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LLNL-TR-733501

Campus Capability Plan

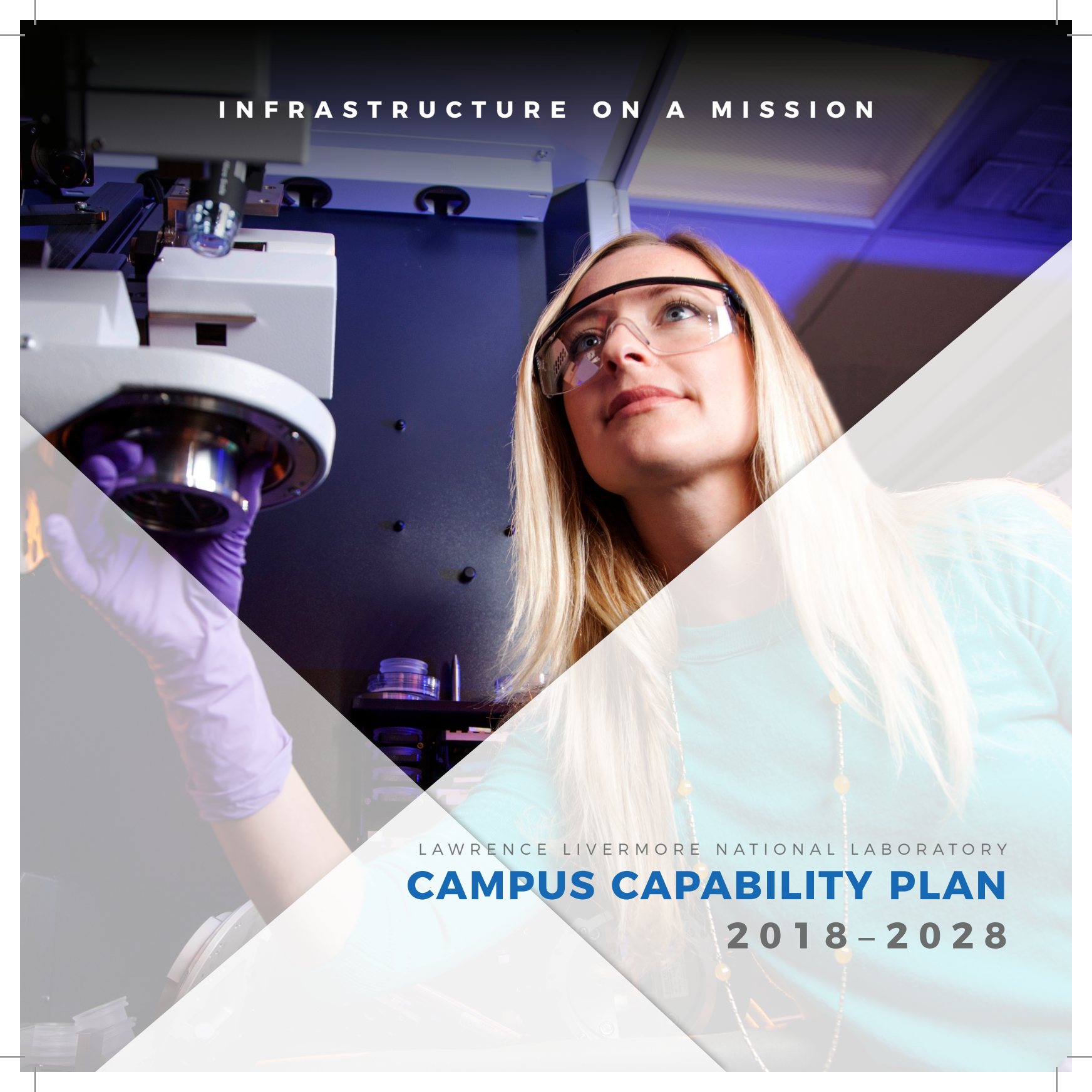
C. Adams, T. Arsenlis, A. Bailey, M. Bergman, J. Brase, J. Brenner, L. Camara, H. Carlton, J. Cheng, P. Chrzanowski, J. Colson, D. East, J. Farrell, L. Ferranti, A. Gursahani, R. Hansen, L. L. Helms, M. Hernandez, J. Jeffries, D. Larson, K. Lu, D. McNabb, M. Mercer, M. Skeate, M. Sueksdorf, B. Zucca, D. Le, R. Ancria, J. Scott, L. Leininger, F. Gagliardi, A. Gash, M. Bronson, B. Chung, B. Hobson, J. Meeker, J. Sanchez, M. Zagar, B. Quivey, S. Sommer, J. Atherton

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A female scientist with blonde hair, wearing safety glasses and a light blue lab coat, is looking upwards while working with a microscope. She is wearing purple nitrile gloves. The background is a laboratory setting with various equipment and shelves. The image is split diagonally, with the top-left portion showing the scientist and the bottom-right portion showing a close-up of the microscope's objective lens.

INFRASTRUCTURE ON A MISSION

LAWRENCE LIVERMORE NATIONAL LABORATORY
CAMPUS CAPABILITY PLAN
2018–2028

About this report

Lawrence Livermore National Laboratory (LLNL) is one of three national laboratories that are part of the National Nuclear Security Administration. LLNL provides critical expertise to strengthen U.S. security through development and application of world-class science and technology that:

- Ensures the safety, reliability, and performance of the U.S. nuclear weapons stockpile.
- Promotes international nuclear safety and nonproliferation.
- Reduces global danger from weapons of mass destruction.
- Supports U.S. leadership in science and technology.

Essential to the execution and continued advancement of these mission areas are responsive infrastructure capabilities. This report showcases each LLNL capability area and describes the mission, science, and technology efforts enabled by LLNL infrastructure, as well as future infrastructure plans.

Contributing Authors

Chris Adams
Ray Ancira
Tom Arsenlis
Andy Ashbaugh
Jeff Atherton
Anna Maria Bailey
Graham Bench
Michele Bergman
Camille Bibeau
Jim Brase
Jeffrey Brenner
Sandra Brereton
Mark Bronson
Jeff Brunetti
Lydia Camara
Holly Carlton
James Cheng
Paul Chrzanowski
Brandon Chung
Jim Colson
Mark Costella

Howard Depew
Doug East
Jill Farrell
Louis Ferranti
Franco Gagliardi
Alex Gash
Anita Gursahani
Rose Hansen
Lanie L. Helms
Maurice Hernandez
Beverly Hobson
Merna Hurd
Jason Jeffries
Jacqueline Kenneally
Buck Koonce
Doug Larson
Dat Le
Lara Leininger
John Lewis
Susan Lind
Dolores Loll
Katy Lu

Michel McCoy
Pete McKereghan
Dennis McNabb
Jacqueline Meeker
Mike Mercer
Trevor Oneal
Jerry Paulson
Terri Quinn
Barb Quivey
John Richards
Jorge Sanchez
John Scott
Michael Skeate
Stanley Sommer
Christopher Spadaccini
Fred Streitz
Mark Sueksdorf
Shivshankar Sundaram
Paul Swyers
Erika Taketa
Mark Zagar
Bonnie Zucca

Responsible Organizations

Operations & Business Principal
Directorate
Laboratory Strategic
Infrastructure Office

Responsible Manager

Cliff Shang

Publication Directors

Jill Farrell
Lanie L. Helms
Andrew Trotta

Publication Editor

Lanie L. Helms

Art Directors

Acen Datuin
Alii Holmberg

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LAWRENCE LIVERMORE NATIONAL LABORATORY

CAMPUS CAPABILITY PLAN

2018–2028



INFRASTRUCTURE ON A MISSION





A NOTE FROM THE DIRECTOR



**William H. Goldstein,
Director**

**Lawrence Livermore
National Laboratory**

Lawrence Livermore National Laboratory (LLNL) has a vital, enduring mission: to make the nation—and the world—safer and more secure through world-class science, technology, and engineering (ST&E). As an innovative “new ideas” laboratory, we deliver game-changing solutions to important problems that arise in a rapidly changing world.

Our outstanding workforce has access to one-of-a-kind research capabilities. People and facilities combine to provide the foundation for LLNL’s continuing success. Opportunities to conduct research at cutting-edge facilities help to attract, train, and retain top-notch scientists and engineers and ensure the ST&E breakthroughs required by our national security missions.

Continual reinvestment is crucial for meeting mission deliverables and sustaining ST&E excellence to respond to future national security challenges. This report focuses on needs to reinvest in the Laboratory’s facilities and infrastructure (F&I). For each of our major research capabilities, we describe the mission driver, the related ST&E, and the necessary infrastructure investments. Many of our

reinvestment needs center on stockpile stewardship, the Laboratory’s defining mission for the Department of Energy’s National Nuclear Security Administration (NNSA). In particular, LLNL has leadership responsibilities for the next two nuclear weapons life-extension programs (LEPs). These LEPs provide the means for introducing more cost-effective program management and production technologies that will help us move toward a modernized, more flexible nuclear weapons enterprise. F&I investments at our Laboratory will support this important goal.

Most of the investments described in this report benefit more than one mission area and address both immediate and long-term mission needs. To help establish priorities, we used a set of optimization tools and enterprise best practices developed at Livermore to ensure that we are making best use of available F&I reinvestment resources.

We have shared these and other tools to support NNSA in achieving the administration’s real property asset management vision. Our laboratory welcomes opportunities to continue to partner with NNSA on this vital effort.

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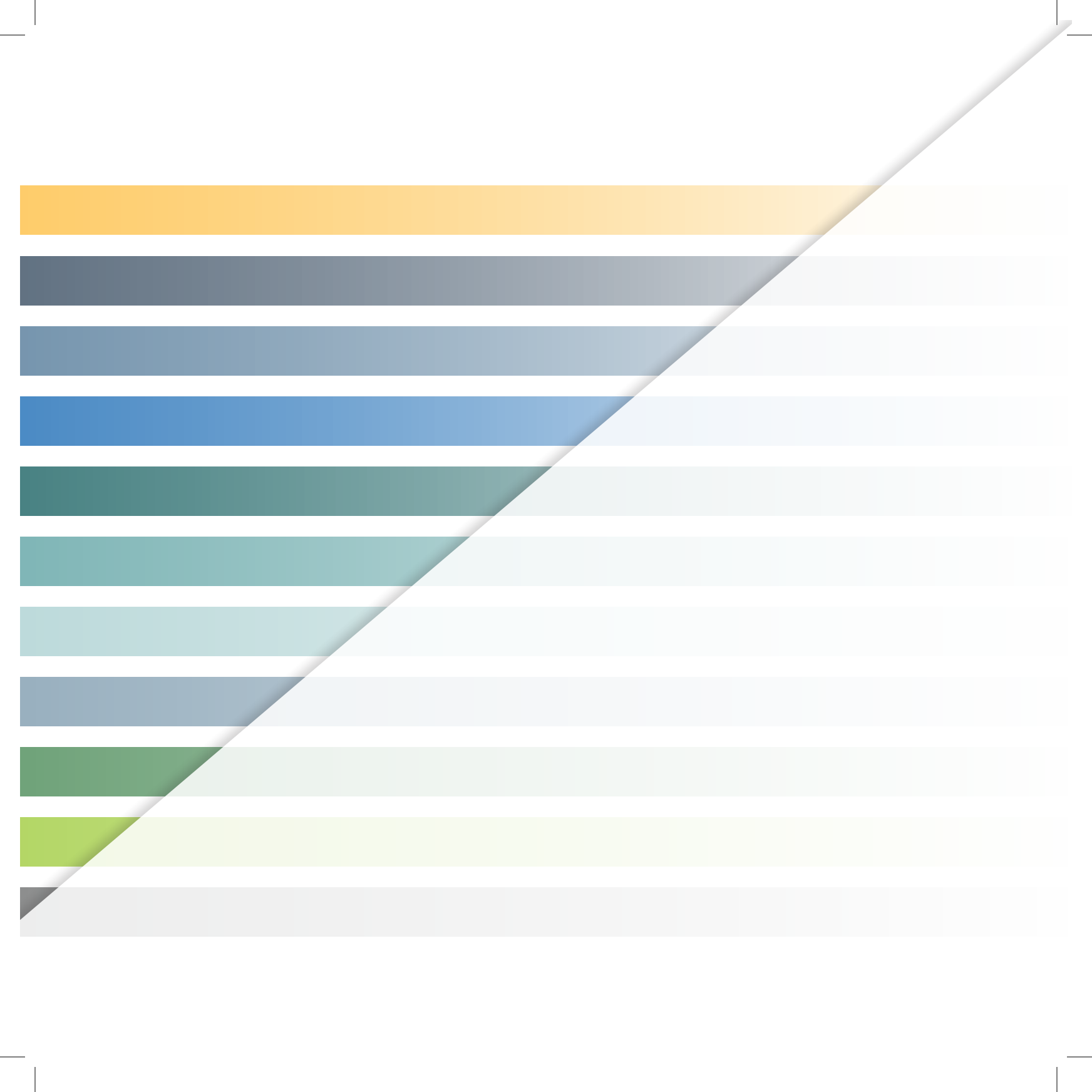
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EXECUTIVE SUMMARY

LLNL AT A GLANCE

\$7B
replacement plant value

7M
gross square footage

7,820
acres across 2 sites

>6,500
employees

~245
postdoctoral researchers

~600
students annually

75%
of the technical staff
hold an advanced degree

40
miles from top universities
and Silicon Valley

>150
petaflops of computing power in 2018

3
Nobel Prizes

6
new elements added to the periodic table

5
endangered species onsite

\$1.8B
annual budget

\$13.8M
raised for charitable organizations

The Mission

Lawrence Livermore National Laboratory (LLNL) applies world-class science, technology, and engineering (ST&E) to enhance national security and deliver game-changing solutions to important problems that arise in a rapidly changing world. The 21st century presents a growing set of challenges that are the focus of the Laboratory's mission as a U.S. Department of Energy (DOE) National Nuclear Security Administration (NNSA) national security laboratory.

Nuclear dangers persist—and in many ways, are growing. Stemming nuclear proliferation is a top national priority. The stockpile life of aging U.S. nuclear weapons must also be extended. NNSA works in partnership with the Department of Defense to ensure that the deterrent is modern, robust, flexible, resilient, ready, and appropriately tailored to deter 21st-century threats and to reassure our allies and partners.

LLNL strives for ST&E breakthroughs to counter existing and anticipated threats and respond to surprises as they arise. Entrusted with critical national security missions, the Laboratory must provide and sustain ST&E excellence over the long term. Continual investments in the Laboratory's foundation—people and infrastructure—are needed to keep LLNL at the frontiers of ST&E in areas central to its missions.

State of Facilities and Infrastructure

LLNL is home to many key facilities that provide essential support to NNSA missions and enable LLNL to pursue many strategic partnership programs that meet a wide range of national security needs. These facilities are located across LLNL's two sites: the Main Site and Site 300, LLNL's remote testing area located approximately 15 miles southeast of the Main Site. Several LLNL facilities are flagships for stockpile stewardship: the Livermore Computing Complex, the National Ignition Facility (NIF), the High Explosives Applications Facility (HEAF), and Site 300's Contained Firing Facility (CFF).

Operating funds needed to sustain these and other mission-critical facilities—together with a long absence of line-item investments—have constrained and accentuated the need for facilities and infrastructure (F&I) investments. Half of the operating buildings are assessed as being inadequate or in substandard condition. The deterioration of assets presents program and operational risks in executing mission needs, attracting and maintaining a high-quality workforce, and meeting regulatory requirements.

To help mitigate this funding challenge, LLNL has implemented a new set of processes and tools to prioritize investments to ensure mission success.

LLNL is working with NNSA to help implement these tools—which include the Mission Dependency Index and BUILDER—widely across the nuclear security enterprise.

Facilities and Infrastructure Investment Strategy

F&I investments enable the mission and form the enterprise's foundation. Modern, reliable, general-purpose infrastructure is critical to successful, efficient mission execution now and in the future and is key to attracting and retaining the exceptional scientific staff. Top-priority investments support LLNL's core nuclear weapons mission, with special attention to LLNL's responsibilities for executing the next two weapon life-extension programs (LEPs):

Applied Materials and Engineering (AME) capability consolidation. AME plans call for recapitalization of four existing facilities and construction of three new laboratory buildings and an office building. The complex will carry out work crucial for LEPs and consolidate capabilities from an over 60-year-old AME building that poses a high risk to personnel safety and program execution.

High-explosives infrastructure revitalization. To support the timely execution of LEP activities, LLNL is implementing investments to sustain and modernize the equipment and utilities at HEAF and 50-year-old facilities

at Site 300. LEP design options require synthesis, formulation, processing, testing, and evaluation of newly manufactured explosives materials.

Exascale Complex Facility Modernization. Leading-edge high-performance computing is essential for conducting numerous high-resolution physics simulations to quantify uncertainties. While taking delivery of Sierra, LLNL must start to prepare for an exascale-class system in 2022 by expanding power and cooling capabilities for Building 453.

Additional critical experimental capabilities for stockpile stewardship warrant attention: NIF is approaching 20 years of operation. Many of its support systems will need to be replaced over the next decade. The flash x-ray machine at CFF is 35 years old—proposed projects aim to enhance its reliability and improve its performance. Revitalization is also needed of the 60-year-old building that houses LLNL's state-of-the-art x-ray nondestructive evaluation equipment.

These major investments provide the foundation for NNSA programs at the Laboratory as well as many strategic partnership projects for other agencies. Additional needs to support LLNL's broader national security mission include:

Network Intelligence Research Facility (NIRF). Program growth necessitates additional special compartment

information facility space at LLNL. NIRF construction provides a long-term solution.

Livermore Valley Open Campus. The campus currently houses more than 200 LLNL researchers that work with visiting academic and industry collaborators. The Advanced Manufacturing Laboratory will be added in 2017. A third-party-financed facility replacing the High-Performance Computing Innovation Center has been proposed. These thrusts—and others highlighted in this report—are guided by an overall F&I investment strategy that balances attention to maintenance, recapitalization, and site redevelopment:

Maintenance. To address deferred maintenance (DM), LLNL uses tools such as BUILDER to focus investments on the greatest areas of risk and future demand. However, meeting objectives to decrease DM is challenging.

Recapitalization. Recently, LLNL allocated an additional wedge of funding to site recapitalization. A new institutional process has been established. Priorities consider a set of six strategic themes and a five-year portfolio has been developed.

Site Redevelopment. New construction combined with closing substandard facilities will reduce LLNL's footprint. Previously closed contaminated, failing, and obsolete facilities await final demolition funding and are maintained in an inactive state.



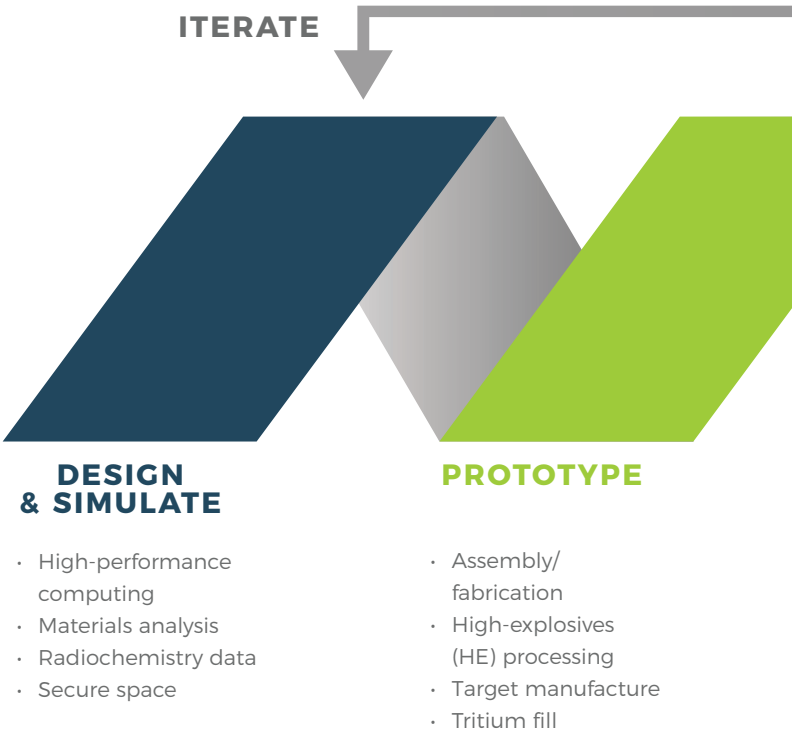
Core Capabilities Support LLNL's Scientific Method

Livermore's defining purpose is to sustain confidence in and to maintain the U.S. strategic deterrent as well as enhance national defense. LLNL continues its strong tradition of scientific and technical excellence—anticipating, innovating, and delivering solutions for the nation's most challenging problems.

