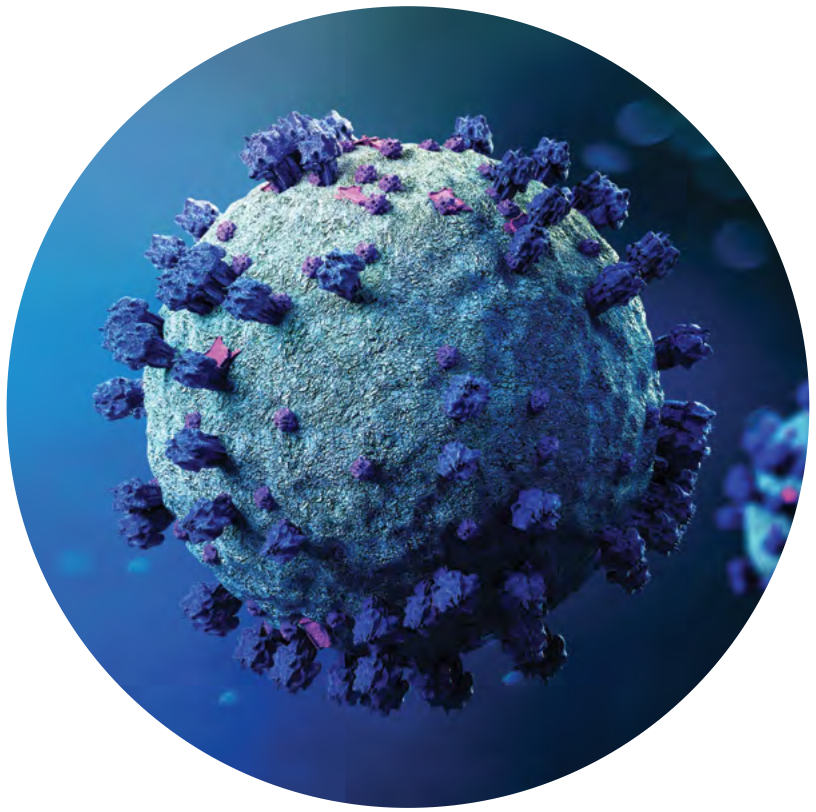
LAWRENCE LIVERMORE NATIONAL LABORATORY

FY 2020 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) 2020 was filled with programmatic successes at the Laboratory and especially marked by the need to respond to the COVID-19 pandemic. The cover illustrates the coronavirus molecule and research projects the Laboratory initiated to help accelerate discovery related to the virus through use of high-performance computing, improve detection capabilities, and help treat those that are affected

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INSIDE FY 2020

SCIENCE AND TECHNOLOGY ON A MISSION

In a year of exceptional challenges and upheaval, Lawrence Livermore National Laboratory continued to advance the frontiers of science and technology to strengthen national security in a rapidly changing world.

LLNL Director William Goldstein

With its principal mission to ensure nuclear deterrence, LLNL provides unique expertise and world-class scientific tools in support of the Department of Energy (DOE) and its National Nuclear Security Administration (NNSA). Through the nuclear stockpile annual assessment process, leadership in the life-extension of aging warheads, and continuous improvement in underlying scientific understanding of nuclear weapon phenomena, we contribute to the safety, security, and effectiveness of the U.S. nuclear deterrent and the reduction of nuclear threats around the world. The special scientific and engineering tools and competencies we rely on to carry out this mission enable us to broadly contribute to the nation's security through technological innovation.

LLNL engineers developed ventilators for easy assembly from readily available parts.

EMERGING SECURITY CHALLENGES

The Laboratory is charged with looking ahead to identify and explore emerging science and technology, especially aspects that might impact national security. For example, early in the 2010s, LLNL focused research and development efforts on advanced manufacturing, foreseeing applications within NNSA. Today this forward-looking work is helping enable success in stockpile modernization efforts. Similarly, in the 1990s, building on the discovery of chromosome sorting methods at LLNL, bioscientists developed DNA-based diagnostic techniques for pathogen detection to address potential biosecurity threats. As a result, Livermore was in a position to contribute unique insight into the anthrax attacks in the early 2000s. Most recently, diagnostic techniques commercialized by LLNL were among the first to be adapted and authorized for SARS-CoV-2 testing.

This annual report highlights more of our contributions to the national pandemic response effort. By early February, LLNL researchers released a preliminary set of 3D protein structures for the virus and, later, an initial set of antibody sequences aimed at binding and neutralizing SARS-CoV-2. In addition, Laboratory engineers developed, prototyped, and commercialized within months a novel device capable of supplementing the nation's limited stockpile of ventilators without further straining the constrained supply chain for components.

STOCKPILE MODERNIZATION

In our primary mission area, the Laboratory is responsible for designing and certifying the nuclear explosive package for both the W80-4 warhead, to be carried on the all-new Long-Range Standoff missile, and the W87-1, for Minuteman-3 and the new Ground Based Strategic Deterrent system. The W80-4 program is the first in the stockpile stewardship era in which a nuclear package is being life-extended for deployment on an all-new delivery system; the W87-1 is the first with the ambitious plan to fully remanufacture all components of the warhead.

To address these challenges, we are working closely with the NNSA production facilities and developing designs that exploit innovations in manufacturing methods. For example, we are piloting a new kind of partnership with Kansas City National Security Complex (KCNSC), to establish a production development enclave at LLNL. The enclave will enable weapon design and production personnel to work side-by-side to rapidly advance manufacturing capabilities and establish readily qualified processes for final production of parts at KCNSC. Once demonstrated, this model of design/production integration can be adapted to impact future modernization programs.

The Laboratory is using the unique power of Sierra, the world's third fastest supercomputer, to perform high-fidelity 3D simulations of weapons performance and run large ensembles of simulations to quantify uncertainties in predictions. These efforts are directly impacting modernization programs and providing new insight into ongoing stockpile assessments. Beyond Sierra, we look forward to delivery in 2023 of El Capitan, NNSA's first exascale supercomputer, which will enable qualitative increases in confidence for the future stockpile. Our flagship experimental facility, the National Ignition Facility, has provided critical validation of design options for the W80-4, while making measurable progress toward meeting the grand challenge goal of fusion ignition in the laboratory. Together, these exceptional capabilities allow us to confidently assess the safety, security, and reliability of the current and planned nuclear deterrent.

BROADER SECURITY CHALLENGES

With our frontier science and technology, we provide unique expertise and capabilities to address threats across the spectrum of weapons of mass destruction and enable high-confidence implementation of arms control, nonproliferation, and other threat reduction measures. We contribute to deterrence broadly, as it intersects with emerging domains of competition and conflict, including space, cyberspace, and the "gray zone." Similarly, we leverage these capabilities to develop solutions for energy and climate security and lend them to expand the endless frontier of basic scientific understanding, the foundation of innovation.

WORKING THROUGH THE PANDEMIC

In FY 2020, LLNL researchers met major milestones in all mission areas despite the COVID-19 pandemic. The health and safety of LLNL personnel has been paramount in managing the extent and pace of onsite activities. The Laboratory entered a state of safe standby in mid-March in response to the imposition of a statewide shelter-in-place order, and began returning personnel to work onsite a week later. Since early July, LLNL has been operating effectively in a posture of Normal Operations with Maximum Telework, with the daily onsite population averaging around one-third of full staff. A rapidly implemented telecommuting infrastructure enables those not onsite to work from home. Work on major onsite construction projects—described in this report and important to future mission success—remains on schedule and on budget.

The dedication and resilience of Laboratory employees, and the extraordinary effort of many mission-support organizations, explain why the Laboratory succeeded this year in the face of exceptional and continuing adversity. In particular, Health Services and LLNL's biosafety team monitored employee health, developed guidelines and work-controls for onsite activities, and advised on pacing the growth of the onsite workforce. Information technology professionals quickly upgraded services to provide thousands of employees the ability to efficiently telecommute. Superhuman efforts also enabled LLNL to meet its aggressive hiring plans for FY 2020, and to enroll nearly 500 students to "virtually" work at the Laboratory last summer.

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.

LLNL biologists use molecular-based technologies, such as PCR, microarray, and genomic sequencing, to characterize microbes and pathogens in samples.

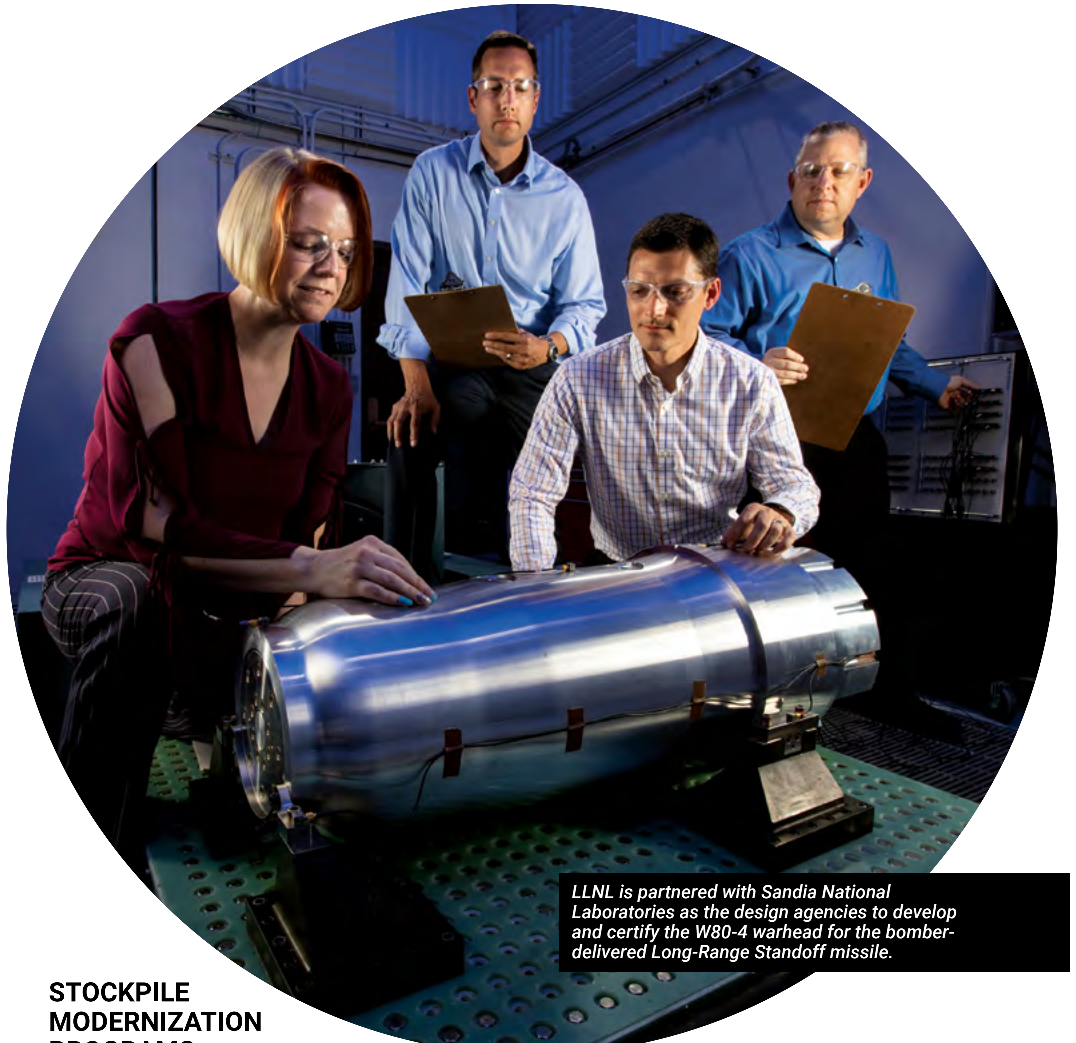
THE FUTURE

Outstanding people are the Laboratory's most important resource. LLNL's success is made possible by their excellence, and shared commitment to our values: new ideas, making a difference, integrity, inclusiveness, and loving the work. I have worked with many of them during my 36 years here, including nearly seven as Laboratory Director. In July, I announced that I will step down as director at the conclusion of the search for my successor. I look forward to welcoming the next director, confident LLNL's unmatched tradition of excellence and record of service to the nation will continue.

