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LDRD FY23 Annual Report PDF

D. Rotman, A. Mosely

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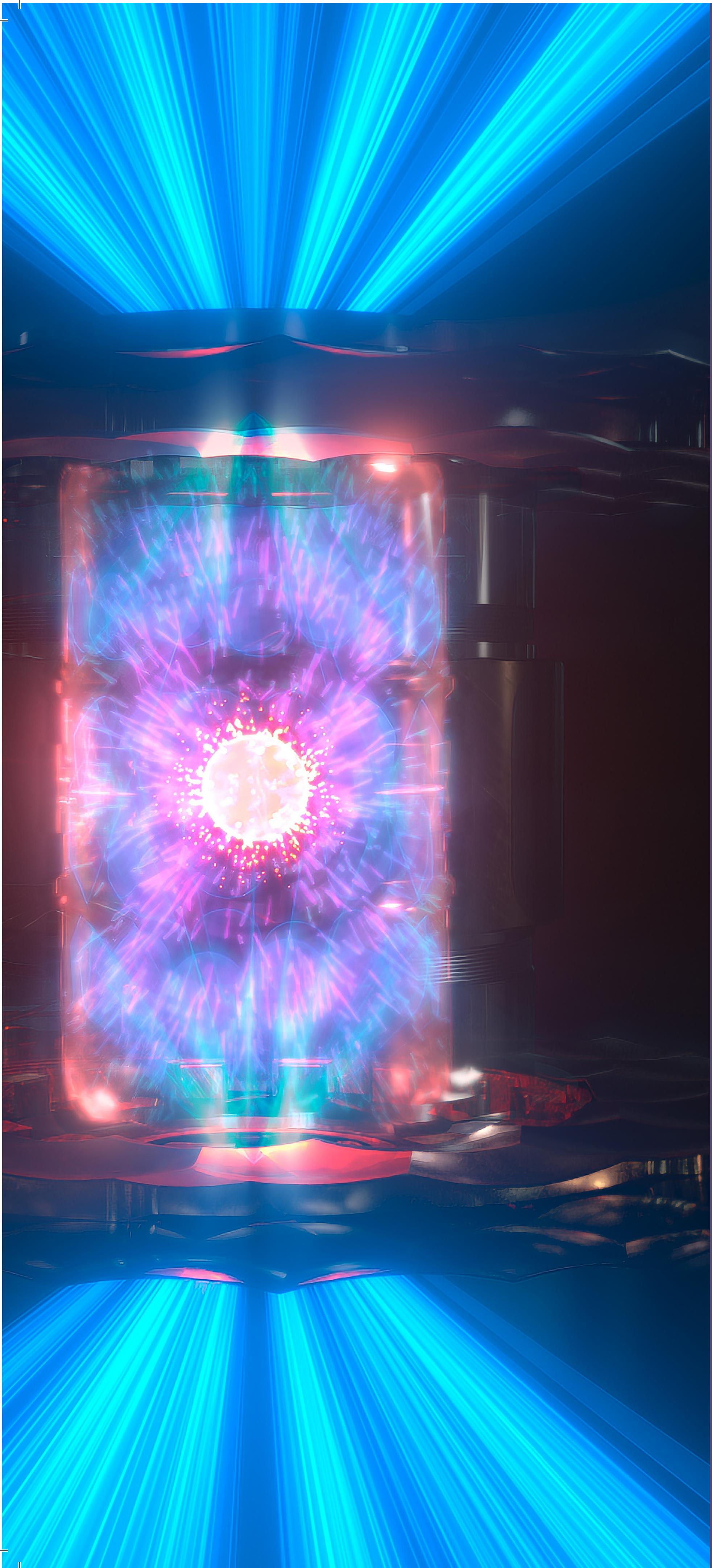

Program Overview

Laboratory Directed Research and Development

Lawrence Livermore National Laboratory

Fiscal Year 2023

Annual Report

Lawrence Livermore National Laboratory

Annual Program Overview

Kimberly S. Budil
LLNL Director

Director's Statement

As Lawrence Livermore National Laboratory's most significant resource for supporting internally directed research and development, the LDRD Program provides investments in cutting-edge science and technology that allow the Laboratory to attract and retain the world's most talented scientists and engineers and enables them to expand the frontiers of knowledge and anticipate emerging national security challenges. In this annual report, we summarize how Lawrence Livermore National Laboratory (LLNL) uses LDRD investments to advance our knowledge in strategic science and technology domains, develop our world-class workforce, and foster innovation in key programmatic areas.

LDRD investments foster mission agility through multidisciplinary research, bringing together diverse teams and collaborators to explore higher-risk, innovative approaches and concepts to fulfill our mission goals. This past year LLNL achieved a historical accomplishment -- on Dec. 5, 2022, LLNL demonstrated fusion ignition for the first time in a laboratory setting. The ground-breaking experiment did not happen overnight; rather it was the result of many innovations, developed over decades by pioneering scientists and engineers at NNSA's national laboratories, working in collaboration with colleagues at other DOE/NNSA Labs and other research institutions. Many of those pioneering new ideas were transformed into solutions through funding provided by Laboratory Directed Research and Development Programs at NNSA Labs. LDRD investments in this foundational work over the last three decades spanned key science and technology areas, including target fabrication, diagnostic tools, and laser-plasma interactions. Since that day in December of 2022, we have achieved fusion ignition three more times – each time learning more and advancing our capabilities. Achieving fusion ignition provides critical insights into physics at extreme conditions essential to key LLNL nuclear deterrence missions and is an important step towards a zero-carbon energy future.

Spanning LLNL's missions, LDRD investments bring together diverse teams and collaborators to push the frontiers of science, technology, and engineering to ensure the technical vitality of the Laboratory and continued impact on global and national security. For example, investigators are using the Laboratory's powerful computers along with state-of-the-art experimental facilities to achieve new understanding across broad disciplines including high energy density science, advanced computing and data science, materials and manufacturing, bioscience and bioengineering, and earth and atmospheric science. Our LDRD program cultivates the creativity of the Lab's most important resource—our workforce. LDRD-sponsored research enables outreach to tomorrow's innovators, as we mentor students, challenge our postdoctoral researchers, and develop the leadership capabilities of early career staff. Mentorship is a hallmark of our program. A multidisciplinary group of senior scientists and advisors encourage our staff to pursue new research directions.

As you browse this report, you will learn about cover-page publications, patents, and science awards that resulted from LDRD investments. Throughout this year's report, we highlight LDRD's investments in areas that make the world a safer place. We review key accomplishments and performance indicators and share highlights from projects led by our talented staff. I encourage you to visit our LDRD website to learn about the more than 260 projects we supported during fiscal year 2023.

Looking to the future, I am confident that LDRD investments will continue to help LLNL remain at the forefront of innovative research and development, positioning us to solve the most complex global and national security challenges.

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Lawrence Livermore National Laboratory

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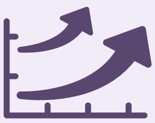
LDRD LABORATORY DIRECTED RESEARCH & DEVELOPMENT
WHERE INNOVATION BEGINS

Program Description

The LDRD program's targeted investments allow LLNL to develop cutting-edge capabilities and foster innovation in key programmatic areas.

Technical Vitality



Mission Agility

Workforce Development

Mission Alignment

Congress established the Laboratory Directed Research and Development program in 1991 to foster cutting-edge scientific and technical vitality at U.S. Department of Energy (DOE) laboratories. The LDRD programs at each laboratory are a unique resource, providing funding for critical research aimed at addressing today's needs and tomorrow's challenges. LLNL's program addresses DOE objectives, while also aligning with National Nuclear Security Administration (NNSA) mission objectives and the Laboratory's own strategic priorities.

As articulated in DOE Order 413.2C, the LDRD program serves to:

- Maintain the scientific and technical vitality of the laboratories.
- Enhance the laboratories' ability to address current and future DOE/NNSA missions.
- Foster creativity and stimulate exploration of forefront areas of science and technology.
- Serve as a proving ground for new concepts in research and development.
- Support high-risk, potentially high-value research and development.

Alignment with NNSA Mission Objectives

A strategic framework—created jointly by NNSA, LLNL, and the other NNSA laboratories—articulates the focus of LDRD programs at NNSA laboratories. LDRD investments support the following NNSA objectives:

- Technical Vitality. Develop innovative capabilities that are required to respond to emerging national security challenges.
- Mission Agility. Enable agile responses to national security challenges by investing in research and development at the forefront of mission-critical science and technology.
- Workforce Development. Recruit, develop, and retain the best and brightest staff, who can help us creatively address tomorrow's dynamic mission needs.

Alignment with Laboratory Missions

In addition to aligning our LDRD investments with DOE and NNSA objectives, we ensure that our LDRD program supports mission priorities articulated in LLNL's annual strategic investment plan. Institutional goals are established and updated through a planning process where multidisciplinary teams identify:

- Mission-related challenges or areas of interest for high-priority research.
- The core competencies that support this high-priority research.
- The scientific and technological needs to address those challenges and enhance related competencies.
- Key topics in fundamental research

Program Oversight

Day-to-day oversight of our program is provided by LDRD Program Director Doug Rotman. Overall program oversight extends beyond the LDRD program office to include the LLNL Director and the LLNL Deputy Director for Science and Technology, along with the Laboratory's scientific and programmatic leaders. This Laboratory team works closely with NNSA's Livermore field office, NNSA's LDRD program leaders, and LDRD program leaders at the Department of Energy.

At the programmatic level, LDRD portfolio management at Livermore is structured to assure alignment with DOE, NNSA, and Laboratory missions. Designated LDRD points of contact for each of the Laboratory's strategic investment areas provide input regarding LDRD investment priorities to Livermore's senior leadership team. These points of contact also advise applicants for LDRD funding regarding the alignment between proposed research and evolving mission needs at our Laboratory.

In addition, programmatic leaders and science and technology leaders participate in a rigorous peer-review process of all proposals for LDRD funding. They evaluate the strategic relevance of each proposal, as well as its technical content. NNSA reviews and concurs on funding decisions. Funded projects are periodically reviewed by senior staff to ensure technical success and continued alignment with mission objectives

PERFORMANCE ASSESSMENT

The LDRD program achieves continuous improvement through internal and external reviews of the program, along with oversight of each LDRD research project.

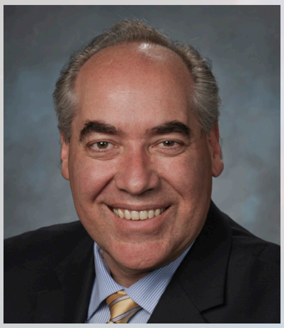
Representatives from LDRD programs at each NNSA laboratory regularly participate in working groups to share best practices and discuss strategies for tracking the long-term impact of LDRD investments.

To assess continued LDRD performance, the LDRD program tracks a suite of short-term and long-term metrics. These performance metrics can be found in the Program Value section of this report and address scientific publications, intellectual property, collaborations, and support for early career staff. Also included are NNSA guided metrics for assessing the long-term impact of LDRD on laboratory staff and capabilities. Our report also includes performance indicators specified by DOE's director of LDRD programs, in accordance with DOE Order 413.2C.

PATRICIA FALCONE

LLNL Deputy Director for Science & Technology

LLNL's Investment Strategy for Science and Technology is updated annually to reflect evolving mission needs, under the guidance of LLNL's deputy director for science and technology. It sets the strategic context for LLNL's annual call for LDRD proposals, and it serves as a resource for investigators as they articulate the ways their proposed research aligns with at least one of these investment priorities.



DOUG ROTMAN

LDRD Program Director

"The LDRD program is an investment in our nation's future, with a mission impact that is often realized many years after an LDRD-sponsored project concludes. I'm extremely proud of everyone at LLNL—from postdocs who serve on LDRD-funded research teams, to senior scientists who help shape our investment strategy—so that together, we can ensure that the LDRD program continues to serve as a valuable national asset."

Investment Portfolio

LDRD investments span a broad range of research topics, helping to ensure that LLNL supports innovation in key programmatic areas. Funded projects address some of our newest mission spaces, including cognitive simulation, predictive biology, space science and security, and hypersonic science. We also invest in the core capabilities and programmatic areas that undergird our Laboratory's technical vitality and mission agility.

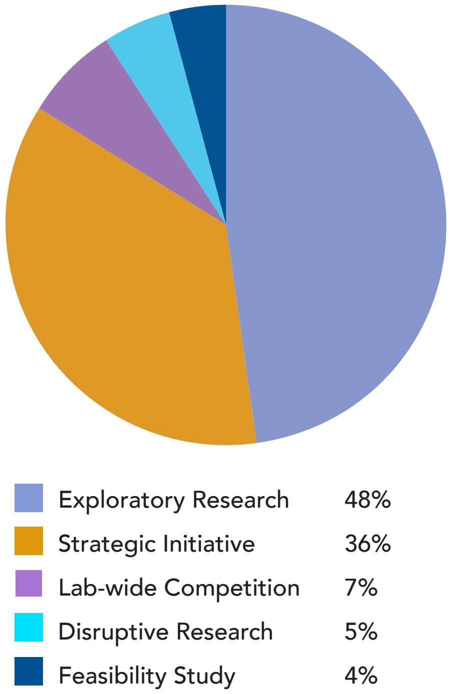
For fiscal year 2023, we carefully structured Livermore's LDRD investment portfolio to promote the short-term objectives and long-term goals of DOE, NNSA, and our Laboratory. The key metrics presented here regarding our FY23 investment portfolio reflect this structure, including how funds are distributed across the program's 5 types of projects and 18 research categories. By strategically selecting the types of projects we fund, along with the amount of funding invested in each project, we help ensure a strong program portfolio.

Funding by Project Type

Livermore's LDRD program includes five types of projects. Each one has a distinctive purpose, duration, and funding limit. For example, our one-year feasibility studies support relatively brief investigations of a specific technical approach. These types of projects can be launched mid-year to rapidly respond to an emerging challenge. Other types of projects span several years, often involving collaborators and research that tackles a broader scope of challenges.

FY23 INVESTMENTS
266 PROJECTS,
~$157M TOTAL FUNDING

Percentage of Funding by Category



Project Type	FY23 Projects Funded	Project Aim
Exploratory Research	141	Address a specific research challenge or enhance a core competency.
Feasibility Study	60	Determine the viability of a new way to address a mission-relevant challenge.
Lab-wide Competition	37	Conduct innovative basic research and enable out-of-the-box thinking.
Strategic Initiative	19	Make significant progress addressing a mission-relevant challenge from a multidisciplinary perspective.
Disruptive Research	9	Pursue novel ideas with the potential to overturn fundamental paradigms or create new research directions.

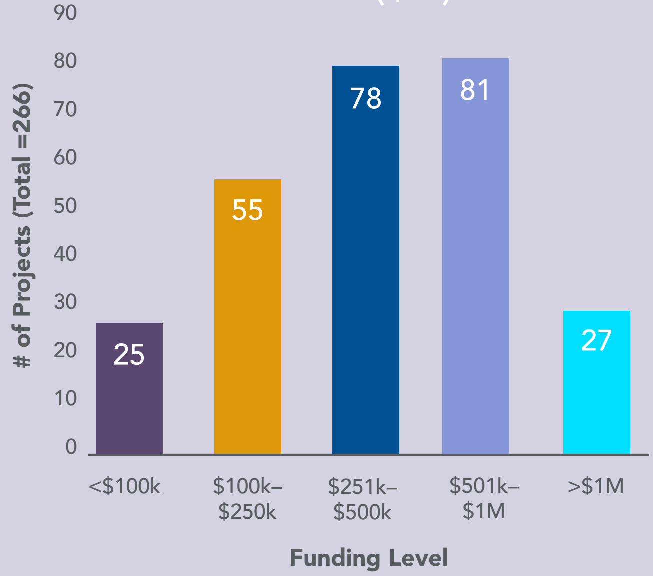
Projects by Funding Level

Our Laboratory's investment strategy includes the flexibility to fund projects at varying dollar amounts, depending on the project scope. This chart presents data on the number of projects funded in FY23, distributed across five funding levels. The largest number of projects (81) fell in a higher funding range, receiving between 501k and 1000k per project. A smaller number of projects received less than $100k in funding (25 projects), or more than $1M in funding (27 projects).