These missions represent an unprecedented challenge, requiring rigorous application of the scientific method to further the

understanding of weapons phenomena, assess the condition of weapons, and pursue programs to extend the stockpile life of aging systems. To understand this method, four integrated parts are shown here, which rely on infrastructure. The process of scientific and technical innovation must be supported by a viable infrastructure foundation. Design and simulation is conducted using high-performance computing, radiochemistry laboratories, and materials analysis, which in many cases requires secure space. The results are prototyped by processing, manufacturing, and fabrication. Experiments and tests are then performed on

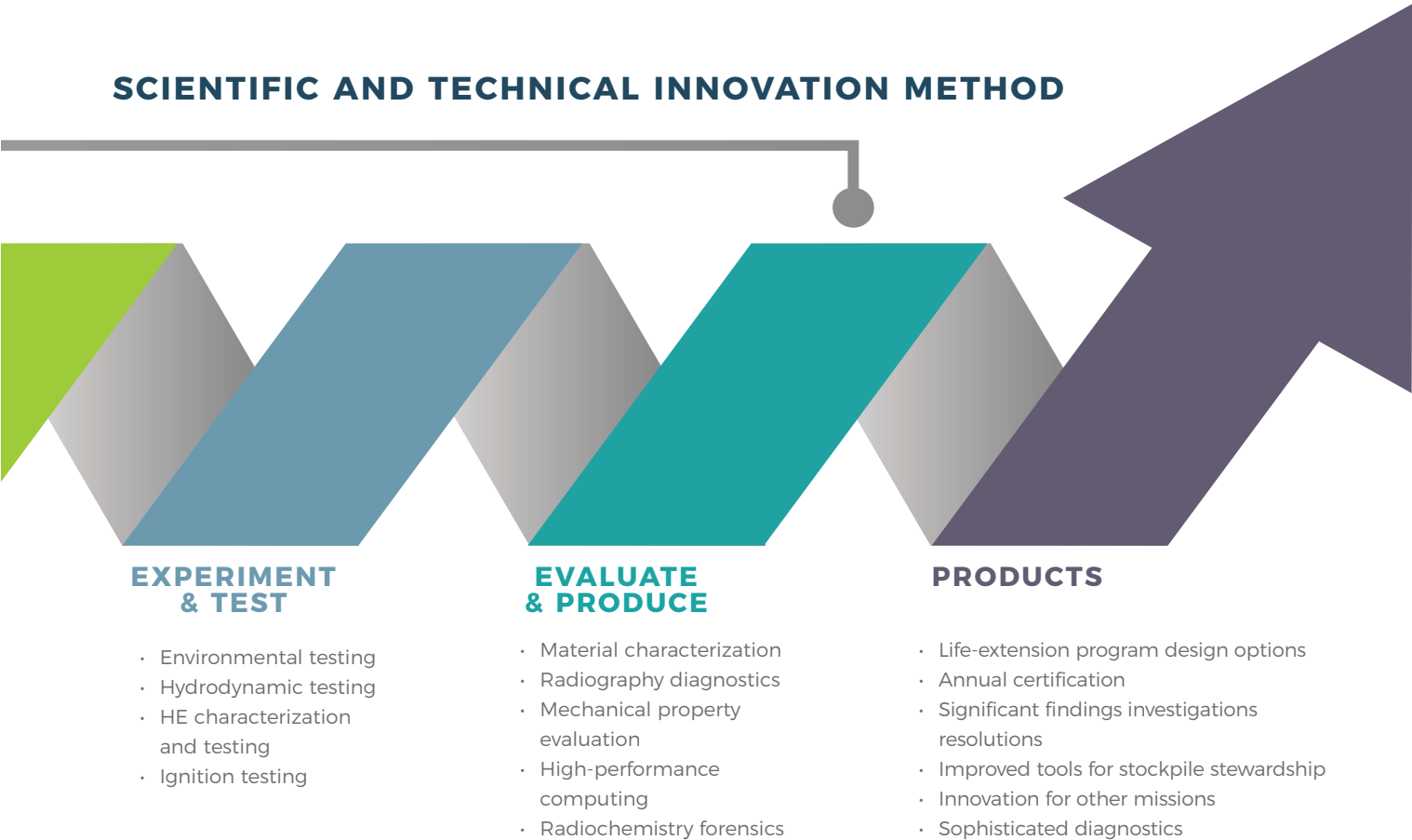
NNSA CAPABILITIES AS EXECUTED BY LLNL		
NNSA Capability Code	NNSA Capability	LLNL Capability
C1.1	Design and Certification	Design and Certification
C1.2	Experiments	High-Energy-Density Physics
C1.3	Simulation	Livermore Computing
C1.4/1.5	Testing and Surveillance	Weapons Engineering
C2/4	Plutonium and Tritium	Special Nuclear Materials
C5	High Explosives	High Explosives
C11/14/16	Counterterrorism and Counterproliferation; Nonproliferation; and Emergency Response	Nuclear Threat Reduction and Response
C12	Support of Other Mission/ Program Capability	Enabling Infrastructure
C15	Security	Security
C17	Work for Others	Strategic Partnering



prototypes in state-of-the-art facilities. Next, performance and accuracy are examined, results of which are iterated back to the beginning of the cycle. Sustaining these cycles of scientific and technical innovation requires a reliable mission infrastructure, as well as institutional support facilities; site-wide electrical, mechanical, and civil utilities; and high-tech communications.

INFRASTRUCTURE
enables cycles of scientific
and technical innovation.

SCIENTIFIC AND TECHNICAL INNOVATION METHOD

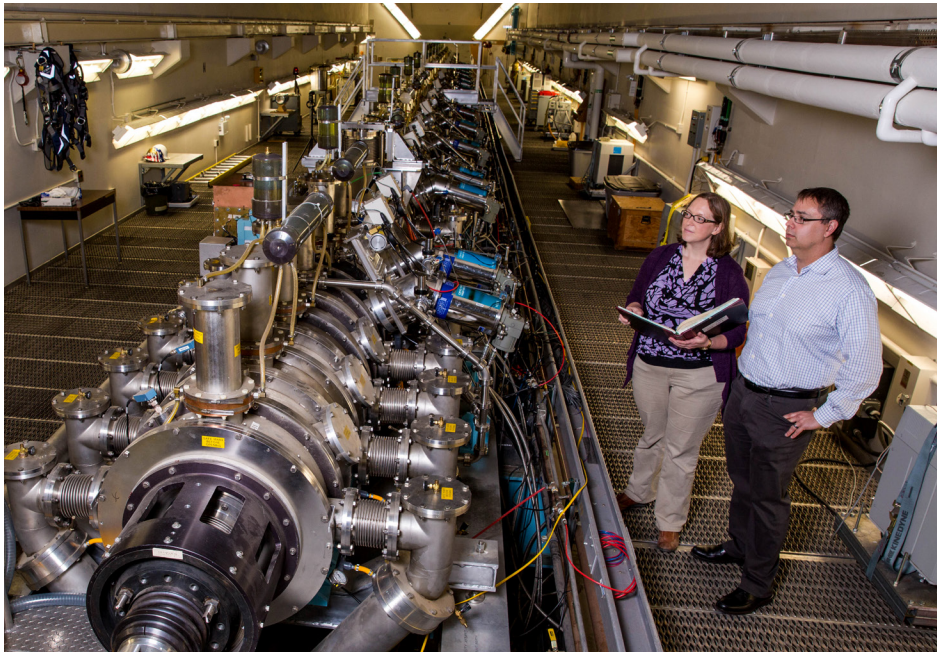


DESIGN AND CERTIFICATION

MISSION LLNL's historic, current, and future missions work provides the nation with safe, secure, and reliable nuclear weapon systems. Any weapon in the U.S. nuclear arsenal, if ever deployed, must work exactly as intended. Responsibility for assuring reliability, performance, and safety of the nuclear weapons stockpile belongs to the nuclear design and production enterprise, which conducts a

variety of activities in the Department of Energy's stockpile stewardship program.

As a design agency for the National Nuclear Security Administration (NNSA), LLNL is responsible for maintaining three of the seven active stockpile weapon systems through the annual weapon certification process and for enabling the future stockpile. LLNL designs the



Site 300's Contained Firing Facility (CFF) is a unique large-volume firing facility unavailable anywhere else in the nuclear security enterprise. Combined with the (above) powerful flash x-ray diagnostic, it is a critical facility required to support the W80-4 life-extension program.

INFRASTRUCTURE PLANS

LLNL has cutting-edge capabilities to support the nation's **weapons design and certification** efforts. However, LLNL needs to modernize its science and technology infrastructure to continue pushing the state of the art. Future plans include:

- B151 radiological glove box room renovation
- B131 high bay HVAC replacement
- B132N variable air control project
- Site 300 firing site support systems upgrade
- B801A weapons test site firing and control system modernization
- B235 and ancillary synthesis chemistry laboratories renovation with fume hood upgrades
- B121 renovation
- B151 high-level radiochemistry laboratories #5-8 renovation
- B131 mission-critical HVAC and DDC control
- B851 firing and control system modernization
- B235 renovation and workplace improvement
- B801A dynamic radiography upgrade
- B131 office space recapitalization
- Nuclear weapons R&D complex
- B431 enhanced capability for sub-critical experiment component testing

nuclear explosives package (NEP) for stockpile life-extension programs (LEPs) and certifies the life-extended weapons as they enter the stockpile. Livermore has been assigned an LEP for the IW1 (W78/88-1) warhead, a system intended to be interoperable between Air Force and Navy missile systems. Current efforts are focused on accelerating the LLNL LEP for the W80-4 warhead, in conjunction with the new U.S. Air Force Long-Range Standoff missile.

Through routine surveillance of the systems and annual stockpile assessment, weapons issues that could lead to future performance degradation, such as aging effects, are discovered and addressed. Depending on the nature of these changes, parts may need to be replaced or refurbished as part of an LEP to meet safety, security, and reliability requirements. In this way, LEPs extend the weapons' lifetimes for an additional 20 to 30 years and are carried out without conducting underground nuclear tests.

Weapons refurbishment efforts enable NNSA to maintain the nation's nuclear deterrent without resuming the production of new weapons or underground nuclear tests. In the 1990s, Lawrence Livermore scientists, engineers, and technicians began the very first LEP without nuclear testing for the W87 ballistic missile warhead. Today, LLNL stands ready to repeat this challenging and exacting endeavor to design, test,

HYDRODYNAMIC EXPERIMENTS AT SITE 300

For nearly a half-century, workers called "ramrods" at Site 300 have kept crucial nonnuclear weapon tests moving on schedule. From the earliest experimental design discussion to firing the shot, ramrods are key to ensuring that hydrodynamic tests are completed on time and within budget and provide maximal data.

During a hydrodynamic test, the detonation of high explosives sends a shock wave through the test material, causing it to flow like a liquid. Liquid behavior is described by hydrodynamic equations, so the experiments are called "hydros."

For stockpile stewardship, hydros are the most valuable experimental tool for diagnosing device performance of the primary stage in modern nuclear weapons. The components in these integrated weapon experiment devices represent full-size quantity and quality of the stockpile, except for the surrogate nonnuclear components.

Hydros are conducted to study the behavior of surrogate primary-stage materials in response to extremely high temperatures and pressures. These tests are essential for the continued refining of computational models that simulate nuclear weapon performance. Ramrods run the diagnostics and the facility, and as such are the glue between the program, engineers, physicists, and technicians. The long record of successful hydrotests shepherded by ramrods ensures the continued confidence in the nation's nuclear stockpile.



LLNL ramrods set up an explosive-driven shaped charge experiment inside the CFF. A series of Site 300 renovation projects will enhance LLNL's mission to test full-scale mock nuclear weapons through hydrodynamic experiments and support additional tests for the National Nuclear Security Administration and other sponsors.



Radiochemists apply nuclear test experience and unique capabilities to new national security and scientific challenges.

and evaluate counterterrorism and counterproliferation tools.

In addition, LLNL researchers use radiochemistry (the study of radioactive isotopes) and nuclear chemistry (which focuses on the properties of atomic nuclei and the processes involved in element transformation) to further understand the nation's stockpile. Radiochemists provided crucial contributions to the Laboratory's nuclear weapons test program by assessing soil samples from the nation's past nuclear testing. They created tracer components for test devices by using actinides—radioactive elements with atomic numbers from 89 through 103, the most abundant of which is uranium. They also assessed a weapon design's performance by studying the radioactive debris and gases produced during an experiment. Since the moratorium on underground nuclear testing, radiochemical research at Livermore continues to support the weapons program through stockpile stewardship and has grown to encompass an even wider range of national security and scientific missions.

Many of LLNL's radiochemistry efforts are carried out in Building 151, where scientists perform radiochemical analyses,

and certify components to extend the life of the W80-4 warhead. Several design and material options are being considered to refresh components while minimizing costs and reducing environmentally sensitive materials and processes.

SCIENCE Lawrence Livermore scientists and engineers use advanced scientific diagnostics, such as high-energy flash x-ray (FXR) radiography and high-speed optics, to capture data from hydrodynamic tests to assess the science and operation of nonnuclear weapon components for LEPs. Hydrodynamic tests involve explosive detonations that create temperatures and pressures so great that solids behave

like liquids. These tests use replacement metals, such as steel, copper, and depleted uranium, in place of nuclear materials.

Hydrodynamic tests are required to compare the phases of hydrodynamic flow from nonnuclear explosives experiments with computational data. Scientists conduct these tests using high explosives at Site 300's Contained Firing Facility (CFF). With its excellent diagnostic capabilities, the CFF/FXR, in combination with other hydrodynamic testing capabilities in the complex, provides designers and engineers working on non-weapons programs with the experimental frequency and capability necessary to develop

RADIOCHEMISTRY RENAISSANCE

fabricate targets, and develop new analytical methods and tools. These processes support NNSA's mission and push the boundaries of fundamental scientific knowledge with the discovery of new heavy elements, including element 116, named after Livermore.

LLNL offers a unique recipe for radiochemistry research, combining nuclear testing expertise and resources (such as rare radioisotopes collected from past underground experiments) with an array of materials handling capabilities and research and isotope production facilities, including the Center for Accelerator Mass Spectrometry and the National Ignition Facility (NIF).

LLNL also works to preserve critical data generated during nuclear testing for future generations. The goal is to scan radiochemical archive materials employing modern technologies to enable efficient and accurate electronic document searches, ultimately providing more effective access to this information. This effort will allow nuclear chemists to use radiochemical information to their full potential, ultimately improving accuracy and precision of the models supporting stockpile assessment.

LLNL leverages an automated ion chromatography fraction collection system, which can chemically separate up to 12 samples simultaneously. While radiochemical data and analyses directly

About a century ago, the enduring dream of alchemists was realized when physicist Ernest Rutherford and his collaborators demonstrated that one element can change into other elements through the process of radioactive decay. Rather than turning lead into gold, Rutherford's discovery led to the founding of radiochemistry—the study of radioactive isotopes—and nuclear chemistry, which focuses on the properties of atomic nuclei and the processes involved in element transformation. Together, these fields form a pillar that supports Lawrence Livermore's nuclear security mission, a role they have held since the institution was founded in 1952.

Today, LLNL offers a unique recipe for radiochemistry research, combining nuclear testing expertise and resources, such as rare radioisotopes collected from past underground experiments, with an array of materials handling capabilities and research and isotope production facilities, including the Center for Accelerator Mass Spectrometry (CAMS) and the National Ignition Facility. LLNL has facilities to safely perform irradiation, chemical separation, and nuclear counting, all onsite. CAMS also produces radioactive isotopes for a variety of chemistry experiments. It is unusual to have all of these facilities in one place.

Whatever the future holds, the need for expertise in radiochemistry and nuclear chemistry is unlikely to wane. Even with much reduced weapons stockpiles worldwide, there will still be a need to understand nuclear weapons and radioactivity for nuclear waste disposal, for example. As they have demonstrated in the post-testing era, Livermore's radiochemistry researchers are ready to respond to new challenges as national needs change.



A Livermore nuclear chemist works with the Laboratory's automated ion chromatography fraction collection system, which can chemically separate up to 12 samples simultaneously.

impact the accuracy and precision of LLNL's stockpile certification for current and future weapon systems, these laboratories also underpin NIF diagnostics and pre- and post-detonation

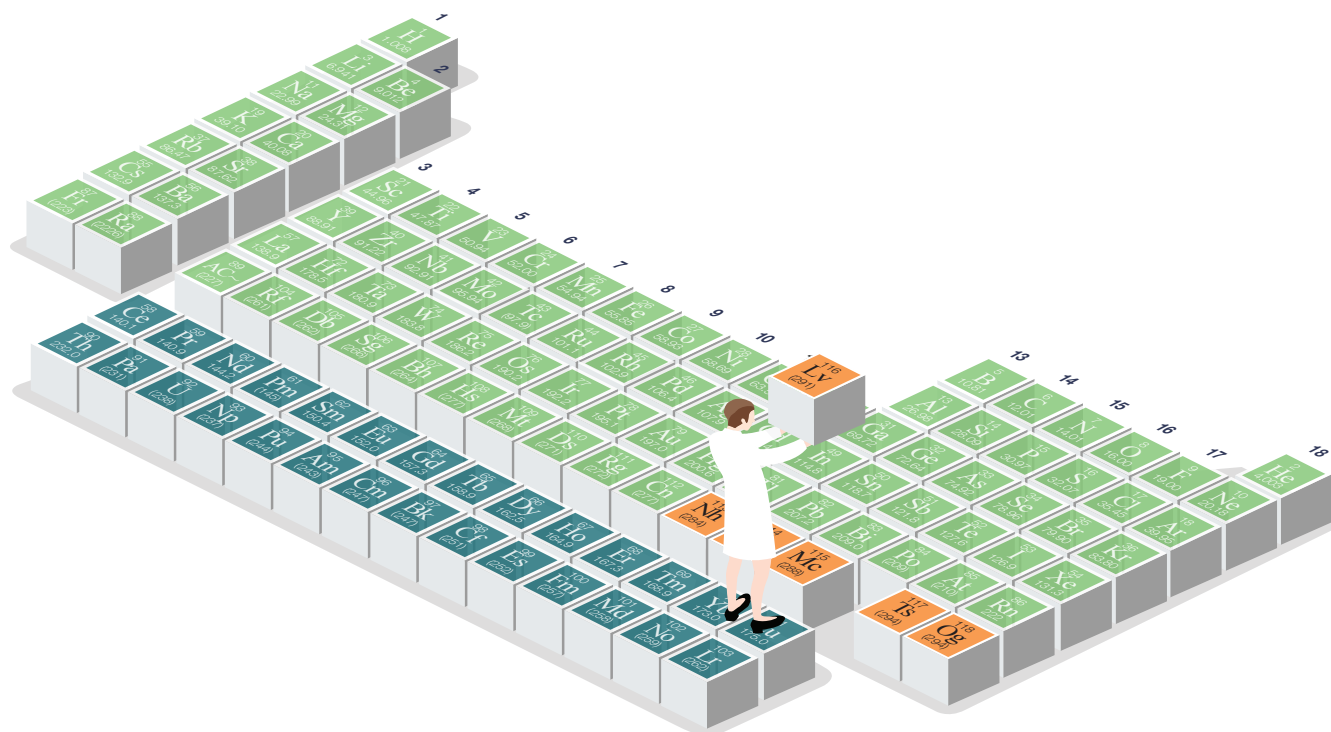
The current periodic table of the elements shows the newly named elements (numbers 113-118) in orange. With the new elements, discovered by a Livermore-Dubna collaboration (and in some cases, with research partners), the seventh row of the table is complete.

forensics and provide a unique capability to nonproliferation and treaty verification.

Retaining design and certification skills, knowledge, and abilities is paramount. Weapons designers used to gain critical experience by performing underground tests. Now, they are obtaining similar experience working on experiments at NIF, CFF, and other NNSA facilities. Physicists and engineers still have to make judgments with incomplete information, just as they

did during nuclear testing. With the cessation of nuclear testing, advances in radiography and x-ray diagnostics are even more critical for designers and engineers in order to certify stockpile weapons and pursue LEPs.

