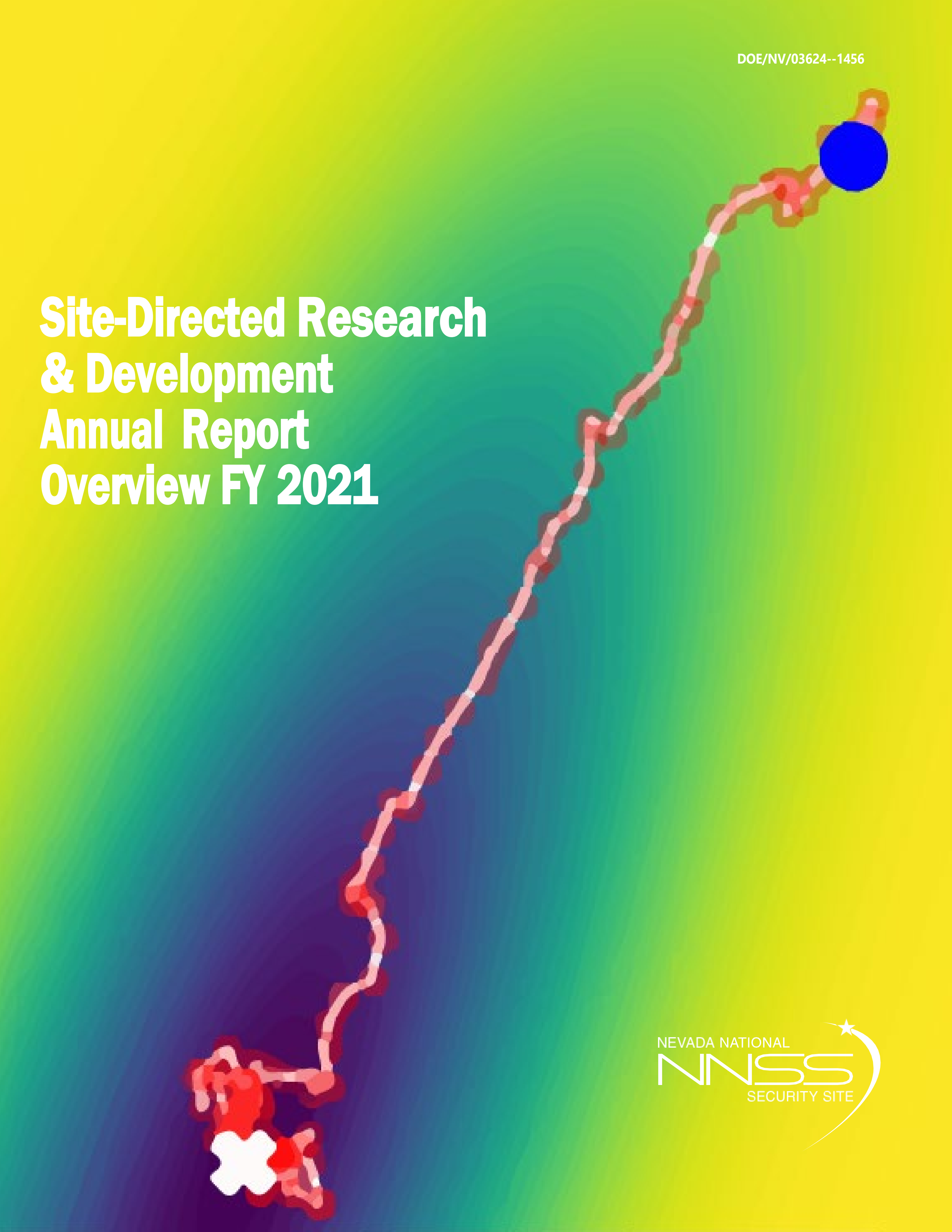
DOE/NV/03624--1456



Site-Directed Research & Development Annual Report Overview FY 2021

NEVADA NATIONAL
NNSS
SECURITY SITE

Site-Directed Research & Development FY 2021 Annual Report Overview

Foreword, José Sinibaldi 1

Program Description **2**

Mission, Alignment, and Objectives 2

Leadership 4

Proposal Cycle and Project Selection 5

SDRD Portfolio 6

Program Accomplishments **7**

Featured Research 7

Radiographic System Imaging and Analysis 8

User-Centered Remote Testing and Operations 9

Neutron Technologies and Measurements 10

Enabling Technologies for Autonomous Systems and Sensing 11

Dynamic Experiments Diagnostics 12

Communications and Computing 13

Program Value **15**

SDRD Program Performance Metrics 15

Impact Stories 17

Afterword, Paul Guss 21

Acknowledgments .... **inside back cover**

FY 2021 SDRD Projects .... **inside back cover**

How to read this report

The SDRD program's annual report for fiscal year 2021 consists of two parts: the program overview, which contains three major sections—Program Description, Program Accomplishments, and Program Value—and individual project report summaries published electronically on the Nevada National Security Site's website, www.nnss.gov/pages/programs/sdrd.html. Complete technical reports for concluding projects are available from the Office of Scientific and Technical Information (OSTI) or the principal investigator.

On the cover

(*front and back cover*) Figures demonstrating the result of one execution of Howard et al.'s (NLV-001-19) automated alignment procedure for a compound refractive lens.

(*inside front cover*) Tinsley et al.'s (STL-012-20) array of seven neutron detectors used to measure neutron flux and emission angle.

(*inside back cover*) Digital elevation model and geode altitude correction of aerial data built into AVID as a web service through Guild-Bingham et al. (RSLN-026-21) project efforts.

Staff

SDRD Program Manager .... **Paul Guss**

Editors .... **Kaela Dotson, Kristen Macias, Katsura Rast, Anne Totten, Dorothy Vanderford**

Design and Layout .... **Kristen Macias**

Web Design and Production .... **Kirsten Kellogg, Kristen Macias**

This work was done by Mission Support and Test Services, LLC, under Contract No. DE-NA0003624, with the U.S. Department of Energy and supported by the Site-Directed Research and Development Program. DOE/NV/03624--1456.

Publication Date: September 2022

www.nnss.gov

SDRD: The key to meeting NNSA's current and future stockpile stewardship and global security missions

As the innovation engine for the NNSS, the SDRD program utilizes the full complement of the Nuclear Security Enterprise (NSE), including its research infrastructure, high-performance computing, specialized material production, and many other capabilities, in our pursuit to solve national security challenges. Having access to large- and small-scale R&D efforts, associated laboratories, and user facilities is critical to enable our scientific and technical staff to accomplish their mission goals.

Our Science, Technology, and Engineering (ST&E) staff working on SDRD projects partner with NSE laboratories and other institutions to fully leverage competencies that exist elsewhere, and thus we amplify our own abilities to meet NNSA mission requirements and provide solutions with far-reaching impact.

Over the last few years, the SDRD program has made significant progress in aligning its management structure and investment portfolio more closely with areas that directly impact NNSA stockpile stewardship and global security missions, as well as strategic partnership and strategic intelligence partnership programs. This alignment enables the program to focus more keenly on seven thrust areas that are critical to the nation's ability to meet current and future nuclear security challenges, namely Radiographic Systems Imaging and Analysis, Neutron Technologies and Measurements, Accelerator Beam Science and Target Interactions, Dynamic Experiment Diagnostics, Enabling Technologies for Autonomous Systems and Sensing, User-Centered Remote Testing and Operations, and Communications and Computing. We believe that this change will enhance our ability to directly support NNSA's Defense Programs, Defense Nuclear Nonproliferation, Nuclear Counterterrorism and Counterproliferation missions, and help ensure the long-term vitality of ST&E advancements at the NNSS.

The SDRD program aims to enable our ST&E workforce to innovate and advance the ST&E state of the art that will transform us into a next-generation NNSS, become a better partner to NSE laboratories, and enhance our agility in responding to future global threats.

April 2022

José Sinibaldi
Program Director and Chief Scientist
Nevada National Security Site

PROGRAM DESCRIPTION

SDRD Program Mission, Alignment, and Objectives

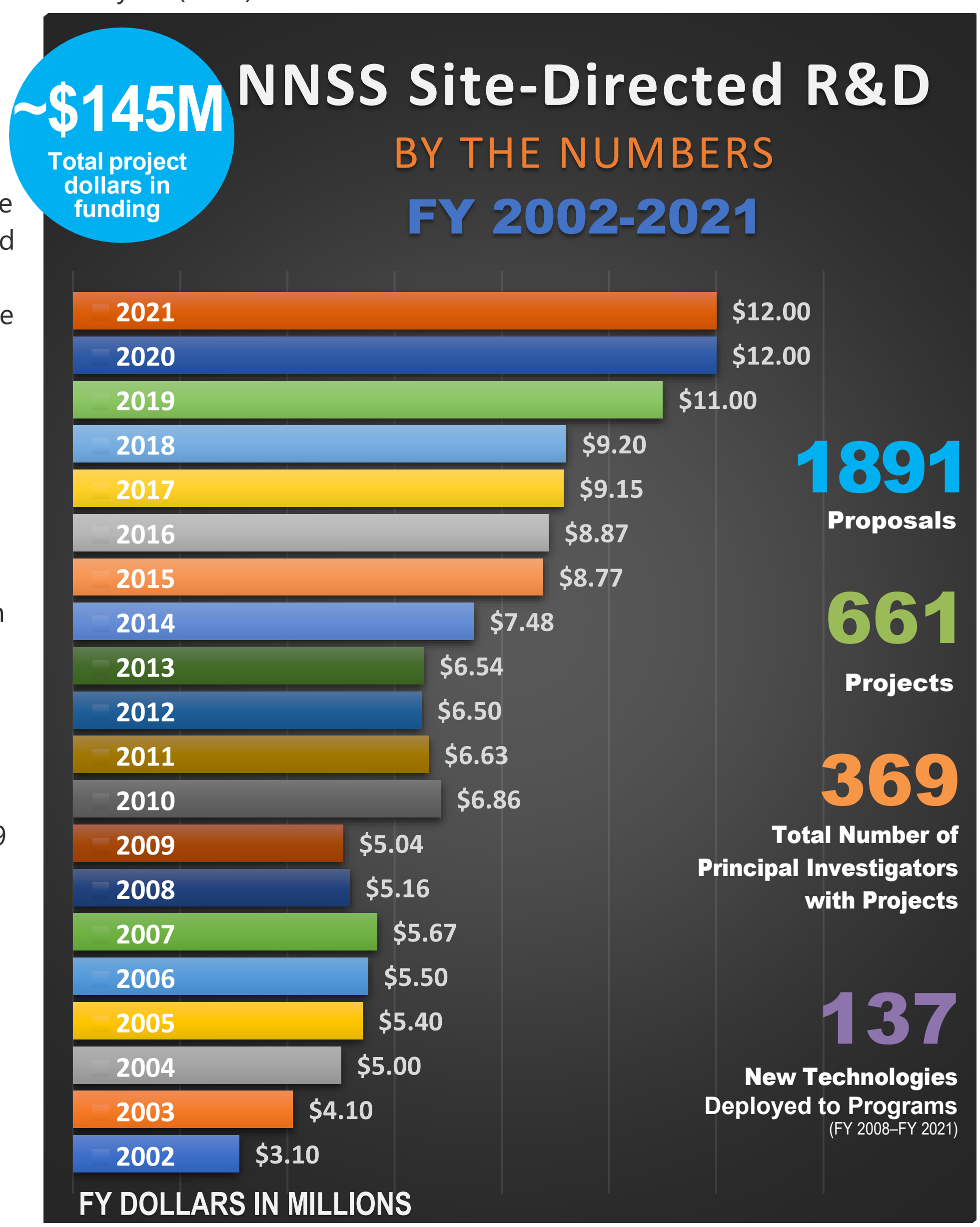
History and Impact

The Site-Directed Research and Development (SDRD) program was initiated through Public Law (P.L.) 107-66, "Energy and Water Development Appropriations Act, 2002," Section 310, which grants the NNSA authority to allow the Nevada National Security Site (NNSS) contractor to conduct an R&D program aimed at supporting innovative and high-risk scientific, engineering, and manufacturing concepts and technologies with potentially high payoff for the nuclear security enterprise.