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. Knowledge gained through experiments, theory, and simulations is applied to assess the condition of stockpile weapons and to develop and certify needed modernizations with confidence in the absence of additional nuclear tests.



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.

ANNUAL STOCKPILE ASSESSMENT

In FY 2020, LLNL completed Cycle 25 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 weapon systems. Experiments performed by Laboratory scientists and enhancements to physics and engineering simulation codes improved predictability and strengthened the technical foundation that supports assessments and certification of weapons. LLNL also completed needed surveillance and analysis activities to assess the condition of and sustain the B83-1, W80-1, and W87-0 stockpile systems.

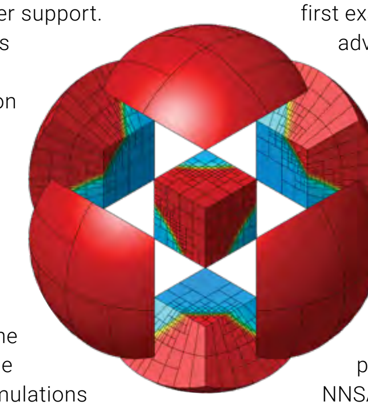
STOCKPILE MODERNIZATION PROGRAMS

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 is about halfway through Phase 6.3 (engineering development). In addition to numerous design reviews, major efforts focused on issuing engineering releases to the production plants and supporting concurrent activities of the U.S. Air Force and its contractors. The design of the nuclear explosives package (NEP) is mature and only one major downselect decision remains. The plans to refurbish or replace aging components and materials include use of new manufacturing methods that minimize costs, increase throughput, and reduce the use of environmentally sensitive materials and processes.

In FY 2020, the W87-1 modernization program passed its first key milestone in Phase 6.2 (program feasibility)—a review of customer requirements—keeping the Laboratory's effort on schedule despite the COVID-19 pandemic. LLNL is NNSA's design agency for the NEP for a ballistic-missile warhead to replace the aging W78. To be deployed the U.S. Air Force's Ground Based Strategic Deterrent in 2030, the W87-1 will be the first modern warhead that is 100 percent newly manufactured. Technical activities are focusing on maturing weapon design options and 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 AND BEYOND

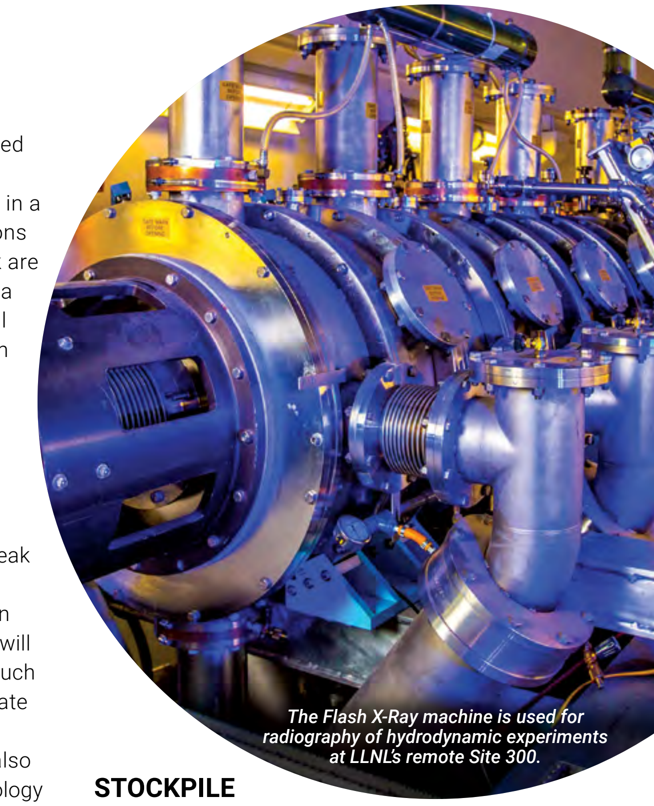
Livermore Computing suffered no interruptions in service due to COVID-19. All classified and unclassified computers were available throughout the year, together with user support. Sierra, the world's third fastest supercomputer on the TOP500 List, makes possible higher-fidelity, more predictive simulations of weapon performance and it provides the ability to run large ensembles of simulations to quantify uncertainties in predictions. This latest NNSA Advanced Simulation and Computing (ASC) Program machine achieves its tremendous speed by using graphics processor units together with central processing units in a heterogeneous architecture. Simulations of high importance for classified work are running more than 10 times faster on a per node basis. Sierra is providing vital support to the stockpile modernization efforts by making high-resolution 3D simulations routine.



LLNL is also preparing for the delivery in 2023 of El Capitan, NNSA's first exascale supercomputer. With its advanced computing and graphics processing units, El Capitan's peak performance is expected to exceed 2 exaflops (quintillion calculations per second). It will run complex simulations much faster than Sierra and operate with 4 times higher energy efficiency. The Laboratory also led ASC's Commodity Technology System CTS-2 acquisition project, which sets the path for the NNSA laboratories' cluster computer purchases for the next 4 or 5 years. The classified Magma cluster, LLNL's last procurement under CTS-1, arrived in 2020.

PULSED POWER MODULES FOR SUBCRITICAL EXPERIMENTS

Despite COVID-19 challenges, LLNL researchers assembled and qualified 16 prototype pulsed power modules for the Los Alamos (LANL)-led Scorpius project. Scorpius aims to generate four high-quality radiographic images in subcritical experiments at the Nevada National Security Site (NNSS). In July, four similarly designed megajoule-class pulsed power modules were delivered to NNSS for another novel diagnostic capability being developed by LANL, NNSS, and LLNL.



The Flash X-Ray machine is used for radiography of hydrodynamic experiments at LLNL's remote Site 300.

STOCKPILE STEWARDSHIP EXPERIMENTS

On May 7, 2020, LLNL's High Explosives Applications Facility conducted its first high-explosives experiment under new work controls to ensure worker safety in response to the COVID-19 pandemic. In mid-July, experimenters fired the first full-scale hydrodynamic test at Site 300's Contained Firing Facility (CFF). Both of these experiments supported stockpile modernization and successfully met all test objectives. Despite the pandemic and later regional wildfires, hazardous air quality, and extreme heat, nearly 50 experiments were conducted at Site 300 in FY 2020, including an integrated weapons experiment that provided key data that supported a critical design decision for the W80-4 LEP. CFF is the only facility in the NNSA complex that could accommodate the configuration and hazards associated with this experiment.

Experiments 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. JASPER experiments in FY 2020 studied an accelerated aged sample of plutonium equivalent to 270 years old.

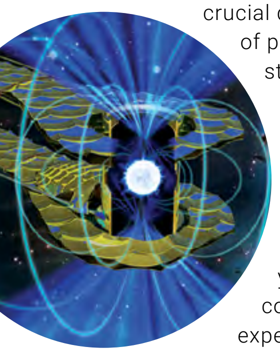
NATIONAL IGNITION FACILITY

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

An LLNL chemist prepares an anti-reflective coating used on NIF optics. The novel coating process was developed to overcome energy-robbing reflections from the rear surface of grating debris shields that protect other laser optics from experimental debris.

Experiments resumed at the National Ignition Facility (NIF) on April 26, 2020, following cessation of all but critical activities at LLNL in mid-March due to the COVID-19 pandemic. The NIF team worked closely with the Health Services Department and environment, health, and safety experts to rapidly develop new protocols to enable operations with the health and safety of workers set as the highest priority. Although limited by the downtime and current operational restrictions, NIF completed 327 experiments in FY 2020, including many critical tests in support of stockpile stewardship.

STOCKPILE STEWARDSHIP HED SCIENCE EXPERIMENTS



NIF high-energy-density (HED) science experiments in FY 2020 provided crucial data about the properties of plutonium and in support stockpile modernization programs. The NIF HED material science team studied the structure and strength of unshocked plutonium squeezed to the highest pressure yet achieved in a ramp-compression diffraction experiment. Other experiments, conducted by a Sandia National Laboratories team with LLNL scientists, collected data to validate codes used to assess weapons system survivability in hostile environments. Many tests jointly address challenges arising in stockpile modernization, underlying weapons physics issues, and the pursuit of inertial confinement fusion ignition. The data are used to improve and validate 3D simulation models of weapons performance.

PROGRESS IN PURSUING FUSION IGNITION

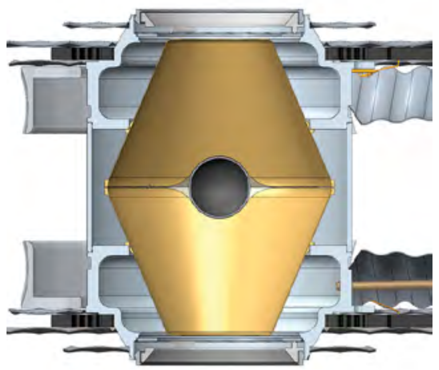
Achieving fusion ignition and energy gain at NIF is a grand scientific challenge. Significant progress is being made through a combination of data from experiments and improved simulation capabilities (see p. 14). Efforts this year directly supported NNSA's 2020 report to evaluate the path forward for inertial confinement fusion (ICF) research. Laboratory scientists completed a series of 3D simulations and massive ensembles of 2D simulations coupled to machine learning (ML) for the purpose of estimating uncertainties in predictions of ignition with multi-megajoule lasers. A series of 3D simulations was also run for an experimentally tested target design and the good agreement between simulations and experimental results across a range of observables provided reassuring validation. This work used LLNL's leading-edge ML tool that is helping to guide decisions about target design, future experiments to conduct, and upgrades to codes and diagnostic improvements.