INFRASTRUCTURE The LEP effort leverages Livermore's expertise in physics, chemistry, materials science, and engineering. The infrastructure that supports this overarching capability includes the workspace for employees,



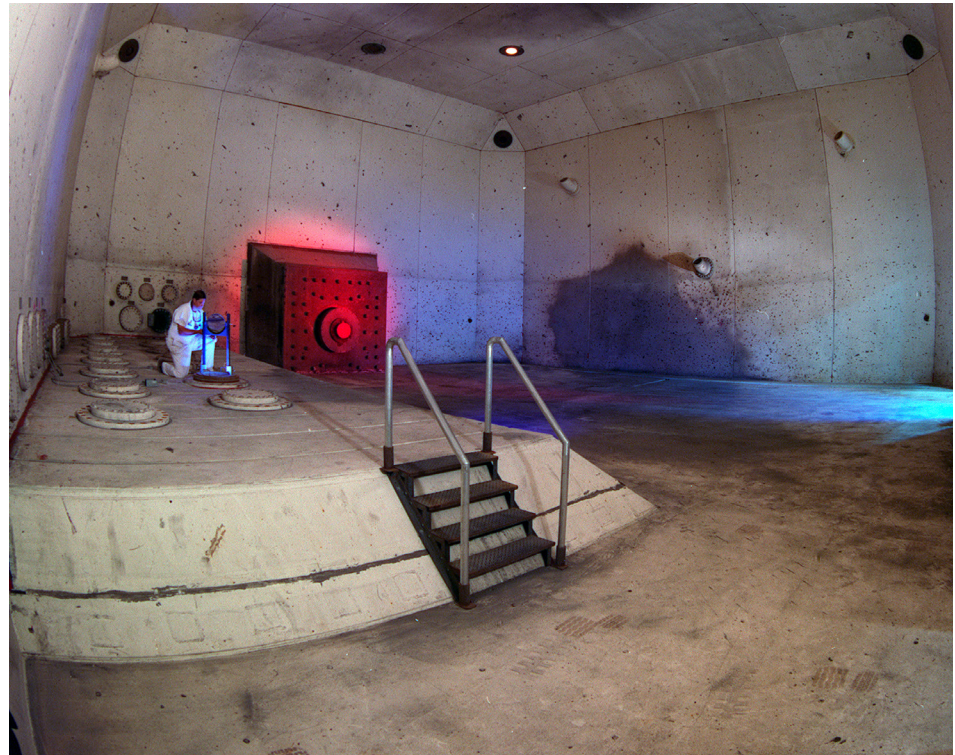
Inside Site 300's CFF firing chamber, a scientist prepares for a hydrodynamic test.

general programmatic equipment, and engineering, science, and technology capability infrastructure at both sites—the Main Site and Site 300. Timely infrastructure modernization is critical to long-term success in science-based stockpile stewardship to support LLNL's national missions.

Large office buildings, such as Buildings 121, 131, 151, and 235, house scientific staff critical to the design and certification capability, among many other capabilities. The first three of these buildings have never been renovated and are over 40 years in age. As such, they require modernization to continue to efficiently, effectively, and safely support LLNL staff.

LLNL's mission-critical facilities, such as the CFF/FXR, that evaluate and test weapon-level subassemblies are aging and in need of maintenance. The FXR machine is in excess of 35 years old and the CFF is now approaching 20. Projects have been proposed to improve FXR system reliability by replacing hard-to-find, custom spare parts and support systems. Projects have also been proposed to extend the life of the facility.

The CFF allows the Laboratory to conduct explosives tests indoors. The facility



has the largest indoor firing chamber in the nation, capable of containing explosive detonations of 60 kilograms (132 pounds). The CFF/FXR diagnostic capability is a critical NNSA infrastructure asset and a flagship facility for LLNL. Importantly, the CFF provides distinct experimental capabilities in support of annual assessments and LEPs for both NEP performance and nuclear safety. The facility provides the throughput required by the National Hydrodynamic Test Plan, which details the integrated work scope and schedule of hydrodynamic testing for Los Alamos and Lawrence Livermore national laboratories conducted at various facilities within the NNSA weapons complex. The

CFF also supports the development of weapon design and engineering skills at the Laboratory; delivers experiments in support of broader national security; and provides a venue, with acknowledged subject matter experts, to mature technologies that enable required future radiographic capabilities. CFF experiments are an important component of the certification plan for the W80-4 LEP and key to NNSA successfully delivering this LEP for the United States Air Force. In addition, the CFF has a significant role in maturing technologies, in collaboration with the United Kingdom through the Joint Technology Demonstrator effort, in anticipation of the IW1 (W78/88-1) LEP.

HIGH-ENERGY-DENSITY PHYSICS

MISSION The most extreme conditions that can be created in the laboratory are in the high-energy-density (HED) regime, where materials often behave in unexpected ways. HED science is essential to mastery of fission and fusion science and its applications, which is critical to LLNL's mission responsibilities and key to the Laboratory's future.

HED material experiments fall broadly into three categories: equation of state, or the relationship between pressure, temperature, and density; strength, that is, the speed and extent of the deformation of a solid; and phase changes, such as from a

solid to a liquid. No previous experimental data exist for these very difficult regimes.

HED research involves examining materials under pressures and densities found until recently only in the cosmos—in stars and the cores of giant planets—or on Earth only in detonating nuclear weapons. The advent of Lawrence Livermore's 192-beam National Ignition Facility (NIF), the world's largest and most energetic laser, now makes it possible to test materials in HED regimes that are inaccessible to scientists by any other means. HED physics provides data for material properties at extreme conditions of temperature and pressure, hydrodynamics, and the interactions of intense radiation fields with matter. This experimental data helps to inform and

validate sophisticated, three-dimensional weapons-simulation computer codes and facilitate a broader understanding of important weapons physics. Without the ability to perform full-scale underground nuclear tests, LLNL, as a nuclear design agency, depends upon this valuable data. NIF experiments are an essential component of the nation's stockpile

A National Ignition Facility (NIF) team prepares for a laser target shot.



INFRASTRUCTURE PLANS

LLNL has cutting-edge capabilities to support the nation's **high-energy-density physics** efforts. However, LLNL needs to modernize its science and technology infrastructure to continue pushing the state of the art. Future plans include:

- B391 sustainable chilled water and heating hot water system replacement
- B581 NIF laser power upgrade
- B581 NIF roof repairs
- B490 HVAC system replacement
- B490 HED physics target diagnostics consolidation
- B381 mission-critical electrical revitalization
- B581 NIF HVAC system replacement
- B174 Jupiter Laser Facility refurbishment
- B581 NIF mission-critical chiller replacement project

STUDYING PLUTONIUM AT NIF

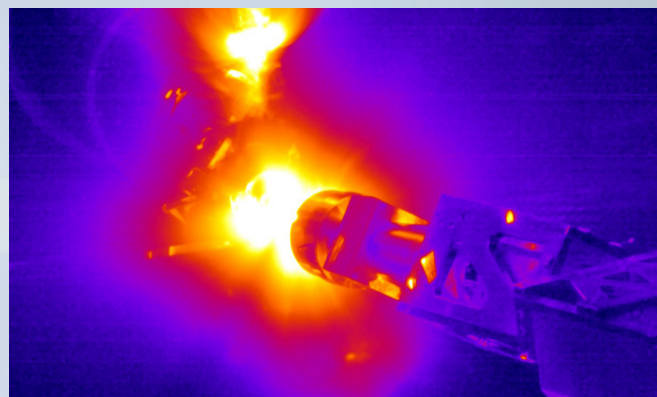
With the cessation of underground nuclear testing in 1992, it was recognized that stockpile stewardship requires experimental access to high-energy-density (HED) regimes to ensure the U.S. nuclear stockpile remains safe, secure, and effective without further underground explosive nuclear testing. It was also understood that the U.S. would need enhanced capabilities to ensure the nuclear deterrent is modern, robust, flexible, resilient, and appropriately tailored to deter modern threats. LLNL's National Ignition Facility (NIF) allows access to HED regimes and provides a platform for experiments critical to stockpile stewardship. NIF experiments are also key for:

- Elucidating key weapons physics issues left unanswered when underground testing stopped, enabling sustainment of the current U.S. nuclear stockpile.
- Developing modern approaches to enhance the safety, security, and robustness of U.S. nuclear weapons without underground nuclear testing.
- Ensuring the nation can assess advances in the nuclear weapons of other nations and avoid technological surprise.
- Providing experimental data that test LLNL's simulation design codes that underpin the predictive science for stockpile stewardship.
- Recruiting, training, testing, and retaining scientists and engineers required to support stockpile stewardship.

Understanding the thermomechanical properties of plutonium as it is compressed is a key piece of physics fundamental to nuclear weapons performance. NIF is uniquely capable of probing the physical properties of plutonium under the most extreme conditions reached during the detonation of a nuclear weapon. By using its flexible laser pulse shaping to tailor the loading history and leveraging the available laser energy to reach the highest pressures in simple planar geometries, NIF can deploy its exquisite diagnostics to measure the crystallinity, compressibility, strength and/or viscosity of plutonium to validate the physics models underpinning the multiphysics codes at the core of the stockpile stewardship program.

Using samples made from a specially prepared plutonium-242 isotope, LLNL scientists have conducted experiments to elucidate the high-pressure crystal structure that previously relied on theory and serves as the keystone for building an equation of state. LLNL scientists have also conducted high-pressure strength experiments to reduce the uncertainty in the understanding of plutonium's high-pressure behavior. These data agree with theory in some regimes and differ from theory in others. LLNL researchers will soon be conducting NIF experiments to directly measure the compressibility spanning the wide pressure and temperature range that NIF provides. This wealth of data allows LLNL researchers to benchmark and refine otherwise untested theoretical models and provides essential input into critical stockpile stewardship simulations.

Photograph of a NIF shot to develop the high-pressure plutonium strength measurement capability, showing the radiographic imaging diagnostic in the foreground.



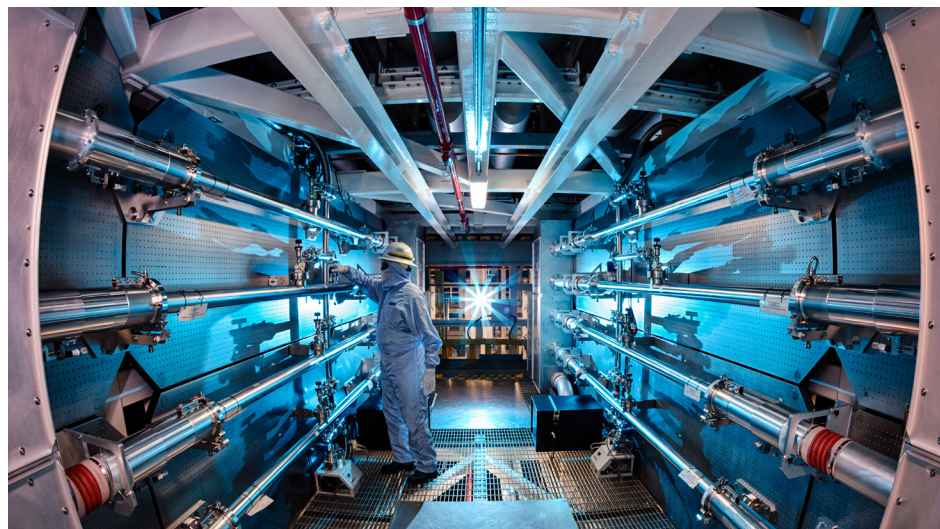
A technician adjusts an optic inside NIF's preamplifier support structure.

assessment and certification strategy because NIF provides the only means by which scientists may access the pressure and temperature conditions relevant to thermonuclear burn.

SCIENCE NIF is the National Nuclear Security Administration's preeminent HED stockpile stewardship experimental facility. NIF users and collaborators include researchers from Department of Energy national laboratories, universities, and other U.S. and foreign research centers.

When a NIF experiment begins, a weak laser pulse—about 1 billionth of a joule—is created, split, and carried on optical fibers to 48 preamplifiers that increase the pulse's energy by a factor of 10 billion, to a few joules. The 48 beams are then split into four beams each for injection into the 192 main laser amplifier beamlines. Each beam zooms through two systems of large glass amplifiers. From the main amplifier, the beams make a final pass through the power amplifier. By now, the beams' total energy has grown from 1 billionth of a joule to 4 million joules—all in a few millionths of a second.

The 192 beams proceed to two ten-story switchyards on either side of the target chamber where they are arranged into quads of 2x2 arrays. Just before



entering the target chamber, each quad passes through a final optics assembly, where the pulses are converted from infrared to ultraviolet light and focused onto the target.

For ignition experiments, the target consists of a tiny metal can called a hohlraum containing a capsule of frozen fusion fuel. Laser beams entering the top and bottom holes of the hohlraum strike its inside walls, creating x rays that compress the fuel capsule to extreme temperatures and densities.

NIF's 192 laser beams travel about 1,500 meters from their birth to their destination at the center of the spherical target chamber. Yet the journey from start to finish takes only about 5 microseconds.

INFRASTRUCTURE To support NIF's demanding mission needs, LLNL has

been required to design, operate, and maintain an extraordinary infrastructure network that includes the primary NIF facility, Building 581, and many support facilities for target fabrication, optic processing and development, target diagnostic development, assembly, and refurbishment, as well as a smaller laser facility for training scientists on executing HED experiments.

The NIF facility itself must meet demanding infrastructure requirements to ensure tight laser pointing and timing to the target, protect the workers and public from neutron and x-ray radiation and contamination, ensure unimpeded high-power laser propagation, protect the unique NIF optical components by providing an environment with appropriate levels of cleanliness and humidity, and power the world's largest capacitor bank that feeds the NIF laser amplifiers.

The requirements to point NIF's 192 beams at the small target and to maintain accuracy between the time of alignment and the shot are extremely demanding. The beam pointing requirement is a small fraction of the 50 micrometer root mean square overall alignment budget, and is equivalent to inserting a quarter in a parking meter at Union Square in San Francisco using a pole held by someone located in Livermore. Failure to maintain this pointing will adversely affect the symmetry of the fuel capsule implosions.

To be able to align the beams to this level of precision and accuracy requires the NIF beam optical elements to be isolated from vibrations in the environment (pumps; heating, ventilation, and air conditioning; people; and traffic, among other factors). Optical components are mounted on solid steel structures placed on concrete slabs and pedestals that are isolated from building vibration sources and the environment. As applicable, the optical support structures also use the inherent high-damping and stiffness characteristics of reinforced concrete, and the structures are designed with relatively high stiffness.

In addition, NIF has very stringent vibration mitigation, which includes vibration isolation for all rotating equipment, damping materials for all utility supports, and energy decoupling of mechanical equipment from the optical supports.



NIF's energy fluence (energy per unit area) is extremely high in many sections of the laser and is very close to the damage threshold of the materials. Any foreign particulate or organic material in the beam enclosures can deposit on the surface of the optics and initiate damage to the optic when exposed to the laser beam. In addition, the 3,000 laser glass slabs degrade when exposed to humidity. A high-volume clean dry air system continually purges the laser and amplifier beam enclosure to prevent degradation.

To maintain pointing once aligned, the NIF infrastructure must maintain a temperature stability of 0.3 degrees Celsius in its laser and beam transport areas. A sophisticated control system manages over 33 air handlers that process up to 90,000 cubic feet per minute. Large fans up to 54 inches in size provide temperature control of NIF's million-square-foot area. NIF has its own dedicated cooling towers, chillers, and boilers to support the air handlers.

A high-flow tempered water system provides cooling water to remove the

internal heat, generated by over 1,000 equipment racks, from the operations areas and prevent local heat and air flow instabilities.

NIF has a specialized set of requirements and associated facilities and equipment needed to support stockpile stewardship. NIF's facility has been well maintained, but after almost 20 years of operation, many systems will need to be replaced over the next decade. Conditions such as temperature stability, pointing stability, and room cleanliness directly impact NIF's ability to execute its mission.

LIVERMORE COMPUTING

MISSION When stockpile stewardship was first formulated, scientists knew that unprecedented computational capabilities were needed to integrate the vast amount of scientific knowledge of nuclear weapons processes and materials and the accumulated experimental data from hundreds of nuclear tests. The Advanced Simulation and Computing (ASC) Program (formerly known as the Accelerated Strategic Computing Initiative) was launched to address this need. Dedicated to improving computational power by at least a

Livermore received the Sierra early-access machine (featured below) to help prepare codes to run on the full version of Sierra as soon as it comes online. Sierra represents the next step toward exascale computing.



millionfold, ASC quickly became one of the most significant accomplishments of the stockpile stewardship era. The program has also contributed to making high-performance computing (HPC) an essential element of scientific research and has spurred the U.S. computing industry.

ASC simulations offer a computational surrogate for nuclear testing. Validated models have been able to accurately simulate much of the extraordinary complexities of nuclear weapons systems. Major advances in hardware and software have made possible a clearer understanding of the issues involved with nuclear weapon performance. Full three-dimensional (3D), high-fidelity simulations allow physicists to observe phenomena nanosecond by nanosecond, with a level of spatial resolution and physics realism previously unobtainable.

Livermore's world-class HPC ecosystem—the hardware, software, facility infrastructure, and computer support staff—empowers scientific discovery and technology development on both classified and unclassified fronts in support of LLNL's vital missions for the nation.

Livermore's most powerful computers are used primarily for stockpile stewardship efforts. As the nation's weapons age long past the point at which the designers assumed they would be replaced, it is important for LLNL to simulate their

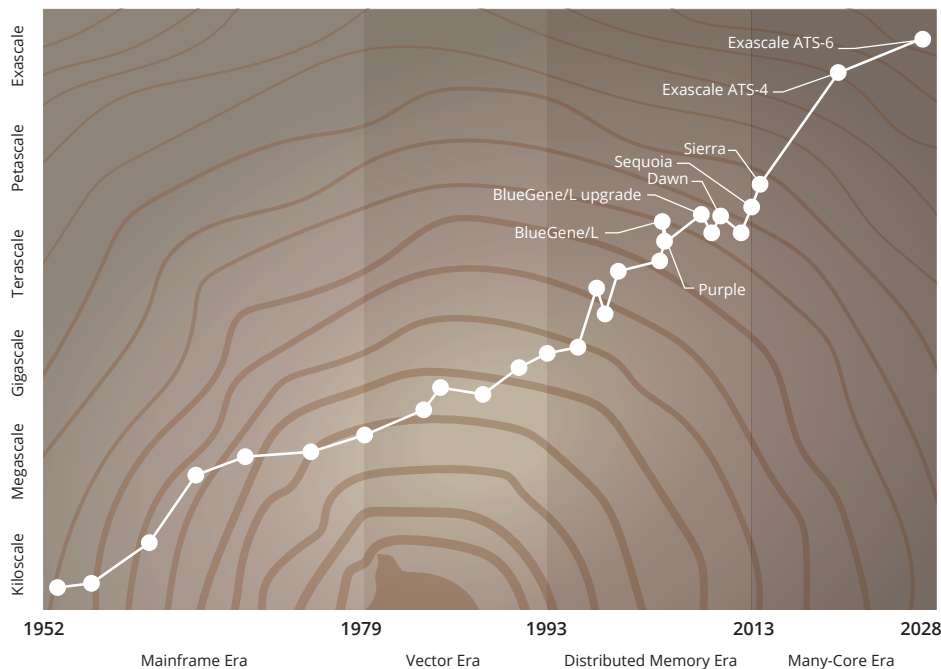
behavior and performance with the highest possible level of confidence. Oftentimes, this means running many iterations of complex simulations of weapons performance and behavior.

SCIENCE The most accurate simulations can reduce design iterations in comparison to constructing prototypes and conducting tests. Therefore, HPC has become essential for numerous scientific and engineering research areas at LLNL. Many of the problems that LLNL tackles are extremely tough. For example, grand

INFRASTRUCTURE PLANS

LLNL has cutting-edge capabilities to support the nation's **high-performance computing** efforts. However, LLNL needs to modernize its science and technology infrastructure to continue pushing the state of the art. Future plans include:

- B654 air handler unit improvement project
- OS454 reverse osmosis project
- B453 chiller replacement project
- B453 upgrades to site 2022 and 2027 NNSA advanced HPC computers
- Exascale Complex Facility Modernization
- B654 expansion



Each era of high-performance computing technology brings its own challenges along with increased performance capabilities. The first three have passed. In the current many-core era, node designs deploy many central processing units cores or a graphics processing unit accelerator with various memory configurations. Livermore's Sequoia stands on the threshold of this era.

be integrated into computing systems for the broader consumer market.

INFRASTRUCTURE Maintaining the necessary competitive edge in the rapidly evolving world of HPC requires that LLNL works on three timescales simultaneously: delivering capabilities today, innovating for and investing in tomorrow, and envisioning what will come the day after tomorrow, that is, what is next on the horizon. The Laboratory is addressing the "tomorrow" trajectory in several ways. One is by modernizing its computing infrastructure.

The National Nuclear Security Administration (NNSA) is moving beyond today's computer systems to usable exascale computing systems, which will eliminate the need for some approximations, allow simulations to run at substantially smaller length scales, and enable more accurate quantification of margins and uncertainties. Advanced 3D simulations in the UQ regime are required

challenges in computational modeling require the best available resolution and accuracy to assess physical, chemical, and biological processes. Many simulations are necessary to study uncertainties in these grand challenges.

