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SDRD

SITE-DIRECTED RESEARCH & DEVELOPMENT

Site-Directed Research & Development Program

FY 2025 Annual Report

How to Read this Report

The SDRD program's annual report for fiscal year (FY) 2025 consists of two parts: the Overview, which contains the three major sections of Program Description, Program Accomplishments, and Program Value; and individual project report summaries. Public summaries are included at the end of this report and published electronically on the Nevada National Security Site's website, https://nnss.gov/mission/sdrd. Controlled project summaries are available in the CUI document. Complete technical reports for concluding projects are available internally on iCon or from the principal investigator. Contact the SDRD Program Office at SDRDAdmin@nv.doe.gov for more information.

On the Cover

Front cover: Still of the numerical inversion of temperature versus the velocity error magnitude from the project "Computational Fluid Dynamic Simulations for Critical Infrastructure (CFD-SCI)," S. Breckling (25-016).

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SITE-DIRECTED RESEARCH & DEVELOPMENT

Site-Directed Research & Development Program

FY 2025 Annual Report

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Letter from the Chief Scientist

As we commemorate the 75th anniversary of the Nevada National Security Sites (NNSS), it is with great pride in our enduring legacy of research and development that I submit the Fiscal Year 2025 (FY25) Site-Directed Research and Development (SDRD) Annual Report.

Since its inception, the SDRD program has been the engine of discovery at the NNSS, developing innovative scientific solutions and rejuvenating the technical foundation necessary for our national security missions. The program is built on three core objectives: ensuring **Mission Agility** to respond to emerging challenges, advancing our **Technical Vitality** by serving as a proving ground for new concepts, and promoting **Workforce Development** to attract and retain tomorrow's critical technical experts.

SDRD projects are aligned with our strategic priorities, driving innovation across key Science and Technology Thrust Areas (STTAs), including:

- Advanced Radiation Sources (ARSO)
- Dynamic Experiment Diagnostics (DED)
- Radiography & Analysis for Photonic Imaging Detector Systems (RAPIDS)
- Emergency Response Operations Sensors and Systems (EROSS)
- User-Centered Remote Testing and Operations (UCRTO)
- Technology and Research in Artificial Intelligence for Nuclear Security (TRAINS)

Key achievements in FY25 underscore the program's impact. Highlights include the development of digitized solid-state photomultipliers to replace obsolete but critical detection hardware, and a novel infrasound analysis technique that leveraged data from the historic Tropicana hotel implosion to improve atmospheric monitoring. These efforts, among many others, exemplify how SDRD continues to enhance our diagnostic and analytical capabilities.

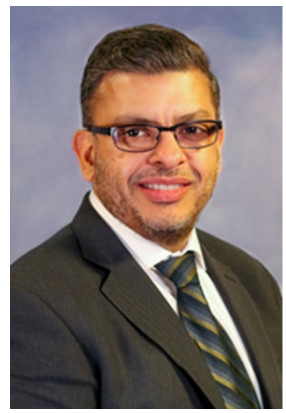
Our commitment to collaboration ensures a vibrant future for the NNSS. The Strategic Initiative Colloquium Series, for example, has been instrumental in bringing external experts from national laboratories and top universities to the NNSS, fostering a collaborative educational environment and developing the skills of our scientists and engineers for future challenges like the Scorpius accelerator.

The excellence of our people and their research was recognized at the highest level this year. I am exceptionally proud to highlight that SDRD Principal Investigator Dr. Amber Guckes received the Presidential Early Career Award for Scientists and Engineers (PECASE) for her pioneering research in next-generation radiation detectors.

Within this report, you will find a detailed overview of the program's accomplishments, performance metrics, and impact stories. It also provides summaries for the 39 projects funded in FY25, showcasing the remarkable breadth and depth of the research undertaken.

I am confident that the SDRD program's unwavering dedication to scientific discovery and collaboration will keep the NNSS at the forefront of innovation, ensuring we remain prepared to meet the complex national security demands of today and tomorrow.

February 2026



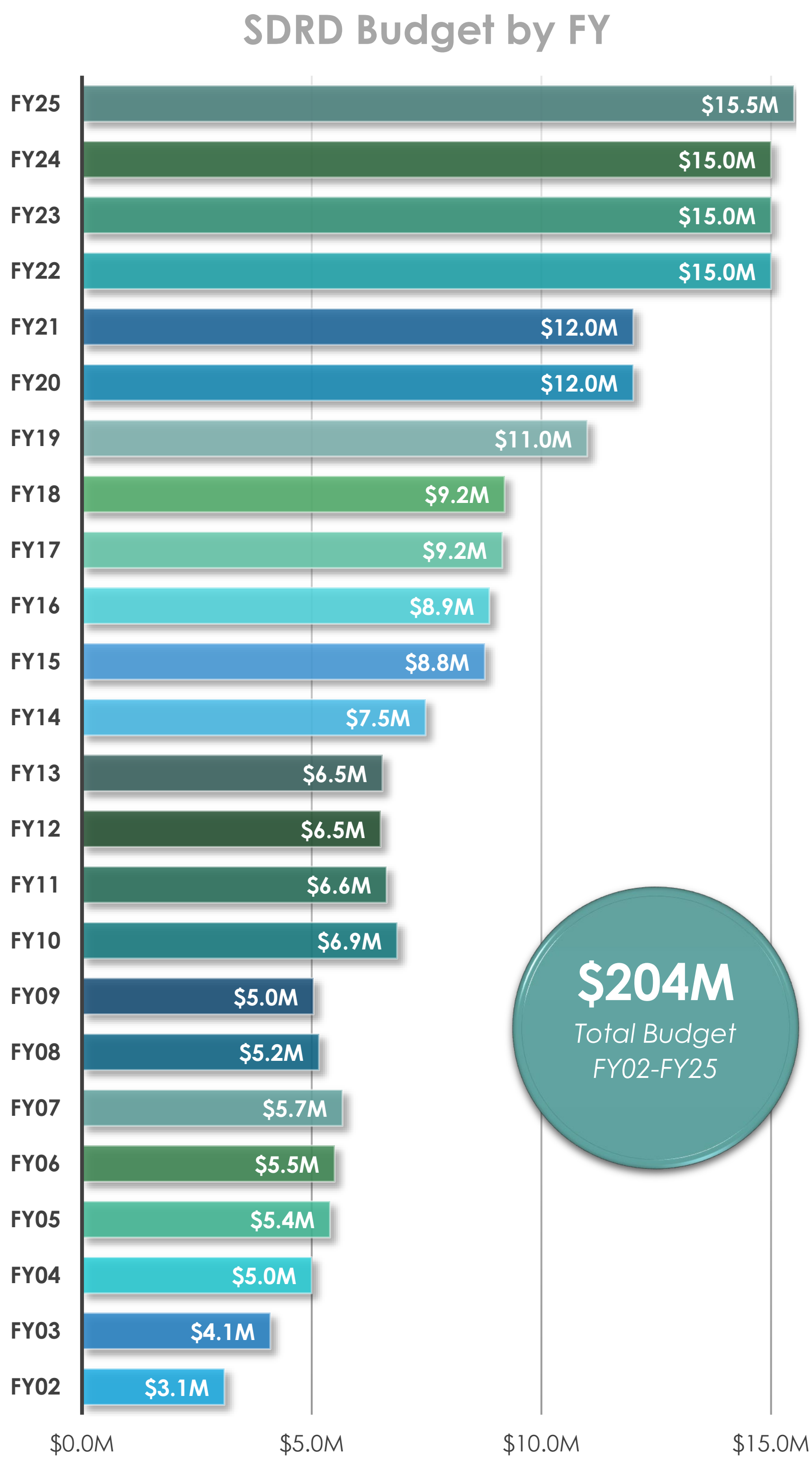
José O. Sinibaldi, Ph.D.
Director of Science & Technology
Chief Scientist

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 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 $15.5M has been allotted for FY 2026 by the senior management team. As the illustration on this and the previous page shows, SDRD has made a significant impact in the past 23 years, providing over 240 innovative technologies to NNSS programs from 2002 to 2025, a high return on the investment of R&D dollars.

2260
Total Proposals

841
Total Projects

239
Total Unique PIs with Projects

373
Gaps or Needs Addressed

243
Technologies Adopted by Programs

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.

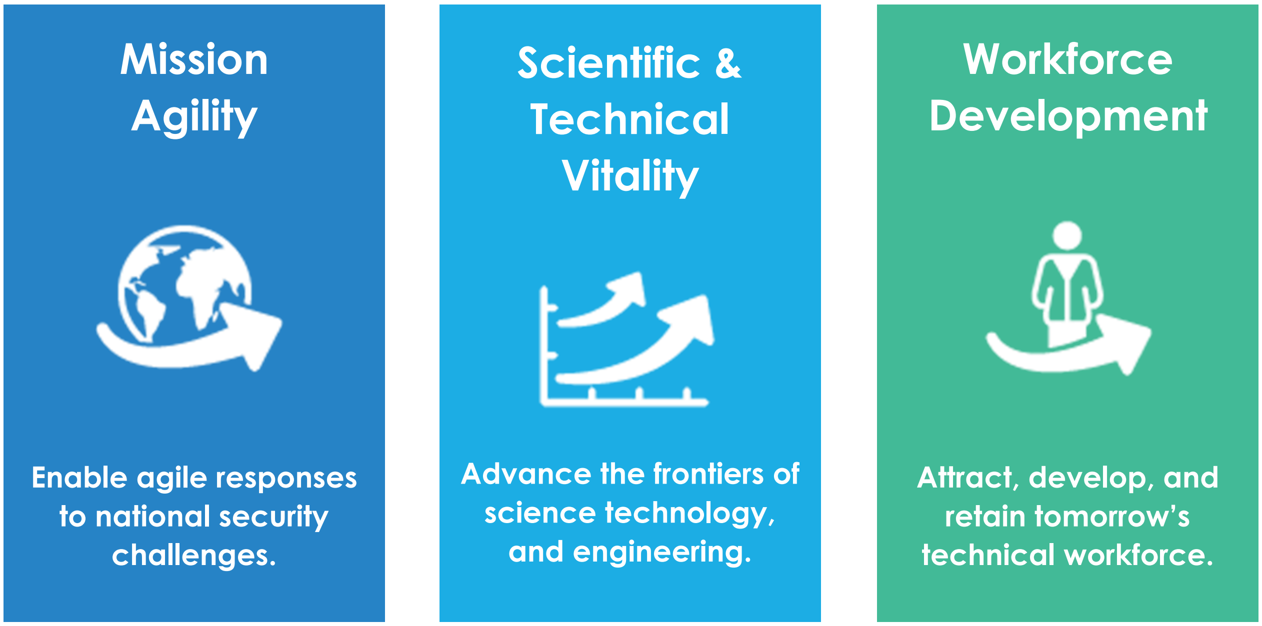
These objectives underpin the 2019 Strategic Framework for the NNSA Laboratory and Site-Directed Research and Development, a document signed in July 2019 by the three NNSA laboratory directors, Mark Martinez (former NNSS President), and Lisa E. Gordon-Hagerty (former Under Secretary for Nuclear Security 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, "[t]hrough 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."

Mission and Objectives

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

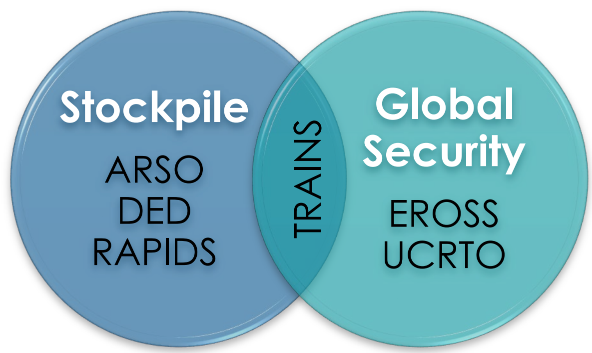
The research projects featured on pages 19-22 are keyed to the three objectives, as indicated by these icons.

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 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 the NNSS mission to the nuclear security enterprise.

The SDRD program manager and deputy program manager are the points of contact for SDRD and are responsible for all practical aspects of the program. The program manager and deputy manager are assisted by the NNSS Science and Technology Thrust Area (STTA) leads and SDRD site representatives to coordinate technical activities undertaken by 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.

Science and Technology Thrust Areas



The NNSS 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.

Each STTA encompasses a specific segment of science and technology conducted at the NNSS. The Emergency Response Operations Sensors and Systems (EROSS) and User-Centered Remote Testing and Operations (UCRTO) STTAs fall within the NNSS' Global Security mission. The Advanced Radiation Sources (ARSO), Dynamic Experiment Diagnostics (DED), and Radiography and Analysis for Photonic Imaging Detector Systems (RAPIDS) STTAs align with the Stockpile Stewardship mission. Technology and Research in Artificial Intelligence for Nuclear Science (TRAINS) uniquely supports both mission areas. STTA leads 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 missions and are an integral component of the SDRD program. The STTA leads are involved in shaping the program as well as integrating STTA goals with defined strategic initiatives directed to SDRD proposers.

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 result in high-reward technological advances of profound benefit to naturally risk-averse programmatic projects.

Call for Proposals

We utilize a two-phase proposal process consisting of a white paper (concept phase) followed by an invited proposal. In the white paper phase, staff are encouraged to submit ideas in a standardized, succinct format that presents the proposed project's essence and impact. In addition, during the white paper 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 Call for Proposals (CFP) and the SDRD Strategic Investment Plan (SIP). Updated annually, the SIP lists Focus Areas that are created from conversations between program Directors and SDRD STTA Leads and helps proposers tailor their proposals to programmatic priorities.

Project Selection

All submitted white papers are evaluated by Program and Senior Director reviewers or their designee. Criteria considered in the evaluation of white papers include their alignment with NNSS' 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 white papers are evaluated with a "cold," "warm," "hot" Likert scale. The scores are then compiled, and a ranking is determined.

Typically, about 50% of the white papers are promoted to full invited proposals. SMEs evaluate how well each proposal addresses the core questions based on the Heilmeier approach to R&D. Invited proposals are also evaluated with a weighted scoring matrix 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 on the SDRD program website.