The program is modeled after the Laboratory Directed Research and Development (LDRD) program, which is conducted in accordance with the guidance provided by U.S. DOE Order 413.2C Chg1, "Laboratory Directed Research and Development," and the supplemental augmenting document "Roles, Responsibilities, and Guidelines for Laboratory Directed Research and Development at the Department of Energy/ National Nuclear Security Administration Laboratories." We are also committed to the guiding principles as outlined in the 2019 Strategic Framework for the NNSA Laboratory and Site-Directed Research and Development.

P.L. 110-161 (H.R. 2764), "The Consolidated Appropriations Act, 2008," provides that up to 4% of the NNSS site costs may be applied to the SDRD program. In addition, SDRD is an allowable cost within the NNSS management and operating contract and as such is identified in the NNSS contractor accounting system. The program is currently funded at 2.5%. In its first year (2002) the baseline budget was $3.1M, and roughly $15M has been allotted for FY 2022 by the senior management team.

As the illustration on this page shows, SDRD has made a significant impact in the past 20 years, providing over 135 new technologies to NNSS programs from 2008 to 2021, a high return on the investment of R&D dollars.



Alignment with the NNSA LDRD/SDRD Strategic Framework

The NNSA laboratories and NNSS R&D programs have five objectives as described in DOE Order 413.2C. They are 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, and
- support high-risk, potentially high-value research and development.

These objectives underpin the *2019 Strategic Framework for the NNSA Laboratory and Site-Directed Research and Development*, a document signed in July 2019 by the three NNSA laboratory directors, Mark Martinez (NNSS President), and Lisa E. Gordon-Hagerty (Under Secretary for Nuclear Security for DOE and NNSA Administrator). This short but key document defines the vision, objectives, and the overarching strategies the R&D programs follow. To quote the Framework, the "NNSA laboratories and NNSS have a shared mission to solve national security challenges by leveraging scientific and engineering excellence." Specifically, the Framework describes how the programs address four important challenges presented in the 2018 Nuclear Posture Review, which are to:

- provide an agile, flexible, and effective nuclear deterrent,
- protect against all weapons of mass destruction threats,
- deter and defend against threats in multiple domains, and
- strengthen our energy and environmental security.

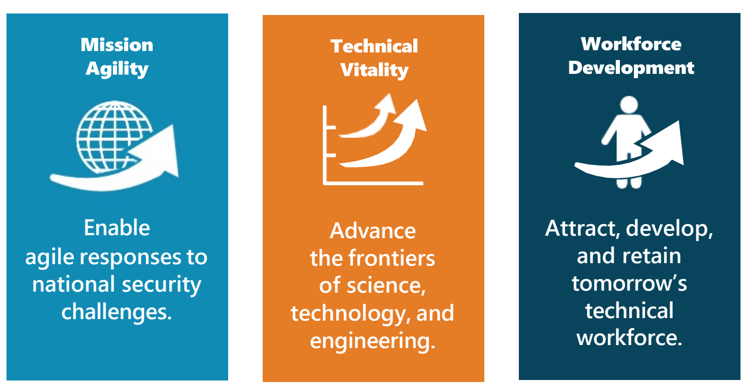
As the Framework also states, "Through their individual strategic planning processes, NNSA laboratories and NNSS use the [R&D] Programs to seed their capability-bases and scientific workforces to prepare for emerging national security challenges, thereby achieving the NNSA mission and supporting the 2018 Nuclear Posture Review."

and rejuvenates the technical base necessary for operations and program readiness at the NNSS. We support high-risk research and potential high-value R&D. Our objectives harmonize with those of the LDRD program, which are:

Mission Agility.
Enable agile technical responses to current and future DOE and NNSA mission challenges.

Scientific and Technical Vitality.
Advance the frontiers of science, technology, and engineering by serving as a proving ground for new concepts, exploring revolutionary solutions to emerging security challenges, and reducing the risk of technological surprise.

Workforce Development.
Recruit, retain, and develop tomorrow's technical workforce in essential areas of expertise critical to mission delivery.



Mission and Objectives

The SDRD program develops innovative scientific and engineering solutions, replaces obsolete or aging technologies,

The research projects featured on pages 8–14 are keyed to the three objectives, as indicated by these icons.

SDRD Program Leadership

The senior leadership of Mission Support and Test Services, LLC (MSTS), the management and operating contractor for the NNSS, which includes the president, vice president, and senior program directors, is committed to advancing the contract's R&D goals. Working closely with senior management and the SDRD program manager, the chief scientist ensures the quality of science and technology across the company's multiple programs and missions; advocates translation of research products through technology readiness levels; and plans and directs new scientific concepts and technologies to provide solutions to identified issues to fulfill our mission to the nuclear security enterprise.

The SDRD program manager is a single point of contact for SDRD and is responsible for all practical aspects of the program. The program manager is assisted by the NNSS Science and Technology Thrust Area (STTA) leads and SDRD technology representatives (see below) to coordinate technical activities undertaken by local principal investigators (PIs). PIs are responsible for all aspects of technical activities on their projects. They deliver monthly updates, present quarterly reviews, submit final annual reports, and report technical outcomes post-project closure. The SDRD program relies on an external advisory board of distinguished individuals from academia, government, and industry to help guide and direct our investments toward the most important areas of national security science and technology. This board has been instrumental in the success of the program since it was instituted in the mid-2000s.

NNSS Science and Technology Thrust Areas

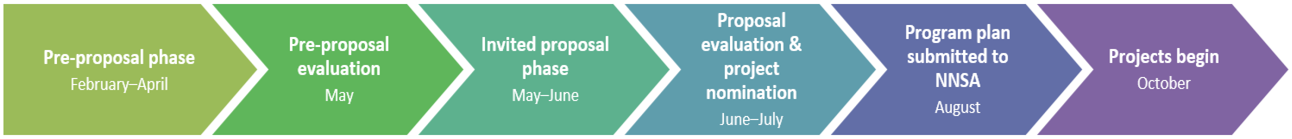
The NNSS Science and Technology Thrust Areas (STTAs) are a focused long-term technical investment to prepare the NNSS technology capabilities for future NNSA missions and to enhance our ability to respond to future global threats.

The NNSS STTAs consist of seven areas, and each STTA encompasses a specific segment of science and technology conducted at the NNSS. The Radiographic Systems Imaging and Analysis, User-Centered Remote Testing and Operations, Accelerator Beam Science and Target Interactions, and Enabling Technologies for Autonomous Systems and Sensing STTAs were activated in FY 2021 (Phase 1). The Neutron Technologies and Measurements, Dynamic Experiment Diagnostics, and Communications and Computing STTAs are set to be activated during FY 2022 (Phase 2). STTA leads or SDRD technology representatives are assigned to lead and support the STTAs. The goals and objectives for the STTAs are to strengthen our technical capabilities in the near term, enhance the readiness of our core competencies in the long term, and make us more agile and adaptable to new global threats.

The STTAs directly align their efforts to support our NNSA and Strategic Partnership Projects missions and are an integral component of the SDRD program. The STTA leads and SDRD technology representatives are involved in shaping the program as well as integrating STTA goals with defined strategic initiatives directed to SDRD proposers.

Activation of the seven STTAs will occur in two phases; those shaded in blue become active in FY 2021 (in conjunction with the FY 2022 call for proposals), followed by the others in FY 2022.

Proposal Cycle and Project Selection



The research undertaken by the SDRD program is inherently staff driven—ideas are submitted annually by staff in response to a call for proposals and these ideas are vetted through a rigorous two-stage review and evaluation process. Proposers are guided by mission needs and other strategic guidance to provide unique solutions to existing and emerging problems. Furthermore, proposers are encouraged to accept higher levels of R&D risk that could nonetheless result in high-reward technological advances that are of immediate benefit to naturally risk-averse programmatic projects.

Call for Proposals

We utilize a two-phase proposal process consisting of a pre-proposal (concept phase) followed by an invited proposal.

In the pre-proposal phase, PIs are encouraged to submit ideas in a standardized, succinct format that presents the proposed project's essence and impact. In addition, during the pre-proposal phase, proposers are encouraged to obtain feedback from subject matter experts (SMEs) to refine their ideas. This phase sparks innovation and initiates a feedback loop that extends to the invited proposal phase. Guidance for proposers is provided in two major documents, the Broad Site Announcement (BSA) and the *NNSS Technology Needs Assessment for R&D*. Updated annually, the assessment helps proposers identify and address technology gaps in existing and emerging technologies. The feedback loop also provides specific, useful guidance.

Project Selection

All submitted pre-proposals are evaluated by reviewers. They evaluate how well each pre-proposal addresses the core questions contained in the short pre-proposal form, which is based on the Heilmeier approach to R&D. Additional criteria considered in the evaluation of pre-proposals include their alignment with NNSS's current strategic priorities and focus areas, their potential to drive innovation and promote technological advances needed to meet emerging mission requirements, and their impact on our ability to develop cutting-edge capabilities and to attract and retain top talent for future challenges. Individual pre-proposals are evaluated with a reduced-weighted scoring matrix. The scores are then compiled and a ranking is determined.

Typically, about 50% of the pre-proposals are promoted to invited proposals. Invited proposals are evaluated according to well-benchmarked and well-established criteria that consist of (1) technical merit, (2) program benefit, (3) probability of success, (4) critical skills, and (5) leverage. Detailed information about these criteria is available for viewing by anyone who has access to the NNSS network. The information is available at all times via the SDRD program website. In addition, the SDRD program posts an article about these criteria on the company's intranet announcement page every year before the invited proposal phase begins.

