of the future.

SAFE, SECURE, AND SUSTAINABLE OPERATIONS

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

Committed to the highest level of operational performance, Livermore employs best practices in environment, safety, and health (ES&H), and security. Management systems support continuous improvement in work practices. Prudent risk management coupled with active measures to prevent accidents ensures the safety of LLNL staff and the public. Investments are targeted to modernize Laboratory infrastructure.

Attention to ES&H

Continuous improvement is a key facet of Livermore's Integrated Safety Management System and its Occupational Health and Safety Management System, which was re-certified this year under the Occupational Health and Safety Assessment Series (OHSAS) 18001 standard. LLNL's injury and illness rates continued to fall and are near historic lows. FY 2017's total recordable case (TRC) rate of 1.18 improves upon the previous year's excellent performance, and the days away, restricted, or transferred (DART) rate, which is a measure of severity of injuries, is 0.44. Both figures are down by about a factor of two since the contract transition in 2008. LLNL's Ergonomics Program, the Wellness Program's annual Get Active campaign—and the Walking is Working campaign to reduce trips and falls—all contribute to employee health and safety. With many infrastructure improvement activities now in progress, construction safety is also a strong focus, and work was completed without any subcontractor safety incidents in FY 2017.

Effective Operations

In FY 2017, operations at LLNL were effectively and efficiently managed, with notable achievements in many areas. Importantly, Livermore is conducting innovative site planning, modernizing infrastructure, and meeting project planning goals (see p. 18). LLNL also conducted well-managed business and financial operations.

(far left) Human Resources staff member Kathlean Batteate-Jordan inquires with health educator Neelam Murthi (right) about the Working Well Program. LLNL's Health Services also holds an Annual Wellness Drop-in Clinic, which offers free flu shots, blood pressure checks, and other health services and consultations.

(left) Cooling towers at LLNL's Central Utility Station were recently replaced, which revitalized a critical part of the site-wide low-conductivity water system. Low-conductivity water is required for cooling electronic equipment, a major use of water at the Laboratory.

Nuclear Operations provided effective performance assessments, improved documentation related to Packaging and Transportation Safety, and supported Laboratory programs and other DOE sites in the areas of Nuclear Criticality Safety and Safety Basis.

In addition, the Laboratory's Security Organization (SO) is revitalizing and modernizing LLNL's physical security and protective force infrastructure. Construction of a new Protective Force Fitness and Training Center is ongoing and SO continues to make cost-effective improvements to enhance perimeter security. Employee security performance also has improved. A Security Culture Campaign helped to heighten awareness and engage employees regarding their security responsibilities and guided staff to adopt better practices.

A New Work-Planning Process

Implementation of the Laboratory's revamped work planning and control (WP&C) process is well under way. This major undertaking is changing how mission, site-wide service, and facility and infrastructure work is planned, scheduled, and released. The new WP&C process is designed to ensure consistent Laboratory-wide practices, increase rigor and efficiency, and add value to work control documents. In FY 2017, all LLNL directorates began applying the new process to newly started work and major changes to existing projects. Feedback has been very positive. Each directorate has committed to a transition plan for all ongoing work projects, which are covered by more than 1,000 existing work control documents. A team from the DOE Office of Enterprise Assessments spent two weeks at the Laboratory in February 2017 assessing the new WP&C process. The team found no deficiencies and noted many of the new processes helped streamline work control.

Improvements in Site Sustainability

Environmentally 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 environmental impact of Laboratory activities. Issued in October 2017, the 2016 Site Annual Environmental Report records LLNL's compliance with environmental standards.