The final selection of SDRD investments for the next fiscal year is made and an annual program plan is submitted to the NNSA in mid-August. Notification of NNSA concurrence is received prior to October 1.

Feasibility Studies

Several investigative feasibility studies are funded each fiscal year. In FY 2025, there were a total of six 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 began as feasibility studies.

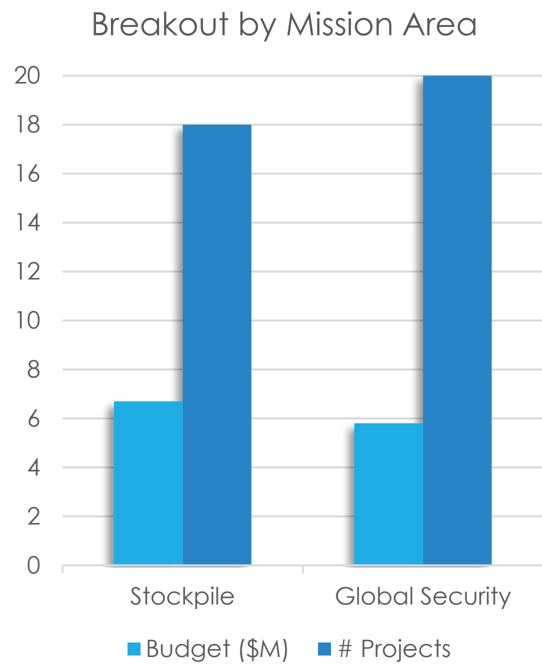
Figure 1. Scorpius modules installed at the Integrated Test Stand in North Las Vegas. Dr. Amber Guckes' FY25 feasibility study ("Combined Radiation Environment Modeling Using Scorpius," 25-170) explored the feasibility of using the Scorpius linear induction accelerator as a unique combined effects simulator.

SDRD Portfolio

Mission Categories

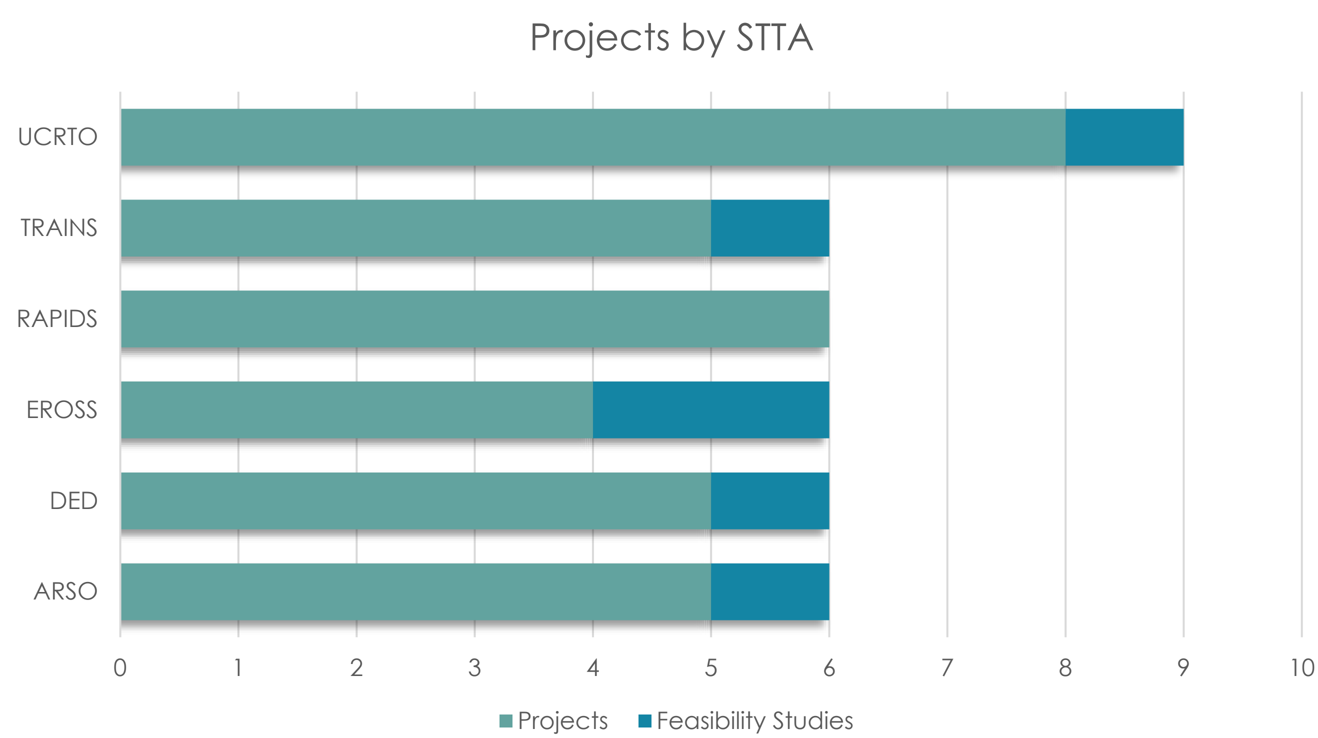
The SDRD portfolio falls into two primary mission categories: stockpile stewardship and global security.

Historically, PIs have submitted a nearly equal number of ideas addressing stockpile stewardship and global security areas. In FY 2025, there were 18 projects and approximately $6.7 million in funding for stockpile stewardship, while global security had 20 projects and approximately $5.8 million. In FY 2025, the total amount of funding requested for SDRD was $15.5M—roughly 43 percent was allocated to the stockpile stewardship mission category and about 37 percent to the global security mission category.



Alignment within Science and Technology Thrust Areas

Beginning FY 2021, each funded project is also aligned with one of the NNSS STTAs according to its focus. In FY 2025, there were a total of 39 projects, of which 6 were feasibility studies and 1 was an Interlaboratory project. The chart below shows the number of FY 2025 projects that fall into each of the six STTAs.



List of All Projects for FY25

Adapting the Continuous Imager to Use High-Z Semiconductors for High-Speed Direct X-Ray Imaging, C. Leak (25-101)

Advancing NNSS Geological Modeling Capabilities, D. Smith (25-091)

Background Subtraction and Noise Reduction via Machine Learning, C. Watkins (25-055)

Cloud-Based Meta-Analysis with Adaptive Learning for Massive Sensor Networks, C. Schuetze (25-117)

Collection and Analysis of NFC Signature Gases with Metal-Organic Framework Solids, M. Morey (25-021)

Computational Fluid Dynamic Simulations for Critical Infrastructure (CFD-SCI), S. Breckling (25-016)

Data Fusion: Reconstructing 3D Hydrodynamic Scenes Utilizing Both Radiography and Momentum Diagnostics, J. Pillow (25-052)

Design of a Multi-Pathway Communications Device with Adaptive Intelligence, J. Essex (25-105)

Design, Analysis, and Testing of Embedded and Free-Standing Asay Window Sensors to Measure Material Density in Dynamic Experiments, G. Stevens (25-082)

Developing Time-Resolved X-Ray Diffraction Capabilities for Dynamic Shock Experiments, M. Wallace (25-134)

Development of Assessment Methodology for Fielded Radiation Detector Crystal Characterizations, J. McCumber (25-012)

Digitized Nanosecond Silicon-Germanium Photomultipliers for Prompt Radiation Detection, J. Mellott (25-069)

Ensuring Diagnostic Readiness for SCEs: Redesigning the Detonator Probe, P. Younk (25-085)

Exploration of 3D Printed Ultrafast and Bright Scintillator Materials, K. Ayalew (25-135)

Feasibility of Reoccupying Historic Testbeds for Future Experiments, I. Bortins (25-120)

Fundamental Experiments for Detonation Signature Modeling, C. Kimblin (25-007)

Improving Infrasound Propagation Analysis with Ambient Noise Level Retrievals, M. Wright (25-142)

Low SNR, High Clutter UAS Detection and Tracking, I. McKenna (25-141)

Magnetic Tune Optimization and Beam Instability Mitigation for LIAs, E. Scott (25-074)

Needle-Washer Diode for Dynamic X-Ray Diffraction on Actinides at Z, S. Haque (25-107)

Novel Photon-Counting Detector Concept for High-Resolution Radiographic Imaging, S. Miller (25-032)

One-Time Waveforms with Low Spectral Signature, J. Mendez (25-051)

Optical Remote Sensing for Facility Monitoring: An Integrated Approach to Modeling, Simulation, and Sensors, C. Burt (25-076)

Pulse Optimization with Solid-State Utilization of Modulation, Z. Shaw (25-036)

Spatial Spectral Observations from Near and Far, M. Howard (25-095)

Staged Z-Pinch and Variable-Energy Laser Ablation-Driven New High-Yield Neutron Source, E. Dutra (25-031)

Strategic Initiative: Developing the NNSS critical skills in Accelerator Science and Beam Physics, P. Wiewior (25-092)

Study of Intense Electron Beam Target Interactions for Radiographic Applications, T. Haines (25-116)

Surface Gas Sampling Payload for Autonomous Underwater Vehicles, C. Priest (25-034)

The Development of Nanocrystalline Quantum Dot Scintillator Plate for Fast Neutron Imaging, A. Guckes (25-133)

Understanding Vaporization Kinetics of Hot Metal Ejecta, B. La Lone (25-077)

Wide-Field Coded Aperture Neutron Imaging by High-Resolution Tungsten Additive Manufacturing, R. Buckles (25-152)

Portable High-Resolution MeV Neutron and X-ray Radiography, C. Leak (25-114IL)

Feasibility Studies

Deep Learning Enabled Spectral Energy Conversion for Complex Geospatial Detection Systems, J. Conde (25-161)

Combined Radiation Environment Modeling Using Scorpius, A. Guckes (25-170)

Leveraging Massive Real-World Sensor Deployment for Neutron Anomaly Detection, S. Suchyta (25-179)

Extending Broadband Laser Ranging Reconstruction Algorithms to Enable Temporal Overlap, A. Kamalov (25-180)

Improving Nodal Seismic Collections by Enabling Data Telemetry for Dense Arrays, R. Turley (25-181)

Feasibility Study for Internal ML Compute Infrastructure at NNSS, N. Eisenberg (25-200)

Program Accomplishments

SDRD at a Glance

$15.5M	$334K	32	17
FY25 Budget	Median Project Size	Total Projects	New Starts

Publications	4
Technology Adopted by Programs	5
Gaps or Needs Addressed	33
Invention Disclosures	20
Patents	7

Featured Research

SDRD projects demonstrate a high level of ingenuity and innovation each year. Selected highlights of the R&D accomplished in FY 2025 by the SDRD program are presented on the following pages. Summaries of all FY 2025 projects can be found at the end of this report (note that CUI summaries are available in a separate CUI document). Full reports of all concluding projects and feasibility studies are available upon request from the SDRD Program Management Office or directly from the PI.

Stockpile Science

Digitized Nanosecond Silicon-Germanium Photomultipliers for Prompt Radiation Detection
James Mellott
DED

Photomultiplier tubes (PMTs) have long been used by the NNSS to detect and amplify light signals. However, they are becoming obsolete in the commercial industry: photonics company Hamamatsu recently announced it would be discontinuing the PMT most frequently used by the NNSS. This PMT was considered unmatched in terms of gain and linearity and worth its expensive price tag. However, its discontinuation has left a gap at the NNSS in terms of what could replace PMTs going forward.

Principal investigator James Mellott believes that solid state is the future of radiation detection. In his SDRD project, James aims to design an avalanche photodiode array (APD) and read out circuitry that are fast enough to measure prompt radiation. If successful, James' APDs could replace PMTs with small and relatively inexpensive application-specific integrated circuit designs and microcontrollers.

In the first year of this project, James and his team primarily tested and reported on existing silicon germanium (SiGe) chips at the University of Nevada, Las Vegas (UNLV). They used SiGe APDs to increase the quantum efficiency of silicon APDS. The APDs are designed to be small, fast, and quickly resettable so that they can be used for prompt detection. APDs that are passively quenched result in higher dark counts and longer reset times, so they designed actively quenching structures to mitigate this issue. The team completed testing on 108 passively quenched structures and plans to test the actively quenching structures as the project progresses.

James' efforts are unique because commercial industry isn't pursuing the same innovations that he and his team are—commercial solid-state replacements being designed are much too slow for the NNSS' prompt radiation detection needs. Without the team's innovation, the NNSS would have to rely on poor performance PMTs or slow commercial PMT replacements in the next ten years.

Figure 2. New Automated Test Setup.

Because James and his team work closely with UNLV, they have been able to leverage student support for their efforts. So far, an undergraduate and a graduate student have worked on the project, with the graduate student staying on as a 2024 summer intern. By working with the students at UNLV and establishing a pipeline from the university to the NNSS, James' project contributes to the SDRD goal of workforce development.

Global Security

Improving Infrasound Propagation Analysis with Ambient Noise Level Retrievals

Melissa Wright
UCRTO

Planned explosions in an urban environment are rare occurrences, so when the implosion of the Tropicana hotel took place on October 9, 2024, Las Vegas residents saw it as a chance to celebrate. In true Vegas fashion, the implosion was accompanied by a fireworks display and drone show as the city said farewell to one of the Strip's original properties. But for principal investigator Melissa Wright, the Tropicana implosion was a chance for an exciting new beginning.

In her 2025 SDRD project, Melissa Wright is setting out to improve the accuracy of prompt diagnostics with urban infrasound and atmospheric datasets. Melissa's goal is to leverage urban datasets from the Tropicana implosion event along with the multiyear Las Vegas Array (LV Array) to develop a technique of extracting atmospheric properties from ambient pre-detonation conditions.

Figure 3. Implosion images from YouTube: https://www.youtube.com/watch?v=4iqpn4Ld2XQ, https://www.youtube.com/watch?v=KZmqMjeTrWI&t=336s

The LV Array was a group of 11 infrasound sensors that were positioned throughout Las Vegas from 2019 to 2022, including three Clark County Fire Stations, one North Las Vegas Fire Station, one Las Vegas Fire Station, two NNSS locations, the Las Vegas National Weather Service, the Las Vegas Water District, and two private residences. For the Tropicana implosion, four Clark County Fire Stations were added to the reestablished LV Array locations to get surrounding coverage of the implosion signal. Preliminary results indicated that the implosion of the Tropicana's two towers was observable in almost all the infrasound stations across the Las Vegas valley. With further analysis to eliminate signal noise, that detectability is expected to increase to all stations.