The final selection of SDRD investments for the next fiscal year is made and an annual program plan is submitted to the NNSA for concurrence by mid-August.

Feasibility Studies

Several investigative feasibility studies are funded each fiscal year. In FY 2021, there were a total of five feasibility studies. These brief studies (three to six months, usually under $100K) focus on topics that may potentially warrant further study and full funding. In the past, successful endeavors, such as broadband laser ranging (see *FY 2020 SDRD Annual Report Overview*, pp. 24–25), began as feasibility studies.

SDRD Portfolio

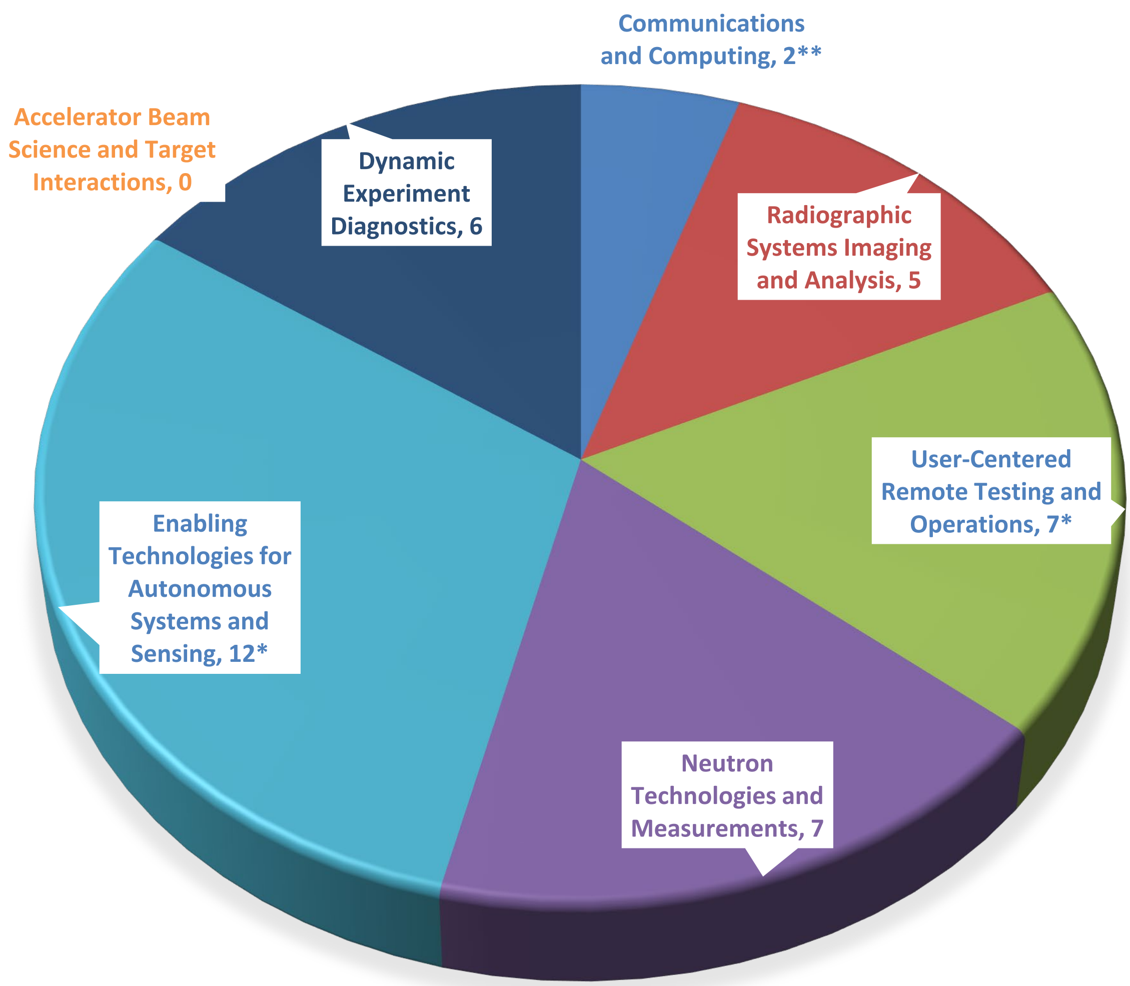
Mission Categories

The SDRD portfolio falls into two primary mission categories: stockpile stewardship and global security.

Historically, PIs have submitted a nearly equal number of ideas addressing stockpile stewardship and global security issues. Dollars requested over the past five years to stockpile stewardship were approximately $27.3M, while global security requested approximately $25M in funding. In FY 2021, the total amount of funding requested was approximately $12M, of which about 58 percent was for the stockpile stewardship mission category and about 42 percent for the global security mission category.

Science and Technology Thrust Areas

Beginning FY 2021, each funded project is also aligned with one of the seven NNSS STTAs according to its focus. In FY 2021, there were a total of 39 projects, of which 5 were feasibility studies. The pie chart below shows the number of FY 2021 projects that fall into each of the seven thrust areas.



*Of which 2 were feasibility studies.
**Of which 1 was a feasibility study.

PROGRAM ACCOMPLISHMENTS

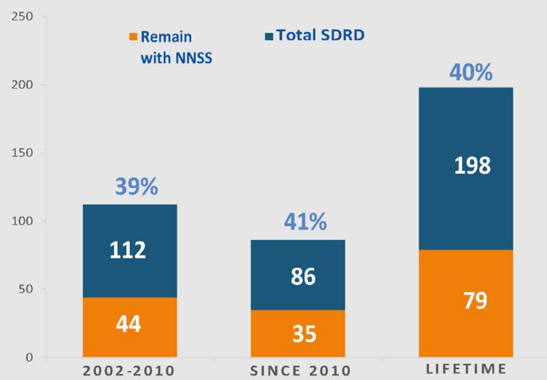
SDRD Statistics at a Glance

FY 2021 SDRD Statistics at a Glance

$12.0M	$314K	39	20
Total program cost	Median project size	Total SDRD projects	New projects in FY21

Employee Retention & SDRD

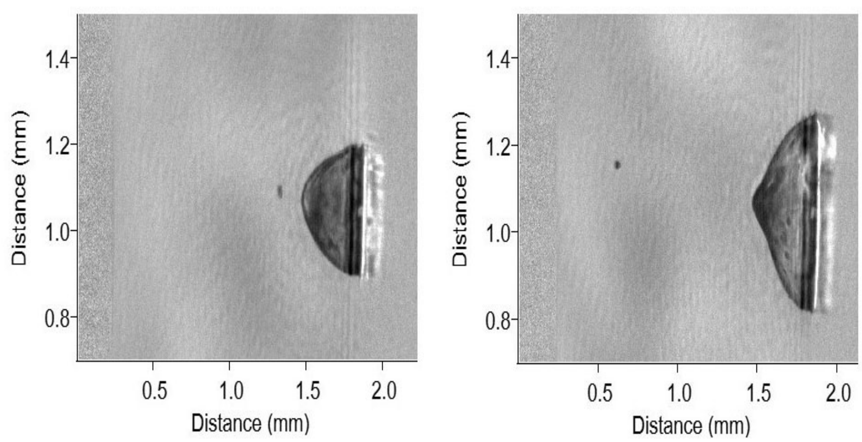
Since 2010, 41% of PIs who had SDRD projects remain employed by NNSS



Publications	21
Technologies transferred to programs	13
Gaps/Needs addressed	18
Invention disclosures	3

Featured Research

SDRD projects demonstrate a high level of ingenuity and innovation each year. Selected highlights of the R&D accomplished in FY 2021 by the SDRD program are presented on the following pages. Summaries of all FY 2021 projects can be found at www.nnss.gov/pages/programs/sdrd.html.

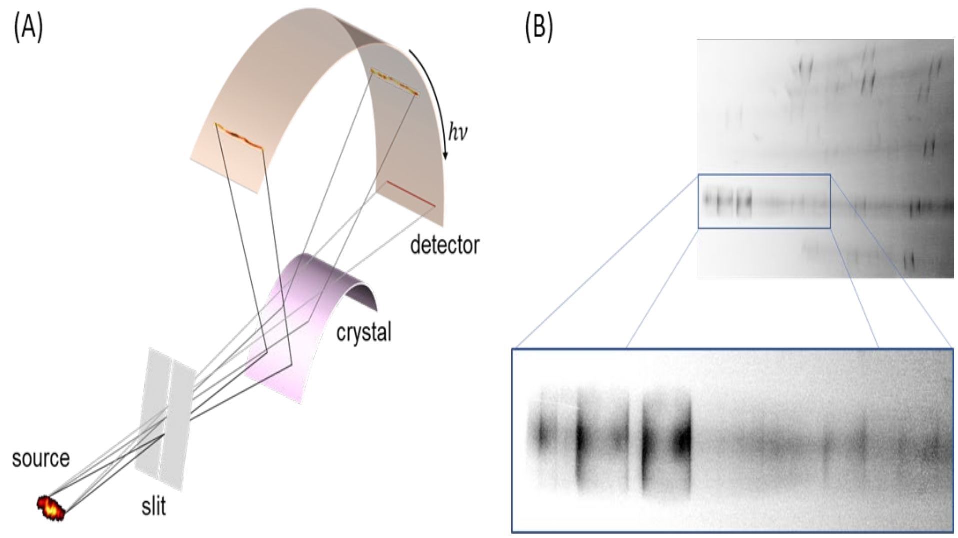


Images from the LIPIT system as part of Staska et al.'s project (STL-025-20) showing a particle being launched by an expanding film bubble. The particle size and velocity are determined from the images.

Radiographic Systems Imaging and Analysis

Broadband X-Ray Imager for Spectroscopic Diagnostics, PI: Radu Presura (SO-001-21, year 1 of 3)

This project is developing an x-ray spectrometer with the ability to image the source in each spectral line over a broad spectral range in order to enable 2D-space-resolved density and temperature measurements of hot and dense plasmas. This is done to better understand the morphology and dynamics of high energy density plasmas and to provide direct measurement comparisons with modeling code outputs in support of improving the predictive capability of both the spectrometer and modeling code.



(A) Schematic of the broadband x-ray imager. Its main component is a crystal bent convexly toward both the x-ray source and the detector; the crystal diffraction images in the direction of spectral dispersion and a slit image in the orthogonal direction. (B) Spectra of a cm-sized Henke source that was obtained with the broadband x-ray imager using a cylindrical potassium acid phthalate (KAP) crystal with 4 in. curvature radius and a flat detector. The left-to-right darker streaks are continuum spectra diffracted by different internal planes of the crystal. The region magnified shows the spectrum from the crystal surface, (001). Each "doublet" observed in the spectra is an image of the x-ray source at the energy of a characteristic line of one of the elements present in the Ag alloy anode.