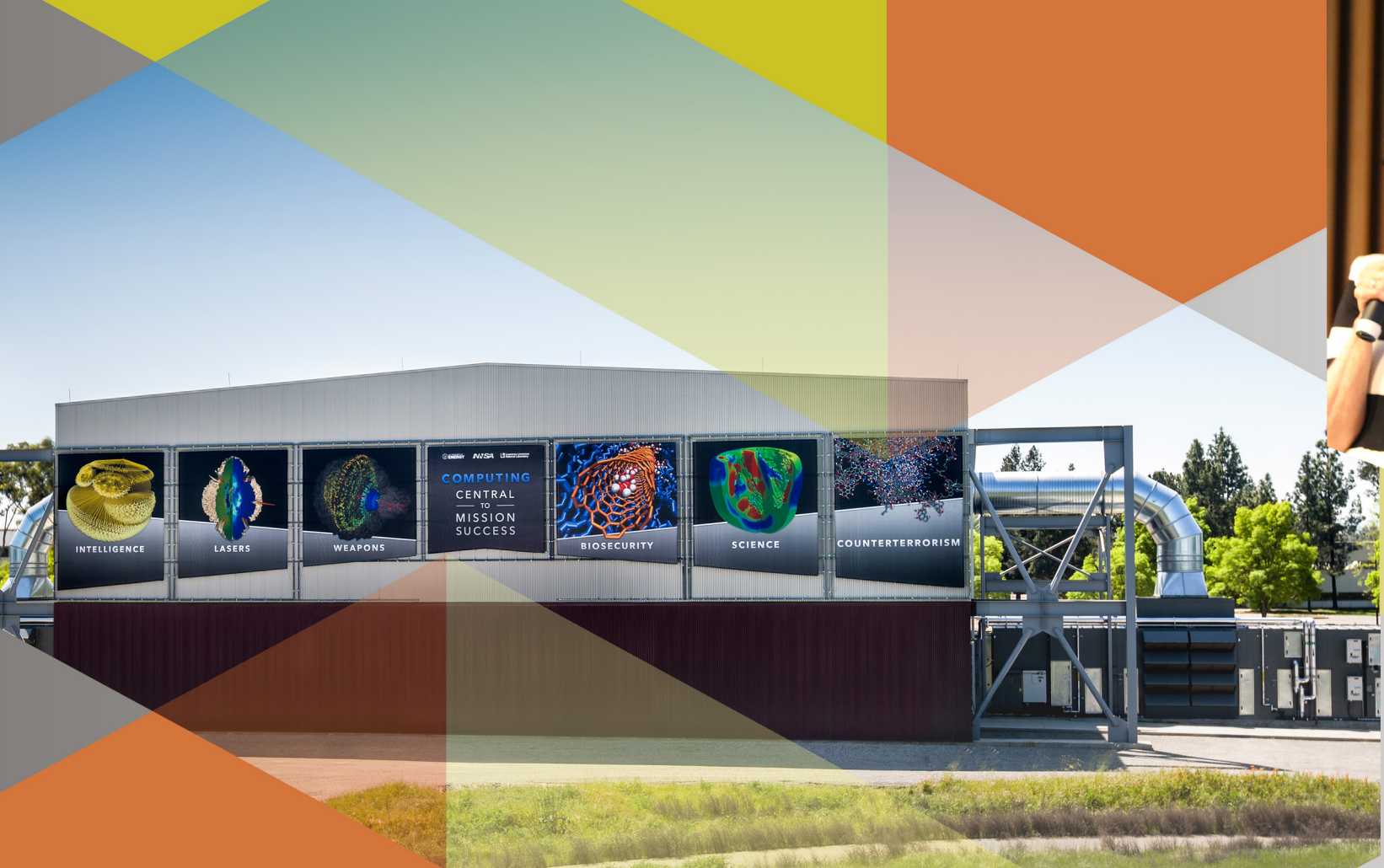
Overall, LLNL met its sustainability goals in FY 2016 and has already achieved its FY 2020 greenhouse gas reduction goal. Livermore is meeting California Governor Jerry Brown's mandatory potable water irrigation reduction requirements. Since FY 2013, irrigation usage has been reduced by about 60 percent. However, the demand for cooling tower water (needed for supercomputing) remains substantial. A 10-acre 3.3-megawatt solar photovoltaic system located in LLNL's northwest buffer zone is generating about 500 megawatt–hours per month to help meet goals for renewable energy use.

"Superfund" Public Tours

LLNL's Environmental Restoration Department, in partnership with the NNSA Livermore Field Office, initiated an annual "Superfund" tour for the general public. Thirty-one members of the community participated in four tours—two at LLNL's main site and two at Site 300. Tour participants learned about the Laboratory's ongoing soil and groundwater cleanup activities since contaminants were first discovered several decades ago. Considerable progress in cleanup has been made at both sites.