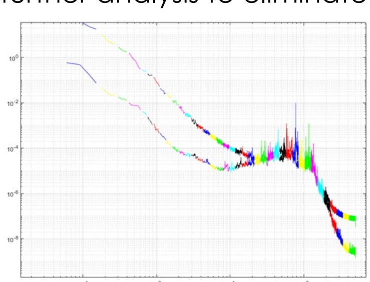


Figure 4. LV Array data.

Since the Tropicana implosion, Melissa and her team have focused on the LV Array, which is the primary dataset for this analysis. The dataset had to be assembled, organized, and moved to a centralized hard drive to streamline the process of analysis. The team is now working to pull out atmospheric features and the associated infrasound signals to begin the process of developing an inverse model to characterize the atmosphere of a propagating infrasound signal.

Cross-Cutting

Cloud-Based Meta-Analysis with Adaptive Learning for Massive Sensor Networks
Carson Schuetze
TRAINS

As artificial intelligence has become more common within scientific research, PI Carson Schuetze recognized an opportunity to improve the efficiency of the nuclear search mission at the NNSS including increased threat detection probability without increasing the false alarm rate, increased analyst sensor throughput, anomaly prioritization, and optimized sensor time on-target. Carson realized that these could all be addressed with the use of machine learning (ML), an idea she began exploring in her FY25 SDRD project.

Carson's approach is to implement a cloud-based architecture that can enable adaptive learning and statistical meta-analysis to be performed on aggregated data from all systems, sensors, and algorithms across space and time. Because the project requires a dense, highly curated historical archive, she can use ML algorithms to identify equipment abnormalities, optimize parameters for meta-analysis, and continuously adapt. She foresees that using ML algorithms in this way will help to pave a path for cloud implementation at the mission level.

In the first year of her project, Carson and her team took a unique approach to developing their methods: they created a simulated dataset based on data from Super Bowl 58 to test the various ML methodologies they identified during their literature review. From this Super Bowl data, the team developed a document for nuisance rejection spectral comparison ratio anomaly detection (NSCRAD) that they can utilize for the duration of the project. In testing their methods against NSCRAD, Carson and her team found that their best model improved detectability in simulated data by over 256%. This means that even highly shielded or very small sources can be detected without increasing the false alarm rate.

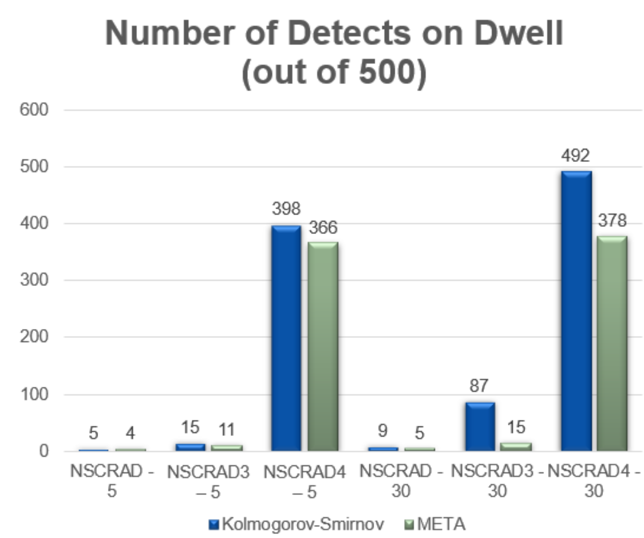


Figure 5. Experiment results show improvement over existing methods.

In FY26, Carson and her team plan to further utilize ML to improve their methods. Currently, her meta-analysis method can only be used to analyze data in post-processing, so her aim is to modify them to work in real time. Such a modification would allow the method to alarm during surveys and events, similar to existing anomaly detection algorithms, and would ensure its use in mission operations. She also plans to incorporate time-based clustering alongside the spatially correlated clusters that the method already uses, which will allow the team to use historical data and previous passes from the same location as context for alarming. Finally, Carson and her team are working to implement the method into the AVID simulator so that they can perform field testing. The team's goal is to curate the AVID data they collect by using a common format, which would enable them to experiment with even more advanced ML models.

SDRD MVPI

With many exceptional projects being conducted across the NNSS, the S&T Directorate is proud to honor SDRD's Most Valuable Principal Investigator (MVPI) in FY 2025. Nominations were submitted directly from peers and objectively reviewed by the Chief Scientist and SDRD Leadership. Nominees came from nearly every STTA and reflect our mission to support innovative and high-risk concepts and technologies for the nuclear security enterprise. The MVPI winner and other nominated PIs are highlighted with their projects below.

Winner

Sean Breckling

This year's MVPI is Sean Breckling for his project "Computational Fluid Dynamic Simulations for Critical Infrastructure (CFD-SCI)" (25-016). Sean was the undisputed favorite among the attendees to the FY25 SDRD Annual Program Review. His presentation impressed the audience; however, it was Sean's unwavering dedication towards the program and colleagues that made him the MVPI winner. One reviewer mentioned that "[Sean] is a leader in providing technical research topics and guidance towards graduate students and interns. This experience is key to the continued growth of the NNSS."

Figure 6. MVPI Winner Sean Breckling presents his project at the FY25 Annual Program Review.

"Sean has continually been a strong performer when it comes to SDRD projects, but also any programmatic work he contributes to."

A PI since 2020, Sean has clearly left a strong impact on the SDRD program with his myriad of successful projects. His current project faced many external obstacles, but he "got a lot done, despite a shifting resource and personnel landscape" according to one reviewer and was labelled as "impressive." The SDRD Program would like to congratulate Sean Breckling on his MVPI win and we hope to see more exemplary SDRD work from him in the future.

Figure 7. MVPI Sean Breckling with faithful collaborator, Mitski.

To read more about Sean's project this year, see his project description on page 88.

The descriptions for the projects of the Runners Up are also available in the Project Summaries section of this report.

Runners Up

Kaleab Ayalew (25-135, RAPIDS)
James Mellott (25-069, DED)
Stuart Miller (25-032, RAPIDS)
Evan Scott (25-074, ARSO)
Jerry Stevens (25-082, DED)
Piotr Wiewior (25-092, ARSO)

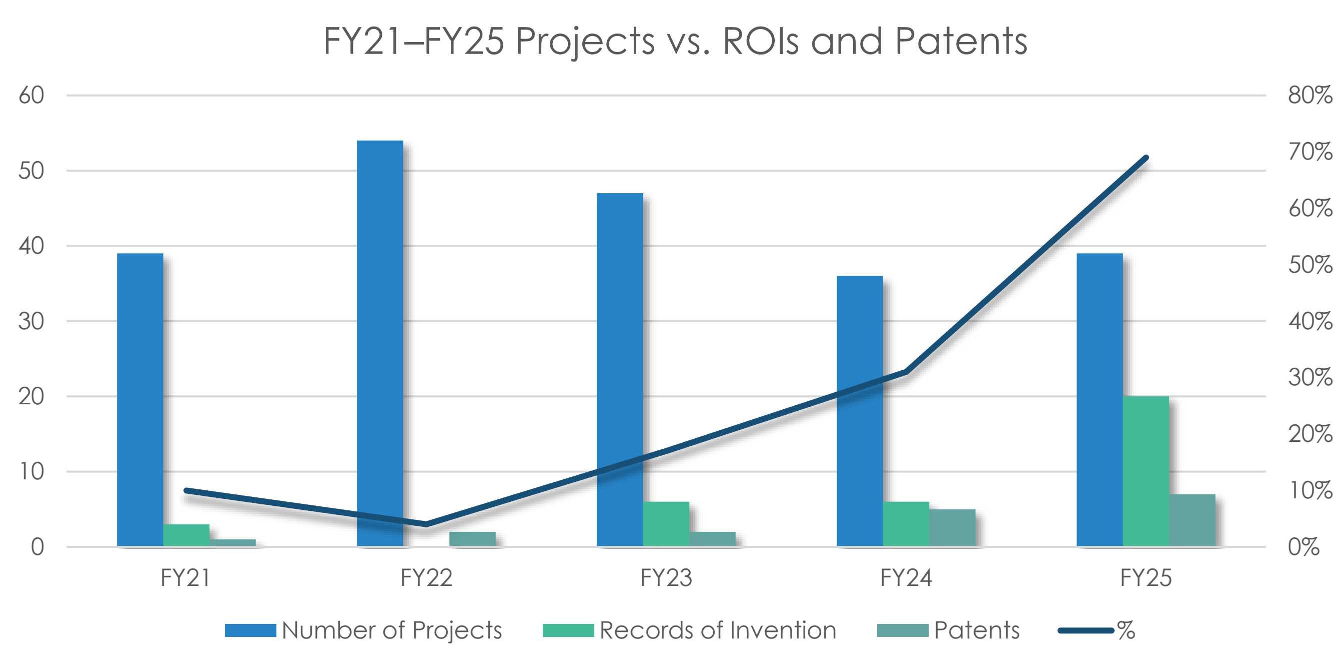
Program Value

SDRD Program Performance Metrics

	FY21	FY22	FY23	FY24	FY25
Number of Projects	39	54	47	36	39
Records of Inventions (ROIs)	3	0	6	6	20
Patents	1	2	2	5	7
Technologies Adopted by Programs	13	9	11	11	5
Gaps/Needs Addressed	18	27	31	24	33
Emerging Areas	18	11	10	9	6
Publications	21	16	5	8	4
Postdocs	12	4	5	1	0

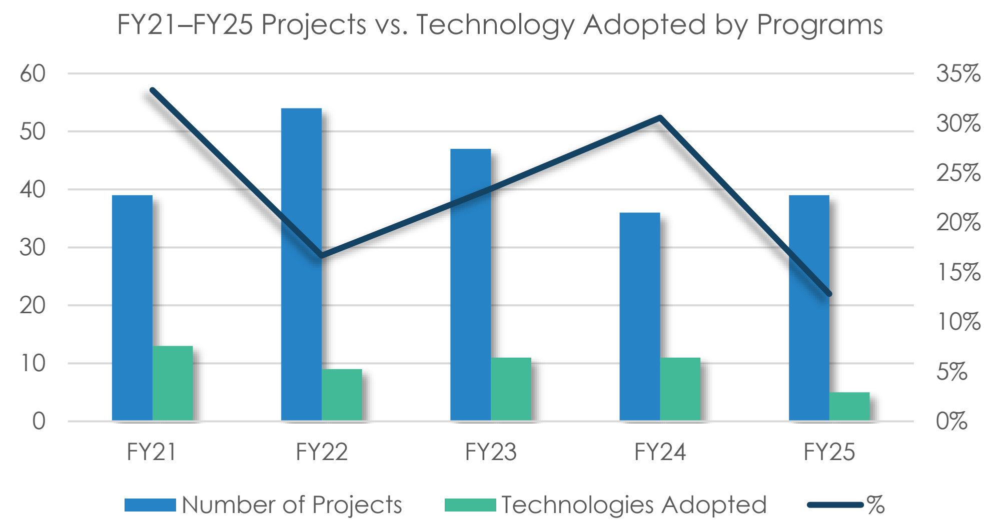
Records of Invention and Patent Applications

When new and novel research, science, or technologies are achieved in SDRD projects, PIs are invited to submit a Record of Invention (ROI) detailing their work and protecting their intellectual property. Patents are pursued when appropriate. In FY 2025, a total of 20 Records of Invention were filed. Subsequently, seven patents were also filed.



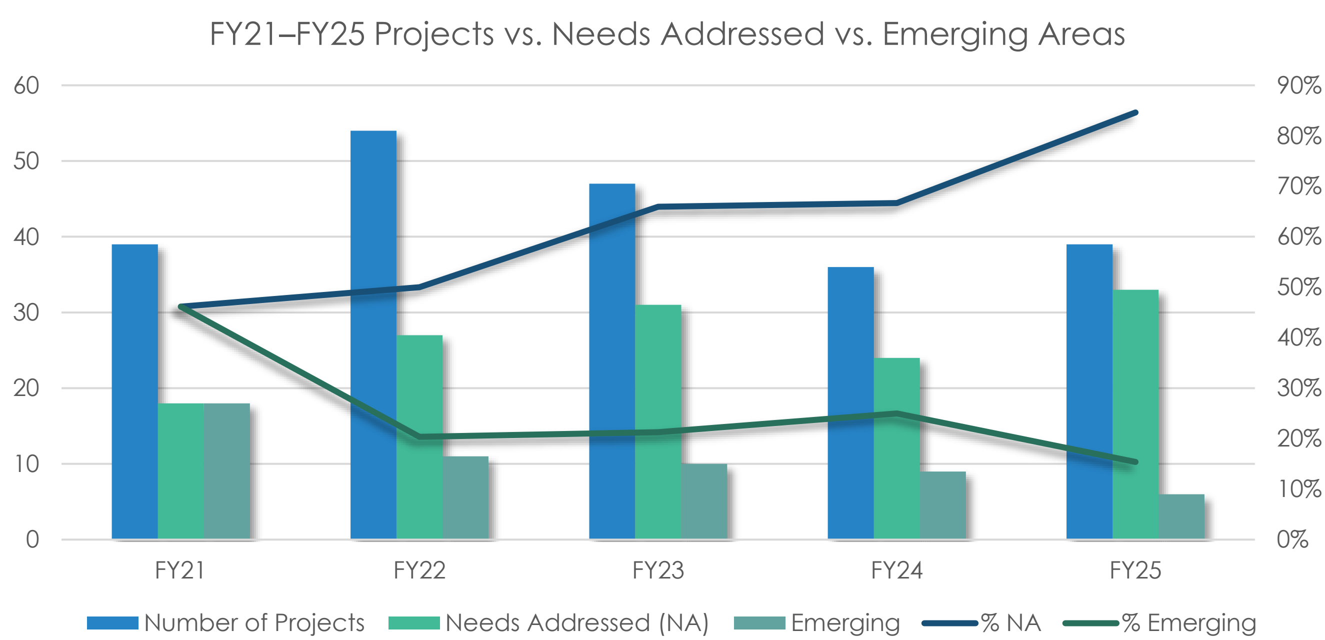
Technology Adopted by Programs

Anticipating needs and providing technology solutions are the cornerstones of the SDRD program, and migrating SDRD-developed technology into programs is a key metric for SDRD program success. In FY 2025, 5 SDRD technologies were adopted by Programs, a rate of nearly 13%.