For stockpile stewardship, research focuses on the need for uncertainty quantification (UQ). HPC simulations must be executed many times with slightly different variables to better quantify the uncertainty in possible outcomes and the accuracy of LLNL's codes. This work is highly demanding computationally, driving LLNL to push the cutting edge in HPC.

Exascale computing, at speeds of 10^{18} floating point operations per second (flops)

and memory of 10^{16} to 10^{17} bytes, is the next step in HPC. To progress toward this goal, a procurement collaboration between Oak Ridge, Argonne, and Livermore national laboratories and industry partners is developing and delivering next-generation, 100-petaflop-scale systems for the three laboratories in FY 2018. LLNL will receive Sierra, the Laboratory's next ASC advanced technology system.

Sierra is the next step towards exascale. Exascale computing is needed for national security applications (such as stockpile stewardship) and will increase U.S. economic competitiveness. Developing the technologies necessary for exascale computing will also stimulate and advance the more mainstream computing market because these technologies will eventually



LLNL recently completed Building 654, a modular and sustainable supercomputing facility, to help meet the growing need for unclassified computing at Livermore and to accommodate a variety of high-performance computing architectures.



to assess multiple threats that could be posed by adversaries over the next decade. A factor of 100 to 1000 improvement in capability over what is available today is

needed within just a few years to assure confidence in assessments, reduce risks of surprise, and meet expected military requirements to counter these threats. This

drives the need for new codes, exascale platforms, and advanced facilities capable of hosting these platforms efficiently. While this national security mission is paramount, there are other nuclear security issues that require far more rapid assessments than are possible today. The insight that comes from simulations will also continue to be vital for addressing nonproliferation and counterterrorism challenges, as well as informing various national security decisions.

Delivering the highest quality and most accurate simulations for an aging stockpile demands powerful and flexible next-generation computing capabilities. Sierra will be more than 30 times faster than today's fastest systems in the U.S., and as such, will have a significantly higher power draw, among other notable utility and infrastructure requirements. LLNL is completing facility upgrades in Building 453 for Sierra and is planning for the next two advanced HPC computers (expected

KEY PERFORMANCE PARAMETERS FOR THE EXASCALE COMPLEX FACILITY MODERNIZATION PROJECT		
Requirements	Threshold	Objective
Scalable facility to ensure adequate square footage to handle exascale systems and their environment	15,000 square feet	24,000 square feet
Power capacity to meet demand from exascale systems	85 megawatts	110 megawatts
Increase water capacity to implement innovative mechanical liquid-cooling solutions	18,000 tons	25,000 tons
Accommodate heavier racks (4'x4')	315 pounds/feet ²	500 pounds/feet ²
Ensure sustainable and energy-efficient facility solutions are implemented	Power usage effectiveness = 1.08	Power usage effectiveness = 1.05

USING HIGH-PERFORMANCE COMPUTING TO ADVANCE HUMAN HEALTH

to be delivered over the next decade). The largest project proposed to address this capability is the Exascale Complex Facility Modernization (ECFM) project. The purpose of this project is to provide capable facilities and infrastructure to site an exascale-class system in 2022, with full production initiating in 2023, and to site a subsequent exascale system in 2028.

Key requirements for the ECFM project are based on HPC vendor platform projections (see table on p. 18). If Building 453 is selected for the ECFM project, the facility's broad infrastructure base will be expanded.

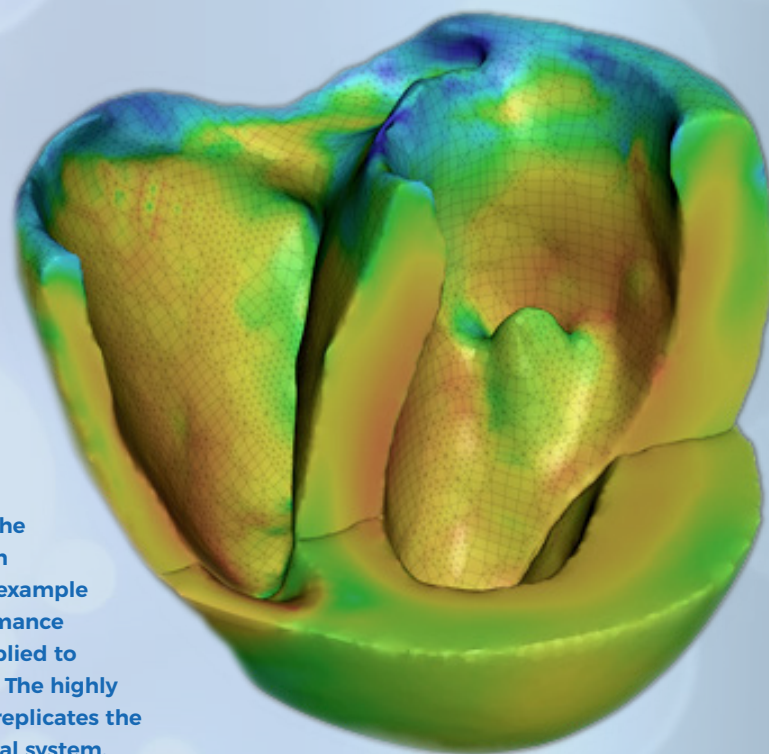
The existing building power capabilities will be scaled from 45 megawatts (MW) to 85 MW by installing a new substation. Tap changers will be provided on the transformer if the key performance parameter threshold power is exceeded as a means of inexpensive contingency planning.

In addition, the existing building's cooling capacity will be increased from 10,000 to 18,000 tons by installing a new low-conductivity water cooling tower to provide direct process loops for energy-efficient computer cooling. The building's structural integrity, specifically of the computer floor, will be adjusted to accommodate heavier systems through an efficient framing plan. Further analysis has proven this reinforcement can be accomplished incrementally based on system placement.

Internally funded projects are already underway at Livermore to build high-performance computing capabilities across an increasing number of disciplines. One such effort is funded by the Laboratory Directed Research and Development Program, Livermore's single most important internal funding resource for fostering innovative science and technology.

This project is aimed at enhancing Cardiod, the world's most detailed model of the electrophysiology of the human heart. Developed in partnership with IBM, the code depicts the activation of each heart muscle cell and the cell-to-cell voltage transfer of up to 3 billion cells. It does so in near-real time and with unprecedented accuracy and resolution. For the first time, scientists are seeing how potentially fatal arrhythmias develop and are influenced by the administration of drugs and medical devices.

Cardiod is the world's most detailed simulation of the human heart in action and an example of high-performance computing applied to human health. The highly scalable code replicates the heart's electrical system.



WEAPONS ENGINEERING

MISSION As a design agency (DA) for the National Nuclear Security Administration (NNSA), LLNL is responsible for ensuring the safety, reliability, and performance of the weapons nuclear explosives package (NEP), without nuclear testing. Weapons engineering plays a key role in ensuring that the design of the NEP meets the Department of Defense's (DOD's) requirements specified by the weapon military characteristics (MC).

LLNL annually assesses the B83, W87, and W80-1 warheads to ensure that they continue to meet DOD requirements. The confidence basis is built on a foundation of historical tests, along with the addition of annual monitoring (formally called surveillance) and DA stockpile tests. This important test data allows the Laboratory to assess and communicate to the Secretary of Energy, Secretary of Defense, and the Nuclear Weapons Council the health of the stockpile.

Weapons refurbishment requires the implementation of NNSA's Phase 6.x Process. This framework is used by weapons engineering to address concerns

Hydraulic tensile testing is performed on a component to confirm that a proposed design is feasible and performing as predicted. This research and development subassembly testing is done before expensive large-scale experimentation occurs.

in enduring stockpile weapons. This weaponization process is like creating a new product, in which it requires design, development, systems integration, testing, production, and surveillance to ensure that nuclear warheads meet the DOD's MC requirements.

Testing and annual surveillance are key capabilities required for weapons engineering.

Testing

SCIENCE Any complicated engineering assembly, such as a car, an airplane, or a nuclear weapon, must use a product lifecycle process to properly bring an idea from concept to fruition. To evaluate whether proposed designs are viable and meet customer requirements, design



INFRASTRUCTURE PLANS

LLNL has cutting-edge capabilities to support the nation's **weapons engineering** efforts. However, LLNL needs to modernize its science and technology infrastructure to continue pushing the state of the art. Future plans include:

- B231 Applied Materials and Engineering (AME) consolidation portfolio project
 - » New AME vapor deposition facility
 - » New AME office building
 - » New AME polymers facility
 - » New AME joining facility
 - » B131 high bay renovations
 - » B321A renovations
 - » B341 renovations
 - » B233 renovations
- AME equipment consolidation and modernization, and IW1 life-extension program (LEP) equipment recapitalization projects
- B810 HVAC system replacement
- B321C LEP and warhead assessment revitalization project
- B321C and B321A facilities upgrade
- Site 300 STS environmental testing
- B327 nondestructive evaluation laboratory renovation
- B327 LEP building recapitalization

SHAKER TESTING AT SITE 300

feasibility must be examined through prototypes and engineering tests. Based on these results, the customer approves full-scale production. In the case of a nuclear weapon, the nuclear security enterprise production agencies receive this approval. For nuclear weapons at LLNL, testing is key to the annual assessment of weapons in the stockpile and to weapons refurbishment. Weapons engineering testing brings together a broad spectrum of people, technologies, and facilities to meet these stockpile stewardship needs.

One type of test, environmental testing, is used to simulate potential environmental conditions. This can include a variety of conditions experienced by a weapon, from temperatures to vibrations to shocks. For example, during the lifetime of an airplane, it will experience some level of turbulence, which causes the wings and frame to flex. To understand the design, aircraft manufacturers will put the wings through a wing load test to determine whether it meets the design requirements. At times, there may be failures during these environmental tests, which may require further material testing. For instance, the aircraft manufacturer may take a piece of a failed wing to conduct material characterization tests. These tests would allow the engineer to assess if the failure was due in part to a material's structure or property. This testing philosophy is applied to all proposed modifications for any weapon component.

LLNL was responsible for conducting several preliminary experiments to support the design, development, and engineering effort of an advanced conventional warhead for the U.S. Air Force Space and Missile Systems Center. Experiments executed at LLNL's Site 300 focused on how well warhead components could withstand violent shaking. One shaker test subjected the warhead to severe heat, shock, and vibration. A second one examined the firing initiation system that the test would use to detonate the warhead. The shaken initiation system was then detonated at Livermore's High Explosives Applications Facility in a heavily instrumented experiment conducted in a firing tank. To validate warhead performance, the team conducted arena tests, in which the warhead was placed on a pedestal, connected to diagnostic instruments, and detonated at Site 300's outdoor firing facility, Building 851. The arena test at Site 300 provided engineers with performance data. This combination of environmental and explosive test facilities allows LLNL engineers to certify, to the Department of Defense, that warheads continue to meet their requirements.



At Site 300's environmental test area, several facilities subject prototype high explosives, detonators, and other energetic materials, as well as nonnuclear stockpile components, to conditions such as vibration, shock, impact, acceleration, twisting, and various combinations of heat and cold. This image depicts non-contact vibration measurements of a W80 test unit using a laser vibrometer.

X-ray diffraction (XRD) is one of the tools LLNL scientists use to characterize a metal's material properties. Performing XRD on a metal indicates the phase(s) that are present, which can change based on how the metal was manufactured or processed. XRD can also provide information on the degree of texture and strain present in the sample.

When a refurbishment (or change) is proposed to weapon device component or subassembly design, testing is essential to understanding whether the design changes will meet specifications. Required core test capabilities consist of material characterization and mechanical testing of polymers and metals, including radioactive materials. In addition, key environmental test capabilities help understand what happens when a weapon device component or subassembly design is subjected to thermal-mechanical environments.

Weapons engineering tests also require advanced material deposition and joining capabilities, such as welding or brazing. LLNL has a vital interest in welds—the melting and fusing together of two pieces of material to make one. Welding is the most widely used method for joining metals and is typically stronger, lighter, and cheaper than other joining methods such as riveting and bolting. Dependable welds are important for maintaining the performance and safety of any joined



component. Initial weld studies are often conducted to ensure that the welded joints are representative of a component design. These welds are then applied to assemblies used in hydrodynamic and environmental tests to provide the most accurate and informative results.

Understanding how materials are affected by the welding process is crucial to validate a component's integrity. When a material is welded, its crystalline structure changes. These microstructural changes interest LLNL because they can affect a material's strength, corrosion resistance, ductility, and mechanical properties. The changes could either enhance the quality of the weld or reduce the weld's integrity. Therefore, LLNL engineers want to understand the welding process by modeling it and then predicting the changes that may occur in the joined component.

INFRASTRUCTURE The infrastructure that supports critical weapons engineering tests will be in high demand to support the current W80-4 life-extension program (LEP) and the upcoming IW1 (W78/88-1) LEP. However, this infrastructure is also in need of maintenance—LLNL proposes to refurbish these facilities where practical and replace them only when required.

Currently, weapons engineering research and development occurs at LLNL's Applied Materials and Engineering (AME) facility, Building 231, which is the largest complex of engineering research, development, test, and evaluation facilities at LLNL. Building 231 is a 140,000 square-foot facility that houses crucial weapons engineering capabilities required to execute NNSA's missions for the stockpile, particularly LEPs and the annual assessment. The

building supports many capabilities, including applied materials work in areas of characterization, specialty fabrication, joining, physical vapor deposition, and mechanical testing. Materials include metals (both radiological and non-radiological), polymers, and powders.

The building, at present, poses a risk to personnel safety and programmatic execution due to failing facility conditions. It has a large maintenance backlog, beryllium contamination, extremely low seismic performance, and has not been recapitalized over the past 20 years. LLNL has already begun to migrate its staff and capabilities out of the building to mitigate potential risks. For a long-term solution, NNSA has requested a strategic plan to replace the more than six-decades-old AME building.

The AME capability migration plan will be coordinated with LLNL's site-wide infrastructure Master Asset Plan. The multi-year plan consists of recapitalizing four existing facilities, remediating a large site, and constructing three new laboratory

The five-year site consolidation strategy includes the capability migration plan for LLNL's Applied Materials and Engineering (AME) building. Relocating the current AME space will provide LLNL with an enduring facility space for 10 mission-critical capabilities to support weapons engineering activities.

buildings and one office building. The current AME space contains ten mission-critical capabilities that will be relocated into enduring facility spaces.

In addition, environmental testing is performed in several Site 300 facilities. These impressive facilities allow for the largest high-explosives loading (200 pounds per test cell) of all environmental test facilities within the nuclear security enterprise. However, these test facilities are averaging 50 years old and are exhibiting signs of significant atrophy and loss of some capabilities.

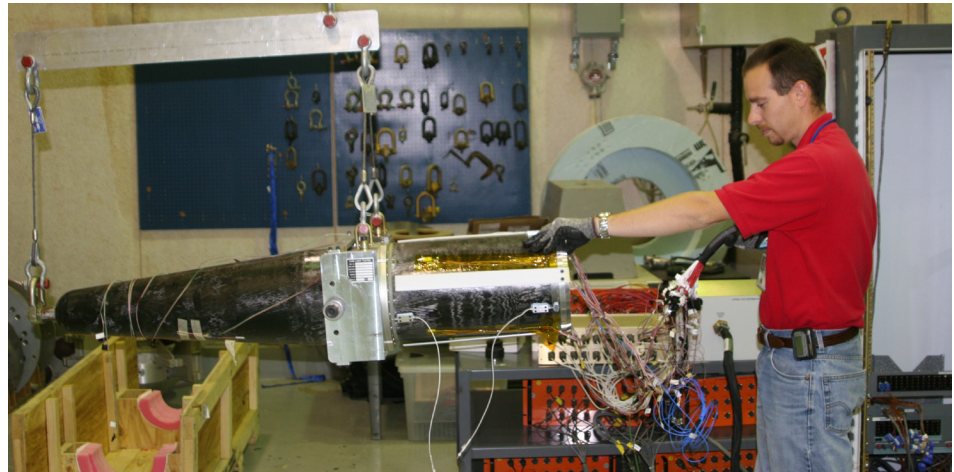
Site 300's high-explosives processing facilities, also over 50 years old, have many

infrastructure gaps and deficiencies in both utilities and real property. LLNL looks to modernize, rather than replace, existing Site 300 high-explosives processing facilities to best utilize cost and space. This effective approach has been demonstrated in Site 300's environmental testing facility, Building 836.

Surveillance

SCIENCE When a car is purchased, the new owner performs preventative maintenance is performed to prolong the life of the car by having critical parts replaced or refurbished. Checks performed by mechanics also ensure that the car is performing as it was designed. Like a





Dynamic shaker testing of a Department of Defense warhead allows engineers to determine if their designs meet the necessary requirements.

human body, without regular checkups, a car can become so “unhealthy” that it simply stops performing.

Maintenance of weapons is performed through a similar surveillance process in which an active weapons system is examined to ensure that the device continues to meet required performance criteria. Twenty-plus years ago, before the Department of Energy (DOE) established the stockpile stewardship program, the primary method of evaluating a nuclear weapon’s health was to essentially destroy it—the weapon was disassembled and each component was tested to ensure the system adhered to its requirements.

Advanced surveillance techniques were instituted as part of the stockpile stewardship program to help maintain existing stockpile weapons components

for as long as possible. Similar to how a physician orders x rays or uses a stethoscope to assess a patient’s health, scientists apply diagnostic tools to weapons systems to interrogate what lies beneath their metallic “skin.” Surveillance has three primary goals: detect stockpile defects, assess and document stockpile condition, and uncover precursors of aging early enough to implement corrective action.

LLNL began to develop enhanced surveillance methods to characterize the health of a material, component, or assembly without causing damage. Multiple nondestructive testing (NDT) techniques provide equivalent or better data than traditional destructive testing methods. A principle capability used in surveillance is the nondestructive evaluation (NDE) technique. NDE

characterizes the internal structure of a material, component, or assembly without causing damage and is applicable to multiple NNSA missions. Modeling and measurement sciences are combined to research, develop, and advance interrogative techniques and procedures. Techniques include three-dimensional measurements of many materials (explosives, foams, and metals), small to large structures (submicrometer to meters), and high-fidelity characterization of materials and assembled targets.

X-ray imaging methods and technologies are used for various industrial and stockpile stewardship missions, such as highly detailed, multidimensional x-ray images of weapons parts, engine parts, and the molds that cast them. These NDE methods are advancing technologies used for airport screenings of passengers, cargo,

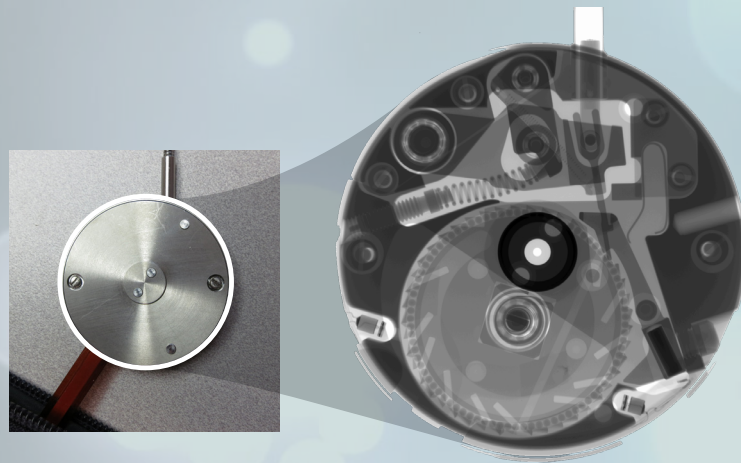
NONDESTRUCTIVE EVALUATION TECHNIQUES FOR STOCKPILE STEWARDSHIP

checked luggage, and carry-on bags. X-ray computed tomography and radiography machines at every airport analyze the contents of all checked and carry-on baggage, searching for hidden explosives and other prohibited items. Livermore experts have worked closely with government agencies and private industry to strengthen existing detection tools and commercialize new technologies.

INFRASTRUCTURE LLNL is a leader in x-ray NDE within the DOE complex of national laboratories. Livermore maintains several dedicated facilities onsite that house a broad spectrum of unique NDE hardware and software systems. Building 327, the flagship NDE facility, is a four-story structure that houses six subsurface, shielded x-ray bays that can handle classified parts. Facility personnel provide capabilities and services to satellite NDE facilities that support missions across the Laboratory. Now over 60 years old, Building 327 obsolescence is beginning impact the efficiency of NDE staff and the building's capacity to house state-of-the-art NDT equipment. Revitalization of the facility will make this a sustainable space that can meet mission demand for the future.

