Lawrence Livermore National Laboratory

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About the Cover

After a radiological or nuclear incident, first responders' ability to accurately detect and respond to radioactive contamination would save many lives. Two groups in Livermore's Global Security Principal Directorate are working on different yet complementary approaches to more efficiently and expertly locate and characterize radioactive materials in the field. The first project aims to implement realism in training exercises for first responders by making operational instruments act as they would with true radiation sources. The second is designed to enhance the effectiveness of searches for radioactive materials in urban areas. An advanced software tool enables search teams to find a stationary source or to declare an area free of potential threats with a quantitative estimate of confidence.

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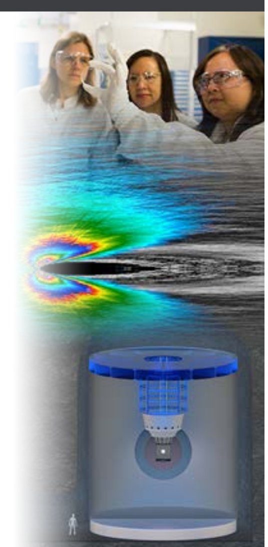

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New Research Explores Asteroid Deflection

An asteroid colliding with Earth could have devastating consequences, but with enough warning time and if the asteroid is not too large, the best strategy for avoiding such a catastrophe would be to deflect the asteroid's path. According to a 2010 report by the National Research Council, the best deflection method would be to intercept the asteroid with high-speed spacecraft before it reaches Earth. Researchers at Lawrence Livermore have been studying the effectiveness of this strategy, called kinetic impact, through three-dimensional simulations of the impact process.

In a paper published in the January 14, 2016, online edition of the journal *Icarus*, Livermore's planetary defense researchers show that the effectiveness of asteroid deflection by kinetic impact depends on various asteroid characteristics, including material strength, porosity, rotation, and shape. By simulating an array of initial conditions for an asteroid of constant size, researchers quantified how asteroid characteristics affect the success of kinetic impact deflection.

"Asteroids are naturally diverse, and researchers have little direct information about their mechanical properties," says Livermore researcher Megan Syal, lead author on the paper. "This study emphasizes the important role of asteroid characterization research, which is needed to constrain the different types of conditions that could be encountered at potential deflection targets." This work, which includes contributions from Livermore co-authors Mike Owen and Paul Miller and other team members, has provided new information for designing future kinetic-impact missions.

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Analytical Chemists Cover Nuclear Forensics

Livermore analytical chemists Mike Kristo and Ruth Kips, in collaboration with researchers from the Australian Nuclear Science and Technology Organisation, wrote an overview that describes how nuclear forensics supports law enforcement and national security investigations. The article, which was featured on the cover of the February 2, 2016, issue of *Analytical Chemistry*, includes examples of how investigators use multiple types of scientific analysis to capture a material's key forensic signatures.

"This work shows how a material's 'signatures'—characteristics such as isotopic abundances, elemental concentrations, physical and chemical forms, and physical dimensions—can be used to link a radioactive material to individuals, locations, or processes," says Kristo. Their article highlights a pair of cases in which the capture of highly enriched uranium specimens by law enforcement officials in two countries and the subsequent analysis of the material by scientists established a link between the cases. The team's research also showed that while the samples may well have a similar origin, they were probably not created at the same time.

The International Atomic Energy Agency maintains the Incident and Trafficking Database (ITDB) to record incidents of nuclear and other radioactive material outside of regulatory control. According to the ITDB, between 1993 and 2013, 16 confirmed incidents involved the unauthorized possession of highly enriched uranium or plutonium. The authors note that because no single nuclear forensics signature exists to identify all unknown nuclear materials, information needs to be gathered through multiple analytical techniques.

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Carbon-14 Measurements Reveal Natural Production Rate

Livermore researchers have measured the carbon-14 (^{14}C) isotope produced by cosmic rays in the stratosphere and found its production rate is lower than most previous estimates. The team, led by Kristie Boering of the University of California at Berkeley, measured the ^{14}C content of carbon dioxide collected by high-altitude balloon flights in 2003, 2004, and 2005, and estimated the contemporary production of ^{14}C in the stratosphere from cosmic rays. The research appears in the February 29, 2016, issue of the journal *Geophysical Research Letters*.

Atmospheric testing of nuclear weapons in the 1950s and 1960s injected massive amounts of ^{14}C into the stratosphere, which hid the natural production of the isotope. Since weapons-generated ^{14}C has mostly dissipated from the atmosphere, the team's measurements indicate that natural ^{14}C production is lower than most previous estimates. Livermore scientist Philip Cameron-Smith, a co-author on the paper, says, "We confirmed our analysis by using IMPACT—an atmospheric chemistry-transport model—to simulate ^{14}C on Livermore's supercomputers."

According to Cameron-Smith, "This work will improve our understanding of the carbon cycle on Earth, including how to distinguish the effects of natural processes from fossil-fuel burning and how quickly atmospheric carbon flows in and out of the biosphere, water, and soil." The lead author of the paper was Lawrence Scholar Amadu Kanu, and additional authors include Livermore's Tom Guilderson and Dan Bergmann as well as researchers from the University of California at Berkeley, the University of Miami, and the National Center for Atmospheric Research.

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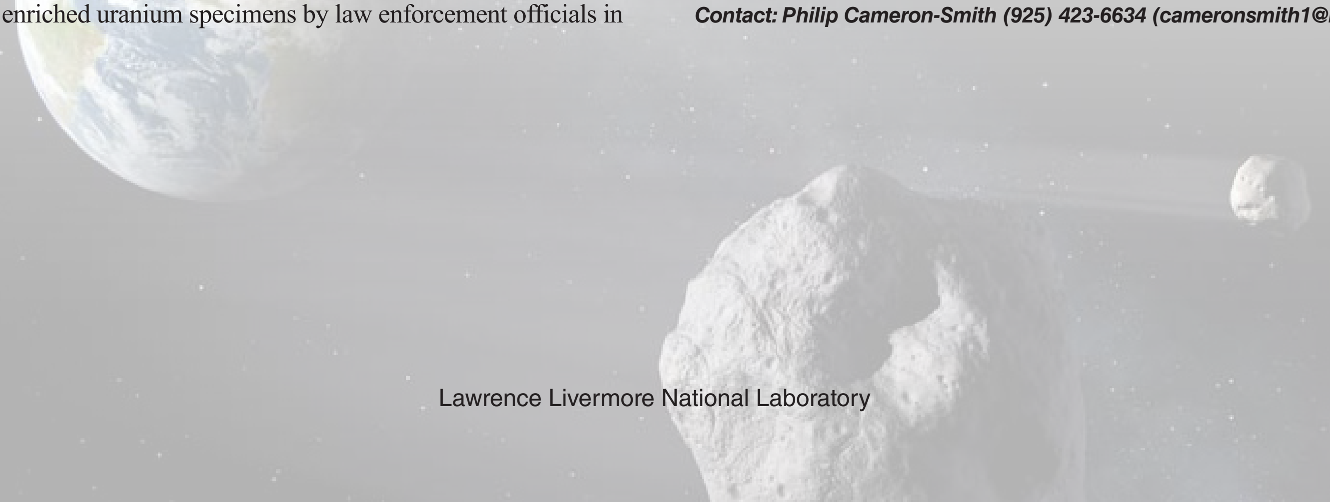


Commentary by Brad Wallin

Science and Technology in Support of Nuclear Nonproliferation

As the availability of nuclear technologies, materials, and know-how continues to spread, nuclear proliferation challenges grow and evolve. In response, Lawrence Livermore scientists and engineers work closely with federal, state, and local agencies to develop technical solutions that can help prevent, monitor, and mitigate proliferation activities. Our efforts include supporting nonproliferation treaties, understanding the threat, advancing radiation detectors and nuclear forensics techniques, locating stolen or hidden nuclear material, and training first responders in case of a nuclear emergency.

The article beginning on p. 4 describes two innovative Livermore approaches to improve radiation detection in support of nuclear nonproliferation. The first is a device called the Spectroscopic Injection Pulser (SIP), which markedly improves radiation detector training for first responders. The second, the Optimization Planning Tool for Urban Search (OPTUS), helps search teams scouring an urban area for nuclear material to cover the area more efficiently.

As explained in the article, SIP is designed to make first-responder training more realistic for conducting searches of localized or dispersed radioactive material. Traditional training on radiation detectors has used relatively harmless—but hardly realistic—isotopes serving as surrogates for uranium, plutonium, and other radiation sources. The Livermore SIP team had a better idea: eliminate the need for surrogates by mimicking the exact signals detectors would receive if these hazardous isotopes were actually present.

While SIP aims to improve emergency preparedness, OPTUS is designed to support field operations. Given time and resource constraints, OPTUS calculates the most efficient route to sweep an area for a hidden nuclear device or other radiation source and gives drivers carrying vehicle-borne detectors turn-by-turn instructions. Livermore experts have played important roles preparing for major national events that could attract terrorists bent on detonating a nuclear device. As an example, in preparation for the 2016 Super Bowl, our experts helped to sweep areas close to Levi's Stadium in Santa Clara, California.

Our influence in the area of nuclear nonproliferation extends globally. In January, ministers and other senior delegates from 37 nations and international organizations gathered at Lawrence Livermore to discuss effective responses to a hypothetical threat involving terrorists and stolen nuclear material. Called Apex Gold, the two-day meeting was the first-ever minister-level gathering to identify potential actions in the event of a nuclear crisis.

Livermore radiological expertise has also been critical to response and recovery activities. Following the 2011 Japanese earthquake and tsunami that resulted in damage to the Fukushima Dai-ichi Nuclear Power Plant complex, several Laboratory capabilities proved essential. Livermore's National Atmospheric Release Advisory Center (NARAC), which provides real-time assessments of dispersion and deposition of radioactive and other toxic materials, was operational for 24 hours a day for several weeks (see *S&TR*, January/February 2012, pp. 12–18). Lawrence Livermore led and performed thousands of analyses of physical samples and data returned by the field teams, which included people from our Radiological Assistance Program.

Since the 1960s, Livermore scientists have supported U.S. efforts and those of other nations to verify disarmament activities. For example, Livermore experts provided technical support for the 2015 negotiation with Iran to significantly diminish its capability to enrich uranium. We have also long provided support to nonproliferation treaties. Livermore staff participated in the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization's (CTBTO's) Integrated Field Exercise, which took place in Jordan in 2014. This exercise tested current on-site inspection capabilities to detect a possible underground nuclear test explosion within a 1,000-square-kilometer area. The exercise involved more than 200 participants, including seven Laboratory scientists, as well as multiple Livermore detection technologies. One such technology was the Smart Sampler system—a device that collects possible subsurface noble gas emissions indicative of a nuclear test (see *S&TR*, June 2015, pp. 12–15).

In addition to our contributions in radiation detection, Livermore advances in seismology also drive nonproliferation progress. The breakthrough seismic monitoring technology called the Regional Seismic Travel Time (RSTT) model and computing code improves the accuracy of locating seismic events caused by an underground nuclear test by incorporating a three-dimensional model of Earth's crust and upper mantle and regional data (see *S&TR*, June 2015, pp. 4–11). RSTT has been deployed to international partners through the CTBTO agency.

We are well aware that our job to advance nonproliferation will never be done as long as nuclear threats from both nation states and terrorist groups remain. Until then, the Laboratory will continue to innovate technologies and provide capabilities in support of this international effort.

■ Brad Wallin is manager of the Nuclear Threat Reduction Program within the Global Security Principal Directorate.

SEEKING OUT HIDDEN RADIOACTIVE MATERIALS

New technology and improved training help first responders to better locate and characterize radioactive materials in the field.