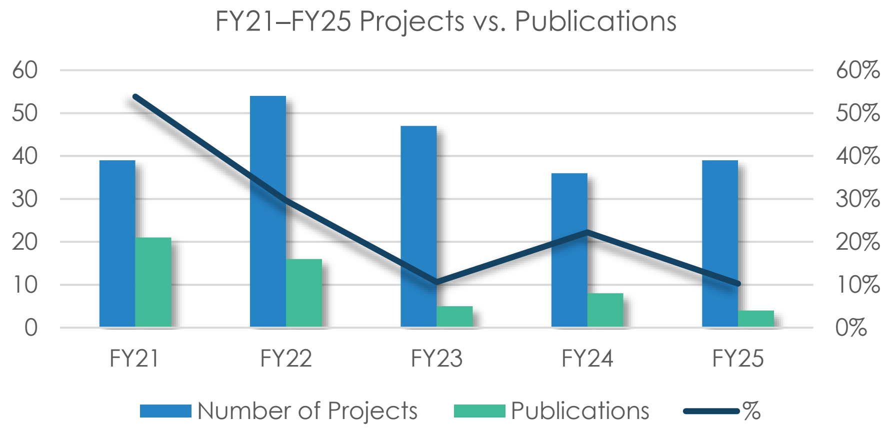


Technology Needs Addressed

Each year, the NNSS creates a Strategic Investment Plan to guide potential PIs in what mission needs are known and anticipated in each STTA. The SDRD proposal process evaluates how closely the pre-proposals align with these mission needs. For FY 2025, 85% of the projects funded directly addressed one of these identified needs. Emerging Areas and Special Opportunities are those that, while not historically under SDRD, fulfill a nationally identified priority. In FY 2025, SDRD had 6 such projects representing 15% of the portfolio.



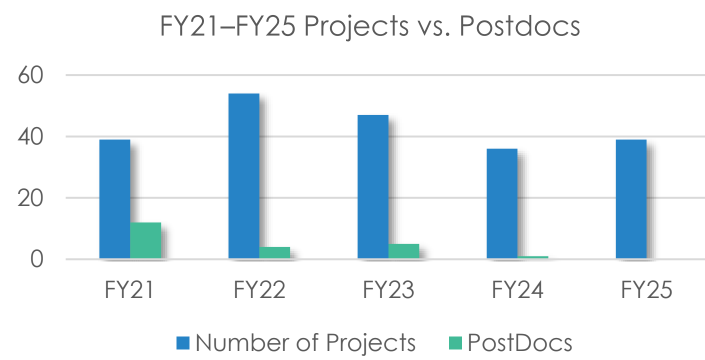
Journal Publications



Publications in peer-reviewed journals showcase the various scientific and technical achievements of our PIs. SDRD had four publications for FY 2025 including prestigious journals such as the *Journal of Applied Physics*, *Electronics*, and *American Institute of Physics Advances*.

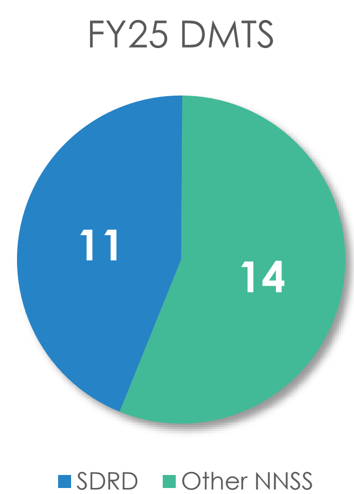
Postdocs

Early Career Employees are essential to bringing in new perspectives and innovative ideas. The SDRD program did not hire any new postdocs in FY 2025.



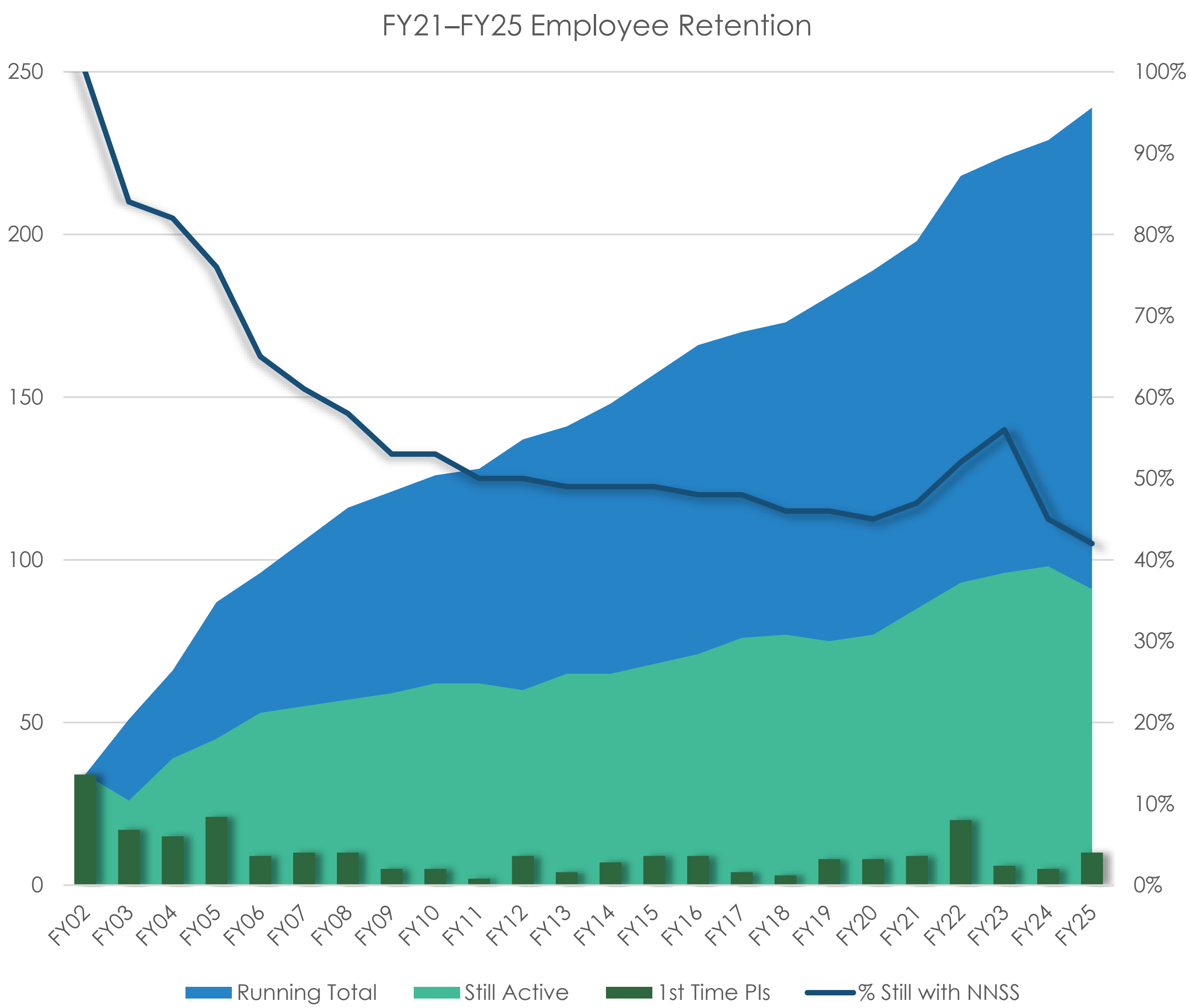
The Top 2%: Distinguished Members of the Technical Staff

The NNSS recognizes the lifetime achievements of its most seasoned scientists and engineers through a promotion to the title of Distinguished Member of the Technical Staff (DMTS). DMTSs are recognized by the NNSS as authoritative sources of information as they provide strategic direction to senior management as well as mentorship to early- and mid-career staff. There were 5 new appointments to DMTS in FY25. Of the 25 total DMTSs currently at the NNSS, 11 are active participants in SDRD.



Employee Retention and the NNSS

Employee conversion and retention reveals the desirability to work at the NNSS. SDRD has brought on 239 unique PIs over the last 23 years and has retained 101 for an overall retention rate of 42%.



SDRD → **Programmatic**

PECASE Winner: Amber Guckes

Early Career Engineer Wins Prestigious Award and Inspires STEM Students

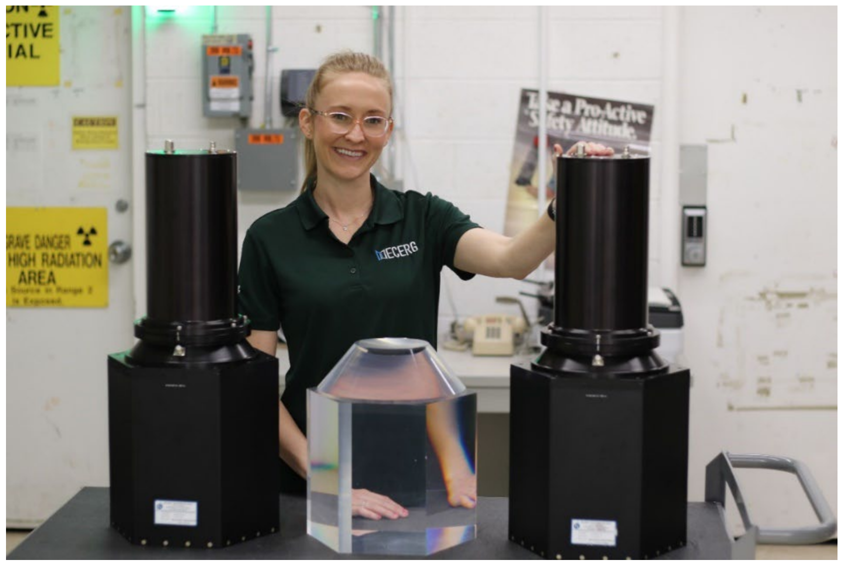


Figure 8. Dr. Amber Guckes in the lab.

SDRD PI Dr. Amber Guckes was awarded a Presidential Early Career Award for Scientists and Engineers (PECASE) on January 15, 2025. For winning the DOE PECASE award, Amber will receive a research grant worth $250,000 over a five-year period while employed within the complex.

Founded in 1996, the PECASE award is the highest honor bestowed by the DOE on outstanding early career scientists and engineers and is meant to honor their exceptional innovation and leadership. This year, nearly 400 professionals across 14 agencies were recognized for their work, with Amber representing the NNSA.

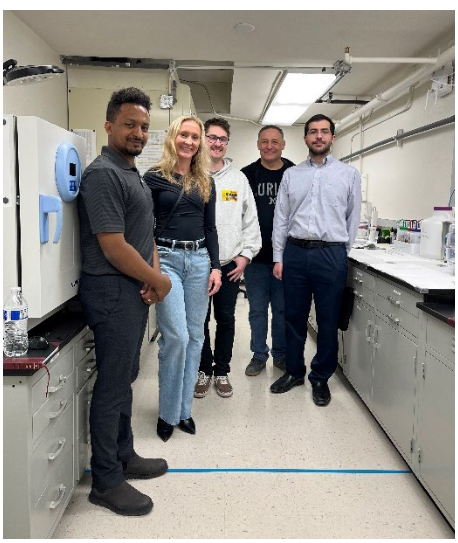


Figure 9. Amber Guckes (2nd from left) and team members Kaleab Ayalew (on left) and UNLV's Teodulfo Alanano, Alex Barzilov, and George Henry Peterson (on right).

Amber was given the PECASE award for her research on developing next-generation current mode radiation detectors for Stockpile Stewardship applications. This includes her work on the Multi-Layered Avalanche Diamond (MAD) detector, which she first developed as a principal investigator for a 2019 Site-Directed Research and Development project.

The MAD detector examines charge multiplication in thin, single crystal chemical vapor deposition diamond to yield a fast neutron detector. Since its inception, it has helped to support the NNSS' Stockpile Stewardship mission and Neutron Diagnosed Subcritical Experiment program by acting as an in-beam detector to improve the performance of the NNSS' dense plasma focus. Amber will be able to use the PECASE grant money to work on maturing the MAD detector's design through further research.

Figure 10. Amber Guckes (right) accepts the FY24 MVPI Award from Cameron Hawkins (left) on behalf of colleague Robert Buckles (not pictured).

In addition to honoring Amber's scientific and technical work, the PECASE award recognizes her efforts to connect with students through STEM outreach programs. Amber began her own career with the NNSS as an intern and strives to give young people the same early experiences with STEM that she received. To that end, she works with students through the Nevada Afterschool Network's NV Flight Crew initiative, NNSS Student Programs, Brigham Young University Engineering capstone student teams, NNSA Stewardship Science Academic Programs, Nevada Science Bowl, and the Girl Scouts of Southern Nevada. Her goal is to inspire young people to pursue a STEM career in their futures.

"To receive this award is an incredibly humbling experience but also serves as a testament to my passion for advancing nuclear technologies, especially through our mission, and getting to help other technical staff develop that same passion and make breakthroughs in nuclear technologies," said Amber. "It is a privilege to represent the NNSS."

Congratulations again to Dr. Amber Guckes. We are incredibly proud of your accomplishments at the NNSS and can't wait to see what you do next!

To find out more about Amber's current SDRD project, see page 68.

Strategic Initiative: Colloquium Series

Piotr Wiewior Brings the World to the NNSS

The SDRD program is instrumental in performing high-risk, potentially high-value experiments to enrich national security science. While each PI is involved in producing knowledge in their subject areas, learning from community partners can often lead to fresh approaches and enhanced collaboration. In the spirit of scientific advancement, SDRD PI Dr. Piotr Wiewior has organized the Strategic Initiative Colloquium, a monthly series of scientific talks given by NNSS collaborators, to support SDRD's Strategic Initiative in Accelerator Science and Beam Physics.

