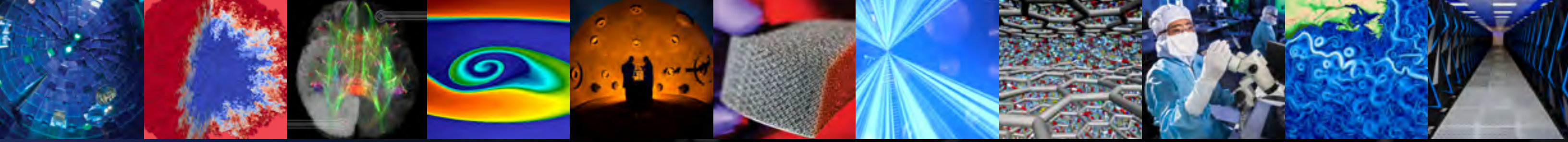
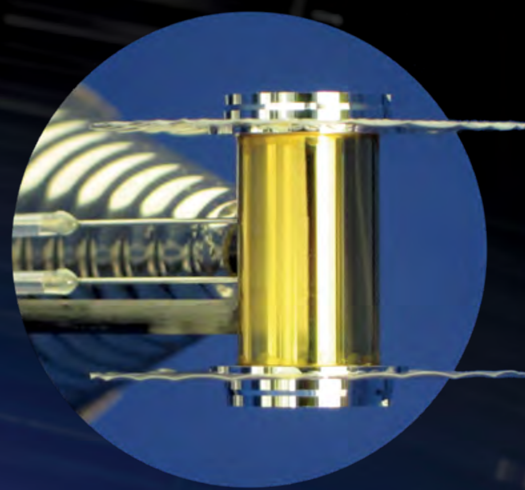
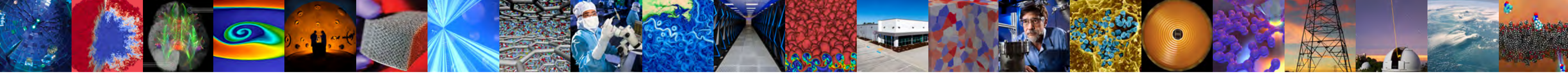


LAWRENCE LIVERMORE NATIONAL LABORATORY

FY 2019 ANNUAL REPORT



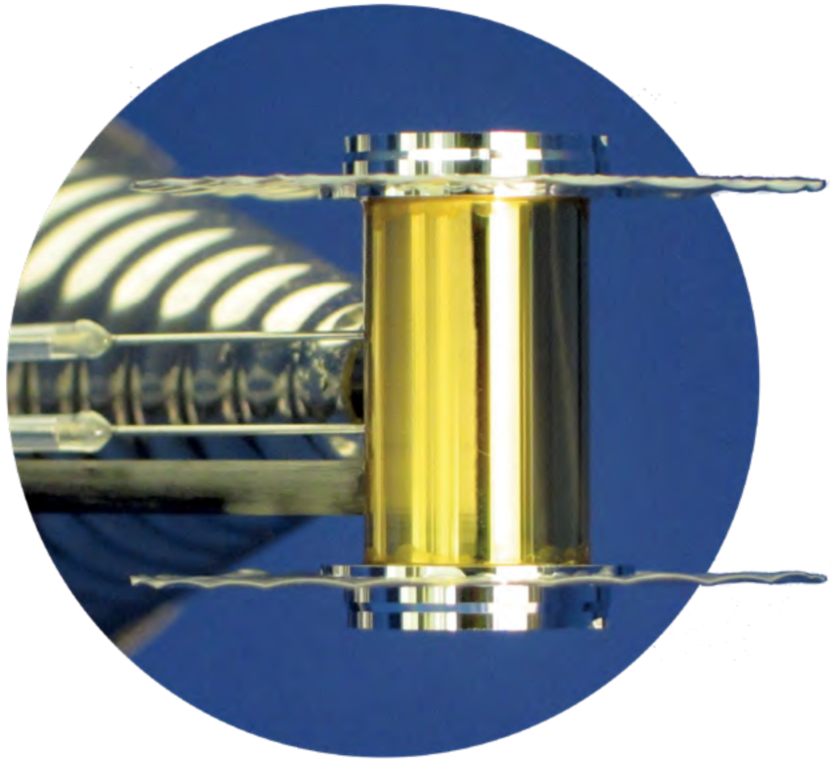
SCIENCE AND TECHNOLOGY ON A MISSION



ABOUT US

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).



ABOUT THE COVER

Fiscal Year (FY) 2019 marked the 10th anniversary of operations at the National Ignition Facility. The cover shows high-energy laser beams converging onto a tiny target to create the extreme conditions that exist inside giant planets, stars, and nuclear explosions. The precision-engineered target (above) is used to collect detailed data about material properties that are vital for NNSA's science-based Stockpile Stewardship Program and advance our understanding of the universe.

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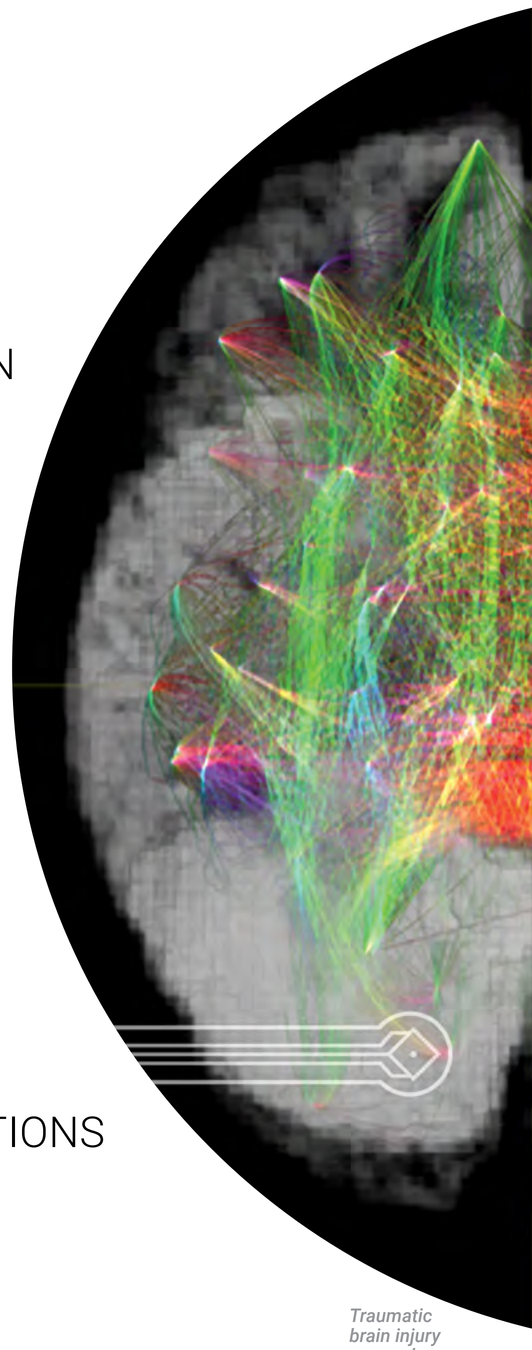
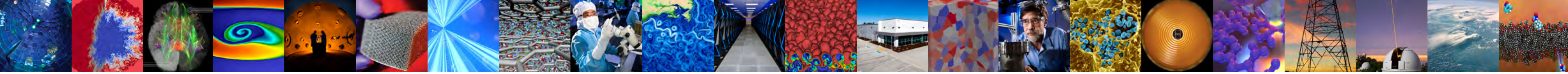
INSIDE FY 2019



Traumatic brain injury research



SCIENCE AND TECHNOLOGY ON A MISSION

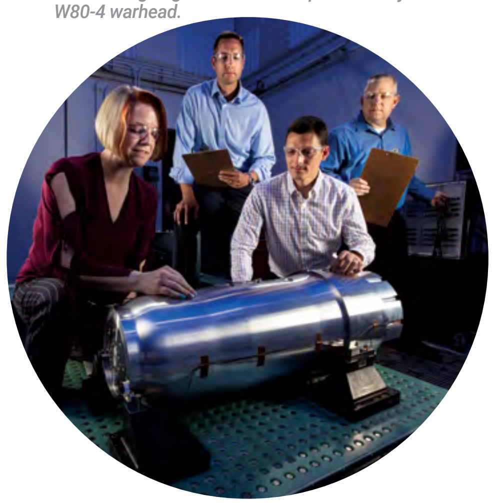
Lawrence Livermore National Laboratory had another exceptional year pushing the frontiers of science and technology to strengthen national security in a rapidly changing world.

LLNL Director William Goldstein

Our primary mission is nuclear deterrence. In support of the Department of Energy (DOE) and its National Nuclear Security Administration (NNSA), we provide special expertise and advanced scientific tools to meet the enduring need for a safe, secure, and effective U.S. nuclear weapons stockpile.

As an NNSA national security laboratory, we also apply our outstanding science and technology (S&T) to a larger set of important national needs. We provide expertise across the spectrum of weapons of mass destruction to enable high-confidence implementation of arms control, nonproliferation, and other threat reduction measures. We further strengthen deterrence more broadly as it intersects evolving threats in space, cyberspace, and missile defense. In addition, our Laboratory develops solutions for energy security and climate resilience and makes significant contributions to the fight against cancer and neural disorders.

LLNL is partnered with Sandia National Laboratories as the design agencies to develop and certify the W80-4 warhead.



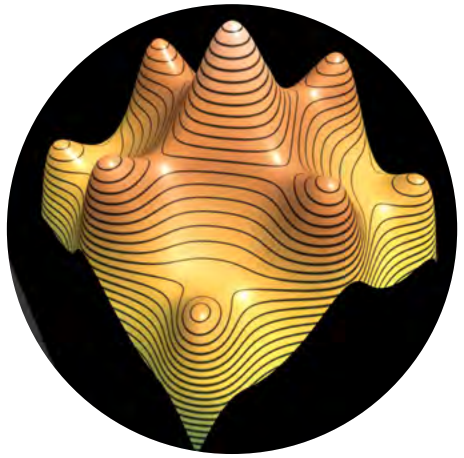
Our mission requires informed anticipation, constant innovation, and disciplined delivery to our sponsors. In FY 2019, we fully met our programmatic and operational responsibilities as we enhanced our S&T leadership in areas vital to our missions. This annual report highlights our many contributions to making the nation—and the world—safer and more secure.

A principal strength of our Laboratory is our heritage of innovation and multidisciplinary, mission-directed S&T. "Science and Technology on a Mission" has its roots in our founders' objectives and sets today's priorities. This precept of building on our history to make dramatic leaps forward was celebrated in a series of events held during a week in early August 2019.

Distinguished guests and Laboratory employees attended a ceremony to mark the National Ignition Facility's (NIF's) 10th anniversary of operations as a precise, reliable tool for high-energy-density (HED) science experiments. After a decade of service and more than 2,700 experiments, NIF still reigns as the world's most energetic laser. It is an indispensable tool for nuclear weapons stockpile stewardship. HED physics experiments at NIF are vital for validating computer simulation models, providing data to assure performance and modernize the stockpile, and training and testing the capabilities of the nation's stockpile stewards. Experiments are also making important progress toward achieving fusion ignition and enabling exciting discoveries in HED physics and astrophysics.

Later that week, contracts were signed with Cray, Inc., to build NNSA's first exascale supercomputer, El Capitan, to be sited at Livermore. The $600-million machine will sustain LLNL's leadership role in high-performance computing (HPC). Earlier in the year, the Laboratory brought into operation the Sierra supercomputer, currently the world's second most capable machine at less than one-tenth the anticipated speed of El Capitan. Sierra is routinely performing high-resolution 3D weapons physics simulations that were considered "heroic" calculations on previous supercomputers. The machine is a "game-changer."

The combination of supercomputer weapons physics simulations and NIF experiments to gather HED physics data and validate simulation models is crucial to modernizing the nation's nuclear stockpile. Lawrence Livermore and Sandia national laboratories are engaged in the design, development, certification, and bringing into production of the W80-4 warhead for the bomber-delivered Long-Range Standoff missile and the W87-1 for the U.S. Air Force's Ground Based Strategic Deterrent. For these weapons systems, we are focusing on design options that are amenable to cost-effective modern manufacturing methods.