NIF experiments have led to a greater understanding of the factors currently limiting overall performance. ICF implosions have been slightly off-center, which degrades hot-spot conditions and reduces fusion yield. The diagnostic windows in the holhraum (which surrounds the target capsule) were identified as an important contributing factor to this asymmetry. Redesign options are being studied. In addition, mixing of ablator material into the hot spot has been reduced significantly by decreasing the diameter of the deuterium–tritium fill tube from 10 micrometers to 2 micrometers. Methods such as adjustments to laser pulse shape, ablator versus fuel thickness, and dopants in the ablator are being considered to further reduce mixing. Experiments have also explored alternative designs of the hohlraum that would permit spherical implosion of larger target capsules and delivery of more energy to the hot spot. Recent tests resulted in record-setting neutron yields and show promise for further improvement.

IMPROVED DIAGNOSTICS

The Stockpile Stewardship Program is greatly benefiting from remarkable advances in diagnostics that support HED experiments at NIF. These improvements have made possible precision HED material science experiments studying equation of state (EOS), x-ray diffraction to study crystalline structure, and material strength. In addition, these new instruments are helping scientists develop a clearer understanding of what is happening in an ICF implosion. LLNL and partner laboratories and universities have designed and built an extensive suite of nuclear diagnostics. Together they aim to provide a comprehensive picture of implosion performance and have enabled the aforementioned recent advances.

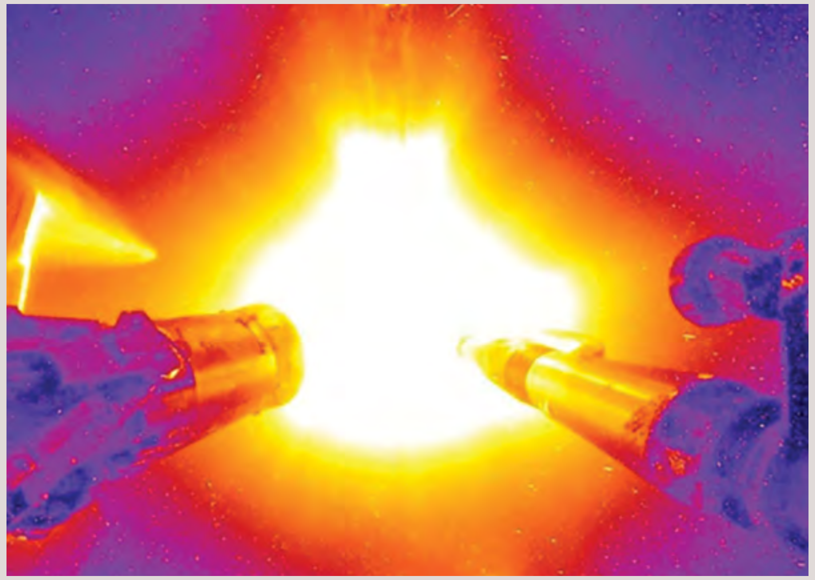
One especially important advance in FY 2020 was creation of the first time-resolved Compton radiograph of an ICF implosion. The technique entails use of the Advanced Radiographic Capability laser to create two intense bursts of high-energy x rays that Compton scatter off electrons in the fuel plasma. At different times (100 to 200 picoseconds apart) during the implosion, the diagnostic creates radiographs of the highly compressed fuel. Compton radiography will find many additional applications supporting stockpile stewardship and is ideal for studying the EOS of low-*Z* materials at extreme conditions.



The frustraum is one of several promising hohlraum designs under development to increase the energy delivered and improve symmetry of the fuel capsule (grey circle) implosion.

DISCOVERY SCIENCE AT NIF

Discovery Science experiments at NIF provide unique opportunities to explore the conditions found at the cores of giant planets and the interior of brown dwarfs (failed stars), and other energetic phenomena in the universe. In FY 2020, researchers used NIF to collide a pair of plasma flows traveling at 1,500 kilometers per second and create a supernova-remnant-like shock, which accelerates electrons to nearly the speed of light, as predicted. EOS experiments created the highest pressures thus far achieved in a controlled laboratory experiment. Scientists successfully conducted the first studies of matter at the conditions in the outer carbon layer of an unusual class of white dwarf stars, gathering data that agreed with current EOS models. In addition, a team of LLNL and Los Alamos researchers devised an innovative technique to apply data about plasma conditions created in ICF experiments to gain valuable insights into the makeup of brown dwarfs.



PLASMA SCIENCE DECADAL REPORT

In May 2020, the National Academy of Sciences, Engineering and Medicine released its *Plasma Science Decadal Report*, an assessment of the state and future of plasma sciences. NIF was prominently featured in the report as the source of multiple breakthroughs in HED plasma science. The report called for a national commitment to build the successors to today's largest experimental capabilities to continue U.S. leadership in plasma science and tackle identified grand challenges.

GLOBAL SECURITY

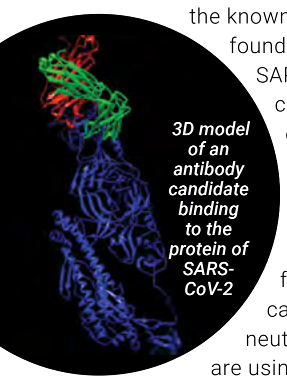
Reducing the threat from terrorism and weapons of mass destruction and enhancing global strategic stability

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.

LLNL researchers characterize nanolipoprotein particle vaccine formulations using a dynamic light-scattering instrument.

COVID-19 ANTIBODIES AND DIAGNOSTICS

In early February, Laboratory researchers rapidly responded to the COVID-19 crisis with a preliminary set of predicted 3D protein structures based on a previously peer-reviewed modeling process, the genetic sequence of SARS-CoV-2, and the known structure of a protein found in the virus that causes SARS. The predictions closely matched the later experimentally determined structures of the key protein. In continuing efforts, LLNL researchers have been searching for candidate antibodies capable of binding and neutralizing SARS-CoV-2. They are using a unique combination of artificial-intelligence virtual screening of antibodies to find possible candidates and simulations on world-class supercomputers to test the molecular interactions for efficacy. In a matter of weeks, this approach narrowed down the number of antibody candidates from 10^{39} possibilities to millions to about 20 initial candidates for synthesis and testing. LLNL's COVID-19 research results are being shared with scientists worldwide through a searchable data portal.



3D model of an antibody candidate binding to the protein of SARS-CoV-2

Three Laboratory-developed technologies are improving the speed and accuracy of diagnostic tests for SARS-CoV-2. In early May, Bio-Rad Laboratories Inc. announced that its SARS-CoV-2 Droplet Digital PCR test kit, based on a technology licensed from LLNL more than a decade ago, had been granted authorization for emergency use by the U.S. Food and Drug Administration. Cepheid Inc., another LLNL licensee, also received emergency use authorization for a diagnostic test based on rapid PCR thermocycling. In addition, the Lawrence Livermore Microbial Detection Array (LLMDA), a DNA-based array that analyzes for more than 12,000 known/sequenced microbes, was rapidly updated to also detect SARS-CoV-2. Laboratory scientists are now using it, in collaboration with healthcare professionals, to analyze samples from COVID-19 patients and identify co-infections with other viruses or bacteria.

VACCINES AGAINST PATHOGENS

Livermore is developing two vaccines based on an LLNL-developed biomedical technology, nanolipoprotein (NLP) particle platforms that can deliver vaccines and drugs inside the human body. NLPs are naturally occurring molecules that serve as structural mimics of cell membranes by self-assembling to provide a platform for connecting other molecules. The NLP platform makes it possible to develop customized vaccines to target a range of pathogens, including a broad-specturm coronavirus vaccine. With support from the National Institutes of Health, LLNL and two University of California campuses—Irvine and Davis—have teamed up to develop a vaccine for chlamydia, a sexually transmitted infection linked with ovarian cancer. In addition, the Laboratory and collaborators have developed a candidate vaccine for tularemia, a pathogen considered to be a biosecurity threat. The DOD Defense Threat Reduction Agency is supporting further development and testing to bring it to readiness for use.

LLNL ON THE WATCH AT MARS MISSION LAUNCH

LLNL's National Atmospheric Release Advisory Center (NARAC) and Nuclear Emergency Response Team have maintained full readiness during the pandemic. In July, two Laboratory scientists deployed to Cape Canaveral Air Force Station for the rocket launch sending the Perseverance rover to Mars with the rover's plutonium-238 nuclear power source on board. They watched lift off from the radiological control center to respond in the unlikely event that a problem occurred during launch. Since 1989, NARAC scientists have supported eight NASA missions in which the spacecraft has carried a radioisotope thermoelectric generator.

PROGRESS IN NUCLEAR NONPROLIFERATION

In FY 2020, the Low Yield Nuclear Monitoring program integrated explosion hydrodynamic codes with far-field energy propagation algorithms and atmospheric transport models and developed new machine learning methods. This advance resulted in improved understanding, prediction, and detection of seismic, acoustic, electromagnetic, and radionuclide signals from underground nuclear explosions. In addition, with LLNL leadership, the program began development of a test bed at the Nevada National Security Site to support integrated field experiments, which are designed to strengthen U.S. capabilities to detect and characterize low yield and evasively conducted underground nuclear explosions. Other efforts aimed to strengthen nonproliferation arms control regimes. During the pandemic, LLNL provided technical experts and presentations at two virtual meetings hosted by the Comprehensive Nuclear-Test-Ban Treaty Organization. In addition, Livermore scientists developed and participated in an interactive session at a ministerial-level event held by the International Atomic Energy Agency.

BRAIN-ON-A-CHIP IN 3D

Laboratory researchers successfully created a 3D "brain-on-a-chip" microelectrode array platform in which they were able to keep hundreds of thousands of human-derived neurons alive, networked, and communicating in a 3D gel. The electrical spikes and bursts were non-invasively recorded for up to 45 days using LLNL-developed, thin-film microelectrode arrays. An important step beyond previously-developed 2D brain-on-a-chip platforms, a 3D culture model can more fully replicate the physiology and functionality of the human brain to understand how it functions and how chemicals or other stimuli can affect it. The team also developed a device capable of reproducing the blood–brain barrier (BBB) in both 2D and 3D, which could enable future devices to be more physiologically relevant. The BBB keeps potentially harmful molecules from entering and affecting the central nervous system but makes it difficult to get a therapeutic drug across the threshold. Laboratory scientists were able to introduce cells and nutrients into the device and remove waste products without stopping the flow. In addition to successfully creating the BBB, the researchers showed the barrier system was responsive.

An engineer examines cells established within the brain-on-a-chip.

FORENSIC SCIENTISTS EARN TWO "A" GRADES

In FY 2020, for the tenth straight year, scientists at the Laboratory's Forensic Science Center (FSC) scored an "A" grade in the environmental proficiency test administered by the Organisation for the Prohibition of Chemical Weapons (OPCW). The Livermore researchers correctly identified all nine reportable spiked chemicals under the test's scenario of samples collected from a laboratory accused of performing chemical weapons research. Since 2003, the FSC has maintained OPCW accreditation as a designated laboratory for sample testing. LLNL has also been an OPCW-designated laboratory for the analysis of biomedical samples since 2016, when the certification process started. In 2020, the FSC also passed its biomedical proficiency test with an "A" grade.