The aim of the Strategic Initiative is to develop the skills of current and future NNSS scientists and engineers with the goal of facilitating a modern experimental and theoretical program in-house. When he first took on the PI role for the Strategic Initiative, Piotr saw an opportunity to draw from his experiences in academia to complement these goals through the implementation of a colloquium, or talk, series. Colloquiums are a standard practice at most universities, and he realized that the NNSS personnel working on the Strategic Initiative might benefit from a similar collaborative and educational venue: "The whole idea was to bring in external experts from their fields to share insights, spark new ideas, help people network, and even kickstart collaborations," Piotr says.

Piotr began reaching out to his university and professional contacts and officially started the Strategic Initiative Colloquium in December 2024 with a keynote presentation by Juan Barraza, Chief Engineer for Advanced Sources and Detectors (ASD) at Los Alamos National Laboratory (LANL). His talk provided a comprehensive overview of the Scorpius accelerator technology. Since then, the Colloquium has presented many talks on topics relevant to NNSS scientists. Dr. Aaron Covington from the Physics Department at the University of Nevada, Reno (UNR) presented the second talk, which was an overview of recent pulsed radiation source development at UNR. In May 2025, the Colloquium hosted Dr. Ray Allen from the Naval Research Laboratory, who discussed his innovative CASTLE Circuit Simulator and its direct application to the Scorpius accelerator. Also in May, during the 2025 Prompt Radiation Detection and Imaging Workshop, the Colloquium invited speaker Dr. Stephen Andrews from LANL to deliver a talk on modeling multi-pulse targets.

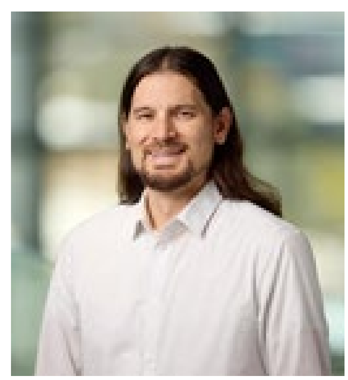


Figure 11. UNLV Professor Dr. Brendan Tran Morris presented on Machine Learning at the July Colloquium.

Dr. Jacob Stephens, an associate professor at Texas Tech University, presented on the topic of solid-state pulsed power for ultra-compact nonlinear transmission lines in June. This was followed by a talk in July by Dr. Brendan Tran Morris, a professor at the University of Nevada, Las Vegas, about computer vision and machine learning. In August, Dr. Benjamin King from UNR's Chemistry Department spoke about his research on polymer and materials chemistry. All three talks were widely attended both in-person and online by employees from across the NNSS.

Figure 12.Piotr Wiewior gives updates on his colloquium series during the FY25 Annual Program Review.

After such a successful start in FY 2025, Piotr has already started curating talks for FY 2026. Dr. David Wetz from the University of Texas at Arlington spoke in October about his research on pulsed power, power systems, electrochemical energy storage, and pulsed dielectric breakdown. On October 29th, the Colloquium officially became "international" with a presentation from Mark Sinclair, who works on pulsed power at the Atomic Weapon Establishment in the United Kingdom and is part of the team working to commission the Merlin IVA at the Epure facility in France. By introducing NNSS scientists to the work being done across the globe, Piotr hopes to make the Enhanced Capabilities for Subcritical Experiments team feel more connected and informed.

"It's been a real boost, bringing in outside thinking and showcasing that there's a wider community doing this work."- Piotr Wiewior

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Piotr's leadership on this Strategic Initiative continues to foster collaboration and creativity, two much needed skills for the NNSS workforce among the various near-future endeavors.

SDRD → Programmatic

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 **Kristen Vernon, Anne Totten**, and **Madeline Gauthier** for technical communications and compiling, editing, and publishing this report; to **Leslie Esquibel**, **Emma Gurr**, and **Kristen Ruocco**, for project management and cost accounting efforts; to **Michael Baldonado** for information system support; to **Elizabeth Davis**, **Eduardo Morales**, **Sandy Young**, and **Stacey Duffy** for financial data reporting; to **José Sinibaldi** for technical guidance and support; and to our STTA leads and site representatives: **Stuart Baker**, **Daniel Champion**, **Edward Daykin, Peter Heimberg**, **Daniel Lowe**, **Michelle Scalise**, **Amy Lewis**, **Jerry Stevens**, **Scott Suchyta**, and **Matthew Wallace.** Thanks as well to members of our External Advisory Board, **Ryan Camacho**, **Larry Franks**, **Carl Ekdahl**, **the late Damon Giovanielli**, **Maurice Sheppard**, **Ralph Schneider**, and **Gerry Yonas**, who supply ongoing, valuable recommendations.

Michael Reed & Cameron Hawkins
SDRD Program Manager & Deputy Program Manager
March 2026

Figure 13. The SDRD PMO attends the FY25 Annual Program Review. From left: Leslie Esquibel, Kristen Ruocco, Michael Reed, Emma Gurr, Kristen Vernon, Cameron Hawkins, and Anne Totten.

FY25 Project Summaries

Advanced Radiation Sources

25-031	*Staged Z-Pinch and Variable-Energy Laser Ablation-Driven New High-Yield Neutron Source*	Eric Dutra
25-036	*Pulse Optimization with Solid-State Utilization of Modulation*	Zachary Shaw
25-074	*Magnetic Tune Optimization and Beam Instability Mitigation for LIAs*	Evan Scott
25-092	*Strategic Initiative: Developing the NNSS critical skills in Accelerator Science and Beam Physics*	Piotr Wiewior
25-107	*Needle-Washer Diode for Dynamic X-Ray Diffraction on Actinides at Z*	Showera Haque
25-170	*Combined Radiation Environment Modeling Using Scorpius*	Amber Guckes

Staged Z-Pinch and Variable-Energy Laser Ablation-Driven New High-Yield Neutron Source

25-031
YEAR 3 OF 3
STOCKPILE STEWARDSHIP
ADVANCED RADIATION SOURCES

Eric Dutra
Livermore Operations

Summary

The project aims to develop a new high-yield neutron source using a high-energy laser and a Z-pinch device – the technique referred to as Laser Ablation Z-pinch Experiment (LAZE). A LAZE-driven neutron source can be a game changer in Nevada National Security Sites (NNSS) mission space. Yields better than 10^{13} n/shot with deuterium-deuterium (DD), short creation time (<30 ns), and small source dimensions could be available from small, robust, and safe without tritium gas. It will substantially impact many NNSS programs, like special nuclear materials (SNM) detection, active interrogation of materials, neutron radiography and spectroscopy, and neutron-diagnosed subcritical experiment.

Technical Readiness Level

Start of Project: TRL 0-2 Fundamental research
End of Project: TRL 3-4 Mission research

Summary of Technical Progress over the FY

This FY, we simulated the Leopard system with both 500 µm and 200 µm laser spot sizes on a deuterated polyethylene target. Recent data indicate that a larger spot size, specifically 500 µm, results in more material near the target, greater radial expansion, and reduced vertical expansion. The current model utilizes the existing return structure with the post removed, allowing for outward material flow. The magnetohydrodynamics (MHD) implosion phase was analyzed using data from the 500 µm laser spot. Data for MHD modeling were collected from Z-pinch experiments using four frames of laser shadowgraphy, a SIMX16 Intensified Charge Coupled Device Camera (ICCD) framing camera, and an optical streak camera to capture the radial implosion. Two-dimensional MHD simulations for the implosion phase are being extended to three-dimensional simulations for the stagnation phase. The primary finding is that fast ions are accelerated both radially and axially by electric fields. The resulting Lorentz (vxB) forces are comparable in magnitude to electric field forces. Due to strong magnetization, ions exhibit radial movement rather than only in the -z direction.

The Monte Carlo fast ion model simulates beam-target interactions to generate the neutron spectrum. Principal results show that pulsed neutron sources produce a dominant peak lasting approximately 10 to 15 nanoseconds, with ion energies in the hundreds of keV range. A 3 MeV characteristic in the radially emitted spectrum indicates neutron emission with high radial motion, confirming that some fast ions enter the solid target radially but are restricted in penetration depth by stopping power.

The collimated outflow of the plume is strongly influenced by the size of the laser focal spot. Density slices reveal that smaller spots generate higher-velocity, more collimated hollow jets, whereas larger or tighter focal spots result in less pronounced mass drop-off and potentially less distinct zippered implosions. A smaller spot size yields improved MR^2 along the z-axis for the hollow shell, which theoretically should enhance implosion performance.

Benefits to Mission/Program

The scientific and technical merit of proposed activities are strongly aligned with key areas identified with the Science and Technology Thrust Areas of Advanced Radiation Sources and Radiography and Analysis for Photonic Imaging Detectors and Systems. The proposed areas of effort will directly address articulated needs, including the need for alternative neutron sources able to produce short neutron pulses with more flux and no after-pulsing. Also, the development of nuclear and particle diagnostics will be addressed, including neutron time-of-flight (n-ToF) and n-activation detectors, as well as applications like neutron imaging. A laser-driven neutron source has the potential for an advantage over dense plasma focus (DPF) for highly important to radiographic imaging, especially with source spot size and stability. Yield is also critical, as well as the beneficial no-tritium feature.

Publications

Two publications in progress.

Presentations & Accolades

Presented at the 25th IEEE Pulsed Power Conference (PPC) and the 52nd IEEE International Conference on Plasma Science on "Beam target neutron production using laser ablated deuterated polyethylene on a 1 MA, 100 ns z-pinch device."

Pulse Optimization with Solid-State Utilization of Modulation

25-036
YEAR 2 OF 2
STOCKPILE STEWARDSHIP
ADVANCED RADIATION SOURCES

Zachary Shaw
North Las Vegas
Ivan Aponte, Sappho Buller, Dawson Wright[1], Keegan Kelp[1], Kirk Schriner[1], Andreas Neuber[1], James Dickens[1], John Mankowski[1], Jacob Stephens[1]
[1]*Texas Tech University*

Summary

A technique was studied for the coupling of two dissimilar pulsed power generators to operate in tandem. Utilizing a fast, solid-state source allows for general wave shaping of a traditional pulsed power generator. It was discovered during this study that design criterion utilizing nanocrystalline or amorphous magnetic cores at high magnetization rates was not clear, leading to investigation of their electrical and physical response.

Technical Readiness Level

Start of Project: TRL 0 Fundamental Research
End of Project: TRL 4 Mission research

Summary of Technical Progress over the FY

Accomplishments for this project fall into two categories: the coupling apparatus and understanding of pulsed, magnetic core physics. Accomplishments for the coupling apparatus include the design and implementation of a 10 stage, solid-state Linear Transformer Driver (LTD) (TRL 7-8), a 3 stage Marx Generator (peak Open Circuit voltage of 60 kV tested, TRL 5-6), a high voltage directional coupler diagnostic for reflections (TRL 9), and a final design for the coupler used to merge the LTD and Marx (TRL 3-4). A single peer reviewed publication on the LTD is currently under review.
The magnetic core physics accomplishments resulted in a core test stand (TRL 8), circuit model equivalent of tested cores (TRL 8-9), FDTD simulation of magnetic core diffusion (TRL 6-7), and two peer reviewed publications.

Benefits to Mission/Program

Pulsed power sources are the drivers for many of the Stockpile Stewardship mission's testbeds. While novel driver topologies are still being produced today, their implementation into pre-existing testbeds would normally require a major redesign or system overhaul. Our path forward included a novel approach to allow for the re-furbishing and enhancement of these testbeds by coupling a pre-existing and new driver together (SDRD Needs Assessment 2025, pp. 10-16). Facilities: Cygnus, Gemini, Zeus.

Publications

1. Kelp, K., Wright, D., Stephens, J., Dickens, J., Mankowski, J., Shaw, Z., & Neuber, A. (2025). Modeling Pulsed Magnetic Core Behavior in LTspice. *Electronics*, *14*(12), 2335.
    a. https://www.mdpi.com/2079-9292/14/12/2335
2. Wright, D., Kelp, K., Klein, T., Stephens, J., Dickens, J., Mankowski, J., ... & Neuber, A. (2025). Assessing nanocrystalline pulsed transformer core performance using Maxwell ANSYS. *AIP Advances*, *15*(6).
    a. https://pubs.aip.org/aip/adv/article/15/6/065323/3350494
3. Kelp, K., Wright, D., Schriner, K., Stephens, J., Dickens, J., Mankowski, J., Shaw, Z., & Neuber, A. (2025). Development and Optimization of a 10-Stage Solid-State Linear Transformer Driver, Under Review *Energies*.

Presentations & Accolades

1. Laboratory Research Graduate Fellowship Award: Dawson Wright
    a. https://www.krellinst.org/lrgf/profile/wright2023
2. 2024 IEEE International Power Modulator and High Voltage Conference (Indianapolis, IN)
    a. Investigation of Pulsed Nanocrystalline Magnetic Core Behavior, Oral presentation.
    b. Simulation of Nanocrystalline Magnetic Cores using Maxwell ANSYS, Oral presentation.
    c. PI served as Session Chair for Plasma Discharge section. Also served on technical committee
3. 2025 IEEE Pulsed Power and Plasma Science Conference (Berlin, Germany)
    a. Development of a High-Current Solid State Linear Transformer Driver, Poster.
    b. Advanced Magnetic Core Modeling for Pulsed Power Systems in LTSpice, Oral presentation.
    c. Impact of Magnetic Cores, Impedance Variations, and Reset Techniques on Linear Transformer Driver Performance, Oral presentation.
4. Completion of 2 PhDs (Dawson Wright, Ivan Aponte), and 2 Master's degrees (Keegan Kelp, Kirk Schriner).