Laboratory researchers are using machine learning to help interpret data.

Importantly, across a wide range of mission areas, we are applying machine learning–based artificial intelligence to integrate simulation, experiment, and enormous data sets to expedite discovery. Examples of groundbreaking applications include learning from and designing NIF inertial confinement fusion experiments, enabling early detection of nuclear proliferation activities, fighting cancer, and dramatically reducing the time required to develop new drugs.

LLNL staff and distinguished guests also celebrated the 40th anniversary of DOE's National Atmospheric Release Advisory Center (NARAC). The center operates 24 hours a day, 7 days a week, providing first responders with plume predictions and real-time assessments of hazardous atmospheric emissions. NARAC is one of Livermore's many "around-the-clock" advisory services and a fundamental part of energy and environment research. In this mission area, we have launched a new strategic initiative to develop technologies for global-scale removal and industrial use of carbon dioxide from the atmosphere.

Yet another celebration in August was the 65th anniversary of the Livermore Laboratory Employee Services Association (LLESA). The organization was founded at the initiative of early Laboratory employees to provide social and recreational activities. A nonprofit corporation, LLESA focuses on our Laboratory's most vital asset: our outstanding workforce. Its programs and services—ranging from a daycare center to dancing lessons—are convenient, enriching, and promote employee health and work–life balance.

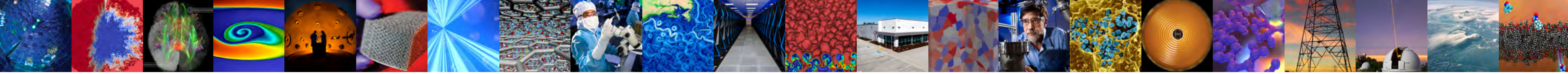
Livermore's accomplishments flow from a world-class workforce committed to our values of developing new ideas, making a difference, embodying integrity and inclusiveness, and loving the work. In 2019, Glassdoor recognized LLNL as one of the top 10 best places to work nationwide. More than 40 percent of our core staff has been hired in the last five years. To better understand our rapidly changing workforce, we conducted an employee culture and climate survey. The results will guide us in making improvements to the work environment.

An outstanding workforce is the Laboratory's principal strength. Our workforce is ever changing, and this year, special thanks go to Tom Gioconda who concluded his distinguished service as LLNL deputy director. Our thanks also go to our "veteran" employees for their remarkable successes and their mentoring of new staff. We welcome our new employees, who will carry forward LLNL's tradition of excellence in mission-focused S&T and exceptional service to the nation.

NNSA Administrator Lisa Gordon-Hagerty lauded NARAC at its 40th anniversary celebration.

THANK YOU, TOM!

In September 2019, Tom Gioconda announced he was stepping down as LLNL deputy director after nine years in this position and returning to Bechtel for a new assignment. Tom assisted three LLNL directors (and an acting director)—watching over day-to-day operations with attention to detail, a focus on continuous improvement, and vigilance in sustaining effective working relationships with sponsors. He helped us all to do our best in service to the nation. In every facet of his job, Tom brought his greatest strength: his people skills. For issues that arose, his approach was "Let's find a solution." Thank you, Tom, for your service!



NUCLEAR DETERRENCE

Ensuring the safety, security, and effectiveness of the nuclear 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 2019, LLNL completed Cycle 24 of the annual stockpile assessment. The process included a formal comprehensive peer review by the nuclear design laboratories (Livermore and Los Alamos) of each other's weapons systems. Laboratory scientists continue to improve the predictability of physics and engineering simulation codes that support the annual assessments and certification of weapons. LLNL completed all planned milestones for weapons surveillance activities and performed associated testing and analyses to assess the condition of and sustain the B83, W78, W80, and W87 stockpile systems.

Leaders of the W87-1 Modification Program Team pose with a model of the ballistic-missile reentry vehicle that will carry the newly manufactured warhead.

THE W80-4 AND W87-1 PROGRAMS

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), which transitioned from Phase 6.2A to Phase 3 (engineering development) in February 2019. Efforts are directed toward executing detailed plans, prepared in Phase 6.2A, for all development activities from design and certification to the end of production at the NNSA plants. The project team has finalized most of the major design decisions about the nuclear explosives package (NEP). The plans to refurbish or replace aging components and materials include use of new manufacturing methods that minimize costs, increase throughput, and reduce the need for environmentally sensitive materials and processes.

In FY 2019, the Laboratory also restarted Phase 6.2 (program feasibility) work on the W87-1 modification program, which will support deployment of the U.S. Air Force's Ground Based Strategic Deterrent by 2030. LLNL is NNSA's design agency for the NEP for a ballistic-missile warhead to replace the aging W87-0. The W87-1 will be the first modern warhead that is 100 percent newly manufactured. The design will have a strong nuclear test–based pedigree. Activities are focused on technology maturation and design options amenable to modern manufacturing methods. The W80-4 and W87-1 programs require the full array of NNSA's computational, experimental, and manufacturing capabilities to meet all the prototyping, proof-of-concept testing, and certification requirements.

SIERRA SUPERCOMPUTER IN OPERATION

In October 2018, NNSA, LLNL, and industry partners officially unveiled Sierra at a dedication ceremony. The IBM/NVIDIA supercomputer has reached 94.6 petaflops (quadrillion floating-point operations per second) in a benchmark test, placing it as the world's second fastest supercomputer on the TOP500 List. This latest NNSA Advanced Simulation and Computing (ASC) Program machine makes possible higher fidelity, more predictive simulations of weapons performance, and it provides the ability to run large ensembles of simulations to quantify uncertainties in predictions. After a period of shake-out and testing codes, Sierra became generally available for classified use at the end of April.

Sierra achieves its extreme speed by using NVIDIA graphics processor units together with IBM central processing units in a heterogenous architecture. The years of work by LLNL computer scientists preparing codes to run efficiently on the new architecture paid off. Simulations of high importance for classified work are running more than 10 times faster than with a homogeneous architecture on a per node basis. Sierra is providing vital support to the W80-4 LEP by making routine what had been "heroic" high-resolution, 3D simulations. The machine is proving to be a "game changer" for the NNSA laboratories. The success of Sierra raises expectations even higher for what will be possible with El Capitan (see the box below).

NNSA'S FIRST EXASCALE COMPUTER: EL CAPITAN

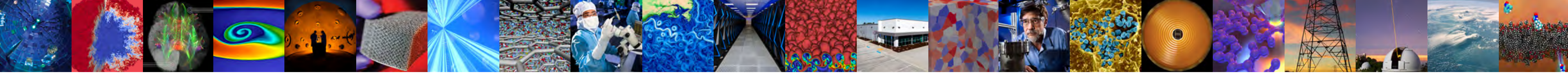
In August, DOE, NNSA, and LLNL announced the signing of contracts with Cray Inc., to build El Capitan, NNSA's first exascale supercomputer. El Capitan's expected peak performance is more than 1.5 exaflops (quintillion floating-point operations per second). To be delivered in late 2022, the $600-million supercomputer will run complex simulations roughly 10 times faster than Sierra and operate with 4 times higher energy efficiency. It will support projects at the three NNSA national laboratories.

Researchers in the High Explosives Applications Facility

STOCKPILE STEWARDSHIP EXPERIMENTS

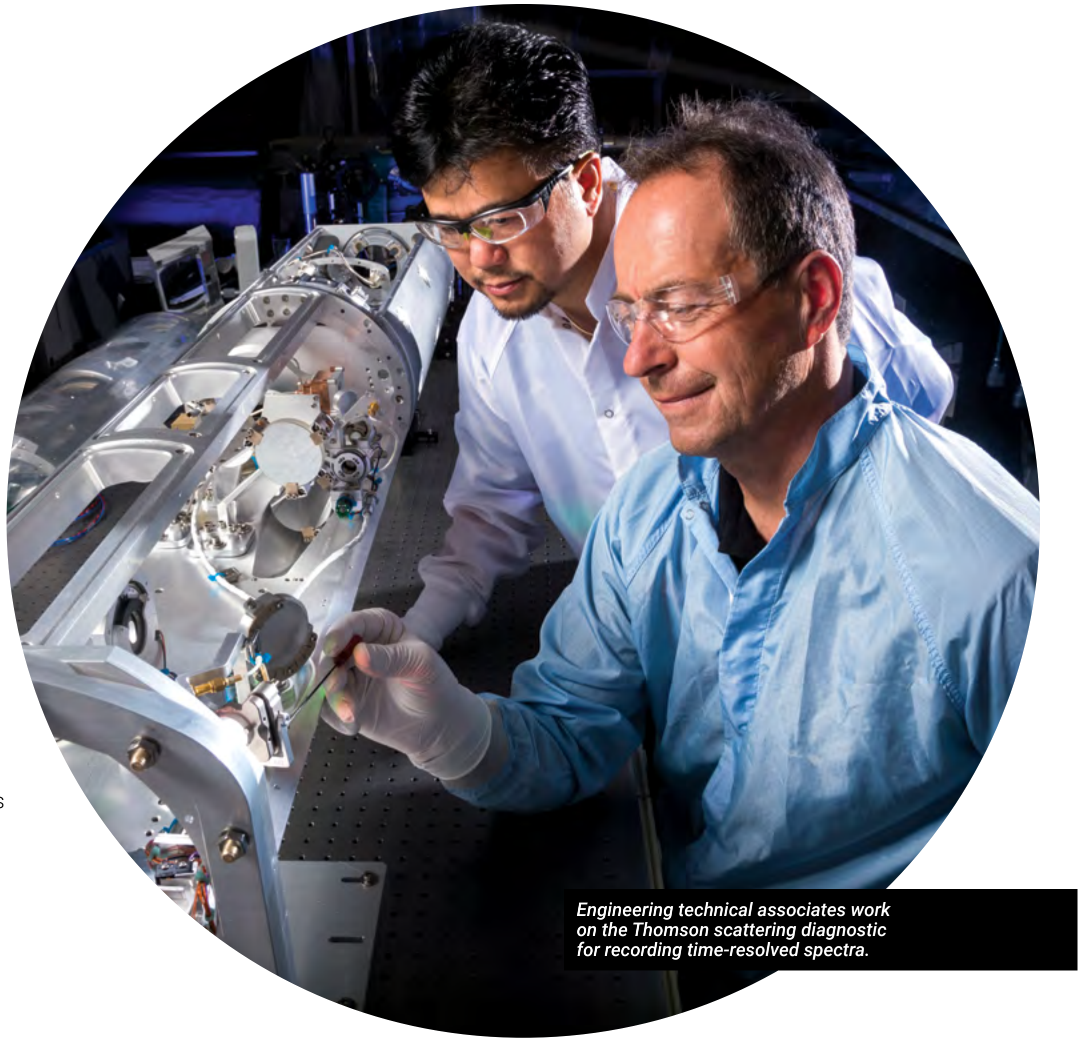
In FY 2019, LLNL performed more than two dozen experimental campaigns at remotely located Site 300, including about 20 hydrodynamic experiments fired in the Contained Firing Facility (CFF). Several key shots in CFF supported downselect decisions for the W80-4 LEP and another national security program. Livermore also successfully executed its first subcritical experiment since 2003. Conducted at the Nevada National Security Site in collaboration with Los Alamos and the Atomic Weapons Establishment, the test yielded high-quality data in support of stockpile safety. Many more experimental activities are underway at LLNL's High Explosives Applications Facility and Site 300 to qualify and remanufacture additional insensitive high explosives to be used in the refurbished W80-4 warheads.

Tests at the Joint Actinide Shock Physics Experimental Research (JASPER) Facility and the National Ignition Facility (see p. 6) provide essential data about plutonium and other materials at extreme conditions. Experiments at JASPER in FY 2019 collected high-precision data about shock-compressed plutonium.