THE specter of terrorists setting off a homemade device containing radiological or special nuclear materials in a densely populated urban area is a harrowing prospect. In such a scenario, finding the device before it explodes would prevent a catastrophe. But should the worst occur, the ability of first responders to accurately locate and effectively identify radioactive contamination would save many lives.

Two groups in Livermore's Global Security Principal Directorate are working on different yet complementary approaches to more efficiently and expertly locate and characterize radioactive materials. The first project, supported through internal Laboratory funding, aims to make training exercises vastly more realistic for first responders who would be called upon in the aftermath of a radiological or nuclear incident. The second, funded by the National Nuclear Security Administration (NNSA), is designed to enhance the effectiveness of searches for radioactive materials in urban areas.

Creating a Realistic Situation

Steven Kreek, leader of Livermore's Nuclear Detection and Countermeasures Research and Development Program, is heading the effort to dramatically improve radiation-detection training. The challenging goal is to provide realistic radiation signals for high-hazard sources that first responders may encounter in an actual incident without such sources being present. Training exercises do not generally use high-hazard radiation sources for reasons of cost, logistics, safety, and security. As a result, training scenarios that would involve highly radioactive radionuclides, such as a post-explosion contamination zone with varying concentrations and compositions of these materials, are unfeasible to construct and execute.

"An important role of government is to ensure we have emergency responders adequately trained to deal with true radiation hazards, such as high-intensity sources that are present either through accidents or acts of terrorism," says Kreek. "Current training and exercises for first responders are inadequate and artificial because trainees cannot practice with their own equipment and exercise with sources of health concern."

Current training with high-hazard sources requires an on-site health physicist federal license and security guards to ensure the source is controlled. Development team leader and computer scientist Greg White says, "Training is not effective if the hidden source is inevitably located close to the person wearing a yellow vest who is trying to act casual."

Alternatively, pinhead-sized point sources can be used, but these materials do not represent real threats because of their nonhazardous strength and inability to be widely distributed in a mock contamination zone. Kreek says, "We need to train responders to find both high-hazard point sources and to work in extensively contaminated areas."

In an effort to enhance realism, some training managers have turned to virtual reality. "Virtual exercises can only go so far," says Kreek. "They don't allow operators to train with actual instruments or fully experience the environments first responders are most likely to face."

Kreek's team has been working to make possible far more realistic training without radioactive sources using a Livermore-developed instrument called the Spectroscopic Injection Pulser (SIP). The early prototype device, a 10-square-centimeter black box with a small liquid crystal display, attaches to a radiation detector's exterior.

SIP injects preprogrammed high-fidelity signals for any isotope or mixtures of isotopes at a given location into the detector's amplifier. "To the detector and the trainee, the signals appear to be generated by a true source," says White. SIP mimics in detail not only the preselected source's spectral shape but also the statistical randomness of radioactive signals and the variation of signal strength with distance.

Depending on the goals for a particular exercise, instructors decide on what and how many radiation sources are included as well as their respective strengths, distribution, and global positioning system (GPS) locations. The SIP then generates the radiation spectra and associated signal strength for any location within the training exercise area. Based on their location, trainees see the same count rate, spectrum, and dose rate on their instruments as they would if the point source or distributed sources (within a contamination zone) were actually present. Trainees can also see background radiation rates that are common to a given area. After training, the SIP is simply detached from the detector, returning the instrument to normal function.

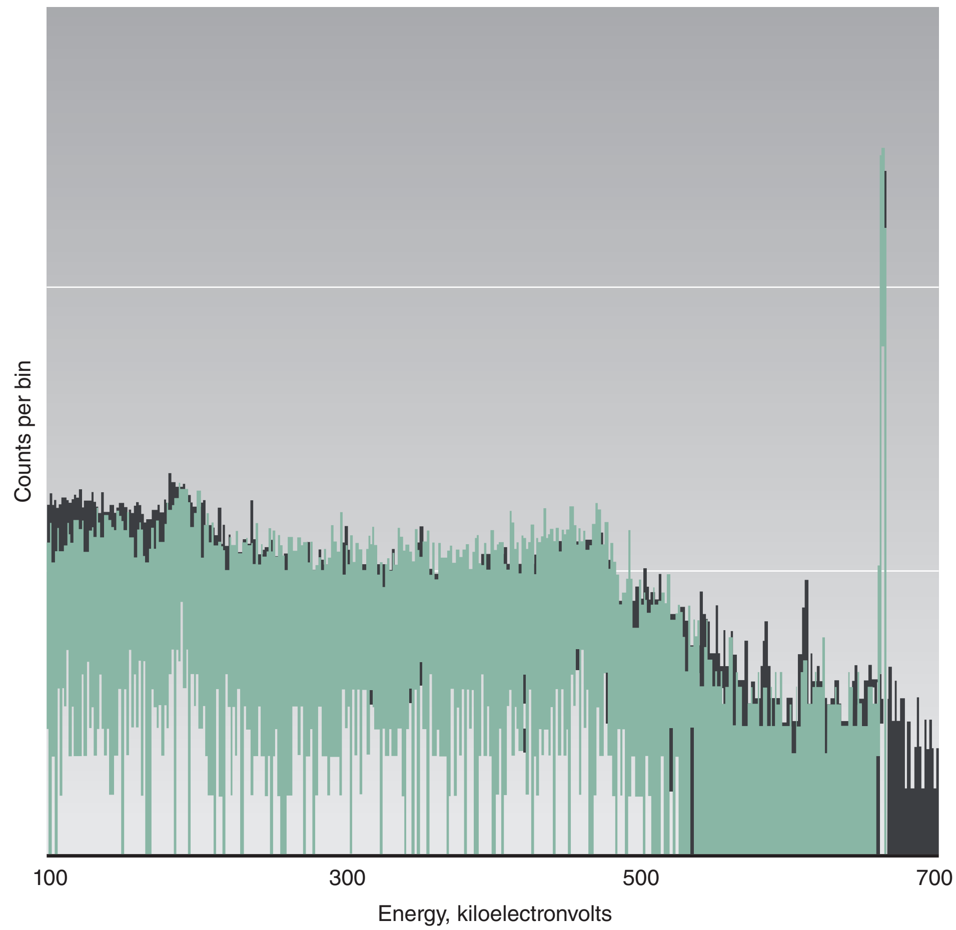
Training exercises, such as the one shown here wherein unsuited Livermore scientists monitor suited first responders, cannot include high-hazard radiation sources. Livermore researchers are developing the Spectroscopic Injection Pulser (SIP) to make radiation-detection training more realistic.

Technology Evolution

The SIP concept was first proposed by Livermore physicist S. John Luke as part of a nonproliferation project. Luke conceived of a device that mimics the pulses generated by a high-purity germanium detector as a way of gaining confidence in laboratory results. The original device was a laboratory instrument plugged into a wall outlet and tied to a desktop computer. Over several years, each generation of prototypes became significantly less expensive and smaller than its predecessor. Kreek and the development team recognized the pulser technology's potential as a training tool if it could be combined with modern capabilities found in a mobile phone, including GPS.

"We reasoned that if we could base the radiation signal on a trainee's location, the unit could keep track of that person's location and generate the appropriate signal," explains Kreek. "The unit generates weaker or stronger responses depending on the person's distance to the virtual source." The unit would also take into account short-lived isotopes—examining an area immediately after a simulated spill of medical isotopes would yield much different detector readings one day later. In addition, a command mode for the exercise leaders would indicate the location of sources or an entire contamination zone, track trainees' locations and responses, and monitor the synthetic count rate, dose rate, and spectra of trainees' instruments. These data would improve exercise execution and inform future detection exercises and response scenarios.

The current development effort is focused on embedding GPS, wireless, and field-programmable gate arrays into a battery-powered, credit-card-size Raspberry Pi computer. The team plans to have a prototype capable of injecting GPS location-dependent signals into a detector and to perform a demonstration by October 2016. The long-term goal is for a similarly miniaturized device to include a variety of network options, share signals across the network, and seamlessly operate with multiple detector types.



Actual (black) and SIP-generated (green) spectra for cesium-137 are essentially indistinguishable.

Tablet Showcases Capabilities

To demonstrate SIP's potential, Livermore researchers in 2012 developed software for a tablet computer that approximated a miniaturized SIP device attached to two different detector types. Coming soon to iOS and Android, the tablet showed how multiple instruments could work in unison in a realistic scenario, including a personal radiation dosimeter that sounds an alarm when a strong source is close by and sophisticated units that reveal the spectra of radioactive isotopes. The team has conducted demonstrations of the technology emulating both synthesized point sources and distributed contamination for representatives from U.S. federal agencies, as well as the International Atomic Energy Agency and the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), both in Vienna, Austria.

People using the tablet saw their location on a GPS map and watched the count rate and spectral information change as they moved closer to or farther away from the virtual sources. Simultaneously, the SIP's wireless communication capabilities permitted instructors to observe trainees' movements, provide guidance, and communicate information to a command center. Instructors could also visualize the extent of the virtual contamination area, something the trainees can only experience from their instrument readings. The SIP's simulated signals currently match those generated by an ORTEC Detective high-resolution gamma-ray detector. In fact, the SIP development team can easily simulate the signals of various instruments. The team is currently seeking to interface the technology with instrument manufacturers through partnership opportunities.

Kreek points out that the Laboratory has a long history of solving radiation detection challenges. For example, the ORTEC Detective has licensed technology from Livermore and is used around the world to identify and quantify radiation sources. The device, which features Livermore's electromechanical cooling system and easy-to-use analysis interface, was used in CTBTO's Integrated

Field Exercise 2014 in Jordan. Kreek was one of several Laboratory scientists and engineers who took part in the exercise. (See *S&TR,* June 2015, pp. 12–15.)

The group has been working with Livermore's Industrial Partnerships Office to encourage manufacturers of radiation detectors to produce equipment that can easily interface with SIP. One company has already modified its instruments to accommodate the technology, and others are considering doing the same. White is leading efforts to port the tablet application from Windows to iPad and Android tablets to demonstrate SIP capabilities on a wider range of platforms—an effort that incorporates work being done by students from the University of the Pacific and Washington State University.

"The SIP technology dramatically improves responder preparedness against the most realistic scenarios," says Kreek. His goal is to have a wide range of civilian and military first-response teams routinely use SIPs in training within a few years, as instrument producers plan upgrades to existing devices and new equipment makes its way into the first-response community. Kreek has demonstrated the technology to representatives from the Departments of Energy (DOE), Defense (DOD), and Homeland Security (DHS); U.S. Coast Guard; U.S. Customs and Border Protection; and to the International Atomic Energy Agency and CTBTO.

The capabilities of the SIP technology are easily expandable to accommodate improvements. For example, a neutron-detection component would be useful to some inspectors. What's more, with appropriate engineering, the SIP concept could work with any scientific instrument that measures physical quantities, such as detectors for chemical and biological weapons, high explosives, and even seismic signals (such as for CTBTO exercises).

Optimizing Searches

Richard Wheeler, Livermore's associate program leader for systems analysis and studies, leads a multilaboratory project to develop, demonstrate, and transition the Optimization Planning Tool for Urban Search (OPTUS) to routine operations. The OPTUS software program is designed to help search teams cover an urban area (up to several square kilometers) more efficiently, given a limited amount of search time. The goal is to either find a stationary radioactive source or declare the area free of potential threat sources with a quantitative estimate of confidence.

By exploiting knowledge of the urban area under investigation, estimates of background radiation, potential threat source materials and locations, and available human and technological resources, OPTUS calculates optimum search vehicle routes. In addition, for high-interest locations that are

SIP mimics radiation sources using the first responders' location and by injecting high-fidelity signals of any isotope or mixtures of isotopes into the amplifiers of their radiation detectors.

searched by pedestrian teams, OPTUS can compute optimal "dwell" times at positions around the location to maximize the probability of detection given the total search time and the area.