Magnetic Tune Optimization and Beam Instability Mitigation for LIAs

25-074
YEAR 1 OF 2
STOCKPILE STEWARDSHIP
ADVANCED RADIATION SOURCES

Evan Scott
North Las Vegas
Paul Stanik III[1], Sean Littleton[2], Carl Hines[3]
[1]Las Vegas Operations; [2]Livermore Operations; [3]Atomic Weapons Establishment

Summary

Development of an automated magnetic transport lattice tuning algorithm for linear induction accelerators using electron beam instability growth criteria and basic electron beam parameters for improved electron beam transport.

Technical Readiness Level

Start of Project: TRL 3-4 Mission research
End of Project: TRL 5+ Technology maturation

Summary of Technical Progress over the FY

Leveraging previous work performed under a feasibility study in 2022, both a beam envelope equation solver and a particle-in-cell (PIC) simulator were linked to an advanced optimization package, Xopt [1], used in the accelerator community. The Xopt framework allows for distributed/parallel evaluation of a particular function, which lends itself well to both direct optimization and data generation applications. Using this methodology, 100,000 envelope equation calculations were performed in approximately 10 minutes and hundreds of PIC simulations in a matter of days.

Training data generated using the framework above was used to train two distinct machine learning (ML) surrogate models and demonstrate advanced ML techniques relevant to experimental data applications. The first surrogate model was trained using data generated using an envelope equation solver. An additional model was trained using the same solver but with one aspect of the fundamental physics removed to simulate an inaccurate simulation. A small dataset generated using a PIC solver was then used to modify the inaccurate model using transfer learning, an ML technique that uses low-fidelity data to train a surrogate model and high-fidelity data to increase that model's accuracy. This approach resulted in a surrogate model that agrees with PIC simulations and runs in less than 1 second as opposed to the PIC simulation running in >3 minutes [2].

An additional model was trained on PIC data in an electron injector's anode-cathode (A-K) gap region that returns the beam current, radius, divergence, energy, emittance, and beam spill values. This model is intended to provide initial conditions to the envelope equation solver for fast evaluation of beam parameters beginning at the injector cathode.

A survey of beam instabilities and phenomena were also investigated for use as optimization objectives, noting effects that lend themselves best to objectives and constraints.

Benefits to Mission/Program

Because this work affects accelerators used for flash radiography, this project directly impacts the stockpile stewardship mission of the NNSA. The results of this project are applicable to every linear induction accelerator in the weapons complex. If successful, this tool would increase tuning efficiency by reducing the amount of time required to develop a tune for a given accelerator and may improve beam transport by providing as yet untried beam tuning solutions. This work may also increase our understanding of instability onset and growth in intense relativistic electron beams and their mitigation.

Presentations & Accolades

- Stanik III, P. (2025, April 10). *Improving Fast Beam Transport Simulations Using Transfer Learning* [Invited talk]. 5th ICFA Beam Dynamics Mini-Workshop on Machine Learning for Particle Accelerators, CERN, Geneva, Switzerland. https://indi.to/BrT4p

References

[1] R. Roussel, C. Mayes, A. Edelen, and A. Bartnik, *Xopt: A Simplified Framework for Optimization of Accelerator Problems Using Advanced Algorithms,* in Proc. of IPAC2023, Venice, Italy, 7–12 May 2023 (JACoW Publishing, Venice, Italy, 2023), pp. 4847–4850.

[2] P. Stanik III, *Improving Fast Beam Transport Simulations Using Transfer Learning*, https://indi.to/BrT4p.

Strategic Initiative: Developing the NNSS Critical Skills in Accelerator Science and Beam Physics

25-092
YEAR 2 OF 3
STOCKPILE STEWARDSHIP
ADVANCED RADIATION SOURCES

Piotr Wiewior
North Las Vegas

Summary

This strategic initiative was developed to remove gaps in critical skills and accelerator capabilities at the NNSS as well as perform fundamental research and mitigate beam-target interactions.

Technical Readiness Level

Start of Project: TRL 0-2 Fundamental research
End of Project: TRL 3-4 Mission research

Summary of Technical Progress over the FY

Fiscal Year (FY) 2025 marked a period of significant progress and strategic development for the SDRD Strategic Initiative, fundamentally strengthening NNSS' capabilities in Accelerator Science and Beam Physics. A cornerstone of this year's success was the deepening collaboration with the University of Nevada, Reno (UNR), formalized through a comprehensive White Paper and CRADA, culminating in the first joint experimental campaign in February. This partnership facilitated the establishment of a cutting-edge laboratory environment at UNR, including the successful installation and commissioning of the Fianium supercontinuum laser and the initiation of transfer for advanced diagnostic equipment like the Andor iStar ICCD [Intensified Charged Coupled Device] camera and Shamrock spectrograph.

Building on this foundation, substantial efforts in FY25 focused on critical infrastructure and expertise development. All UNR students and staff completed essential safety training, and robust Class IV laser safety systems were meticulously designed, built, and tested. The Laser Ablation Plume Experimental apparatus (LAPEx) was re-commissioned, and its core laser diagnostics were precisely re-aligned and calibrated, enabling future studies of beam-target interactions. Students received hands-on training across a spectrum of optical and spectroscopic techniques, utilizing LAPEx as a vital testbed. Furthermore, preparations for high-impact Z-pinch electron-target interaction studies advanced significantly, culminating in team training for the upcoming X-pinch radiography campaign.

Beyond direct experimental work, FY25 saw the continued advancement of critical modeling capabilities, particularly our LIA [Linear Induction Accelerator] modeling within the Bmad framework, with initial steps taken in simulating Beam Breakup (BBU) instability. The project also maintained active engagement with the broader scientific community through its successful colloquium series, bringing diverse external expertise to NNSS. These achievements collectively underscore FY25 as a pivotal year in which foundational capabilities were established, critical skill gaps addressed through active student development, and the stage set for advanced research and development activities in FY26 and beyond.

Benefits to Mission/Program

This strategic initiative is directly tied to operational support and data collection for hydrodynamic and subcritical experiments.

Presentations & Accolades

This Strategic Initiative Project was chosen for presentation to the National Nuclear Security Administration Laboratory-Directed Research & Development Working Group.

Needle-Washer Diode for Dynamic X-Ray Diffraction on Actinides at Z

25-107
YEAR 2 OF 2
STOCKPILE STEWARDSHIP
ADVANCED RADIATION SOURCES

Showera Haque
Livermore Operations
Matthew Wallace[1], Robert Guyton[1], Cody Kensler[1], Zachary Wolff[2], James Heinmiller[1], Radu Presura[3], Dale Welsh[4]
[1]Livermore Operations, [2]North Las Vegas, [3]Semsol, [4]Voss Scientific, LLC

Summary

Sandia's actinide science experiments on Z require pulsed x-ray diffraction. The existing x-ray sources are insufficient for this task: the laser-driven sources cannot reach the photon energies required and the Marx-driven coaxial diode is not intense enough. The leading option is an upgrade of the coaxial diode with a needle anode and a washer cathode successfully used on dynamic materials experiments on Thor. The improved system needs to produce an order of magnitude higher intensity, higher photon energy, and a small source size. Here we propose a computational study of the processes and parameters responsible for the x-ray emission in the coaxial diode, to guide the development of an x-ray source suitable for dynamic materials studies of actinides on Z.

Technical Readiness Level

Start of Project: TRL 0-2 Fundamental research
End of Project: TRL 3-4 Mission research

Summary of Technical Progress over the FY

In the final year of this project, we were able to set up and take measurements with the experimental testbed required to empirically verify the simulation results from the first year. Upon receiving a needle-washer diode and Supersaver Marx bank that were approved to operate at Livermore Operations, our team began setting up diagnostics to observe the diode's behavior under varying conditions. The diagnostics fielded included an x-ray pinhole camera, x-ray spectrometer, x-ray photodiode, dosimeters, and multi-frame visible imaging.

The spot size, spectrum, x-ray intensity and pulse duration measured by the diagnostics informed us on the diode performance and variability between shots and anode configurations. Our study began with obtaining baseline measurements for standard anode materials and shapes before trying modifications. We tested Tungsten, Tantalum, and Copper anodes and tried different anode tip shapes. Our simulation results showed that x-ray line emission tended to increase with shorter needle lengths. Experimental results agreed with this prediction overall. We found that the x-ray performance was very sensitive to the anode shaping.

We used a gated 16-frame visible imaging camera to look at the time evolution of the anode-cathode gap. For this setup, we used an optical relay line consisting of a zoom lens and a 30 cm plano-convex lens to send a 10x magnified image of the diode region to the imaging camera. We installed a periscope in front of the diode head with an aluminized pellicle as the mirror immediately in front of the diode, so that we could concurrently field x-ray diagnostics. The visible images showed where glow, arcing and discharges occurred before, during, and after the pulsed power drive. There was high variability between shots, indicating areas to improve performance.

Benefits to Mission/Program

The need for bright pulsed x-ray sources appears in multiple contexts in the FY 2024 NNSS R&D Technology Needs Assessment, with an emphasis on multi-pulse operation. The main applications are pulsed x-ray diffraction (for phase change diagnostics, e.g. for actinide science) and soft x-ray radiography (in support of advanced hydrodynamic, SCE, HED, and ICF testing, e.g. for ejecta imaging). Modeling and simulation of the x-ray sources will provide information for diagnostic selection and for design optimization. The computational effort is likely to also benefit the development of man-portable radiographic sources in the MeV x-ray range.

Combined Radiation Environment Modeling Using Scorpius

25-170
Feasibility Study
Stockpile Stewardship
Advanced Radiation Sources

Amber Guckes
North Las Vegas
Daniel Lowe
North Las Vegas

Summary

The radiation effects communities within the US Department of Energy and US Department of Defense are currently seeking, and in some cases building, combined radiation effects simulators [1]. While Scorpius is intended primarily for radiographic applications, its solid-state injector technology may allow it to serve as a unique combined effects simulator. This feasibility study will establish the initial framework and preliminary estimates, using MCNP [Monte Carloe N-Particle], of the maximum X-ray dose followed by the maximum neutron dose that this asset could provide.

Technical Readiness Level

Start of Project: TRL 1
End of Project: TRL 2

Summary of Technical Progress over the FY

This work leveraged the results of the FY24 SDRD project 24-044, *Exploration of an electron linac-driven photoneutron source based on Scorpius*. The specific application of this work towards a radiation effects simulator was investigated. Such a simulator requires two distinct electron pulses: the first into a Bremsstrahlung X-ray target and the second into a photoneutron target. Specific X-ray and neutron yields are required. The X-ray yield is defined as dose in rem to the device under test (DUT). The neutron yield is defined as 1-MeV Damage Equivalent in Silicon (DES) neutron fluence. Furthermore, the incidental neutron production during the X-ray pulse and the inverse must be minimized. X-ray and neutron spatial uniformity across the DUT must be maintained at ± 20%. Scorpius performance metrics restrict the X-ray and neutron pulse widths to ~300 ns, electron energy up to 22.4 MeV, and electron beam current to ~1.4 kA.

The optimized photoneutron target design of an 11-mm-thick depleted uranium target found from the prior work was employed in this work. A 1-mm-thick tungsten target was used as the Bremsstrahlung X-ray target. Various configurations of target positions with relation to the DUT were evaluated using MCNP6.3 simulations to maintain uniformity and reduce neutron contamination during the X-ray pulse and X-ray contamination during the neutron pulse. The addition of moderators and reflectors was considered to increase the 1-MeV DES neutron fluence into the DUT. The target configuration yielding the highest X-ray dose and 1-MeV DES neutron fluence on the DUT is shown in Figure 1. Although this configuration yields the highest X-ray dose and 1-MeV DES neutron fluence on the DUT, it has poorer uniformity across the DUT and higher contamination of undesired radiation during each pulse. Thus, a second configuration as shown in Figure 2 was derived.

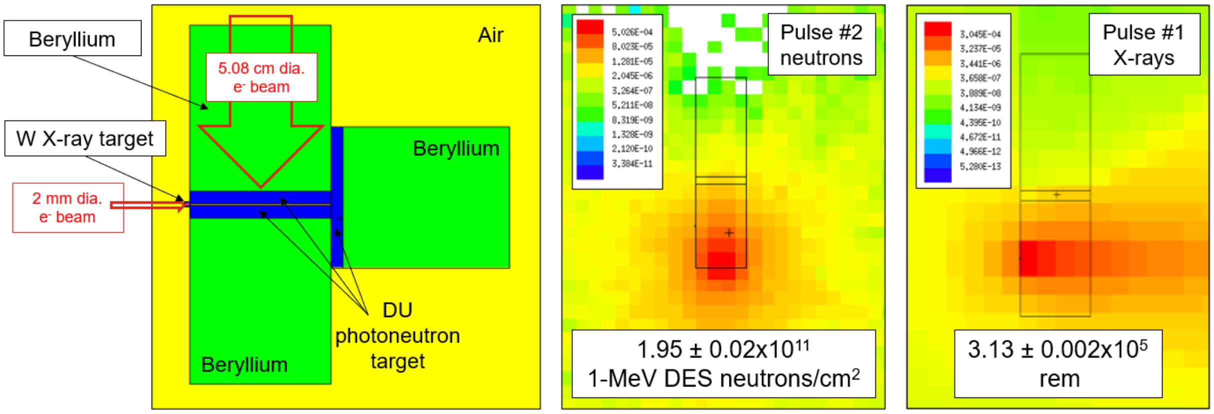

Figure 1. X-ray + photoneutron target configuration which maximizes X-ray dose and 1-MeV DES neutron fluence on DUT.