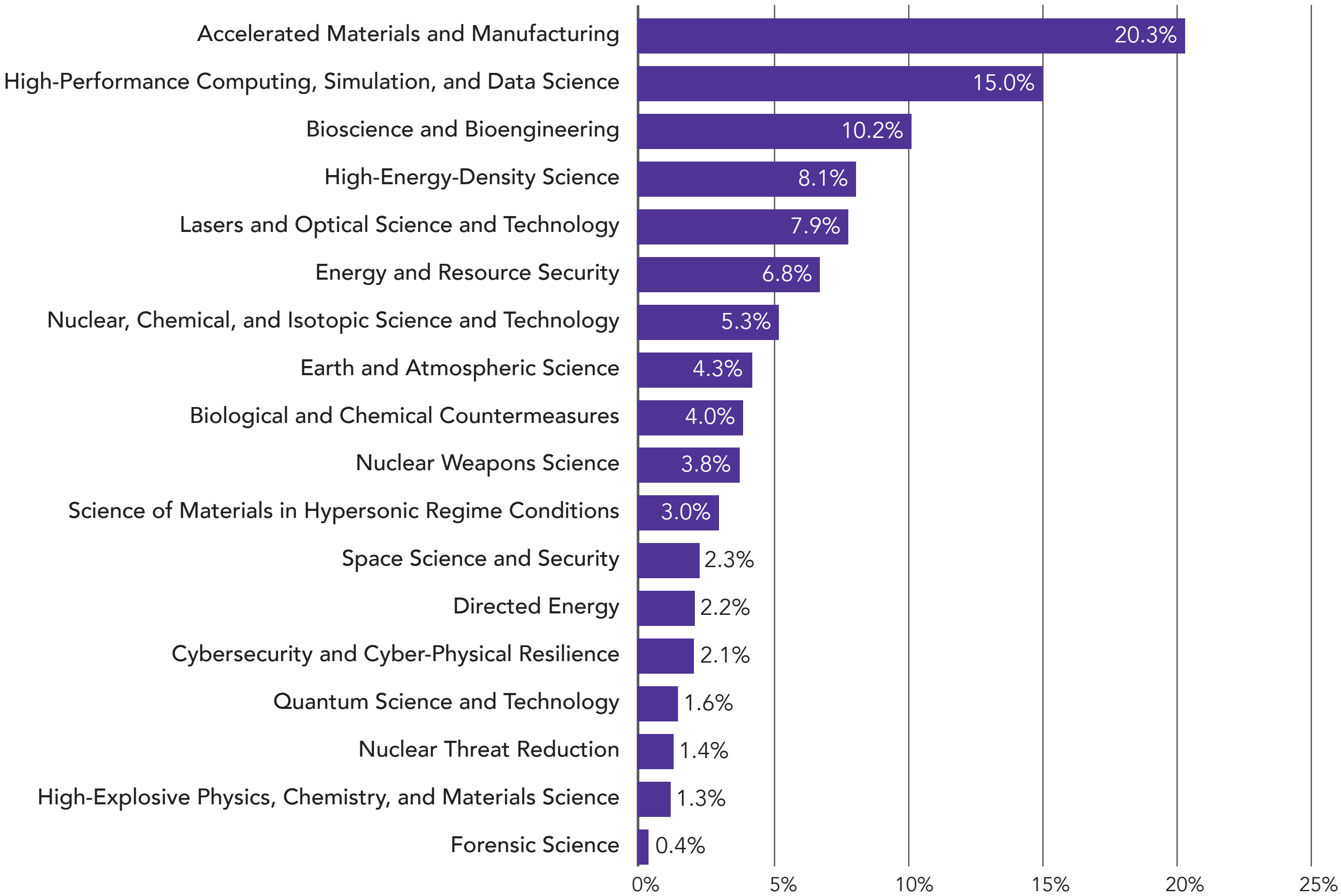
Funding by Research Area

Every LDRD project is assigned to at least one of the Laboratory's research areas in the LDRD investment portfolio. The categories include 11 mission-driven research challenges and 7 core competencies—capabilities that enable us to conduct high-priority, mission-relevant research. (Note that this chart only includes research categories where at least one project designated the category as a primary research focus.)

$590,000 AVERAGE FUNDING LEVEL PER PROJECT ($K)



Percentage of Project Cost by Research Category



Program Value

By almost any measurement, the LDRD program contributes far more to publications, intellectual property, collaborations, and recruitment of postdoctoral researchers—dollar for dollar—than any other program at the Laboratory.

75 INSTITUTIONS
were involved in formal collaborations with LLNL as part of LDRD-funded research teams in FY23.

Collaborative Explorations

External collaborations are essential to the innovative research that takes place at LLNL, including LDRD-funded projects. By collaborating with other national laboratories, academia, and industry, our investigators can engage with experts from other institutions and access world-class experimental facilities.

The following table provides our most recent data regarding formal collaborations, which we define as LDRD-funded projects where an external collaborator received LDRD funds from LLNL. In addition, our investigators frequently participate in informal collaborations with researchers at other institutions, which often involve joint scientific publications. Both types of collaborations are a key indicator of the broad i

Collaborations	FY19	FY20	FY21	FY22	FY23
LDRD-funded projects with one or more formal collaborations	74	78	88	79	81
Percentage of all projects at LLNL	30%	32%	33%	32%	30%

New research shows successful ab initio crystal structure prediction of energetic materials

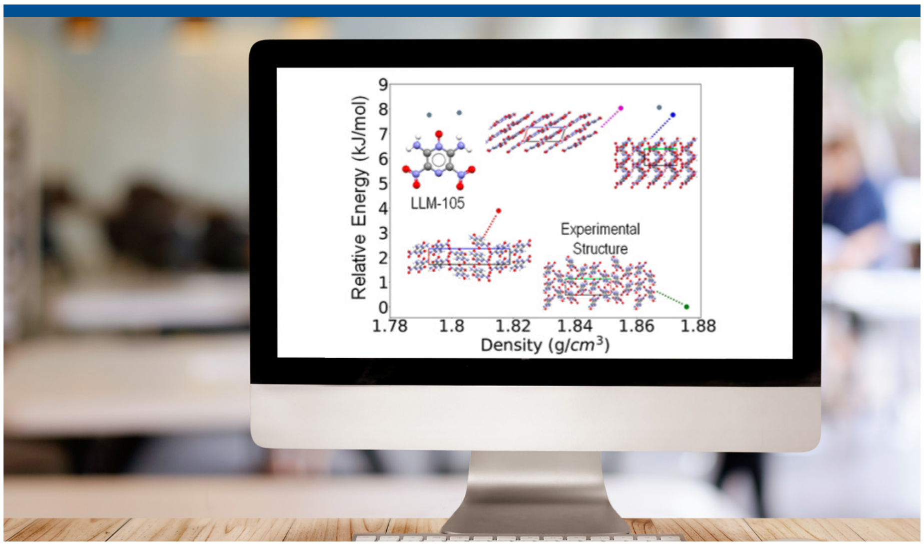
New research by Lawrence Livermore National Laboratory researchers and collaborators from Carnegie Mellon University (CMU) demonstrates that crystal structure prediction is a useful tool for studying the various ways the molecules can pack together, also known as ubiquitous polymorphism, in energetic materials. The research also shows promise of becoming an integral part of the energetic materials development pipeline.

Experimental synthesis of novel energetic materials can be a costly, time-consuming and hazardous process, sometimes requiring a significant amount of trial and error. If material properties could be predicted ahead of time, compound selection and solid form development process could be streamlined.

Predicting materials properties with a physics-based approach requires knowledge of the crystal structure. The work, featured in the Aug. 16 edition of Crystal Growth & Design by the American Chemical Society, has demonstrated that the crystal structure of commonly used energetic materials LLM-105, RDX, and HMX can be predicted using ab initio (i.e.

Principal Investigator: T. Yong-Jin Han

LDRD Project: 19-SI-001 Accelerating Feedstock Optimization Using Computer Vision, Machine Learning, and Data Analysis Techniques



The figure shows the energy ranking, where lower energy means higher stability, as a function of density for the most stable crystal structures generated by the algorithm. The experimentally observed structure of LLM-105 is the most stable and has the highest density. The algorithm also produces putative crystal structures in a variety of packing motifs. Crystal structures in which the molecules are arranged in layers have been associated with low sensitivity, and the structure indicated by the purple marker has a layered packing motif. This demonstrates how simulations can help discover new crystal structures with desirable properties.

without experimental input) crystal structure prediction methods, showing the viability and usefulness of this approach.

The work was led by Brad Steele and Anna Hiszpanski from LLNL's Materials Science Division in collaboration with Noa Marom from the Materials Science & Engineering Department at CMU. T. Yong-Jin Han served as primary investigator. CMU Ph.D. student, Dana O'Connor, received a DOE Office of Science Graduate Student Research (SCGSR) award to conduct research at LLNL.

Steele compared crystal structure prediction to going on a long road trip and trying to pack as much stuff as possible in your car's trunk, rearranging the stuff until the space is optimally packed.

"In our case, the 'stuff' are molecules, and the trunk is the unit cell — which is a 'box' with variable shape and size — that is repeated periodically in three dimensions to form the crystal lattice," Steele said. "The way molecules are packed in the crystal affects key properties and performance parameters of energetic materials, such as the density and the shock sensitivity."

Steele said the paper describes the workflow of the crystal structure prediction simulations. The algorithm is a physics-based approach that works by randomly generating crystal structures, optimizing them and ranking the resulting structures by their predicted stability.

"The work impacts the mission of the Lab because it is a new method that could be useful in the development of novel energetic materials," said Brad Steele. "The paper demonstrates that if we have knowledge of the molecular structure of an energetic material, then we can predict its crystal structure and then a variety of other important material properties."

Intellectual Property

Year after year, projects sponsored by LDRD achieve a disproportionately large percentage of the patents and copyrights issued for LLNL research. As illustrated in the following tables, LDRD-funded work has been key in developing more than half of the Laboratory's patents, one-third of the Laboratory's copyrights (chiefly computer code), and more than half of the Laboratory's records of invention.

LDRD-funded work has played a key role in developing

MORE THAN 50%

of the Laboratory's patents.

Patents	FY19	FY20	FY21	FY22	FY23
All LLNL patents issued	143	200	166	166	197
LDRD patents issued	95	131	96	103	116
LDRD patents as a percentage of total	66%	66%	58%	62%	58%

Copyrights	FY19	FY20	FY21	FY22	FY23
All LLNL copyrights	118	138	125	142	166
LDRD copyrights	24	31	42	47	44
LDRD copyrights as a percentage of total	20%	22%	34%	33%	26%

Records of Invention	FY19	FY20	FY21	FY22	FY23
All LLNL records	129	126	89	70	120
LDRD records	65	56	53	40	64
LDRD records as a percentage of total	50%	44%	60%	57%	53%

LLNL biomedical licensee collaborating with two drug companies to advance treatments for autoimmune diseases

People afflicted with autoimmune diseases may someday receive help through treatments now under development by a Lawrence Livermore National Laboratory (LLNL) licensee and its' collaborations with two major pharmaceutical companies.

In late 2017, LLNL licensed a biomedical technology called nanolipoprotein particles (NLPs), which can deliver vaccines and drugs inside the cells in the human body, to Ann Arbor, Michigan-based EVOQ Therapeutics.

Over the past two years, EVOQ Therapeutics has announced two major agreements with Gilead Sciences Inc. and Amgen Inc. to work on the preclinical development of novel medicines to combat autoimmune diseases. Part of the LLNL-developed NLP technology could be used as the vaccine delivery platform.

In January, Foster City, California-based Gilead Sciences and EVOQ announced they will collaborate on the preclinical development of vaccines to treat rheumatoid arthritis and lupus. The EVOQ technology is designed to enable lymph targeted delivery of disease-specific antigens for autoimmune diseases.

"The impact of LLNL's technologies has been tremendous and we appreciate the opportunity to work alongside such a talented and dedicated organization," said David Giljohann, EVOQ's chief executive officer. "Our partnership with LLNL has enabled us to tackle complex challenges and may help us bring innovative solutions to patients with autoimmune diseases."

LLNL biologist Nicholas Fischer is analyzing the size of the nanolipoprotein particles (NLPs) by dynamic light scattering in preparation for their use in vaccine applications. Fischer and two former LLNL researchers are key developers of the NLP technology. Photo by Blaise Douros.

Principal Investigator: Nicholas Fischer

LDRD Project: 20-ERD-004 Delivering Ribonucleic Acid Vaccines Using Nanoparticles

Yash Vaishnav, a business development executive in the Lab's Innovation and Partnerships Office, who negotiated the 2017 license agreement with EVOQ Therapeutics and who continues to manage the development of the intellectual property portfolio in this area as well as industry partnerships, said the intellectual property developed with taxpayer funding by LLNL scientists is now moving toward preclinical studies for developing vaccines for several major autoimmune diseases.

"This is one of the first biomedical technologies in the areas of vaccines and therapeutics from the Department of Energy complex to enter preclinical trials," Vaishnav said. "While there are drugs available for the treatment of autoimmune diseases, there are currently no vaccines approved by the U.S. Food & Drug Administration for the prevention or treatment of autoimmune diseases."

Developed by LLNL biomedical researchers over a decade starting in 2005, NLPs are water-soluble molecules that are 5 to 30 billionths of a meter in size and resemble HDL particles, which are the human body's good cholesterol. The NLPs were developed with about $7.4 million of Laboratory Directed Research and Development funds, which is internal research money.

Among the Livermore inventors on the licensed patents are LLNL biologist Nicholas Fischer, Craig Blanchette, a biophysicist now at Genentech; and former LLNL bioorganic chemist Paul Hoeprich, who has retired.

"We are very pleased that the research we conducted with the support of LLNL is now helping companies develop therapies for the millions of individuals with autoimmune diseases," Fischer said.

Scientific Publications

Laboratory scientists and engineers publish more than a thousand papers each year in a wide range of peer-reviewed journals, of which LDRD-funded work accounts for a large portion. The numerous publications made possible through LDRD-sponsored research help the Laboratory maintain a strong presence in the broader scientific community, extending the impact of LDRD research beyond the DOE mission space into the wider scientific arena. In addition, the impact of these publications documenting LDRD project results extends long after articles appear in the journals, increasing the value of LDRD investments in these projects.

Journal Articles	FY19	FY20	FY21	FY22	FY23
All LLNL articles	1,281	1,149	1,256	1,149	1,218
LDRD articles	553	428	509	490	495
LDRD articles as a percentage of total	43%	37%	41%	43%	41%

LLNL chemists double down with breakthrough method to study radioactive materials

Studying radioactive materials is notoriously difficult due to their radiation-induced toxicity and risk of contamination when handling. The cost of the radioactive isotopes used in research also is a major barrier, with some costing more than $10,000 per microgram. Certain radioisotopes also cannot be produced in sufficient quantity, so it is simply impossible for researchers to study them with current laboratory techniques.

A new approach developed at Lawrence Livermore National Laboratory (LLNL) allows for the study of radioactive and/or precious elements in a much more efficient way, requiring 1,000 times less materials than previous state-of-the-art methods, without compromising the data quality.

The method and its application have recently been reported in two successive articles, one in Nature Chemistry and one in Inorganic Chemistry. The research was featured on the front cover of both journals, as well as highlighted in the journal Nature.

"This is a nice recognition that out-of-the-box ideas can, with enough work and dedication, lead to interesting breakthroughs in science, even for relatively mature research areas like radiochemistry," said LLNL scientist and project lead Gauthier Deblonde. "The most exciting part is that this is just a beginning. Now that the proof-of-concept has been demonstrated, we will be able to move forward and apply our new method to really expand

Principal Investigator: Gauthier Deblonde

LDRD Project: 20-LW-017 Elusive Actinium: A First Glimpse into the Coordination Chemistry of Element 89

A new line of research developed at LLNL allows for the study of radioactive and/or precious elements in a much more efficient way, requiring >1000 times less materials than previous state-of-the-art methods, without compromising the data quality. The research led by Gauthier Deblonde (LLNL) has recently been featured on the front covers of the journals Nature Chemistry and Inorganic Chemistry (upcoming). Image credits: Tulsi Voralia (Springer Nature) and Gauthier Deblonde (LLNL); Adam Connell (LLNL).

chemical knowledge on some of the most elusive and radioactive elements on Earth."