Given the same search assets and search time, OPTUS increases the probability of clearing an area compared to conventional methods. Alternatively, an OPTUS plan can be as effective as a conventional search method but takes much less time. The software tool is intended for use on a laptop computer by teams from the NNSA, DHS, local and state law-enforcement agencies, and potentially by teams for international search operations.

Searches Often Necessary

Law enforcement and homeland security agencies typically need to ensure that an area is clear of radiological or nuclear threats prior to special events. Such searches are conducted when credible reason exists that a device could be planted in a given area or as part of a general sweep in advance of a special event that represents a potential target. For example, sweeps are routinely conducted for major sporting events, parades, political speeches, or a presidential inauguration. Personnel from DOE (including a team from Lawrence Livermore) and the Federal Bureau of Investigation are available to support these sweeps.

Wheeler notes that urban searches for radioactive materials often result in inefficient use of the limited number of trained personnel and vehicle-mounted and human-portable detectors available. Search teams typically divide an area and do their best to search their assigned portion under severe time constraints. The teams are left with uncertain confidence about the effectiveness of their searches. "We needed to be able to optimize a search quickly, without a large computational effort, so we turned to developing smart algorithms that calculate how to best route multiple vehicles in a limited amount of time," says Wheeler. The team focused on developing a family of computationally efficient algorithms that optimize search assets within time restrictions. OPTUS can, for example, direct a vehicle to make multiple passes by a suspicious address to increase confidence that a radioactive source is not present.

OPTUS uses a detailed description of the physical characteristics of the urban search environment. Map data are read into OPTUS along with historical background radiation readings. The software assembles a model of the search area to define potential source and detector locations. This model includes the road network; metadata associated with individual road segments, such as road class or number of lanes; turn restrictions at intersections; building locations and footprint; and other urban features.

The software assumes the radioactive source is stationary and can be located anywhere in the outside search area. For example, a source can be in a parked car on the street. OPTUS shows how to most efficiently search the prescribed area, given the number of available vehicles with radiation detectors and pedestrians equipped with handheld detectors. For vehicle-based searches, the software

Livermore's tablet prototype illustrates how multiple detectors would work in unison during a realistic training scenario using SIP. (left) A Google Earth map of the United Nations building in Vienna, Austria, shows two radioactive sources (red dots) of virtual cobalt-60 and cesium-137 and a person (yellow dot) operating two detection instruments. The gamma-radiation detector shows the synthetic spectra (upper right) of cobalt-60, while the personal radiation dosimeter readings (bottom right) indicate the person is close to the source.

calculates turn-by-turn instructions that users upload to a navigation device such as a cell phone or laptop computer equipped with GPS.

OPTUS also provides a confidence level as to how effectively the search effort clears the designated area. A "coverage estimator" is computed and the results displayed by color-coding each possible source location corresponding to the confidence the source is not there. Initially, this calculation will be done in advance of the search to explore optimal performance under various conditions and assumptions. During an actual search, OPTUS can estimate at any time the degree of clearing that has been achieved up to that point. The color-coded "heat map" would be updated to allow personnel to see the extent of the cleared area as the search proceeds. The result is a search conducted in as little as half the usual time, or a more thorough search (hence greater confidence) in the same amount of time.

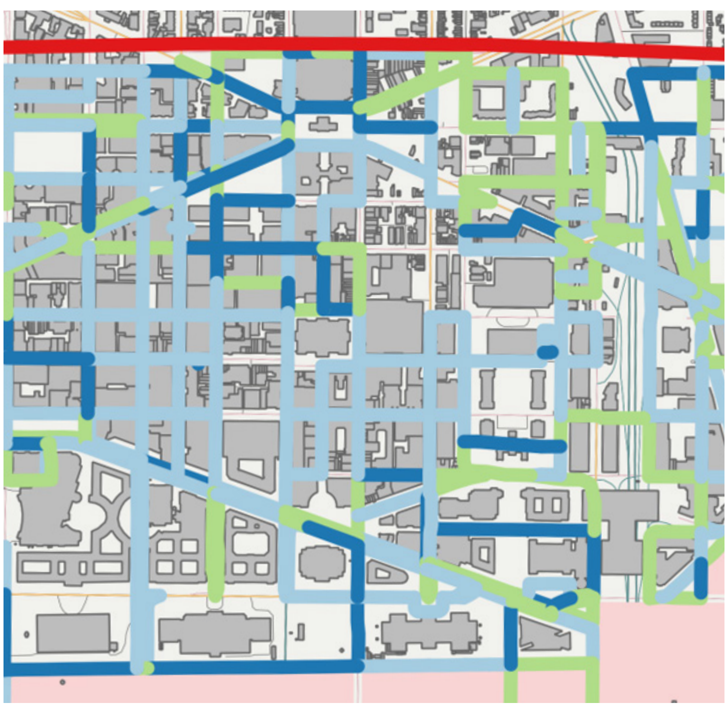
Two Different Searches

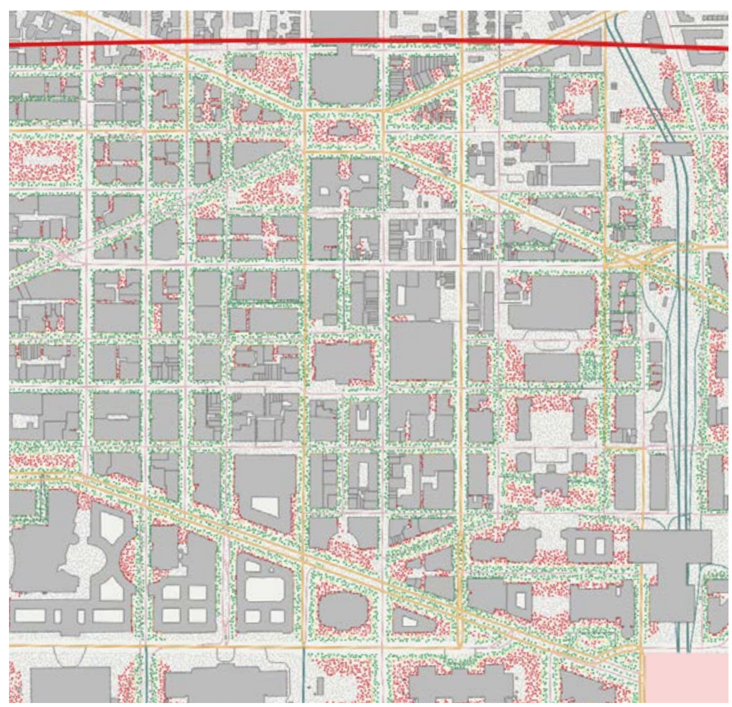
When complete, OPTUS will calculate optimal plans for both wide-area exterior searches and those for high-interest locations. The first is done with vehicle-mounted detectors whose movement is constrained by the road network. Dan Faissol, operations research expert and principal Livermore OPTUS researcher, notes, "The vehicles must perform the search while following the flow of traffic, so OPTUS optimizes both the number of times to traverse each road segment as well as the driving route to achieve those traversals. For example, a good route may revisit the hardest-to-clear road segments multiple times while avoiding time-consuming left- and U-turns."

The second search approach involves a closer pass of high-interest locations by an individual carrying a detector on foot or in an all-terrain vehicle. A high-interest location could be a place frequented by individuals of interest, a possible hiding spot for a weapon, or a good place to detonate a device so that it causes significant damage or casualties.

Complicating urban search efforts are common building materials such as concrete, granite, and brick that contain naturally occurring, long-lived radioactive isotopes. As a result, the background radiation of the search area needs to be taken into account to estimate the performance of the detection algorithms. Possible approaches to estimating background radiation include taking baseline readings in advance by driving through the area, using data collected

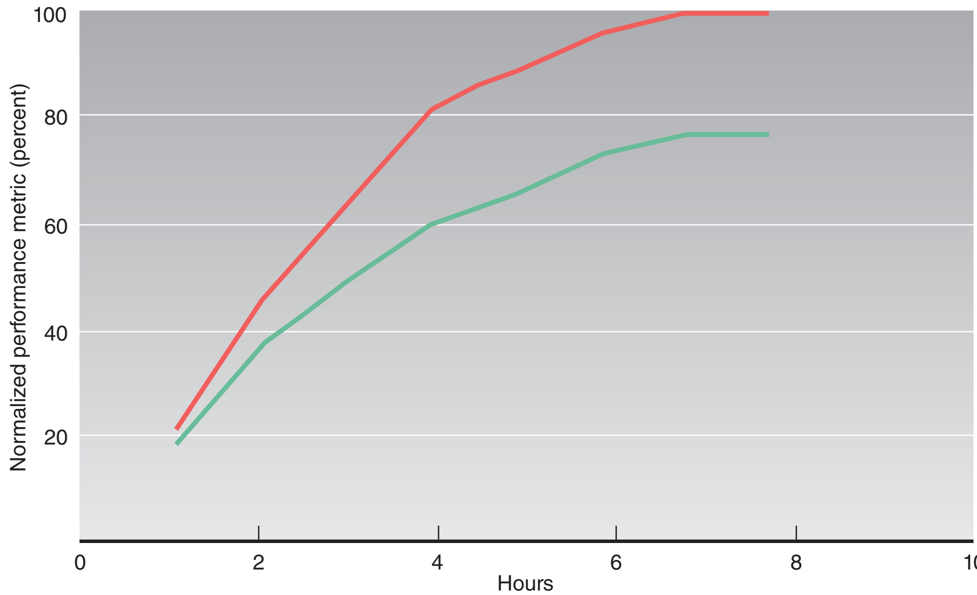
The Optimization Planning Tool for Urban Search (OPTUS) helps search teams sweep a selected urban area more efficiently in a limited amount of time. (left) OPTUS-optimized driving routes indicate the areas that will be passed one (green), two (light blue), or three (dark blue) times. (right) When a search is complete, OPTUS provides an estimate of the search effectiveness. In this hypothetical example, green areas are considered cleared while red areas are not.





from previous searches, or using physics models together with building construction information gathered from city databases.

Each assigned detector location has an associated background radiation estimate as well as a signal attenuation factor from all potential source locations. Faissol points out that radiation from a source decreases as the square of the distance. For example, a detector located 8 meters away from a radioactive source produces a signal one-fourth as strong as a detector located 4 meters away. Intervening materials between the source and detector, such as building walls, further attenuate signals.



Searches with OPTUS (red line) are more effective over the allotted time interval or perform as well as conventional searches (green line) in about half of the time.

A Multilaboratory Effort

Livermore is the lead OPTUS development institution, with contributions from Lawrence Berkeley and Oak Ridge national laboratories, the Remote Sensing Laboratory (RSL) at the Nevada National Security Site, and graduate students from Carnegie Mellon University-Silicon Valley. The Livermore technical team, led by Faissol, includes researchers Claudio Santiago, Thomas Baginski, Pedro Sotorrio, Tom Edmunds, and Karl Nelson, and is responsible for developing and writing the software to implement the optimization algorithms. In addition, Livermore has overall responsibility for the software and data integration, including a user interface. To produce the current OPTUS prototype, the Livermore team developed simplified versions of all the required models.

In March, the team completed a prototype tool that is currently being tested and evaluated by search teams and planners from Lawrence Livermore and RSL. After incorporating suggestions from these early users, a refined version of the software will be available for additional field testing. Wheeler expects that a true "version 1.0" (scheduled for 2017) will be adopted for evaluation by both civilian and military agencies for planning large national and regional events.

The project has a user advisory board that provides additional feedback from NNSA's Office of Defense Nuclear Nonproliferation Research and Development and Office of Nuclear Incident Response, DHS's Domestic Nuclear Detection Office, and DOD's Defense Threat Reduction Agency. Wheeler has also been in discussion with the police department of a major U.S. city that is interested in OPTUS because of the large number of high-visibility events it hosts.