Mission Agility

Technical Vitality

The ray-tracing calculations and the measurements to date have confirmed that it is possible to build an instrument capable of providing data for 2D plasma density and temperature mapping. Additional measurements will further constrain the design parameters and their value ranges. Further diffraction curve modeling and measurements are required. In aggregate, this information will be used to design instruments for specific high energy density plasma measurements. The design will include the option of using a multi-frame gated x-ray imager as a detector in order to provide data with spectral, spatial, and temporal resolution.

Mission Impact: The broadband x-ray imager for spectroscopic diagnostics is suitable for characterizing high energy density plasmas that are used to investigate radiation transport, radiation effects, and inertial confinement fusion. The technique is applicable for relatively large, cm-sized x-ray sources (such as the z-pinches produced on the Z machine or the dense plasma focus) and possibly for National Ignition Facility hohlraums. Directly or in conjunction with modelling, it will offer pointers for improving the target design. The rich information provided will offer opportunities for improving plasma and radiation modelling codes.

User-Centered Remote Testing and Operations

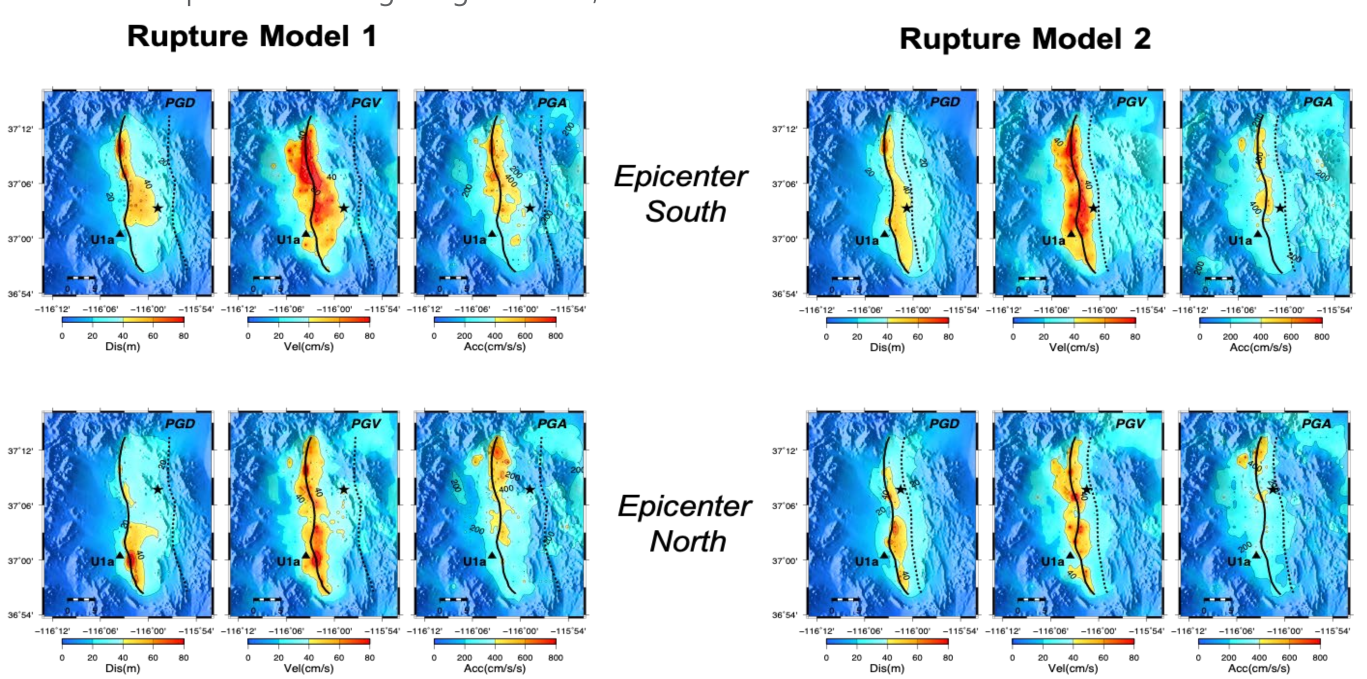
Determining the Seismic Hazard in Subsurface Facilities, PI: Michelle Scalise (NLV-003-21, year 1 of 2)

This project utilizes high-performance computing and physics-based models to simulate ground motion of a hypothetical magnitude 6.5 earthquake on the Yucca fault at the underground working level of critical facilities. Simulation results characterize the impact to critical facilities and improve resiliency in the event of strong seismic shaking.

Mission Agility

We have demonstrated a successful methodology to perform ground motion estimates for seismic hazard analysis of underground critical infrastructure at the NNSS. The capability heavily relies on comprehensive 3D geologic models, available geophysical data, and high-performance computing resources. Using alternative fault geometries and rupture initiations, simulations have determined that U1a is located near an area of amplified ground motion. Results have begun to capture variability in ground motion, but further simulations are necessary to fully analyze expected ground motion. Moving forward we plan to compute additional simulations and analyze the effect on the underground U1a facility.

Mission Impact: Having a methodology to quickly and efficiently model areas with critical infrastructure or potential testbeds is an important capability. This work will allow us to improve the accuracy of our strong ground motion predictions for future earthquakes and other seismic sources, and will help us develop appropriate measurements needed for protecting facilities located in areas with high seismic hazard. Models will provide information needed to protect valuable instrumentation that is critical to the facility from damage due to strong seismic shaking. Results support NNSS safety and resiliency. The



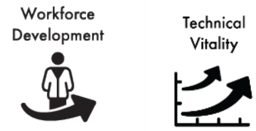
Ground motion simulations of a magnitude 6.5 earthquake on the Yucca fault. The solid black line indicates the surface fault trace; the dashed line is the fault plane at depth. The black star indicates the earthquake epicenter location. Rupture Model 1 assumes a shallow fault geometry, whereas Rupture Model 2 assumes a steep fault plane. PGD is peak ground displacement, PGV is peak ground velocity, and PGA is peak ground acceleration of a single scenario at the surface.

methodologies produced in this study can also be used to predict ground motion from underground explosions, and thus have the potential to advance our ability to detect nuclear testing. The modelling can provide a template for future development as well as provide a tool for operational mission partners to better understand whether an unknown signal is natural or man-made. Having accurate models is a core capability for discriminating signals and for determining accurate locations and yields also. Models that can accurately predict ground motion amplitudes provide critical information for determining more accurate yield estimates and locations of underground nuclear explosions.

Neutron Technologies and Measurements

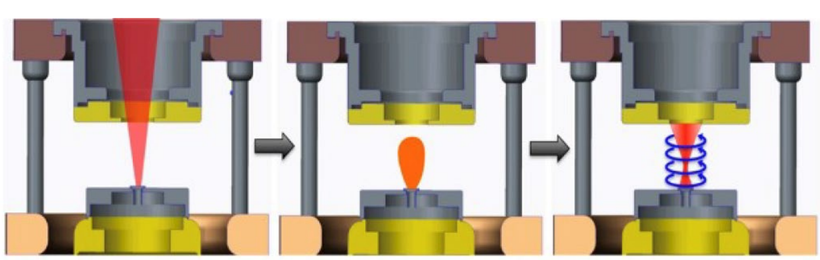
Z-Pinch and Laser-Ablation-Driven High-Yield Neutron Source, PI: Piotr Wiewior (LO-005-20, year 2 of 3)

The main objective of this project is to develop a new high-yield neutron source. Our novel concept uses a high-energy pulsed laser focused on a deuterated solid target to pre-ionize an ablation plume that is then pinched inside a z-pinch generator. This project will demonstrate the feasibility of this new approach, maximize the neutron flux, and obtain experimental data that will allow us to better understand the neutron production mechanism. The collaboration with UNR on this project also allows us to expand the number and diversity of students in the recruiting pipeline though a unique suite of experimental learning opportunities. In FY 2021, we performed the preparation work, re-commissioned most of the experimental systems, and rescheduled the experimental campaigns at UNR for FY 2022.



Our previous experimental results show promise for neutron production using the Laser Ablation Z-pinch Experiment (LAZE) method. Many parameters for pinching ablation plumes have not been explored, yet preliminary yields suggest that the LAZE technique is very encouraging. Yields in the mid 1012 neutrons/shot with very short creation time (<30 ns) were routinely possible and higher yields seem attainable. The data we have indicate that, in the experimental configuration we have investigated to date, a vast majority of neutrons are created by D+ ions that escape the plasma column and hit a catcher on the cathode on the z-pinch generator's target chamber. These data should help to inform improved models, such as magnetized plasma acceleration mechanisms that create supra-thermal ion and electron beams, and help to clarify the role of competing neutron production mechanisms. From the more practical point of view, the data suggest that it may be possible to significantly improve neutron yield by placing more deuterated material at the base of the plume. We must conduct further experiments to confirm the capabilities of the LAZE method. In FY 2022, we intend to conduct experiments with deuterated poly(ethylene) targets using different configurations and optimize neutron yield.

Mission Impact: A new neutron source driven by the laser/z-pinch combo can be a game-changer in the Nevada National Security Site (NNSS) mission space. Yields better than 10^{14} neutrons per shot with short creation time (<30 ns) can be available from a small,



Simplified scheme and time sequence of the proposed technique. The laser beam hits the target mounted on the z pinch generator's cathode plate. A plasma plume is launched across the anode–cathode gap, and then the plume is pinched by a magnetic field on the z-axis.

robust, safe platform. This will have a substantial impact on many mission-related programs, like special nuclear material detection, active interrogation of materials, neutron radiography, spectroscopy, and neutron-diagnosed subcritical experiments. The advantages of the new source are: high shot rate with excellent shot-to-shot reproducibility; targets can be made from non-traditional materials; targets are pre-ionized and more uniform; near solid-state density of deuterated material; relatively simple experimental setup with precise variable timing control between the laser pulse and z-pinch; and the laser can be focused off the *z* axis for asymmetric configurations and other "exotic" target geometries. Students participate in this project, so it will also become a recruiting pipeline for future NNSS personnel.