The radiotoxicity, cost and low-availability constraints are particularly magnified for the heavy elements of the periodic table, which chemists call "actinides." The actinides are a family of 15 radioactive elements, with the most famous ones being plutonium and uranium. Beyond plutonium, other elements include americium, curium, berkelium, californium, etc. These are the heaviest elements that can be produced on Earth and for which chemistry experiments can potentially be done. However, beyond plutonium, the availability of research isotopes drops exponentially, the elements are increasingly radioactive and the cost of producing them increases dramatically. As a result, relatively little is known about the chemical properties of these elements.

The new method involves polyoxometalate ligands (POMs), a class of molecules that has so far been largely overlooked for radiochemistry applications. The intrinsic properties of the POMs allow scientists to easily form compounds with the targeted radioisotopes, crystallize them and study them with a wide variety of spectroscopic techniques while just using a few micrograms (compared to multiple milligrams or more for previous methods). This drastically cuts costs, hastens discoveries and lowers the toxicity risk for researchers, according to Deblonde.

The new approach could be used to synthesize many new compounds containing rare isotopes, such as actinides, and study them in detail. The LLNL team plans on continuing this research to offer a new perspective on the chemistry of some of the rarest and most toxic elements on Earth, for which previous methods have remained inapplicable.

Early Career Opportunities: Students and Postdoctoral Fellows

By funding exciting, potentially high-payoff projects at the frontiers of science, the LDRD program attracts top talent in new and emerging fields of science and technology. As shown in the following tables, LDRD investments contribute to the health and robustness of LLNL's student and postdoctoral researcher programs..

Students	FY19	FY20	FY21	FY22	FY23
Students supported by LDRD	160	101	136	149	185
Percentage of all students	23%	18%	24%	23%	24%

Postdoctoral Researchers	FY19	FY20	FY21	FY22	FY23
Postdoctoral researchers supported by LDRD ≥10% of their time	170	208	208	240	213
Percentage of all postdoctoral researchers	57%	63%	54%	56%	51%
LDRD postdoctoral researchers converted to full staff	46	60	50	72	56
Percentage of all conversions	68%	77%	82%	77%	70%

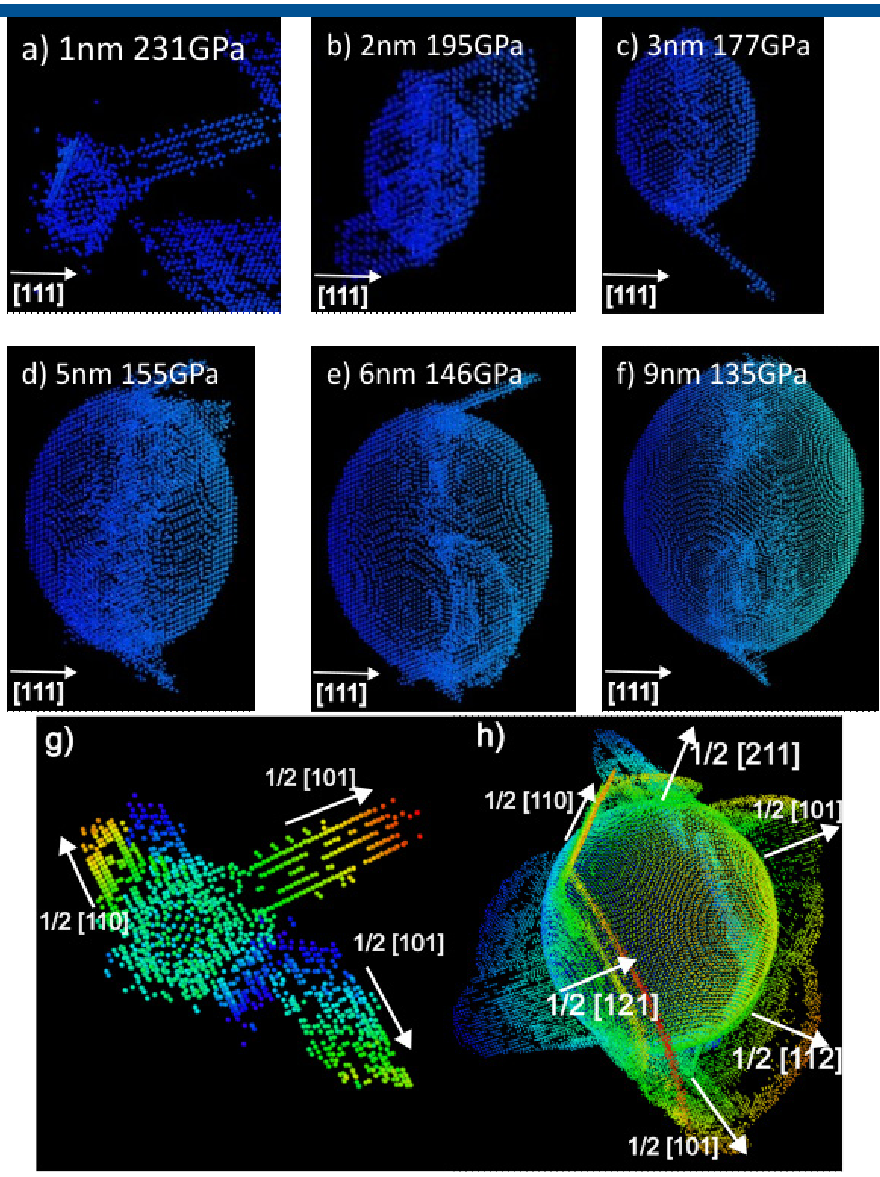
Understanding the plasticity of diamond for improved fusion ignition

Alex Li, a Lawrence Livermore National Laboratory (LLNL) summer student in the Computational Chemistry and Materials Science Summer Institute, recently led a study published in the journal *Matter* to investigate the evolution of plasticity in diamond along different loading orientations and the effects that voids (pores) within the material can have on stresses within the diamond.

While diamond carbon is one of nature's strongest naturally occurring materials, it is known to undergo irreversible plastic deformation when loaded at high rates. Rob Rudd, LLNL scientist and Li's mentor, notes, "We

Principal Investigator: Jon Eggert

LDRD Project: 21-ERD-032 Investigating the Relationship Between Microstructure and Dynamic Response Using X-Ray Free-Electron Lasers



MD Simulations showing the threshold for dislocation generation for different void sizes and the shock pressure at which they first form dislocations from the void. a) 1nm, 231 GPa b) 2nm, 195 GPa c) 3nm, 177 GPa d) 5nm, 155 GPa e) 6nm, 146 GPa f) 9nm, , 135 GPa g) and h) Differences in Dislocation configurations between g) 1nm and h) 9nm voids. Only dislocations on {100} planes with direction [110] are formed in the 1nm void , whereas in the 9nm void multiple dislocations are created along parallel planes and both{100} and {111} planes are activated. The 1nm simulation also had a large number of dislocations emanating from the planar impact surface, whereas in the 9nm void case the pressure was too low for surface dislocations to form.

usually think of diamond as brittle, strong and unyielding until it cleaves. Shocked diamond is different. Alex did a fantastic job working out the complex and unexpected details of the deformation."

The nature of this deformation is important for high-energy-density experiments on high-energy laser systems such as the National Ignition Facility (NIF), as well as for further evolving scientific understanding of carbon-rich exoplanets. At NIF, diamond carbon is used as an ablator and capsule material for producing the extremely high pressures needed to cause nuclear fusion reactions that are being intensively investigated as a source of energy.

In many shock-compression experiments, diamond has shown little to no plastic behavior until reaching extreme pressure and temperature conditions. Because diamond exhibits strong anisotropic behavior — that is, has different properties in different locations, depending on the direction of applied stress — it can be difficult to anticipate how diamond will react under such extremes. Defects present within the diamond capsules that hold the fusion fuel can cause imperfect compression, resulting in a failure to ignite.

Using molecular dynamics and analytical calculations on three diamond orientations under shock compression, Li's team demonstrates that both the stress needed to generate defects and the character of the defects depend on the orientation. In addition to computer simulations, the team used the Omega Laser Facility at the University of Rochester's Laboratory of Laser Energetics to shock diamonds under extreme loading conditions and recover them for subsequent microscopic analysis. Omega's high laser energy enabled the imposition of the extreme stress- and strain-rate conditions. Stress refers to the force applied to a material per unit area, while strain refers to the deformation or change in the material's shape resulting from the applied force.

Out of the three orientations that were tested, two showed significantly more defect activity, with even more defects being generated when a void was intentionally introduced. Building a better understanding of diamond's behavior under shock loading can help researchers optimize the diamond capsules used at NIF, thereby suppressing undesired effects such as instabilities and leading to the development of better models or capsules to get closer to realizing fusion as an energy source.

Professional Fellows

One relevant indicator of advancement and leadership in a scientific field is the election of individuals as fellows of professional societies. This indicator reflects success for both the individual researcher and the Laboratory as a whole.

American Physical Society (APS) fellowships are awarded based on scientific merit and impact over an extended period, and the evaluation process relies on nomination and recommendation by peers. As such, data regarding the history of APS fellowships awarded to LLNL physicists provide an important indicator regarding the key role that the LDRD Program plays in developing the technical, scientific, and leadership skills of early career staff. As presented in the following table, for fiscal year 2023, 100% of the new APS Fellows from LLNL have early career LDRD experience.

Because the quantity of awards each year is a small number, we also present multi-year statistics. For example, over the last 20 years, more than 90% of the APS Fellows at LLNL had early career LDRD experience.

HISTORY OF APS FELLOWS AT LLNL

	Single-Year Statistics			Multi-Year Statistics		
	FY21	FY22	FY23	FY14–18	FY19–23	FY14–23
Total APS awards	3	2	2	28	17	45
Awards with LDRD roots	3	2	2	27	16	43
% with LDRD roots	100%	100%	100%	96%	94%	96%
Average years from first LDRD experience	4.7	15	15.5	15.6	14.8	15.3

TRACING IMPACT TO LDRD ROOTS

Throughout this section, we mention "LDRD roots." Much discussion with principal investigators has transpired about what it means for an accomplishment to have LDRD roots. A simple case would be if an idea for an invention arises during an LDRD project and work on the invention is completed during the period of LDRD investment. But R&D often does not advance on such a short timescale. In general, an accomplishment (invention, paper, capability, etc.) is determined to have LDRD roots if at least one LDRD project needed to occur for the accomplishment to take place. In other words, if one can identify an LDRD project that was critical to the accomplishment, then it is considered to have LDRD roots. Two LLNL scientists were selected as 2023 fellows of the American Physical Society. The new fellows were both selected by the APS Division of Plasma Physics.

2023 APS Fellows at LLNL

Two LLNL scientists selected as 2023 American Physical Society fellows

Lawrence Livermore National Laboratory (LLNL) scientists Manyalibo "Ibo" Matthews and Frank Graziani have been named 2023 American Physical Society (APS) fellows.

Matthews was selected from the Forum in Industrial and Applied Physics unit "for pioneering research in optimizing metal 3D printing and laser materials processing."

Frank Graziani was chosen from the Division of Plasma Physics unit, "for original theoretical and computational contributions on the frontiers of fundamental properties of non-ideal plasmas, and for exceptional leadership in the national boost initiative, including mentoring and educating the broader high energy density physics community."

IBO MATTHEWS

As a 17-year Lab veteran, Matthews started his career in industrial research at Bell Laboratories where he worked for eight years in photonic materials research. He is a trained experimental condensed matter physicist and currently serves as the division leader for Materials Science within the Physical and Life Sciences Directorate.

"I am truly humbled and honored to be named an APS Fellow, and I'm very grateful for all the support I've received from LLNL and my colleagues," he said.

Matthews' work over the years has largely focused on light-matter interactions and has included light scattering and absorption spectroscopy to characterize material properties as well as processing of materials using intense and/or high average power laser light. A large part of his research at LLNL occurred in the NIF & Photon Science Directorate where he studied problems related to laser damage, laser materials processing and directed energy weapon systems. That work in laser materials processing eventually branched out to include studies to understand the physics of laser-based 3D printing of metals and other activities across the Lab's programs.

2023 APS Fellows at LLNL

FRANK GRAZIANI

Graziani has had an evolving career during his 34 years at the Laboratory. He started off interested in the fundamental understanding of burn physics and finding a better way to validate physics models used in radiation-hydrodynamics codes. He then became interested in non-ideal plasmas or warm dense matter. Five years ago, he looked into quantum computing and never looked back.

"I fell in love with the field. It is extremely challenging, but it holds so much promise for the future," he said.

"Being named a fellow of the American Physical Society was a tremendous honor," he said. "This honor is a testimony to all of the brilliant students, postdocs and scientists who I have worked with over my 34 years at LLNL. Science, especially the type of big science we do at the national laboratories, is a community affair. In pursuing the science I am passionate about; I am fortunate enough to have a network of colleagues around the world who I also count as my friends."

Graziani now serves as the director of the High Energy Density (HED) Science Center at LLNL where he helps provide the international HEDS community with a wide variety of classes ranging from plasma diagnostics to spectroscopy to an overview of HEDS. The center hires about a dozen summer interns every year, and Graziani has even mentored some of them.

Long-term Impact

The LDRD program is an investment in our nation's future, ensuring mission support that is often realized many years after an LDRD-funded project concludes. Recognizing this long-term impact of the LDRD program, we believe it is important to highlight indicators that span multiple years, demonstrating the true impact of LDRD as a national asset.

We collaborated with our colleagues from LDRD programs at other NNSA institutions to identify ways that we could best represent the long-term impact of LDRD investments. As each institution issues its LDRD program report for fiscal year 2023, we present a common set of long-term performance indicators including the content provided below.

Distinguished Member of the Technical Staff

One relevant indicator of career advancement in a science and technology field is the recognition of individuals as distinguished members of the technical staff at the institution. Individuals who receive this recognition are identified as being in the top 1% or 2% of the institution's scientific and technical staff, similar to a lifetime achievement award, or in this case, for their contribution to the Laboratory's mission.

HISTORY OF DMTS AWARDS AT LAWRENCE LIVERMORE NATIONAL LABORATORY

	FY21	FY22	FY23	FY14-18 (5 yrs)	FY19-23 (5 yrs)	FY14-23 (10 yrs)
Total DMTS awards	0	26	0	19	32	51
DMTS with LDRD roots	N/A	20	N/A	17	26	43
% with LDRD roots	N/A	77%	N/A	89%	81%	84%
Average years from first LDRD experience	N/A	16.4	N/A	21.5	16.7	18.6

At LLNL, appointment as a Distinguished Member of the Technical Staff (DMTS) is reserved for Laboratory scientists and engineers who have demonstrated a sustained history of high-level achievements in programs of importance to the Laboratory, become a recognized authority in the field, or made a fundamental and important discovery that has sustained, widespread impact.

As presented in the table, a vast majority of these distinguished staff at LLNL had early career experience with LDRD projects, which helped them develop their scientific, technical, and leadership skills.

R&D 100 Awards

Over the last 10 years, **OVER 40% OF LLNL'S R&D 100 AWARDS** had roots in the LDRD Program.

Another indicator of advancement and leadership in a scientific field is the R&D 100 Award program, which honors the top innovations of the past year. R&D 100 Awards can occur a long time after the initial ideas are developed, often during LDRD projects. Typically, it takes 5 to 10 years (or longer) from concept development to receiving an award, including the time needed to move through patenting an invention and demonstrating its commercial applications.

The LDRD program is an investment in our nation's future, ensuring mission support that is often realized many years after an LDRD-funded project concludes. Recognizing the is long-term impact of the LDRD program, we believe it is important to highlight indicators that span multiple years, demonstrating the true impact of LDRD as a national asset.