The increased adoption of OPTUS and the improved training that SIP provides are certain to make searches for radioactive materials more efficient and cost effective. Both SIP and OPTUS showcase Livermore's ongoing efforts to strengthen capabilities and training for guarding against the use of weapons of mass destruction by either terrorists or a rogue nation. The new technologies are examples of understanding customer needs, applying relevant technologies, and partnering with other institutions to meet the demands of national security.

—Arnie Heller

Key Words: first responder, gamma-ray detector, Optimization Planning Tool for Urban Search (OPTUS), ORTEC Detective, Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), radioactive material, Spectroscopic Injection Pulser (SIP).

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Optics Become Less Rough, More Tough

Livermore chemist Rusty Steele (left) and principal investigator Tayyab Suratwala observe a workpiece being polished using the CISR (convergent, initial-surface-independent, single-iteration, rogue-particle-free) polisher. (Photo by Lanie L. Rivera.)

LIVERMORE'S National Ignition Facility (NIF), the world's largest and most energetic laser, uses more than 7,500 large optics to guide, reflect, and amplify its beams. The extraordinarily high energies produced by NIF make the sophisticated optics susceptible to life-limiting damage. Over the last decade, Livermore researchers have developed methods for producing highly damage-resistant fused silica (glass) optics (see *S&TR*, January 2015, pp. 19–22), yet these scientific investigators continue efforts to better understand and mitigate optics damage in support of NIF and its missions.

One feature of an optic that can influence damage initiation is its surface finish. Rougher optical surfaces scatter more laser light, which can affect the integrity of surrounding optics, reduce the quality of experimental data, and necessitate optics refurbishment or replacement. A Lawrence Livermore team, funded by the Laboratory Directed Research and Development Program, is investigating how surface roughness is created during the final polishing phases of fabrication. Examining the nanometer-scale chemical and mechanical processes that occur during manufacturing is crucial for identifying methods to further improve optics production.

From an Art to a Science

Standard polishing processes for glass optics use a slurry, an abrasive and corrosive aqueous solution that typically contains small polishing particles ranging from 1 micrometer to a few hundred nanometers. The slurry is used along with a polishing pad to smooth the optic's surface. "The physics and chemistry involved in making glass optics are quite complex," explains Tayyab Suratwala, Livermore's program director for optics materials science and technology. "The physical and chemical interactions that occur between the polishing agent and the pad with the optic, for example, occur simultaneously and affect the final product."

For hundreds of years, skilled laborers and opticians have used an artisanal approach to creating glass optics for scientific instruments, such as telescopes, microscopes, and lasers. Historically, opticians had to manually correct surface defects to create the smoothest surface possible. Although these traditional artisanal methods delivered high-quality products, they also required iterative steps, making the process time consuming and costly.

Over a decade ago, Livermore researchers developed a more science-based, streamlined approach to optics production by investigating three metrics of optical polishing: surface figure (overall optic shape), subsurface damage (scratches), and roughness. Through its work studying the first two metrics, the team developed CISR (convergent, initial-surface-independent, single-iteration, rogue-particle-free) polisher. CISR integrates a technique known as convergent polishing, wherein both flat and spherical glass components can be polished in a single iteration regardless of the workpiece's initial shape. (See *S&TR*, October/November 2014, pp. 8–9.)

Most optics' surfaces look perfectly clear and smooth to the naked eye, but in NIF's energy regime, the tiniest flaw—scratches or defects on the order of 1–2 nanometers—can affect laser performance. By combining simulations and experiments, the team aims to reduce defect sizes to 0.1 nanometers, making optical surfaces 10 times smoother than they are today. Suratwala says, "We are working to make a great optic into a spectacular one without added cost."

A Mysterious Layer

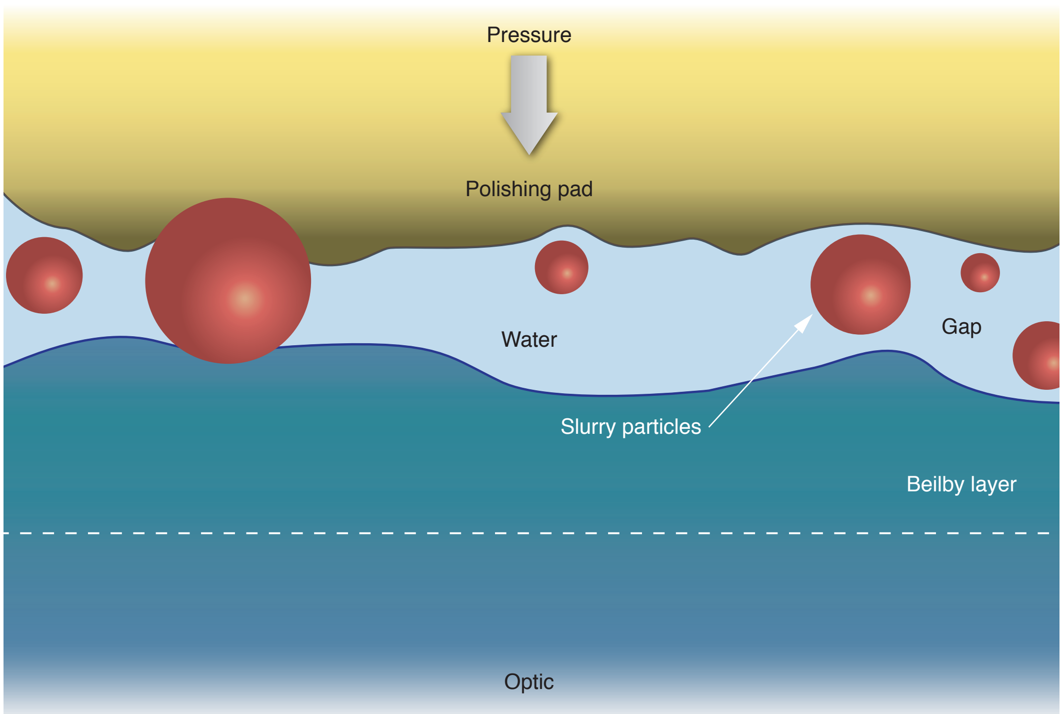
Years ago, opticians noted that a thin defect layer (approximately 0.7 nanometers deep), called the Beilby layer, forms in the surface of optics during polishing. The layer can cause subtle changes in light-reflection properties and can reduce the optic's resistance to laser damage. The Livermore researchers are the first to attempt to understand how the Beilby layer forms, what factors influence its thickness and composition, and how it changes over time.

The research team conducted experiments in which pieces of glass optics were exposed to slurries containing different chemical contaminants—concentrations of hydrogen and cerium, for example. The team discovered that the material properties of the Beilby layer constantly evolve throughout the polishing process because the chemicals in the slurry diffuse into and react with the glass surface. Ultimately, the team identified three primary materials in the slurry that affect the makeup of the Beilby layer: the polishing compound, alkali metal hydroxides (used to control the slurry's pH), and water. These new insights into the chemistry of the Beilby layer help develop a more quantitative understanding of the polishing process and how to reduce nanoscale surface roughness.

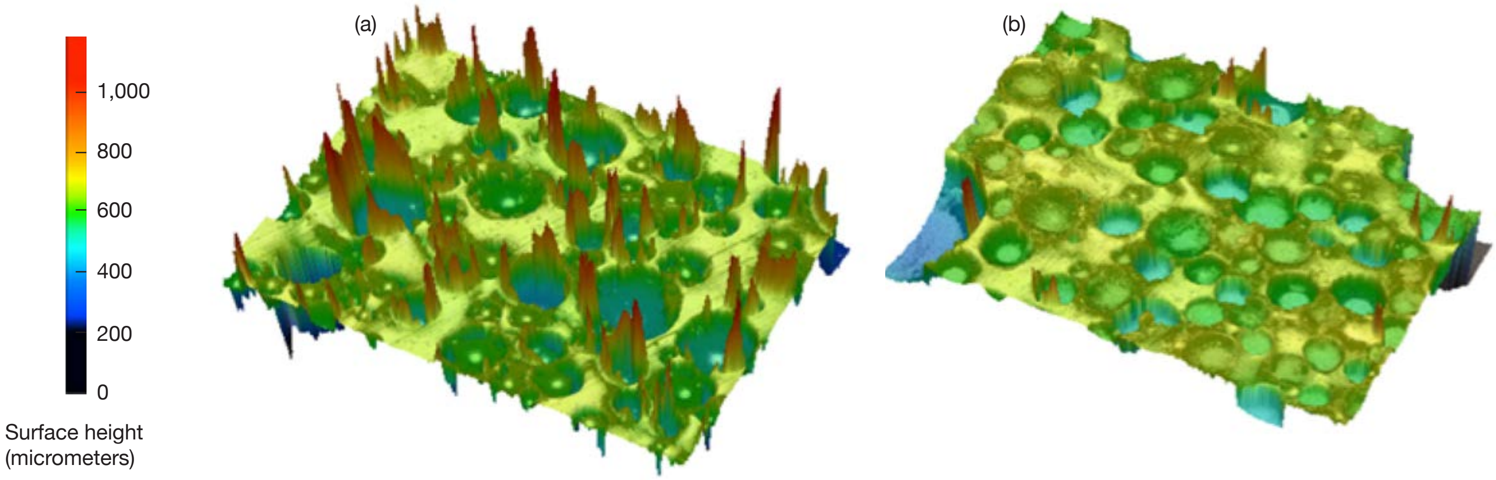
Scratching the Surface

As part of the team's simulation effort, the researchers created the Ensemble Hertzian Multigap (EHMG) model to study the origins and affects of nanoscratching on an optic. The model helps predict how much glass is removed by a single particle in the slurry, the removal rate, and overall surface roughness, given input parameters.

Optics polishing and particle removal processes are similar to using sandpaper. Coarser grit sandpaper quickly removes more material, leaving a rougher surface, whereas finer grit sandpaper lengthens the process but results in a smoother finish. However, when finer grit sandpaper is applied with greater pressure, surface material can be removed more quickly while retaining smoothness. Simulations showed the Livermore researchers that the same is true for optics polishing—surface smoothness depends on the size



The Ensemble Hertzian Multigap model simulates trends in observed roughness over a variety of polished surfaces. This schematic illustrates the relationships between the optic workpiece, Beilby layer, slurry particles, and polishing pad.

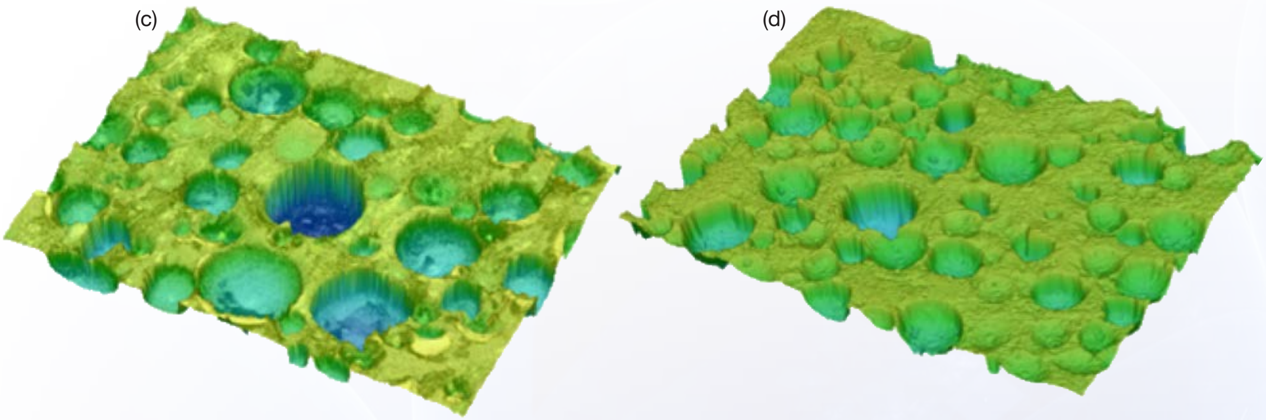


of the particles in the slurry and the pressure applied between the polishing pad and the optic.

