SCIENCE & TECHNOLOGY ON A MISSION

LAWRENCE LIVERMORE NATIONAL LABORATORY

Lawrence Livermore National Laboratory

ABOUT THE LABORATORY Lawrence Livermore National Laboratory (LLNL) was founded in 1952 to enhance the security of the United States by advancing nuclear weapons science and technology. LLNL ensures for a safe, secure, and effective nuclear deterrent. With a talented and dedicated workforce and world-class research capabilities, the Laboratory strengthens national security with a tradition of science and technology innovation—anticipating, developing, and delivering solutions for the nation's most challenging problems. LLNL is one of the U.S. Department of Energy's 17 national laboratories.

"At LLNL, our work is to diminish the likelihood and impact of war, of terrorism, and of natural and manmade disasters through the innovative application of cutting-edge science and technology."

William H. Goldstein

Director

Science and Technology on a Mission

Lawrence Livermore National Laboratory (LLNL) is an exciting place. We have a vital national security mission and are tasked to tackle grand challenges that our nation faces.

To deliver on our mission responsibilities, Laboratory researchers bring to bear creative thinking, teamwork, and a very special integration of leadership in applying high-performance computing combined with cutting-edge experimentation. This distinctive combination was pioneered by LLNL co-founder and Nobel Prize recipient E. O. Lawrence and provides the foundation for our many successes. It is manifest in our current research efforts and guides our future in service to the nation.

We explain how we work through a variety of perspectives:

Innovation Focused on Mission

Innovation focused on mission is a hallmark of the Lawrence Livermore National Laboratory (LLNL). Our mission is to develop and apply world-class science, technology, and engineering (ST&E) to strengthen national security.

Founded in 1952 as a branch of Professor Ernest O. Lawrence's Radiation Laboratory, LLNL was established as a "new ideas" laboratory to accelerate nuclear weapons design and development. Spectacular success came within the decade, with the innovative design of a thermonuclear warhead small enough to be launched from a submarine. This breakthrough ensured that the nation's nuclear deterrent would survive an all-out attack and kept the Cold War cold.

Now supporting the Department of Energy's National Nuclear Security Administration, Laboratory scientists and engineers are entrusted with sustaining a safe, secure, and effective nuclear weapons stockpile without conducting nuclear explosive tests. To meet this unprecedented challenge, we have pushed the state of the art in simulating science on the world's largest supercomputers and built remarkable experimental tools such as the world's largest laser to assess the performance of aging nuclear weapons and extend their stockpile lifetime.

Livermore researchers also develop innovative technical solutions to help meet important, pressing national and global security needs. Our work aims to stem nuclear proliferation and the threat of terrorism; counter the use of chemical and biological agents; and strengthen the U.S. military. LLNL-developed technologies also enhance the security of cyberspace, space assets, and the nation's infrastructure and energy future. We focus in areas that take full advantage of our unique research capabilities and special expertise.

Innovation arises naturally out of our focus on mission combined with ST&E excellence and Livermore's signature approach to problem solving. We tackle large, complex, multidisciplinary projects—often long term, with significant scientific and technical risk, and aimed at breakthroughs that offer dramatic benefits for the nation. Multidisciplinary teams of scientists and engineers seamlessly integrate experiments with simulations to transform an innovative idea into a solution.

A submarine conducts a test launch of a Polaris missile, developed to carry the Laboratory's breakthrough warhead design. Weapons comprising the nation's nuclear deterrent are based on that design.


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Simulating Everything in All Its Complexity

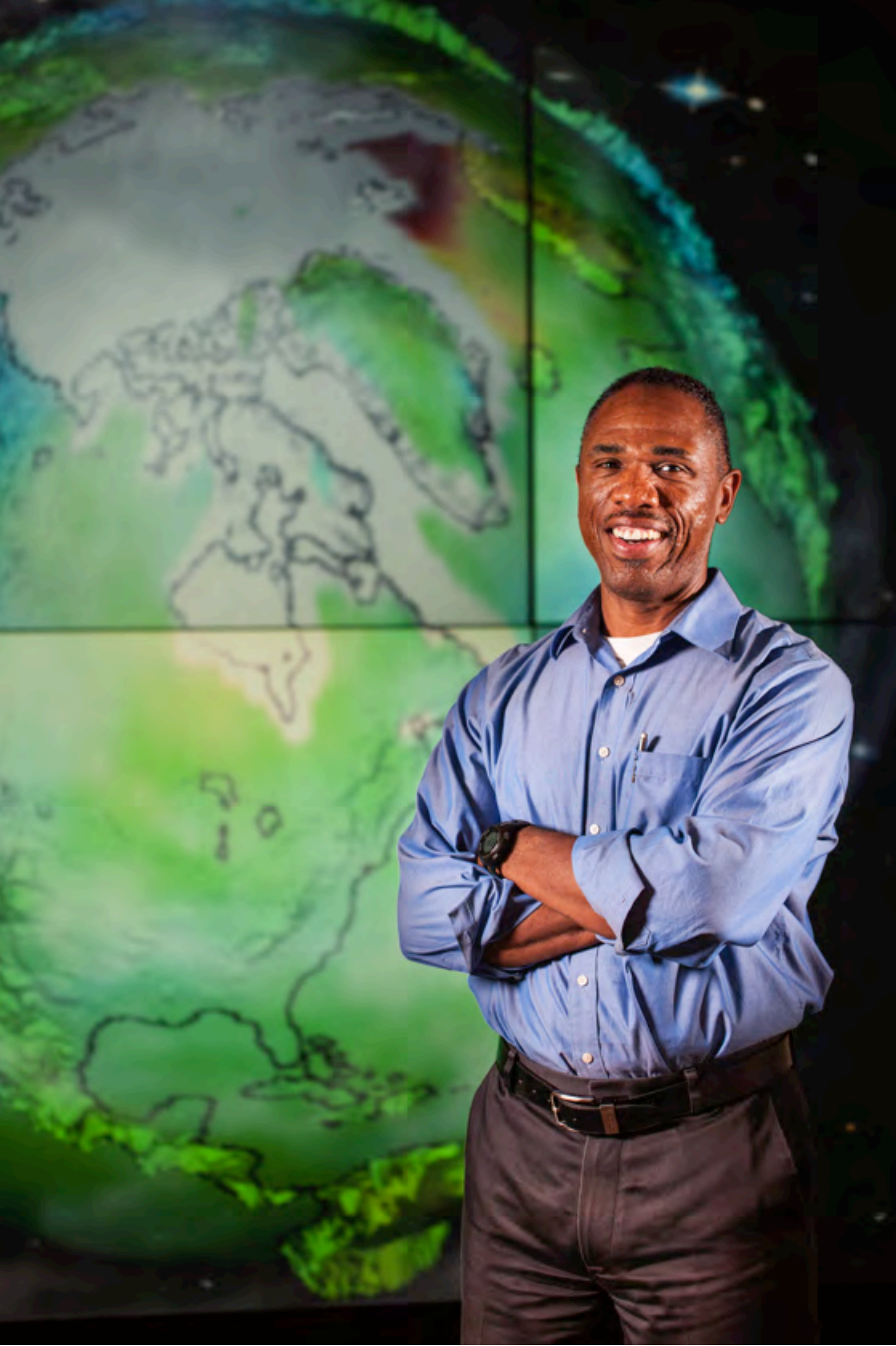
Even before our doors opened for business, the most powerful computer available, the Univac-1, was ordered for the new Laboratory. Ever since, Livermore has been a recognized leader in the development, deployment, and application of high-performance computing (HPC) to solve complex science, technology, and engineering (ST&E) problems. HPC is an essential tool for the nuclear weapons program and central to progress in every major mission area. Amazing science is possible with HPC.