Maintaining the Infrastructure

LLNL invested nearly $33 million from the site support budget to improve the workplace environment. Some projects were real property replacements that benefit maintenance. Others improved laboratory spaces, expanded utilities, and contributed to site remediation. Investments included infrastructure improvements at Site 300 to ramp up for W80-4 life-extension program activities and supported construction of the Advanced Manufacturing Laboratory (see p. 18). In addition, site demolition and site preparation of "Block 2200" readied the area for new construction to consolidate applied material and engineering activities at the Laboratory. LLNL is also poised to begin decommissioning and disposition of several contaminated legacy facilities.



MANAGING FOR THE FUTURE

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

In FY 2017, the Laboratory engaged sponsors and stakeholders, provided technical leadership in key mission areas, and strengthened the foundation for future successes.

Strategic Engagements and Initiatives

Laboratory Director William Goldstein and his management team engaged in discussions about national security and the evolving strategic landscape with wide-ranging audiences. Livermore welcomed many visitors from DOE and NNSA headquarters, Congress, and the executive branch (including unified combatant commands), as well as work sponsors. Notably, LLNL conducted workshops and tabletop exercises on multi-domain deterrence in 2016 and 2017 and co-hosted with the U.S. Air Force a meeting on the subject in Washington, D.C. In addition, Lawrence Livermore, Los Alamos, and Sandia national laboratories prepared joint background papers providing technical perspectives on issues pertaining to nuclear force posture.

As described elsewhere in this Annual Report, Livermore is providing technical leadership in many areas of its national security mission. Examples include the W80-4 life-extension program, the advancement and application of high-performance computing, key nuclear threat reduction initiatives, NNSA complex modernization, and technical areas such as additive manufacturing and petawatt laser development.

New Facilities and Modernized Infrastructure

Construction of LLNL's Advanced Manufacturing Laboratory (AML) is nearly completed. Sited at a public-access location, this 13,700 square-foot facility will house cutting-edge manufacturing research capabilities for use by Livermore employees working with industry and academic partners. Many other projects are in preparation or under way as part of a $150 million facility construction/acquisition portfolio that the Laboratory is executing. These include the $31 million Expand Electrical Distribution project, a new $32 million Emergency Operations

(far left) Displaying the Laboratory's missions, newly constructed Building 654 provides unclassified high-performance computing support to NNSA's Advanced Computing and Simulation Program, other national security missions, and collaborations with industry and academia.

(left) Postdoctoral fellow Ashley Campbell (right), winner of the 2017 Research Slam!, converses with master of ceremonies Dona Crawford, retired LLNL Computation associate director and now president of the Livermore Lab Foundation (see the box).

Center, and a $90 million Exascale Computing Facility Modernization project, which are at various stages of Critical Decision approval. In addition, some 30 general plant projects are ongoing.

The effective facility and infrastructure (F&I) investment planning tools developed and used by Livermore are benefiting revitalization of the LLNL campus. They are also helping NNSA institute an enterprise-wide Master Asset Plan (MAP) to align infrastructure investments with mission goals and reduce risks to mission success. LLNL is working as an innovative partner with NNSA's Office of Safety, Infrastructure, and Operations (NA-50) to develop the methodologies, templates, and tools for MAP. In addition, LLNL pioneered the "Deep Dive" meeting process with NNSA in 2016. With NNSA's improved F&I management process now in its second year, Livermore continues to lead the way and set a high standard of success for other NNSA sites.

Sustaining Workforce Excellence

An outstanding workforce is the Laboratory's principal strength. Staff members bring to their jobs impactful new ideas, work with integrity and zeal, and thrive in an inclusive work environment. LLNL was named to Reuter's list of Top 25 Global Innovators—Government, which identifies and ranks the publicly funded institutions doing the most to advance science and technology. The Laboratory's many accomplishments highlight staff quality and the importance of recruiting and nurturing future programmatic and technical leaders. Notably, two Laboratory employees were among the 100 recipients of the prestigious Presidential Early Career Awards for Scientists and Engineers (see p. 22).