To inform the EHMG model, the team conducted atomic force microscopy experiments to examine the surface characteristic of different polished optics and visualize how individual particles affect surface roughness for various particle sizes and loads. In this technique, an extremely sharp probe tip attached to an atomic force microscope senses the surface shape of a sample. A computer records the tip's path and slowly builds up a three-dimensional image. Suratwala says, "We used the microscope to mimic the pressure a particle would experience during optics polishing to see how much material is removed from the substrate through nanoscratching."

The experimental data was incorporated into the model, which simulated one particle at a time sliding across the optic's surface. The process was repeated for hundreds of thousands of different particles with varying sizes under applied pressures, until the final surface roughness was reached. The simulations indicated that the amount of material removed per slurry particle and the particle load distribution are key factors influencing an optic's surface roughness.

Livermore optics scientists (from left) Nan Shen, Lana Wong, and Rebecca Dylla-Spears examine an optic prior to imaging its surface. (Photo by Lanie L. Rivera.)



Confocal microscope images show the surface characteristics of the polishing pad (a) before and (b) after polishing an optic. The team's modified diamond-conditioning treatments lasting (c) 5 minutes and (d) 45 minutes reduced tall asperities on the pad surface and increased its overall smoothness. By applying the smoothest pad to an optic with more pressure, surface removal rates increased from 0.08 to 2.1 micrometers per hour.

Pad Plays a Part

Polishing processes conducted in optics-related industries often apply diamond conditioner to used polishing pads to remove the film of glass particles (called "glazing") that accumulates on a pad's surface during the polishing process and reduces its efficiency. In some cases, as in the semiconductor industry, pads must be constantly conditioned to remove the excess glass, but with each subsequent conditioning, the pad becomes rougher and its useful life is reduced. "The diamond wears down the pads enough that they usually have to be thrown away after a few hundred hours," says Suratwala.

The Livermore team took a novel approach to diamond conditioning and discovered that, under certain conditions, the procedure could be modified to make the pads smoother rather than rougher. The researchers used the diamond conditioner only once to remove glazing spikes on the pad's surface. Then, they applied an ultrasonic cleaning method where gentle vibration and water shake loose any residual glass from the pad. "Using this process, the pad remains flat, the glass is quickly removed, and roughness is reduced," says Suratwala. The team also found that by applying the smoother pad to an optic with greater pressure, polishing time was significantly reduced. The surface removal rate accelerated from 0.08 micrometers per hour without the conditioning treatment to 2.1 micrometers per hour after treatment. "Our polishing pads remove more material faster and last for thousands of hours."

With the team's insights into how a pad's surface characteristics, nanoscratching, and the Beilby layer affect optics quality, Livermore remains at the forefront of optics polishing research. "These major findings are unique and influential to the optics polishing industry," says Suratwala. A second-generation CISR, to be finished this year, will incorporate the team's most recent improvements for increasing surface smoothness. Once the team fully integrates its process optimizations into current polishing methods, the Laboratory and the optics industry will have a new tool for creating the clearest, smoothest optics available.

—Lanie L. Rivera

Key Words: atomic force microscopy, Beilby layer, CISR (convergent, initial-surface-independent, single-iteration, rogue-particle-free) polisher, Ensemble Hertzian Multigap (EHMG) model, Laboratory Directed Research and Development Program, nanoscratching, National Ignition Facility (NIF), optics polishing, polishing pad.

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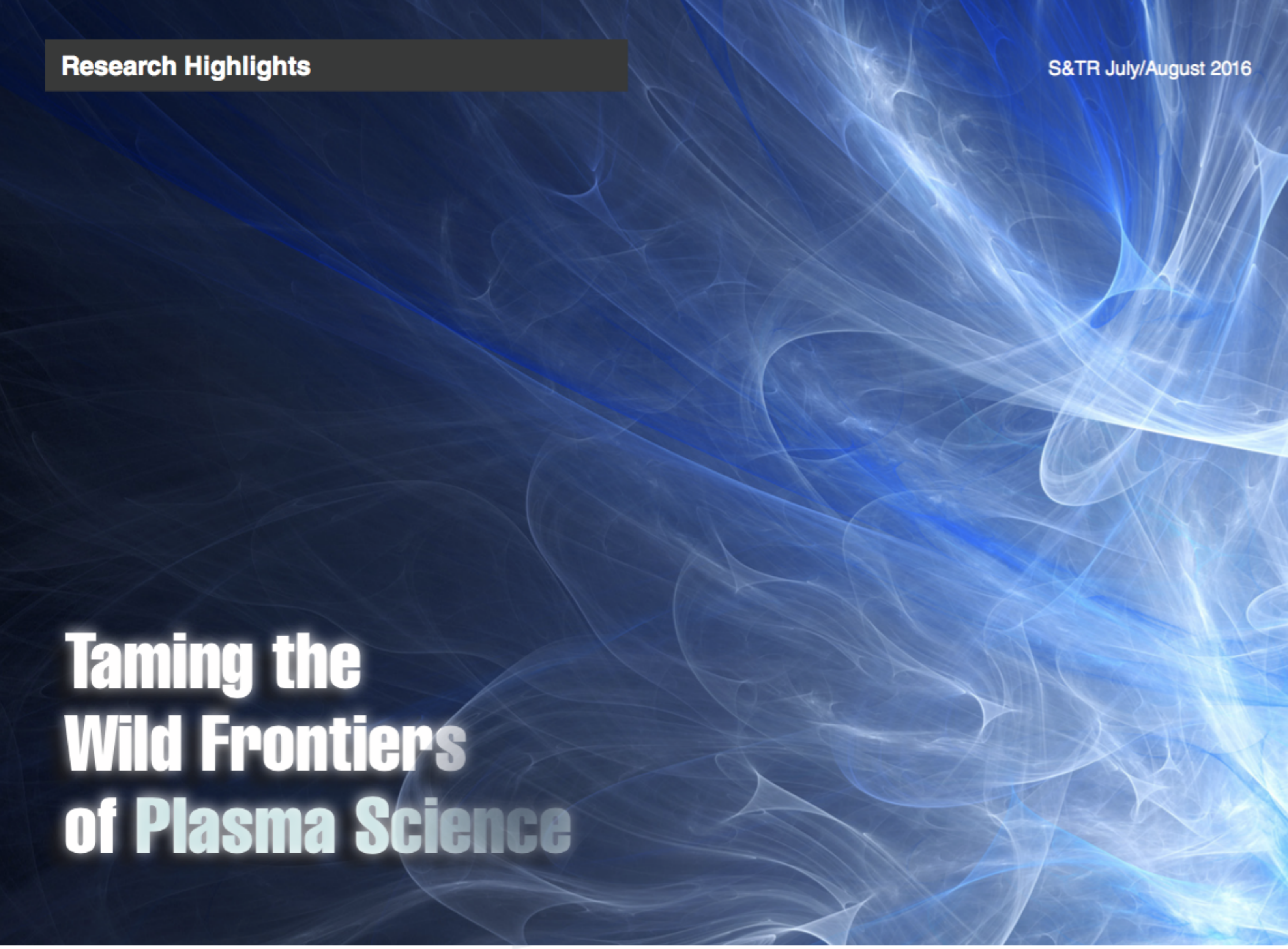


Taming the Wild Frontiers of Plasma Science

PLASMAS are involved in a wide range of atmospheric and astrophysical phenomena, from lightning flashes to accretion disks around black holes. Of particular interest to Livermore researchers are nonequilibrium (multi-temperature) plasma systems that exist at extreme conditions: temperatures of a million or more kelvins, pressures of a million or more times Earth's atmosphere at sea level, and densities equivalent to those of many metals. Such plasmas occur in stellar interiors, giant planets, nuclear weapons detonations, and inertial confinement fusion (ICF) experiments. Studying these conditions on Earth, in the absence of nuclear testing, is no easy task.

Livermore physicist Frank Graziani is working to facilitate the study of plasma physics through more realistic computational models. "While investigating burn physics for programmatic applications, I began to question the fidelity of the plasma models we were using in our radiation–hydrodynamics codes," says Graziani. "The regimes we care about are extreme and complex, and experimental data is limited with which we can compare our simulations, so we have to rely on theory and approximations." Graziani and colleagues including Los Alamos National Laboratory's Michael Murillo, an expert in matter at extreme conditions, and Livermore computational physicist Fred Streitz, formulated a different approach to plasma studies by creating a "virtual plasma" and probing it just as experimentalists would diagnose a real one.

A Powerful, Scalable Code

The research team explored the virtual plasma concept through the Cimarron project, an ambitious initiative funded by the Laboratory Directed Research and Development Program. The initiative was designed to predict and measure the properties of dense plasmas. Over the course of eight years, Cimarron grew to encompass collaborators from three national laboratories and five universities, including theorists for modeling, experimentalists to gather validation data, computational physicists to run simulations, and computer scientists to keep calculations running smoothly on some of the largest and most sophisticated computers available.

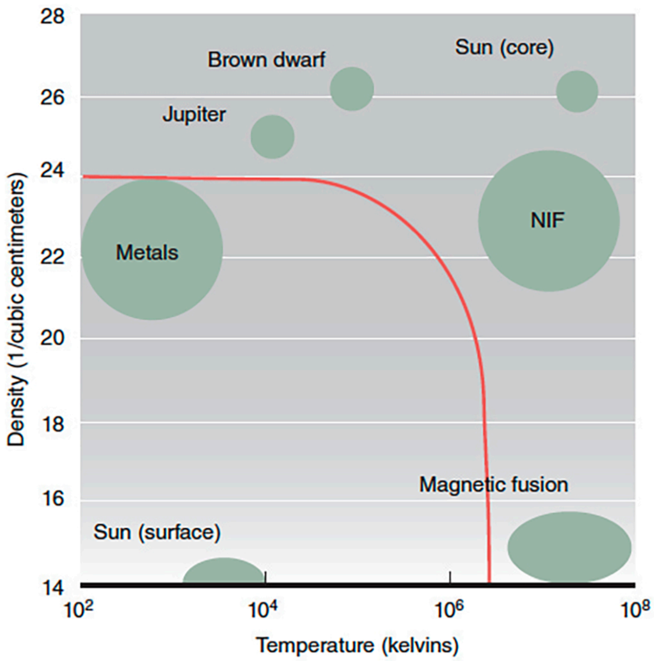
The Livermore-developed massively parallel molecular dynamics (MD) code ddcMD served as the backbone for the initiative. MD codes offer a different approach to modeling compared to traditional hydrodynamics codes. MD simulations follow the trajectory of each particle in a system, while

hydrodynamics simulations treat particles as a fluid that flows through a mesh. MD simulations allow researchers to study the behavior of matter on nanometer (billionth-of-a-meter) and femtosecond (one-quadrillionth-of-a-second) scales, while hydrodynamics simulations are used to study matter on, at minimum, micrometer and picosecond scales—a million times larger.

Modifying ddcMD, initially created for materials science applications, for plasma studies posed a computational challenge. A plasma is a cloud of charged particles (ions and electrons) created when electrons detach from their respective atoms and molecules. The detached electrons enable the plasma to act as a whole rather than simply a cluster of individual particles. Given the significant role electrons play in plasma behavior, the code had to describe them accurately. The problem was that MD is typically used to simulate the movement of atoms, molecules, or ions, but almost never electrons. "With the Cimarron code, we broke the electrons out and let them do what they wanted," notes Murillo, evoking the project's name, which means "wild and untamed" in Latin-American Spanish.