Laboratory scientists use HPC to study everything from the nano-scale mechanics of pathogens docking at protein receptors, to natural and human influences on the Earth's climate. For example, a code called Cardioid simulates the beating of a human heart—at the resolution of single muscle cells—to examine the potential effects of promising new pharmaceuticals. We have performed billion-molecule simulations to study the type of instability that causes ocean waves to break in the wind. Our extreme-scale graph analysis tools are making sense out of "big data", and the "Livermore Brain," the world's largest neural network, is teaching itself how to analyze photographs.

Most importantly, we use state-of-the-art HPC to assess the functioning of nuclear weapons in as much detail as possible. Exploring how aging nuclear weapons might fail is a very difficult job. Since the start of the Stockpile Stewardship Program in the 1990s, we have worked hand-in-hand with U.S. industry to improve computing power for ST&E simulation more than a million-fold. The nuclear weapons laboratories need high-resolution 3D simulations with far better representation of the physics involved since we no longer have nuclear explosive testing to adjust approximate models.

We are reaching for an overall billion-fold improvement, to exascale computing (10^{18} operations per second). The next big step—with the next revolutionary design change—is the Sierra supercomputer, which will be delivered to Livermore in 2017–2018. We have to rethink our current algorithms, simulation codes, and many other aspects of supercomputing to take full advantage of new system's capabilities.

Climate analyses conducted at Livermore exercise the Laboratory's leadership in high-performance computing—from physics-model development and uncertainty quantification to visualization of "big data."



Providing Modern Deterrence and Security

Since the end of the Cold War, the U.S. has provided international leadership in striving to reduce nuclear armaments. Yet, dangers persist and are of growing concern in parts of the world with regional animosities. National policy states that the U.S. "will sustain a safe, secure, and effective nuclear arsenal as long as nuclear weapons exist." Those nations that depend on the U.S. must be confident that our forces effectively deter and protect against any level of nuclear aggression.

LLNL has lead responsibility for refurbishing the next two warhead systems undergoing life extension. The work is necessary because the weapons (and their delivery systems) have aged beyond planned retirement and components must be replaced. The refurbished warheads will be carried on new cruise missiles and silo-based and submarine-launched ballistic missiles. As we develop plans to modernize the nation's nuclear deterrent, we will be examining ways to improve warhead safety and security, streamline production, and reduce costs.

Livermore has the scientific, technical, and engineering (ST&E) capabilities and mission responsibilities to engage in many additional facets of national security in an increasingly complex world. Many nations, and potentially non-state entities, possess some form of weapons of mass destruction (WMD), and dangerous new threats can arise and surprise us from the rapid global advance of technology. It is our responsibility to explore what is technically possible, understand what others are up to, and devise innovative ways whereby advances in ST&E can benefit national security.

We pursue activities for national-security sponsors in areas such as counterterrorism and nuclear nonproliferation, biosecurity, cybersecurity, space situational awareness, reconnaissance and intelligence, and advanced conventional munitions and directed energy weapons. These programs—and those in areas such as energy and environmental security—draw on Livermore's unique ST&E capabilities.

Experiments at LLNL's High Explosives Applications Facility (HEAF) support stockpile stewardship, projects for the Department of Defense, and evaluations of improvised explosive devices that terrorists might use.