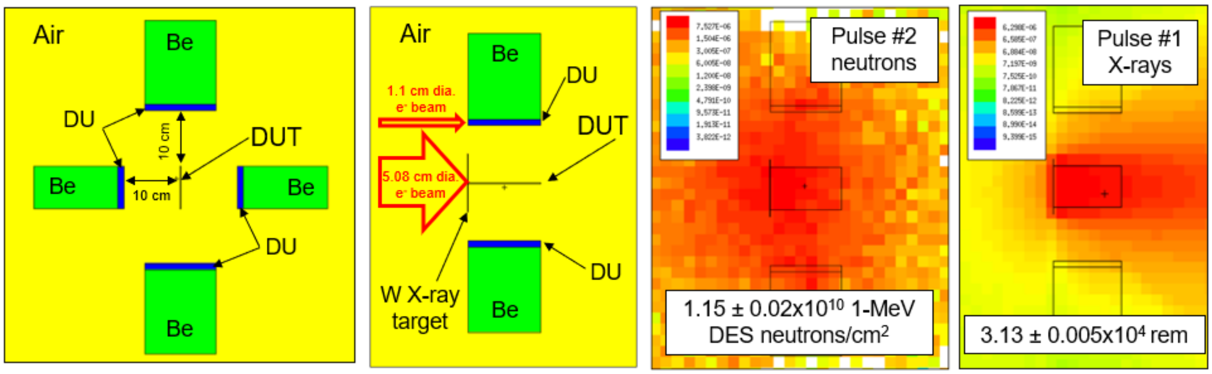

Figure 2. X-ray + photoneutron target configuration which improves uniformity and decreases contamination on DUT.

Benefits to Mission/Program

The National Nuclear Security Administration (NNSA) will directly benefit from the diversification of a $3B asset located at the Principle Underground Laboratory for Subcritical Experiments (PULSE) facility. By potentially having multiple types of users, the ability to fund staff and diversify the mission space is enhanced.

Publications

If accepted for presentation at the 2026 Hardened Electronics and Radiation Technology (HEART) Conference, we intend to submit a paper on the same subject to the *Journal of Radiation Effects, Research and Engineering.*

Presentations & Accolades

Intent to present at the 2026 HEART Conference was submitted on August 20, 2025. Full summary to be considered for a presentation will be submitted on or before the conference deadline of September 26, 2025. The HEART conference will take place in Shreveport, LA, April 13-17, 2026.

Dynamic Experiment Diagnostics

25-069	*Digitized Nanosecond Silicon-Germanium Photomultipliers for Prompt Radiation Detection*	James Mellott
25-077	*Understanding Vaporization Kinetics of Hot Metal Ejecta*	Brandon La Lone
25-082	*Design, Analysis, and Testing of Embedded and Free-Standing Asay Window Sensors to Measure Material Density in Dynamic Experiments*	Gerald Stevens
25-085	*Ensuring Diagnostic Readiness for SCEs: Redesigning the Detonator Probe*	Patrick Younk
25-134	*Developing Time-Resolved X-Ray Diffraction Capabilities for Dynamic Shock Experiments*	Matthew Wallace
25-180	*Extending Broadband Laser Ranging Reconstruction Algorithms to Enable Temporal Overlap*	Andrei Kamalov

Digitized Nanosecond Silicon-Germanium Photomultipliers for Prompt Radiation Detection

25-069
Year 2 of 3
Stockpile Stewardship
Dynamic Experiment Diagnostics

James Mellott
North Las Vegas
Robert Buckles
North Las Vegas

Summary

This project aims to revolutionize prompt radiation detection by developing a digital replacement for traditional photomultiplier tubes (PMTs) using nanosecond Silicon-Germanium (SiGe) photomultipliers. Our core objectives include actively quenching and resetting SiGe avalanche photodiodes (APDs) within 1 nanosecond, achieving a 1 GHz count rate through time-interleaved readout, and integrating on-chip counters and storage systems to reduce reliance on bulky external equipment. The device is designed for broad applicability in neutron, gamma, X-ray, and emissive diagnostics, offering single-photon sensitivity with high flux capabilities. The year's efforts have progressed from establishing design infrastructure at the University of Nevada, Las Vegas (UNLV) and developing fundamental circuit elements to refining the overall array design based on critical reviews, all leading towards final fabrication submission. This technology is envisioned to transition into programmatic development, reaching TRL 4-5 and becoming fieldable within a few years, addressing critical needs for high-performance, compact radiation sensors.

Technical Readiness Level

Start of Project: TRL 0
End of Project: TRL 3

Summary of Technical Progress over the FY

This year, the project successfully established critical design infrastructure at UNLV, including the setup of Silvaco software, leveraging expertise in APD and chip design. We progressed to defining and laying out fundamental circuit elements with stringent requirements for small size and high speed. A pivotal achievement was identifying a critical design flaw in array integration through a significant multi-team design review, leading to a refined approach focused on flux measurement over dose measurements. Innovative solutions were developed to address challenges in high-speed counting, including doubling counters per single-photon avalanche diode (SPAD) group, implementing 1 ns time-interleaved measurements with variable delays, and integrating digital time resolved spot diagnostic (DTRSD)-inspired readout architectures. Furthermore, we devised strategies for on-chip multi-phase signal generation and column bus buffering, utilizing TowerJazz SiGe BiCMOS [Bipolar Complementary Metal-Oxide Semiconductor] heterojunction bipolar transistors (HBTs). These efforts culminated in a focused push towards finalizing the design for fabrication, ensuring robust, high-performance digital PMT replacement capable of single-photon sensitivity and high flux for diverse prompt radiation diagnostics.

Benefits to Mission/Program

This project directly addresses critical mission and program requirements for "fast alpha" and "digital alpha" capabilities, which are currently unmet by traditional analog PMTs that are becoming obsolete. By developing a fully integrated, digitized nanosecond SiGe photomultiplier, this project provides a modern, high-performance solution that offers superior sensitivity and speed, while simultaneously reducing the need for cumbersome external equipment. The innovative on-chip design for counting and storage, coupled with high-flux and single-photon detection capabilities, positions this device to fill a significant technological gap for prompt radiation diagnostics across a wide range of applications.

Understanding Vaporization Kinetics of Hot Metal Ejecta

25-077
YEAR 1 OF 2
STOCKPILE STEWARDSHIP
DYNAMIC EXPERIMENT DIAGNOSTICS

Brandon La Lone
Special Technologies Laboratory
Gerald Stevens,[1] Ben Valencia,[1] Rick Allison,[1] Chris Kayda,[1] Chusia Moua,[1] Aaron Poletti,[1] Brian Jensen,[2] Dan Dolan[2]
[1]*Special Technologies Laboratory,* [2]*Washington State University*

Summary

The ejecta created from hypervelocity impacts can be at a high-enough temperature that a significant quantity of material vaporizes in the collision. The liquid-to-vapor transition is a kinetics-limited process. The goal of this project is to experimentally validate a vapor production model that our team has previously developed for single particles. Dynamic ejecta experiments were conducted at the Special Technologies Laboratory (STL) powder gun and at the Institute for Shock Physics at Washington State University in order to test our vapor production models.

Technical Readiness Level

Start of Project: TRL 3-4 Mission research
End of Project: TRL 3-4 Mission research

Summary of Technical Progress over the FY

Under this project we extended our vaporization model for ejecta clouds to include a particle size distribution and a cloud density. Our model differs from prior efforts in that it handles the kinetics of the liquid to vapor transition and predicts time dependent temperature decay due to the vaporization process. We conducted dynamic experiments in which Mie scattering was used to estimate particle size distributions and multiband pyrometry was used to measure the temperature decay of the ejecta.

Novel Mie scattering and analysis techniques were used for this effort. Mie scattering methods involve measuring the angular distribution of light scattered from particles in order to estimate the particle sizes. In prior ejecta experiments, the light scattering pattern was measured at a few discrete angles. In our work we collected a continuum of scattering angles using a Fresnel lens and a high-speed camera. We developed analysis routines to estimate particle size distributions from the scattering pattern.

Under this project, we have established a collaboration between the NNSS and the Institute for Shock Physics (ISP) at Washington State University. In September of 2025 we conducted 2-stage light gas gun shots where we measured the Mie scattering pattern of Sn ejecta and time resolved temperatures of the ejecta particles. High quality data was collected but the results have not yet been analyzed.

Benefits to Mission/Program

During shallow bubble collapse experiments (in collaboration with Lawrence Livermore National Laboratory [LLNL]) we observed very high temperature ejecta that rapidly cools in vacuum. This led to the development of an ejecta vaporization kinetics model that helped to explain the rapid cooling. The model, still unpublished, is already being embraced and circulated in our working groups with LLNL and Los Alamos National Laboratory (LANL) scientists, even though some parameters in the model have yet to be experimentally validated. This work will not only help understand vapor production but will also provide insights into ejecta particle sizes though temperature and Mie scattering measurements. Our new collaboration with Washington State University will be a recruitment opportunity for future scientists to come to work for the NNSS.

Presentations & Accolades

Presented this work at the Institute for Shock Physics seminar series.

Design, Analysis, and Testing of Embedded and Free-Standing Asay Window Sensors to Measure Material Density in Dynamic Experiments

25-082
Year 1 of 2
Stockpile Stewardship
Dynamic Experiment Diagnostics

Gerald Stevens
Special Technologies Laboratory

SEE CUI REPORT.

Ensuring Diagnostic Readiness for SCEs: Redesigning the Detonator Probe

25-085
Year 1 of 1
Stockpile Stewardship
Dynamic Experiment Diagnostics

Patrick Younk
Los Alamos Operations

See CUI report.

Developing Time-Resolved X-Ray Diffraction Capabilities for Dynamic Shock Experiments

25-134
YEAR 1 OF 2
STOCKPILE STEWARDSHIP
DYNAMIC EXPERIMENT DIAGNOSTICS

Matthew Wallace
Livermore Operations
Showera Haque[1], Robert Guyton [1], James Heinmiller [1], Aimee Neilsen [1], Cody Kenstler [1], R. Knight [1], Eric Dutra [1], Sarah Thomas [2], Radu Presura [3*]
[1]Livermore Operations, [2]Los Alamos Operations, [3]Sandia Operations [*]Current affiliation: Sem-sol

Summary

A new vessel design able to accommodate multiple portable flash x-ray sources is proposed in order to make time resolved x-ray diffraction measurements.

Technical Readiness Level

Start of Project: TRL 3-4 Mission research
End of Project: TRL 3-4 Mission research

Summary of Technical Progress over the FY

A series of materials relevant to dynamic shock experiments were added to existing ray-tracing tools developed under earlier SDRD projects. These materials included Cadmium Sulfur, Tin, Copper, Aluminum, and lastly and important for next year's experiments, Bismuth. The ray-tracing tools previously developed for spectroscopic purposes were benchmarked against Cadmium Sulfur diffraction patterns for the sample in multiple orientations, demonstrating the two sources relevant to this project. A multi-source x-ray system is designed and planned for next FY's experiments. The x-ray source(s) for next year are being built up at Livermore Operations, with one source currently operational and spectroscopic testing underway to determine the best spectral line emitting anode dimensions and material. Simulations for Bi at C3's experimental parameters began this FY.

Benefits to Mission/Program

This project brings back the capability to study the phase transitions of shocked materials in containment vessels. Improvements in vessel design are referenced in the 2025 SDRD Needs Assessment for the study of ejecta. This project directly addresses improvements to the x-ray source, readout, and x-ray optics implementation. Improvements made by ray-tracing port design will also support x-ray imaging.

Extending Broadband Laser Ranging Reconstruction Algorithms to Enable Temporal Overlap

25-180
FEASIBILITY STUDY
STOCKPILE STEWARDSHIP
DYNAMIC EXPERIMENT DIAGNOSTICS

Andrei Kamalov
North Las Vegas

Summary

We propose to extend the Broadband Laser Ranging (BLR) technique's data reconstruction algorithm to instances where a single measurement's dispersed optical pulse duration exceeds the periodicity of the laser source. Current analysis techniques require that individual measurements are separated by some amount of 'dead time,' which is practically accomplished by limiting optical bandwidth and measurement rates. We seek to determine whether these limitations can be softened without adversely impacting overall BLR measurement quality.

Technical Readiness Level

Start of Project: 4
End of Project: 6

Summary of Technical Progress over the FY

A Python-based algorithm for processing Broadband Laser Ranging (BLR) data has been developed as part of this feasibility study and successfully applied to real data. This algorithm has been fielded on testing data with limited temporal overlap and a pathway for processing data with time overlap caused by higher measurements rates is viable. We ran out of time to quantitatively test the limits of how much temporal overlap can be permitted without negatively impacting data quality. We intend to propose follow up work that applies the algorithm to testing data with greater temporal overlap, and ultimately execute a test shot to show that high repetition rate BLR is feasible.

The algorithm developed for this work cannot outperform the existing BLR investigative tool (BLRiT) technique for well-behaved BLR systems, but has flexibility to process BLR data for instances where the BLR interference pattern includes systematic artifacts. One such artifact, dispersion mismatched signal and reference pulses, have been observed in data associated with a recent subcritical experiment and efforts will continue in early FY26 to demonstrate that the novel algorithm can mitigate the effects of these artifacts. From algorithm applications performed for this feasibility study, some datasets that were previously obscured by artifacts have been improved and made legible, while other artifact-laden data sets could not be improved.

The improved flexibility of the algorithm developed for this feasibility study does not benefit data taken for systems that follow the constraints of the BLRiT technique, but offers pathways for processing data collected with BLR systems that do not meet BLRiT's stringent requirements.

Therefore, the algorithm accomplishes one of the study's goals for softening design constraints of BLR systems.

Benefits to Mission/Program

This study aims to push the boundaries of the current BLR data reconstruction algorithm, which influences multiple components of BLR system designs. Our goal is to show that the algorithm can be expanded on such that design requirements can be made less restrictive. Softening the current guidelines could remove the need for filters, which reduce the launch power and repetition rates of BLR systems. Besides the benefits of improved sensitivity and finer temporal resolution, this study could enable Stockpile Enterprise Operations (SEO) experimental setups to be built around higher rate broadband laser sources, which are the industry standard. We would be able to use systems that are more robustly developed and are historically more reliable than the lasers that are currently used for the National Nuclear Security Administration's BLR setups.