ENERGY AND ENVIRONMENT

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


Enhanced Geothermal Systems team members install instrumentation for an underground experiment testing means to convert heat from dry rock into low-carbon-emitting power.

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

BOUNDING CLIMATE CHANGE ESTIMATES

An international team of scientists, including researchers from LLNL, published a multi-year study that narrowed the bounds of uncertainty in the effect increased atmospheric carbon dioxide (CO_2) would have on Earth's climate. Estimates of the global equilibrium temperature have been between 2.7–8.1˚Fahrenheit higher for a doubling of CO_2 compared to preindustrial levels. This comprehensive analysis of climate sensitivity concluded that the world would likely experience between 4.1–8.1˚F warming with a doubling of CO_2 and that there would be less than a 5 percent chance of warming less than 3.6˚F. Livermore's contribution included dealing with climate feedbacks that amplify or diminish warming trends and cloud feedbacks, in detail, which are the greatest source of uncertainty. LLNL scientists are recognized leaders in cloud processes research, including their diagnosis with observations, their parameterization and evaluation in climate models, and their response to climate change.

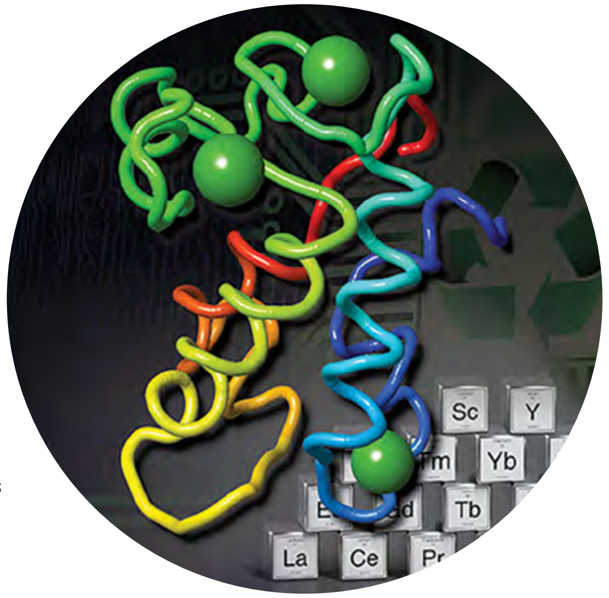
MITIGATING CLIMATE CHANGE

Working in a deep underground tunnel at the Sanford Underground Research Facility, a team of DOE researchers, the Enhanced Geothermal Systems (EGS) Collab, is learning how to convert heat from dry rock into clean, low-carbon-emitting power. A borehole injects pressurized water, which migrates deep underground through rock fractures to another borehole that brings the heated water to the surface for energy generation. DOE's Frontier Observatory for Research in Geothermal Energy (FORGE) is a test bed for studying key mechanisms in creating and sustaining fracture networks in rock formations that would be needed for a viable large-scale EGS. As part of the EGS Collab effort, LLNL is providing expertise in high-performance computing (HPC) to design experiments, build integrated data sets from observations, and perform simulations that compare experimental data to models of fluid-induced fracturing of the subsurface rock. Livermore is also contributing "edge computing" to the project—distributed computing and data storage made available closer to the users' location for more timely access to data.

FORGE is one of many ongoing technology development projects under way at Livermore to mitigate climate change and to capture, sequester, and convert CO_2 into useful products and fuels. LLNL's Carbon Initiative aims to identify and develop solutions to enable global-scale CO_2 removal from the atmosphere and hit global temperature targets.

RECOVERING RARE EARTH ELEMENTS

Laboratory researchers and collaborators have designed a new process, based on a naturally occurring protein, that could selectively extract and purify rare earth elements (REE) from low-grade sources. REEs are essential for U.S. competitiveness in clean energy industries because they are used in many devices important to a high-tech economy and national security. The protein, lanmodulin, enables a one-step extraction and purification of REEs from complex metal mixtures, including electronic waste and coal byproducts. Researchers have also developed a scalable biosorbent material—microbe-embedded polymer beads—that could be used to recover REEs from end of life products that use neodymium magnets. The microbeads selectively adsorb REEs and can be reused after desorption.



A small protein, lanmodulin, is a bio-sourced alternative to extract, purify, and recycle rare earth elements from various sources, including electronic waste.

PARTNERSHIPS WITH U.S. INDUSTRY

In FY 2020, DOE announced two rounds of award-winning projects under the High Performance Computing for Energy Innovation (HPC4EI) Program. Led by LLNL for DOE, the program supports public–private collaborations that leverage the HPC capabilities at the national laboratories to help U.S. industry improve energy efficiency and streamline manufacturing processes. These awards include funding for six projects that are led or co-led by Livermore researchers working with industry partners. Three projects combine Laboratory expertise in artificial intelligence and HPC simulations. One, in particular, will use an experimentally tested data set of roughly 100 molecules and molecular dynamics calculations to train an algorithm that predicts corrosion inhibition performance of organic molecules—greatly reducing the experimental time needed to develop products. Other projects aim to lower the cost of synthetic fuel production, reduce energy consumption and improve glassmaking, and further the development of next-generation lightweight high-strength steel.

CARBON NEUTRALITY IN CALIFORNIA

In a groundbreaking study, LLNL scientists identified a robust suite of technologies to help California become carbon neutral by 2045. *Getting to Neutral: Options for Negative Carbon Emissions in California* thoroughly assesses the advanced carbon reduction technologies now available, their costs, as well as the tradeoffs necessary to reach the state's decarbonization goal. The study team identified a portfolio of approaches for achieving greater than 125 million tons per year of negative emissions for California by 2045. They also evaluated the scope of state and private investment to best achieve the goal. The report, funded by the the Livermore Lab Foundation with grant support from the ClimateWorks Foundation, serves as a resource for policymakers, government, academia, and industry.

CARBON NANOTUBE MEMBRANES

Membrane-based systems have great potential in applications such as desalination, pharmaceutical recovery, and waste treatment. One team of LLNL researchers has created carbon nanotube pores that self-insert into membranes to form artificial biological water channels with enhanced flow and strong ion rejection. These tiny pores are just 0.8 nanometers in diameter. In comparison, a human hair is 60,000 nm across. Another team created the largest defect-free membrane to date with high density, single-walled nanotubes, which were grown on 4-inch silicon wafers.

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

In response to a potential surge in demand for ventilators due to the COVID-19 pandemic, Laboratory mechanical engineers and technicians tested and validated simple ventilator prototypes that could be easily assembled from readily available parts.

Through its science and technology 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.

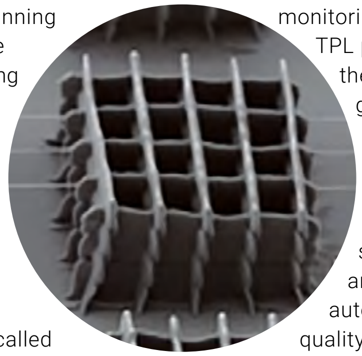
MECHANICAL VENTILATORS

Quickly responding to the COVID-19 crisis, an LLNL team of engineers and scientists self-assembled to address the shortage of mechanical ventilators due to the COVID-19 pandemic. Working long hours with clinicians, doctors, and ventilator manufacturers, the team came up with two promising prototypes in the span of just two weeks. The selected option is a simple design for quick and easy assembly. It contains parts that are not being used by commercial ventilator manufacturers to avoid disrupting already thin supply chains. Under a quickly established Cooperative Research and Development Agreement, LLNL and medical device startup company BioMedInnovations (BMI) LLC produced several iterations of what would become BMI's SuppleVent™. In early June, the U.S. Food and Drug Administration authorized the ventilator for emergency use. The suitcase-sized ventilator has a simple user interface and large LCD screen for monitoring pressures and air flow. It can operate in a continuous ventilation mode and can adapt to patients who spontaneously breathe on their own.

ADVANCES IN ADDITIVE MANUFACTURING

Combining high-fidelity computer simulations with ultra-high-speed x-ray imaging, researchers at LLNL devised a strategy for reducing defects in parts built through laser powder bed fusion additive manufacturing. This metal 3D-printing process produces a spatter of powder particles ejected from the laser's path—potentially leading to pore formation and defects on the part. The team compared the results with virtual experiments using a "digital twin" of the process, which led to development of a scanning strategy that adjusts the laser's power output along the path to improve overall part reliability.

Another Laboratory team developed a scalable method of nanoscale 3D printing up to 1,000 times faster than previous methods. The improved process, called femtosecond two-photon lithography (FP-TPL) potentially opens the door to cost-effective, large-scale 3D nanoprinting. With FP-TPL, the process is parallelized by using a broadband, ultrashort-pulsed laser, vastly improving throughput and enabling smaller feature size. The LLNL engineers produced the thinnest nanowires ever printed by any similar 3D-printing system—about 400 times finer than human hair. Machine learning was also applied to address monitoring of part quality during TPL printing and determining the right light dosage for a given material. The learning algorithm was trained on thousands of video images of builds to identify the optimal parameters for settings, such as exposure and laser intensity and to automatically detect part quality at high accuracy.

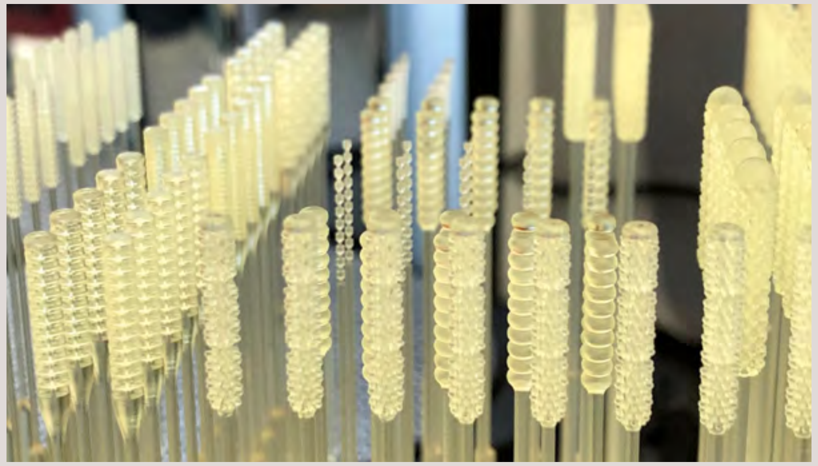


A printed cubic structure with nanoscale features

MATERIAL DYNAMICS AT THE NANOSCALE

Simulations and experiments at the nanoscale provide Laboratory scientists insights into the dynamic properties of materials, contributing to scientific discovery and finding diverse mission applications. For example, an LLNL-led team performed atomistic simulations to find out how metals hardened when deformed. The exact root cause was unknown. Stretching the limits of supercomputer simulation capabilities, the team stressed 300 million atoms and watched their motion for tens of nanoseconds. They found that at all stages of the process, hardening is a direct result of crystal rotation under uniaxial strain. Other LLNL researchers took high-speed videos during the laser powder-bed fusion process to visualize the ductile-to-brittle transition in 3D-printed tungsten in real-time. They observed how microcracks initiated and spread in the metal. Tungsten is a popular choice for applications involving extreme temperatures; however, additive manufacturing with tungsten is challenging. The team is using the results together with simulations of the process to devise means to mitigate microcracking.