Inside Planets, Stars, and Nuclear Weapons

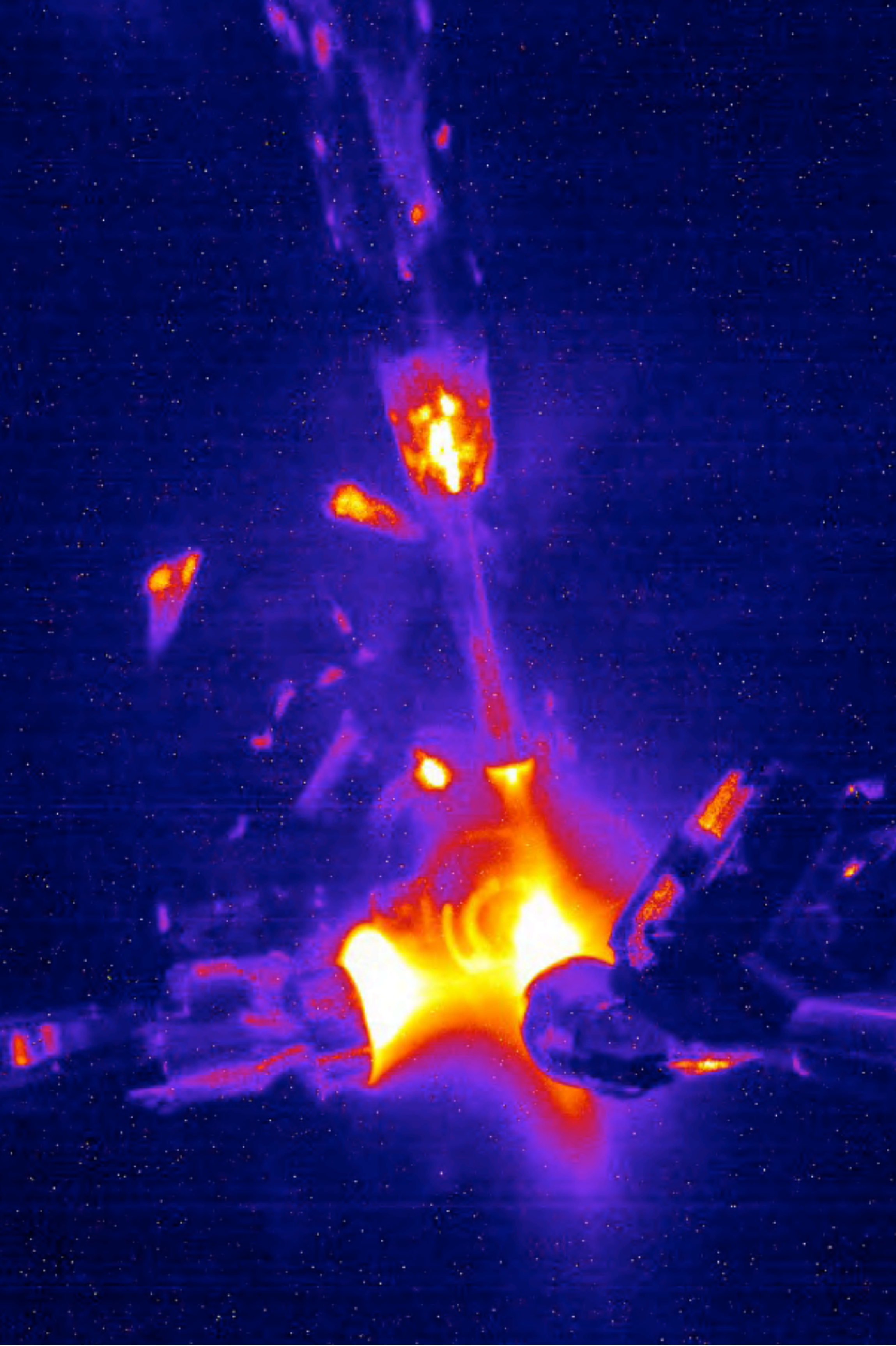
High-performance computing is central to most of Livermore's research programs, and especially the nuclear weapons program. However, simulation codes need input data and their predictive capability must be validated. And, the more detailed the simulation predictions become, the more critical it is to gather precise data. Accordingly, in the absence of nuclear explosive testing, the nation has invested in an array of experimental facilities—none more astonishing than the National Ignition Facility (NIF).

The size of a sports stadium, NIF houses the world's largest and most energetic laser. Nearly 40,000 optics precisely guide, reflect, amplify, and focus 192 laser beams onto a target about the size of a pencil eraser. Scientists create extreme states of matter—conditions that exist inside giant planets, stars, and exploding nuclear weapons, with temperatures of more than 100 million degrees and pressures that exceed 100 billion times Earth's atmosphere. No other facility can match NIF's experimental capabilities to study "high-energy-density" (HED) physics.

Predictive simulation models require as input accurate data to characterize how a material behaves under the conditions that exist when a nuclear weapon begins to explode. NIF enables scientists to collect that equation-of-state data. Then other experiments are performed to create the dynamic conditions with turbulent mixing of materials at extreme conditions. These experiments test the predictive capabilities of weapons physics simulation codes. This dual use of NIF—to gather necessary data for simulations and to validate some aspects of the models—has enabled scientists to garner a deeper understanding of how nuclear weapons work.

Similarly, dynamic HED physics experiments at NIF re-create energetic phenomena that we observe elsewhere in the universe. As an example, experiments at NIF recently explained formation of the astonishing Pillars of Creation in the Eagle Nebula. NIF is also used to gather equation-of-state data to understand the conditions inside giant planets.

In fiscal year 2016, researchers conducted 417 experiments at NIF—311 for stockpile stewardship and 38 shots for Discovery Science, including this experiment to better understand the synthesis of elements deep within stars.