HISTORY OF R&D 100 AWARDS AWARDS AT LAWRENCE LIVERMORE NATIONAL LABORATORY

	FY21	FY22	FY23	FY14-18 (5 yrs)	FY19-23 (5 yrs)	FY14-23 (10 yrs)
Total R&D 100 awards	3	3	3	17	14	31
Awards with LDRD roots	0	2	3	6	7	13
% with LDRD roots	0%	67%	100%	35%	50%	42%
Average years from first LDRD investment	N/A	7.5	14.7	7.5	11.9	9.8

Lab scientists and engineers garner three awards for top inventions in the R&D 100 competition

Lawrence Livermore National Laboratory (LLNL) scientists and engineers have netted three awards among the top 100 inventions worldwide.

The trade journal *R&D World Magazine* recently announced the winners of the awards, often called the "Oscars of innovation," recognizing new commercial products, technologies and materials that are available for sale or license for their technological significance.

With this year's results, the Laboratory has now collected a total of 179 R&D 100 awards since 1978.

This year's LLNL R&D 100 awards include a software suite that helps apply deep-learning techniques to major science and data challenges in cancer research; software that helps better understand the power, energy and performance of supercomputers; and a number format that permits fast, accurate data compression for modern supercomputer applications.

All three of LLNL's R&D 100 award winners received internal "seed money" from the Laboratory Directed Research and Development program. This funding enables the undertaking of high-risk, potentially high-payoff projects at the forefront of science and technology.

"The R&D 100 awards highlight the most game-changing technologies each year," Lab Director Kim Budil said. "Researchers at LLNL strive to address the most significant challenges facing the world today through innovative science and technology and these awards are an important recognition of the impact of this work."

SOFTWARE AIDS SCIENTIFIC DISCOVERY

A team of LLNL computer scientists has developed Variorum, a vendor-neutral software library for exposing and monitoring the power, energy and performance of low-level hardware dials across diverse architectures in a user-friendly manner for supercomputers.

It is part of the Department of Energy's (DOE) Exascale Computing Project (ECP), specifically the Argo Project in which Variorum is a key component for node-level power management in the high-performance computing (HPC) PowerStack Initiative.

R&D 100 AWARDS

THE RENOWNED R&D 100 COMPETITION, NOW IN ITS 61ST YEAR, RECEIVED ENTRIES FROM 15 COUNTRIES AND REGIONS AROUND THE WORLD.

A team of LLNL computer scientists have developed software that helps better understand the power, energy and performance of supercomputers. Team members include (left to right): Stephanie Brink, Tapasya Patki, Barry Rountree, Eric Green, Kathleen Shoga and Aniruddha Marathe.

Variorum focuses on ease of use and reduced integration burden in scientific applications and workflows. It has enabled support for all three upcoming U.S. exascale supercomputers — El Capitan at LLNL, Aurora at Argonne National Laboratory and Frontier at Oak Ridge National Laboratory — and many other HPC systems.

The Variorum team is led by Lab computer scientist Tapasya Patki and includes computer scientists Aniruddha Marathe, Barry Rountree, Eric Green, Kathleen Shoga and Stephanie Brink.

ACCELERATING DATA MOVEMENT FOR SUPERCOMPUTERS

A team of LLNL researchers has developed ZFP, an open-source software that compresses numerical data exceptionally fast and allows reductions in data movement, something that is critical to today's high-performance computing (HPC) applications. HPC performance is largely limited by data movement rather than raw compute power.

ZFP allows computer users to store numerical data using less space, so that they can cram larger data sets into memory or reduce how much disk space they need. ZFP also allows users to transfer data, such as between memory and disk, between different compute nodes on a supercomputer and across the internet, more quickly by having the sender compress it, transmit the data in reduced form and have the receiver decompress it in order to reconstruct the original data.

ZFP effectively expands available central processing unit and graphics processing unit memory by as much as 10-fold; reduces offline storage by10-fold to 100-fold; and — by reducing data volumes — speeds up data movement.

Contrary to competing compressed formats designed for file storage, a unique feature of ZFP is that it supports high-speed random access to array elements — both for read and write operations — suitable also for in-memory storage.

ZFP was developed by a team of LLNL researchers led by computer scientist Peter Lindstrom and includes computer scientists Danielle Asher and Mark C. Miller. In addition, three former Lab employees — Stephen Herbein, Matthew Larsen and Markus Salasoo — who have since left LLNL were part of the team.

CANDLE AIDS CANCER PATIENTS

The ECP-CANDLE Project (Exascale Computing Project — CANcer Distributed Learning Environment) brought together the combined resources of the DOE and the National Cancer Institute to accelerate cancer-specific research by applying machine learning and deep learning techniques to large-scale cancer datasets in a distributed computing environment.

The resultant software suite, called CANDLE, provides cancer researchers with key functions and capabilities so they can study molecular interactions using dynamic simulations and predict responses to treatment as well as patient trajectories and outcomes.

As part of the five-lab consortium, this work led to a specific focus for the LLNL team within CANDLE on the development of scalable distributed deep learning tools, algorithms and methods within the open-source Livermore Big Artificial Neural Network toolkit (LBANN) and targeting the development of neural network models representing the state transition of the RAS-RAF protein complex as it binds to a lipid membrane.

Several of the key innovations developed by the LLNL research team were the creation of a scalable deep learning tournament algorithm, scalable distributed in-memory data storage optimized for deep neural network training, improved methods for tensor and model parallelism, as well as the capability for dynamic tuning of compute kernels that are optimized for next generation HPC hardware architectures.

Additionally, the CANDLE project and LLNL team worked to enable external deep learning toolkits, such as PyTorch, DeepSpeed, and Megatron-LM, to run on the first generation of exascale computers as well as help optimize their performance on these systems.

The CANDLE collaborators are Argonne, Oak Ridge, Lawrence Livermore and Los Alamos national laboratories as well as Fredrick National Laboratory for Cancer Research.

The LLNL part of the ECP-CANDLE team is led by Lab computer scientist Brian Van Essen and chief computational scientist Fred Streitz and includes current team members Tom Benson, Adam Moody, Tal Ben-Nun, Nikoli Dryden, and Pier Fiedorowicz as well as former Lab employees David Hysom, Sam Ade Jacobs, Naoya Maruyama and Tim Moon.

NARAC: Providing Operational Response to Atmospheric Releases of Concern

LABORATORY DIRECTED RESEARCH & DEVELOPMENT

R&D Challenge

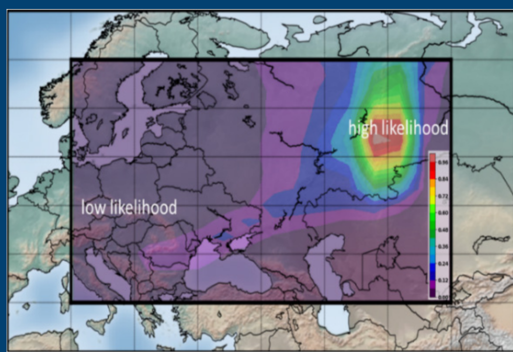
Provide timely and confident technical support for emergency response to hazardous atmospheric releases

- Deterministic analysis by experts, while necessary and important, is laborious and time-consuming for events of high uncertainty.
- Validated models must be developed for next-generation HPC architectures utilizing GPU acceleration and Artificial Intelligence.

Approach

Develop novel approaches to improve simulation speed and accuracy and quantify uncertainties related to source terms, meteorology, and fallout.

NARAC leveraged novel machine learning tools developed by LDRD investment with its advanced atmospheric dispersion models; in a mere 4 days this tool quantified the probable location and amount of a 2017 radioactive release detected across Europe.



LLNL develops 3D models for atmospheric transport and fallout after a decade of groundbreaking work in atmospheric science

1986 Chernobyl reactor explosion: calcul ated possible dose to people in Europe

Hurricane Katrina: provided airborne hazard predictions

ARAC stood up as center to respond to Three Mile Island nuclear power plant accident

Dynamic Data-Driven Event Reconstruction for Atmospheric Releases (04-ERD-037)

Fukushima Daichi nuclear emergency: 24/7 response for almost 4 weeks, dose predictions for Japan, plume arrival predictions for US

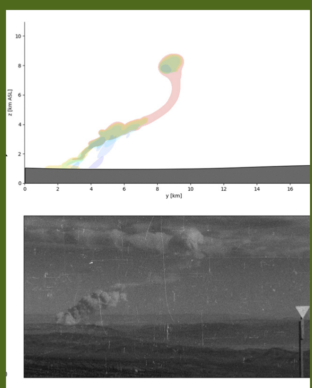
1970's **1979** **1986** **2004** **2005** **2011**

Lawrence Livermore National Laboratory · Los Alamos National Laboratory EST. 1943 · Sandia National Laboratories · Nevada National NNSS Security Site

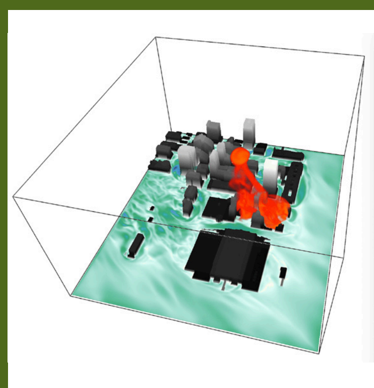
As part of the LLNL LDRD Annual report, each year we will include a chart showcasing the long term impact of LDRD on a LLNL program. This year, we highlight the National Atmospheric Release and Advisory Center (NARAC). For several decades, the LDRD program at Lawrence Livermore National Laboratory (LLNL) has funded technical support to respond to nuclear, radiological, chemical, biological, and hazardous natural materials released into the atmosphere in the United States and around the world. Resources include emergency planning, real-time assessment, emergency response, and detailed studies of atmospheric releases at the National Atmospheric Release Advisory Center (NARAC), a national support center. LDRD support has improved the fundamental science of the NARAC modeling and analysis system which has improved the speed and accuracy of national and international responses to atmospheric releases providing enhanced national security.

Impact and Benefit

NARAC's predictive capabilities can now quickly quantify confidence by leveraging available data and high-performance computing, further enabling its nuclear response mission.



NARAC is leveraging LDRD investment into validated high-fidelity models for next generation HPC architectures. Accelerated CPU-GPU models are 100x faster than currently used high-fidelity models.



2014 — *Atmospheric Source Reconstruction with Uncertainty Quantification (14-ERD-006)*

2017 — *Localized source of ruthenium-106 detections in Europe*

2018 — *Modeling Nuclear Cloud Rise and Fallout... (18-ERD-049)*

2019 — *NARAC 40th anniversary celebration with NNSA Administrator*

2022 — *NARAC provides support to Ukraine for preparatory consequence management*

2024 — *Accelerated Atmospheric Models for Rapid Response (24-SI-001)*

National Nuclear Security Administration

Program Accomplishments

LDRD-funded research explores the frontiers of science and technology in emerging mission spaces, with projects guided by an extremely creative, talented team of scientists and engineers.

Featured Research

LDRD funded 266 projects in the fiscal year 2023. Brief summaries of each project are included in the Project Highlights section of our online report at ldrd-annual.llnl.gov. Here, we provide a closer look at a handful of projects that underscore the exciting, innovative research in this year's LDRD portfolio.Research finds mechanically driven chemistry accelerates reactions in explosives.

Advanced masking technology enables new applications for metasurface optics

Optics researchers at Lawrence Livermore National Laboratory (LLNL) have refined their novel metasurface process to create taller features without increasing feature-to-feature spacing, an advance that unlocks exciting new design possibilities.

"We have refined our process to create metasurfaces that allow for a wide optical bandwidth and a large span of incidence angles for an antireflection layer," said LLNL research scientist Eyal Feigenbaum, the principal investigator. "We can now cover bandwidth range all the way from the ultraviolet to wavelengths larger than 2 microns, which is extraordinary. That wasn't possible with the existing technology."

The result is reported in a new paper, "All-Glass Metasurfaces for Ultra-Broadband and Large Acceptance Angle Antireflectivity: from Ultraviolet to Mid-Infrared," the cover story for the December 2023 issue of *Advanced Optical Materials*.

Metasurface is an approach to optics design in which the surface of a material is carefully altered, creating an ultrathin "metasurface" with properties that differ from those within the bulk of the material by introducing features smaller than the optical wavelength. Feigenbaum's team have been developing a scalable process for engraving metasurfaces into fused silica glass, part of a Laboratory Directed Research and Development project ending this year.

The LLNL method seeks to replace the need for broadband anti-reflective (AR) coatings with a metasurface that is monolithic to the optic — essentially becoming a seamless part of the optic — to enhance its endurance and stability. Furthermore, the team has presented and continues developing different alterations of this method for implementing sub-micron thick optical elements, such as lenses, and polarization altering waveplates.

For the National Ignition Facility (NIF) and other advanced laser systems, such metasurface optics could be transformative, replacing multiple optics with a single, more robust, slimmer optic.

Their four-step process, consisting of ultrathin metal film deposition, dewetting, etching and mask removal, results in an all-glass metasurface.

Standing in LLNL's Center for Micro Nano Technology, Nathan Ray holds a marvel of optical engineering, a 5-centimeter metasurface optic with deep, closely spaced surface features that allow for a wide optical bandwidth and a large span of incidence angles for an antireflection layer. Photo by Jason Laurea/LLNL.

Principal Investigator: Eyal Feigenbaum

LDRD Project: 21-ERD-002 Glass-Engraved Meta-Optics for High-Power Lasers

While relatively simple, the process provides substantial tunability and control over metasurface features. Their most recent advances came from two significant changes to their process: changing the deposition material from gold to platinum and advancing the dewetting mask technology.

"This is what allowed us to etch deep features while maintaining the same feature spacing," said LLNL staff research scientist Nathan Ray, the lead author of this study.

The challenge in producing a metasurface that operates over a broad band of wavelengths is manufacturing a feature height-to-width aspect ratio that is large enough. For that purpose, the nanofeatures' widths and spacing must be made smaller than the shortest wavelength, while the depth of the nanofeatures must be close to half of the longest wavelength in the band of operation.

The team invented a technique they call "seeded dewetting," which allows increasing the mask nanoparticle height while maintaining the inter-particle spacing. For the metasurface to function as an AR, the inter-particle spacing must be substantially smaller than the light wavelength, yet the height of the mask nanoparticle determines how tall the metasurface features can be made.

Traditional dewetting has a limited design space, since an increase in the nanoparticle height goes hand-in-hand with an increase in the inter-particle spacing. The researchers found that seeded dewetting, or subsequent depositions and dewetting of ultrathin metal film on top of preexisting nanoparticle "seeds," maintains the original inter-particle spacing while each step steadily increases the height due to metal accumulation around the initial nanoparticle seeds.

Using this advanced mask technology, they were able to create metasurfaces with nanoscale all-glass metasurface features with height-to-width ratio as large as about 14, where the mean base diameter of the cone-like features is 62 nanometers. They demonstrated this metasurface on both sides of a 2-inch-diameter fused silica window.

The AR performance of such an optic is capable of eliminating reflected light over unprecedented wavelength ranges covering ultraviolet, visible, and infrared, both P- and S-polarizations, and a broad range of acceptance angles. Such optics could enhance the efficiency of light delivered through protective windows of photovoltaic cells, the throughput of multiharmonic lasers, and laser systems that combine beams from different angles or that dynamically vary the beam direction over large angular spans.

“This technology could be transformative for solar-cell windows,” explains Ray. “Using current AR technologies on protective window coverings for solar cells, the efficiency of the AR coating depends on the angle it makes with the sun and the wavelength of the incident light and is polarization dependent. The metasurface optic we demonstrated works for a wide range of angles — so there is no need to move the cell — handles both polarizations and demonstrates near-negligible reflection over the entire solar spectrum.”

Metasurface optics using this technology could enable a broader design space for the variety of lasers developed for and operated at LLNL, with monolithic antireflective coatings also providing robustness and endurance for use with high-powered lasers.

The researchers are now working to tailor the AR to specific applications, apply the methodology to substrates beyond the fused silica glass used to make many of NIF’s optics, and increase the scale. Two inches is large in the world of optics, but quite small in comparison to those found in NIF.