Leadership development is crucial to LLNL's future. During FY 2017, Skillsoft and Elearning! presented Livermore top honors for implementing a comprehensive leadership development training program designed to grow leaders at all levels of the organization. The Laboratory's program includes online resources and courses, coaching opportunities, and instructor-led workshops. Other special opportunities for building skills include Research Slam! for postdoctoral fellows. They are offered coaching help and invited to compete in giving the best three-minute presentation answering the question, "Why is your research important?" In addition, 15 LLNL scientists and engineers were honored in the annual Early and Mid-Career Recognition Program. Winners received cash awards and some institutional funding to pursue research activities in their areas of interest.

LLNS Board of Governors Activities

The LLNS Board of Governors and its committees provide oversight to the Laboratory and delve into issues crucial to mission and mission-support activities. External review committees (ERCs), panels of independent experts including Board members, held six meetings in FY 2017 to critically assess the quality of LLNL's technical workforce and the effectiveness of research efforts in meeting mission goals and future national needs. Their reports, which provided DOE/NNSA with an independent validation of work quality, consistently affirmed the mission relevance and high impact of Laboratory research. Functional Management Reviews (FMRs) chartered by the Board examined issues on an as-needed basis. Seven FMRs were completed in FY 2017 in topical areas ranging from computerized maintenance management to work planning and control. Recommendations provided by Board committees, ERCs, and FMRs have led to substantive responsive actions.

Establishing the Livermore Lab Foundation

Formed as a 501(c)(3) nonprofit organization, the Livermore Lab Foundation (LLF) provides opportunities for philanthropic support of scientific research, technology development, and educational endeavors at LLNL. LLF provides donors exciting opportunities to help advance fundamental knowledge; create transformative technologies; and enhance human health, safety, and quality of life for current and future generations. The foundation also aims to support community educational initiatives and was proud to kick off its activities with a Girls Who Code workshop at the Edward Teller Education Center (see p. 21).

COMMUNITY CONNECTIONS

Supporting local communities through science education and charitable giving

As a good neighbor, the Laboratory engages in a wide range of community activities. Many are directed at enhancing science, technology, engineering, and mathematics (STEM) education. Community outreach also includes employees' volunteer work and charitable giving that support local service agencies. In addition, LLNS conducts an annual grant program that invests in community education, arts, and services.

Science That's Fun

Each year, more than 12,500 children at the fourth- and fifth-grade levels, along with their chaperones, are introduced to scientific concepts through the Laboratory's ever-popular Fun With Science program. This program offers young minds a tour of the Laboratory's Discovery Center, followed by participation in hands-on experiments that introduce students to a scientific curriculum. Fun With Science is a mainstay at the Discovery Center, and the show has become a featured event at summer street fairs, science festivals, and other special events throughout the greater San Francisco Bay Area.

Science Fare at the Fair

LLNL promotes science through various fairs and festivals. In November, the Laboratory participated in the 6th 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 participating in presentations of Fun With Science, attendees took 3D virtual tours of the Laboratory via several immersive videos, while children were challenged to hop aboard special energy bikes and transform their kinetic energy into power to run small household items and make lights glow.

The Laboratory continued to sponsor the annual Alameda County Science and Engineering Fair (ACSEF), held in March. More than 700 middle- and high-school students and 175 teachers from 18 school districts participated in the fair, earning awards and scholarships. In addition, 60 special awards were given by national and local government and industry

((far left) LLNL's Discovery Center offers interactive learning displays aimed at fostering curiosity and a better understanding of scientific principles. Teachers and students are invited to participate in Fun With Science field trips that combine science displays, group activities and hands-on experiments.

(left) LLNL scientist Harold Rogers' Fun With Science presentations, 3D virtual tours of Laboratory programs, and other interactive displays were crowd pleasers at Discovery Day, which attracted 30,000 visitors to AT&T Park.

sponsors. The science fair winners move on to the Intel International Science and Engineering Fair, the California State Science Fair, and the national Broadcom Masters competition.