NATIONAL IGNITION FACILITY

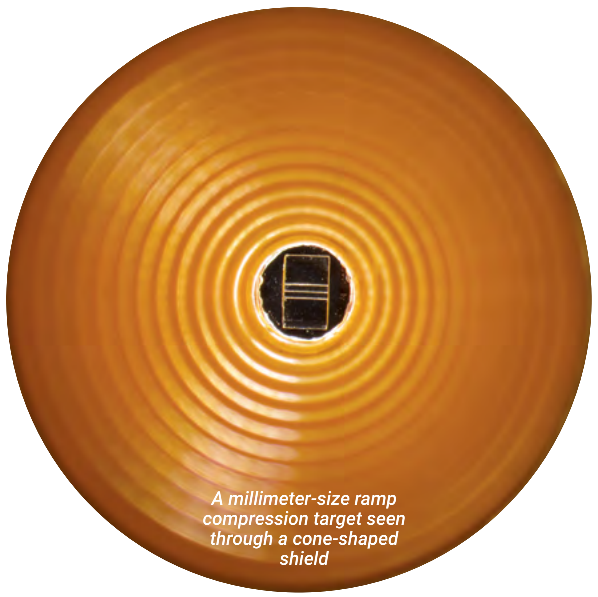
Supporting stockpile stewardship through a wide range of experiments and pursuit of laser fusion ignition, and operating as a national user facility for high-energy-density science



Engineering technical associates work on the Thomson scattering diagnostic for recording time-resolved spectra.

STOCKPILE STEWARDSHIP HED SCIENCE EXPERIMENTS

National Ignition Facility (NIF) high-energy-density (HED) science experiments in FY 2019 provided crucial support to the W80-4 life-extension program. These tests helped weapons designers evaluate replacement options for aged materials in the W80 warhead that meet high standards for safety, security, and effectiveness. Such experiments will also be vital to the success of the W87-1 modification program (see p. 4). Moreover, HED science experiments at NIF explore wide-ranging physical phenomena central to stockpile stewardship. Many tests jointly address challenges arising in stockpile modernization, the pursuit of inertial confinement fusion (ICF) ignition, and developing a deeper understanding of physics issues pertinent to stockpile stewardship. The shots provide information about the properties of materials at extreme conditions, radiation hydrodynamics and transport, thermonuclear processes, and material mixing. The data are used to improve and validate 3D simulation models of weapons performance.



A millimeter-size ramp compression target seen through a cone-shaped shield

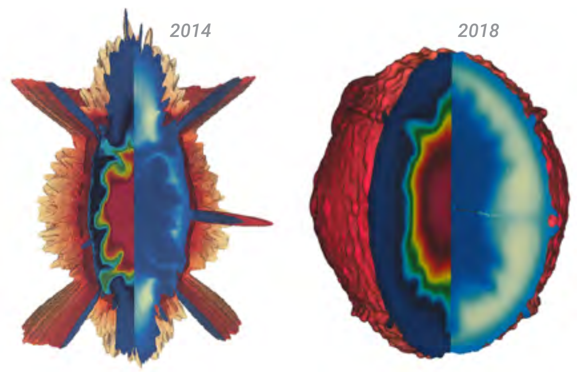
RAMPING-UP PRESSURE ON MATERIALS

In FY 2019, Laboratory researchers made significant advances in capabilities to perform ramp compression experiments. Ramp compression is important to several types of HED materials science experiments: equation of state (EOS), x-ray diffraction to study crystalline structure, and material strength. In these experiments, x rays from a laser-heated holhraum gradually compress a material sample so that it remains relatively cool as it is squeezed to extreme pressure conditions—up to 50 megabars for diamond. Materials now being tested range from diamond and iron (for planetary science) to materials of special interest for stockpile stewardship. In April 2019, researchers conducted the first ramp compression experiment with plutonium-242 (a low-radioactivity isotope).

For EOS experiments, the principal diagnostic is line-imaging VISAR (Velocity Interferometer System for Any Reflector), invented by Sandia National Laboratories (SNL) in the 1970s and matured at LLNL for NIF. In 2019, a joint LLNL–SNL team successfully commissioned a line-imaging diagnostic at Sandia's Z Pulsed Power Facility, where high magnetic fields and electrical currents compress targets to HED conditions. Technology transfer of the diagnostic was challenging because of space constraints and the Z machine's more difficult operating environment.

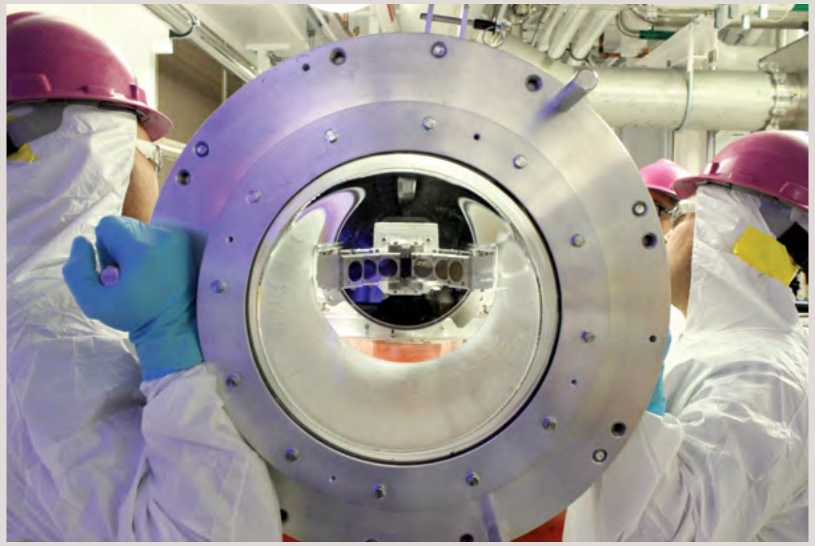
PROGRESS IN PURSUING FUSION IGNITION

Achieving fusion ignition and energy gain at NIF is a grand scientific challenge. Significant progress is being made through a combination of data from experiments, greatly improved 3D simulations, and machine-learning (ML) techniques. Using the data from many target implosion simulations, an LLNL-developed leading-edge ML tool is able to determine the range of simulation input parameters that reproduce the measured results from any selected past experiment. With this information, scientists have identified principal barriers to achieving ignition and can better gauge uncertainties. Importantly, this new capability to fuse experiments, high-fidelity simulations, and ML helps guide decisions about target design, future experiments to conduct, and upgrades to codes and diagnostics.



Improvements in ICF capsule implosions replicated in 3D simulations

Scientists are examining ways to make high-velocity implosions more spherical. To better manage problematic laser–plasma instabilities, researchers are combining improvements in the design of the fuel capsule and the surrounding hohlraum, proper pulse shaping and beam energy balance, and to the extent possible, increased NIF laser energy. The NIF team must also reduce hydrodynamic instabilities in the imploding capsule and the mix of materials into the fuel's central hot spot. To this end, engineers from LLNL and General Atomics developed and tested a fill tube 2 micrometers in diameter. The 10-micrometer-diameter fill tube has been a significant source of hot-spot degradation. Engineers are also exploring ways to produce more uniform capsules to reduce instabilities and jets of materials into the hot spot. As for diagnostic improvements, the advanced radiographic capability (ARC) short-pulse, high-intensity laser obtained the first radiographic images of an imploded fuel and shell. The images confirmed the presence of low-mode asymmetries, which had been inferred from other detectors.

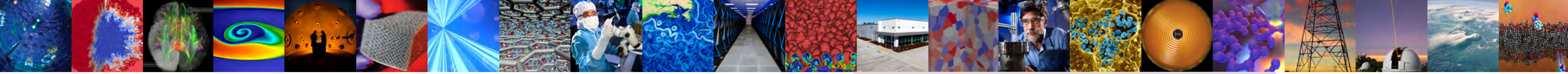


NUCLEAR SURVIVABILITY OF COMPONENTS

Target area operators remove a diagnostic assembly with six samples after a test. NIF provides a critical capability for testing the survivability of components from nuclear weapons and other military assets that may face real-world nuclear environments. Researchers subject parts, such as electronics, and other materials to intense doses of x rays and neutrons, and in other experiments, they probe material properties at extreme pressures and temperatures.

DISCOVERY SCIENCE AT NIF

Discovery Science experiments at NIF provide unique opportunities to answer challenging questions about HED science and advance knowledge in nuclear physics, plasma physics, materials science, and astrophysics. In many cases, experiments have required development of new types of diagnostics that have become very useful for national security applications or have led to significant scientific breakthroughs. In FY 2019, LLNL researchers and collaborators published results of proton-acceleration experiments in the journal *Physics of Plasmas*. Using NIF and ARC, the team produced beams of protons with 10 times more energy than expected—14 to 18 million electronvolts. Such beams can be precisely targeted on materials and provide new ways for studying extreme states of matter, such as that found in stellar and planetary interiors. Proton acceleration has potential for many other applications in HED science and ICF research.



GLOBAL SECURITY

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

A highly trained team of operations scientists, engineers, and technicians maintains NARAC's ability to provide round-the-clock atmospheric monitoring capabilities.

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

NUCLEAR NONPROLIFERATION ANALYSES AND EXPERIMENTS

Laboratory researchers are developing new deep-learning and high-performance computing algorithms that sift through massive amounts of data for evidence of nuclear proliferation activities. Advanced Data Analytics for Proliferation Detection (ADAPD), a five-laboratory effort led by LLNL, is aimed at improving early detection of nuclear proliferation activities. ADAPD pushes the limits of deep learning by using neural networks to "map" images, text, and video into a feature space. All relevant data is categorized based on how it relates to the processes involved in building a nuclear weapon. ADAPD will make it easier for analysts to evaluate evidence of proliferation activities by prescreening millions of images and hundreds of videos.

An LLNL computer scientist leads application of deep learning to nonproliferation analyses.

In addition to building more sophisticated analysis tools, Livermore scientists are conducting high-explosive experiments to improve the nation's ability to detect and identify low-yield nuclear explosions. The tests are part of the multilaboratory Source Physics Experiments and the Low-Yield Nuclear Monitoring venture, which LLNL manages for NNSA. In FY 2019, Livermore carried out experiments at Site 300 and the Nevada National Security Site for these programs.

NARAC CELEBRATES 40 YEARS OF SERVICE

In August 2019, the National Atmospheric Release Advisory Center (NARAC) celebrated its 40th anniversary. NARAC serves as DOE's plume-modeling center for real-time and predictive assessments of atmospheric releases of nuclear, radiological, chemical, biological, and hazardous natural materials. The first emergency call came to NARAC (then ARAC) following the accident at the Three Mile Island nuclear power plant. The team worked around the clock for the next 10 days to generate maps that were used to determine the impact of the radiological material released.

This year, subject matter experts from LLNL emergency response programs, including NARAC and the Radiological Assistance Program (RAP) Region 7, participated in multiple real-world missions. NARAC staff provided monitoring support in response to the fire at the Susana Field Laboratory, and RAP team members were deployed to collect field samples, some of which were returned to and analyzed at LLNL. NARAC also assessed actual and potential contamination during the Hanford Plutonium Finishing Plant demolition project. For this effort, NARAC put into operation its recently developed high-resolution computational urban dispersion model.

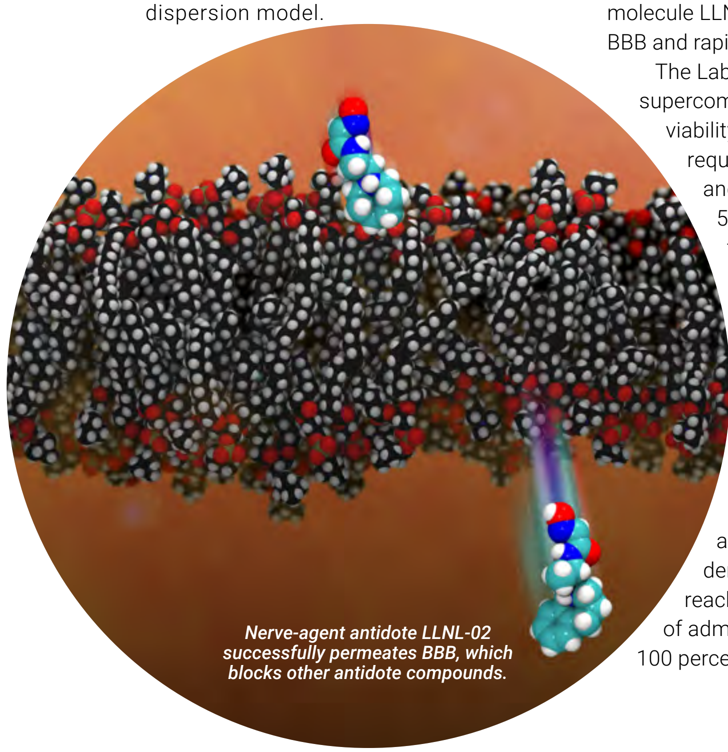
LLNL'S NEXT-GENERATION NANOSATELLITE

Launched in December 2019, the MiniCarb cube satellite or "CubeSat" features a next-generation CubeSat bus developed at Livermore. The nanosatellite carries an instrument for measuring the concentration of greenhouse gases in the Earth's atmosphere at specific altitudes of interest. Pursued in collaboration with NASA's Goddard Space Flight Center, the project is part of a growing Space Science and Security Program at the Laboratory.