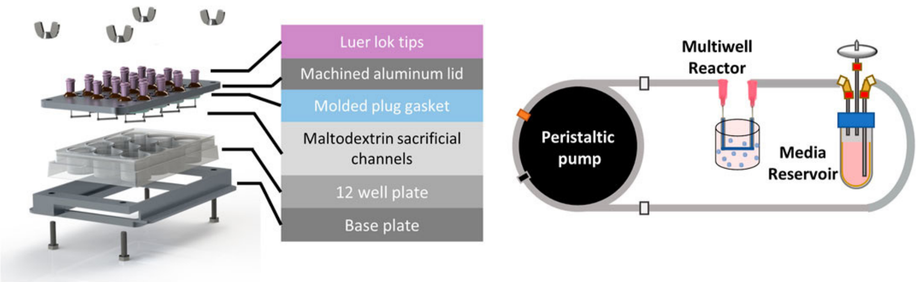
Platform tests colorectal cancer therapies in vitro

Colorectal cancer (CRC) — cancer of the colon or rectum — is the third-most common cancer in both men and women in the United States and the second-most common cause of cancer-related death in developed countries.

Although surgery is highly successful for patients with a localized disease or disease confined to a narrow region (stages I–III), a total of 60% of CRC patients are diagnosed with Stage IV liver metastasis (CRCLM), for which surgery is insufficient. While combination regimes of chemotherapeutic agents and targeted therapies benefit some patients, the five-year relative survival rate for metastatic CRC remains just 14%. Thus, there is an urgent need to develop additional therapies for CRCLM.

In fact, patient-derived organoids (PDOs) — sampled patient tissue — are emerging as reliable preclinical tools to develop and test therapies for metastatic CRC. PDOs have been shown to mimic drug response behavior of the tumor from which they are derived and retain genomic and some phenotypic characteristics of the original tumor. Therefore, PDOs can be used as models to understand patient-specific drug responses and investigate cancer cell growth.

However, because studying drug transport in tumors in vivo is complex, in vitro platforms are also needed to better understand tumor progression



An exploded view of the perfused multi-well bioreactor platform, designed to utilize a 12-well tissue culture plate for ease of handling and fabrication. Patient-derived organoids (sampled patient tissue) were prepared and placed into each well.

Principal Investigator: Elizabeth Wheeler

LDRD Project: 19-SI-003 Engineered and Instrumented Three-Dimensional Tumor-Immune Model System

and treatment resistance. In support of this need, Lawrence Livermore National Laboratory scientists and collaborators have developed a platform capable of studying CRCLM PDO response to various chemotherapeutic gradients. Their research is detailed in a recent Frontiers in Bioengineering and Biotechnology paper.

The team's perfused multi-well bioreactor platform was designed around a standard 12-well cell culture plate to minimize the number of custom parts and enable easy assembly. This layout provides 12 independently fed wells that can be used to study multiple drug concentrations or combinations in one experiment.

When testing this platform, the team investigated how tumor organoids respond to a common cancer drug treatment, 5-fluorouracil (5-FU), in varying environments. Patient-derived colorectal liver metastasis organoids were cultured in the multi-well bioreactor platform and organoid response was compared to organoids cultured in media and static hydrogel, which are two common PDO culture models routinely used for drug testing. Researchers ran computer simulations prior to testing to determine how the drug would be distributed in each platform.

The simulation verified that after seven days of exposure to 5-FU in the bioreactor, a concentration gradient formed, reaching a higher average concentration close to the channel (region 1) and a lower average concentration far from the channel (region 2). This gradient correlates to a lower viability in region 1 than region 2. The simulation results helped ensure the cumulative dose the organoids received for the duration of the experiment were comparable across platforms.

Despite the organoids in each condition receiving comparable cumulative doses of drugs, organoids cultured in media had a significantly lower viability, suggesting that cumulative dose alone does not explain differences in cell viability and that culturing PDOs in a 3D hydrogel influences drug response. Additionally, organoids in media were immediately exposed to 5-FU while the static gel and bioreactor were exposed slowly as the drug diffused through the hydrogel.

"Our results demonstrate the platform's ability to generate gradient conditions and test multiple drug concentrations on PDOs at once while also highlighting the importance of using transport simulations to properly assess culture environment and obtain accurate interpretations of drug response," said LLNL scientist Elisa Wasson. "Using our platform and transport modeling, flow parameters may be tuned to control these gradients and enable testing of a range of therapeutic agents and different dosing strategies."

Future studies could utilize the platform to investigate how other microenvironmental gradients such as oxygen or tumor promoting soluble factors influence PDO drug response. Additionally, tumor-immune interactions may be investigated by circulating immune cells through the channel and observing invasion into the surrounding PDOs loaded hydrogel.

Sterile neutrino research ramps up

An international collaboration of researchers from Lawrence Livermore National Laboratory (LLNL) and other scientific institutions is ramping up its studies into "sterile neutrinos" to discover and better understand dark matter.

Sterile neutrinos are theoretically predicted new particles that offer an intriguing possibility in the quest for understanding the dark matter in our universe.

Unlike the known "active" neutrinos in the Standard Model (SM) of particle physics, these sterile neutrinos do not interact with normal matter as they move through space, making them very difficult to detect.

Scientists from four countries, led by LLNL and the Colorado School of Mines, have demonstrated the power of using nuclear decay in high-rate quantum sensors in the search for sterile neutrinos. Their findings, initially made in 2021, are the first measurements of this kind.

Principal Investigator: Stephan Friedrich
LDRD Projects: 20-LW-006
A Search for Sterile Neutrino Dark Matter

An international collaboration of scientists from four countries is extending its studies into "sterile neutrinos" to discover and better understand dark matter. In early April, 25 physicists and material scientists from the collaboration – known as "BeEST," for Beryllium Electron-capture with Superconducting Tunnel junctions – met for two days at the University of California Livermore Collaboration Center. Two leaders of the collaboration are shown seated, Kyle Leach of the Colorado School of Mines (left) and Stephan Friedrich of LLNL. Photo by Randy Wong/LLNL

The primary aim of the team's research is to seek out one of the most promising candidates for dark matter, the strange unidentified material that permeates the universe and accounts for 85% of its total mass.

In early April, 25 physicists and material scientists from the collaboration — known as "BeEST," for Beryllium Electron-capture with Superconducting Tunnel junctions — met for two days at the University of California Livermore Collaboration Center.

Among those participating were researchers from LLNL, the Colorado School of Mines, Vancouver-based TRIUMF, Canada's particle accelerator center; the University of Strasbourg (France), the NOVA University of Lisbon (Portugal) and two companies — Santa Fe, N.M.-based STAR Cryoelectronics and Oakland-based XIA.

LLNL physicist Stephan Friedrich leads the LLNL portion of the sterile neutrino collaboration. Friedrich's team at LLNL includes physicists In Wook Kim and Geon-Bo Kim, who analyze experimental data, researchers Amit Samanta and Vince Lordi, who perform the material science simulations and Connor Bray, a physics graduate student from the Colorado School of Mines, who will do his thesis project on this experiment.

The team's LLNL experiment involves implanting radioactive beryllium-7 atoms into superconducting sensors developed at Livermore. When the beryllium-7 decays by electron capture into lithium-7 and a neutrino, the neutrino escapes from the sensor, but the recoil energy of the lithium-7 provides a measure of the neutrino mass. If a heavy sterile neutrino were to be generated in a fraction of the decays, the lithium-7 recoil energy would be reduced and produce a measurable signal, even though the elusive neutrino itself is not directly detected.

Friedrich describes the sterile neutrino search problem in this manner: how do you find something that doesn't emit light, doesn't absorb light and doesn't interact with material except through its mass? He likens the sterile neutrino search to firing a gun.

"If you know how much gun powder [or energy] you have and you can measure the recoil, then you can infer the properties of the bullet. The energy of the recoil is a measure of the energy and mass of the projectile," Friedrich said, "just like the energy of the lithium-7 recoil is a measure of the energy and the mass of the neutrino."

Friedrich helped develop a set of radiation detectors known as superconducting tunnel junctions (STJs) while he was a Ph.D. student at Yale University in the 1990s. These detectors consist of two metal films separated by a thin insulator, and they are cooled to ultra-low temperatures close to absolute zero, or -459 degrees Fahrenheit, so that they become superconducting and can act as high-precision detectors.

He initially developed the detectors for X-ray astronomy for NASA and later for experiments at Lawrence Berkeley's Advanced Light Source to understand how plants produce oxygen. In 2018, Friedrich met Kyle Leach, a nuclear physicist at the Colorado School of Mines, who suggested that the STJ detectors would be perfect for detecting sterile neutrinos.

The LLNL sterile neutrino research started in 2019 and received three-and-a-half years of Laboratory Directed Research and Development funding before bridging over to funding from the Department of Energy's Office of Nuclear Physics.

In their initial one-month experiment with a single STJ detector, the data excluded the existence of sterile neutrinos in the mass range of 100 to 850 kiloelectron volts down to a 0.01% level of mixing with the active neutrinos — better than all previous decay experiment in this range.

"Since that time, we've been working to make our experiments bigger and better and therefore more sensitive," Friedrich said.

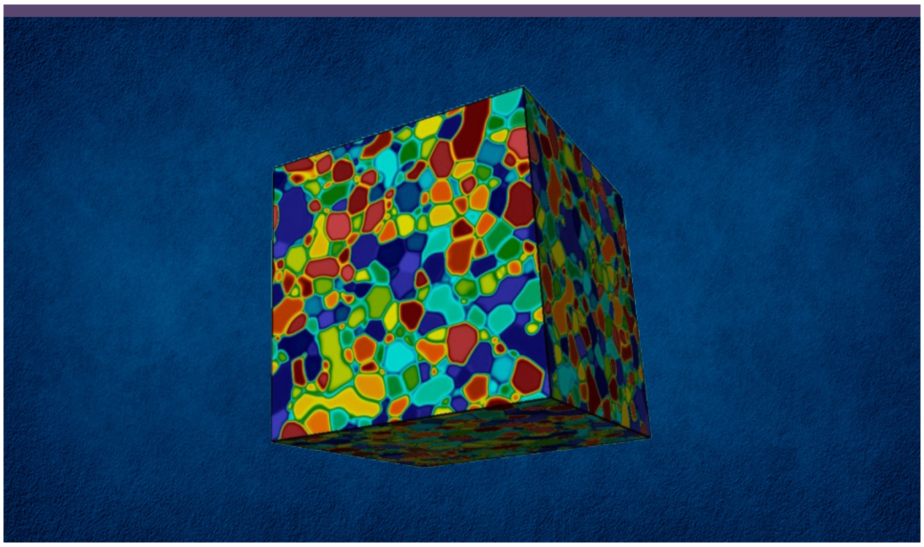
In their recent experiments, the team has run 20 sensors for two months with a higher dose of beryllium-7, taking some 160 terabytes of high-quality data that is now undergoing analysis, according to Friedrich. Future experiments are expected to run 100 sensors for three months and will be among the world's most sensitive searches for a suite of potential new "dark" particles.

Understanding material degradation in titanium alloys

Titanium (Ti) and its alloys are attractive for a wide variety of structural and functional applications due to the metal's excellent strength, toughness and stiffness, and corrosion resistance. Specific applications include lightweight structural materials, bioimplants, and energy storage materials. However, if exposed to hydrogen sources, these alloys are susceptible to hydrogen incorporation and hydride formation, leading to crack initiation and mechanical failure resulting from lattice deformation and stress accumulation. When it comes to understanding hydrogenation and hydride formation in Ti alloys, many unanswered questions and challenges remain.

Principal Investigator: Brandon Wood

LDRD Project: 20-SI-004 Predicting and Controlling Corrosion



Digital representation of a titanium oxide microstructure simulated using phase-fielding modeling.

In a recent perspective article, LLNL researchers and collaborators propose new ideas on how to solve these issues and close knowledge gaps by discussing and demonstrating specific opportunities for integrating advanced characterization and multiscale modeling to elucidate chemistry and composition, microstructure phenomena, and macroscale performance and testing. The team's paper draws on their own work, as well as a contextual review of existing literature studies focused on the integration of novel experimental and computational tools for a detailed mechanistic understanding. Their research aligns with an LLNL strategic initiative on corrosion science, supporting critical mission areas related to materials aging, degradation, energy, and climate security.

Overall, the team's research emphasizes that because combined theory–experiment approaches can uniquely and holistically investigate surface morphology, chemical composition, and hydrogen transport, future investments along these lines will be crucial. Such investments, if properly realized, can guide forthcoming strategies for slowing hydriding of Ti alloys in corrosion-resistant structural applications.

A rock hard technique to harvest atmospheric CO2

Carbonate minerals are formed when carbon dioxide reacts with magnesium and calcium-rich rocks. But where does that CO2 come from?

If it comes from the atmosphere, this process at sufficient scale may be able to reliably draw down atmospheric greenhouse gas levels, according to new research by Lawrence Livermore National Laboratory (LLNL) scientists. The research appears in the journal *Nuclear Instruments and Methods in Physics Research*.

Carbon mineralization — the formation of solid carbonate minerals from CO2— is one of the most stable methods for sequestering carbon. This process occurs naturally at the Earth's surface when magnesium (Mg)- and calcium (Ca) - enriched rock types, known as ultramafics, are exposed to CO2-rich water. After CO2 dissolves in water to form bicarbonate, it can react with the Mg or Ca ions released during rock weathering. Previous work has demonstrated that they actively draw down local carbon dioxide (CO2) concentrations.

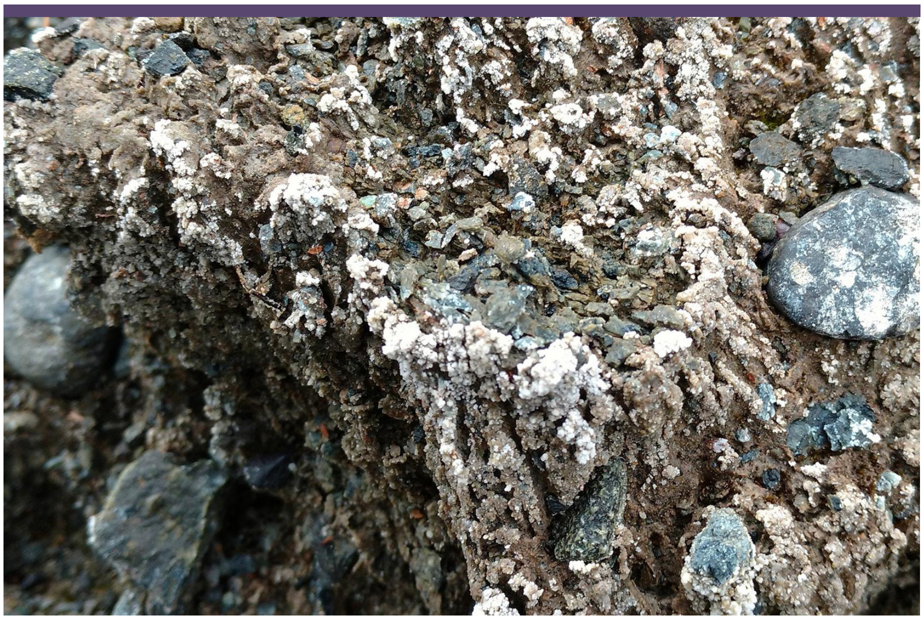
But there hasn't been a method for unambiguously attributing the sequestered carbon solid product to atmospheric sources until now. LLNL researchers used radiocarbon to verify that the carbon being incorporated into carbonate minerals during carbon mineralization is atmospheric in origin.

"We were able to identify some environments and locations where all the carbon in the carbonates almost certainly came from the atmosphere," said LLNL scientist Kari Finstad, lead author of the paper. "It proved what we suspected, that carbonate minerals passively forming in these ultramafic environments are naturally sequestering atmospheric CO2."

This passive reaction is well-documented at mine sites composed of processed ultramafic material. Previous work demonstrated that these mine and tailings wastes actively convert available CO2 to more stable solid carbonate materials, but future large-scale implementation of this

Principal Investigator: Kari Finstad

LDRD Project: 18-FS-024 Determining the Rate of Natural Carbonate Precipitation Using Bomb-Pulse Radiocarbon Dating



Visible white carbonate crusts growing on surface of soil at Swift Creek Landslide. White crusts were manually removed and collected to sample the crust. Material beneath the white crusts was collected as a bulk surface soil sample.

process to mitigate climate change will require a method to "fingerprint" both the nature and quantity of the CO2 source in the final material (e.g., "new" atmospheric versus geologically "old" and recycled carbon).