Saturday Is Science Day

LLNL's Science on Saturday (SOS) lecture series for middle- and high-school students plays to sold-out crowds every year. More than 6,000 people attended this season's 16 lectures held in Livermore, Tracy, and Oakland, California. Each lecture highlighted cutting-edge science and technology at the Laboratory. This season, SOS presented themed discussions on "Ingenious Inventions"—pairing Laboratory researchers with local science educators to discuss topics such as DNA applications in forensic science; new materials for additive manufacturing; and building "nano-bots" as a new approach to vaccines, drug delivery, and energy needs. The events were recorded for the University of California's TV website and YouTube.

Each year the Laboratory gets up close with Hollywood's perspective on science and technology through the Science on Screen lecture series for students ranging from middle-school to college level. It combines popular feature-length movies with prominent researchers from the Laboratory, who discuss the scientific viability of what's depicted in these classic science fiction films. This year's series of three lectures, again playing to sold-out audiences, looked at 3D printing and shape-shifting technology, countering biological outbreaks, and the search for new elements.

Expanding Students' Horizons

LLNL continues to sponsor Expanding Your Horizons, held several times a year throughout the San Francisco Bay Area, to introduce STEM careers to middle- and high-school girls. The free events pair women scientists and engineers with students to conduct hands-on demonstrations of science and discuss career paths.

In addition, working with the Livermore Valley Joint Unified School District and the national Girls Who Code program, LLNL offers special workshops for middle- and high-school students to build skills in computer-aided design. This year's day-long event (for both boys and girls) was sponsored by the newly formed Livermore Lab Foundation (see p. 19). The Laboratory also partners with Las Positas College for an annual Science and Engineering Seminar Series, in which LLNL researchers present "behind the scenes" perspectives of how multidisciplinary science actually works. The seminars help to connect students to potential career paths.

HOME Campaign and Community Gifts

Employees and LLNS raised more than $3.8 million in the 2017 HOME (Helping Others More Effectively) campaign, an annual charitable drive that benefits community and nonprofit agencies in the Tri-Valley, San Joaquin Valley, and greater San Francisco Bay Area. Employees pledged almost $2.8 million, while LLNS contributed $1 million in matching funds.

In October, the Laboratory's Deputy Director for Science and Technology Patricia Falcone presented checks totaling $100,000 to the recipients of the 2017 LLNS Community Gift Program. LLNS received 71 applications requesting nearly $550,000. Thirty-seven applications were selected for awards serving children in Alameda, Contra Costa, and San Joaquin counties, with a focus on literacy; science, technology, engineering, and math education; and cultural arts. Other gifts focused on children, families, senior citizens, and individuals in need of assistance.

Partnerships in Education

Each summer, educators depend on LLNL's Teacher Research Academy to gain key skills they need to bring state-of-the-art science into their classrooms—from 3D printing and astrophysics to biotechnology and high-performance computing. In addition to training teachers from all over California, in FY 2017 LLNL hosted more than 500 students across the nation—at the Laboratory for internships and educational training.

WORKFORCE RECOGNITION

Acknowledging exceptional performance and expertise

Peers, stakeholders, and the broader scientific community recognize the achievements and high-quality work of Livermore's talented and innovative workforce. These awards are a testament to the value of LLNL's research and service to the nation—as well as neighboring communities.

Prestigious PECASE Honor

LLNL researchers Jon Belof and Eric Duoss received the Presidential Early Career Award for Science and Engineering (PECASE). Belof was honored for his work in phase transition dynamics and nonequilibrium systems. Duoss received his PECASE award for research in advanced materials and manufacturing combined with microarchitected design. Both Belof and Duoss volunteered substantial time to educational outreach.

NNSA Gold Award

Jay Zucca received an NNSA Distinguished Service Gold Award for his work in nuclear security and nonproliferation. Anne Harrington, deputy administrator for nuclear nonproliferation, presented this high honor.

National Academy of Engineering Membership

The National Academy of Engineering bestowed its highest honor, membership in the Academy, to retired Livermore senior scientist Charlie Westbrook, for his "pioneering development, applications, and leadership in chemical kinetic modeling to advance combustion science and technology."