LLNL researchers and collaborators successfully obtained the first nanoscale video of copper deforming under extremely high strain rates, part of an Army-funded project aimed at designing next-generation armor. Combining a specially designed straining apparatus with LLNL's Movie Mode Dynamic Transmission Electron Microscope, the researchers pulled apart copper samples at strain rates comparable to the impact of a bullet. With up to nine images in each experiment, they studied at the nanoscale the metal's deformation as it happened. Another research team used atomic resolution scanning transmission electron microscopy to observe multiple grain-boundary structures in copper as they transform from one form to another. Grain boundary phase transitions open up new strategies to invent better materials.



RESPONDING TO THE NATIONAL SHORTAGE OF SWABS

To address the national shortage of nasopharyngeal swabs, Laboratory engineers formed an ad hoc, rapid response team that has tested more than a dozen novel, 3D-printed nasal swab designs (hundreds of individual swabs) from a grassroots coalition of commercial and academic partners. The mechanical tests performed at LLNL—simulating how the swabs printed at the Advanced Manufacturing Laboratory might be used in a clinical environment—provided valuable feedback that improved the designs, enabling them to meet requirements for COVID-19 testing.

PARTNERING TO FIGHT CANCER

A Livermore-led team was awarded Best Paper at the SC19 supercomputing conference in November 2019 for work sponsored by the 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 on a macroscale, as well as on a molecular scale. Importantly, a machine-learning algorithm saves a vast amount of compute time by determining which lipid "patches" are interesting enough to more closely examine with micromodel simulations. Scientists ran nearly 120,000 simulations on the Sierra supercomputer, using 5.6 million general-processor-unit hours of compute time and generating a massive 320 terabytes of data. The macro-to-micromodel simulations allowed researchers to see how 300 different RAS proteins interacted on a cell membrane, generating data that can be tested experimentally to ensure the models are representative of actual biological results.

Award-winning SC19 supercomputing team

In addition, an LLNL–Duke University research team paired 3D bioprinting and computer modeling to examine cancer spread in blood vessels. Tumor cells tend to escape from a primary tumor and travel through the circulatory system. They eventually attach to the vascular endothelium (cells that line the interior surface of a blood vessel wall), spreading the cancer. LLNL researchers printed vasculature out of human cerebral endothelial cells, covering the walls of channels in a device. Breast cancer cells were then injected into the device to see how and where the tumor cells began to metastasize. The results were then compared to 3D

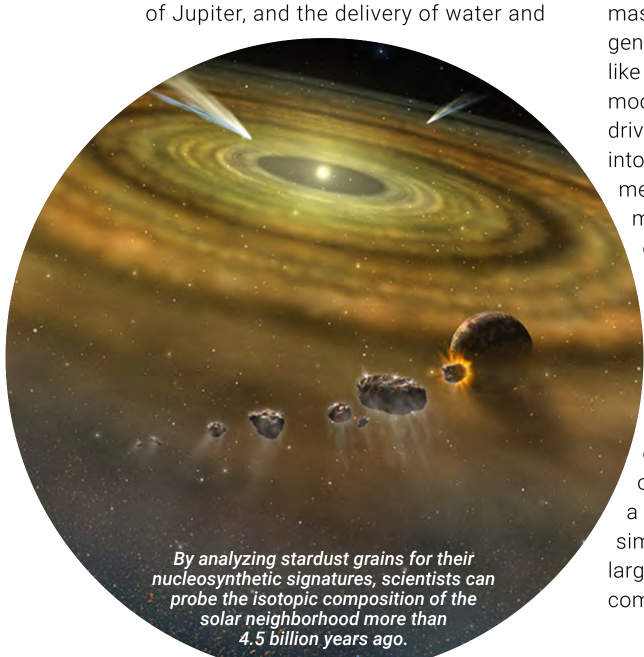
SCIENCE AND TECHNOLOGY

computational simulations replicating experimental geometries, enabling accurate fluid dynamics analysis of the attachment conditions.

UNDERSTANDING THE SOLAR SYSTEM

A Laboratory scientist and collaborators dated micrometer-sized silicon carbide stardust grains extracted from the Murchison meteorite. The team was surprised to find that some of the grains formed anywhere from 1.5 million to 3 billion years before the formation of our solar system. Stardust grains are the oldest datable solid samples available for laboratory study and provide invaluable insight into the presolar chronology of our galaxy. By analyzing these stardust grains for their nucleosynthetic signatures, scientists can probe the isotopic composition of the solar neighborhood more than 4.5 billion years ago, when it was a diverse place with stars at various evolutionary stages. Many of the parent stars of the grains were even more evolved than our solar system. In another LLNL-led study, the researchers considered the fundamental dichotomy in the isotopic composition (containing carbon or not) of meteorites and gained new insights into the dynamics and large-scale structure of the solar protoplanetary disk, the formation and growth history of Jupiter, and the delivery of water and highly volatile species to Earth.

The Cerebras Systems CS-1 artificial intelligence (AI) computer is now paired with Lassen, a quarter-size unclassified companion to Sierra, making LLNL the first institution to integrate the cutting-edge AI platform with a large-scale supercomputer.



By analyzing stardust grains for their nucleosynthetic signatures, scientists can probe the isotopic composition of the solar neighborhood more than 4.5 billion years ago.

Other LLNL scientists concluded that massive compressive shearing forces generated by the tidal pull of Jupiter-like planets on their rocky ice-covered moons may form a natural reactor that drives simple amino acids to polymerize into larger compounds. These extreme mechanical forces strongly enhance molecule condensation reactions, opening a new arena of possibilities for the chemical origins of life on Earth and other rocky planets. As a test case, the team focused on glycine, the simplest protein-forming amino acid found in astrophysical icy bodies, and developed a new computer modeling approach based on laboratory experiments. Above a certain pressure, every shearing simulation predicted the formation of large polymeric molecules and surprisingly complex chemistry.

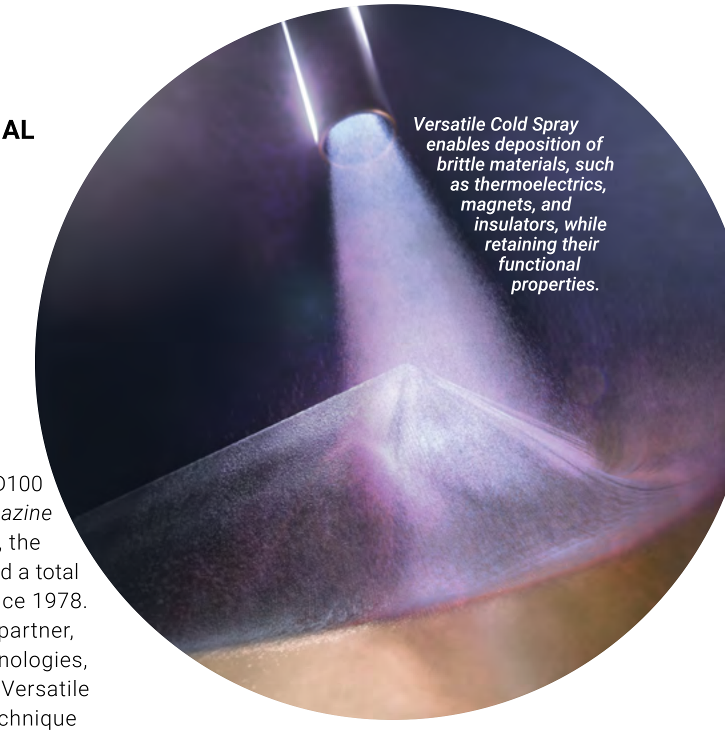
SUPERCOMPUTING WITH AI

Four of the world's top 100 computer systems (according to the TOP500 list) are located at LLNL. Ranked No. 14 on the list, Lassen is now integrated with the 1.2 trillion transistor Wafer-Scale Engine chip—designed by Cerebras Systems specifically for machine learning (ML) and artificial intelligence (AI) applications. Through the support of NNSA's Advanced Simulation and Computing Program, LLNL is the first institution to integrate this world's largest computer chip with a large-scale supercomputer to support a radically new type of computing called cognitive simulation. The chip will greatly benefit early applications of cognitive simulation at the Laboratory, which include inertial confinement fusion experiments performed at the National Ignition Facility, material science studies, and rapid design of new prescription drugs for COVID-19 and cancer (through the Accelerating Therapeutic Opportunities in Medicine, or ATOM project).

Expertise in AI and ML is finding applications in many other program areas. For example, a team led by an LLNL computer scientist developed and applied a novel deep learning approach to improve the reliability of models designed for predicting disease types from diagnostic images (and provide a medical expert an accurate interpretation). Another interdisciplinary LLNL team is developing ML techniques to dramatically decrease the time and effort required to test and evaluate the performance of candidate materials such as TATB, an insensitive high explosive used in stockpile modernization. Yet another application is assisting early discovery of proliferation activities. In addition, two papers authored by Laboratory scientists and collaborators were presented at the 2020 International Conference on Machine Learning, one on uncertainty quantification and the other on meaningful text generation.

EXPANDING INDUSTRIAL PARTNERSHIPS

LLNL is benefiting the U.S. economy with innovative technology and methods. In FY 2020, LLNL obtained 198 new patents, asserted 78 new copyrights, and executed 80 new licenses. Licensing income for the year totaled approximately $4.6 million. Among many honors, LLNL earned an R&D100 award from *R&D World Magazine* and with this year's results, the Laboratory has now captured a total of 170 R&D 100 awards since 1978. Working with an industrial partner, TTEC Thermoelectric Technologies, researchers developed the Versatile Cold Spray (VCS), a new technique for depositing on industrial parts with complex shapes a broad range of brittle and glassy materials, including functional materials such as thermoelectric devices, which transform heat into useful energy. LLNL researchers also won a national Federal Laboratory Consortium (FLC) award for Excellence in Technology Transfer for developing the IMPEDE® Embolization Plug that prevents continued blood flow to diseased vessels. In addition, LLNL received two FLC regional awards in 2020, bringing the total to 38 awards for technology transfer from the FLC since 2007. The creation of the Advanced Manufacturing Laboratory brought LLNL a Best in Class Award from the DOE Technology Transfer Working Group.



Versatile Cold Spray enables deposition of brittle materials, such as thermoelectrics, magnets, and insulators, while retaining their functional properties.