Discovery

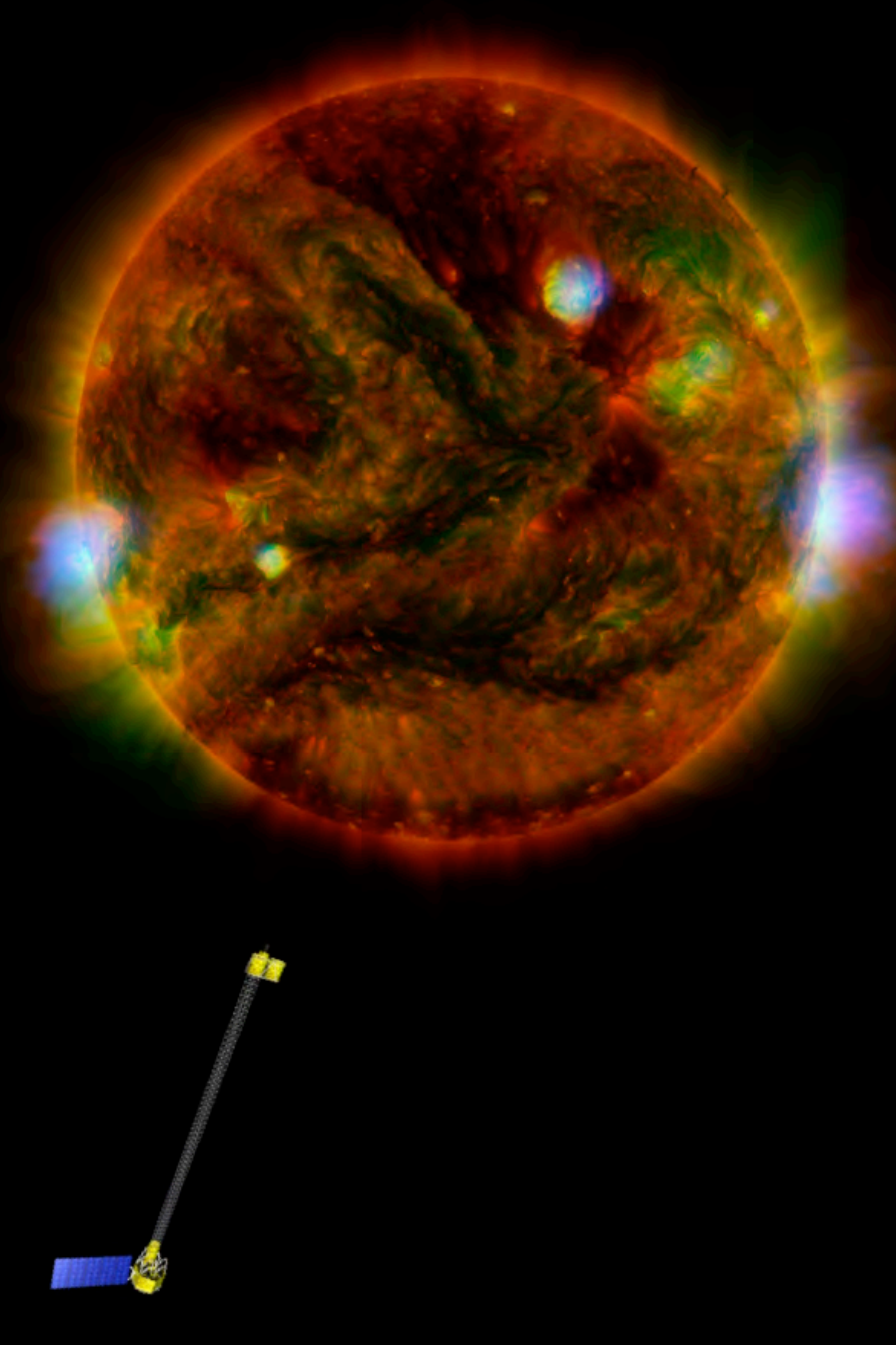
“Science and Technology on a Mission” leads to discoveries, which traditionally have come from theory and experiments. An exemplary case is Robert Laughlin’s discovery in 1983 of the wave function for the quantum Hall effect. He and the experimentalists who first observed the effect won the Nobel Prize for Physics in 1998. Laughlin credits the Laboratory’s multidisciplinary team science for the discovery. He was a postdoctoral fellow at LLNL at the time learning plasma physics from his colleagues when the idea came to him.

Livermorium is newly named element 116. To date, nine new elements have been discovered by LLNL scientists and Russian colleagues using the cyclotron at the Joint Institute for Nuclear Research in Dubna, Russia. Their first discovery was element 114 in 1998, and, as they say, the rest is history.

Laboratory scientists have also pioneered discovery through predictive simulations. For example, seminal work by Stirling Colgate and Richard White on supernova explosions in 1966 led to the first publication in astrophysics based on computer simulations of hydrodynamics. In the 1950s, Chuck Leith performed the first global circulation (global climate) simulations and Berni Alder invented computational molecular dynamics. Today, LLNL’s first-principles molecular dynamics code Qbox is an open-source resource for researchers. Qbox has unraveled some long-standing mysteries about the behavior of water molecules and is used, for example, to study complex biological molecules.

Livermore researchers also design and build innovative tools for discovery. At small scale, LLNL developed instruments able to image transient behavior at the resolution of nanometers and nanoseconds. Our adaptive-optics systems are dramatically improving ground-based astronomy by taking the twinkle out of starlight and enabling discovery of distant planets. Other advanced technologies pioneered by LLNL have been critical to the success of numerous NASA missions. At the largest scale, the National Ignition Facility is at Livermore and we are an integral part of the team building the world’s largest camera, the 8.4-meter Large Synoptic Survey Telescope.

With LLNL-designed x-ray optics, the Nuclear Spectroscopy Telescope Array (NuSTAR) has led to discoveries about black holes and supernovas, providing a unique view of high-energy phenomena that take place in the Sun.