If only atmospheric CO2 is incorporated into a material (as opposed to CO2 derived from other geological, biological or anthropogenic processes), then the radiocarbon (carbon 14) content of the material should match that in the atmosphere at the time of formation.

"The radiocarbon content of carbonates may provide a unique tool for verifying the sequestration of atmospheric CO2 and determining the proportion of the carbon that is atmospheric in origin," Finstad said.

Charging up with carbon nanotubes

Lawrence Livermore National Laboratory (LLNL) scientists have created vertically aligned single-walled carbon nanotubes on metal foils that could be a boon for energy storage and the electronics industry.

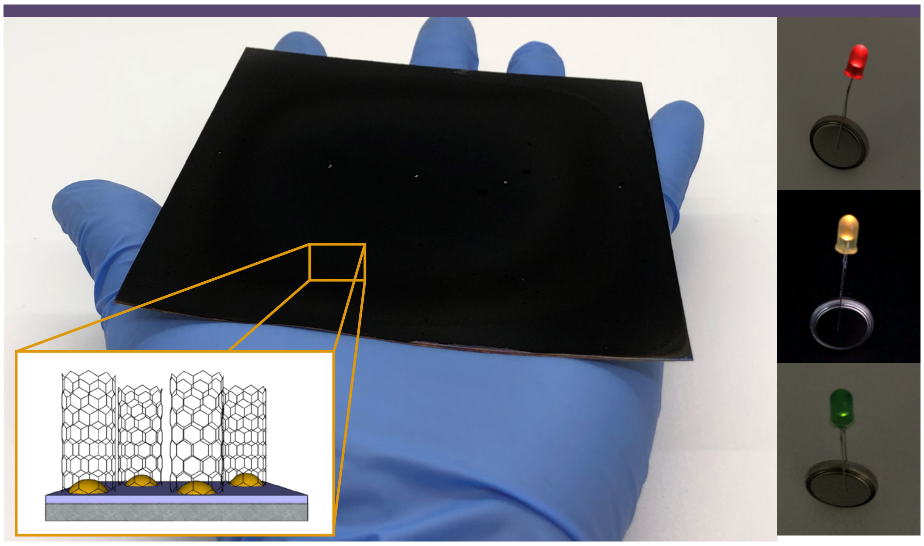
Vertically aligned carbon nanotubes (VACNTs) have exceptional mechanical, electrical and transport properties in addition to an aligned architecture, which is key for applications such as membrane separation, thermal management, fiber spinning, electronic interconnects and energy storage.

To date, widespread integration of VACNTs into next-generation technologies is thwarted by a lack of compatible, economic, mass-production capabilities. High-quality VACNTs are typically made on substrates such as silicon (Si) or quartz wafers that are rigid, expensive and electrically insulating.

After exploring metal foil options in scientific literature, the LLNL team turned to Inconel metal substrates allowing them to integrate VACNTs into

Principal Investigator: Kathleen Vanderburgh

LDRD Project: 21-LW-020 Overcoming Cycling Limitations for High-Energy-Density Lithium-Ion Batteries



Photograph and schematic representation (inset) of a scaled-up sample of vertically-aligned single-walled carbon nanotubes (VA-SWCNTs) grown on Inconel metal foil. Side pictures show half-cells based on VA-SWCNT anodes illuminating red, yellow and green LEDs.

flexible devices, eliminate a transfer step from Si to other substrates and minimize electrical or thermal transport resistances at the interface between CNTs and the substrate, which is critical for electronic and energy storage applications. Inconel is a family of nickel-chromium-based superalloys that are oxidation-corrosion-resistant materials well-suited for service in extreme environments subjected to pressure and heat.

"Transitioning growth of high-quality CNTs from traditional Si substrates to metal foils opens the door to more economical, large-scale, semicontinuous and roll-to-roll manufacturing of multifunctional CNT composites, nanoporous membranes and electrochemical devices," said LLNL scientist Francesco Fornasiero, co-author of a paper appearing in the journal *Applied Materials & Interfaces.*

Synthesis of high-quality single-walled CNTs (SWCNTs) on metal foils would be especially valuable for energy-storage devices, such as lithium-ion batteries (LIBs). While graphitic materials are common LIB anodes, their capacity falls short of rapidly evolving energy-storage needs.

"The high surface area and exceptional electronic conductivity of CNTs make them prime candidates for high-capacity, high-rate electrochemical applications," said LLNL scientist Kathleen Moyer-Vanderburgh, lead author of the paper. "In particular, VA-SWCNTs grown on metal foils could provide a binder-free platform with strong adhesion between the SWCNT and current collector, enhanced conductivity and aligned channels for rapid Li-ion diffusion."

The LLNL team grew forests of vertically aligned SWCNT on Inconel metal for use as a LIB anode. Team members found nearly invariant structural properties of the CNT forests over a wide range of synthesis conditions and for multiple metal substrates. Fabricated VA-SWCNT LIB anode displayed stable cycling for hundreds of cycles and large capacity even at high cycling rates.

"Our results suggest that these SWCNTs on Inconel metal are promising materials for high-performance electrochemical devices," said LLNL scientist Jianchao Ye.

Lawrence Livermore National Laboratory achieves fusion ignition

The U.S. Department of Energy (DOE) and DOE's National Nuclear Security Administration (NNSA) announced the achievement of fusion ignition at Lawrence Livermore National Laboratory (LLNL) — a major scientific breakthrough decades in the making that will pave the way for advancements in national defense and the future of clean power. On Dec. 5, 2022, a team at LLNL's National Ignition Facility (NIF) conducted the first controlled fusion experiment in history to reach this milestone, also known as scientific energy breakeven, meaning it produced more energy from fusion than the laser energy used to drive it. This first-of-its-kind feat will provide unprecedented capability to support NNSA's Stockpile Stewardship Program and will provide invaluable insights into the prospects of clean fusion energy, which would be a game-changer for efforts to achieve President Biden's goal of a net-zero carbon economy.

"This is a landmark achievement for the researchers and staff at the National Ignition Facility who have dedicated their careers to seeing fusion ignition become a reality, and this milestone will undoubtedly spark even more discovery," said U.S. Secretary of Energy Jennifer M. Granholm. "The Biden-Harris Administration is committed to supporting our world-class scientists — like the team at NIF — whose work will help us solve humanity's most complex and pressing problems, like providing clean power to combat climate change and maintaining a nuclear deterrent without nuclear testing."

"We have had a theoretical understanding of fusion for over a century, but the journey from knowing to doing can be long and arduous. Today's milestone shows what we can do with perseverance," said Dr. Arati Prabhakar, the President's chief adviser for Science and Technology and director of the White House Office of Science and Technology Policy.

"Monday, December 5, 2022, was a historic day in science thanks to the incredible people at Livermore Lab and the National Ignition Facility. In making this breakthrough, they have opened a new chapter in NNSA's Stockpile Stewardship Program," NNSA Administrator Jill Hruby said. "I would like to thank the members of Congress who have supported the National Ignition

"The pursuit of fusion ignition in the laboratory is one of the most significant scientific challenges ever tackled by humanity, and achieving it is a triumph of science, engineering, and most of all, people."

LLNL Director Dr. Kim Budil

Facility because their belief in the promise of visionary science has been critical for our mission. Our team from around the DOE national laboratories and our international partners have shown us the power of collaboration."

"The pursuit of fusion ignition in the laboratory is one of the most significant scientific challenges ever tackled by humanity, and achieving it is a triumph of science, engineering, and most of all, people," LLNL Director Dr. Kim Budil said. "Crossing this threshold is the vision that has driven 60 years of dedicated pursuit — a continual process of learning, building, expanding knowledge and capability, and then finding ways to overcome the new challenges that emerged. These are the problems that the U.S. national laboratories were created to solve."

"This astonishing scientific advance puts us on the precipice of a future no longer reliant on fossil fuels but instead powered by new clean fusion energy," U.S. Senate Majority Leader Charles Schumer (NY) said. "I commend Lawrence Livermore National Labs and its partners in our nation's Inertial Confinement Fusion (ICF) program, including the University of Rochester's Lab for Laser Energetics in New York, for achieving this breakthrough. Making this future clean energy world a reality will require our physicists, innovative workers and brightest minds at our DOE-funded institutions, including the Rochester Laser Lab, to double down on their cutting-edge work. That's why I'm also proud to announce today that I've helped to secure the highest-ever authorization of over $624 million this year in the National Defense Authorization Act for the ICF program to build on this amazing breakthrough."

"After more than a decade of scientific and technical innovation, I congratulate the team at Lawrence Livermore National Laboratory and the National Ignition Facility for their historic accomplishment," said U.S. Senator Dianne Feinstein (CA). "This is an exciting step in fusion and everyone at Lawrence Livermore and NIF should be proud of this milestone achievement."

This is an historic, innovative achievement that builds on the contributions of generations of Livermore scientists. Today, our nation stands on their collective shoulders. We still have a long way to go, but this is a critical step and I commend the U.S. Department of Energy and all who contributed toward this promising breakthrough, which could help fuel a brighter clean energy future for the United States and humanity," said U.S. Senator Jack Reed (RI), the chairman of the Senate Armed Services Committee.

"This monumental scientific breakthrough is a milestone for the future of clean energy," said U.S. Senator Alex Padilla (CA). "While there is more work ahead to harness the potential of fusion energy, I am proud that California scientists continue to lead the way in developing clean energy technologies. I congratulate the scientists at Lawrence Livermore National Laboratory for their dedication to a clean energy future, and I am committed to ensuring they have all of the tools and funding they need to continue this important work."

"This is a very big deal. We can celebrate another performance record by the National Ignition Facility. This latest achievement is particularly remarkable because NIF used a less spherically symmetrical target than in the August 2021 experiment," said U.S. Representative Zoe Lofgren (CA-19). "This significant advancement showcases the future possibilities for the commercialization of fusion energy. Congress and the Administration need to fully fund and properly implement the fusion research provisions in the recent CHIPS and Science Act and likely more. During World War II, we crafted the Manhattan Project for a timely result. The challenges facing the world today are even greater than at that time. We must double down and accelerate the research to explore new pathways for the clean, limitless energy that fusion promises."

LLNL's experiment surpassed the fusion threshold by delivering 2.05 megajoules (MJ) of energy to the target, resulting in 3.15 MJ of fusion energy output, demonstrating for the first time a most fundamental science basis for inertial fusion energy (IFE). Many advanced science and technology developments are still needed to achieve simple, affordable IFE to power homes and businesses, and DOE is currently restarting a broad-based, coordinated IFE program in the United States. Combined with private-sector investment, there is a lot of momentum to drive rapid progress toward fusion commercialization.

Fusion is the process by which two light nuclei combine to form a single heavier nucleus, releasing a large amount of energy. In the 1960s, a group of pioneering scientists at LLNL hypothesized that lasers could be used to induce fusion in a laboratory setting. Led by physicist John Nuckolls, who later served as LLNL director from 1988 to 1994, this revolutionary idea became inertial confinement fusion, kicking off more than 60 years of research and development in lasers, optics, diagnostics, target fabrication, computer modeling and simulation and experimental design.

To pursue this concept, LLNL built a series of increasingly powerful laser systems, leading to the creation of NIF, the world's largest and most energetic laser system. NIF — located at LLNL in Livermore, California — is the size of a sports stadium and uses powerful laser beams to create temperatures and pressures like those in the cores of stars and giant planets, and inside exploding nuclear weapons.

Achieving ignition was made possible by dedication from LLNL employees as well as countless collaborators at DOE's Los Alamos National Laboratory, Sandia National Laboratories and Nevada National Security Site; General Atomics; academic institutions, including the University of Rochester's Laboratory for Laser Energetics, the Massachusetts Institute of Technology, the University of California, Berkeley, and Princeton University; international partners, including the United Kingdom's Atomic Weapons Establishment and the French Alternative Energies and Atomic Energy Commission; and stakeholders at DOE and NNSA and in Congress.

Illuminating the science of black holes and gamma-ray bursts using high-power lasers

High-power lasers now create record-high numbers of electron-positron pairs, opening exciting opportunities to study extreme astrophysical processes, such as black holes and gamma-ray bursts.

Positrons, or "anti-electrons," are anti-particles with the same mass as an electron but with opposite charge. The generation of energetic electron-positron pairs is common in extreme astrophysical environments associated with the rapid collapse of stars and formation of black holes. These pairs eventually radiate their energy, producing extremely bright bursts of gamma rays. Gamma-ray bursts (GRBs) are the brightest electromagnetic events known to occur in the universe and can last from ten milliseconds to several minutes. The mechanism of how these GRBs are produced is still a mystery.

That's where high-power lasers come in. In the laboratory, jets of electron-positron pairs can be generated by shining intense laser light into a gold foil. The interaction produces high-energy radiation that traverses the material and creates electron-positron pairs as it interacts with the nuclei of the gold atoms along its path

An LLNL researcher and collaborator have reviewed how lasers can create energetic electron-positron pairs that are common in extreme astrophysical environments associated with the rapid collapse of stars and formation of black holes. Artist's conception of a black hole with material swirling around it in an accretion disk, and also a jet of matter blasting away from it." Credit: NASA/JPL-Caltech

Principal Investigator: Hui Chen

LDRD Project: 20-LW-021 Capturing a New State of Matter: Relativistic Electron-Positron Plasma

A new review of the current breakthroughs in the creation of electron-positron pair plasma, its main challenges and the future of the field, authored by Lawrence Livermore National Laboratory (LLNL) physicist Hui Chen and SLAC National Accelerator Laboratory scientist Frederico Fiuza, appears in Physics of Plasmas.

"The ability to produce relativistic pair plasmas in the laboratory provides a unique opportunity to advance our understanding of these exotic plasma regimes and to benchmark current theoretical models and numerical simulations of the roles these plasma processes play in astrophysical environments," Chen said.

Electron-positron pair plasmas are abundant in high-energy astrophysical systems, such as those associated with neutron star and black hole environments. The interactions of photons with each other and with strong magnetic fields lead to prolific pair creation via electromagnetic cascades. These pair plasmas are typically hot and can be accelerated to high speeds in the winds or jets associated with these compact astrophysical objects, including pulsar magnetospheres, jets from active galactic nuclei and GRBs.

Using ever more energetic lasers, Lawrence Livermore researchers in 2015 produced a record high number of electron-positron pairs, breaking a prior record from previous experiments at LLNL's Titan laser in 2008, when Chen's team had created billions of positrons.

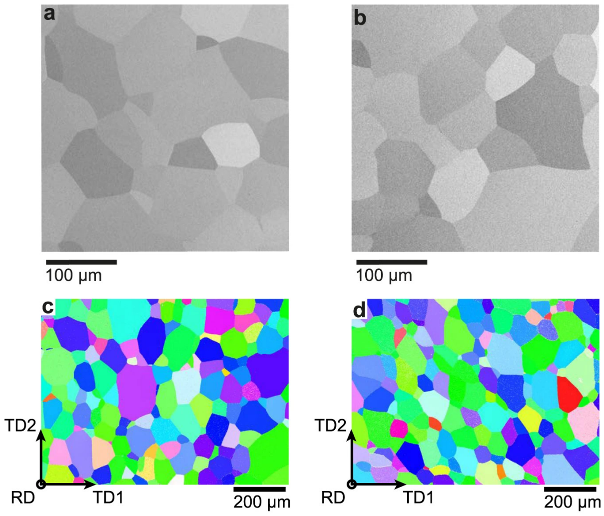
In the past decade, extraordinary discoveries associated with extreme astrophysical plasmas have excited scientists and the public alike — from the first images of the plasma orbiting a black hole to the high-energy cosmic rays and radiation produced by relativistic jets and gamma-ray bursts to fast radio bursts from galactic neutron stars. It has long been long been known that the plasmas at the cores of these extreme environments are relativistic and often electron-positron-pair-dominated.