PENETRATING THE BLOOD–BRAIN BARRIER

LLNL researchers are developing innovative countermeasures to biological and chemical agents and disease. The team is particularly focused on drugs that could permeate the blood–brain barrier (BBB), which protects the brain by separating its blood supply from foreign fluids in the central nervous system. In an important breakthrough, they found a promising candidate antidote to counter nerve agents, molecule LLNL-02, which is able to cross BBB and rapidly reach the brain.

The Laboratory is using its supercomputers to test antidote viability. Each potential drug requires hundreds of simulations, and each simulation involves 5 quadrillion equations. In tandem, Laboratory scientists synthesize selected compounds and test them for BBB permeability to validate simulation results. LLNL-02 successfully passed toxicology tests at the U.S. Army Medical Research Institute of Chemical Defense. At Livermore, initial in vivo animal tests of LLNL-02 have demonstrated that the molecule reaches the brain within 5 minutes of administration and provides a 100 percent survivability rate.

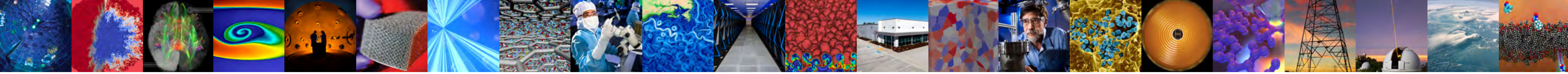


Nerve-agent antidote LLNL-02 successfully permeates BBB, which blocks other antidote compounds.

Laboratory researchers have also developed and tested an artificial BBB, which will contribute to LLNL's iCHIP (in vitro chip-based human investigational platform) project. Using iCHIP technology, researchers can test new pharmaceutical drugs to treat neurological disorders without the need for human or animal subjects. The Laboratory's "brain-on-a chip" is a microelectrode array that listens to bursts of electrical energy emitted by neural cells living on a chip when communicating with each other. It has been used to analyze rodent brain cells' electrical activity and the physiological responses of cells on the platform for up to 30 days. Efforts are underway to validate the technology and demonstrate that the cells on the engineered platforms can generate human-relevant data.

FORTIFYING THE POWER GRID

LLNL researchers launched the Quantitative Adversary Risk Assessment (QIARA) project to model power outages. QIARA, affectionately called "Squirrel," aims to develop a powerful tool for identifying weaknesses in the power grid. Squirrel combines with the LLNL-developed open source grid simulator (GridDyn) to determine points of failure in the grid that could cascade into major, long-term blackouts. Identification of these points and their potential impact will help government agencies and utilities prioritize investments to increase grid resilience against cyberattackers, hackers, and mischievous squirrels.



ENERGY AND ENVIRONMENT

Using science and technology to improve national energy security, protect the environment, and understand and mitigate climate change

A Livermore materials scientist checks the performance of a methane flow-through device for a 3D-printed reactor containing genetically modified microbes.

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

ENGINEERING THE CARBON ECONOMY

LLNL is pursuing a strategic initiative to capture, sequester, and convert carbon dioxide (CO_2) to useful products and fuels. The work builds on LLNL's development of a novel carbon-capture technology that uses CO_2 sorbents in microcapsules to collect effluent carbon from power plants and smaller facilities. In the case of biogas-generating facilities such as sewage digesters, a mixture of CO_2 and methane is produced. By removing CO_2 with microcapsules, the resulting pure methane (natural gas) can be used as a renewable fuel or to make specialty chemicals.

A scientist collects core samples to determine carbon content.

Laboratory scientists are developing modular electrochemical reactors that use electricity to efficiently convert CO_2 to valuable chemicals. Guided by computer models that span atomic to macro scales, the researchers are optimizing the catalytic process through control of the local reaction environment and by designing 3D microstructures of metal catalysts and other materials.

Another LLNL research team is working on more efficient ways to convert methane into useful products. The team is using metanotrophs—genetically modified microbes that convert methane to organic acids—to "print" bacterial microbes in the polymer walls of 3D-printed chemical reactors. Other Laboratory researchers are exploring approaches for returning carbon to soil in long-lived forms to reduce atmospheric CO_2 and make farmland more productive.

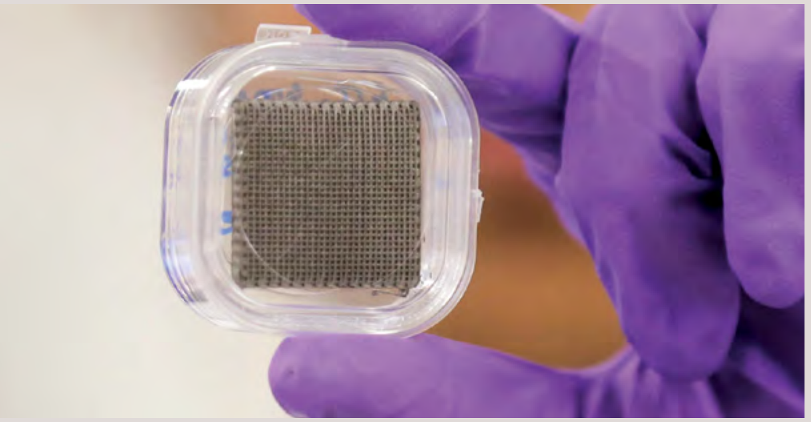
NEW INSIGHTS INTO CLIMATE CHANGE

In March 2019, climate scientists at LLNL announced the release of new data sets for the international community to analyze and enhance understanding of climate change. These new data sets, based on next-generation simulations performed at Livermore and other climate research centers, significantly contribute to the Coupled Model Intercomparison Project, now in it its 6th phase (CMIP6). The project's goal is to define standard simulations that can be compared to gain new insights into climate change. LLNL researchers have helped lead CMIP activity since the effort's inception 20 years ago, providing day-to-day coordination, developing software, and helping to set requirements. Livermore also provides leadership for DOE's development of the E3SM next-generation Earth system model, which was used for some of the CMIP6 core simulations.

This year, Livermore researchers and collaborators published work to refine an evaluation technique (called emergent constraints, or ECs) that is used to bound uncertainties in climate predictions. ECs arise from general agreement in a prediction (e.g., seasonal cycles in temperature) across an ensemble of climate models—but the prediction may be valid or an artefact of the simulations. The authors describe methods to substantiate validity (e.g., identification of a plausible mechanism) and improve predictions through effective use of confirmed ECs together with the increasing amounts of high-quality observation data being gathered.

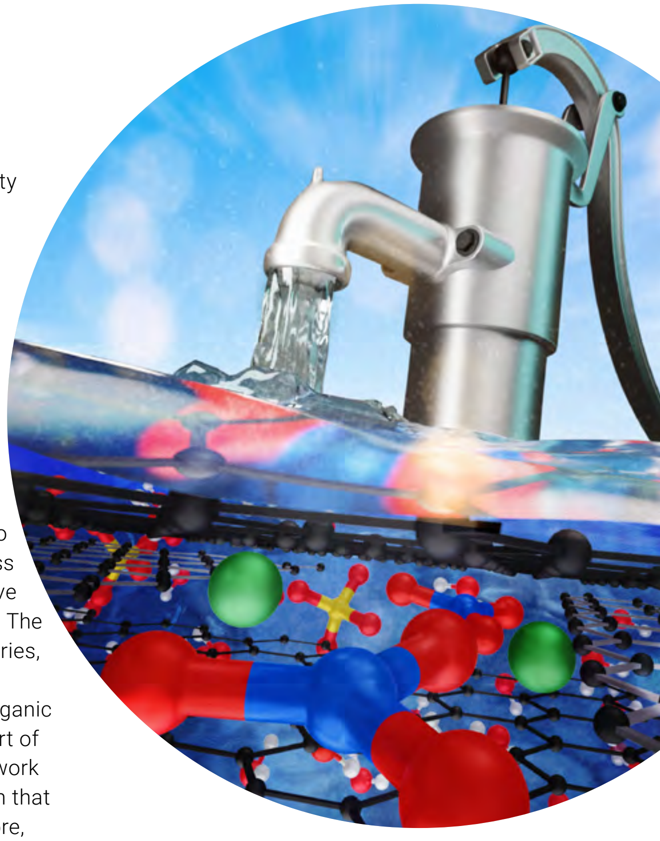
PARTNERSHIPS TO ENHANCE U.S. INDUSTRY

In FY 2019, DOE's Advanced Manufacturing Office announced the 8th round of new awards in its High-Performance Computing (HPC) for Manufacturing program (now part of the larger HPC for Energy Innovation program). Laboratory researchers are working on a project to optimize operating conditions in a glass manufacturing process using radiative transport methods developed at LLNL. The Laboratory is also helping PPG Industries, Inc., by using molecular dynamics calculations to determine if certain organic molecules can inhibit corrosion as part of the HPC for Materials program. This work will be applied to training an algorithm that predicts corrosion. Lawrence Livermore, in partnership with Lawrence Berkeley and Oak Ridge national laboratories, has led these industry-outreach programs for DOE since their inception in 2015.



A RECORD-BREAKING SUPERCAPACITOR

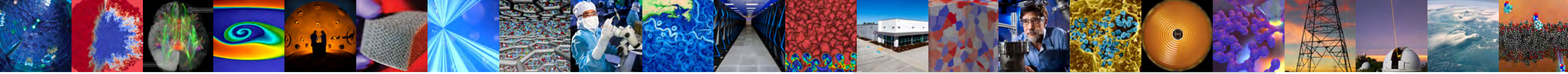
Researchers from LLNL and the University of California at Santa Cruz have created 3D-printed electrodes for supercapacitors capable of achieving record-breaking performance. The porous graphene aerogel structures support ultrahigh levels of manganese oxide for chemical storage of electric charge. The resultant supercapacitor has the highest recorded electric charge stored per unit area recorded to date. The breakthrough opens avenues to using supercapacitors as ultrafast-charging power sources for devices such as cell phones, laptops, and other small electronics.



Using capacitive deionization, nitrate is adsorbed into carbon slit pores (black) less than 1 nanometer in size.