Designing and Building First-of-a-Kind Things

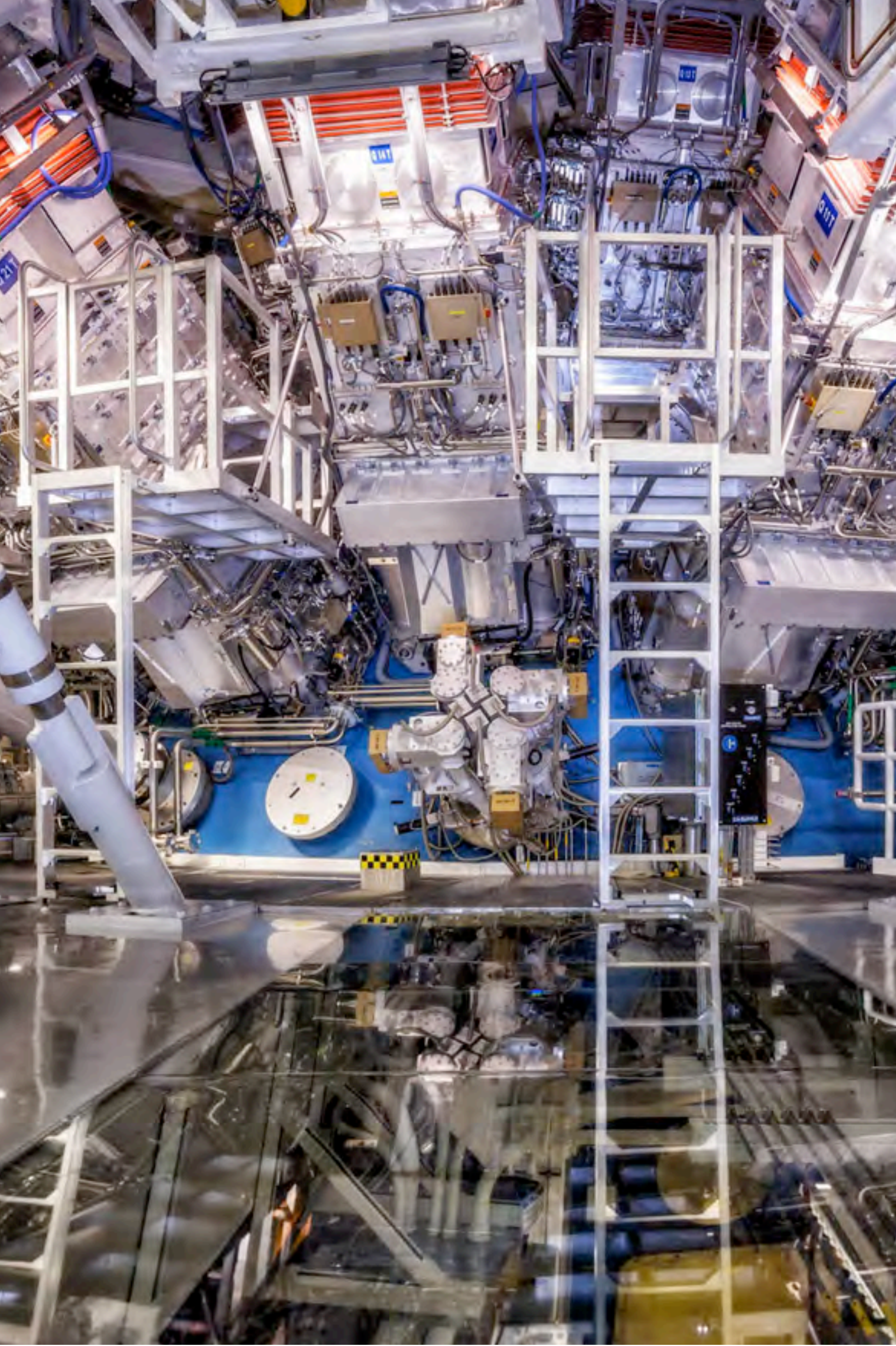
Creative ideas become real-world innovations when things are built. Following the model established by E. O. Lawrence, LLNL has always pursued “big science” through multidisciplinary teams, integrating science and engineering and iterating between modeling and experiment. We constantly push the state of the art to meet sponsors’ most challenging needs and enhance the research tools we have at the Laboratory, for example by improving diagnostics and instrumentation.

Livermore pioneered modern precision engineering in the 1950s to make weapon parts to exacting standards and then pushed the development of precision optics for large laser systems. We design and make x-ray mirrors that are used, for example, at the SLAC National Accelerator Laboratory in experiments to study the structure of complex molecules. Targets used in experiments at the National Ignition Facility (NIF) require nanoscale precision. NIF itself is a gigantic precision-optics instrument, and Livermore is building its next first-of-kind laser for the European Union’s Extreme Light Structure Beamlines facility. It will be the world’s highest average-power petawatt (quadrillion watt) laser system, incorporating groundbreaking technological advances.

LLNL researchers are also advancing the state of the art in manufacturing technologies to get new products out the door more quickly. This is important for avoiding national-security surprises and for improving the competitiveness of U.S. industry. For example, in work for the Department of Defense, we demonstrated remarkable new product-engineering capabilities to accelerate the design-to-development-to-production cycle. To meet an urgent military requirement, in 15 months time LLNL designed and readied for production a new low-collateral-damage conventional munition.

Working with industrial partners, Livermore is also making major advances in processes and technologies for additive manufacturing (AM). We are developing AM technologies to make complex, detailed parts more quickly, formulating inks for printing parts made of exotic materials, and producing parts with elaborate microstructures designed to confer special, unusual bulk properties.

NIF has nearly 40,000 optics that precisely guide, reflect, amplify, and focus 192 laser beams onto a target about the size of a pencil eraser. It is the world’s largest and most energetic laser facility.



Materials—from Aging to the Unimaginable

Fundamentally, much of the research at Livermore is about materials. We have to know how existing materials behave under extreme conditions, how they age, and how to use them most effectively, or where necessary, create new materials, to accomplish mission goals. LLNL provides a vast array of unique computational and experimental tools to study material behavior at the detail of atoms and molecules to deduce material properties at the macro scale.

Materials used in nuclear weapons present particularly difficult mission challenges. Now with an aging nuclear deterrent, we have to thoroughly understand how materials change over time in the radioactive confines within a weapon. Plutonium itself has the most complex properties of all elements. By combining cutting-edge computer simulations with innovative experiments, we gained confidence that plutonium will continue to age gracefully. This finding delayed the need to construct a multi-billion dollar facility to produce new plutonium parts for weapons.