In addition to industrial partnering success with the mechanical ventilator (see p. 12), LLNL's Innovation and Partnerships Office is making available many other relevant technologies and capabilities under special non-exclusive licenses to help address the COVID-19 pandemic. These royalty-free licenses aim to expedite access to the Laboratory's technology and software. LLNL also is part of DOE's National Virtual Biotechnology Laboratory and provides the COVID-19 High Performance Computing Consortium exceptional computing resources with memory and data storage capabilities optimized for data-intensive COVID-19 research and pandemic response (see p. 8). Visit the LLNL COVID-19 Research and Response website (www.llnl.gov/coronavirus) for more information.

LLNL TELESCOPES FOR NANOSATELLITES

LLNL and Tyvak Nano-Satellite Systems Inc. have entered into a Cooperative Research and Development Agreement (CRADA) to develop innovative compact and robust telescopes for nanosatellites. The CRADA will combine LLNL's Monolithic Telescope (MonoTele) technology with Tyvak's expertise in producing high-reliability spacecraft. The MonoTele technology provides imaging for nanosatellites, about the size of a large shoebox and weighing less than 22 pounds, and microsatellites, about the size of a dorm refrigerator and weighing up to several hundred pounds.

SAFE, SECURE, AND SUSTAINABLE OPERATIONS

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

The Laboratory's new Emergency Operations Center will consolidate Livermore's emergency response functions and facilitate better collaboration with external emergency-response partners.

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.

RESPONDING TO THE PANDEMIC

The Laboratory responded quickly and effectively to the COVID-19 pandemic, enabling mission work to continue during these challenging times. At the end of January, when the COVID-19 threat was emerging, LLNL stood up its Pandemic Response Team and began moving to a safe standby operational posture on March 16th. Only the personnel needed to monitor Laboratory security, health of facilities, critical programmatic equipment, and to fulfill regulatory or other ongoing requirements had a routine presence onsite. Employee leave and work reporting options to staff and capabilities for wide-scale telecommuting were quickly established. Protocols and practices were developed and implemented, ensuring onsite workers would remain healthy.

On March 24th, Livermore received NNSA concurrence to resume additional onsite work. The restarted activities initially focused on core national security missions and progressed with gradual, deliberate resumptions until LLNL reached a state of *Reduced Mission-Critical Operations* on March 31st. By mid-May, a *Mission-Critical Operations* status was achieved. The Laboratory continued to resume and augment activities consistent with programmatic priorities and local conditions. *Limited Operations* was reached in early June and since early July the Laboratory has been operating effectively in *Normal Operations with Maximum Telework* status, with the daily onsite population reaching around 2,700 (roughly one-third full staff). Effective controls have minimized COVID-19 cases among the workforce and limited onsite transmission. LLNL has been able to continue working, with minimal impact to commitments and milestones.

Modifications to the National Ignition Facility control room include the erection of spray barriers and other steps to ensure social distancing.

SAFE AND EFFECTIVE OPERATIONS

The health and safety of LLNL personnel has been paramount in the management decisions about the pace of increasing onsite activity. Health Services developed and implemented new protocols needed to ensure proper case management and contact tracing, and created a database to manage critical case iinformation. In concert, LLNL's biosafety team stayed abreast of the evolving guidance from health agencies—providing training courses, FAQs, risk assessments, and recommendations for face coverings and disinfection materials. Respirator Services worked to fit test and issue new models of respirators to workers. To address virus-related risks, new work controls were established that included administrative controls to limit population density, physical modifications in areas requiring long-term proximity, and work guidelines on personal protective equipment and social distancing requirements.

Within a week after moving to a safe standby operational posture, an extraordinary effort by LLNL information technology (IT) teams provided thousands of employees the ability to telecommute and work remotely. Researchers were able to maintain productivity, and major programmatic delays were mitigated. In spite of the pandemic, the Laboratory was able to sustain operations effectively and efficiently and meet mission commitments with high-quality deliverables. LLNL worked closely with NNSA's Livermore Field Office to ensure that resources were allocated to maximum benefit in meeting FY 2020 program objectives. The necessary work adjustments and newly added IT capabilities have led to a substantial advancement in the efficiency of operations, safety, security, and environmental management and state-of-the-art business practices and processes. The Laboratory now operates with a new robust, secure virtual private network (VPN) for telecommuting—greatly enhancing work environment flexibility for employees.

INVESTING AND REINVESTING IN INFRASTRUCTURE

In 2019, LLNL established an institutional Project Management (PM) Office, which provides modern PM processes and procedures to ensure on-cost, on-schedule project execution. In FY 2020, the $34-million Expand Electrical Distribution System Project was completed ahead of schedule, nearly $1 million under budget, and with no reportable injuries. New 15-kilovolt power cables were installed to eliminate single-point failures to current facilities and support planned development. The project involved excavating a trench more than 2 miles long and removing more than 20,000 cubic yards of soil. Other large scope projects, described on p. 18–19, are tracking to cost and schedule objectives. After a temporary halt in March, all mission critical construction activities and other essential programmatic work were restarted safely.

The Laboratory continuously upgrades facilities and equipment to help carry out LLNL's mission safely and effectively. For example, an LLNL construction team completed a five-year major upgrade for the Laboratory's wastewater monitoring and diversion system, known as the Sewer Monitoring Complex (SMC). The SMC is critical infrastructure and provides monitoring capability for LLNL to assure compliance with permitted sanitary sewer discharge limits as well as the capability to divert contaminated effluent in an emergency.

Work crews pose beside the final excavation needed to complete the Expand Electrical Distribution System project.

RADIOACTIVE WASTE REMOVAL FROM LLNL

In September 2020, drums of meticulously characterized and packaged highly radioactive transuranic (TRU) waste began to be shipped to the DOE Waste Isolation Pilot Plant (WIPP) at Carlsbad, New Mexico. Removal from LLNL of accumulated TRU waste, generated from research and development activities, has been a key NNSA goal for several years. WIPP Central Characterization Program personnel established three waste characterization capabilities in Livermore's Radioactive and Hazardous Waste Management facilities. In 2019, LLNL was certified that its processes met stringent WIPP requirements. TRU waste characterization concluded in March 2020. A total of 624 drums and 13 standard waste boxes had been sent when the final shipment departed in October.

MANAGING FOR THE FUTURE

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

(from left) Livermore Field Office manager Peter Rodrik, Deputy Director for S&T Patricia Falcone, former National Nuclear Security Administration (NNSA) administrator Lisa E. Gordon-Hagerty, Deputy Director Linda Bauer, and Laboratory Director William Goldstein celebrated the NNSA 20th anniversary in September 2020.

FY 2020 was a year of engagement with sponsors and stakeholders, providing technical leadership in key mission areas, and building for future successes.

STRATEGIC LEADERSHIP

LLNL is strongly focused on its national security mission and works closely and effectively with DOE and NNSA, as well as other sites in the NNSA complex, research partners, and other work sponsors to ensure accomplishment of program objectives. Our strategic plans closely align with NNSA's strategic vision and are central to its success. With the W80-4 life-extension and the W87-1 modernization programs, Livermore is working with NNSA's production facilities to bring modern manufacturing processes into the NNSA nuclear security enterprise (NSE) to make it more cost effective, agile, and responsive. The combination of high-performance computing simulations, experimental testing, and machine learning that are supporting stockpile modernization have many other mission applications.

LLNL's Senior Management Team met in June to discuss current issues, strategic approaches to position the Laboratory for continued success in meeting mission requirements, and research opportunities.

Livermore is also providing leadership to NNSA in the development and application of data-intensive, mathematical models to support decision making regarding the stockpile, workforce, infrastructure, and costs. Based on NSE data collected over the past 15+ years, these models are used to evaluate the NNSA program of record for customers across the NSE. They also have been instrumental in planning investments to modernize the NSE's aging infrastructure. Detailed consideration must be given to the condition of facilities and equipment, their importance to mission success and consequences of their failure, whether to refurbish or replace, and managing yearly costs in the face of constrained budgets.

NEW FACILITIES AND MODERNIZED INFRASTRUCTURE

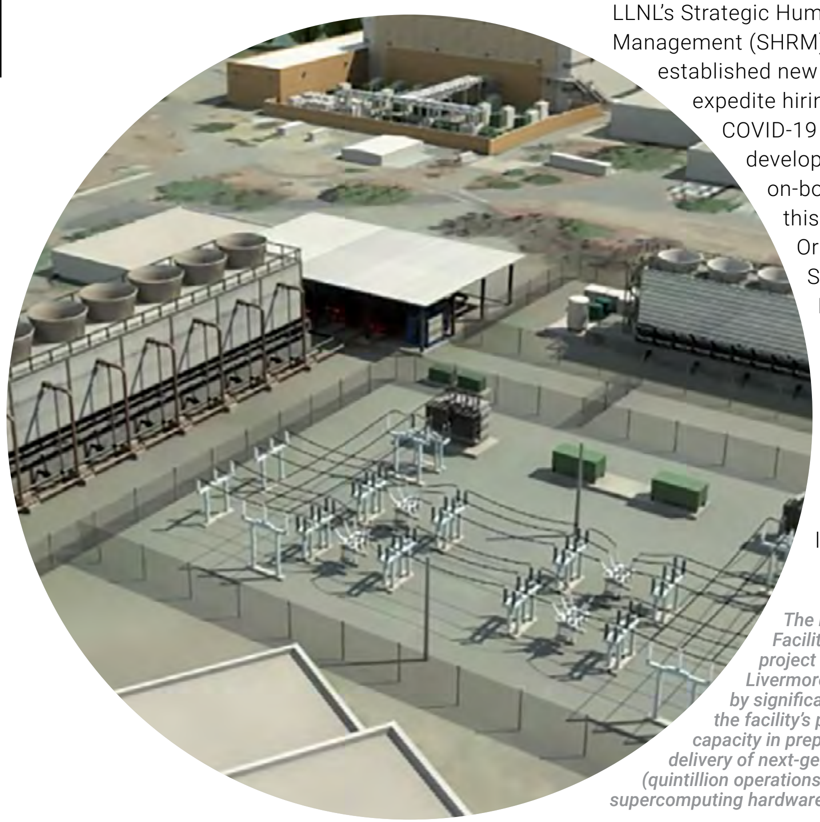
In early FY 2020, doors opened for research collaborations at LLNL's Advanced Manufacturing Laboratory, sited at the Livermore Valley Open Campus. The new 14,000-square-foot one-of-kind facility houses leading-edge additive-manufacturing machines and equipment. In addition, a ribbon-cutting ceremony officially opened the Applied Materials and Engineering (AME) campus during the NNSA administrator's visit to LLNL at the end of FY 2020. Created through a novel approach to infrastructure modernization featuring area plans, the campus includes three new buildings together with several existing facilities. It will significantly reduce the existing site footprint by consolidating capabilities that are critical to stockpile modernization. AME will feature a polymers laboratory; advanced manufacturing including 3D printing, brazing, and welding; and office and collaborative space.