Enabling Technologies for Autonomous Systems and Sensing

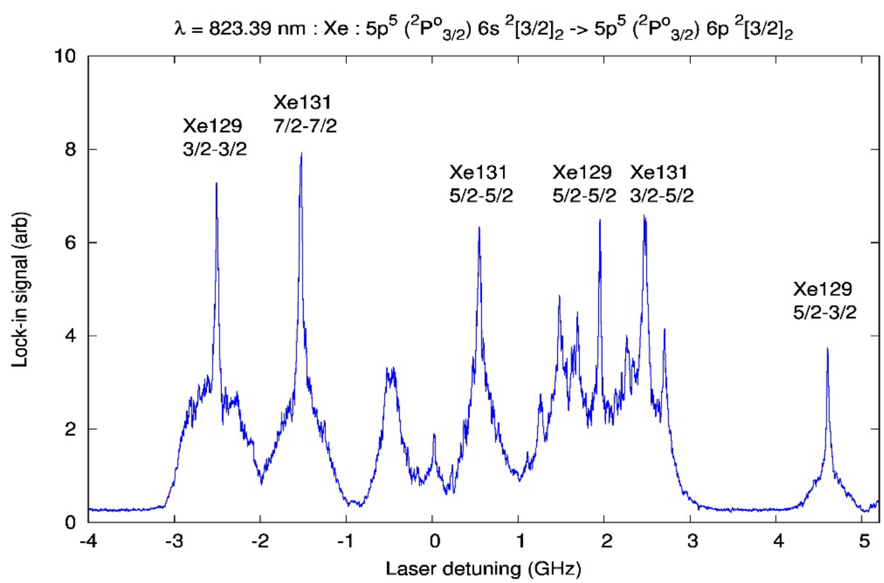
Radioactive Noble Gas Detection, PI: Rusty Trainham (STL-007-21, year 1 of 2)

Two methods of atomic hyperfine spectroscopy are being explored as a means to detect and quantify isotopic and isomeric abundances of the noble gases, xenon and krypton. One motivation for doing a hyperfine measurement is that it can potentially be several orders of magnitude more sensitive than a standard nuclear measurement when applied to radioactive noble gases, especially if the nuclear measurement requires a coincidence technique.

Technical Vitality

We investigated an atomic photo-absorption technique and design of a prototype portable instrument that should enhance sensitivity of radioactive noble gas detection by several orders of magnitude over standard nuclear detection techniques. The project team utilized a collinear fast beam laser spectroscopy (CFBLS) as a means for measuring atomic hyperfine structure of noble gases, and is exploring a design and viability for constructing a portable CFBLS apparatus for field deployment. Preliminary results from the discharge apparatus indicate that isotope populations can be measured by their hyperfine signatures. The results are from natural xenon, with only the isotopes ^{131}Xe and ^{129}Xe exhibiting hyperfine structure. The integer spin isotopes without hyperfine structure appear as a jumble of partially overlapping peaks, and are smaller in intensity than expected. Other excited state transitions may prove to be more favorable, especially when the radioactive isotopes ^{135}Xe and ^{133}Xe contribute to the jumble of resonances.

Mission Impact: Hyperfine spectroscopy can be utilized to measure isotope ratios of noble gas samples, and can potentially increase detection sensitivity by several orders of magnitude over standard nuclear spectroscopic techniques. Smaller volumes of air would need to be processed, and measurement times can be vastly reduced. The technique does not require radiation shielding, so a



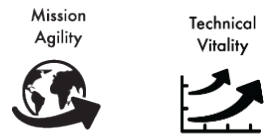
Xenon hyperfine resonance spectra from the rf discharge plasma. The scale of the laser detuning and the peak identifications are preliminary and uncertain.

portable apparatus can potentially be deployed closer to sites of suspected nuclear proliferation activities. Actionable data can be produced in a matter of minutes. As of this report, the plasma discharge apparatus is already producing preliminary data on natural xenon. The Fast Beam Laser Spectroscopy (FBLS) apparatus is still being refurbished, and is expected to become operational later in FY 2022.

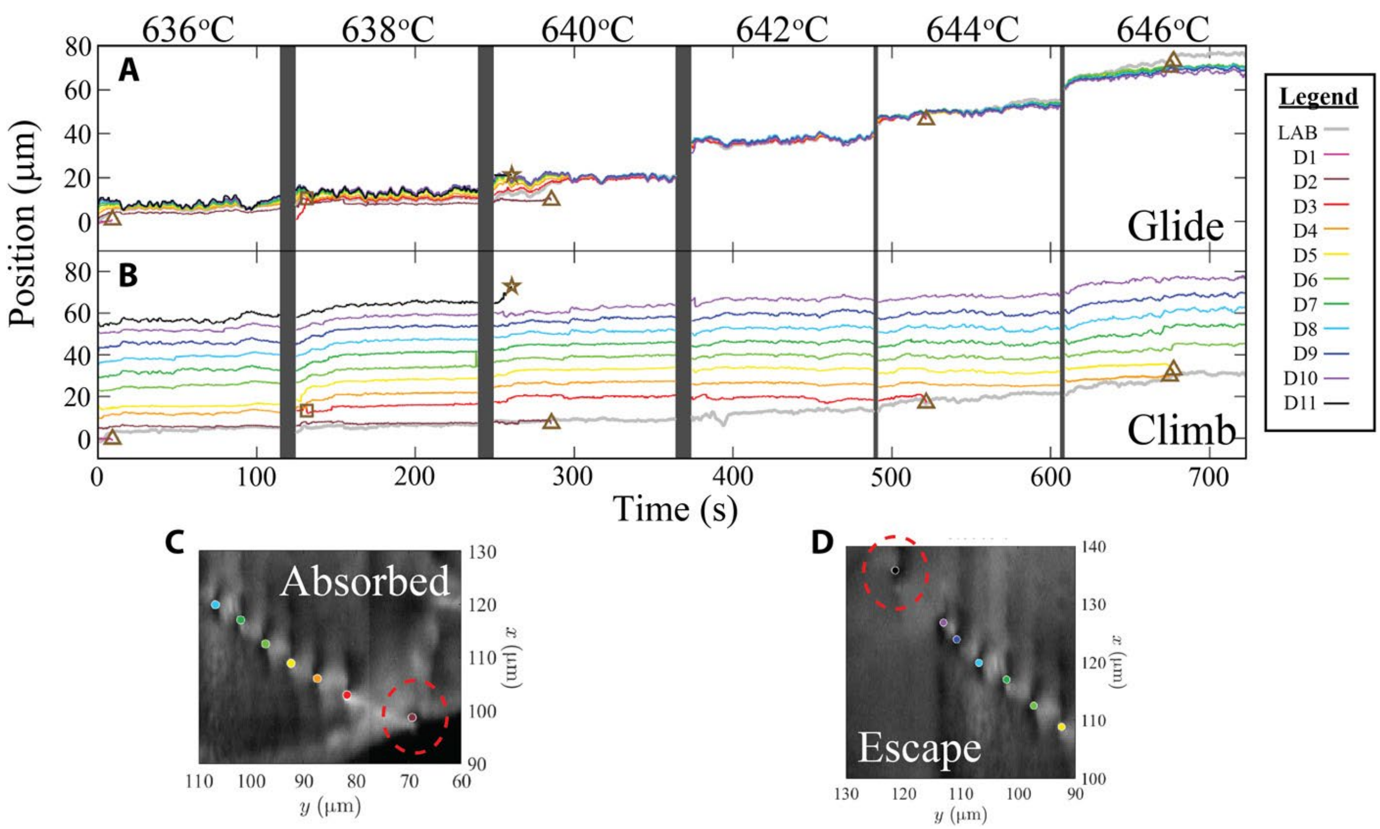
Dynamic Experiment Diagnostics

Dynamic Measurements of the Structural Evolution of Material Defects at the Mesoscale, PI: Marylesa Howard (NLV-001-19, year 3 of 3)

We have designed experiments and developed analytical methods using images from x-ray and electron microscopy in order to quantify the behavior of crystal dislocation defects at their native nanometer-length and micro-length scales. The results of these analyses are used to directly inform theoretical physics models and guide interpretation of dark field x-ray microscopy (DFXM) images that offer spatial resolution surpassing the resolution of beamline optics.



Dislocations are an extended linear defect in the atomic lattice that enables crystalline materials to prominently change their shape under mechanical loading. One focus of this project has been the development of analytic tools, using data collected from experiments at the European Synchrotron



The graphs in (A) and (B) above show the full evolution of the DB over six temperatures, from 0.97 to 0.99 Tm. We show the position of each dislocation in the boundary at each time and resolve the motion along the glide (A) and climb (B) directions. In both plots, 0 corresponds to the position of the first dislocation in the first frame at T = 636° C. The positions where dislocations are absorbed into low-angle boundary (LAB) are marked by brown triangles, the position where a dislocation escapes into the crystalline domain is marked by a star, and the position at which D3 inserts into the DB is marked by a square. To demonstrate how dislocations exit the boundary, we show representative frames of (C) how D2 is absorbed into the LAB and (D) how D11 escapes into the crystal, both at T = 640° C (exiting dislocations are circled in red).

Radiation Facility (ESRF), to map how dislocations move and interact in delocalized processes deep inside bulk materials. New tools were developed and implemented to resolve the individual and collective motion of the dislocations that comprise a dislocation boundary (DB) approximately 200 µm beneath the surface of single-crystal aluminum. Dislocations appear in DFXM images as bright/dark region pairs, and we can now quantify their behavior by identifying and tracking them within frames. The results of these analyses are used to directly inform theoretical physics models and guide interpretation of DFXM images that offer spatial resolution surpassing the resolution of beamline optics. Additionally, we developed new analytical methods to automate the alignment of optics hardware used in both synchrotron and x-ray free electron laser beamline facilities. The tools and workflows developed for this project are now being deployed as proof-of-concept in reaction history analysis for future programmatic integration.

Mission Impact: Fatigued materials may have a different response under extreme conditions than non-fatigued materials. The Stockpile Stewardship program develops theory to understand how materials fatigue over long timescales and how fatigued materials behave during a shock loading. The development of novel imaging tools in close collaboration with mathematical analysis developers will help us understand how defects form and cause material fatigue, allowing us to evaluate the potential role defects will play in these materials under extreme conditions. The image processing algorithms explored and developed over the duration of this SDRD project are currently being applied to nuclear event film analysis used in reaction history analysis. The goal of applying these methods is to improve film reading by enhancing the signal and quantifying the contribution of noise (film grain, in particular) to signal measurements and to produce a robust synthetic film dataset.

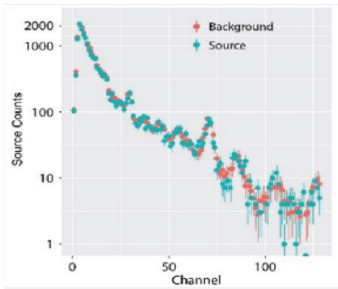
Communications and Computing

Incorporation of Physics Phenomenology into an Adaptive Algorithm Framework, PI: Carmelo Gonzales (RSLA-002-20, year 2 of 2)

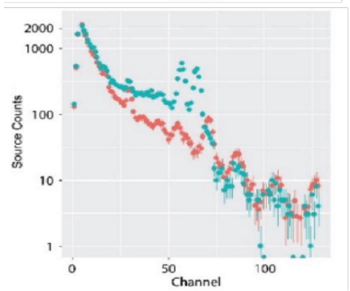
The primary focus of this project is to use physics-informed machine learning to enhance understanding of results produced by machine-developed algorithmic methods for the classification of spectra. Some may argue that this is unnecessary if the machine learning procedures are outperforming the human spectroscopists; however, the community has been resistant to the logic of proven best performance. Therefore, in this project we attempt to create models that provide a human interpreter with high confidence in the results, even if the actual statistical performance is not improved and may in fact be degraded to some degree.