To do so, the code needed to account for electrons' short-range interactions—collisions with protons and other electrons—and their longer range interactions, particularly their attraction to and repulsion of other particles from electric charge, known as the Coulomb force. The Cimarron team incorporated functions derived from fundamental laws of quantum mechanics into ddcMD, which enabled the code to accurately calculate electron interactions at both length scales during the course of a simulation.

How the code breaks up the problem and maps the pieces to computer processors is an important consideration, as it helps determine the maximum problem size and the speed at which the problem can be solved. (See *S&TR*, July/August 2006, pp. 17–19.) "The short- and long-range interactions have a different computational character, so we map them accordingly," notes ddcMD architect and Cimarron team member Jim Glosli. "Allocating a small piece of the machine to long range and the bulk to short range minimizes global communication cost." The result is one of the world's fastest and most scalable Coulomb solvers. An early simulation incorporating 2.4 billion particles run on the Laboratory's Sequoia supercomputer earned Cimarron team members recognition as finalists for the 2009 Gordon Bell Prize for outstanding achievement in computing. (See *S&TR*, September 2010, pp. 13–15.)

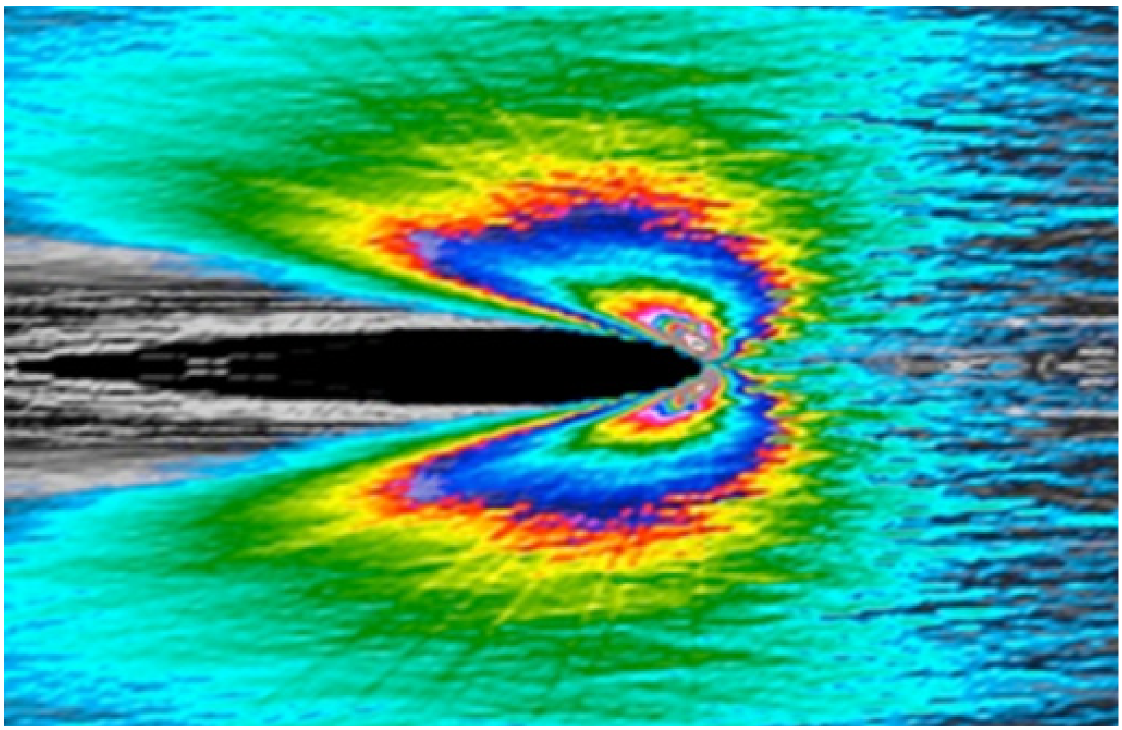


The Cimarron project aimed to understand extreme states of matter, those beyond the red 100-gigapascals pressure line shown here. This region includes plasmas featuring high temperature and density, such as those produced in National Ignition Facility (NIF) experiments and stellar interiors, and lower temperature, high-density plasmas found in giant planets such as Jupiter. By contrast, the surface of the Sun is relatively cool and dilute.

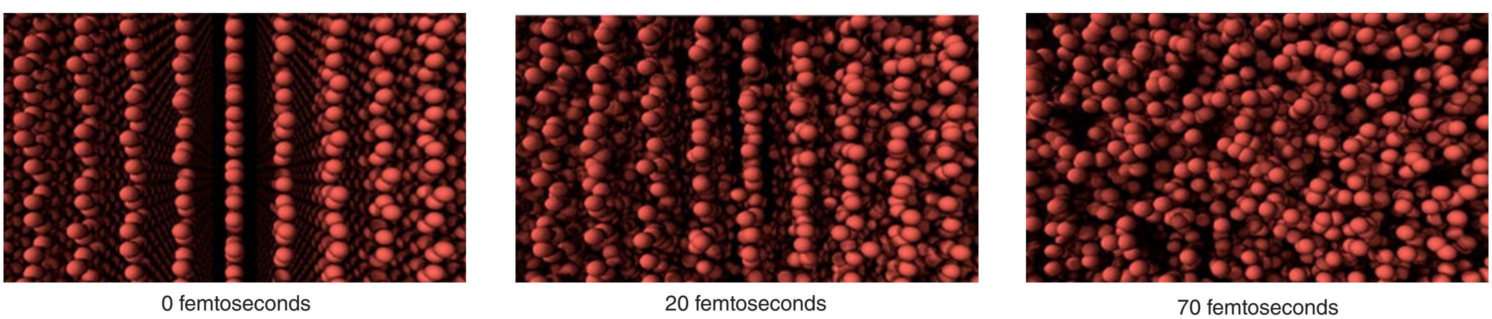
Accounting for the Physics

Once ddcMD was adapted for plasma physics, the Cimarron team began incorporating capabilities for simulating and investigating key atomic, radiative, and nuclear processes. "The plasmas we care about involve different types of ions," explains Graziani. "At the temperatures we're interested in, plasmas of low-*Z* elements (elements with low atomic numbers) such as hydrogen, have completely ionized electrons. But higher *Z* plasmas, such as those containing argon or silver, have only some electrons stripped off, so we have to account for their atomic physics effects." The challenge was addressed, in part, by adding atomic physics to the code—a feature that no other MD code possesses and that is currently being used to develop a biomolecule x-ray imaging capability. (See *S&TR*, April/May 2016, pp. 15–16.)

Experimental validation of ddcMD results, an important component of the Cimarron project, focused on regimes where experiments were likely to produce useful data. If the results of the experiments and the code match, it boosts confidence that the code can predict results at more extreme temperatures and densities. Using short-duration x-ray pulses at SLAC National Accelerator Laboratory's Linac Coherent Light Source (LCLS)



As part of the Cimarron project, researchers used the molecular dynamics code ddcMD to study stopping power—the rate at which high-energy projectiles slow down, deposit energy, and start to heat the surrounding plasma. This simulation, run on the Laboratory's Sequoia supercomputer, shows the stopping power of a 100-million-particle hydrogen–argon plasma. The bright colors show how much energy the projectile (black) and the plasma (gray) are exchanging. Blue regions indicate where energy is being transferred to the plasma from the projectile, and red regions suggest where energy is being transferred from the plasma to the projectile.



The Cimarron team used the ddcMD code to simulate the structure of graphite as well as plasma formation within the material as it was exposed to intense x-ray pulses at the Linac Coherent Light Source. Shown here is the lattice structure of graphite as it evolves over 70 femtoseconds.

and short, intense laser pulses at Livermore's Jupiter Laser Facility, scientists excited and heated graphite targets. When plasma formed, they probed the samples for information on the plasma's properties and behavior. These data were then compared to results from the ddcMD simulations. Although the team has identified several areas where more physics could be added to enhance the code, the match was quite good. Experimentalist Stefan Hau-Riege observes, "We are now routinely using ddcMD to describe nonequilibrium conditions encountered at LCLS."

Beyond Cimarron

The Cimarron project ended in 2014, but the pursuit of a better understanding of dense plasmas continues. At Los Alamos, Cimarron's successor, "Nambe," explores MD, kinetic, and hybrid approaches to plasma simulation. Efforts at Livermore focus on the application of ddcMD to increasingly complex problems. Design physicist Heather Whitley, for instance, performs dynamic ddcMD simulations of shocks for comparison with hydrodynamic codes. "We're at the point where we can use ddcMD to directly examine problems," she says. "Much of my current work is focused on designing National Ignition Facility (NIF) experiments to measure some of the properties that we've examined with ddcMD."

Physicists Tomorr Haxhimali and Robert Rudd are using ddcMD on Lawrence Livermore's Vulcan supercomputer to study transport processes under plasma conditions relevant to NIF's ICF experiments. Their work is helping researchers understand how the fusion fuel mixes with the plastic shell of an ICF target capsule, an undesirable but common occurrence. Whitley has also used this simulation capability to complete a major research milestone for the National Nuclear Security Administration.

The Cimarron project and its successors have deepened scientists' theoretical understanding of dense, nonequilibrium plasmas—an effort that benefits national security and energy research. In addition, the project has been successful in other ways. Its position at the cutting edge of computational physics and computer science has attracted a talented and varied group of collaborators from many disciplines, institutions, and levels of experience, including skilled early-career scientists. Seven postdoctoral researchers involved in the project have taken staff positions at Livermore and other national laboratories, and two Lawrence Scholars pursued their thesis work as part of the Cimarron team. Notes Murillo, "What made this project unique were the people involved. Never before have I seen a group of people from such diverse scientific backgrounds work together so well."

—Rose Hansen

Key Words: Cimarron project, ddcMD code, hydrodynamics, inertial confinement fusion (ICF), kinetic theory, Laboratory Directed Research and Development Program, molecular dynamics (MD), National Ignition Facility (NIF), plasma.