The nondestructive evaluation (NDE) technique, a key capability for the stockpile stewardship program, is used to understand the internal structure and makeup of a variety of industrial parts, subcomponents, and full assemblies in government, industry, and academia. Current NDE methods allow for highly detailed, multidimensional x-ray images that can be used for reverse engineering, quality assurance, or surveillance testing to characterize the health of nuclear weapons components. As illustrated in the image below, three-dimensional (3D) x-ray computed tomography can be used to measure the dimensions of the mechanical safe arming detonator for assessment without taking the component apart. Such techniques can also be used for 3D measurements of a wide range of materials (explosives, foams, and metals), with inspected object sizes ranging from small (submicrometer) to large (several meters).

NDE is a complex and multidisciplinary science involving the use of sophisticated sources, detectors, data acquisition electronics, computer simulation models, algorithms, and scientific visualization to support spin-off academic, commercial, and government projects, many of which are unique.



The mechanical safe arming detonator (MSAD) is an extremely intricate nuclear safety component used by the National Nuclear Security Administration. (left) Traditional destructive testing would require the device's top cover to be removed, while (right) three-dimensional x-ray computed tomography capabilities allow the MSAD to be assessed without disassembly.

SPECIAL NUCLEAR MATERIALS

MISSION LLNL's work with special nuclear materials—including highly enriched uranium, plutonium, and tritium—is conducted at the Superblock facility, one of just two defense plutonium research and development facilities in the nation. Livermore's Superblock complex includes Buildings 239, 331, 332, 334, 334O, and 335, among others.

The Superblock supports a wide variety of activities sponsored by the National Nuclear Security Administration (NNSA), the Department of Energy (DOE), and the Department of Defense (DOD). Stockpile stewardship, however, encompasses the majority of the Superblock's programmatic activities. These efforts contribute to the annual process of providing the technical basis of an assessment for the U.S. president of the safety and reliability of nuclear components for which LLNL is responsible. The Superblock houses modern equipment for research and engineering testing of nuclear materials. The facility has been upgraded over time to ensure it meets the latest nuclear safety requirements.

Stockpile stewardship program activities at the Superblock include material characterization and analytical chemistry of plutonium and highly enriched uranium components of U.S. stockpile weapons to ensure that current weapons function as designed, fabrication of plutonium targets to determine dynamic plutonium properties (to update and refine material

property models), plutonium aging studies to determine when current weapons need to be remanufactured, and plutonium science and corrosion studies to determine when current weapons need to be refreshed. The Superblock is also a critical component of certification activities for remanufactured pits to assure they meet design intent, testing and certification activities for life-extension program (LEP) nuclear material components to ensure that designs for the W80-4 and IW1 (W78/88-1) warheads meet design requirements, and the development of plutonium processing and fabrication technologies that decrease costs.

SCIENCE Since the end of nuclear testing, LLNL's annual assessment efforts have been predicated on a fundamental understanding of the nuclear weapons stockpile, which includes deep understanding of the properties of plutonium and how plutonium performs in weapons. Researchers must grasp the physics of how plutonium material ages and its behavior under extreme conditions, such as ultrahigh temperatures and pressures. Since its discovery, plutonium has constantly surprised researchers and engineers with its unique and unprecedented properties, meaning that developing accurate physics models for plutonium is not easily accomplished by extrapolating models of other materials. Instead, LLNL has focused on understanding plutonium through a

combination of unique experimental and computational tests.

LLNL researchers run state-of-the-art high-performance computing calculations to predict the properties of plutonium in conditions unachievable by experiment. These calculations are validated and benchmarked with high-fidelity

INFRASTRUCTURE PLANS

LLNL has cutting-edge capabilities to support the nation's **special nuclear materials** efforts. However, LLNL needs to modernize its science and technology infrastructure to continue pushing the state of the art. Future plans include:

- B331 tritium process room airflow system reconfiguration
- B332 diesel generator replacements
- B331 legacy low-level tritiated waste glovebox capability
- B332 ventilation control system upgrade for fume hood exhaust system
- B332 room ventilation fan fume exhaust control system design and replacement
- B332 criticality alarm system replacement
- Superblock glovebox system recapitalization

experiments at ambient conditions and elevated pressures. LLNL continuously pushes the frontiers of high-pressure science to develop new platforms that can reach more extreme conditions and interrogate material properties in those new regimes. These new experiments help refine theoretical models, more accurately predict observed phenomena in plutonium, and connect those phenomena to performance.

Planning the future needs of the U.S. nuclear weapons stockpile and complex depends in part on maintaining confidence in the long-term stability of the pit, or core, of plutonium-239

residing inside every weapon. Scientists and engineers who ensure the safety and reliability of the nation's stockpile have long been concerned that the damage accumulated over decades as plutonium-239 self-irradiates could eventually compromise weapon performance.

Scientists and technicians in the Superblock also work with tritium—a radioactive form of hydrogen. Tritium research and development work in support of enduring nuclear weapon stockpile activities is conducted in conjunction with Sandia National Laboratories/California, along with basic

research applicable to fusion-energy tritium issues. The number and complexity of experiments using tritium will continue to increase in support of stockpile experiments, fusion energy, neutron generation, and other research and development activities.

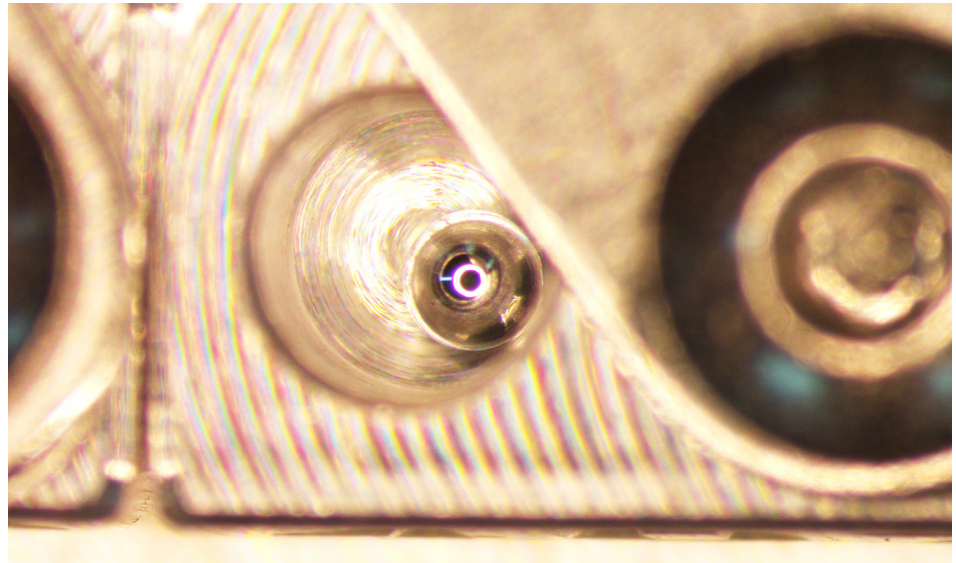
With the National Ignition Facility's expected long lifetime and continued inertial confinement fusion (ICF) program target needs, LLNL will need to maintain target fill and other tritium support capabilities. Tritium recovery operations, mostly from obsolete illumination devices, are expected to continue, as are container maintenance and surveillance activities.



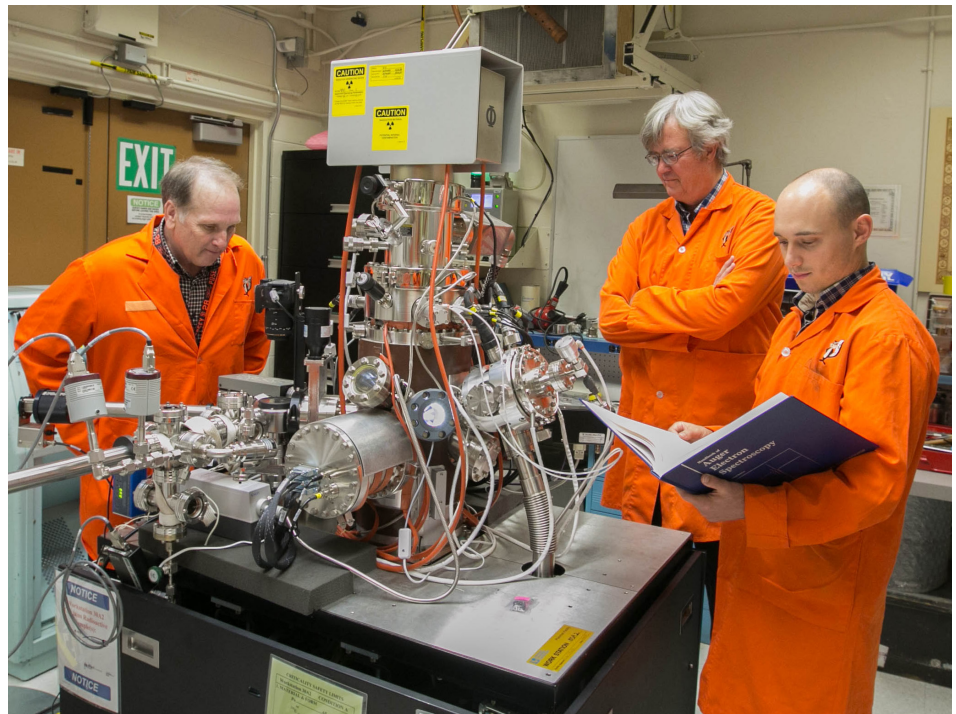
INFRASTRUCTURE Plutonium processing, characterization equipment, and associated capabilities in Building 332 support pit certification, environmental testing, and materials processing missions, all of which are key to assuring that LLNL can meet current and anticipated stockpile stewardship needs. LLNL routinely performs facility upgrades to ensure the Superblock facilities meet the latest nuclear safety requirements. The Superblock will remain

LLNL's work with special nuclear materials—including highly enriched uranium, plutonium, and tritium—is conducted at the Superblock complex, one of two defense plutonium research and development facilities in the nation.

A precisely fabricated spherical target capsule (approximately 800–2100 micrometers in diameter) used for inertial confinement fusion experiments conducted at the National Ignition Facility.



Researchers examine a scanning Auger nanoprobe, one of two experimental capabilities recently added to the Superblock.



PLUTONIUM AT 150 YEARS

capable and ready to support additional programmatic needs.

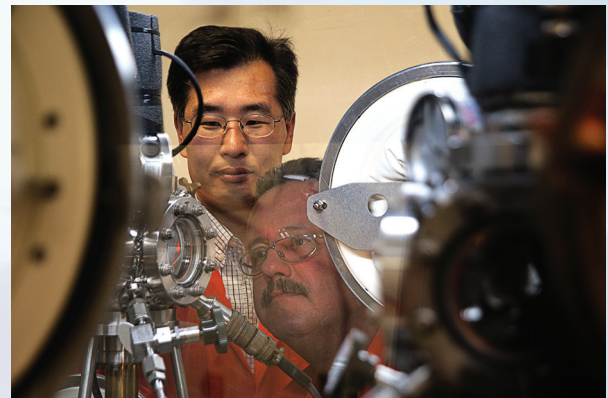
LLNL will continue to rely on its core capabilities to fulfill its role as a national asset by meeting and addressing the nation's security challenges. The existing mission areas are expected to continue, but with changes anticipated to support each mission's evolving focus. Future Superblock recapitalization projects will address potential modifications to LLNL infrastructure to support these missions, including retiring legacy facility liabilities and managing recapitalization of special nuclear materials facilities.

To meet program requirements, existing LLNL tritium facility capabilities and assets will need to be maintained and remain operational with high reliability. An additional tritium facility capability, the diffusion fill system, has been completed and is operating in support of ICF experiments at the National Ignition Facility and the Omega Laser Facility. Additional higher pressure capability is pending approval for operation. LLNL is evaluating the need for additional glovebox and fume hood workspace to support expanded tritium services and other recapitalization needs.

Plutonium is often called the most interesting and perplexing element in the periodic table. The radioactive metal has seven distinct crystallographic phases; its dimensions change with temperature, pressure, and impurities; and it has many different oxidation states. In addition, the material's properties do not always change in linear fashion. Over the past two decades, researchers at Livermore and Los Alamos national laboratories have greatly improved scientific understanding of plutonium, in particular how its aging mechanisms might degrade pit performance.

Independent research teams at the two laboratories performed extensive mechanical testing and laboratory-based experiments on aged samples of a plutonium-239 alloy—plutonium mixed with a small amount of gallium to stabilize the material in its delta phase at room temperature. Alloy samples were taken from 15- to 44-year-old plutonium pits and from plutonium that was artificially aged to 65 years. These tests showed no significant changes in important physical properties such as density and strength. In analyzing the test results, the research teams determined that the minimum lifetime for plutonium pits was at least 85 years—25 to 40 years longer than previously estimated. Six years later, these same naturally aged samples were 50 years old, and the accelerated alloy samples reached an equivalent age of 150 years. Both sample lots continue to age gracefully, and extremely sensitive tests and high-resolution electron microscope images by LLNL chemists validate the confidence-building conclusions of the earlier study.

A Livermore chemist and a mechanical technologist peer through a glovebox to check the setup on the dilatometer that measures the dimensions of plutonium samples.



HIGH EXPLOSIVES

MISSION The high-explosives (HE) research and development program is one of the Laboratory's core competencies as well as an integral element of the National Nuclear Security Administration's (NNSA's) design and development effort that supports nuclear weapons stewardship and broad national security missions. The energetic materials enterprise has a highly skilled workforce with broad experimental and modeling capabilities.

The HE program conducts research, development, test, and evaluation (RDT&E) activities using a multidisciplinary approach to synthesis, formulation, characterization, processing, and testing of energetic materials, components, and warhead subassemblies. RDT&E activities directly support stockpile stewardship for energetic materials with weapons assessments, stockpile maintenance, sustainment through life-extension programs (LEPs), weapons surveillance, significant findings investigations (SFIs), and technical guidance for weapon dismantlement and disposition. These activities are collectively conducted at Livermore's High Explosives Applications Facility (HEAF) and at Site 300, LLNL's remote testing site located approximately 15 miles southeast of the Main Site.

Lawrence Livermore is the lead design agency for the W80-4 and IW1 (W78/88-1) warhead LEPs. Replacement of the

HE and insensitive HE (IHE) detonator, booster, and main charge are included in the design options. The research and development work requires synthesis, formulation, processing, test, and evaluation of newly manufactured explosives materials. This will require significant effort to mature, down-select, and qualify explosives, binders, and explosive components.

SCIENCE Explosives react violently and should be protected from abnormal stimuli environments, which include frictional forces, excessive pressures and temperatures, shock and impact, and electrostatic discharge. Not all types of explosive materials and formulations react the same to a given stimulus condition. Explosives are divided into primary and secondary categories based on their sensitivity to various stimuli. Primary explosives are those that respond violently to relatively low levels of stimulus, while secondary explosives require higher levels. This classification can be further extended to IHEs, which require extremely high stimulus levels before reacting violently. For instance, a creditable accident environment will not initiate an IHE. Therefore, using an IHE offers many benefits to the stockpile by improving safety and security, allowing robust use control, and facilitating production efficiencies.

Insensitive explosive formulations are continually being developed to

achieve performance and operational requirements while also improving safety margins. The probability of accidental initiation or transition from burning or deflagration-to-detonation (DDT) is negligible for this particular class of explosive when subjected to unplanned heat, shock, fragment or bullet impact, electrostatic discharge, or other unplanned stimuli. To be classified as an IHE, the candidate explosive formulation must behave within specified reaction limits as defined by a battery of sensitivity tests. The Department of Energy (DOE) standard on explosives safety establishes the IHE definition, required qualification tests, and approval procedures.

INFRASTRUCTURE PLANS

LLNL has cutting-edge capabilities to support the nation's **high explosives** efforts. However, LLNL needs to modernize its science and technology infrastructure to continue pushing the state of the art. Future plans include:

- High-explosives process area revitalization
- B191 HEAF fume hood exhaust ventilation system replacement
- B832E high-explosives materials management structural study
- Laser-Explosives Applications Facility

Explosives RDT&E efforts at LLNL provide the scientific understanding for ensuring that the warhead initiation train functions as designed and is safe, secure, and reliable. The HE enterprise conducts experiments and modeling activities to qualify and predict behavior of explosives under a variety of operating conditions in support of stockpile stewardship. The work also involves a range of activities to understand the properties, engineering, and physics performance of the energetic materials, explosive components, and warhead-level assemblies.

Researchers conduct performance and safety tests to assess and ensure the explosives used in nuclear warheads remain functional and reliable over their expected

lifetime and beyond. They also assess how newer and safer explosives may behave as replacements. Regularly occurring stockpile stewardship surveillance tests examine the physical, chemical, detonation, and mechanical properties of HE reclaimed from the nuclear stockpile and help scientists and engineers determine the safety and performance of aging explosive components.

INFRASTRUCTURE Lawrence Livermore has unique experimental facilities at both the Main Site and Site 300. Paramount to the HE research and development program are HEAF, a DOE/NSA complex-wide Center of Excellence for HE research and development, and the Contained Firing

Facility (CFF), the largest indoor firing chamber in the nation, capable of containing detonations of explosives up to 60 kilograms (132 pounds) and features a wide field-of-view radiography capability for imaging integrated experiments. Collectively, these key facilities have enabled better understanding of energetic materials. Scientists apply expertise in explosives synthesis and formulation, material characterization techniques, and detonation sciences, and integrate experimental data with computer simulations to understand and predict the safety and performance of energetic materials.

HEAF is a centralized, fully contained HE facility with office and meeting spaces, explosives-rated laboratories, assembly areas, storage magazines, and seven firing tanks capable of detonating up to 10 kilograms (22 pounds) of explosives while using advanced diagnostics to characterize energetic materials and detonation phenomena. The facility also has a research gun with a 100-millimeter bore diameter. The gun fires into a specially designed tank for high-velocity

LLNL's High Explosives Applications Facility (HEAF) is a multidisciplinary center for explosives research that contains a comprehensive variety of developmental and experimental capabilities centralized in a single unique facility.





Researchers prepare to conduct an experiment in the spherical firing tank, the largest chamber located at HEAF, capable of detonating 10 kilograms (22 pounds) of explosives.



(top) An LLNL machinist prepares test specimens from a polymer-bonded explosive (PBX) 9502 billet at (bottom) Site 300's high-explosives machining facility.

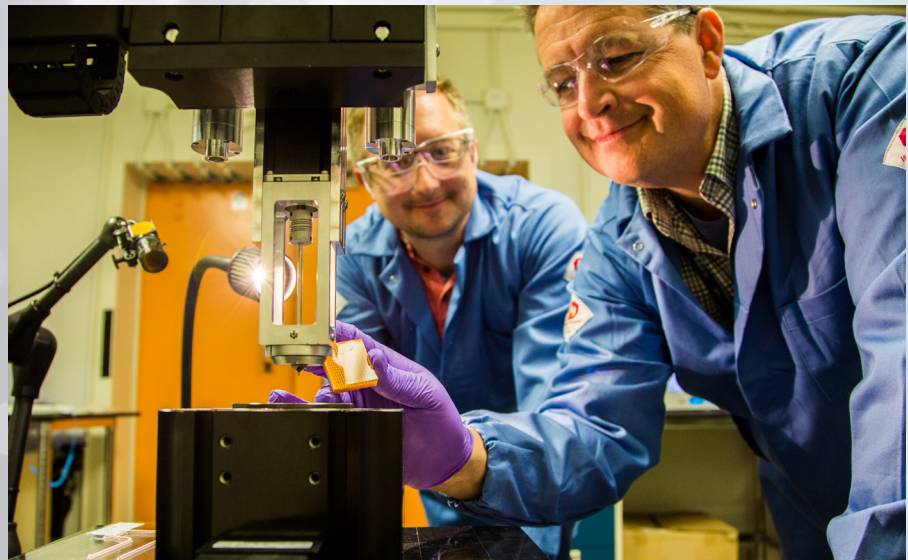
ADDITIVE MANUFACTURING OF HIGH EXPLOSIVES

impact studies. Most energetic materials research and development is performed with relatively small quantities of explosives in this facility.

Explosives capabilities at Site 300 support stockpile stewardship, nuclear nonproliferation, nuclear counterterrorism missions through explosives, warhead components/assembly processing, fabrication, test and evaluation, diagnostics development, and disablement technologies. Site 300 HE capabilities exceed those at HEAF—Site 300 facilities can handle and test larger quantities of explosives and warhead-level components and assemblies for technology maturation, prototyping, proof-of-concept design testing, certification, and surveillance activities. Site 300 infrastructure consists of more than 50 facilities and storage magazines supporting large-charge explosives work. This infrastructure includes pilot-scale synthesis, formulation and casting capabilities, inert and explosives machining capabilities, radiography, assembly areas, storage, and explosives waste disposal facilities.