We have developed physics-informed machine learning models that incorporate empirical physics knowledge into the latent space representation of an input, giving more insight into why models make certain predictions. Additionally, by bringing the distribution closer to a true probability distribution, our refinements in the softmax output provide classification results that are more interpretable. Finally, by assembling these techniques and using an applicability study in classifying spectra, we have shown that there may be a significant increase in in-domain awareness, where a multi-machine approach that both classifies input spectra and performs anomaly detection is utilized. This incorporation of physics knowledge into machine learning gives a human interpreter more insight into why machines behave the way they do, and may save time when using machine learning models in time-sensitive scenarios.

Mission Impact: Accuracy improvements may result from incorporating prior physics knowledge into adaptive models for spectral identification and detection, but the bigger impact is on interpretability, with the machine learning model now offering the analyst a thought process, rather than just a classification probability. Greater fidelity in classification, in terms of precision and accuracy, is naturally of interest in the radiological domain from a national security perspective. However, the greater value in this work is a methodology that emphasizes results that are more interpretable rather than more accurate; in this way the analyst will have more valuable information from which to form an opinion.

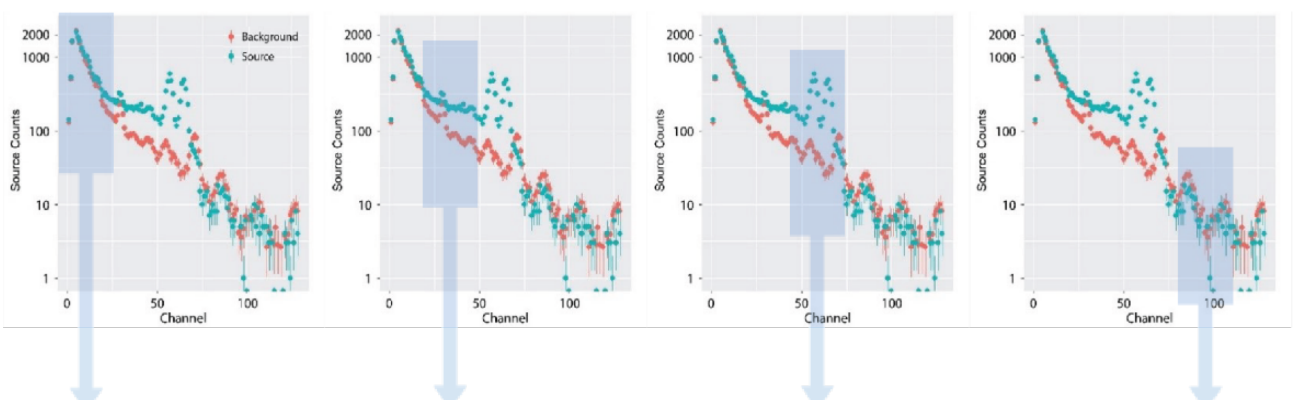


Class	Probability (%)
Background	**88.54**
^{152}Eu	1.314
⋮	⋮
^{137}Cs	0.325
^{60}Co	0.010



Class	Probability (%)
Background	0.233
^{152}Eu	1.161
⋮	⋮
^{137}Cs	2.411
^{60}Co	**96.01**

The two spectra show clearly identifiable sources: one background and one ^{60}Co. The machine classification is correct, but no reason can be assigned by the human analyst.



Class	Probability (%)
Background	3.5
^{152}Eu	7.1
⋮	⋮
^{137}Cs	**16.2**
^{60}Co	9.3

Class	Probability (%)
Background	0.5
^{152}Eu	3.2
⋮	⋮
^{137}Cs	**9.2**
^{60}Co	**14.3**

Class	Probability (%)
Background	0.003
^{152}Eu	0.023
⋮	⋮
^{137}Cs	**0.013**
^{60}Co	**99.032**

Class	Probability (%)
Background	**14.3**
^{152}Eu	2.1
⋮	⋮
^{137}Cs	**13.8**
^{60}Co	**13.1**

In this same example as above, the ^{60}Co spectra are now piecewise analyzed by the machine and individual probabilities assigned—the resulting overall analysis is the same, but now the human spectroscopist can see the machine's reasoning.

PROGRAM VALUE

The SDRD program uses quantifiable metrics to track the performance of our R&D investment from year to year. Metrics such as intellectual property, technology transfer to our programs, addressing R&D needs and requirements, and publications are some of the most common types of measurable outcomes. We also consider the importance of other factors, such as follow-on programmatic or external funding received, new methods developed that effectively reduce costs, and overall enhanced staff capabilities. These are further indicators of innovation productivity and are also a direct measure of investment return. SDRD provides our staff with opportunities to explore and exercise creative motivations that ultimately lead to new knowledge and realized technologies.

SDRD Program Performance Metrics

Invention Disclosures and Patents

Invention disclosures are the first step in our intellectual property pursuit and are often followed by patent applications when deemed appropriate. SDRD has generated well over half of all inventions disclosed company-wide since FY 2002. Since FY 2016 about one-third of our projects have generated new invention disclosures, which is a reasonably high ratio given that projects can vary widely from basic concept, low technical readiness to much higher more applied development efforts. In fact, our programs benefit from a high rate of technology utilization precisely due to this diverse project mix.

	FY17	FY18	FY19	FY20	FY21
Number of projects	30	28	28	29	39
Invention disclosures and patents	4	2	4	4	3
	13%	**7%**	**14%**	**14%**	**8%**

Technology Transfer

Approximately 1 in 3 SDRD projects produce technology that is subsequently adopted by a direct NNSS program. The ratio of needs addressed to total projects is also indicative of a trend that aligns efforts strategically with the NNSS mission. The program strives to effectively contribute new technology into key programmatic efforts as quickly as possible. New strategic efforts are also providing greater emphasis on forward-looking needs efficiently coupled with long-term visionary goals.

	FY17	FY18	FY19	FY20	FY21
Number of projects	30	28	28	29	39
Technology adopted by programs	4	2	11	9	13
	13%	**7%**	**39%**	**31%**	**33%**

Technology Needs Addressed

The NNSS technology needs assessment document includes guidance regarding technology gaps and challenges facing mission areas. Our directed research emphasis areas this year targeted key investment needs, including nuclear security, information security/assurance, high energy density physics diagnostics, integrated experiments, advanced analysis, and safeguarded energy. The *NNSS Technology Needs Assessment for R&D* is developed from a broad base of input from the national security complex, including laboratories, NNSA, and other external agencies, and it is updated annually. In addition to the assessment, at the beginning of each year's proposal call, we issue a Broad Site Announcement that contains detailed information on strategic initiatives in our directed research areas. A number of projects, but still a small percentage, are targeting emerging fields and new initiatives intended to incorporate higher risk; these projects explore opportunities for enhanced mission outside of traditional NNSS areas of expertise.

	FY17	FY18	FY19	FY20	FY21
Number of projects	30	28	28	29	39
Gap or need addressed	13	11	14	12	18
	43%	**39%**	**50%**	**41%**	**46%**
"Emerging Area and Special Oppor-tunity" effort*	5	6	3	6	18
	13%	**7%**	**39%**	**21%**	**46%**

* As defined in the *NNSS Technology Needs Assessment for R&D*

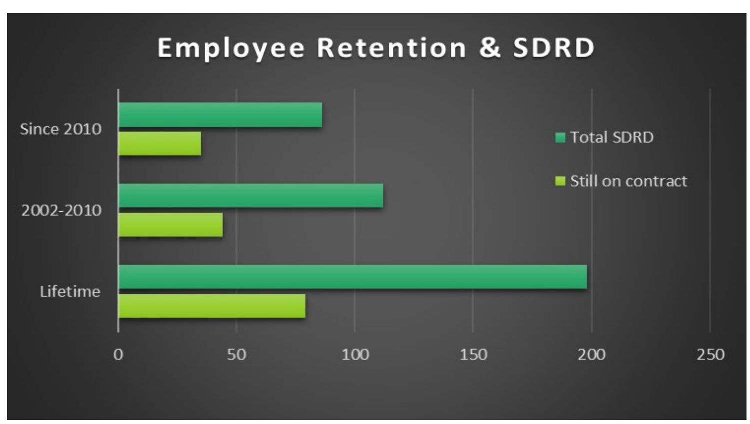
Publications

Publications are another indicator of R&D output and provide an archival record of the investments made, which are then available to the broader scientific and technical community. We place a strong emphasis on high-quality, high-impact journal publications. We generally expect about half of all SDRD projects will publish in a given year.

	FY17	FY18	FY19	FY20	FY21
Journal publications	8	8	10	24	21

Postdocs and Interns

The SDRD program welcomed its first postdoctoral PI in 2015. Since then it has attracted numerous postdocs and interns.
The contribution of these early-career scientists is significant. The program continues to enjoy the contributions of this group, having converted most to full-time staff. Since 2010, 41% of staff who participated in the SDRD program remain in the workforce, and from 2002 until the present 40% have been retained.



SDRD Impact Stories

The long-term value of SDRD is demonstrated by projects whose benefits to the NNSA's mission and then to the program emerge over many years. An SDRD project's lifespan may be only one to three years long, but research that is subsequently adopted by programs and funded by programmatic dollars can mature and provide the basis for long-lasting technologies. Following the evolution of our SDRD projects over five or more years demonstrates how our initial R&D investments yield a high return of programmatic capability.