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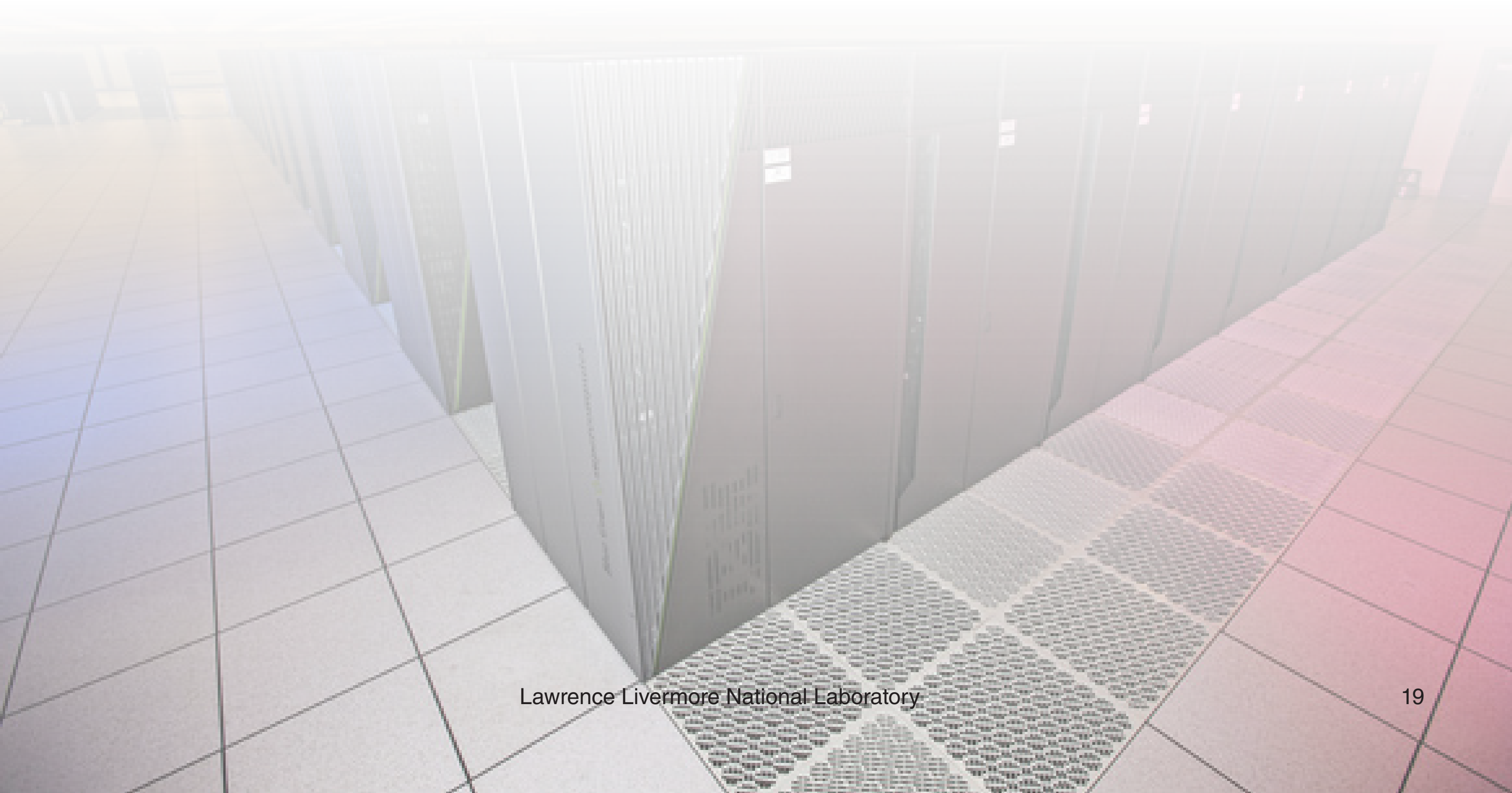


A *Detector* to *Study* the **Neutrino's Nature**

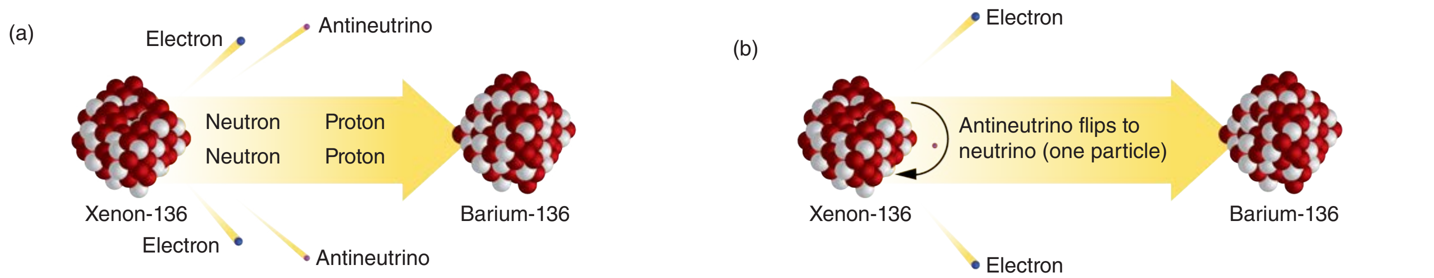
The Enriched Xenon Observatory 200 (EXO-200) experiment provides the basis for current work on a more sensitive xenon-based detector for observing neutrinoless double beta decay (NDBD). Shown here are the EXO-200 readout wires and avalanche photodiodes used to measure induced and collected charge and scintillation light from particle decays in the detector's main vessel. (Photo courtesy of SLAC National Accelerator Laboratory.)

SCIENTISTS have encountered many mysteries in the search to find and understand elementary particles, the most basic units of matter. Some elementary particles, such as the electron, are relatively well understood, while others, such as the elusive neutrino, present the physics community with many unanswered questions. One of those questions concerns a process called neutrinoless double beta decay (NDBD)—a radioactive decay process that, if detected, would have significant implications for the field of particle physics. Livermore physicist Mike Heffner says, "Furthering our understanding of neutrinos and their properties could provide tremendous insight into the fundamental makeup of our universe."

The neutrinoless Enriched Xenon Observatory (nEXO) collaboration is poised to dive deeply into the behavior of neutrinos, the lightest massive particles known to science. Funded by the Department of Energy's (DOE's) Office of Science and the National Science Foundation (NSF), the nEXO collaboration is a joint effort among Lawrence Livermore, SLAC National Accelerator Laboratory, Stanford University, and several other U.S. and international institutions to detect the NDBD phenomenon and further characterize the neutrino. The Nuclear Science Advisory Committee, which advises DOE and NSF on basic nuclear science research, recently identified detecting NDBD as top on its list of scientific priorities for the near future. A selection process is underway to award a grant to the project that shows the most promise, and nEXO collaborators have their eye on the prize.

An Imbalance in Matter

Vastly abundant in the universe, neutrinos are produced by nuclear fusion in stars and through radioactive decay. In addition, countless neutrinos created during the Big Bang still travel



(a) In the double beta decay process, two neutrons simultaneously convert to two protons, emitting two electrons and two electron antineutrinos that share the energy generated from the decay. (b) During NDBD, the nucleus would emit only electrons, which carry the full energy of the decay, because the antineutrinos would have been reabsorbed as neutrinos.

through the universe. With no electric charge and nearly no mass, neutrinos interact so weakly with matter that they are extremely difficult to detect and measure. In fact, each second billions of neutrinos pass through a human body and everything around it at nearly the speed of light without disturbing anything.

The current understanding of elementary particles, as described in the Standard Model of physics, dictates that all particles—matter—with mass and charge have a complementary antiparticle—antimatter. Yet neutrinos may not follow this tenet. In 1937, Italian physicist Ettore Majorana postulated that a particle with no charge could function as its own antiparticle. Scientists theorize that the neutrino may be such a particle, and if so, the nEXO project aims to confirm it. “A central, still unanswered question is why the universe is largely composed of matter instead of equal parts matter and antimatter,” says Giorgio Gratta, a professor of physics at Stanford University and the nEXO spokesperson. “If we can determine that the neutrino is a Majorana particle, we can gain insight into this mystery.”

Neutrinos are known to come in three distinct “flavors,” each with a different mass, and they can oscillate between the states. Physicists postulate that if an extremely light neutrino exists, there might also be an extremely heavy neutrino that has never been observed. “If the neutrino is a Majorana particle,” Heffner explains, “the very heavy form of the neutrino would have decayed rapidly just after the Big Bang. As the universe developed, this asymmetry would have magnified, resulting in the imbalance between matter and antimatter that we observe today.”

Catching a Glimpse

In normal beta decay, a neutron decays into a proton with the emission of an electron. The emitted electron is accompanied by what physicists identify as the neutrino’s antiparticle, or antineutrino. Some isotopes undergo the rarer process of double beta decay, in which two neutrons simultaneously convert to two protons, emitting two electrons and two electron antineutrinos that share the energy generated from the decay. If the NDBD phenomenon exists, the decaying nucleus would emit only electrons, which carry the full energy of the decay, because the antineutrinos would have been reabsorbed as neutrinos. Thus, NDBD is only possible if the neutrino is a Majorana particle.

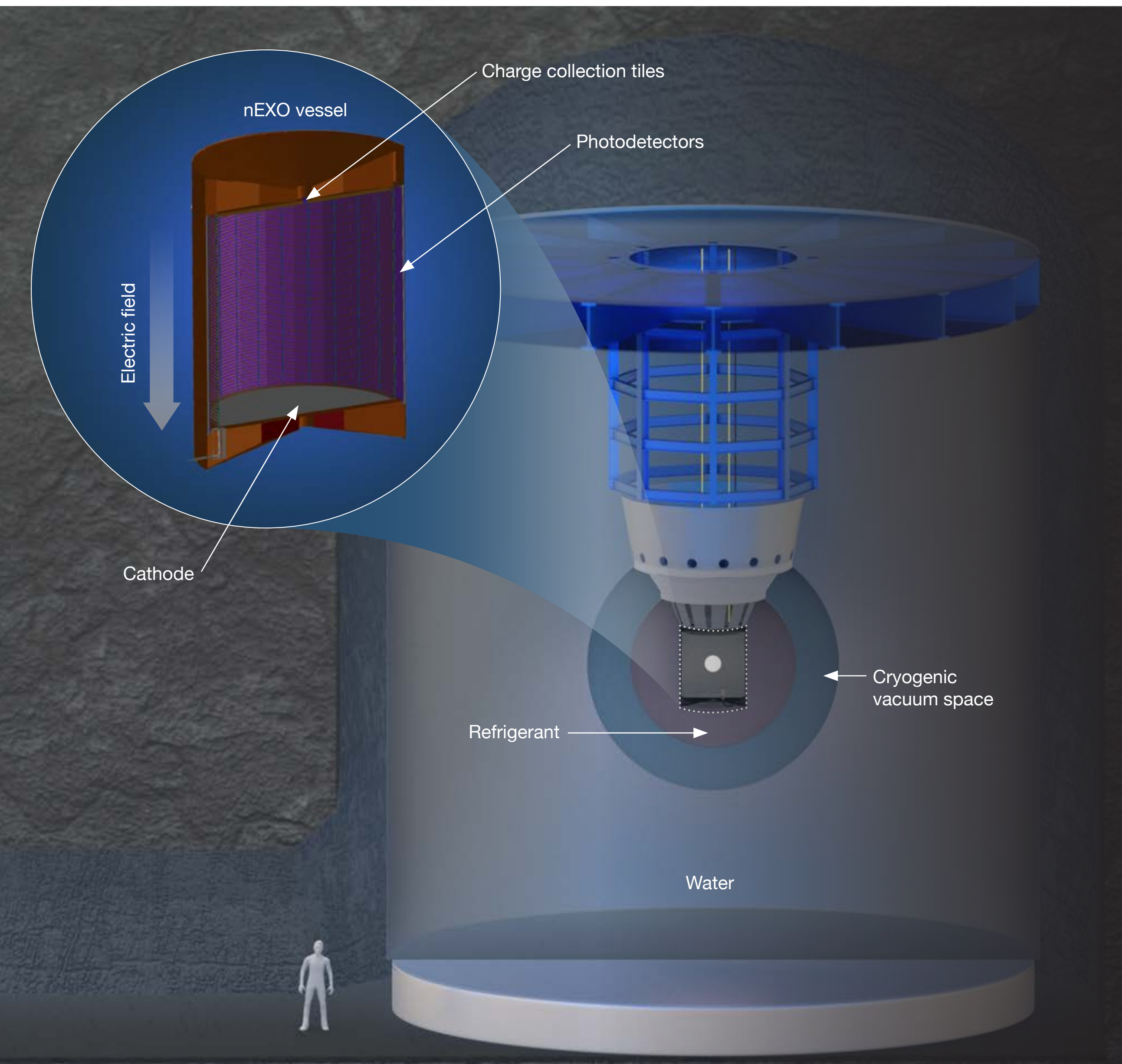
“A previous experiment searching for NDBD, called EXO-200, provides the basis for our work,” says Livermore mechanical engineer and nEXO project manager Allen House. Similar to its predecessor, the nEXO detector will use a vessel filled with liquid xenon, chilled to approximately –108 degrees Celsius. Heffner explains, “The liquid is enriched with xenon-136 (^{136}Xe), one of a few dozen nuclei that undergo standard neutrino double beta decay. Xenon-136 was selected because of its relatively high-energy release during double beta decay and its qualities as a detector material.” Whereas EXO-200 contained about 200 kilograms of enriched xenon, nEXO will use 5 tons (5,000 kilograms)—the entire amount of ^{136}Xe produced annually through global production of xenon. “The more xenon, the more likely we’ll see NDBD,” says Heffner.