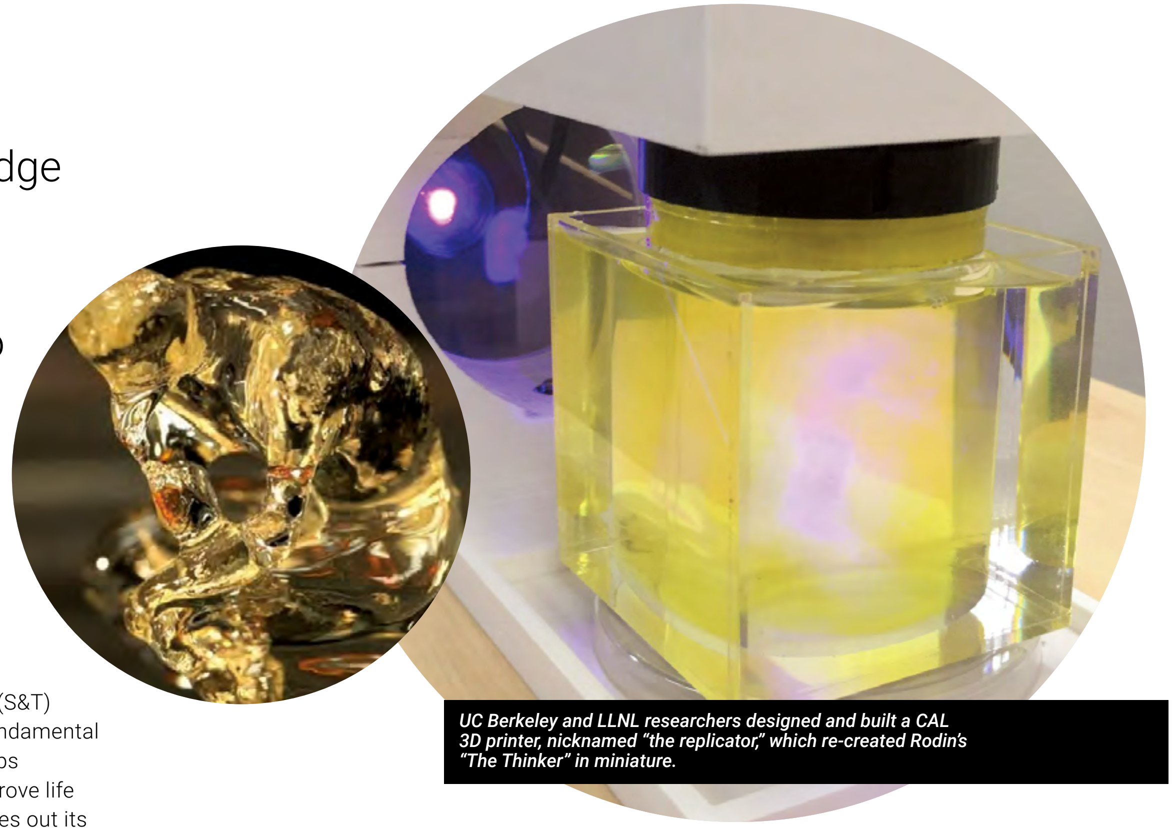
FRESHENING UP CONTAMINATED WATER

Researchers from LLNL and Stanford University have developed a technology that can remove nitrate from water selectively, preserving beneficial minerals and dramatically reducing the cost of treatment compared with other purification methods. The contamination of water resources with nitrate is a growing significant problem. In agricultural regions, many wells exceed the Environmental Protection Agency's limit for nitrate in drinking water due to runoff of fertilizer. The research team focused on capacitive deionization (CDI), a water treatment technology that can be used to remove salt from brackish water. CDI electrodes—made from ultramicroporous carbon with less than 1-nanometer-size pores—are perfect for removing nitrate molecules in fertilizer. The team conducted tests on runoff containing chloride, sulfate, and nitrate and demonstrated selective adsorption of nitrates. They also performed high-fidelity molecular dynamics simulations to confirm the experimental results and better understand the mechanisms involved.



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



UC Berkeley and LLNL researchers designed and built a CAL 3D printer, nicknamed "the replicator," which re-created Rodin's "The Thinker" in miniature.

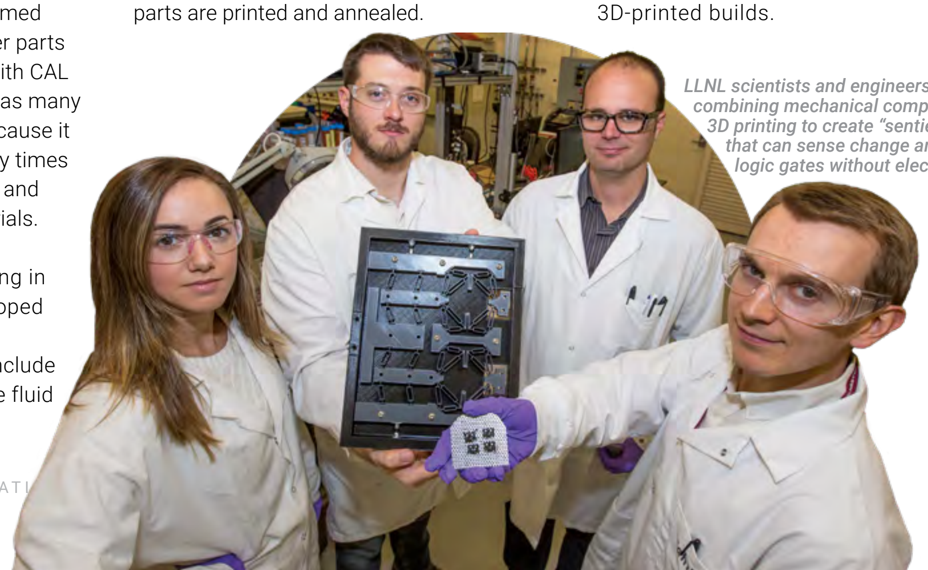
With its science and technology (S&T) capabilities, Livermore makes fundamental discoveries about nature, develops innovative technologies that improve life and drive the economy, and carries out its mission to improve national security.

ADVANCES IN ADDITIVE MANUFACTURING

A breakthrough technology developed by a University of California (UC) at Berkeley–Livermore team creates an entire 3D part at once. Like computed tomography in reverse, the process is called computed axial lithography (CAL). A projector beams a series of computer-generated images into a container of photosensitive syrup-like resin while the container rotates. After a few-minute exposure, the fluid is drained, leaving behind a complete, fully formed 3D object. Uniquely shaped polymer parts can be made much more quickly with CAL than layer-by-layer methods. CAL has many potential industrial applications because it is easy to use, less expensive, many times faster than existing 3D techniques, and amenable to a wide range of materials.

Livermore made many other advances in additive manufacturing in FY 2019. LLNL researchers developed "field-responsive mechanical metamaterials" (FRMMs), which include a viscous, magnetically responsive fluid that is injected into the hollow struts and beams of 3D-printed lattices. FRMMs are a new class of metamaterials that can almost instantly respond and stiffen into 3D-printed structures when exposed to a magnetic field. They could be applied to next-generation helmets, wearable armor, and many other applications. An LLNL–UC Davis team developed techniques to reduce effective residual stress in 3D-printed metal parts by 90 percent. By using laser diodes, originally developed for the National Ignition Facility, temperature gradients and cooling rates can be better controlled as parts are printed and annealed.

A Livermore–UCLA team developed 3D-printed mechanical logic gates that could be printed onto materials, allowing them to respond to environmental changes such as temperature, pressure, and radiation, creating "sentient" materials. Livermore researchers also created the first research-grade, open-architecture multibeam metal 3D printer. They are developing advanced diagnostics to better understand the mechanics behind the multibeam process. These multibeam systems will help increase the size and speed of 3D-printed builds.



LLNL scientists and engineers are combining mechanical computing with 3D printing to create "sentient" materials that can sense change and control logic gates without electricity.

50-YEAR-OLD BETA DECAY PUZZLE SOLVED

An international team including Livermore scientists found the answer to a 50-year-old puzzle. Beta decays of atomic nuclei are slower than expected due to correlations and interactions between two nucleons. The findings fill a long-standing gap in physicists' understanding of beta decay (when protons inside atomic nuclei convert into neutrons or vice versa), a key process stars use to create heavier elements. For decades, experimental measurements of beta decay did not match theoretical predictions. Combining modern theoretical tools with advanced computation, the team reconciled the discrepancy for a considerable number of nuclei.

INNOVATIVE NANOMATERIALS

Manipulating matter at the atomic and molecular levels allows scientists to optimize material properties for applications ranging from energy or information storage to biomedical technologies. In FY 2019, Livermore researchers and their partners studied spiders to learn how silk nanostructure feedstocks are assembled within glands to produce silk, a biomaterial with a tensile strength similar to steel wire of the same thickness. This knowledge could lead to the development of artificial silks for use in biomedical, architectural, and mechanical applications. Another research team developed synthetic solid-state nanopores that can discriminate between sodium and potassium ions, which are similar in size. These nanoporous materials function much like the biological channels that allow a neuron to fire, and they could one day be used to repair damaged living tissue.

New research by Livermore scientists shows that solar cell efficiency can improve by using metal nanowire meshes that provide high transmissivity and electrical connectivity. The experimental results of an international team that included LLNL scientists may help increase the energy efficiency of smart phones and enable more data storage. They examined at the atomic level how phase-change materials, used in modern smart phones, transition from glassy to crystalline material states to store information. The knowledge gained can be applied to better optimize materials. Finally, a Livermore team developed a new class of metals that makes possible many applications in electronics and electrical wiring. In the past, as metal strength increased, electroconductivity decreased. These new materials, micro-alloys of copper and silver, have high tensile strength and high electroconductivity.

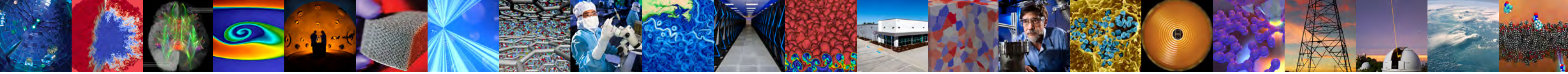
PARTNERING TO FIGHT CANCER

A Livermore-led team was awarded Best Paper at the SC19 supercomputing conference in November 2019 for work sponsored by DOE and the National Cancer Institute. A first-of-its-kind multiscale simulation predictively modeled the dynamics of RAS proteins—a family of proteins whose mutations are linked to more than 30 percent of all human cancers. Scalable to next-generation supercomputers, the Multiscale Machine-Learned Modeling Infrastructure built by the team simulates the interaction between RAS proteins and eight kinds of lipids at the macroscale, as well as on a molecular scale. Importantly, a machine-learning (ML) algorithm saves a vast amount of compute time by determining which lipid "patches" are interesting enough to more closely examine with micromodel simulations. The generated predictions will be tested experimentally, with results feeding back to further improve the ML model.

High-performance computing (HPC), ML, and big-data analytics are also central to work LLNL is performing with the Cancer Registry of Norway (CRN). One focus of the U.S.–Norwegian partnership is combining CRN's vast amount of data from a broad range of cancer types and using the data to develop algorithms to predict cancer occurrence and five-year survival rate.

In one of many experimental efforts, a team of Livermore scientists developed a way to determine how many cancer cells are required to initiate a tumor in another part of the body. Metastatic cancer is generally incurable and accounts for the majority of cancer-related deaths. Understanding the molecular and biological basis of metastasis is essential for conquering it. Their method uses the Laboratory's accelerator mass spectrometer, which can detect a single cancer cell among a million noncancer cells.

Researchers use biological accelerator mass spectrometry to study metastatic cancer.

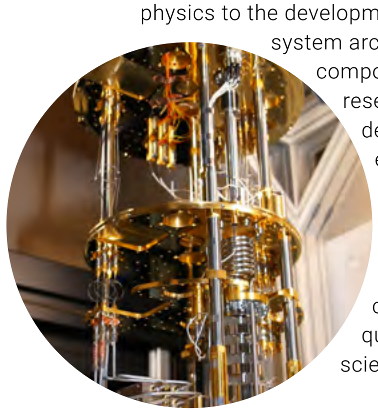


SCIENCE AND TECHNOLOGY

CUTTING-EDGE SUPERCOMPUTING

Seven of the world's top 100 computer systems (according to the TOP500 List) are located at LLNL. They are applied by researchers to address the Laboratory's challenging missions and advance S&T. Ranked No. 2 and No. 10, Sierra and its quarter-size unclassified companion, Lassen, are setting the path toward exascale computing (see p. 5). Their hybrid architecture features significant reliance on graphics processing units, which demands major changes to system-supporting software (see the R&D100 awards on p. 15) and simulation codes. One example is LLNL researchers' performance optimization of Cardioid, a code that simulates the electrophysiology of more than 400 million cells in a beating human heart. Cardioid is being readied for virtual drug screening and clinical applications. In 2019, Livermore also accepted delivery of Corona, a new HPC cluster that will provide unique capabilities for the Laboratory and industry partners to explore data science, ML, and big data analytics. Laboratory researchers are scaling ML algorithms for use on its HPC systems. They are applying ML to scientific analysis problems with large data sets such as detecting illicit nuclear proliferation activities by analyzing Internet data as well as big data problems in inertial confinement fusion and protein biology.

LLNL is also home to two quantum computing system testbeds—one for quick tests and prototyping of components and the other for mature experiments. Researchers are bringing expertise in HPC, engineering, materials science, and cryogenic and quantum physics to the development of innovative system architectures and components. These research and development efforts span qubit design, quantum-processor-unit configuration, quantum chip circuitry, and quantum materials science.