LLNL physicist probes causes of life-shortening "dwell fatigue" in titanium

"Dwell fatigue" is a phenomenon that can occur in titanium alloys when held under stress, such as a jet engine's fan disc during takeoff. This peculiar failure mode can initiate microscopic cracks that drastically reduce a component's lifetime.

The most widely used titanium alloy, Ti-6Al-4V, was not believed to exhibit dwell fatigue before the 2017 Air France Flight 066 incident, in which an Airbus en route from Paris to Los Angeles suffered fan disc failure over Greenland that forced an emergency landing. The analysis of that incident and several more recent concerns prompted the Federal Aviation Administration and European Union Aviation Safety Agency to coordinate work across the aerospace industry to determine the root causes of dwell fatigue.

According to experts, metals deform predominantly via dislocation slip — the movement of line defects in the underlying crystal lattice. Researchers hold that dwell fatigue can initiate when slip is restricted to narrow bands instead of occurring more homogenously in three dimensions. The presence of nanometer-scale intermetallic Ti3Al precipitates promotes band formation, particularly when processing conditions allow for their long-range ordering.



In a recent study by a multi-national team, including current and former Lawrence Livermore National Laboratory scientists, researchers used synchrotron X-rays to track discrete slip avalanche events in titanium held under load at room temperature to examine causes of "dwell fatigue" in titanium alloys.

Principal Investigator: Joel Bernier

LDRD Project: 20-ERD-044 Uncertainty Quantification and Experimental Design Using a Quantitative Forward Model for Kinematic X-Ray Diffraction

Things get dicey when this banding behavior occurs across a contiguous group of 'soft'-oriented grains, termed a "macrozone," researchers explained. The resultant deformation concentration, where the band meets a "hard"-oriented grain outside the macrozone, leads to a stress concentration, initiating the cracking process. Further complicating things, dislocation slip occurs intermittently in bursts or "avalanches," similar to how small fault slippage events can initiate more significant earthquakes. The magnitude and frequency of these slip avalanches strongly influence the initiation of dwell fatigue.

In a recent study by a multi-national team, including current and former Lawrence Livermore National Laboratory (LLNL) scientists, researchers used synchrotron X-rays to track discrete slip avalanche events in titanium held under load at room temperature. A team from Imperial College London provided specimens of specially prepared Ti–7Al, an alloy representing a surrogate for the primary phase in Ti-6Al-4V. The populations of two-point defect types were modulated across the specimens: interstitial oxygen content and the amount of ordered Ti3Al precipitates.

The study, published in *Nature Communications*, shows that where the Ti3Al exhibits ordering, slip avalanches are more severe in associated stress magnitude. In contrast, increasing the amount of interstitial oxygen appears to reduce the severity, promoting more frequent smaller avalanches.

"This work offers a novel, mesoscale view of the intermittent deformation events (little "bursts" of plastic slip) underpinning dwell fatigue, specifically how the frequency and magnitude of those events depend on oxygen content and alloying," said co-author and LLNL physicist Joel Bernier. "These data can help guide processing to avoid microstructures that have a deleterious effect on resistance to dwell fatigue."

Bernier helped execute high-energy X-ray diffraction microscopy measurements at the Cornell High Energy Synchrotron Source (CHESS) and performed the data reduction using the LLNL-developed HEXRD software library. The team quantified the frequency and magnitude of stress bursts resulting from slip avalanches and found that both types of point defects had pronounced effects on slip occurring on the crystal lattice's basal planes.

Researchers discovered that this deformation mechanism becomes easier to activate after the initial yielding, a softening known to be a precursor to damage accumulation and failure in instances of dwell fatigue. Among the key findings: higher concentration of oxygen interstitials reduced the average magnitude of the basal slip avalanches by promoting more frequent lower-magnitude events.

In contrast, expanding the size of ordered Ti2Al precipitates, by aging the material at an elevated temperature, increased both the frequency and the magnitude of slip avalanches, increasing the probability of crack initiation. According to the team, these findings can help optimize the processing of titanium alloys for resistance to dwell fatigue.

Lab researchers study Rift Valley fever virus: Immune responses could be supported by drugs to help people recover from brain infections caused by Rift Valley fever virus

Research by Lawrence Livermore National Laboratory (LLNL) scientists suggests that immune responses could be bolstered by drugs to help people recover from brain infections caused by an emerging pathogen. The emerging pathogen studied by the team, known as Rift Valley fever virus (RVFV), is a disease that, to date, has been limited to outbreaks in Africa and the Arabian Peninsula.

But, as LLNL biologist and team leader Dina Weilhammer points out, "The reason we're concerned about it is because, like the West Nile virus, the Rift Valley fever virus also could spread to North America from Africa."

A paper about the team's research has been published in the Public Library of Science (PLOS) Pathogens, a San Francisco-based online journal.

"Fundamentally, we were trying to understand how the immune response in the brain controls infections with Rift Valley fever virus. It's a mosquito-borne disease that can infect many types of livestock and people," Weilhammer said.

RVFV is a highly pathogenic virus capable of causing hepatitis, encephalitis, blindness, hemorrhagic syndrome and death in humans and livestock. It is most commonly seen in domesticated animals, such as cattle, buffalo, sheep, goats and camels. Upon aerosol infection with RVFV, there is an increased incidence of viral replication and tissue damage in the brain.

RVFV is classified as a category A biodefense pathogen by the National Institute of Allergy and Infectious Diseases due to its potential to be aerosolized as a bioterrorist agent. The disease was first reported among livestock in the Rift Valley of Kenya in the early 1900s; the virus was first isolated in 1931.

LLNL researchers, from left to right, Nicholas Hum, Feliza Bourguet, and Dina Weilhammer perform molecular characterization research for the brain's response to a Rift Valley fever virus infection. Photo by Garry McLeod.

Principal Investigator: Dina Weilhammer

LDRD Project: 17-LW-038 Investigating the Role of Innate Immunity in Viral Encephalitis Caused by Rift Valley Fever Virus

When the virus is contracted by mosquito bite, it usually produces flu-like symptoms and liver inflammation but rarely brain infection in humans. When the virus is released as an aerosol, brain infection occurs at a much higher incidence.

"Data from animal handlers who have usually been involved in butchering and who have been exposed to animals infected with RVFV, along with a handful of laboratory exposures, show a higher incidence of brain infections from aerosol exposure to the virus," Weilhammer said

Mouse models have confirmed that what happens with the RVFV in humans also occurs in mice. Mice injected with the virus had, like humans, a low frequency of brain infections, while those exposed by aerosol had a higher incidence of brain infections.

In their research with mouse models, the team found that the RVFV infects a special immune cell called microglia that exists only in the brains of people and mammals.

"We were surprised by the robust response of the microglia to the RVFV," Weilhammer said. "When the microglia are infected by the RVFV, these cells produced a robust type I interferon response, which is a first-line defense against viruses."

The LLNL scientists are the first researchers to discover the strong response of the microglia to a RVFV infection and also are the first researchers to find that when the brain is attacked by a RVFV infection, the body recruits natural killer cells to assist the microglia in fighting the infection.

"What we're thinking is: is there a way to help the natural killer cell response or the microglia with drugs be even better at controlling infections?" Weilhammer asked. "Our research suggests that there are immune responses that could be manipulated therapeutically to help people recover from brain infections.

Graphite changes to hexagonal diamond in picoseconds

The graphite-diamond phase transition is of particular interest for fundamental reasons and a wide range of applications.

On very fast compression time scales, material kinetics hinder the transition from graphite to the equilibrium cubic diamond crystal structure that we commonly know as diamond. Shock wave compression of graphite typically requires pressures above 50 GPa (500,000 atmospheres) to observe the phase transition on the time scale of shock compression experiments. Further, the hexagonal polytype of diamond called Lonsdaleite has been observed in shock compressed material subsequent to meteorite impact events, suggesting that the time scale of compression plays a strong role in the phase transition.

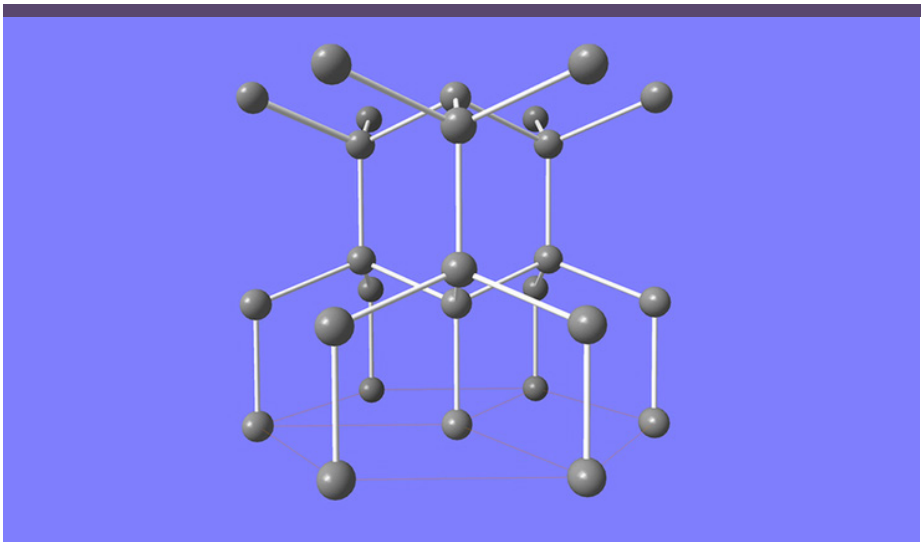
In new experiments, Lawrence Livermore National Laboratory (LLNL) scientists have emulated the conditions of Lonsdaleite formation using picosecond time scale laser compression and observed the transition with state-of -the-art material characterization using femtosecond X-ray pulses.

The observation of Lonsdaleite subsequent to shock compression has been a persistent mystery, including debate over whether hexagonal diamond exists as an extended structure, or is cubic diamond with defects. Previous studies of the phase transition of graphite to diamond or Lonsdaleite under moderate shock compression support a diffusionless mechanism for the phase transition, but these studies did not observe atomic structure through the transition, so the transformation mechanism was not revealed.

"Lonsdaleite is formed under rapid compression – unique to shock compression," said LLNL scientist Mike Armstrong, lead-author of a paper appearing in a special Shock Behavior of Materials issue of the *Journal*

Principal Investigator: Jon Belof

LDRD Project: 16-ERD-037 Ultrafast Shock Kinetics of High-Atomic-Number Materials with High Throughput



The hexagonal polytype of diamond called Lonsdaleite has been observed in shock compressed material after meteorite impact *of Applied Physics*. "There has been speculation for decades about the mechanisms and intermediate states of this phase transition and why it only forms under rapid compression. Here we show that the Lonsdaleite structure is likely an intermediate state in the phase transition to cubic diamond."

In the experiments, the team used the unique capability of the Matter in Extreme Conditions instrument on the Linac Coherent Light Source to explore the phase transition behavior of carbon subsequent to a picosecond scale compression shock rise followed by ~100 ps of sustained compression. Ultrafast compression experiments have been used to investigate previously unknown states of matter under extreme elastic compression, sub-100 ps diffusionless phase transitions and strain rate dependent shock induced chemistry, but the response of graphite to ultrafast compression has not previously been investigated on picosecond time scales.

"These experiments are analogous to early time domain experiments to identify the transition state in physical chemistry," Armstrong said. "Due to the very short observation time scale, this experiment has the capability to observe short-lived phase transition intermediates, analogous to the transition state in chemical reactions."

Team members saw a phase transition where the product phase is strongly correlated to the initial phase. They observed highly textured, nearly single crystal product within 20 ps after compression.

"This confirms early speculation that this phase transition is diffusionless, and that Lonsdaleite may be an intermediate, even in the transformation to the equilibrium final state, cubic diamond," said LLNL scientist Harry Radousky, a co-author of the study. "This experiment addresses decades of speculation about the nature of this phase transition, which has been the subject of considerable theoretical work."

The experiments achieved the time and length scales of state-of-the-art simulations, which are normally extrapolated to compare with longer time scale experiments.

Scientific Leadership and Service

LDRD projects are distinguished by their mission-driven creativity. LDRD-funded research often launches stellar careers, initiates strategic collaborations, produces game-changing technical capabilities, and even lays the foundation for entirely new fields of science. It is no surprise that every year, LDRD principal investigators from LLNL are recognized for the groundbreaking results of a project or long-term contributions to their fields. The following examples highlight recognition received during fiscal year 2022, attesting to the exceptional talents of these researchers and underscoring the vitality of Livermore's LDRD program.

FELLOWS

The Association for Computing Machinery (ACM) named Lawrence Livermore National Laboratory's Chief Technology Officer for Livermore Computing Bronis R. de Supinski (right) as a 2022 ACM fellow, recognizing him for his contributions to the design of large-scale systems and their programming systems and software.

LLNL's Bronis R. de Supinski named 2022 ACM fellow

The Association for Computing Machinery (ACM) has named Lawrence Livermore National Laboratory's

Chief Technology Officer for Livermore Computing (LC) Bronis R. de Supinski as a 2022 ACM fellow, recognizing him for his contributions to the design of large-scale systems and their programming systems and software.

The prestigious ACM fellows program honors the top 1% of ACM members for their outstanding accomplishments in computing and information technology and/or outstanding service to the organization and the larger computing community. Fellows are nominated by their peers, with nominations reviewed by a distinguished selection committee, according to ACM.

"I am pleased to be elevated to an ACM fellow," de Supinski said. "This honor validates that LLNL's LC and its Center for Applied Scientific Computing (CASC) perform world-leading computer science. Throughout my career, I have had the pleasure not only of standing on the shoulders of giants but also of working shoulder-to-shoulder with many outstanding computer scientists and computational scientists — many of whom still work at LLNL, while some now work (or always have) at other institutions. LLNL has provided me the opportunity to pursue interesting work of importance to the nation. I hope others will see this distinction as motivation to consider similar career choices."

As CTO of LC, de Supinski is responsible for formulating and overseeing implementation of LLNL's large-scale computing strategy, requiring managing multiple collaborations with the HPC industry and academia. He has led several research projects in CASC. He also has co-led the Advanced Simulation and Computing program's Application Development Environment and Performance Team (ADEPT), which is responsible for the development environment, including compilers, tools and runtime systems on LLNL's large-scale systems. He is the chair of the OpenMP Language Committee.

FELLOWS

LLNL's Chandrika Kamath honored as 2023 SIAM fellow

The Society for Industrial and Applied Mathematics has selected Chandrika Kamath as a member of the SIAM Fellows Class of 2023.

The Society for Industrial and Applied Mathematics (SIAM), the world's premier professional organization for applied mathematicians and computational scientists, has selected Lawrence Livermore National Laboratory research staff member Chandrika Kamath as a member of the SIAM fellows class of 2023.

The prestigious fellow designation is a lifetime honorific title and honors SIAM members who have made outstanding contributions to fields served by the organization. Fellows are nominated by SIAM members and chosen annually by a 16-member selection committee.

"When I changed my field from parallel numerical algorithms to scientific data mining over 25 years ago, I wasn't sure how it would turn out; I have since worked on many interesting and challenging problems," Kamath said. "Finding solutions and learning multiple disciplines in the process has been its own reward. Being selected a SIAM fellow is icing on the cake. I am honored, and grateful to all those who supported me along the way."

Kamath has worked at LLNL since 1997, where she specializes in analyzing data from scientific simulations, experiments and observations. An expert in data mining, Kamath also has led projects analyzing uncertainty in additive manufacturing, improving large-scale data exploration and analysis, integrating wind energy on the power grid and on intelligent reduction of data from exascale simulations. Her expertise includes image and video processing, feature extraction, dimension reduction, pattern recognition, high performance computing and machine learning. Kamath's current focus is on techniques for sampling and surrogate modeling, especially for small data sets in high dimensions.

"I am thrilled to have Chandrika honored in this way for her stellar career" said Bruce Hendrickson, LLNL's associate director for Computing. "She has been a pioneer and leader in embracing data science for scientific and engineering applications."

At LLNL, Kamath served as project lead and contributor for Sapphire, a project to develop scalable algorithms for the interactive exploration of large, complex multi-dimensional scientific data. The Sapphire team won an R&D 100 award in 2006.