In the detector, when a xenon atom undergoes double beta decay, it emits two electrons. These electrons will then interact with other xenon atoms, producing fluorescent light, or scintillation, and a cloud of electrons. Photodetectors that line the nEXO vessel will detect the light, while the charge of the electron cloud will be transported and recorded with the help of an electric field. By detecting both the light and charge separately, the detector provides information about the time, three-dimensional location, and energy deposit of the decay. Heffner says, "With NDBD, we won't see the neutrinos at all. If all of the decay energy has gone into the electrons, the signal would look like a little spike at the end of the electron energy spectrum—if we see that spike, we'll know the neutrino is its own antiparticle."

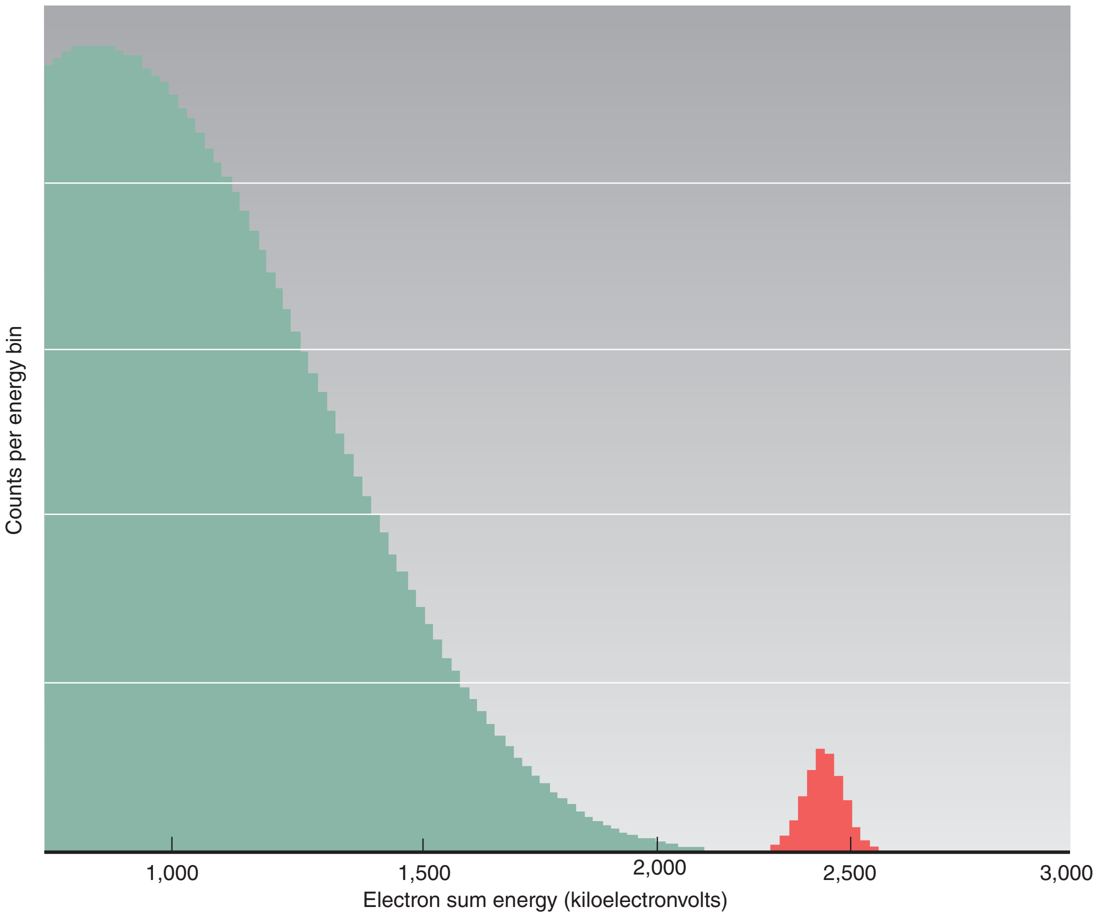
For nEXO, Livermore researchers are providing project management, leading the engineering efforts, and spearheading simulation work. Staff scientist and simulation expert Samuele Sangiorgio is using high-performance computers to understand how much background radiation the experiment can tolerate. These data will inform decisions regarding the choice of construction materials and the design of the detector components. "Simulations can also tell us how signals form in the detector, should an NDBD or a background event occur, and we can use this information to improve the experiment's sensitivity," says Sangiorgio. Livermore's simulations group is also working with universities to model the detector's components before manufacturing.

An International Effort

The expected location for the nEXO detector is Canada's underground Sudbury Neutrino Observatory (SNOLAB), one of two facilities where scientists discovered that neutrinos have



The nEXO vessel will contain 5 tons (5,000 kilograms) of enriched liquid xenon for observing the NDBD process. (inset) Inside the vessel, photodetectors will record scintillation light produced from the decay process, while an electric field transports the electrons to collection tiles that record their energies. To reduce the risk of interference from background radiation, nEXO will be located underground and have a containment system comprising a low-radioactivity refrigerant, a cryogenic vacuum space, and a water tank equipped with photomultiplier tubes to track and reject background signals. (Rendering by Ryan Chen.)



The broad spectral shape (green) of standard double beta decay results from combined electron energies over several events. NDBD, if detected, will appear as a small energy spike (red) alongside the broad spectral shape.

mass. (This research won the 2015 Nobel Prize in physics). The detector will be located 2 kilometers underground in a mine shaft to protect it from background radiation signals produced by cosmic rays. In addition, the natural radioactivity of the surrounding rock could mask the NDBD signature. To reduce the risk of interference from these sources, the detector vessel will be surrounded by a containment system comprising a low-radioactivity refrigerant, a cryogenic vacuum space, and a water tank equipped with photomultiplier tubes to track and reject background signals.

"Our nEXO project is uniquely equipped to take on the challenge of revealing NDBD and characterizing the neutrino," explains Heffner, whose own work is funded through Livermore's Laboratory Directed Research and Development Program. "We're bringing together DOE resources, scientific and academic institutions from the San Francisco Bay Area, and national and international collaborators, including researchers from Canada, China, Germany, South Korea, Switzerland, and Russia." Gratta says, "This project exemplifies the idea that physics knows no boundaries—irrespective of political events, scientists from all over the world are united in their common pursuit of advancing fundamental science and understanding the elusive neutrino."

—Maren Hunsberger

Key Words: antimatter, antiparticle, Big Bang, Department of Energy (DOE), electron, isotope, Majorana particle, National Science Foundation (NSF), neutrino, neutrinoless double beta decay (NDBD), neutrinoless Enriched Xenon Observatory (nEXO), Nobel Prize, Nuclear Science Advisory Committee, particle physics, radioactive decay, SLAC National Accelerator Laboratory, Sudbury Neutrino Observatory (SNOLAB).

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Patents and Awards

In this section, we list recent patents issued to and awards received by Laboratory employees. Our goal is to showcase the distinguished scientific and technical achievements of our employees as well as to indicate the scale and scope of the work done at the Laboratory. For the full text of a patent, enter the seven-digit number in the search box at the U.S. Patent and Trademark Office's website (http://www.uspto.gov).

Patents

Engineered Microorganisms Having Resistance to Ionic Liquids
Thomas Lawrence Ruegg, Michael P. Thelen
U.S. Patent 9,290,768 B2
March 22, 2016

Nanolipoprotein Particles Comprising a Natural Rubber Biosynthetic Enzyme Complex and Related Products, Methods, and Systems
Paul D. Hoeprich, Maureen Whalen
U.S. Patent 9,303,273 B2
April 5, 2016

Microwave Heating of Aqueous Samples on a Micro-Optical-Electro-Mechanical System
Neil Reginald Beer
U.S. Patent 9,313,833 B2
April 12, 2016

High Surface Area Graphene-Supported Metal Chalcogenide Assembly
Marcus Worsley, Joshua Kuntz, Christine A. Orme
U.S. Patent 9,314,777 B2
April 19, 2016

Awards

Laboratory physicist **Tammy Ma** has been selected for a **2016 Presidential Early Career Award for Science and Engineering** (PECASE), 1 of 106 recipients nationwide and 1 of 13 from the Department of Energy. The awardees will be honored in a ceremony later this year. Ma was recognized for her "innovation and leadership in quantifying hydrodynamic instability mix in the hot spot of inertial confinement fusion implosions on the National Ignition Facility; key contributions to experiments demonstrating fusion fuel gains exceeding unity; and broad educational outreach and service to the scientific community." PECASE is the highest honor bestowed by the U.S. government on science and engineering professionals in the early stages of their independent research careers.

Livermore's **Forensic Science Center** received an **"A" grade** from the **Organization for the Prohibition of Chemical Weapons** (OPCW) on its most recent proficiency test. OPCW administers the Chemical Weapons Convention treaty, which has been in force since 1997 and has been ratified by 190 nations, including the United States. Each October, a score of chemists at Livermore's Forensic Science Center, along with researchers from 23 other laboratories around the world, face the challenge of passing the OPCW proficiency tests to maintain their designation as one of its laboratories. The challenge involves identifying the presence of chemical weapons compounds in six samples within a 15-day period. To be OPCW-certified, a laboratory must maintain a three-year rolling average of at least two "A" grades and one "B." The latest test results mark the sixth straight "A" grade earned by Laboratory researchers.

Eighteen teams, which included **17 Laboratory employees**, recently received **Excellence Awards** from the **National Nuclear Security Administration's** (NNSA's) **Office of Safety, Infrastructure, and Operations** (NA-50). The annual program recognizes teams and individuals for exceptional accomplishments made in support of NA-50 efforts to achieve the NNSA mission.

Recipients were honored for work performed in 2015 that demonstrated extraordinary achievements on key projects at the Livermore site. Livermore employees **Lisa Clowdus, Mark Costella,** and **Greg Stremel** were individually recognized for their efforts and achievements as team leads for three different projects. In total, Livermore personnel participated on six of the winning teams.

Abstract

Seeking Out Hidden Radioactive Materials

Two groups in Livermore's Global Security Principal Directorate are working on different yet complementary approaches to more efficiently and expertly locate and characterize radioactive materials. The first effort aims to make training exercises more realistic for people who must respond to a radiological or nuclear incident. The work involves a Livermore instrument called the Spectroscopic Injection Pulser. The device attaches to the exterior of a radiation detector and injects high-fidelity signals for any isotope or mixtures of isotopes into the detector's amplifier, mimicking the signals from real sources. The second project is a software program called the Optimization Planning Tool for Urban Search (OPTUS) that is designed to enhance the effectiveness of searches for radioactive materials in urban areas. OPTUS helps search teams cover an area (up to several square kilometers) more efficiently in a limited amount of time. The goal is to either find a stationary radioactive source or declare the area free of potential threat sources with a quantitative estimate of confidence.

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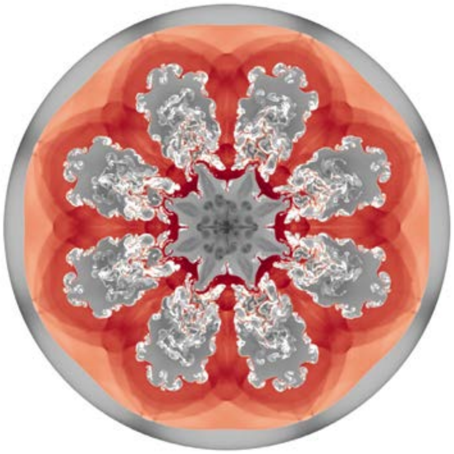
Investments Drive the Future of Computing



Projects funded by the Laboratory Directed Research and Development Program are building a foundation for exascale systems and subsequent scientific breakthroughs.

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