Radiation also "ages" biological materials, and in the 1960s Livermore launched a biological science program to study the effect of ionizing radiation on life forms. We developed innovative technologies to study chromosomes, which, in turn, led to the launch of the human genome project. Today Livermore's focus is on biosecurity: developing capabilities for rapid, reliable detection and identification of pathogens, for understanding human physiology, and for rapidly devising countermeasures.

We also create materials with special properties to meet demanding mission needs. These have included new ceramics, lightweight fiber-composites, and lighter-than-air structural materials, called aerogels, which are finding exciting applications such as energy storage. Researchers have also developed unique capabilities for making large diffraction gratings, rapidly growing large crystals, and locating and repairing defects in precision optics. Additive manufacturing is enabling production of tailored materials with unimaginable properties. For example, LLNL researchers have produced a structural material able to withstand 160,000 times its own weight.

Advancing the state of the art in additive manufacturing, LLNL researchers are printing supercapacitors, made of super-light graphene aerogels, for energy storage and new materials for use in weapon life-extension programs.

Have a National Security Issue? Call Us

In early 1978, soon after a Soviet satellite with a nuclear reactor aboard broke up over northern Canada, 39 Livermore experts clad in cold-weather survival gear helped find and recover the pieces. In 1991, an LLNL engineer participated in the first United Nations inspection team sent to Iraq after Operation Desert Storm. Livermore personnel were in other inspection teams. One team discovered a uranium enrichment facility that the Iraqis attempted to hide. Another was confined by armed soldiers for five days to a site in Baghdad and the team left with a cache of “smoking gun” documents about the Iraqi nuclear program. In 2015, a Livermore scientist was a technical expert at the table in the negotiations of the Joint Comprehensive Plan of Action with Iran.

We are here to help—to provide expertise and technical analyses. After the Deepwater Horizon oil spill, more than two dozen LLNL scientists and engineers served shifts for many months at BP’s Houston headquarters. They were part of a technical advice team staffed by the National Nuclear Security Administration’s national security laboratories. Livermore’s National Atmospheric Release Advisory Center (NARAC) provided critical support to agencies in the United States and Japan responding to the Fukushima nuclear reactor disaster. NARAC is on call 24/7 to provide up-to-date accurate atmospheric dispersion predictions after a release of toxic substances.

LLNL’s Counterproliferation Analysis Planning System is used by U.S. combatant commands to help them plan missions against facilities that support the production of weapons of mass destruction. Established by the Department of Homeland Security, the Biodefense Knowledge Center at Livermore is a national resource for biothreat analyses and development of analysis tools. The Forensic Science Center, which performs fast, accurate chemical, nuclear, and biological analysis, is one of two U.S. laboratories to be internationally certified for identifying chemical-warfare agents. The center also serves as an FBI hub laboratory, providing 24/7 support to federal agencies during domestic special events and after incidents worldwide.

After the Fukushima nuclear reactor disaster, NARAC operated around the clock for 22 days and generated a steady stream of up-to-date atmospheric dispersion predictions, plume projections, and radiation dose estimates.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Monitoring for WMD and Disorders in the Brain

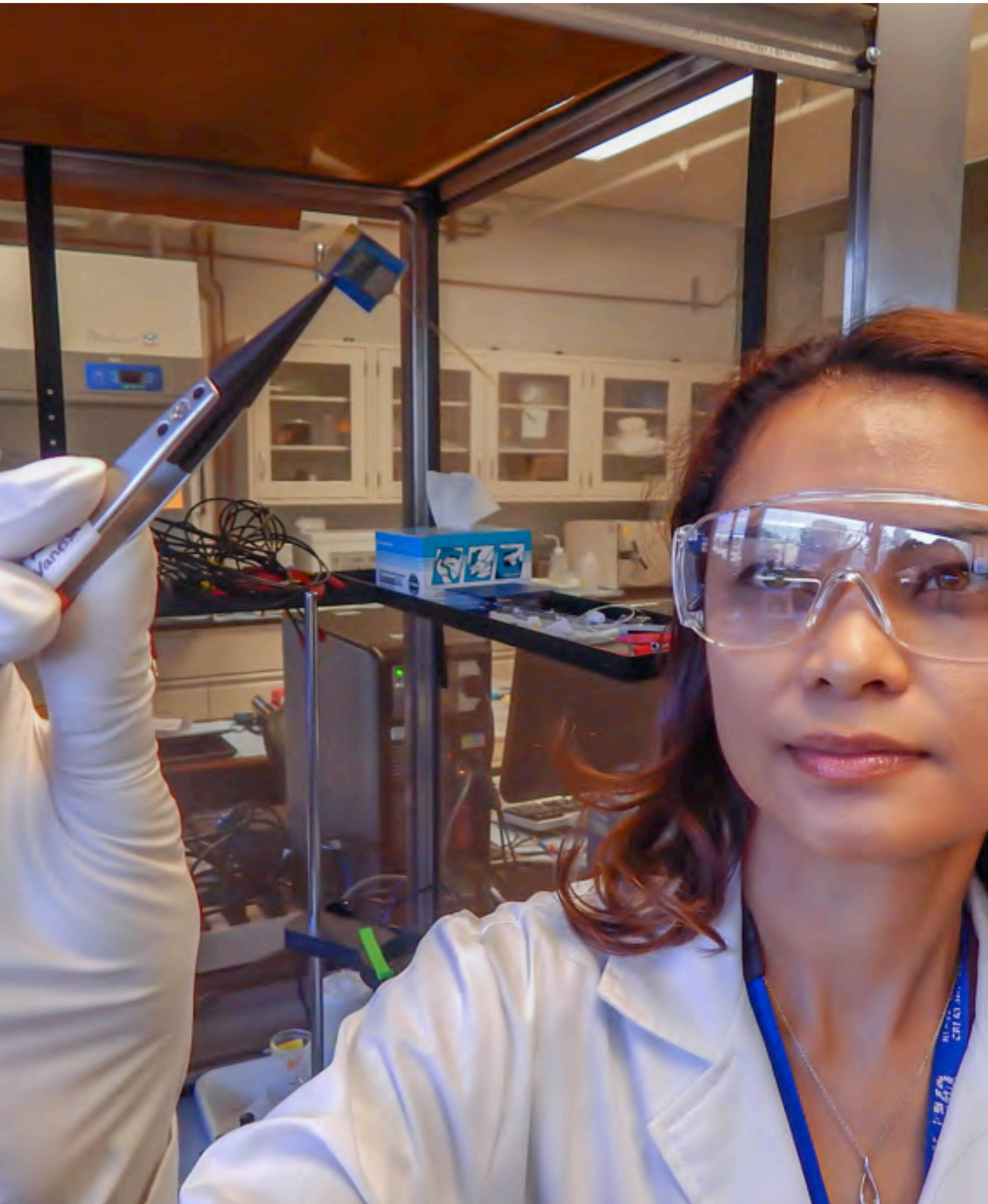
In the late 1990s, Laboratory scientists turned their attention to the development of more capable detector systems. Concerns were emerging In the post-Cold-War world about the security of nuclear materials worldwide and the lurking danger of weapons-of-mass-destruction (WMD) terrorism.