To support the timely execution of LEP activities, LLNL has implemented a range of investments to sustain and modernize the equipment and facilities at the Main Site and Site 300. These recapitalized capabilities also provide core competencies for the weapons program's annual assessment of energetic materials, components, and subassemblies.

Laboratory scientists are developing methods and cultivating expertise in additive manufacturing (AM) techniques to make polymer-bonded explosive (PBX) components. This material is a composite, predominately consisting of explosive crystals bonded together with a small amount of polymer. AM methods, in which layers of material are built up as prescribed in a digital file, are used to quickly and precisely create objects with highly tailored material properties and performance. AM provides an opportunity to gain more control over the sensitivity, safety, and performance of the explosive. This technology has recently been demonstrated by producing booster-size test articles that were successfully detonated. Boosters are used to initiate the main high-explosives charge of a nuclear device. Further research and development is required, but this technology may have potential for use in future stockpile life-extension programs.



Materials scientists are developing new techniques to additively manufacture high-explosives components.

NUCLEAR THREAT REDUCTION & RESPONSE

MISSION The nuclear threat reduction and response effort at LLNL applies multidisciplinary science and technology to anticipate, innovate, and deliver responsive solutions to complex needs. This includes support of the U.S. government's efforts to:

- Defend against the catastrophic threat posed by the malicious use of weapons of mass destruction.
- Serve as an important national resource for addressing nonproliferation challenges through innovative technical solutions.
- Act as a key contributor to the Department of Energy (DOE)/National Nuclear Security Administration (NNSA) emergency operations mission by providing critical technical capabilities and scientific expertise during radiological/nuclear incidents

in collaboration with the interagency preparedness and response community.

Livermore's nuclear threat reduction and response effort can be thought of in three parts: counterterrorism and counterproliferation; nonproliferation; and emergency response.

Counterterrorism and Counterproliferation

SCIENCE LLNL has an integrated nuclear counterterrorism and counterproliferation program, part of

In 2016, a two-day meeting called Apex Gold was held at LLNL. It was the first-ever minister-level gathering to identify potential national and international actions in the event of a nuclear crisis.

a national endeavor to prevent and mitigate potentially catastrophic incidents involving nuclear and radiological devices. In a world where threats are continuously changing, the Laboratory provides unparalleled expertise in threat and risk assessment, detection of threat materials, understanding and

INFRASTRUCTURE PLANS

LLNL has cutting-edge capabilities to support the nation's **nuclear threat reduction and response** efforts. However, LLNL needs to modernize its science and technology infrastructure to continue pushing the state of the art. Future plans include:

- B170 classified computing and communications upgrade
- B140 server room chiller replacements
- B170 HVAC control system
- B262 radiation detection capabilities for nuclear security
- Secure training and communications center
- Network Intelligence Research Facility
- Forensic Science Center
- Nuclear Security Science Center
- Integrated Global Security Center
- 24/7 Joint Operational NARAC and Render Safe Home-Team Facility



mitigating the consequences of attacks, and forensic analysis, among other notable contributions.

Nuclear counterterrorism and counterproliferation enable the U.S. government to assess the motivation and planning of nation and non-nation states regarding their intent to create or execute a nuclear event.

LLNL applies its science-based, intelligence-informed expertise to address issues associated with nuclear counterterrorism. The Laboratory provides the methodologies and tools to deny, deter, and dissuade potential actors from acquiring the materials or technologies needed to execute such an event. LLNL also leverages its science and technologies toward detecting (and if possible, countering) the development of any device or capability that may lead to an event.

These efforts include the development and application of a data-fusion platform to organize, make accessible, and facilitate the study of information to

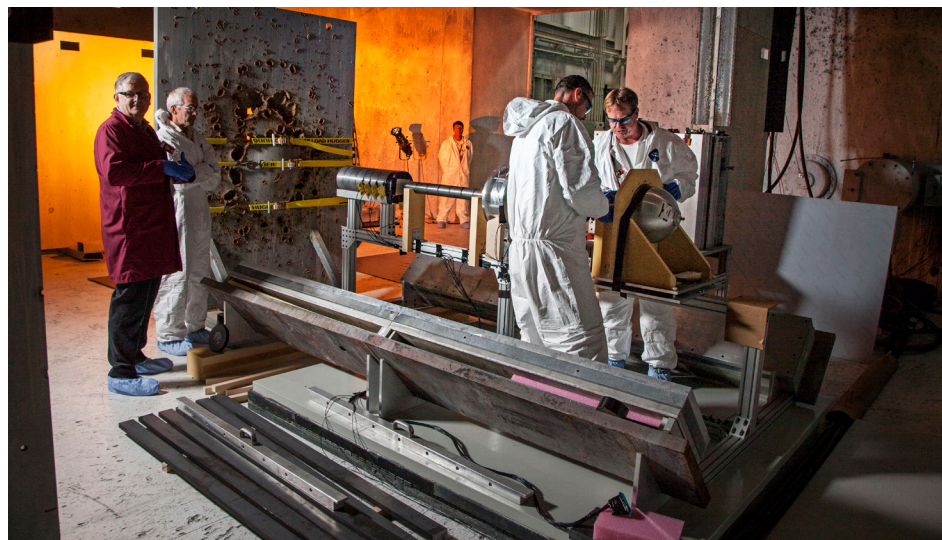
LLNL scientists prepare for an explosive-driven shaped charge experiment inside the Contained Firing Facility at Site 300. A series of renovation projects at Site 300 will enhance LLNL's mission to test full-scale mock nuclear weapons through hydrodynamic and environmental tests.

help assess the risk of terrorist use of an improvised nuclear device. In addition, LLNL supports, validates, and helps to update the nuclear threat device task list through experiments, development of improved models, and analyses. The list includes threat concerns that must be assessed to improve understanding of security requirements, device weaknesses, and threat effects, sensitivities, and uncertainties. The task list changes as the concerns about the threats change.

In addition, the Laboratory works on many technologies to detect uranium and plutonium, ranging from very high-end, high-purity germanium detectors (which are licensed and provide the gold standard for detection) to new, lower

cost, portable scintillator detectors made using specially designed crystals and plastics. Machine-learning algorithms are being developed to reduce the number of false alarms at portal monitors. The Laboratory is also working on methods to enhance the effectiveness of searches for radioactive materials in urban areas and on making training exercises more realistic for first responders who would be called upon in the aftermath of a radiological or nuclear incident.

LLNL's work to counter nuclear weapons is focused on the Standoff Disabling Project. This project involves the development of tools that could be used if custody of a nuclear weapon is lost to prevent rogue use against

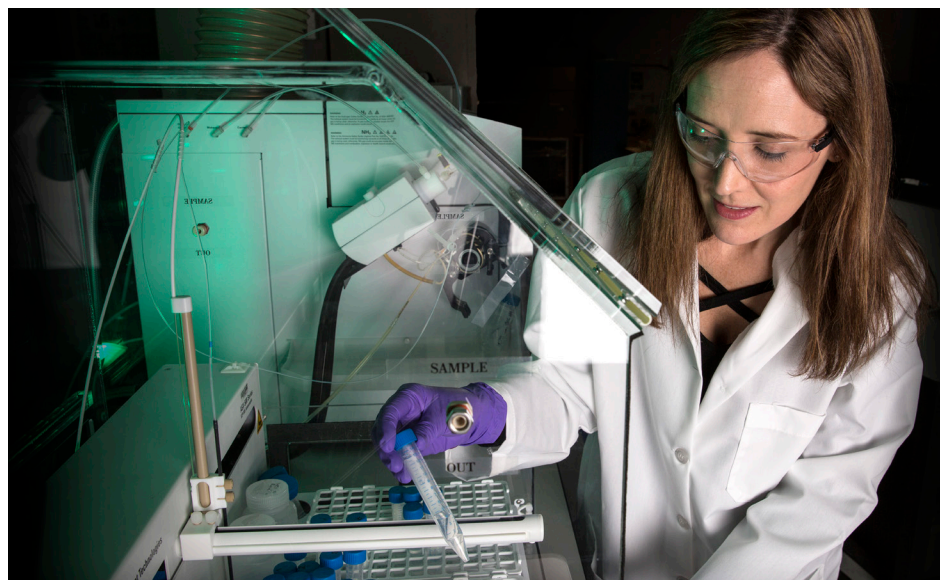


The Forensic Science Center uses a range of mass spectrometry techniques to analyze interdicted samples and deliver key assessments to the intelligence community, law enforcement, homeland security, and health professionals.

the U.S. or its allies. A summary report provided to NA-82 explains the overall experimental program and how the data from the NNSA effort can ultimately be incorporated into existing and certified Department of Defense (DOD) software and tools. Phase 1 of the demonstration project will be conducted at LLNL's Site 300 and will provide data needed for informing options.

INFRASTRUCTURE LLNL maintains key science and technology infrastructure to anticipate, innovate, and deliver responsive solutions to complex nuclear threat reduction needs. The International Security Research Facility, Building 140, and the Forensic Science Center (FSC), Building 132N, are two such examples. To continue to be effective with future technological advances, LLNL needs to upgrade these facilities.

LLNL's FSC is one of two U.S. laboratories internationally certified for identifying chemical-warfare agents. FSC is home to nationally recognized experts and facilities that support nuclear, chemical, biological, and high-explosives counterterrorism. The center also conducts basic research in the



areas of analytical science and instrument development, nuclear forensic analysis, and the synthesis of new molecular and tailored nanostructured materials.

LLNL will develop, enhance, and apply expertise and capabilities to analyze nuclear technologies; develop nuclear detection and countermeasures strategies and hardware; provide expertise, analysis, and disablement technologies in support of emergency response; and perform the full range of nuclear materials analysis and pre- and post-detonation nuclear forensics to support attribution and consequence management. Secure high-side space will be needed to enable this growing mission. A General Plant Project-scale plan to create space and the Network Intelligence Research Facility will address current and forecasted needs.

Nuclear counterterrorism and counterproliferation efforts comprise only a portion of the overall nuclear threat reduction and response mission. LLNL uses its significant multidisciplinary science and engineering expertise and nuclear weapons design knowledge to create an integrated approach to the broad spectrum of nuclear security challenges. In the long term, a proposed new facility, the Nuclear Security Science Center, would provide integrated infrastructure, including testbeds, forensics laboratories, and computing to advance science and technologies in fundamental materials understanding, material forensics, diagnostics and defeat tools, and assessments.

In addition, LLNL utilizes its significant systems engineering expertise to create integrated countermeasures to

ENERGY-PARTITIONING, ENERGY-COUPLING EXPERIMENTS AT NIF

varied and, at times, coupled threats. An Integrated Global Security Center would bring together diverse teams to anticipate threats, innovate solutions, and create deployable systems of countermeasures.

Nonproliferation

SCIENCE With globalization and the spreading availability of technologies, proliferation challenges continue to grow and evolve. The proliferation risk landscape is dynamic, and a flexible, resilient program is required to address changes over the medium to long term. U.S. national monitoring capabilities and cooperative international mechanisms to detect and constrain these evolving nuclear weapons activities are essential. There must also be continued emphasis on nuclear security to prevent theft of nuclear materials as a shortcut to proliferation or nuclear terrorism.

LLNL's nonproliferation program supports NNSA by providing expertise pertaining to weapons of mass destruction worldwide and leadership in advancing technologies to monitor, detect, and limit or prevent the proliferation of materials and technology. The goal of the program is to prevent proliferation and reduce the global risk posed by inadequately secured nuclear and radiological materials. The program covers a broad spectrum of activities from weapons dismantlement to physical protection

If a nuclear device were to be detonated near or above Earth's surface, defense agencies would rely on forensic technologies to quickly detect, locate, and assess the blast. Acoustic signatures—atmospheric and seismic disturbances resulting from the detonation—would likely be some of the first data available for analysis. To better understand these signatures and improve U.S. nuclear forensics capabilities, scientists at Lawrence Livermore conducted a series of energy-partitioning, energy-coupling experiments at the National Ignition Facility. These nonnuclear shots replicated, at a very small scale, the physical processes occurring in a nuclear detonation, allowing researchers to closely examine the weapons effects produced by a blast.



An energy-partitioning, energy-coupling experiment at the National Ignition Facility.

upgrades. LLNL applies unique capabilities in computing, materials development, and sensor technologies as well as its nuclear weapons expertise to enable the nonproliferation mission.

The Laboratory supports the International Atomic Energy Agency's (IAEA's) nuclear safeguards mission by developing new technologies and providing expert advice to the agency and to U.S. policy makers. LLNL personnel not only work with international partners to strengthen safeguards implementation, but also take leaves of absence to serve as IAEA staff members. LLNL scientists have developed both portable and stationary tools to detect and characterize materials produced as part of the nuclear fuel cycle. One example is GeMini, a handheld high-resolution gamma spectrometer that does not need liquid nitrogen for cooling and thus can be used in the field to accurately identify nuclear materials.

As part of LLNL's nonproliferation effort, scientists have long been leaders in seismic research to support international nuclear explosive testing treaties, which date back more than a half-century. Treaty verification research includes developing complex models of geologic structures that are used to understand how seismic waves are distorted while propagating from source to receiver.

Seismic waves from earthquakes, volcanoes, and man-made explosions

can propagate through Earth's interior for thousands of kilometers. Tens to hundreds of events per day are routinely detected by hundreds of seismometers arrayed around the world. These seismic signals are carefully scrutinized to determine whether any one of the events was an underground nuclear explosion, which would violate the Comprehensive Nuclear-Test-Ban Treaty (CTBT). The CTBT is a key global tool for preventing the proliferation of nuclear weapons.

Livermore scientists and engineers are also conducting chemical explosives tests to refine models of seismic wave generation and using advanced "big-data" technologies—that is, data-intensive computational science—to glean new insights from the vast amount of seismic data accumulated over six decades of nuclear monitoring.

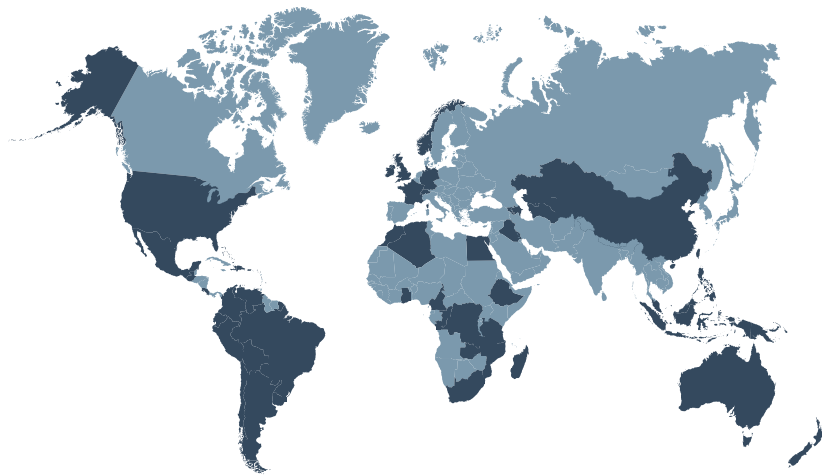
One of LLNL's most significant accomplishments in the seismic sciences is a revolutionary seismic monitoring technology called the Regional Seismic Travel Time (RSTT) model and computing code. Developed with colleagues from Los Alamos and Sandia national laboratories, RSTT improves the accuracy of locating seismic events by incorporating a three-dimensional model of Earth's crust and upper mantle, as well as regional data—which are needed for enhanced detection—into existing monitoring systems established in the 1960s through the present. RSTT



An LLNL team prepares for a Source Physics Experiment (SPE), detonated at the Nevada National Security Site (NNSS) and sponsored by the National Nuclear Security Administration. The SPE test team is comprised of scientists and engineers from Lawrence Livermore, Los Alamos, and Sandia national laboratories, the University of Nevada-Reno, the Air Resources Laboratory, the Desert Research Institute, and NNSS.

also offers blazing speed: in less than one millisecond, the system calculates the seismic-wave travel times that are used to locate seismic events through triangulation.

INFRASTRUCTURE LLNL leverages the capabilities researchers have developed and world-leading expertise in radiation detection and nuclear forensics to support stockpile stewardship and the



To date, 66 nations (dark blue) have adopted the Regional Seismic Travel Time model and computing code in the international effort to monitor seismic events, including underground nuclear explosions.

nation's goals in nonproliferation. Specific capabilities include nuclear forensics, radiation detection, seismic modeling, tags and seals, high-performance computing, and policy support.

LLNL's nonproliferation program relies heavily on the capabilities provided from NNSA-funded activities at LLNL and other sites. In keeping with the vision of One NNSA, this program is critically dependent upon the infrastructure investments and capability stewardship provided by Defense Programs (NA-10) supporting the programmatic requirements of Defense Nuclear Nonproliferation. Specifically, infrastructure projects, including the recapitalization of radiochemistry laboratories and the Livermore Advanced Computing Complex, directly support nonproliferation mission activities.

Emergency Response

SCIENCE LLNL provides key technical capabilities and scientific expertise during radiological and nuclear incidents in collaboration with the interagency preparedness and response community. LLNL partners with other national laboratories and sites to support emergency response capabilities, including the nuclear Accident Response Group, the Joint Technical Operations Team, the Radiological Assistance Program, the DOE Radiological Triage, and nuclear/radiological Consequence Management.

Livermore experts have played important roles preparing for major national events that could attract terrorists bent on detonating a nuclear device. For example, in preparation for the 2016 Super Bowl,

LLNL SUPPORTS NONPROLIFERATION

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



LLNL researchers have long partnered with organizations, such as the International Atomic Energy Agency, to support nonproliferation efforts.



LLNL researchers demonstrate capabilities in support of emergency response (Radiological Assistance Program/Joint Technical Operations Team/Accident Response Group).

LLNL experts helped sweep areas close to Levi's Stadium in Santa Clara, California.

LLNL enhances NNSA's emergency response programs by applying qualified subject matter experts, state-of-the-art tools, scientific knowledge, and technical training to provide both pre- and post-event response and reach-back support. LLNL, for example, develops models that track the transport and deposition of hazardous materials released into the atmosphere. These models are used in the National Atmospheric Release Advisory Center (NARAC). This federal facility, located at the Main Site, serves as DOE's plume-modeling center for real-time assessments of the impacts of nuclear, radiological, chemical, biological, or natural emissions. NARAC has responded

to numerous emergencies over more than three decades, beginning with the Three Mile Island nuclear power plant incident in 1979.

NARAC simulations couple meteorological, geographical, and material property data with computer models that account for the physical processes affecting the dispersion and deposition of radioactive and other toxic materials. For example, fallout simulations can show the trajectory of the plume and how much material is deposited onto buildings and streets. Maps of fallout plumes and ground concentrations inform disaster response plans and are valuable in training first responders on what to expect.



LLNL's National Atmospheric Release Advisory Center facility includes an operations room, a dedicated computer center, redundant communications systems, and 24/7 electrical power systems.

INFRASTRUCTURE NARAC is a national support and resource center for planning, real-time assessment, emergency response, and detailed studies of incidents involving a wide variety of hazards, including nuclear, radiological, chemical, biological, and natural emissions. The center provides the government with tools and expert services that map the probable spread of hazardous material accidentally or intentionally released into the atmosphere to help protect the public and the environment.

NARAC's software system requires significant modernization to ensure that it can continue to provide cost-effective long-term support and to be responsive to the evolving requirements of DOE

NARAC HELPS RESPOND TO TSUNAMI IN JAPAN

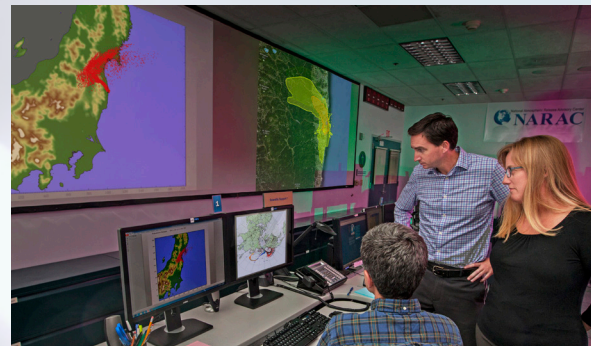
missions. In addition, upgrades are needed to NARAC's classified capabilities.

It is anticipated that major recapitalization projects for NARAC will be required due to the age of the current facility. This effort will be pursued in conjunction with an upgrade to LLNL's other render safe and consequence management home-team facilities that support an integrated response to both unclassified and classified incidents. A longer term solution is the 24/7 Joint Operational NARAC and Render Safe Home-Team Facility.