In June, construction began 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 in 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 capability for the W80-4 life-extension and W78-1 modernization programs. In addition, a groundbreaking ceremony in September launched construction of a new Emergency Operations Center (EOC). The 20,550-square-foot facility will consolidate emergency response functions and provide 24/7 operations. The EOC is an NA-50 Pilot Project to streamline commercial-like Line Item projects in the $20–$50-million total cost range. It is designed to survive earthquakes and will be self-sustaining for up to 72 hours before needing resupply. City, county, state, and federal emergency personnel also will have access to the new facility.

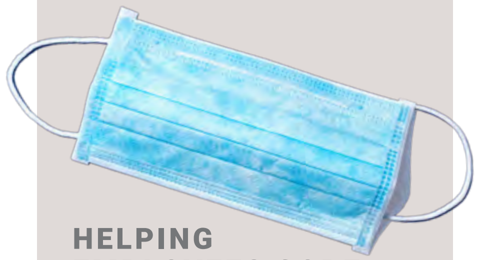
A CHANGING WORKFORCE

An outstanding workforce is Livermore's principal strength. Recruiting, training, and retaining the best and brightest are top priorities at LLNL to sustain excellence at a time of rapid change in our workforce. Many senior staff members have been retiring and nearly 50 percent of the core staff have been hired within the last six years. The incoming employees bring impactful new ideas to their jobs, work with integrity and zeal, and thrive in an inclusive work environment. In December 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 on their jobs and work environments.

Despite the ongoing pandemic, FY 2020 was a successful year of hiring. LLNL's Strategic Human Resources Management (SHRM) department established new processes to expedite hiring and after COVID-19 struck, quickly developed means to virtually on-board new staff. Using this New Employee Orientation process, SHRM brought into LLNL about 450 new employees, more than 60 postdoctoral fellows, nearly 400 students and faculty scholars, and supplemental labor personnel.



The Exascale Computing Facility Modernization project will upgrade the Livermore Computing Center by significantly expanding the facility's power and cooling capacity in preparation for delivery of next-generation exascale (quintillion operations per second) supercomputing hardware.



HELPING EMPLOYEES COPE

Recognizing the importance of the well-being of Laboratory staff and their families, LLNL has offered employees help in managing health care issues and difficult work/life balance demands during the pandemic. Authorized leave was made available for use by employees at the onset of local COVID-19 shelter-in-place orders. Staff were allowed to be advanced 80 hours of sick leave if needed and were given latitude to use more of their sick leave time to care for others. The Lab Employee Services Association (LLESA) "went virtual" with many of their offered activities and in July, more fully opened the LLESA Children's Center, which operates in compliance with strict local and state restrictions and licensing guidelines.

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 2020 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. Eight FMRs, both virtual and in-person, were completed in FY 2020 in topical areas ranging from Commercial Practices to Oversight During the Pandemic. Recommendations provided by Board committees, ERCs, and FMRs have led to substantive responsive actions.

COMMUNITY CONNECTIONS

Partnering with our neighbors through science education and charitable giving

Participants posing in T-shirts provided to them (together with workshop supplies) are among the more than 150 middle- and high-school girls that took part in a virtual Expanding Your Horizons conference.

The Laboratory is an active member of local communities, offering a wide variety of activities to enhance science, technology, engineering, and mathematics (STEM) education. Outreach has a wider scope than just 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. In FY 2020, many of the Laboratory's efforts went virtual to keep these vital community connections firmly in place.

STEM GOES VIRTUAL

In December 2019, LLNL and Las Positas College celebrated the start of the tenth 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. This seminar series and other STEM outreach efforts were forced to go virtual after the COVID-19 outbreak.

A 2020 National Ignition Facility (NIF) summer scholar poses with her laptop sporting the NIF logo from her home, where she remotely conducted analyses for the Neutron Imaging System project.

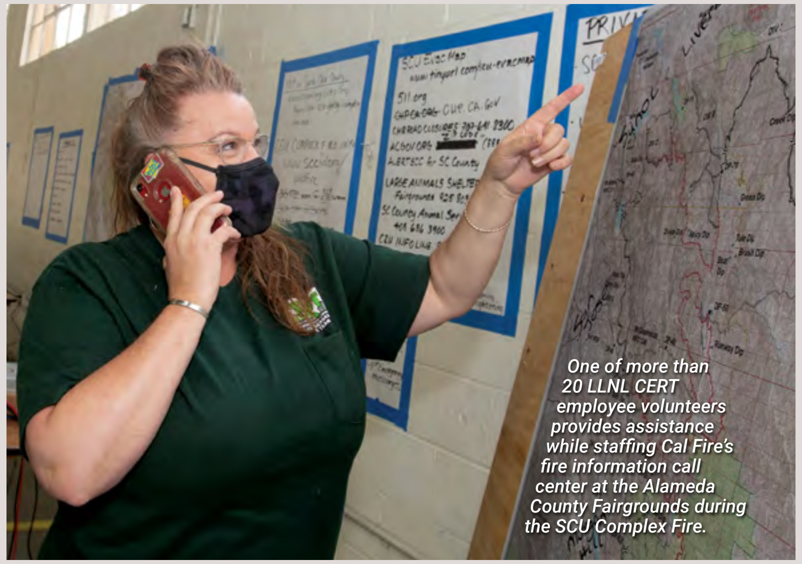
For example, LLNL continues to sponsor Expanding Your Horizons, held several times a year throughout the San Francisco Bay Area, to introduce STEM careers to middle- and high-school girls. These free events pair women scientists and engineers with students to conduct hands-on demonstrations of science and discuss career paths. This year, more than 150 girls joined the virtual conference, participating in workshops and activities with supplies received in a special drive-thru pickup. Similarly, this year's Data Science Challenge with the University of California (UC), Merced was an all-virtual offering. The two-week challenge involved 21 Merced students who worked from their homes through video conferencing and chat programs to develop machine learning models.

LLNL also successfully pivoted its annual summer student program to an entirely online "virtual" experience. Teams quickly organized and devised ways to hire students remotely, onboard students virtually, and provide them secure cloud-based computing as well as enriching activities. These efforts enabled Livermore to engage approximately 500 students over the summer, enabling them to continue their career growth and the Laboratory to sustain an essential workforce pipeline.

VIRTUAL TOURS, CLASSROOM VISITS, AND EXPERIMENTS

The Laboratory's education outreach begins with fourth and fifth graders. In a typical year, more than 12,500 students, along with their chaperones, are introduced to scientific concepts through the Fun With Science program. The ever-popular Fun With Science 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 labs and interact with scientists at popular tour stops such as the Additive Manufacturing Laboratory or the National Ignition Facility.

In FY 2020, these activities have gone virtual (see st.llnl.gov/sci-ed/class-visits-resources). Fun With Science segments were added to LLNL's YouTube page, allowing students and teachers to have this educational resource available at the click of a button. High school teachers are invited to bring their class for a virtual visit to one of our premier facilities at the Laboratory. In addition, LLNL partnered with the Livermore Lab Foundation and the Livermore Valley Joint Unified School District for "Ask a Scientist" events, virtually bringing Livermore scientists into classrooms and giving hundreds of local students a stimulating learning experience. An innovative "Physics with Phones" learning series offers downloadable physics lessons and experiments for high school students and teachers.



One of more than 20 LLNL CERT employee volunteers provides assistance while staffing Cal Fire's fire information call center at the Alameda County Fairgrounds during the SCU Complex Fire.

LLNL'S CERT TEAM ANSWERS THE CALL

In August, a lightning-storm-sparked conflagration threatened communities in the Livermore valley. CalFire, through the State's Office of Emergency Services, reached out to LLNL's Community Emergency Response Team (CERT) for assistance. Team members are trained employee volunteers ready at a moment's notice to support local first responders. More than 20 Laboratory volunteers answered phone calls from concerned residents, reaching 800–1,000 calls per hour at its peak, and helped with food delivery and training activities. CERT members worked 57 six-hour shifts, including overnights, with many individuals volunteering more than 30 hours.

An LLNL scientist presents a special virtual session of the Laboratory's popular Fun With Science program, available on LLNL's YouTube channel.

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 3,000 people attended this shortened season with only four lectures. The presentations highlighted cutting-edge science and technology, and paired Laboratory researchers with local science educators. The SOS lectures took participants into space, featuring the geological evolution of a young moon, development of new health tools for future voyages to Mars, and the science behind planetary defense. The events are recorded for UC's TV website as well as LLNL's YouTube channel.

HOME CAMPAIGN AND COMMUNITY GIFTS

Employees and LLNS raised a record $3.9 million in the 2020 HOME (Helping Others More Effectively) campaign, a charitable drive that benefits community and nonprofit agencies in the Tri-Valley, San Joaquin Valley, and greater San Francisco Bay Area. Employees pledged more than $2.9 million, while LLNS contributed $1 million in matching funds.

In December, LLNS announced the recipients of the 2020 Community Gift Program, totaling $150,000. Many of the awards serve children in the Tri-Valley area as well as Contra Costa, San Francisco and San Joaquin counties, with a focus on literacy, STEM education, and cultural arts. Other award recipients focus their charitable efforts toward children, families, senior citizens, and individuals in need of assistance.

WORKFORCE RECOGNITION

Acknowledging exceptional performance and expertise

The 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.

DOE AND NNSA AWARDS

In honor of more than 40 years of service to the U.S. Air Force, the DOE, and NNSA, former LLNL deputy director **Tom Gioconda** was awarded the NNSA Administrator's Gold Medal, the highest recognition bestowed by NNSA.

LLNL staff were presented six DOE Secretary's Honor Awards, which are bestowed on teams that have achieved a singular accomplishment that demonstrates high-level performance and dedication to public service. The teams (some multi-laboratory) are: Foreign Nuclear Weapon Analysis Team, High-Value Component Design and Manufacture Team, Summit Sierra Team, Warhead Measurement Campaign, Korea Denuclearization Team, and Pit Production Analysis Team.

Former DOE Secretary of Energy Rick Perry presented members of LLNL's 34-member High-Value Component Design and Manufacture Team with Secretary's Honor award for "their extraordinary efforts in which they successfully invented advanced materials, manufacturing and metrology technologies that have pushed the boundaries of what is possible."

Kavli Fellow winner Félicie Albert

Physicist **Federica Coppari** and microbiologist **Erin Nuccio** are among the 76 scientists nationwide who were recipients of the DOE Office of Science Early Career Research Program award. Under the program, Laboratory scientists typically receive $500,000 per year research funding for five years.

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

Nine LLNL employee teams were honored with Excellence Awards from NNSA's Office of Safety, Infrastructure and Operations (NA-50) for exceptional accomplishments in support of NA-50 efforts to achieve NNSA mission goals.