An early innovation was a handheld gamma-ray detector with precise energy resolution. The technology was commercialized for homeland security applications and flew on the NASA MESSENGER spacecraft, which orbited Mercury for four years in a spectacularly successful mission. Continuing work on detecting nuclear weapons material has led to additional breakthroughs, such as plastic materials to make affordable detectors that can effectively discriminate weapons-usable materials from other sources of radiation.

LLNL also pioneered the development of portable systems to rapidly detect and identify pathogens. The DNA of minute collected samples is rapidly reproduced through the polymerase chain reaction (PCR), and a pathogen is identified if a specially designed probe molecule attaches to DNA. Detectors based on this technology have been widely deployed since the 9/11 attacks. For biosecurity and disease detection, we also developed the Lawrence Livermore Microbial Detection Array, which features 360,000 probes to detect any bacteria or virus that has been previously sequenced.

The technology breakthrough of miniaturized PCR-based detectors required the development of biocompatible materials for the microfluidics system that handles samples. Further work at LLNL led to a flexible biocompatible electrode array for an artificial retina. The technology is helping people regain limited vision. Now Laboratory researchers have unique capabilities to produce implantable neural interfaces that connect to hundreds (and in the future thousands) of individual neurons. In one of many applications in development with research partners, electrode arrays implanted in human patients are being used to decode human speech and study neuropsychiatric disorders like anxiety, depression, and post-traumatic stress disorder.

Laboratory researchers and collaborators are working on implantable electrode array technology for monitoring brain activity to better understand how the neural circuitry of the brain works during memory retrieval.



Reaching Out through Partnerships

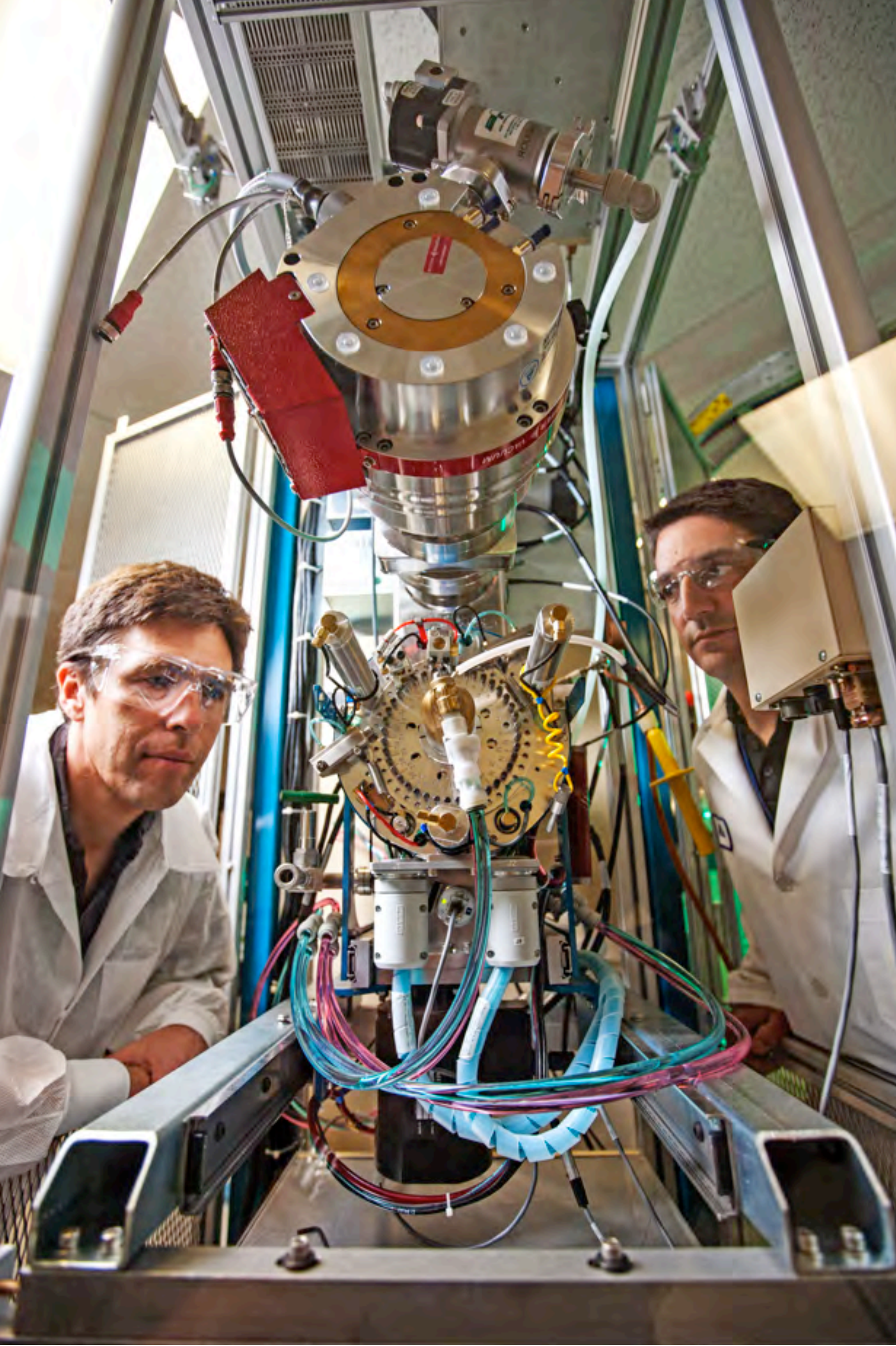
Often LLNL projects are conducted in collaborations with other laboratories, academic institutions, and U.S. industry—drawing on the special strengths of the participating institutions. The Stockpile Stewardship Program is a large partnership among NNSA laboratories and production facilities with centers of excellence, shared user resources, and cooperative technical competition among the national laboratories. The competition helps to sustain effective peer review, which is particularly essential in the absence of nuclear explosive testing.