In 2011, a 9.0-magnitude earthquake triggered a devastating tsunami on the northeast coast of Japan. Soon the news worsened: Japan found itself on the brink of a major nuclear crisis after a 14-meter (45-foot) wave struck the Fukushima Daiichi nuclear power plant complex. The plant itself survived, but electrical power to cool the reactors was lost and backup generators were damaged. The resulting heat buildup in reactor cores and in spent fuel pools led to the release of radioactive materials.

LLNL experts, using sophisticated computer systems that model the spread of nuclear materials in the atmosphere, worked to provide government officials in the U.S. and Japan with answers to some of the most urgent questions on everyone's mind: how much radiation was being released, where it would travel, and what protective actions might be warranted.

NARAC was tasked with making projections of plume arrival times in U.S. territories with corresponding radiation doses. NARAC models correctly estimated an initial four- to five-day transit time before radioactivity would reach the West Coast and predicted that the radioactivity was unlikely to reach the U.S. at hazardous levels after the trans-Pacific journey.



In response to the 2011 devastating tsunami on the coast of Japan, the National Atmospheric Release Advisory Center provided daily meteorological forecasts and atmospheric dispersion predictions to government officials in the U.S. and Japan. The center conducted over 300 plume analyses, such as this one, in collaboration with the Department of Energy's Consequence Management Home Team, the Nuclear Regulatory Commission, and other agencies.

ENABLING INFRASTRUCTURE

MISSION LLNL is comparable to a small city—it provides utility services to nearly 700 buildings, roads, and basic support services for its population. The Main Site and Site 300 have their own electric, gas, water, communications, and sewage collection systems, as well as fire stations. At the Main Site, there are three additional site-wide utilities that support scientific endeavors, including low-conductivity water, deionized water, and compressed

air. The sites are equipped with pathways, parking lots, and storm drainage services, and buildings are protected with life-safety alarm systems. Cafeterias, maintenance shops, analytical laboratories, and business functions are included as mission support assets.

SCIENCE LLNL is home to world-class science facilities that enable the execution of its missions, including bioscience, counterterrorism, defense, energy, intelligence, nonproliferation, science, and weapons. These facilities demand round-the-clock, highly reliable utilities and support services. Many of these facilities are unique to Livermore and require responsive operations and maintenance, such as the National Ignition Facility (the world's most energetic laser) and the High Explosives Applications Facility (a Center of Excellence for high-explosives experiments).

LLNL's cutting-edge national security and science efforts depend on the Laboratory's facilities, which in turn depend on a properly articulated infrastructure vision and long-term planning. LLNL leaders must critically inspect and prioritize their infrastructure portfolios on strategic importance.

Like many other government agencies, cities, and counties, LLNL is running facilities and infrastructure longer than expected due to limited capital to rebuild. Optimal maintenance improves the utilization, efficiency, and longevity of the

INFRASTRUCTURE PLANS

Mission support utilities and infrastructure are the backbone to all LLNL mission facilities. However, LLNL needs to modernize its **enabling infrastructure** to continue pushing the state of the art. Future plans include:

- Utility valve, water distribution piping, and tank replacements
- Domestic water system treatment plant upgrades
- B511/411 maintenance and materials operations center
- Fire protection and life-safety system replacements
- Utility distribution system replacement and upgrades
- Site 300 electrical utility 2nd source, SCADA upgrade, generators
- Network communications center replacement
- New Emergency Operations Center
- Seismic risk mitigation
- Generic office buildings
- ES&H analytical laboratories replacement
- LLNL southwest quadrant major office space renovation
- Legacy-process contaminated facility demolition

AT A GLANCE

51
miles of roads
465
miles of communication lines
316
electrical distribution substations/ transformers
70
miles of underground water distribution pipelines
19
miles of perimeter fencing
160
acres of Amsinckia grandiflora reserve (endangered large-flowered fiddleneck)

While the Laboratory has ~6,500 employees, its peak power demand for scientific and computing missions would serve a typical city of 65,000 residents. LLNL is dual sourced by PG&E and WAPA, with automatic transfer.

current infrastructure stock and makes the most of existing assets. Therefore, LLNL is pioneering computational models to calculate the optimal levels of operations and maintenance and when best to recapitalize. These models help inform decision makers regarding maintenance and project budgets.

One such LLNL-developed model calculates the rate of degradation, deterioration, and failure of facilities and infrastructure over time, and helps users successfully manage and predict future facility conditions. Another model estimates predicted equipment service lives with actuarial



science. By better projecting future facility conditions, these models greatly benefit facility management, budgeting, and capital projects.

INFRASTRUCTURE Support utilities and infrastructure are the foundation of all mission facilities. These systems were installed in 1944, when LLNL was a naval air station, and have since aged. The

systems have been modified over time, with some thought to future growth, as the Laboratory has expanded to keep pace with arising program missions. Much of this infrastructure is past its useful life, however, increasing maintenance costs and reliability risks.

Electrical, Mechanical, and Civil Utilities

Components within LLNL's utility systems are over 50 years old, have aged to the point of unreliability, and/or can no longer be maintained. Leaks and system failures are impacting mission facility availability.

LLNL's drinking water is provided by a pristine Sierra reservoir, Hetch Hetchy, located in Yosemite National Park and delivered to a pumping station south of LLNL by the San Francisco Public Utility Commission. The Zone 7 Water Agency provides backup service.



Aging of LLNL's utilities and need for reliable, code-compliant systems create gaps that require ongoing investment. In addition, existing capacity must be adjusted to meet the projected load increases demanded by future National Nuclear Security Administration (NNSA) requirements and strategic plans.

Investments must be made to replace and upgrade electrical systems—

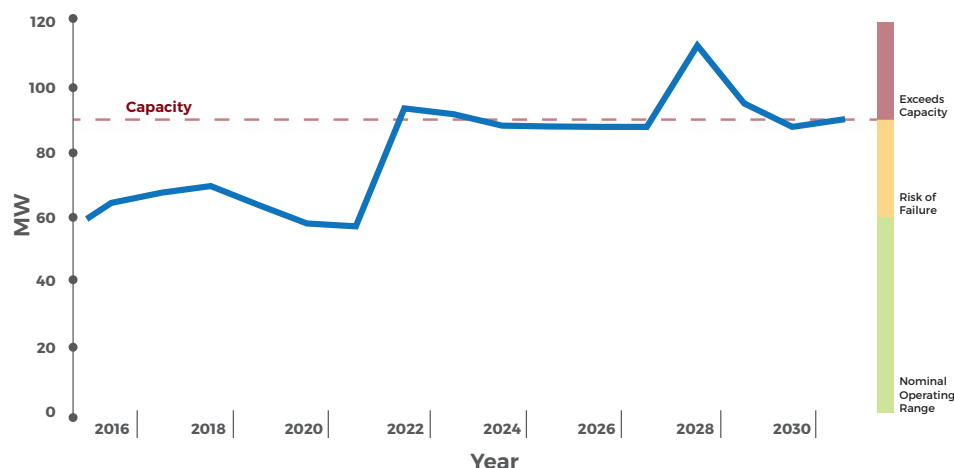
including life-safety, mechanical, and civil utilities—to ensure reliability and allow for preventive maintenance without major planned outages and interruptions to mission significant facilities. Infrastructure projects include utility valves and water distribution piping replacements, Site 300 erosion control systems installation, paving systems replacements, facilities fire protection and life-safety systems

replacement, and domestic water system treatment plant upgrades.

Information Technology Utility

Mission-enhancing scientific computing and networking capabilities need to be robust and reliable. Networking capabilities must include first-in-class core and distribution layers and pervasive indoor and outdoor wireless access. Not all buildings support network speeds that are fast enough for today's scientific computing.

LLNL ELECTRICAL LOAD & CAPACITY



LLNL's current firm-substation electrical utility capacity at the Main Site is 90 megawatts (MW), and demand is 65 MW. With the anticipated addition of exascale computing, programmatic loads and other new demands will increase to reach 90 MW by 2023 and exceed firm-substation capacity by 2028.

The networking and telecommunications hub for LLNL is a single-point-failure risk. The facility is insufficient to support modern, robust, and reliable network and telecommunications equipment. Shown below is legacy telephone and cabling infrastructure. A replacement facility will leverage architectural, structural, and systems designs that emphasize sustainability features.





Cooling towers at the Central Utility Station (U235) were recently replaced, which revitalized a critical part of the site-wide low-conductivity water system.

Continued investment is needed in network communications systems as well as in the central networking and telecommunications facility.

Seismic Safety

LLNL must provide safety-compliant retrofits of enduring facilities. LLNL is located in a seismically active region and there is a 72% probability that one or more earthquakes of a 6.7 magnitude or greater will occur within a 30-year period. LLNL has many enduring facilities that are in need of a seismic retrofit. This will be accomplished through the seismic risk mitigation project.

Emergency Operations

LLNL must coordinate its emergency response operations to comply with the Department of Energy and



applicable state and federal regulatory requirements. This includes onsite emergency response to regional earthquakes and other significant onsite incidents that require a collaborative response by LLNL with the city, county, state, and federal agencies. Coordinated operations are to take place in a new Emergency Operations Center.

There are many functional gaps within LLNL's existing Emergency Operations Center (EOC). A new EOC will consolidate emergency management, communications, and response teams and assets, and meet Department of Energy and state requirements to provide a self-sustained protective environment for a minimum of 72 hours.



In LLNL's Environment, Safety, and Health analytical laboratories, roof leaks and frequent heating, ventilation, and air conditioning (HVAC) failures result in operation issues. Pictured above is a fume hood that is over 30 years old—heavy acid use is causing rust, making the sashes difficult to operate.

Analytical Laboratories

Aging infrastructure is beginning to affect operation of LLNL's Environment, Safety, and Health (ES&H) analytical laboratories. Facilities and equipment are beyond expected service life, and there are tremendous opportunities to modernize, integrate, and streamline them. A project for safety modification of the analytical laboratories will improve ES&H services to programs, lessen the risk of ES&H mitigations, and reduce long-term costs.

Replacement Space

LLNL will need to replace substandard trailers and World War II-era buildings with General Plant Project-scale replacement generic office buildings. These projects

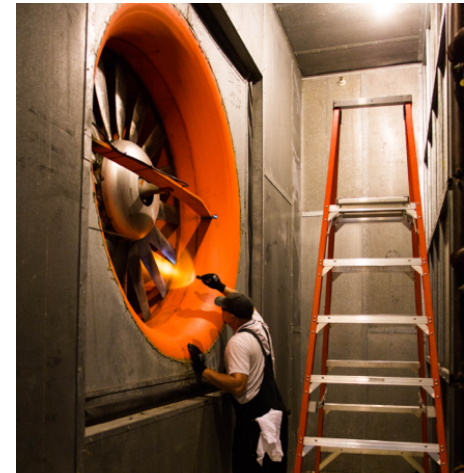
will provide a dual benefit by eliminating maintenance backlog and providing quality space to fulfill the need for laboratory and office housing. Office modules will collocate dispersed groups to reduce operational costs, improve efficiency, and promote collaboration. Laboratory units will be designed and configured for shared limited-term use.

Asset Management Programs

Using asset management programs (AMPs), LLNL will group similar building system replacements together to cost effectively arrest the growth of deferred maintenance. Similar to the roof AMP, NNSA is beginning reinvestment programs for other aged building system areas. Benefits include centralized and simplified procurement, tradeoffs evaluated at the site- and enterprise-levels by key stakeholders, and development of expertise in building system assessment, design, and installation. LLNL is leading the complex-wide cooling and heating AMP (CHAMP) to replace aged chiller, boiler, and ventilation systems.

Transition and Demolition

Demolishing legacy facilities will help clear the sites for redevelopment; eliminate maintenance backlog and ES&H and security risks; reduce surveillance and maintenance costs; support sustainability goals by eliminating the energy and water usage of excess facilities; and improve the sites' appearance to attract and retain



The average age of LLNL's critical HVAC systems is 30 years old. These systems suffer from frequent breakdowns, are energy deficient, have hard-to-find replacement parts, and inconsistently provide proper temperature and humidity controls for mission activities.

the next-generation workforce. LLNL is continuing its footprint-reduction efforts through the removal of trailers and other cold and dark facilities and planning for the demolition of LLNL's legacy-process contaminated facilities. While the facilities await final demolition funding, the following transition, disposition, and stewardship actions have been implemented:

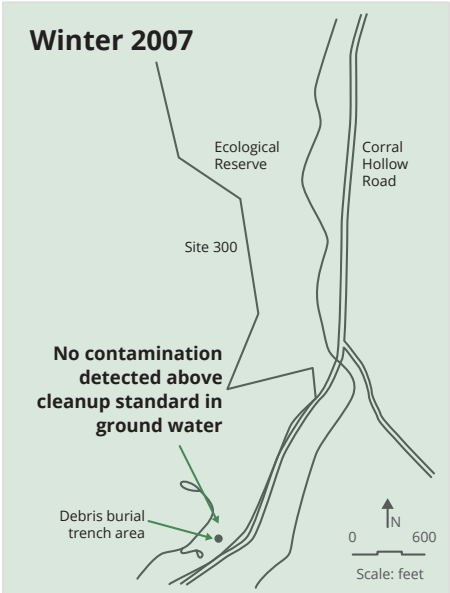
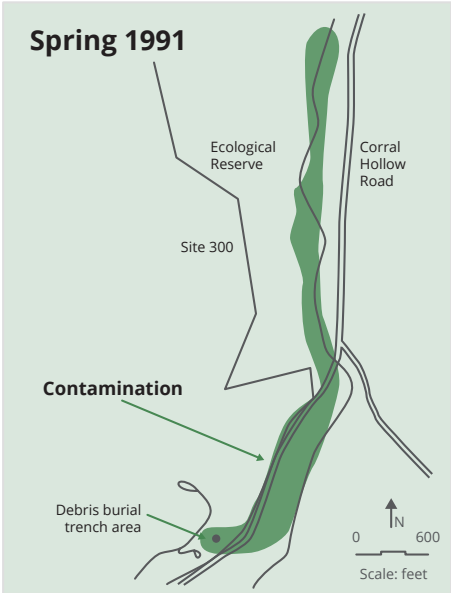
- Reduction of operating and maintenance costs by achieving an inactive state;
- Maintenance of required safety controls; and
- Execution of monitoring and surveillance activities.

HIGH-PRIORITY PROCESS CONTAMINATED FACILITIES

Facility ID	Facility Name	Rank after EM Walkdown	GSF
280	Livermore Pool-Type Reactor	1	5,469
251	Heavy Elements Facility	2	31,128
175	MARS E-Beam Facility	3	16,656
292	Rotating Target Neutron Source	4	20,811
212	OS212 Slab/Accelerator Building 212	5	61,898
241	Pluto Project Testing and Fabrication Facility	6	54,369
343	Explosives and High-Pressure Testing Facility	7	27,368



A DOE Environmental Management (EM) Review Team concluded that LLNL's legacy-process contaminated facilities are aligned with EM's transfer and stabilization criteria, and that the identified high-priority facilities represent significant risk and should be high priorities for decontamination and demolition. Pictured above is Building 280, an experimental reactor decommissioned in 1980.



In the 1960s and 1970s, volatile organic compound (VOC)-contaminated debris was buried in Site 300's Eastern General Services Area (GSA), causing contamination of the ground water and subsurface soil. Ground water extraction and treatment began as a non-time-critical removal action in 1991 and continued as a remedial action. In 2007, it was found that there was no VOC plume left in the area, and in 2017, it was deemed that the necessary degree of cleanup was achieved in the Eastern GSA.

SECURITY

MISSION The Laboratory is charged with protecting Department of Energy (DOE) and National Nuclear Security Administration (NNSA) interests against a broad range of threats. Security threats include unauthorized access; cyber threats and electronic intrusion; theft or diversion of nuclear material; sabotage; espionage; loss or theft of classified matter and proprietary information; destruction of government-owned and Laboratory-managed property; and other hostile acts that may cause unacceptable adverse impacts on national security or on the health and safety of DOE and contractor employees, the general public, or the environment. The responsibility to protect

LLNL's Protective Force Division works 24 hours a day, 7 days a week to protect the Laboratory's two sites.

LLNL against these threats is carried out by the Security Organization(SO).

The SO is part of the Laboratory's core infrastructure that supports program mission accomplishment and compliance with DOE/NNSA contractual requirements. The SO provides security expertise and guidance in support of LLNL's mission. The SO also maintains a secure environment that appropriately protects personnel, information, property, and nuclear material while complying with laws, policies, and procedures in a cost-effective manner. The director has assigned responsibility to line management for implementing safeguards and security policies in work activities and for ensuring that personnel and the work they perform meets all appropriate security requirements commensurate with security threats and risks. The SO facilitates this commitment by supporting LLNL's

line management and workers in their responsibilities.

INFRASTRUCTURE To execute its safeguards and security mission, the SO operates and maintains a number of site infrastructure facilities and systems. These include Protective Force training and operations facilities; physical protection elements (fences, gates, access control and intrusion detection systems, video surveillance systems, and barriers); and

INFRASTRUCTURE PLANS

LLNL has cutting-edge capabilities to support the sites' **security** efforts. However, LLNL needs to modernize its infrastructure to continue pushing the state of the art. Future plans include:

- Security fitness and training center facility construction
- Site 200 perimeter surveillance cameras installation
- Site 300 small firearms training facility construction
- Site 300 limited-area fence repairs
- Vasco post entrance canopy construction
- Physical security office and workshop facility construction
- Site 200 perimeter entrance enhancements



systems supporting security clearance and badging functions. To execute all of these protective actions, the SO must have ready and reliable facilities and assets.



The Security Organization operates three vehicle entry gates into LLNL's Main Site property protection area and two into a large limited area, all staffed by Protective Force officers. Pictured here is the Westgate entry at the Main Site.



The Main Site's new armory, Building 275, replaced a leaky 30-year-old trailer and adjoining transportainers.

ARGUS OVERSEES AND PROTECTS

LLNL is home to a broad spectrum of classified research and is responsible for protecting it, which requires high-level security measures. A primary aspect of the LLNL protection strategy is a sophisticated, computerized security system called Argus. Argus was designed, engineered, and installed at Livermore and is continually being upgraded and enhanced.

Argus meets such stringent security requirements that the Department of Energy's (DOE's) Office of Defense Nuclear Security has cited it as the standard for physical security systems protecting facilities where the consequences of intrusion are significant.

As it monitors and controls entry into high-security buildings, Argus is simultaneously monitoring both the Main Site and Site 300 for security threats and can alert and direct security forces to those threats. The Laboratory's classified documents, materials, and facilities are thoroughly protected, intruders can be detected in real time, and intrusions and emergencies receive instantaneous response from police and investigative personnel. The Laboratory is provided with high-level security 24 hours a day, 7 days a week.

Argus is a highly configurable and scalable system of integrated hardware and software components. Extensive features are necessary because Argus must accommodate many different configurations of security rules within one security complex, and sometimes one complex may have multiple geographical locations.

In addition to LLNL, the Argus system is operating at five other DOE sites and at one Department of Defense site to protect high-consequence assets or nuclear material.



Remote-access panels are the primary interface between users and the Argus system and are the means by which badged employees enter controlled areas and buildings.

STRATEGIC PARTNERING

MISSION Enhancing national security in a rapidly changing world requires innovative thinking on emerging threats. LLNL engages in productive partnerships with academia, industry, and government. The institutional strategy includes deliberate engagements with external partners, long-term investments in LLNL capabilities and people, and compelling narratives that communicate LLNL's mission and accomplishments. These elements

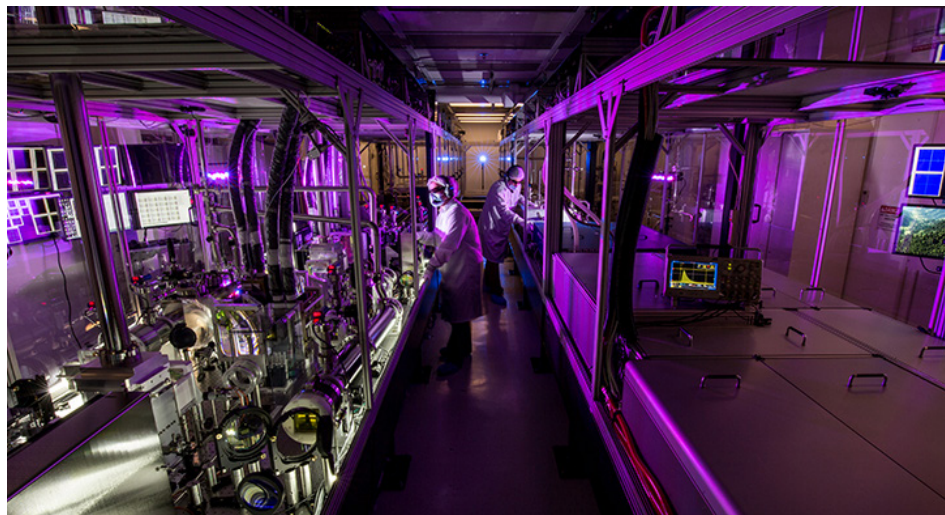
The High-Repetition-Rate Advanced Petawatt Laser System set a world record for diode-pumped petawatt lasers, with energy reaching 16 joules and a 28 femtosecond pulse duration (equivalent to ~0.5 petawatt/pulse) at a 3.3 hertz repetition rate (3.3 times per second).

collectively enhance the Laboratory's ability to transform basic and applied research into outcomes that address problems of national and global importance.