Livermore's Biomedical Foundry includes a clean room that is recognized nationally as a unique thin-film neural interface facility. Here researchers fabricate components for the Livermore Flexible Probes.

NEUROTECHNOLOGIES MONITOR THE BRAIN

In an event held at the Laboratory in August 2019, U.S. Secretary of Energy Rick Perry and Sandy Weill, founder of the Weill Family Foundation, signed a memorandum of understanding that formally initiated a public–private partnership for advancing artificial intelligence (AI) to diagnose and treat neurological disorders. The previous November, LLNL's leadership in neurotechnology was featured at the Defense Advanced Research Projects Agency (DARPA) 60th Anniversary Symposium. The Laboratory's flexible, high-density implantable multielectrode arrays are central to the DARPA Systems-Based Neurotechnology for Emerging Therapies (SUBNETS) program. The research aims to develop novel neural interface technologies for treating neuropsychiatric conditions such as anxiety, depression, post-traumatic stress disorder, and chronic pain.

Researchers from Livermore and UC San Francisco are using the implantable arrays to collect real-time data across multiple areas of the brain. The new platform is capable of continuously measuring the activity of nearly 400 single neurons over a period of at least five months from devices distributed in multiple regions of rodent brains. The team is working toward technologies for high-fidelity, long-term monitoring to study patterns of learning and how memory changes over time. LLNL researchers and collaborators have also combined clinical data with HPC simulations to make breakthrough advances in understanding traumatic brain injury. In June 2019, officials from the National Football League visited Livermore to learn about the work.

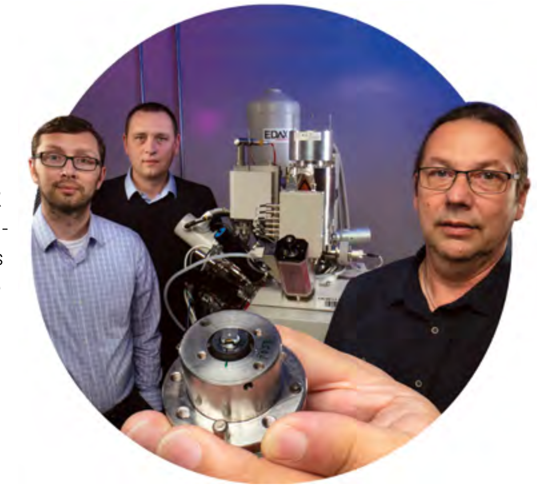
DIAMOND ANVIL CELLS REVEAL MATTER'S BEHAVIOR

Livermore's interest in materials at high-energy-density (HED) conditions ranges from static properties found in the core of giant planets to the phase changes that occur under dynamic conditions. To study static properties, researchers use diamond anvil cells (DACs), small mechanical presses, to slowly squeeze materials to ultrahigh pressures. These experiments have been limited to pressures of about 300 gigapascals (GPa), somewhat less than the pressure at the center of the Earth. LLNL's new toroidal DAC has successfully compressed seven different metals beyond 400 GPa and can squeeze materials to pressures approaching the conditions at the cores of giant icy planets.

In addition, scientists from LLNL and several European institutions developed a next-generation dynamic diamond anvil cell (dDAC) that is more than a thousand times faster than current capabilities. Installed at the Deutsches Elektronen-Synchrotron, the dDAC can be used to simulate fast dynamic processes such as earthquakes and asteroid impacts. In other HED experiments, conducted at Argonne National Laboratory's Advanced Photon Source, LLNL researchers and collaborators used laser shock compression to discover a new structure in gold that exists at two-thirds the pressure found at the center of the Earth.

ANTINEUTRINO DETECTION WITH PROSPECT

LLNL and collaborating institutions brought into operation the Precision Reactor Oscillation and Spectrum Experiment (PROSPECT), an antineutrino detector sited near a nuclear reactor to probe the possible existence of a new form of matter—sterile neutrinos. The great technical achievement of PROSPECT was developing detection technology that could preferentially select the extremely rare antineutrino interactions of interest with high efficiency, while simultaneously identifying and rejecting vastly more frequent background neutron interactions stemming from the nuclear reactor, which is the antineutrino source.

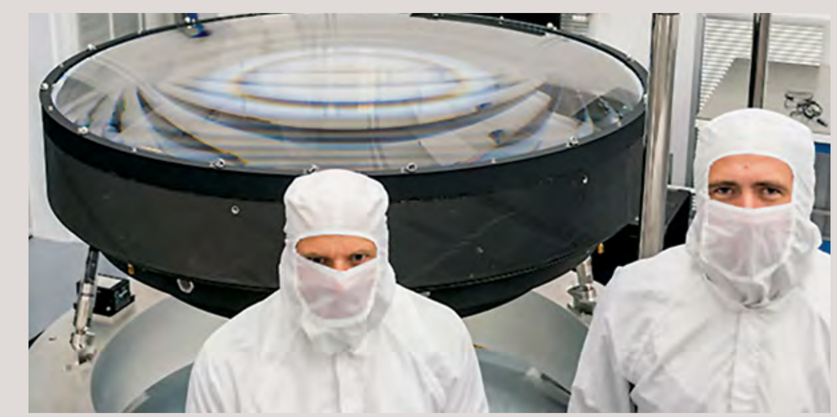


LLNL researchers show a DAC with a toroidal anvil, developed to be used in high-pressure experiments.

EXPANDING INDUSTRIAL PARTNERSHIPS

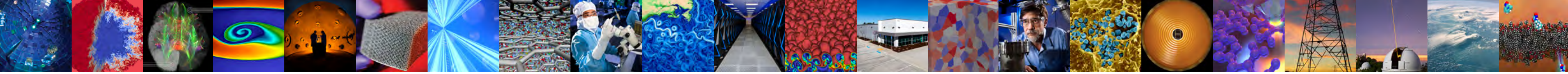
LLNL is benefiting the U.S. economy with innovative technologies and processes. In FY 2019, LLNL obtained 141 new patents, asserted 40 new copyrights, and licensed 14 new technologies. Licensing income for the year totaled approximately $5.6 million. LLNL had a highly successful year competing for DOE Technology Commercialization Fund grants. Altogether, Laboratory researchers will receive more than $6.2 million, which includes about $3.6 million in matching funds from industrial partners. The winners were: additively manufactured high-performance magnets; sorbents to remove carbon dioxide from mixed streams of gases; commercialized feedstocks for 3D printing energy products; instrumentation for realistic training of radiological response teams; and advanced technologies for subsurface imaging.

Livermore researchers captured four R&D 100 awards in 2019. This year's winners include: SPACK, a software-package management tool for HPC applications; IMPEDE®, a medical device that reduces blood flow to reduce health risks; SCR, a software package for HPC simulations to take advantage of hierarchical data storage systems; and the MC-15 Neutron Multiplicity Detector for quickly identifying and assessing nuclear threats. In addition, the Applied Biosystems™ Axiom™ Microbiome Array (ABAMA), based on LLNL technology, is the most comprehensive microorganism detection platform built to date and won an Excellence in Technology Transfer Award from the Federal Laboratory Consortium.



WORLD'S LARGEST OPTICAL LENS SHIPPED

When the Large Synoptic Survey Telescope (LSST) starts imaging the southern sky in 2023, it will take photographs using optical assemblies designed by Livermore researchers and built by Laboratory industrial partners. A key feature of the camera's optical assemblies is its three lenses. One is 1.57 meters (5.1 feet) in diameter—the world's largest high-performance optical lens (shown). LSST will take digital images of the entire visible southern sky twice each week, revealing unprecedented details of the universe and helping unravel some of its greatest mysteries.



SAFE, SECURE, AND SUSTAINABLE OPERATIONS

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

Work is underway at the Applied Materials and Engineering campus. The multiyear undertaking entails upgrades to several existing facilities and construction of two new laboratories and an office building.

Committed to the highest level of operational performance, LLNL implements 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 employees and the public. Investments are targeted to modernize the Laboratory's infrastructure.

ATTENTION TO ES&H

Safe, secure, and environmentally responsible operations are of special importance with the ongoing high-priority life-extension and weapon modification programs, nuclear operations and waste disposal activities, work involving hazardous materials, and numerous new construction and maintenance initiatives. Many construction projects are in progress, and the subcontractor record was excellent in FY 2019. More than 280,000 hours of work were performed without an Occupational Safety and Health Act (OSHA) recordable case or lost time incident.

Overall ES&H performance under Livermore's Integrated Safety Management System exceeded contract expectations. Performance metrics were positive and improvement initiatives in many functional areas were completed or are underway. LLNL achieved recertification for the International Organization for Standardization (ISO) 14001 Environmental Management System and the Occupational Health and Safety Management System 18001 standards with 15 noteworthy practices identified. In addition, LLNL continues implementing its new work planning and control process designed to ensure consistent Laboratory-wide practices, increase rigor and efficiency, and add value to work control documents. The goal is to convert all existing work control documents to the new system by the end of FY 2020.

EFFECTIVE AND SECURE OPERATIONS

In FY 2019, operations at LLNL were well managed, with significant accomplishments in many areas in addition to ES&H. The Laboratory conducted efficient, effective business operations and financial management. Individuals and teams achieved many notable successes in nuclear operations, information technology management, and emergency management. Personnel in the Supply Chain Management Department were honored with more than 20 awards this year. They are streamlining procurement services and delivering on socioeconomic, customer satisfaction, and procurement quality goals. The Laboratory is also benefiting from continuing efforts to enhance awareness, modernize and upgrade the physical security infrastructure, and reduce the security footprint. Employees' strong commitment to security is exemplified by a reduced number of significant security incidents compared to the prior year. In addition, fence relocations at the Laboratory reduced the Limited Area footprint by 15 percent, which lowers security costs.

PROGRESS TOWARD SITE SUSTAINABILITY GOALS

Environmentally responsible work practices are ensured by LLNL's Environmental Management System. These practices provide a systematic approach to identifying and reducing the environmental impact of Laboratory activities. Issued in October 2019, the 2018 *Site Annual Environmental Report* documents LLNL's compliance with environmental standards.

Overall, LLNL is on track to meet many of its sustainability goals. The 2025 goals for clean and renewable energy usage, reduction of fleet petroleum usage, acquisition of zero-emission vehicles, electronic stewardship, and pollution prevention–waste reduction are on track or have already been achieved. However, goals in areas such as energy intensity (including associated greenhouse gas emissions) and water usage reduction are challenged by mission requirements for high-performance computing that demand substantial energy and water for cooling. The new Advanced Manufacturing Laboratory achieved LEED Gold certification, but aging facilities onsite limit options for improving overall energy efficiency of buildings.

INFRASTRUCTURE INVESTMENTS

In response to rapid growth in capital projects at the Laboratory, LLNL established an institutional Project Management (PM) Office in FY 2019 and modernized its PM processes and procedures to ensure on-cost, on-schedule project execution. At the end of the year, the large portfolio of work consisted of 216 projects (103 in active execution) with a total project cost of $613 million.

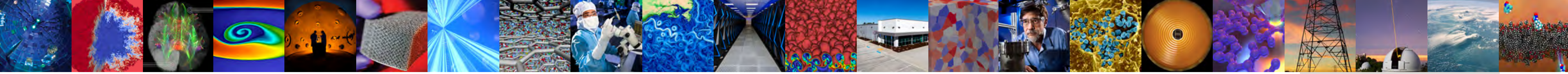
The $34-million Expand Electrical Distribution System (EEDS) Project was nearing completion—it was recently finished ahead of schedule and nearly $1 million under budget. New 15-kilovolt power cables were installed to eliminate single-point failures to existing facilities and support planned development. In June 2019, Laboratory and NNSA officials celebrated the groundbreaking for the jointly sponsored Applied Materials and Engineering (AME) campus at LLNL. The "area plan" collocates synergistic capabilities into new and renovated repurposed buildings on the campus to gain efficiencies and reduce overall site footprint. AME is urgently needed to support the warhead modernization programs.

A ribbon-cutting ceremony celebrated the completion of an extensive renovation of Livermore's radiochemistry laboratories.