Kamath is among the top 2% of the most cited researchers worldwide throughout their careers, according to Stanford University. She holds six patents in data mining and organized various data mining workshops and conferences, including the SIAM Conference on Data Mining, where she served as the chair of the conference's steering committee from 2007-2014. Her book, "Scientific Data Mining: A Practical Perspective," was published by SIAM in 2009. She also is one of the three founding editors-in-chief of the Wiley journal, Statistical Analysis and Data Mining, where she focused on the practical applications of data analysis techniques.

Prior to joining LLNL, Kamath was a consulting software engineer at Digital Equipment Corporation, developing high-performance mathematical software. She holds a Ph.D. and master's degree in computer science from the University of Illinois at Urbana-Champaign and earned her bachelor's degree in electrical engineering from the Indian Institute of Technology in Bombay.

SIAM, the world's largest scientific society devoted to applied mathematics, comprises more than 14,000 computational mathematicians, computer scientists, numerical analysts, engineers, statisticians, physicists, educators and students from more than 100 countries.

The goals of the fellows program are to honor SIAM members recognized by their peers as distinguished for their contributions to the discipline, to help make outstanding SIAM members more competitive for awards and honors and support the advancement of SIAM members to leadership positions in their own institutions and in the broader society, according to the organization's website.

OTHER AWARDS

Physicist Otto "Nino" Landen receives prestigious Edward Teller Award

Otto "Nino" Landen, a distinguished member of the technical staff and the inertial confinement fusion (ICF) experiments group leader at Lawrence Livermore National Laboratory (LLNL), has been awarded the 2023 Edward Teller Medal.

The Fusion Energy Division of the American Nuclear Society (ANS) presented the award to Landen this week during the International Conference on Inertial Fusion Sciences and Applications 2023 (IFSA) held in Denver, Colorado. Landen was honored for his "pioneering contributions to ICF and high energy density science (HEDS) and for (his) leadership in achieving ignition on the National Ignition Facility (NIF)."

"I have benefited over the years from the freedom to explore and develop new techniques at LLNL's state-of-the-art ICF and HEDS instrumentation, target fabrication capability, and high-power laser facilities," Landen said. "I'm indebted to the dedicated teams I have worked with and especially grateful for their patience and persistence to get past disappointments and for their enthusiasm in following up on successes. I am truly honored to receive this recognition."

Landen's contributions to the scientific community have been widely recognized. He was elected a fellow of the American Physical Society in 2002 in recognition of his pioneering work in the fields of picosecond laser-plasma interactions, advanced diagnostics, X-ray-driven ICF implosions and time-dependent hohlraum symmetry control. In 2022, Landen was part of an LLNL burning plasma team that was awarded the John Dawson Award for Excellence in Plasma Physics Research.

OTHER AWARDS

Two LLNL scientists named Optica Senior Members

Lawrence Livermore National Laboratory (LLNL) scientists David Gibson and Paul Pax have been named senior members of Optica (formerly OSA). Senior membership status recognizes members with more than 10 years of professional experience in optics or an optics-related field.

Gibson, a staff scientist in the National Ignition Facility and Photon Science (NIF&PS) Directorate, is working on directed-energy research projects such as diagnostics development and analysis for the diode-pumped alkali laser efforts. Recently, he supported an upgrade to NIF's Advanced Radiographic Capability for improving the pulse contrast and studies of multi-pulse damage thresholds for NIF optics for potential future diagnostics.

"It's a great honor to be recognized by Optica and I appreciate the support for my nomination," Gibson said. "Sometimes it's hard to tell how broad of an impact you are having, so this is very gratifying. In my career at LLNL, I've had the opportunity to work on so many important, challenging projects."

Pax, a staff scientist in the Computational Engineering Division, has worked on many projects in NIF&PS over his 18 years at LLNL. He is leading optical modeling for the design of a new high-gain amplifier for NIF, a critical component of NIF sustainment. Most recently, he led the construction and deployment of a front-end system for a high-energy laser project.

"I'm honored to have been nominated to the 2023 class of Optica senior members," he said. "It's gratifying to be recognized by the Lab and Optica society. The Lab's an amazing place, there's so much going on here — so much opportunity to learn!"

OTHER AWARDS

Terri Quinn named among “2023 People to Watch” by *HPCWire*

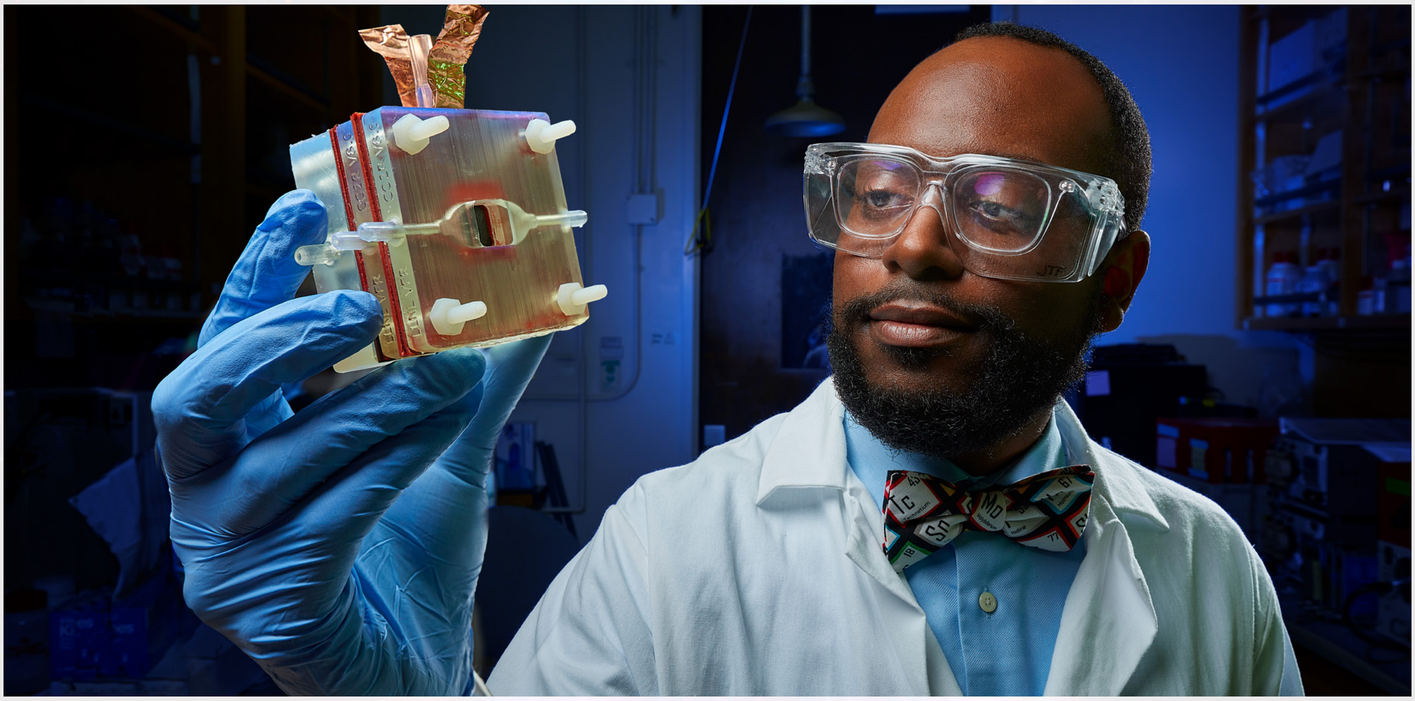
The publication *HPCwire* announced Lawrence Livermore National Laboratory’s Deputy Associate Director for High Performance Computing (HPC) Terri Quinn has been named among its “People to Watch” for 2023.

Celebrating its 21st year, the annual *HPCwire* program recognizes HPC professionals who play leading roles in driving innovation within their chosen fields and make significant contributions to society in general. To date, the publication has recognized 200 people in HPC for their achievements, including luminaries from leadership HPC centers, technology companies and community-led projects.

“I am delighted to be recognized by *HPCwire*,” Quinn said. “I feel the recognition has as much to do with the stature of Livermore Computing as the opportunity I’ve had to contribute. I was nudged into HPC early in my career, expecting to move on in a few years. But once I got involved, I was hooked and didn’t want to leave. I was fortunate to get that first nudge.”

In her role as Livermore’s deputy AD of HPC, Quinn establishes long-range directions and priorities for the Lab’s Computing Directorate and for the Multiprogrammatic and Institutional Computing program, which provides cost-effective computing services to LLNL programs and scientists. Quinn also is associate program director for Livermore Computing (LC) for the Weapons Simulation and Computing program, where among other responsibilities, she is helping Chief Technology Officer for LC Bronis de Supinski prepare for the exascale-class supercomputer El Capitan. El Capitan is scheduled for delivery at LLNL later in 2023.

Jeremy Feaster named to American Institute for Chemical Engineering's "35 Under 35"



Lawrence Livermore National Laboratory staff scientist Jeremy Feaster has been named as one of the American Institute for Chemical Engineering's (AIChE) "35 Under 35" award winners for 2023. The recognition honors chemical engineers under the age of 35 who have made outstanding contributions to their field and to the chemical engineering community, according to the organization.

"This award means a lot to me and to my family, friends and community," Feaster said. "From the beginning, I've wanted to use chemistry to help communities and solve problems. Seeing how chemical engineering can be used to serve people inspired me to pursue it as a degree and a career, and my heart for using chemistry and service to help communities has only grown. I hope that through this award, I can continue to inspire more students – especially from underserved communities – to want to learn more about chemistry and chemical engineering, not just for the science, but for building a sustainable and compassionate society."

Feaster's research at LLNL focuses on designing and creating 3D-printed electrochemical reactors that convert air into fertilizer and carbon dioxide into valuable products such as plastics or fuels, to help address climate change and sustainability concerns. He also serves as co-chair for LLNL's African American Body of Laboratory Employees.

Feaster earned his master's degree and Ph.D. in chemical engineering from Stanford University after completing his bachelor's degree in chemical and biomolecular engineering at Georgia Tech.

OTHER AWARDS

DOE honors two early-career Lab scientists

Two scientists from Lawrence Livermore National Laboratory (LLNL) are recipients of the Department of Energy's (DOE) Office of Science Early Career Research Program award.

Daniel Casey and Gauthier Deblonde are among 93 awardees receiving the recognition. Under the program, typical awards for DOE national laboratory staff are $500,000 per year for five years

"Supporting America's scientists and researchers early in their careers will ensure the United States remains at the forefront of scientific discovery," said U.S. Secretary of Energy Jennifer M. Granholm. "The funding announced today gives the recipients the resources to find the answers to some of the most complex questions as they establish themselves as experts in their fields."

The Early Career Research Program, now in its 14th year, is designed to bolster the nation's scientific workforce by providing support to exceptional researchers during crucial early-career years, when many scientists do their most formative work.

Casey, a physicist, was chosen for his work in fusion energy sciences. Chemist Deblonde was selected for his work in basic energy sciences.

DANIEL CASEY

Casey is a physicist who works in the National Ignition Facility (NIF) and Photon Science Directorate and serves as the low mode working group lead for the Inertial Confinement Fusion (ICF) program. His work focuses on diagnosing and assessing the impact of asymmetries in ICF implosions.

"I am so honored and humbled to be recognized for the DOE Early Career award by the DOE Office of Science/Fusion Energy Sciences," he said. "I have been so fortunate to work with so many great and talented colleagues at LLNL over the years. That we have been selected for this award is a recognition of how our many capabilities can contribute to the growing promise of fusion energy. It's really a reflection of the importance and the impact of the work that we do here at NIF and LLNL to be selected for this funding award. I am particularly excited because this award also is a recognition of the potential impact our research can have on inertial fusion energy."

GAUTHIER DEBLONDE

As a staff scientist in the Nuclear and Chemical Sciences Division and the Physical and Life Sciences Directorate, Deblonde's work focuses on developing new techniques to decipher the chemistry of radioactive elements.

"I'm elated and honored to join the small group of scientists who have been awarded a DOE Early Career award," he said. "This is extremely competitive because applicants are national laboratory scientists and university professors from many disciplines (physics, chemistry, biology, computing, etc.) and, in the 14 years of existence of the award, I am the first LLNL employee to get it in the category 'Basic Energy Sciences,' so the news felt even better. It is not just my success but also that of the colleagues and collaborators who helped me build a consistent and competitive research portfolio."

OTHER AWARDS

LLNL experimental physicist Alex Zylstra awarded 2023 Fabre Prize

Alex Zylstra is honored with the Edouard Fabre prize for his exceptional contributions to the physics of laser-driven inertial confinement fusion (ICF) and laser-produced plasmas. Photo by Brandi Caskey.

Lawrence Livermore National Laboratory (LLNL) physicist Alex Zylstra has been awarded the 2023 Edouard Fabre Prize for his experimental leadership of the milestone "Hybrid-E" campaign that achieved fusion ignition at the National Ignition Facility (NIF).

The inertial confinement fusion (ICF) campaign used increased laser energy to compress deuterium and tritium (DT) fuel, resulting in the first laboratory demonstrations of a burning plasma, ignition and target gain greater than one.

Named for one of the founders of ICF in Europe, the Edouard Fabre Prize is awarded to active, mid-career researchers within 15 years of their doctoral degree. Zylstra was recognized for his "exceptional contributions to the physics of laser-driven ICF and laser-produced plasmas."

"It's been a remarkable opportunity for me to be at LLNL and have access to tremendous resources to pursue this groundbreaking work at NIF," Zylstra said. "It's been a unique privilege to be part of research that pushes the boundaries of what's possible in the field of fusion research."

Zylstra and his team led improvements in recent years in the scientific design and required technologies to enable increased performance of NIF experiments through the burning plasma and ignition regimes.

The Hybrid-E ICF implosion design increased hohlraum energy efficiency and used larger radii capsules to enhance the energy coupled to the DT fuel inside the capsule. The campaign used cross-beam energy transfer to control the implosion symmetry by operating NIF's 192 laser beams at slightly different wavelengths. It also used an experimentally based model of "low-mode" asymmetry that describes how an implosion responds to hohlraum, capsule, and laser design parameters.

Those advances culminated with LLNL's achievement of fusion ignition for the first time on Dec. 5, 2022, at NIF.

"While it's been a team effort, much of the success can be attributed to Alex's deep understanding of the physics principles, common-sense judgement, and his tenacity of sticking with it amidst challenges," said Omar Hurricane, chief scientist of the LLNL ICF program.

In addition to the Hybrid-E success, Zylstra has done considerable technical work in the areas of ICF and high energy density (HED) physics, including nuclear astrophysics, charged-particle transport and the development of other novel inertial fusion designs. He also has led hot-spot and ignition metrics analysis of NIF experiments.

"Being recognized by the ICF community holds special significance, as the fusion ignition achievement at NIF is a culmination of decades of work within this community," Zylstra said. "It underscores the importance of collaborative efforts and the progress we've together made to advance the frontiers of ICF and HED physics science."

OTHER AWARDS

Four Lab postdocs selected to attend the 72nd annual Lindau Nobel Laureate meeting

Wonjin Choi, Sarah Sandholtz, Sinja Huang, and Sean Leonard were selected to attend the 72nd annual Lindau Nobel Laureate meeting in Germany.

Four Lawrence Livermore National Laboratory (LLNL) postdoctoral appointees were selected to attend the 72nd annual Lindau Nobel Laureate meeting in Germany thanks to the University of California President's 2023 Lindau Nobel Laureate Meetings Fellows Program. The four selected to attend are Wonjin Choi, Sean Leonard, Sijia Huang and Sarah Sandholtz.

The Lindau Nobel Laureate meeting is an international scientific forum that provides an opportunity for about 600 students and postdocs from around the world to meet with 30 to 40 Nobel laureates. The meeting will foster an exchange among scientists of different generations, cultures and disciplines.

Image: Artist interpretation of the moment of fusion ignition at the National Ignition Facility, Lawrence Livermore National Laboratory. Credit: Jacob Long.

NNSA National Nuclear Security Administration

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