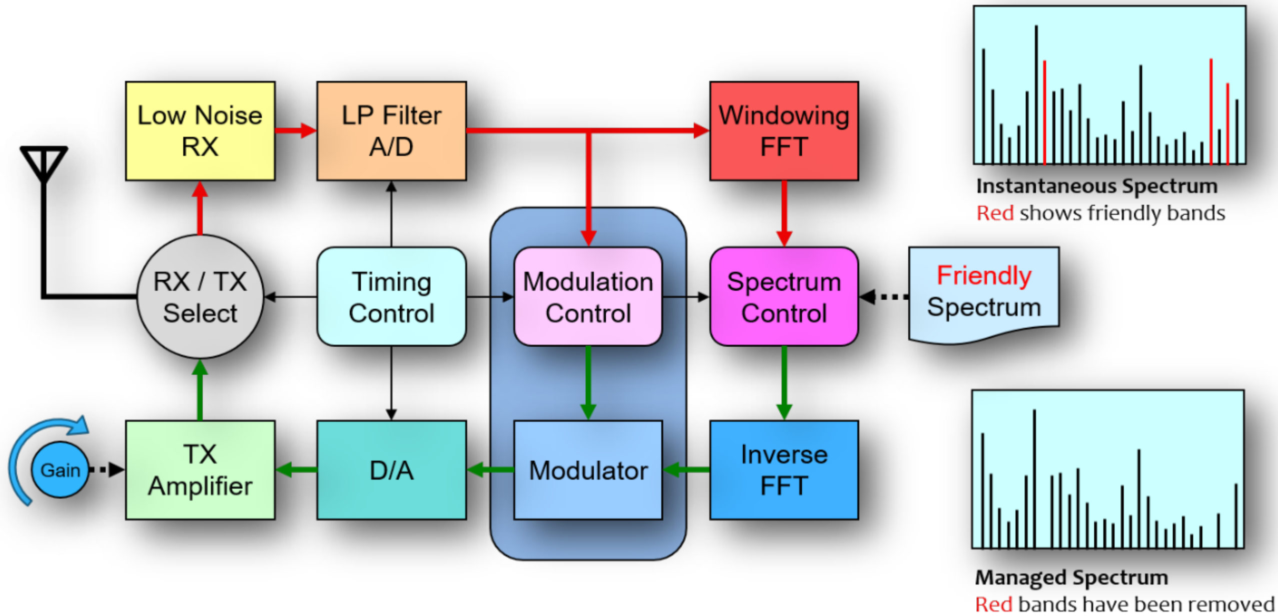
The two SDRD projects we highlight have reshaped the programs they impacted.

SDRD long-term project success: Patent to commercial startup

During the last decade, Nevada National Security Site (NNSS) Sr. Principal engineer Douglas Seastrand and an NNSS team have successfully leveraged project funding from the NNSS Site-Directed Research and Development (SDRD) Program to develop patented electromagnetic spectrum management technology. Seastrand worked with Rudolpha "Dolly" Jorgensen, Eric Schmidthuber, Ryan Martin, and Sean Sheehan on the Electromagnetic Spectrum Management System (ESMS) project, which developed into two patents for technologies to prevent unwanted radio frequency (RF) communications that are useful to the national security and law enforcement mission spaces. This SDRD project, initially developed in 2015 and patented in 2017, opens the way for possible follow-on work, such as exploring modulation control, inserting new or modified modulation, or providing real-time situational awareness of the RF environment.

The team's 2015 one-year SDRD project was titled "Concurrent Transceiver with Ultra-high-speed Fourier Transforms for Unrealized SIGINT Applications," (aka ESMS) and was created to control the RF radio waves propagating through an area. The ESMS system provides a revolutionary approach to controlling RF signals, removing all modulation from every RF signal that is not designated as "friendly," and optionally replacing it with new modulation—thus preventing (or jamming) and controlling all RF communications. The ESMS system selectively allows friendly RF signals to pass without being jammed—including frequency hopping and spread spectrum communication systems. The ESMS technology can near-simultaneously RX [receive] and TX [transmit] to let friendly communications through while blocking all other/unknown communications. ESMS is able to selectively pass or jam any RF signal within its bandwidth, currently up to 8 GHz.

Conventional jamming techniques have high power requirements. In contrast, the ESMS efficiently tailors each RF carrier output amplitude relative to the signal strength of its received carrier, and the user can determine the hemispherical area of influence to further limit power. ESMS inherently works with all modulation techniques and requires no foreknowledge of the unwanted carrier frequencies.



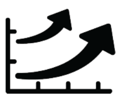
ESMS block diagram. The ESMS rapidly alternates between receive (RX) and transmit (TX) in order to digitize the received RF to produce an Instantaneous Spectrum of all RF carriers. This list of carriers is compared with the Friendly Spectrum to remove them from the Managed Spectrum list. The remaining carriers are considered unfriendly, so they are converted back into RF and retransmitted without their original modulation or with new modulation. The area of jamming influence is dependent upon the RF gain of the TX Amplifier.

It was so promising that, in 2021, Seastrand was nominated and accepted as a FedTech Startup Studio Finalist. FedTech connects scientific work done at the government level with public sector, first-time startup entrepreneurs who plan to grow and monetize inventions for the commercial market using government-generated intellectual property. The vetted entrepreneurs gain access to intellectual property information and federal funding and grants, while the NNSS gains recognition for its groundbreaking work that can be used to improve technology on a large scale. Although other NNSS cohorts were invited to compete for FedTech, Seastrand's invention was the first and only one successfully paired with the correct entrepreneurs, who have since worked with the NNSS to begin the engineering and commercialization of the ESMS product, forming the company Enfluxx Tech. Seastrand was involved in helping the newly founded company to understand the technology and identify potential customers. Enfluxx Tech worked with the mission and operations contractor's (MSTS's) Legal department for licenses to advance the technology from TRL 3 to TRL 6. Enfluxx Tech currently has an MSTS legal agreement for an R&D license to use the technology, and they are in the process of refining the engineering for commercial use.

Patent Notes: Patent filed on Apr 4, 2016. Patent (# 9,559,803 B2) First Awarded on Jan 31, 2017 and Patent (# 9,794,021 B2) Perfected on Oct 17, 2017. Patent Holders: Douglas Seastrand, Rudolpha "Dolly" Jorgensen, Eric Schmidthuber.

This work was done by Mission Support and Test Services, LLC, under Contract No. DE-NA0003624 with the U.S. Department of Energy, the Office of Defense Programs, supported by the Site-Directed Research and Development Program. DOE/NV/03624—1456

SDRD researchers are working with next-generation talent to lay the groundwork for machine learning in stockpile science at NNSS



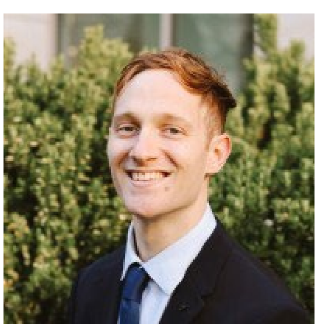
Margaret Lund, senior scientist and mathematician in the NNSS Computing and Data Science group, is leading a dynamic team investigating and developing deep learning methods for applications in stockpile science, specifically in the area of radiographic systems imaging and analysis. Deep learning is a branch of machine learning that uses neural networks to process information in layers. A deep neural network has multiple hidden layers between input and output layers, and as such, has a greater capacity to learn and generalize more complex datasets. Deep learning techniques are especially useful for analyzing complex data such as images. The primary goal of Lund's two-year R&D project is to lay the groundwork for deep learning capabilities within the radiography analysis team at the NNSS. The project is currently in the second year, building on the work accomplished in FY 2021.

Dr. Margaret Lund

Year 1 of the project focused on improving training efficiency and network accuracy, which resulted in the development of a new pooling technique, the implementation of a new unsupervised method for improving training sets, and the exploration of a new technique for identifying the scope of a trained network. Lund said that every member of her team played an active role in achieving these results. In particular, she pointed out how important it was for her to have two talented and driven summer student interns on her team. The 2021 NNSS student internship program enabled her to hire two recent graduates from Brigham Young University (BYU). Chelsey Noorda, with her primary research interest in novel pooling methods, and Jared Slone, with his research focus on uncertainty quantification methods, brought different but complementary skill sets to the team. They contributed independently to the project, but they also worked well as a team, brainstorming ideas and formulating creative solutions to difficult problems. "This model of independent research combined with team problem-solving worked so well that I've decided to hire two interns again this summer," said Lund.

Intern Chelsey Noorda of BYU

The project team also hosted a group of undergraduate students from the Mathematics Department of Embry-Riddle Aeronautical University (ERAU) last spring. In partnership with ERAU faculty member Mihhail Berezovski, four students from Berezovski's Research Projects in Industrial Mathematics class spent the semester working on developing neural networks for this SDRD project. This partnership was so successful that six students from Berezovski's class have chosen to participate in the project this spring. Additionally, the team hosted three Research Experience for Undergraduates program students, two students from ERAU and one student from the University of Toledo, last summer. The students spent the summer months testing the capabilities of the new pooling method the team developed and wrote a research paper to submit to *The Beyond: Undergraduate Research Journal*, ERAU's peer-reviewed research publication.



Intern Jared Slone of BYU

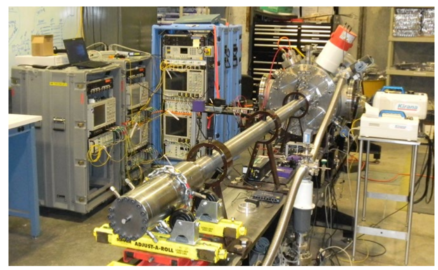
"I will say one thing about these collaborations," said Lund. "There are times when these students are even better suited to doing this work than I am. When I was in undergrad, my university had zero classes in machine learning. When I was in my master's program, there was one class in machine learning.... Students now are learning things far more advanced than I ever learned. This SDRD project is so well suited to capitalizing on these student skill sets." This project illustrates the important role the SDRD program plays in maintaining the scientific and technical vitality of the NNSS through investing in and promoting workforce development. As noted in the 2019 Strategic Framework document for the NNSA LDRD and SDRD programs, "Cutting-edge research and development across the technical spectrum attracts cutting-edge talent." This SDRD project is an example of how the SDRD program helps recruit, train, and retain tomorrow's technical workforce in essential areas of expertise critical to national security.

Find more information about this work on the OSTI.gov website.

Aligning SDRD: Building Foundations, Building the Future

As the SDRD program emerges from the continuing challenges of the limitations and restrictions imposed by the world-wide pandemic, SDRD continues to be positioned for a stimulating future.

In FY 2021, the NNSS realigned the SDRD program with the new Science & Technology (S&T) directorate's strategic vision, which was developed in conjunction with seven thrust areas. These thrust areas have a strategic alignment to the following NNSA mission areas: NA-10 Office of Defense Programs; NA-20 Office of Defense Nuclear Nonproliferation; NA-40 Office of Emergency Operations; NA-80 Office of Counterterrorism and Counterproliferation; NA-IM Office of Information Management; and Strategic Partnership Projects/Strategic Intelligence Partnership Projects. The goal of this realignment is to provide enhanced (or new) ST&E capabilities to the NNSS that will enable agility at responding to future national security threats. As the SDRD program engages this transition, it is better positioned to peer further into the future than it has since its beginning in 2002 as it incorporates the nascent NNSS Science and Technology Thrust Areas (STTAs).



The Hybrid Electromagnetic Launcher holds the promise to provide drastic improvements on operational tempo which may significantly reduce costs of operating JASPER leading to increased shot availability for the labs to gain better understanding on SNM EOS.