The Laboratory also continuously upgrades facilities and equipment to help carry out LLNL's mission safely and effectively. In November 2018, radiochemists in the Nuclear and Chemical Sciences Division celebrated completion of a $5.1-million renovation of their laboratory space—now modernized with new equipment that support multiple mission areas.

SUSTAINABLE LANDSCAPE ALONG EAST AVENUE

East Avenue, the busy thoroughfare that runs between Lawrence Livermore and Sandia national laboratories, is graced with a new look, thanks to the efforts of LLNL's Landscape and Pest Management team. They eagerly took on the task of creating a landscaping design that is both environmentally sustainable and aesthetically appealing, using drought-resistant plants and other natural materials. The team hopes to follow this successful effort with more such projects at other locations around the LLNL main site.



MANAGING FOR THE FUTURE

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

FY 2019 was a year focused on engaging with stakeholders and sponsors, providing technical leadership in key mission areas, and building for future successes.

LLNL Director William Goldstein, NNSA Administrator Lisa Gordon-Hagerty, and NNSA Livermore Field Office Manager Peter Rodrik pose for a picture at the NIF 10th anniversary celebration.

STRATEGIC ENGAGEMENTS AND LEADERSHIP

In August 2019, DOE Under Secretary for Nuclear Security and NNSA administrator Lisa Gordon-Hagerty came to Livermore, along with other distinguished guests, to attend a series of events celebrating past accomplishments and NNSA's high-performance computing (HPC) future. The under secretary also accompanied U.S. Secretary of Energy Rick Perry in a subsequent visit to launch a public–private partnership for applying DOE's HPC resources and machine-learning capabilities to fight neurological disorders (see p. 14). These and many other engagements by Laboratory programmatic and technical leaders with key stakeholders are vital to understanding stakeholders' needs, sharing LLNL expertise, and helping to shape the evolving strategic landscape.

The signatories display an agreement for a partnership to fight neurological disorders.

LLNL is providing the nation with technical leadership in many facets of its national security mission. Livermore is engaged in two nuclear warhead modernization programs and is leading a multilaboratory effort to improve early detection of nuclear proliferation activities. With the W87-1 modification program, Livermore is helping to bring modern manufacturing processes into the NNSA nuclear enterprise, and the Laboratory is at the forefront of NNSA's efforts to modernize infrastructure life-cycle management. Other examples of programmatic and technical leadership, such as in HPC, are described elsewhere in this annual report.

NEW FACILITIES AND MODERNIZED INFRASTRUCTURE

In early FY 2019, doors opened for research collaborations at LLNL's 14,000-square-foot Advanced Manufacturing Laboratory, sited at the Livermore Valley Open Campus. The new $10-million facility houses leading-edge additive-manufacturing machines and equipment. LLNL scientists and engineers are welcoming academic and industrial partners for innovative collaborations at this one-of-a-kind facility. Groundbreaking also occurred this year for the Applied Materials and Engineering (AME) campus, which entails upgrades to several existing facilities and construction of two new laboratories and an office building (see p. 16–17).

The Laboratory is engaged in the formal design and ready to begin work on the Exascale Computing Facility Modernization (ECFM) project. ECFM serves to meet LLNL infrastructure demands over the next decade for two future exascale computer systems. The first, El Capitan, will arrive as early as 2023 (see p. 5). The extensive ECFM project will involve upgrading Building 453, where El Capitan will be housed, and constructing infrastructure to provide necessary additional power and cooling. El Capitan will provide critically needed computing power for the W80-4 life-extension and W87-1 modification programs. LLNL is also working in partnership with NNSA to begin construction of a new Emergency Operations Center (EOC) at the Laboratory. The EOC project is at the forefront of an NNSA pilot program to deliver more cost-effective approaches to projects in the $20 to $50-million total cost range.

At the new Advanced Manufacturing Laboratory, equipment was moved into the large work areas to prepare for collaborations with industry and academia.

A CHANGING WORKFORCE

An outstanding workforce is Livermore's principal strength. Recruiting, training, and retaining exceptional talent is a top priority at LLNL to sustain excellence at a time of rapid change in our workforce. Many senior staff members have been retiring, and 41 percent of the core staff have been hired within the last five years. Staff members bring impactful new ideas to their jobs, work with integrity and zeal, and thrive in an inclusive work environment. In 2019, Glassdoor recognized LLNL as one of the top 10 best places to work nationwide. Its Employees' Choice Award program is based on employees' input about their jobs and work environments.

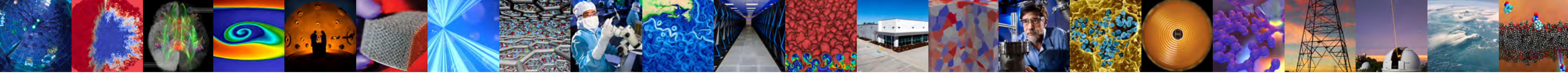
To understand and better respond to LLNL's changing workforce, the Laboratory commissioned the 2019 Employee Culture and Climate Survey and more than 50 percent of the employees participated. Laboratory Director William Goldstein reported that results were "encouraging" but also pointed to a need for improvements. The gathered data was shared with employees and continues to be analyzed. The senior management team is committed to promoting positive cultural and behavioral change at the Laboratory. Actions are underway to foster workplace improvements at Livermore and further contribute to future success.

WELCOME, LINDA BAUER!

In November 2019, Dr. Linda R. Bauer was welcomed to Livermore as LLNL deputy director and vice president of LLNS. As deputy director, Bauer participates in the day-to-day management of the Laboratory—acting as director in William Goldstein's absence; providing executive-level guidance and direction within the senior management team; and interfacing with the NNSA Livermore Field Office, the LLNS Board of Governors, and many of LLNL's partners. She brings to Livermore a wealth of career experience managing operations at other facilities and sites within the NNSA nuclear weapons complex.

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, periodically met in FY 2019 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. The Board chartered functional management reviews (FMRs) on an as-needed basis. Five FMRs were completed in FY 2019 in topical areas ranging from welding to work planning and control. Recommendations provided by Board committees, ERCs, and FMRs have led to substantive responsive actions.



COMMUNITY CONNECTIONS

Helping our neighbors through science education and charitable giving

Students learn how 3D printers work during STEM Day at the Laboratory.

The Laboratory strives to be a good neighbor within its community, offering a wide variety of activities to enhance science, technology, engineering, and mathematics (STEM) education. In addition, students of all ages benefit from training programs LLNL has established. Outreach does not stop with education—each year LLNL staff and LLNS donate more than $3 million to local nonprofits, while hundreds of employees donate their time to local service agencies.

SCIENCE THAT'S FUN-DAMENTAL

The Laboratory's education outreach begins with 4th and 5th graders. Each year, more than 12,500 students, along with their chaperones, are introduced to scientific concepts through the Fun With Science program. The ever-popular program offers young minds a tour of LLNL's Discovery Center, followed by a presentation of hands-on experiments that introduce students to scientific curricula. The Laboratory also offers special tours for high school students, who get to visit the inner workings of biology and chemistry laboratories and interact with scientists at popular tour stops, such as the Additive Manufacturing Laboratory or the National Ignition Facility.

Fun With Science presenter Nick Williams

Fun With Science is a mainstay at the Discovery Center (open to the public Tuesday through Saturday), and the show is featured at events throughout the greater San Francisco Bay Area. For example, each year LLNL participates in the Bay Area Science Festival's Discovery Day, which attracts more than 30,000 young scientists and family members to Oracle Park in San Francisco. Fun With Science is featured at LLNL's booth, along with a series of virtual experiments to teach attendees about coding, plant biology, planetary physics, global warming, and much more.

EXPANDING YOUR HORIZONS

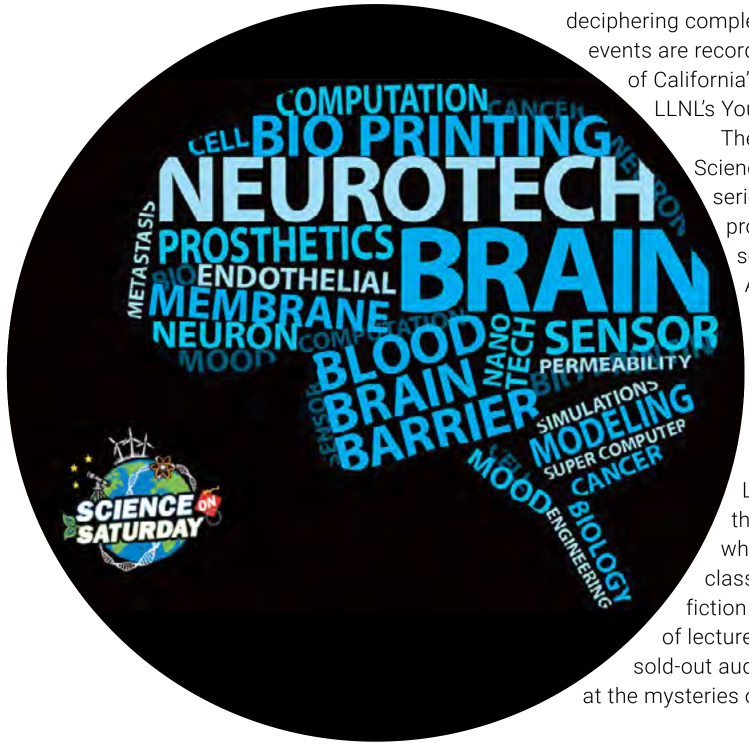
LLNL continues to sponsor Expanding Your Horizons, held several times a year throughout the San Francisco Bay Area, to introduce STEM careers to middle- and high-school girls. These free events pair women scientists and engineers with students to conduct hands-on demonstrations of science and discuss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

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 really works. The seminars help to connect students to potential career paths. In addition, LLNL unveiled a new "apprenticeship" program for high school–age students considering careers as engineers, welders, or machinists. In 2019, the weeklong workshop provided hands-on training using milling and welding machines for 27 students.

These workshops and internships are a small sampling of the Laboratory's educational outreach. Each year, LLNL hosts more than 800 students who participate in summer internships, hackathons, and other programs to prepare them for STEM careers. Twice yearly, 200 underrepresented middle- and high-school students from around the Bay Area visit the Laboratory for STEM Day and participate in interactive presentations designed to spark interest in science and technology.

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 the cities of Livermore, Tracy, and Oakland. Each topic highlighted cutting-edge science and technology, and paired Laboratory researchers with local science educators. This season, SOS presented discussions that dug deep into the human brain, from sensors that listen to brain cells, to new methods for combatting tumors, to deciphering complex brain signals. The events are recorded for the University of California's TV website as well as LLNL's YouTube channel.



The Laboratory's popular Science on Screen lecture series continues to provide a bridge between science fact and fiction. Attracting science students and movie buffs of all ages, the series combines popular feature-length movies with prominent researchers from the Laboratory, who discuss the scientific viability of what's depicted in these classic, cult, and science fiction films. This year's series of lectures, again playing to sold-out audiences, also looked at the mysteries of the human brain.

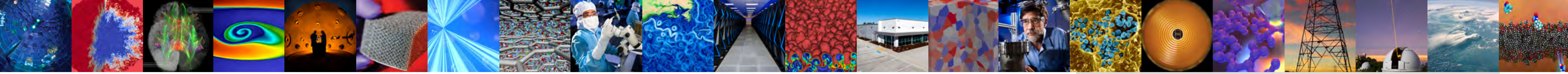
HOME CAMPAIGN AND COMMUNITY GIFTS

In 2019, employees and LLNS raised more than $3.7 million in the annual HOME (Helping Others More Effectively) campaign, a charitable drive that benefits community and nonprofit agencies in the Tri-Valley, the San Joaquin Valley, and the greater San Francisco Bay Area. Employees pledged more than $2.7 million, while LLNS contributed $1 million in matching funds.

In November, at a ceremony in the LLNS office, Laboratory Director William Goldstein presented checks totaling $150,000 (an increase of $50,000 over 2018). The selected awards serve children in the Tri-Valley, East Bay, Contra Costa, and San Joaquin counties, with a focus on literacy, science, technology, engineering, and math education and cultural arts. Other recipients include children, families, senior citizens, and individuals in need of assistance.