Many collaborations exist with other DOE laboratories, such as the Accelerated Climate Modeling for Energy project for the DOE Office of Science. LLNL has been an internationally recognized center for climate model analysis since the early 1990s and a key contributor to the assessment reports of the Intergovernmental Panel on Climate Change. We provide strong leadership in the development of big-data management systems and visualization and analysis tools for the climate modeling community.

With its heritage as part of the University of California, the Laboratory partners with researchers at many universities and hosts many students and postdoctoral fellows. More than half the scientific papers published by LLNL researchers are co-authored by university collaborators. These interactions strengthen Livermore's ST&E foundations, provide peer review of our work, and serve as a pipeline to bring new ideas and new talent into our workforce.

Partnerships with U.S. industry provide essential support to the Laboratory in advancing technologies needed to accomplish mission goals. For example, we work with high-performance computing (HPC) industry leaders to design, develop, and deploy ever more capable computing systems. Livermore also strives to help U.S. industry turn technological advances into new products. Over $350 million in goods and services were produced last year using LLNL intellectual property. Livermore is striving through the Livermore Valley Open Campus and its High Performance Computing Innovation Center to assist U.S. industry in using HPC to accelerate product development and improve international economic competitiveness.

The Center for Accelerator Mass Spectrometry meets a broad spectrum of scientific needs to measure rare isotopes; it has hosted over 1000 faculty and student visitors, resulting in over 300 Ph.D.s and Masters degrees.



Great People

Lawrence Livermore National Laboratory offers outstanding people the opportunity to work on important issues for the country, the prospect of technically challenging careers and ready access to one-of-a-kind research tools. We value having colleagues that bring impactful new ideas, work with integrity and zeal, and thrive in an inclusive work environment. Exceptional individual and multidisciplinary team efforts—coupled with visionary leadership—enable the Laboratory to make breakthrough advances in science and technology to address the nation's most daunting problems. That is our heritage and our future.

Livermore's most valuable asset is its outstanding workforce. The tradition of scientific and technical excellence began in 1952 when Herbert York, then 32 years old, led an opening-day staff of 75 to set up shop. Ernest O. Lawrence picked out young people to do the work and he made good choices. Activities began with a very brief mission statement and a commitment by York and his team to be a "new ideas" laboratory. It was an outstanding team, which, after early missteps, achieved spectacular successes.

Edward Teller was the senior scientist; youngsters that got the Laboratory going included Harold Brown, John Foster, Jr., and Michael May—each with a long, distinguished career of leadership in service to the nation. Many exceptional technical and programmatic leaders have followed, including a Nobel Prize for Physics laureate, a National Medal of Science honoree, a Hans A. Bethe Prize winner, and 29 scientists and engineers presented with the E. O. Lawrence Award.

The tradition continues. Over the past decade, 14 of our researchers have won Presidential Early Career Awards for Scientists and Engineers. Currently, four of 17 Department of Energy national laboratories are led by directors with career experience at Livermore. Great people are attracted to a great laboratory: LLNL was named to the 2016 Forbes list of America's Best Large Employers, ranking No. 102 out of the 500 employers that made the cut and the only national laboratory on the list.

In the inaugural year of LLNL's Early- and Mid-Career Recognition Program, 15 scientists and engineers were recognized for their notable contributions to the Laboratory's missions and to science—five gather to discuss their work.

For more than 60 years, the Lawrence Livermore National Laboratory has applied science and technology to make the world a safer place.

Lawrence Livermore National Laboratory is a multi-program national security laboratory with 6,500 full-time equivalent employees. The staff includes 2,600 scientists and engineers, nearly half of whom hold doctoral degrees. The one-square-mile main campus is located in Livermore, California with a remote 11-square-mile experimental site near Tracy, California. Plant replacement value is about $6 billion. The annual federal budget is about $1.6 billion.

LLNL is managed and operated by Lawrence Livermore National Security, LLC, for the National Nuclear Security Administration (NNSA), a semi-autonomous agency within the U.S. Department of Energy. NNSA is the primary sponsor of work at the Laboratory. LLNS is a limited liability company managed by Bechtel National, Inc.; the University of California; BWXT Government Group, Inc.; and the URS Division of AECOM. Battelle Memorial Institute is a teaming subcontractor.

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