Paul Guss
SDRD Program Manager
Nevada National Security Site

As the STTAs quickly mature, our principal investigators and their teams will be challenged to take on strategic initiatives in focused areas that are the foundations of future technologies, the technologies of decades to come. This calculated leap forward is propelling the program into an exciting new era and to the next level of innovation and expansion that will benefit all facets of our national security mission. SDRD will deliver innovative, advanced technical capabilities in support of NNSA missions for defense experimentation, defense nuclear nonproliferation, nuclear threat reduction, and other national security endeavors.

August 2022

Acknowledgments

SDRD requires a talented team of individuals to ensure success from year to year. Without their support, none of this would be possible.

Special acknowledgment and appreciation go to Kaela Dotson, Kristen Macias, Ki Park, Anne Totten, and Dorothy Vanderford, assisted by editor Katsura Rast, for technical communications and compiling, editing, and publishing this report; to Kristen Macias for providing document design; to Leslie Esquibel, Emma Gurr, and Sally Matthews for project management and cost accounting efforts; to Michael Baldonado for information system support; to Elizabeth Davis, Eduardo Morales, and Stacey Duffy for financial data reporting; to Larry Franks and Lynn Veeser for technical guidance and support; and to our SDRD technology representatives and technical review committee: Jesse Bonner, Frank Cverna, Eric Dutra, Daniel Frayer, Rick Freeman, Brady Gall, Paul Guss, Marylesa Howard, Brandon La Lone, Amy Lewis, Mary O'Neill, Alex Plionis, Patrick Sawyer, Jerry Stevens, and Rusty Trainham. And, finally, special thanks to members of our external advisory board, Ryan Camacho, Larry Franks, Carl Ekdahl, Damon Giovanielli, Ralph James, Paul Rockett, Maurice Sheppard, Ralph Schneider, and Gerry Yonas, who graciously give their time and provide ongoing, valuable recommendations.

FY 2021 SDRD Projects

(www.nnss.gov/pages/programs/sdrd.html)

(U) Physics-Informed Deep Learning with Uncertainty Quantification for Weapons Radiography, M. Lund (NLV-003-21)

4-D Aggregate Deconvolution for Aerial Measurements, A. Guild-Bingham (RSLN-026-20)

Advanced Characterization of Spatial Aspects of Image System Blur, D. Frayer (NLV-004-19)

Broadband X-Ray Imager for Spectroscopic Diagnostics, R. Presura (SO-001-21)

Design and Produce Machined Spectrometer Frame, D. Baldwin (STL-045-21), Feasibility Study

Detection and Defeat of Autonomous System Sensors, J. Brookley (STL-044-21), Feasibility Study

Detector Wall Research for Fast Gamma Signal Detection in Neutron-Diagnosed Subcritical Experiment Applications, S. Baker (LAO-026-20)

Determining the Seismic Hazard in Subsurface Facilities, M. Scalise (NLV-030-21)

Dual Comb Spectroscopy for Definitive Identification of Gas at Speeds Faster than Turbulence Effects, E. Larson (STL-006-19)

Dual-Use High-Z, High-Cross-Section Materials for Neutron Imaging and In Vivo X-Ray Cancer Drugs, J. Di Benedetto (STL-039-21)

Dynamic Measurements of the Structural Evolution of Material Defects at the Mesoscale, M. Howard (NLV-001-19)

Dynamic Submicron Particulate Behavior in Turbulent Media, C. Kimblin (STL-008-20)

Electromagnetic Launch Modification to C3 Launcher for Increased Velocity, M. Hawkins (NLV-018-21)

Enhancing Deep Cavity Detection Using Orthogonal Measurement Techniques, M. Howard (NLV-030-20)

Evaluating Use of the NASA Nowcast of Atmospheric Ionizing Radiation for Aviation Safety (NAIRAS) System for Verifying/Validating AMS Cosmic Background Radiation Measurements, B. Mcgee (RSLA-006-20)

Fast Methods for Geometric Inference in Limited-Angle Tomography, S. Breckling (NLV-019-20)

Gamma Single-Hit Detector for NDSE, D. Schwellenbach (LAO-034-21)

High Energy Neutron Production in a Laser-Generated High Density Plasma, J. Tinsley (STL-012-20)

High-Fidelity Dynamic Neutron Imaging and Radiography for Subcritical Experiments and Other Applications, M. Wallace (LO-005-19)

Incorporation of Physics Phenomenology into an Adaptive Algorithm Framework, C. Gonzales (RSLA-002-20)

Indirect Measurement of Underground Facility Expansion/Extent through the Multi-Modal Use of Cyber Metadata (Traceroutes) and Physics-Informed Models Applied to Pre-Post Digital Surface Mapping, D. Champion (NLV-012-21)

Laser-Induced Particle Impact Test (LIPIT) and Micro-Pin Investigation of Ejecta/Surface Interactions, M. Staska (STL-025-20)

Measurement of Dynamic Melting and Re-Crystallization of Shocked Metals, R. Scharff (LAO-031-21)

Micro-Ion Traps for Real-Time Chemical Analysis in Harsh Environments, M. Manard (STL-002-20)

Millimeter-Wave Imaging Diagnostic for High-Explosive Fireball Characterization, I. Mckenna (STL-011-19)

Multi-Layered Avalanche Diamond Detector for Fast Neutron Applications, A. Guckes (NLV-003-20)

Multi-Modal, Multi-Energy Approach for Neutron Interrogation of Spent Fuel, P. Guss (RSLN-022-19)

New Methods to Study the Kinetics of Phase Transformation in Shocked Cerium Metal, G. Stevens (STL-031-21)

Nuclear Thermal Rocket Testbed Restart Feasibility Study, C. Rosaire (NLV-019-21), Feasibility Study

Optical Phased Array Feasibility Study, B. La Lone (STL-029-21), Feasibility Study

Performance Monitoring by Simultaneous Sensing of Integral Gas Exchange and Respiration Patterns—Pythia Phase II, E. Stassinos (STL-037-21)

Phenomenology and Node-Level Processing of MASNIT Sensor Data Distributed Sensor Networks, E. Miller (STL-016-19)

Predicting Potential 'At Risk' Power Infrastructure: A Study of the Feasibility of Predicting the Downing of Power Lines At NNSS, S. Kamath (STL-021-21), Feasibility Study

Radioactive Noble Gas Detection, R. Trainham (STL-007-21)

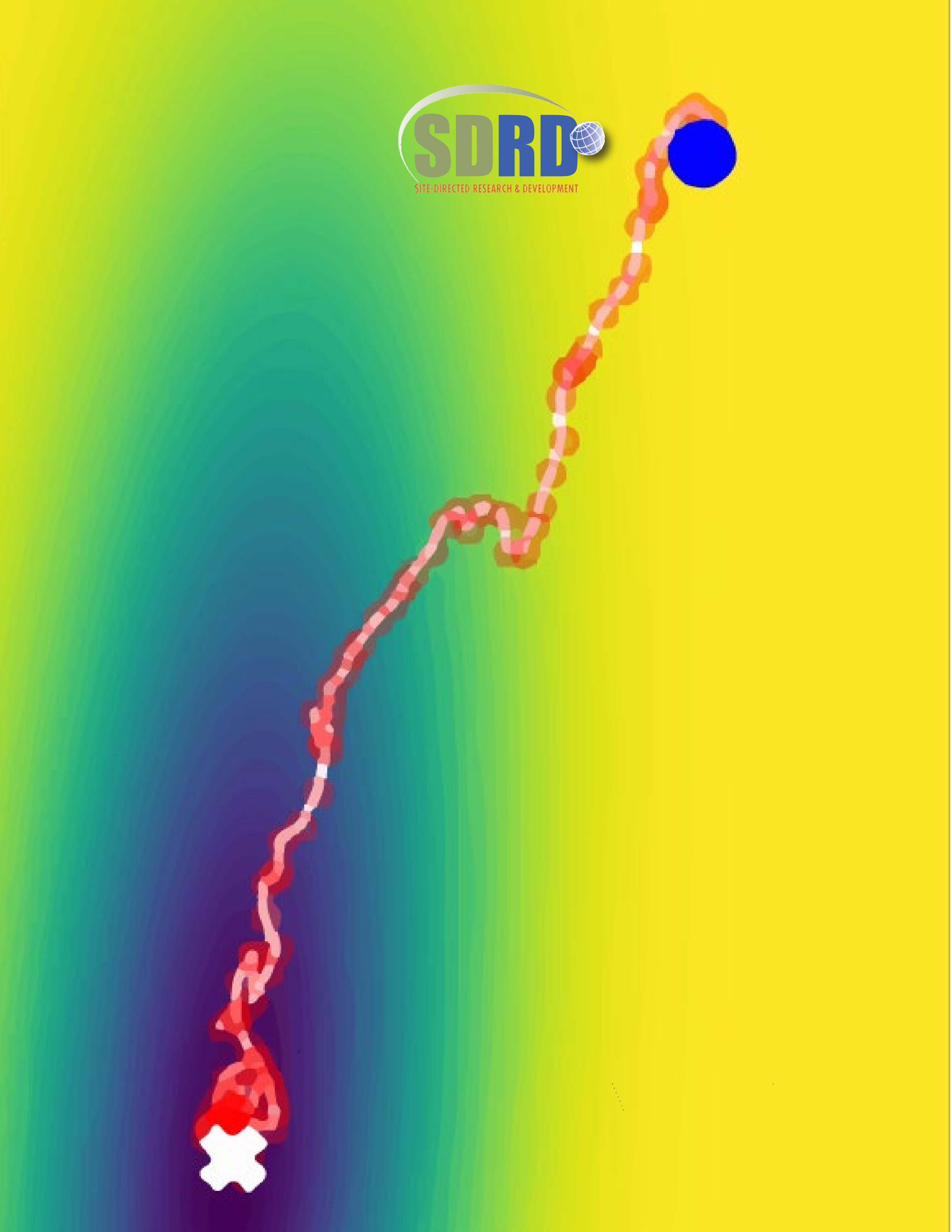
Re-Purposing Old Seismic Data to Calibrate Nuclear Test Monitoring Sites in Sparse Seismic Regions, R. Turley (NLV-026-21)

SWIR LED-Based Dual Comb Spectroscopy for High Value Gas Detection, D. Baldwin (STL-038-21)

UAS Sensors in Difficult Locations, R. Trainham (STL-016-20)

Using CARS to Determine the Dynamic Temperature of Ejecta Particles Reacting with Surrounding Gas in a Shock Compression Experiment, J. Mance (STL-042-19)

Z-Pinch and Laser-Ablation-Driven High-Yield Neutron Source, P. Wiewior (LO-005-20)


SDRD
SITE-DIRECTED RESEARCH & DEVELOPMENT