PROFESSIONAL SOCIETY FELLOWS AND SENIORS

Physicist **Félicie Albert** was elected a Kavli Fellow of the U.S. National Academy of Sciences (NAS) and presented a poster at the NAS Frontiers of Science (virtual) symposium, the academy's premier activity for distinguished young scientists. She is the Laboratory's seventh Kavli Fellow since the program started in 1989.

Four LLNL scientists have been selected as 2020 fellows of the American Physical Society (APS): **Richard Berger**, **Art Nelson**, **Max Fenstermacher**, and **Laurent Divol**. The new fellows represent a wide range of physics expertise, from laser plasma physics to magnetic fusion plasmas, to theoretical and computational understanding of plasma interactions and soft x-ray and free electron laser platforms.

The American Astronomical Society (AAS) has selected LLNL scientist **Peter Beiersdorfer** as a fellow in its inaugural class of this accolade, which recognizes AAS members for achievement and extraordinary service to the field of astronomy and the AAS.

SPIE, the International Society for Optics and Photonics, elected LLNL research engineer **Richard Leach** as a senior member of the organization. SPIE recognizes senior members based on exceptional professional experience, active involvement with the optics community and/or significant performance.

SCIENCE AND TECHNOLOGY AWARDS

LLNL atmospheric scientist **Ben Santer** was honored with the American Geophysical Union's 2020 Bert Bolin Award. The award is presented annually and recognizes groundbreaking research or leadership in global environmental change through research in the past 10 years.

Audrey Williams, the director of LLNL's Forensic Science Center, received the 2020 Outstanding Early Career Achievement in Forensic Science Award. This award for demonstrated leadership and outstanding achievement is presented annually by the American Academy of Forensic Sciences Past Presidents Council.

LLNL physicist **Yuan Shi** has earned APS's Marshall N. Rosenbluth Outstanding Doctoral Thesis award for his work in plasma physics. The award recognizes exceptional young scientists who have performed original thesis work of outstanding scientific quality and achievement in plasma physics.

Livermore physicist **Natalie Hell** was awarded the 2020 Dissertation Prize from the Laboratory Astrophysics Division of the American Astronomical Society. Hell received the prize for groundbreaking laboratory measurements necessary for accurate, reliable interpretation of x-ray spectra from astronomical sources.

Livermore climate scientist **Karl Taylor** received the California Air Resources Board's Haagen-Smit Clean Air Award for 2019. Taylor was commended for his contributions in building essential infrastructure to improve climate modeling and for his own far-reaching research.

Physicist **Denise Hinkel** was elected vice chair of the APS Division of Plasma Physics (DPP). Hinkel brings deep expertise in plasma physics from her work at LLNL. Her multi-year leadership commitment with APS will culminate with service as APS-DPP chair.

Three scientists from LLNL are recipients of the 2020 John Dawson Award for Excellence in Plasma Physics Research from the APS. **Hye-Sook Park**, **Steven Ross** and **Dmitri Ryutov** are part of an international team of researchers that was cited for their work generating Weibel-mediated collisionless shocks in the laboratory

LLNL geologist **Lars Borg** and physicist **Megan Bruck Syal** were named by the National Academies of Science to a pair of Planetary Science and Astrobiology Decadal Survey committees tasked to assess the current state of knowledge and to identify the most important scientific questions to be addressed by the year 2032.

SPECIAL HONORS

A team of current and former LLNL and IBM scientists won the annual "Test of Time" award at the 2020 Supercomputing Conference for a published paper outlining LLNL's Blue Gene/L, the first in a series of massively parallel supercomputers under IBM's Blue Gene project. The machine was predicted to vastly outperform the fastest supercomputers that existed at the time.

LLNL was honored with a Glassdoor Employees' Choice Award, recognizing the Laboratory as one of the top 10 best places to work nationwide in 2020. The award is based on the input of employees.

Workforce magazine named LLNL a General Excellence winner in the 2020 Optimas Awards. General Excellence was awarded to Livermore for demonstrating excellence in at least six of the ten specified categories assessing successful measurable business outcomes.

HONORING THE NOBEL PRIZE IN PHYSICS WINNER

LLNL congratulates Professor Andrea Ghez at the University of California, Los Angeles (UCLA), on her co-award of the 2020 Nobel Prize in physics for the discovery of the black hole at the center of the Milky Way galaxy. In the 1990s, Ghez (center) and LLNL scientist Scot Olivier and former LLNL scientists Claire Max (right) and Bruce Macintosh (left) were instrumental in standing up the UC Center for Adaptive Optics. LLNL had a lead role in the development of the instruments and Ghez had a lead role in the use of those instruments at the W.M. Keck Observatory to infer the presence of the supermassive black hole at the galactic center.

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 Board members with senior LLNL managers

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.

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BOARD OF GOVERNORS COMMITTEES

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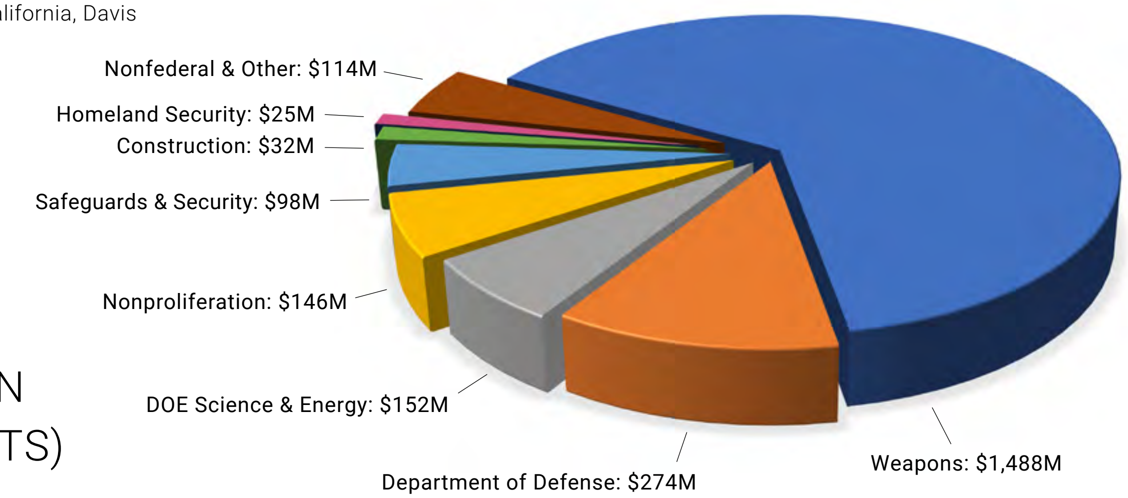
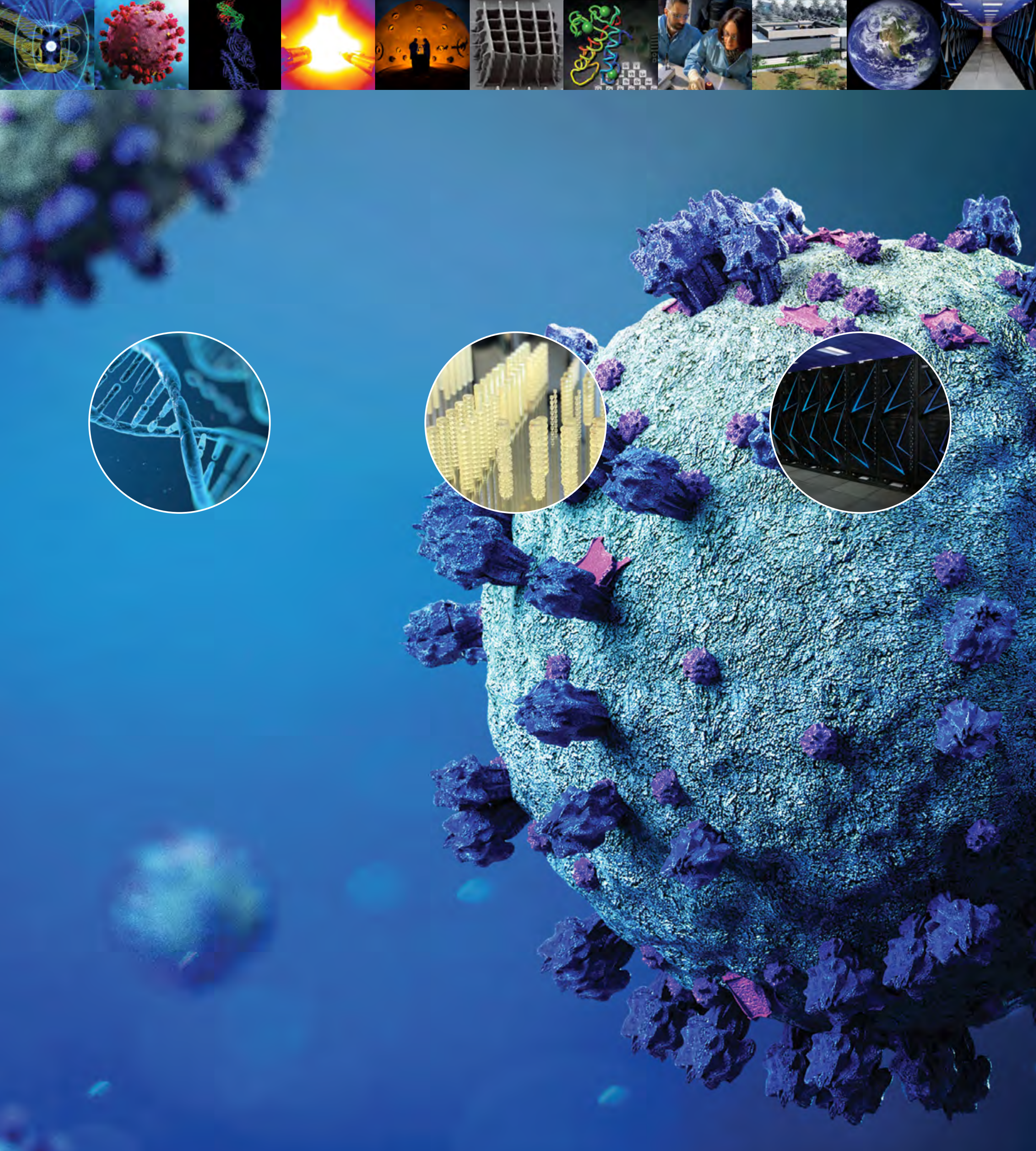
THE SEARCH FOR THE NEXT LABORATORY DIRECTOR

In late July, the search began for the next director of LLNL. As agreed to by the LLNS partners, the University of California (UC) is responsible for leading the search. Charlene Zettel, UC regent and chair of LLNS Board of Governors, chairs the search committee and Charlie McMillan, former Los Alamos director and before that a longtime LLNL employee, led the screening task force. The position was posted nationally with applications and nominations submitted by mid-October. At the conclusion of the process, the Laboratory director candidate nominated by UC was submitted to the LLNS Board of Governors for approval and the DOE for concurrence

LLNL FY 2020 PORTFOLIO: $2.329 BILLION (ACTUAL COSTS)





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