Jon Belof and Eric Duoss

Jay Zucca

Charlie Westbrook

Félicie Albert

Tammy Ma

Kellie Glaser

DOE Secretary's Appreciation Awards

Fifteen LLNL employees were honored with Secretary's Appreciation Awards for their work on three teams: the Ebola task force, the Cancer Moonshot work, and Technology Convergence working group.

DARPA Program Manager of the Year

The Defense Advanced Research Projects Agency (DARPA) named engineer and physicist Vincent Tang as a Program Manager of the Year for 2016, recognizing him for leading a program involving multiple agencies.

Professional Society Fellows

The American Physical Society (APS) named Adam Bernstein, Omar Hurricane, Hui Chen, and James Trebes as fellows.

Chris Barty, National Ignition Facility (NIF) chief technology officer, was named a 2017 Fellow of the Institute of Electrical and Electronics Engineers.

The Optical Society selected physicist Manyalibo Matthews as a fellow.

Atmospheric scientist Ben Santer was selected a fellow by the American Meteorological Society.

Livermore mathematician Carol Woodward was named a fellow by the Society for Industrial and Applied Mathematics.

Professional Society Senior Members

Physicist Craig Siders was named a senior member of the Optical Society of America. He evaluates and develops laser technologies for future advanced photon sources and their applications.

Physicist Regina Soufli has been elected as a senior member of SPIE, the international society for optics and photonics.

APS Awards

Dmitri Ryutov won the James Clerk Maxwell Prize for Plasma Physics. The American Physical Society (APS) honored his "many outstanding contributions to the theoretical plasma physics of low- and high-energy-density plasmas, open and closed magnetic configurations, and laboratory and astrophysical systems."

Andrew MacKinnon was awarded the John Dawson Award for Excellence in Plasma Physics Research by APS's division of Plasma Physics. The award cited his pioneering use of proton radiography to reveal new aspects of flows, instabilities, and fields in high-energy-density plasmas.

Physicist Félicie Albert received the 2017 Katherine E. Weimer Award from APS's division of Plasma Physics. She was cited for developing and characterizing x-ray sources from laser-wakefield accelerators and Compton scattering gamma-ray sources.

Fabre Prize

Félicie Albert won the 2017 Edouard Fabre Prize for her contributions to the physics of laser-driven inertial confinement fusion and laser-produced plasmas. The prize is given by the European Cooperation in Science and Technology Network for Inertial Confinement Fusion.

Fusion Power Awards

The Fusion Power Associates Board of Directors presented NIF scientific diagnostic leader Joe Kilkenny with its Leadership Award for "leadership provided for inertial confinement fusion for nearly four decades."

The Institute of Electrical and Electronics Engineers' Nuclear and Plasma Sciences Society selected LLNL researcher Wayne Meier as the recipient of its 2016 Fusion Technology Award, recognizing his career of research and leadership advancing the science and technology of fusion power plants.

NNSA Defense Program Awards of Excellence

Eight teams of Livermore researchers and engineers and one individual were presented with the NNSA Defense Program Awards of Excellence. Brigadier General Michael Lutton, principal deputy administrator for Defense Programs, presented the awards.

ACM Best Paper Award

The technical program co-chairs at the 26th International Association for Computing Machinery (ACM) Symposium on High-Performance Parallel and Distributed Computing gave the Karsten Schwan Best Paper award to Livermore's Edgar A. León and collaborators from Virginia Tech University.

STEM Advocate of the Year

LLNL education outreach manager Joanna Albala was named the STEM (science, technology, engineering, and mathematics) Advocate of the Year by the Executive Council of the North Central Valley STEM Center. She was honored for going above and beyond in creating opportunities for students.

Workforce Game Changers

Kellie Glaser, program manager for the Livermore Laboratory Employee Services Association, received a 2017 Workforce Game Changers Award from *Workforce Magazine* for her efforts to engage LLNL's workforce through innovative programs designed to improve work-life balance.

Hutcheon Fellowship

LLNL's David Weisz was named by the Department of Homeland Security to receive the first Dr. Ian Hutcheon Post-Doctoral Fellowship. The fellowship honors the Livermore scientist who played a significant role in developing nuclear forensics.