VETS2TECH MARKS FIVE YEARS

The Laboratory's Vets2Tech marked its 5th anniversary of assisting military veterans in reentering the workforce. The program, which is now expanded to include civilian students, addresses the labor market shortage for mechanical technologists. Vets2Tech has graduated 44 students with associate degrees, 25 of which now work at LLNL. The program is a partnership between LLNL, Las Positas Community College, Alameda County Workforce Development Board, the Tri-Valley Career Center, and Growth Sector. Vets2Tech has become a model for many of the DOE laboratories and several large companies in the region.



WORKFORCE RECOGNITION

Acknowledging exceptional performance, service, and expertise

LLNL researchers Richard Kraus, Arthur Pak, Daniel Casey, and Félicie Albert are recipients of the Presidential Early Career Award for Scientists and Engineers—the highest honor given by the U.S. government to early-career researchers.

Recognition by the scientific community and other stakeholders affirms the high quality of Livermore's work and innovative spirit. The awards on these pages showcase the efforts of the Laboratory's talented staff.

PECASE HONORS

Four LLNL scientists received the prestigious Presidential Early Career Award for Scientists and Engineers (PECASE). **Félicie Albert**, **Daniel Casey**, **Richard Kraus**, and **Arthur Pak** were awarded the highest honor bestowed by the U.S. government on scientists and engineers who are early in their careers and have distinguished themselves in their respective fields. PECASE awardees also have demonstrated public service through educational and community outreach.

WILLIAM PROCTER PRIZE

Climate scientist **Benjamin Santer** received the 2019 William Procter Prize for Scientific Achievement from the Scientific Research Honor Society Sigma Xi. The prize is awarded to a scientist who has made an outstanding contribution to scientific research and has demonstrated an ability to communicate the significance of this research to scientists in other disciplines. Previous recipients include E.O. Lawrence.

Proctor Prize winner Benjamin Santer

DOE AND NNSA AWARDS

Physicist **Jingke Xu** and computer scientist **Kathryn Mohror** are among the 73 scientists nationwide who were recipients of the DOE Office of Science Early Career Research Program award. Under the program, Laboratory scientists typically receive research funding totaling $500,000 per year for five years.

Seven LLNL project teams were recognized with NNSA Defense Programs Awards of Excellence for important contributions to the Stockpile Stewardship Program and strategic deterrence.

DOE awarded Director's Office staff member **Paul Chrzanowski** the Derivative Classifier of the Year award for 2019.

LLNL and staff members **Charity Follett**, **Candice Gellner**, and **Quentin Vaughan** were awarded the best-in-class National Technology Transfer Award by the DOE Technology Transfer Working Group for innovation in partnering related to the Accelerating Therapeutics for Opportunities in Medicine (ATOM) consortium.

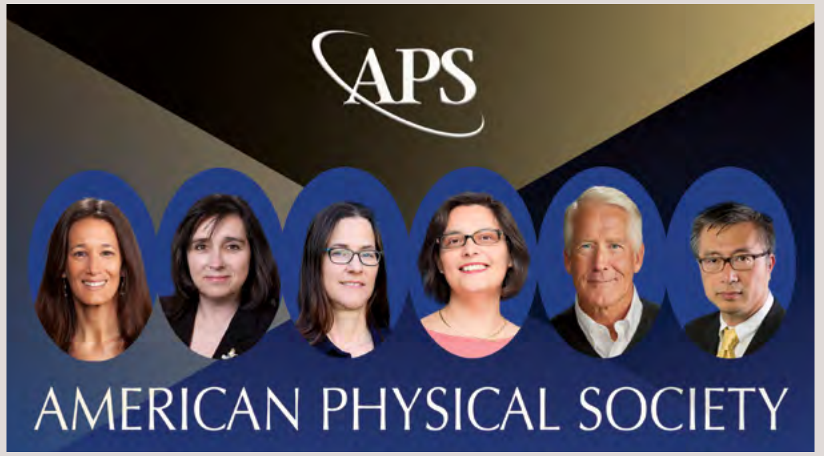
Engineer **John Schindler** was awarded the Supply Chain Management Center (Kansas City) Small Business Advocate of the Year Most Valuable Person by the NNSA administrator.

SPECIAL SERVICE AWARDS

The U.S. Air Force recognized the distinguished performance of physicist **César Pruneda** with an Award for Meritorious Civilian Service while on an off-site assignment as scientific advisor to the Air Force Global Strike Command.

PROFESSIONAL SOCIETY FELLOWS

Six scientists have been selected as 2019 fellows of the American Physical Society (see the box at right).



Six LLNL scientists have been selected as 2019 fellows of the American Physical Society: **Félicie Albert**, **Kim Budil**, **Jutta Escher**, **Sofia Quaglioni**, **Harry Robey**, and **Ye Zhou**. The new fellows represent a wide range of physics expertise, from computational physics and shock compression of condensed matter to instrument and measurement science.

Physical chemist **Nerine Cherepy** was elected to the rank of fellow of SPIE, the international society for optics and photonics.

Climate scientist **Karl Taylor** has been selected as a fellow of the American Geophysical Union for improving capabilities to evaluate and intercompare climate models and advance understanding of climate responses.

Atmospheric scientist **Stephen Klein** was selected as a fellow of the American Meteorological Society for outstanding contributions to atmospheric sciences and applications over his nearly 30-year career.

Physicist **Jon Belof** was elected a Kavli Fellow of the U.S. National Academy of Sciences (NAS) and presented his research at the NAS Frontiers of Science symposium, the academy's premiere activity for distinguished young scientists.

Scientists **Félicie Albert**, **Eyal Feigenbaum**, and **Bruce Warner** have been named senior members of the Optical Society, recognizing their more than 10 years of professional experience in optics or an optics-related field.

SCIENCE AND TECHNOLOGY AWARDS

Research scientist **Paul Durack** was awarded the World Climate Research Programme 2018 Data Prize for his leadership of the input4MIPs project.

Geochemist **Thomas Kruijer** has won the F.W. Clarke Award from the Geochemical Society. The award honors an outstanding contribution to geochemistry or cosmochemistry, published by an early career scientist.

National Ignition Facility (NIF) researcher **Eyal Feigenbaum** received the Alexander Glass Best Oral Presentation Award from SPIE for his presentation at the Laser Damage 2018 conference.

Daniel Clark, leader of NIF's Capsule Modeling Working Group, won the 2018 American Institute of Physics Ronald C. Davidson Award for Plasma Physics, recognizing outstanding published research.

Senior engineering associate **Carlos Castro** won the 2019 Larry Foreman Award for innovation and excellence in inertial confinement fusion target fabrication.

Nuclear physicist **Maria Gatu Johnson**, engaged in experimental campaigns at NIF, was named winner of the Katherine E. Weimer Award recognizing outstanding plasma science research by a woman physicist in the early stages of her career.

Computer scientist **Ignacio Laguna** was selected as one of four 2019 Better Scientific Software Fellows, recognizing his leadership and advocacy of high-quality scientific software.

The Laser Institute of America recognized laser safety officer **Jamie King** with the R. James Rockwell Jr. Educational Achievement Award for his outstanding contributions in laser safety education.

SPECIAL HONORS

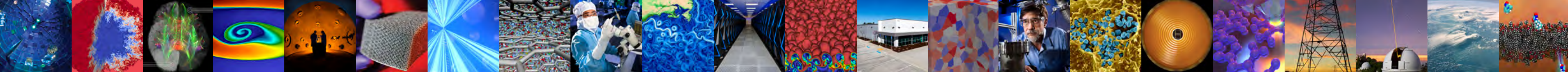
HPCwire named **Lori Diachin**, serving as deputy director for DOE's Exascale Computing Project, as one of its "People to Watch" in 2019. The honor recognizes people who are likely to propel the high-performance computing industry forward.

Colin Yamaoka, program coordinator for the Livermore Laboratory Employee Services Association, was named as a 2019 Game Changers award winner. *Workforce Magazine* selects the top human resources practitioners under the age of 40 dedicated to pushing forward innovative people-management practices.

Philip Adams, chief technical officer for NIF, was recognized with a 2018 Oracle Excellence Award for exceptional use of Oracle solutions to accelerate innovation and drive business transformation.

Artist **John Jett** was honored with a 'Best Comic Design' Adobe Government Creativity Award for his educational comic book explaining NIF and the types of careers that support its operation.

Physicist **Tammy Ma** was named Woman of the Year for the 16th Assembly District by Assemblymember Rebecca Bauer-Kahan for her commitment to mentoring young students who share her passion for science.



LAWRENCE LIVERMORE NATIONAL SECURITY, LLC

Overseeing management and operation of the Laboratory for the U.S. Department of Energy and the National Nuclear Security Administration

LLNS is a limited liability company managed by Bechtel National, Inc.; the University of California; BWXT Government Group, Inc.; and AECOM Energy & Construction, Inc. 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.

LLNS Community Gift Program ceremony

ORGANIZATION AND LLNS BOARD MEMBERS IN FY 2019

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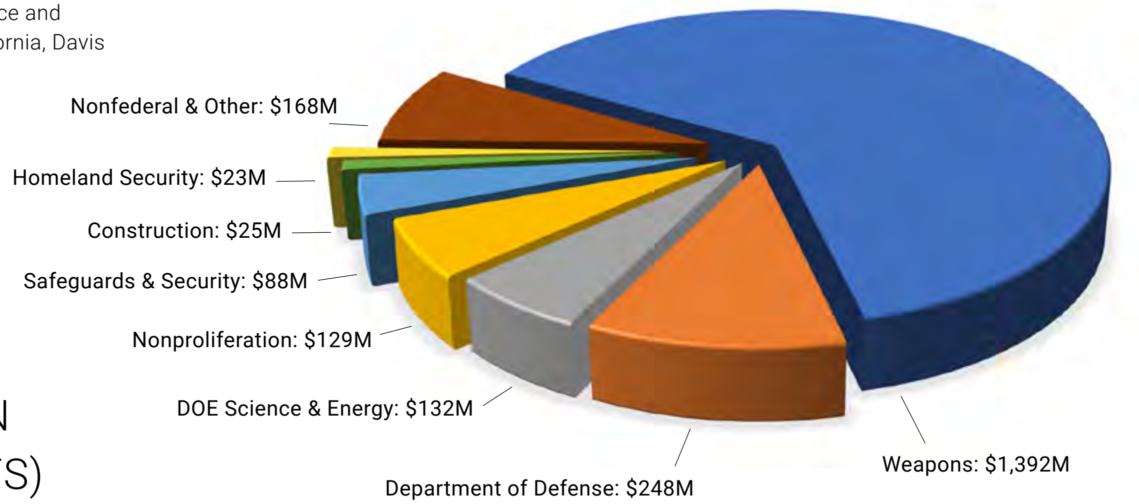
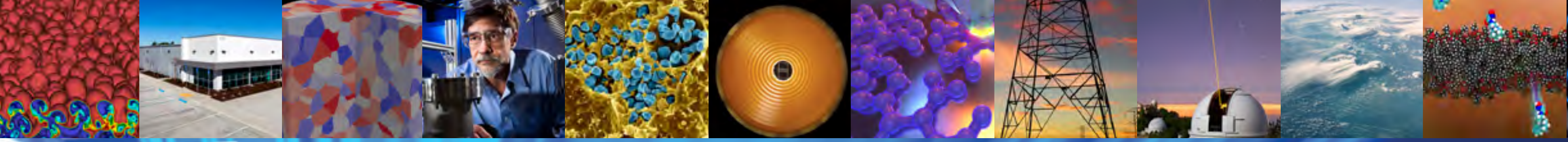
U.S. Strategic Command

AMBASSADOR LINTON BROOKS HONORED WITH FOSTER MEDAL

National security leaders past and present paid tribute to Ambassador Linton Brooks as he was presented the John S. Foster Jr. Medal in November 2019. Brooks was recognized for his exceptional leadership in advancing U.S. national security as a strategic thinker and ambassador for arms control, a visionary administrator of the National Nuclear Security Administration, and a dedicated nuclear submarine officer. He is the 5th recipient of the Foster Medal, which is administered by LLNS and honors exceptional service in support of U.S. nuclear security.

LLNL FY 2019 PORTFOLIO: $2.206 BILLION (ACTUAL COSTS)





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