Supporting this effort is LLNL's Strategic Partnership Program (SPP), which comprises a broad portfolio of projects in three central areas: nuclear security, national security, and energy and environmental security. The SPP leverages the Laboratory's core competencies, world-class infrastructure, and talented technical staff to deliver practical solutions. The work conducted in SPPs reflect LLNL's ability to address sponsor needs through multidisciplinary teaming and research approaches that provide insights into the disruptive and dynamic nature of global threats.

The three primary national security agencies with Laboratory SPP agreements include the Department of Defense (DOD), the intelligence community, and the Department of Homeland Security (DHS). For DOD and the intelligence community, LLNL provides a range of support that includes research and development and complex analysis for agency missions. For DHS, LLNL provides research and development and technical analysis for threats related to weapons of mass destruction.

The SPP brings mutual benefit to LLNL and partnering agencies. For example,



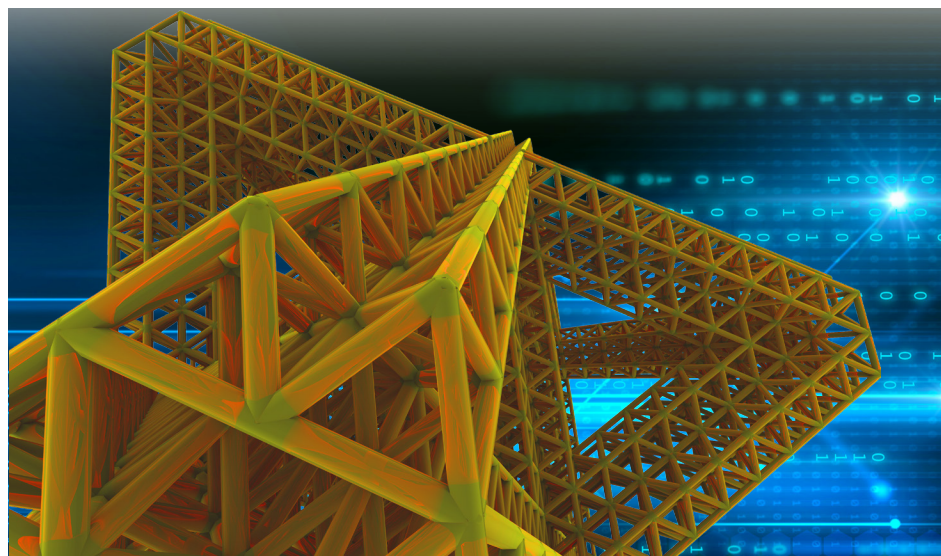
INFRASTRUCTURE PLANS

LLNL has cutting-edge capabilities to support the nation's **strategic partnering** efforts. However, LLNL needs to modernize its science and technology infrastructure to continue pushing the state of the art. Future plans include:

- Biosecurity and biosciences facilities upgrades portfolio
- Multi-program applied research facility
- LVOC office facility
- B490 secure laboratory conversion
- B153 Materials Technology Center clean room addition

the expertise developed in support of the nuclear weapons program has been leveraged to assist several sponsors in developing materials and techniques for the creation of new radiation detectors. In turn, these materials and techniques have circled back to the National Nuclear Security Administration (NNSA) for use as test diagnostics in support of stockpile stewardship as well as deployable units for defense nuclear nonproliferation missions. Similarly, DOD's Defense Advanced Research Projects Agency has funded a multi-year SPP project that brings together bioengineering, medicine, and computing to develop a sophisticated implantable electronics system for memory restoration. This work extends LLNL microfabricated sensor technology for sensitive, high-throughput measurements in harsh environments. LLNL's broader participation in the neurosciences—analyzing complex systems and developing new directions in neuromorphic computing—brings value and new expertise to high-performance computing (HPC) capabilities for NNSA missions.

LLNL also conducts scientific research for the Department of Energy's (DOE's) Office of Science. These projects often are multi-year efforts that enable remarkable discoveries and transform LLNL's basic understanding of fundamental science. This research frequently pushes the limits of LLNL's computational and experimental capabilities and builds



deeper knowledge within LLNL's core competencies. Together these elements keep LLNL's workforce sharp, engaged, and primed to take on the next set of challenges posed by NNSA.

Partnering with industry and government agencies through SPP agreements is one of many contracting mechanisms that extend the Laboratory's impact. Cooperative Research and Development Agreements (CRADAs), Agreements for Commercializing Technology, and interagency agreements offer alternative ways in which LLNL's technical staff engages with researchers external to NNSA. Notable recent examples include the High Performance Computing for Manufacturing (HPC4Mfg) program, the High-Repetition-Rate Advanced Petawatt Laser System (HAPLS) project, and the Joint Design of Advanced Computing Solutions for Cancer program.

As part of the High Performance Computing for Manufacturing Program, researchers have combined high-performance computing (HPC) and additive manufacturing technology to design, build, and test new devices with materials that have unique physical and microstructural properties. This rendering depicts a novel octet truss structure created using microstereolithography.

SCIENCE The HPC4Mfg program brings together world-class computing resources and expertise of DOE national laboratories with U.S. manufacturers to deliver solutions that offer the potential to revolutionize manufacturing. Led by LLNL and partner national laboratories, the HPC4Mfg program aims to infuse advanced HPC expertise and technology into the manufacturing industry to reduce resource consumption and accelerate



technology innovation to strengthen U.S. competitiveness. Industry partners are expected to participate through CRADAs and cost sharing.

The HAPLS project recently demonstrated a diode-pumped, repetition-rated, femtosecond, solid-state laser employing a multitude of innovative technologies. The project team leveraged prior work and new concepts, and in just three years, produced a fully integrated system with world-record performance. HAPLS represents a new generation of application-enabling, high-energy, and high-peak-power laser systems originating from DOE's fusion laser research and development. The HAPLS achievement will enable a new generation of spin-offs to the defense community and industry.

LLNL scientists are also partnering with the National Cancer Institute (NCI) of

The Advanced Manufacturing Laboratory's (AML's) cutting-edge capabilities and public-access location will provide a space for LLNL employees to work with industry and academic partners. The 13,700 square-foot facility will contain two laboratories and a collaboration space that includes workstations and a multimedia conference room. The AML will be the first new building at LLNL with a Leadership in Energy and Environmental Design Gold certification.

the National Institutes of Health in the development of exascale-ready tools, algorithms, and capabilities through the Joint Design of Advanced Computing Solutions for Cancer program. LLNL will focus on co-design research that will be coordinated with parallel efforts by the NCI to develop the field of predictive oncology. This program is designed to push the frontiers of HPC with the NCI's pressing need to improve targeting of drug therapy for cancer patients, produce an unprecedented scale of dynamic simulation for the Ras oncogene to

facilitate drug discovery and development, and to apply real-time, big-data analytics to a suite of national cancer databases to optimize cancer therapies.

The suite of partnership programs enhances core capabilities, nourishes cross-fertilization of ideas and approaches, and contributes to maintaining a vibrant intellectual environment. In turn, sponsors receive access to world-class science and technology capabilities and benefit from a multidisciplinary approach to tackling problems. In addition, strategic partnering

includes working with academia and the local community. Agreements with universities bring fresh ideas and talent to basic research projects. LLNL supports hundreds of student interns annually, many of which later become LLNL employees. These students bring a vibrancy to the LLNL campus and surrounding communities. Further, science education programs are a key element of LLNL's workforce development strategy. These programs benefit the local community and build valuable support for LLNL's mission.

INFRASTRUCTURE To ensure that the national laboratories have the resources required to address the spectrum of national security needs, an NNSA enterprise-wide plan includes investments in capabilities and infrastructure. The approval of the Livermore Valley Open Campus (LVOC) is an example of a forward-thinking concept that has helped transform the LLNL and Sandia National Laboratories/California (SNL/CA) campuses.

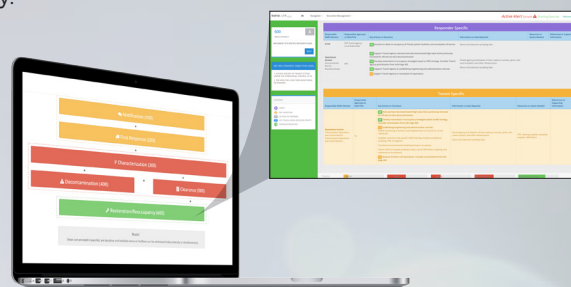
The LVOC is an unclassified research and development campus that houses more than 250,000 square feet of laboratory, office, and collaboration amenities on the east side of the LLNL and SNL/CA sites. The LVOC is designed to facilitate interactions with industry, government, and academia on research in various fields that include HPC, energy and environmental security, biosecurity, cybersecurity, and nonproliferation. The newest facilities at LLNL include the High

RAPID RECOVERY OF INFRASTRUCTURE

Livermore recently supported an Underground Transport Restoration (UTR) project to streamline the necessary steps for quickly responding to, remediating, and restoring an underground transportation system following a chemical, biological, or radiological attack. Developed as part of this effort, a new tool helps response and recovery personnel react to and recover public transportation systems following such an attack. This tool is a first-ever Web-based decision framework that guides first responders through steps to bring an attacked transportation system to full service.

The restoration process is complex. First, response teams and laboratories must quickly and accurately collect and analyze hundreds to thousands of samples so they can identify the type of threat agent released and determine the extent of contamination. This phase of the process must then be followed by characterization of the agent, decontamination, and clearance before the system can be reoccupied.

Funded by the Department of Homeland Security's Science and Technology Directorate, the UTR project also involves collaboration with transportation groups and supporting federal, state, and local regulatory agencies to develop the most rapid and efficient return-to-service strategy possible. Workshops, experiments, and technology demonstrations conducted with key collaborators have permitted LLNL to gain specialized knowledge to optimize the recovery strategy.



A first-ever Web-based decision framework guides users through a step-by-step decision tree for bringing an underground transportation system back to full service following a biological agent attack. Shown on the computer screen are the six distinct phases of restoration as seen in the framework. (inset) A snapshot of the reoccupancy interface illustrates the steps involved during this phase of restoration.

The HPC Innovation Center has become a hub of collaborative activity and workshops, such as the 24-hour “hackathons” sponsored by Livermore’s Computation Directorate to encourage collaborative programming and creative problem solving by employees and students at LLNL.



Performance Computing Innovation Center (HPCIC) and the Advanced Manufacturing Laboratory (AML).

The HPCIC provides LLNL’s workforce with a more accessible venue to engage with partners on leading-edge, high-impact projects aligned with capability development for NNSA missions. Strategic partnerships boost the development of modeling and simulation, data analytics, and cyber programming models and methods that can then be applied to national security missions. In addition, public-private partnerships help drive the computer industry to develop new hardware and software with capabilities that benefit NNSA, DOE, and other government agencies. The HPCIC is currently housed in temporary modular trailers. Future plans would replace the trailers with a modern building capable of housing LLNL staff and collaborators.

The AML’s reconfigurable layout allows rapid response to dynamic mission

requirements and sponsor needs. Its LVOC location enhances LLNL’s ability to actively promote collaborative relations between NNSA laboratories, production plants, academia, and industry, providing mutual benefit to the Laboratory and its partners. NNSA is currently investing in advanced manufacturing initiatives that support the modernization of its manufacturing infrastructure, ultimately reducing time to product, decreasing manufacturing footprint, and minimizing waste. LLNL anticipates that researchers will produce breakthroughs and lead development of new technologies that strengthen advanced manufacturing companies and enhance the domestic supply of machines and materials. These efforts will support NNSA missions that include stockpile stewardship, energy security, and intelligence, as well as other DOE thrusts, including economic competitiveness.

Biology research at LLNL is conducted in a group of biosecurity and bioscience buildings that support a diverse sponsor

base and other national laboratories. Most of these buildings are over 50 years old and require significant infrastructure investment, particularly for Building 361, LLNL’s flagship biology research facility that houses the nation’s resource for biomedical accelerator mass spectrometry. The building has poor heating, ventilation, and air conditioning systems; a failing roof; and inadequate information technology systems. Replacement of and upgrades to these systems is necessary to uphold the safety and security needs for biology research facilities.

Partnering agreements and new facilities offer expanded opportunities for LLNL to engage with external entities, maintain second-to-none science, technology, and engineering capabilities, and attract and retain the workforce needed for national security missions.

CELEBRATING TEAMWORK AND COLLABORATION AT CAMS

From the beginning, the Center for Accelerator Mass Spectrometry (CAMS) has brought together creative researchers in an environment that encourages collaboration. Its genesis occurred in 1985, when the University of California Regents joined Lawrence Livermore and Sandia national laboratories as equal partners to fund the Multi-User Tandem Laboratory.

The Multi-User Tandem Laboratory initially focused on using AMS to diagnose fission products of atomic tests and to conduct research in materials science, nuclear astrophysics, nuclear spectrometry, and neutron physics. By 1988, the increasing number of experiments with academic users required LLNL to establish CAMS to accommodate the growing interest in this facility by the scientific community.

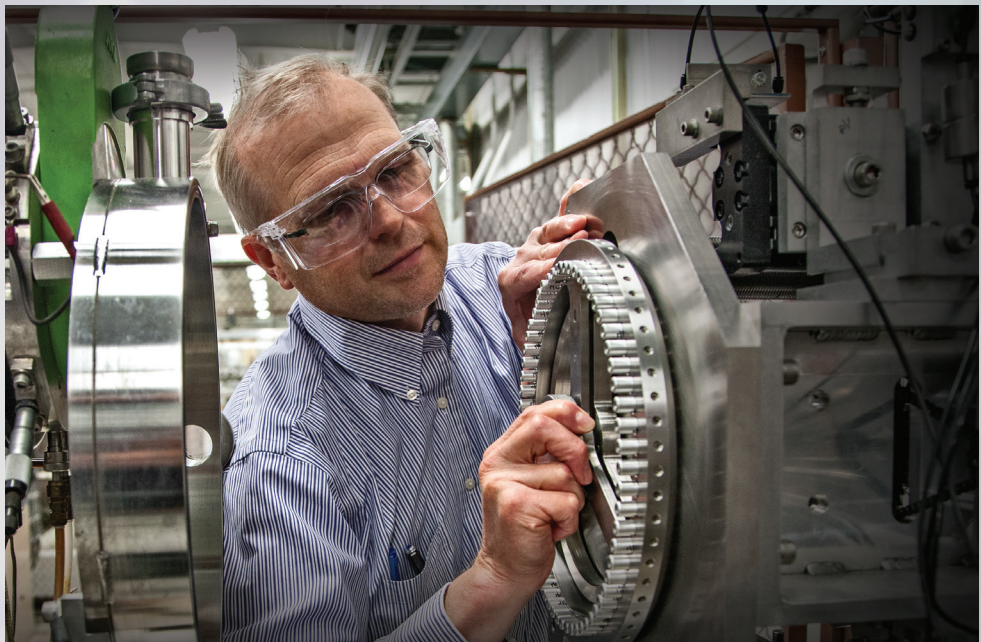
Today, CAMS is the world's most versatile and productive AMS facility. The center operates around the clock, performing up to 25,000 measurements annually. The research made possible by CAMS covers areas as diverse as archaeology, atmospheric chemistry, biomedicine, carbon-cycle dynamics, earth system processes, cell biology, alternative fuels, forensic dating, and forensic reconstruction of radiation doses.

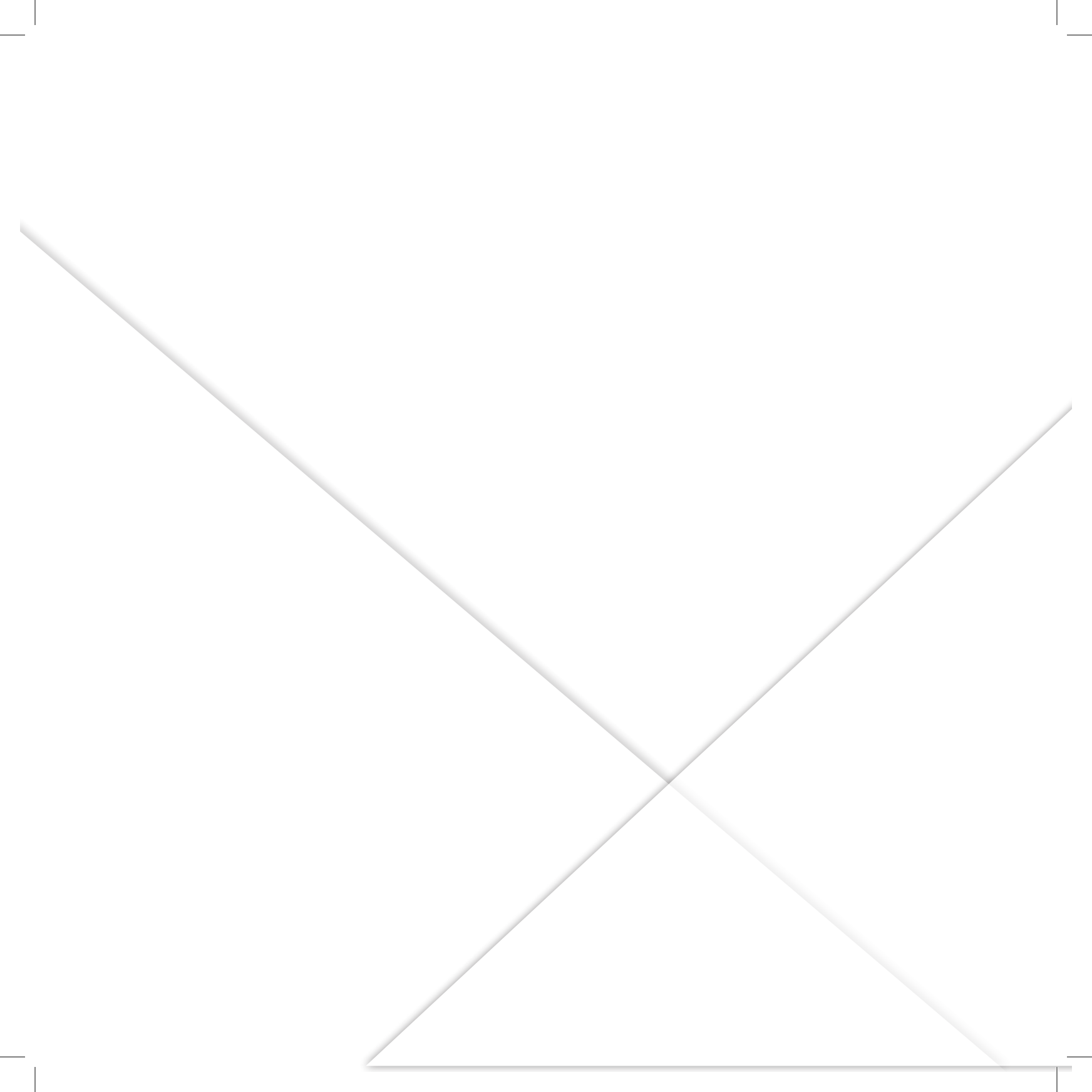
AMS is an exceptionally sensitive technique for measuring concentrations of isotopes in small samples, typically less than one milligram, and the relative abundance of isotopes at low levels.

For example, it can identify one carbon-14 isotope among a quadrillion other carbon atoms. By measuring the carbon-14 isotopes in various samples, CAMS researchers have helped solve cold cases and plumb the mysteries of the human brain and eye, tested the efficacy of cancer drugs, and established the age of a potential Mayan codex.

In addition, CAMS offers research opportunities for graduate students and postdoctoral fellows. The center has generated data for more than 300 graduate-level theses and annually supports the work required for 20 Ph.D. candidates—a number that even a first-flight academic department would envy.

An LLNL scientist loads a wheel of samples into the spectrometer at LLNL's Center for Accelerator Mass Spectrometry to determine the materials' concentration of carbon-14.





INFRASTRUCTURE ON A MISSION