Greenman Award

Julio Friedmann received the Greenman Award by the Greenhouse Gas Control Technologies conference series for his tireless efforts to promote carbon capture and storage, particularly at large scale.

Meeting of the New Champions

Tammy Ma was invited to the World Economic Forum's Annual Meeting of the New Champions in Dalian, China. Ma was one of 55 scientists from around the world that were invited to attend as part of the Young Scientists Class of 2017, honoring researchers under the age of 40 for their groundbreaking work.

Deputy Director for Science and Technology Patricia Falcone and Livermore Mayor John Marchand pose front and center with award recipients at the annual LLNS Community Gift Program ceremony at the LLNS office in downtown Livermore.

LAWRENCE LIVERMORE NATIONAL SECURITY, LLC

Overseeing management and operating the Laboratory for DOE/NNSA

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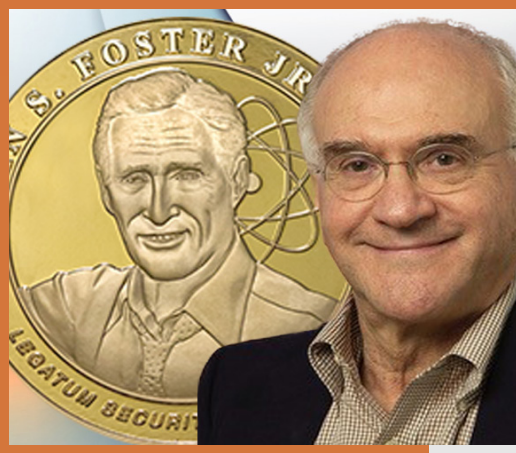
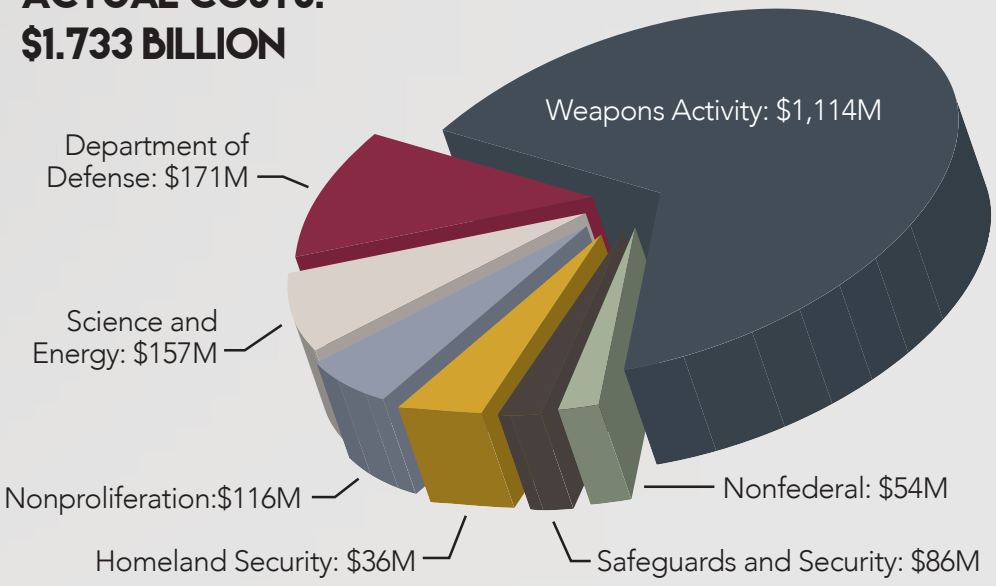


Foster Medal Awarded to Victor H. Reis

Current and former DOE Tri-Lab directors, colleagues, and contemporaries of Victor "Vic" Reis, the "architect" of the Stockpile Stewardship Program, gathered at the Laboratory on November 3, 2017, to honor him with the John S. Foster Jr. Medal. The award recognized Reis for his significant contributions to national security. His innovative leadership in science and technology and dedication to national service was particularly important for guiding the nation's nuclear program through an uncertain time of budget cuts and the end of underground testing. Reis is the third recipient of the Foster Medal.

LLNL FY 2017 ACTUAL COSTS: $1.733 BILLION



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