Emergency Response Operations Sensors & Systems

25-012	*Development of Assessment Methodology for Fielded Radiation Detector Crystal Characterizations*	Joshua McCumber
25-105	*Design of a Multi-Pathway Communications Device with Adaptive Intelligence*	James Essex
25-141	*Low SNR, High Clutter UAS Detection and Tracking*	Ian McKenna
25-161	*Deep Learning Enabled Spectral Energy Conversion for Complex Geospatial Detection Systems*	Jonathan Conde
25-179	*Leveraging Massive Real-World Sensor Deployment for Neutron Anomaly Detection*	Scott Suchyta

Development of Assessment Methodology for Fielded Radiation Detector Crystal Characterizations

25-012
YEAR 1 OF 1
GLOBAL SECURITY
EMERGENCY RESPONSE OPERATIONS SENSORS &SYSTEMS

Joshua McCumber
Livermore Operations
James Heinmiller, Sam Trent, Aimee Nielsen
Livermore Operations

Summary

Predictive lifetime performance models are needed for fielded port of entry radiation detectors and portal monitors. Scintillating crystal detection systems will go through rapid aging cycles to determine how the crystals response changes as they age. Aging models will be developed based on this data. This effort will aid in making efficacy and replacement decisions based on real data from sitting locations. This tool will be able to predict efficacy changes over time, aid in identification of higher-risk location detectors, and help inform replacement and characterization and calibration schemes based on environmental and mechanical stressors over time.

Technical Readiness Level

Start of Project: TRL 3-4 Mission research
End of Project: TRL 3-4 Mission research

Summary of Technical Progress over the FY

Over FY25 we were able to engage with the relevant stakeholders who have authority and an identified need for this type of research. Contacts were made with the US Department of Homeland Security (DHS) office of Countering Weapons of Mass Destruction (CWMD) to determine their interest and identify the specific make and manufacturer of equipment in the field. Identified equipment (PVT [polyvinyl toluene] type scintillation detectors) was procured in addition to spectroscopic based scintillation detectors (NaI(Tl)) from the Remote Sensing Laboratory (RSL). These pieces of equipment were received and baselined with Sealed Radionuclide Source available on-site at the laboratory. Additional radioisotopes were procured to aid in expanding the spectrum of energies to be tested better in-line with current American National Standards Institute (ANSI)/Institue of Electrical and Electronics Engineers (IEEE) testing. Relevant environmental factors were examined for a number of areas and equipment was down selected and sourced based on this data (temperature and reaction history [RH]). Equipment was procured for conductance of the RH and temperature aging processes. Additional consultation was performed with the Asphalt Research Consortium (ARC) of the University of Nevada Reno to gain access to modelling software to base the vibration testing on. This modelling and simulation data allowed for relevant construction factors for ports of entry to be factored into the vibration aging of scintillation detectors due to the constant exposure to loaded and unloaded vehicles passing in close proximity.

Preliminary testing was performed for an accelerated age (AA) period of 5 years showing losses in detection efficiency and spectroscopic resolution across both NaI(Tl) and PVT type detectors. The initial efficiency algorithms were updated with this data; however, with the long time to get in equipment (~10 months), only one month's worth of data (5-years artificial) was able to be collected. This experiment showed promise as a method for determination of detector lifetime with the added benefit of being tailored (through mechanical shock and vibration based on construction materials, and environmental factors due to geographical location) to specific sites of interest.

Benefits to Mission/Program

DHS has engaged the Nevada National Security Sites (NNSS) to discuss the assessment of fielded radiation detectors as well as efficacy and lifetime analysis for scintillation crystals. This business opportunity could translate into a large-scale effort for NNSS support encompassing DHS's inventory of radiation detectors, portal monitors, and other specialized equipment. NNSS will leverage its knowledge of radiation, detectors and crystals, access to its laboratories, and subject matter experts (SMEs) to develop simulation of thermal, chemical, mechanical, and structural degradation of these detectors. This could be valuable to the operation of instrumentation in the field over years of deployments.

Design of a Multi-Pathway Communications Device with Adaptive Intelligence

25-105
Year 1 of 3
Global Security
Emergency Response Operations Sensors & Systems

James Essex
Remote Sensing Laboratory

Summary

This project aims to revolutionize field data communications in challenging and dynamic environments by integrating top-tier communications hardware into a unified platform. This platform will feature a modular, open-source software framework to enable custom, adaptive, and intelligent data telemetry. The project specifically targets global security missions that critically depend on timely sensor data assimilation.

Technical Readiness Level

Start of Project: TRL 3-4 Mission research
End of Project: TRL 5+ Technology maturation

Summary of Technical Progress over the FY

A C++ codebase containing classes and header files designed to help third parties develop plugins called modules was developed. These modules come in four types: Filter, Cloud, Device, and Storage, each serving a specific function within the system. The codebase, Scepter, facilitates the creation of Enclaves which are virtual containers holding Modules. Modules operate on physical nodes and interact via supported interfaces. Directives, in JSON [JavaScript Object Notation] format, control these Enclaves, configuring Modules and defining acquisition and telemetry cycles managed by Triggers and worker threads called Elves. Scepter emphasizes modularity and dynamic configuration. This design allows for flexible deployment and greater command and control from the end-user. The naming conventions within Scepter, like "Module," "Enclave," and "Directive," are intended to be easily understood and leveraged by large language models (LLMs) and Retrieval-Augmented Generation (RAG) systems, potentially simplifying sensor integration and knowledge extraction from the codebase.

This year, we developed a RAG system tailored to enhance interaction with the Scepter codebase and wiki. A key component of this work was building a custom chunking library using Tree-sitter, enabling hierarchical parsing of source code across multiple languages as well as markdown files. Unlike traditional line-based chunking, this approach preserves the structural integrity of the code, allowing for more meaningful embeddings and efficient semantic search. These chunks are stored in a vector database, making them easily retrievable for downstream tasks such as question answering and contextual assistance.

In addition, we developed a chatbot library featuring a flexible ChatBot class capable of interfacing with local models. This chatbot was integrated into our current RAG pipeline that combines the chunking and chat libraries with OpenWebUI, creating an easy-to-use user experience. We implemented custom backend logic to chunk and index the Scepter codebase and its associated wiki, allowing users to query and interact with the system through a web interface. The entire pipeline was containerized, ensuring reproducibility and ease of deployment across environments.

Benefits to Mission/Program

The Nevada National Security Sites (NNSS) Global Security divisions and emergency responders rely on data communications. The geographical expanse and urgency of their missions require home-team operations and remote support. Innovations depend on quickly aggregating sensor data for cloud-based machine learning/artificial intelligence analysis, needing capable, sensor-agnostic, turn-key devices.

An auxiliary benefit is a "cloud-first" turn-key sensor telemetry solution that is modular, extensible, open-source, and API [Application Programming Interface]-accessible. This will drive innovations at NNSS within NA20 and Strategic Partnership Projects/Strategic Intelligence Partnership Projects sectors, where computing and data science initiatives are stalled due to technology gaps and high start-up costs.

Low SNR, High Clutter UAS Detection and Tracking

25-141
Year 3 of 3
Global Security
Emergency Response Operations Sensors & Systems

Ian McKenna
Special Technologies Laboratory

See CUI report.

Deep Learning Enabled Spectral Energy Conversion for Complex Geospatial Detection Systems

25-161
FEASIBILITY STUDY
GLOBAL SECURITY
EMERGENCY RESPONSE OPERATIONS SENSORS & SYSTEMS

Jonathan Conde
Remote Sensing Laboratory
Diana Kauviyekal, Anna Duke
Remote Sensing Laboratory

Summary

This study developed a deep learning approach to convert spectra into radiation exposure from sodium iodide detectors in complex, in-situ environments. The neural network aimed to correct non-linear and non-proportional detector responses, achieving higher measurement accuracy than traditional spectra-to-exposure methods.

Technical Readiness Level

Start of Project: 3
End of Project: 5

Summary of Technical Progress over the FY

Deployable NaI(Tl) and Ion Chamber (IC) detectors were characterized, and base computational models were constructed. Stochastic operational variation was estimated and included in the modeling. A large training and validation set was composed. A Deep Learning (DL) neural network was designed and trained on the data set. Analytical techniques were compared to the DL approach via the validation set and Ion Chamber measurements were compared against identical source terms and modeling. Expectations for in-situ accuracy of current methods (analytic and IC) were established. The DL approach achieved higher accuracy and precision over the entire energy spectra of interest (20 keV–3 MeV) exceeding that of the analytical methods with an R^2 score of 0.9983 and Mean Absolute Percentage Error (MAPE) of 0.892%. In addition, the DL approach excelled against the IC measurements expected ± 20% accuracy and achieved ± 5% accuracy over a U.S averaged background energy range for which current implemented methods are optimized towards. This indicates that DL with in-situ NaI(Tl) is a suitable, and possibly a more accurate alternative, to replace currently fielded pressurized ion chambers. The precision advancement could also lead to increased sensitivity in exposure-based alarming algorithms for static detection systems in medicine and industry.

Benefits to Mission/Program

- Demonstrate application of trusted machine learning (ML)/artificial intelligence (AI) techniques within specific National Nuclear Security Administration (NNSA) mission space.
- Expand knowledge of cutting-edge ML/AI technologies within the NNSA workforce.

- Improve accuracy and reliability of radiation dose prediction in real-time, enhancing decision-making in emergency response scenarios.
- Reduce reliance on traditional, time-intensive numerical methods by leveraging automated ML/AI solutions.

Publications

Conde, Jonathan Carlos and Kauveiyakul, Diana and Duke, Anna and Golmohammadi, Mobina and Tank, William and Bahadori, Amir, Deep Learning enabled spectral energy conversion for in-situ exposure measurements. Available at SSRN: https://ssrn.com/abstract=5760799 or http://dx.doi.org/10.2139/ssrn.5760799

Leveraging Massive Real-World Sensor Deployment for Neutron Anomaly Detection

25-179
FEASIBILITY STUDY
GLOBAL SECURITY
EMERGENCY RESPONSE OPERATIONS SENSORS & SYSTEMS

Scott Suchyta
Remote Sensing Laboratory

SEE CUI REPORT.

Radiography & Analysis for Photonic Imaging Detector Systems

25-032	*Novel Photon-Counting Detector Concept for High-Resolution Radiographic Imaging*	Stuart Miller
25-101	*Adapting the Continuous Imager to Use High-Z Semiconductors for High-Speed Direct X-Ray Imaging*	Charles Leak
25-114	*Portable High-Resolution MeV Neutron and X-ray Radiography* (InterLab project)	Charles Leak
25-116	*Study of Intense Electron Beam Target Interactions for Radiographic Applications*	Todd Haines
25-133	*The Development of Nanocrystalline Quantum Dot Scintillator Plate for Fast Neutron Imaging*	Amber Guckes
25-135	*Exploration of 3D Printed Ultrafast and Bright Scintillator Materials*	Kaleab Ayalew
25-152	*Wide-Field Coded Aperture Neutron Imaging by High-Resolution Tungsten Additive Manufacturing*	Andrew Green

Novel Photon-Counting Detector Concept for High-Resolution Radiographic Imaging

25-032
YEAR 3 OF 3
GLOBAL SECURITY
RADIOGRAPHY & ANALYSIS FOR PHOTONIC IMAGING DETECTOR SYSTEMS

Stuart Miller
Los Alamos Operations
Jesus Castaneda, Luke Hovey, Charles Leak, Bob Malone, Jacob Marks, Lakhena Raingsan
Los Alamos Operations

Summary

This work has successfully demonstrated a new concept for imaging different types of ionizing radiation with particular advantages for high energy gammas and neutrons. Multi-angle gated imaging concept (MAGIC) is a new technique consisting of two cameras that focus inside a scintillator to image scintillation events from two vantage points. The transparent scintillators can be made thick to provide higher stopping power, and the events can be located within the scintillator volume with high accuracy in three dimensions. This provides not only high spatial resolution, but also depth of interaction (DOI) information which is related to particle energy. The high-resolution radiograph is then formed by constructing the projected image back towards the source.

This successful project has laid the groundwork for potential new detector developments in applications such as global security, for example to improve radiography of "black boxes." As new detectors with higher sensitivity and speeds are developed, this could open up the future possibilities for many other Department of Energy (DOE) and Department of Homeland Security mission-relevant activities, including stockpile stewardship and nuclear security.

Technical Readiness Level

Start of Project: TRL 0-2 Fundamental research
End of Project: TRL 3-4 Mission research, Proof of concept established

Summary of Technical Progress over the FY

During this FY the project came to fruition to demonstrate the concept with gammas, as well as neutrons with energies ranging from cold to fast (3 mev to 14 MeV). To accomplish this, a portable two-camera imaging system was designed and built. This included a dark box and camera mounts with mirrors to assure that the cameras are positioned outside of the direct beam. This system was first field tested at the North Las Vegas (NLV) source range where gammas from Co-60 and Cs-137 sources were used to image objects with CsI:Tl scintillators up to 20 mm thick. Also, fast neutrons were imaged from a Thermo Fisher deuterium-tritium (DT) neutron source using a 38-mm-thick organic glass scintillator (OGS). Here we were successful in constructing the first images with penetrating radiation.

The next trip was to Oak Ridge National Lab (ORNL) to the Spallation Neutron Source (SNS) to image with cold to epithermal neutrons at the pulsed VENUS beamline. This successful trip happened about one month from the end of the project and data is still being processed.

Benefits to Mission/Program

Successful development could greatly advance Defense Nuclear Nonproliferation (DNN), NA-22, and Global Security capabilities to supplement current X-ray imaging with high resolution neutron imaging, a need referenced in the FY 2022 DNN Topic of Interest on near-field detection. The detector developed here will provide an improved method for passive imaging where gamma and neutron events can be separated. This project started at a low TRL and is now TRL 3-4, having demonstrated the proof of concept of this new approach to radiography. There is great potential for deeper development of this methodology.

Publications

The first publication of this work is being drafted now.

Presentations & Accolades

This project was highlighted in the August SDRD Highlight article.

Adapting the Continuous Imager to Use High-Z Semiconductors for High-Speed Direct X-Ray Imaging

25-101
YEAR 1 OF 2
STOCKPILE STEWARDSHIP
RADIOGRAPHY & ANALYSIS FOR PHOTONIC IMAGING DETECTOR SYSTEMS

Charles Leak
Los Alamos Operations
Kevin Thomas[1], Kevin O'Flarity[2], Mike Jones[2], Ivan Pegram[2], Kaleab Ayalew[3], Eric Schmidthuber[1]
[1]Remote Sensing Laboratory, [2]Los Alamos Operations, [3]North Las Vegas

Summary

Semiconductor sensors are being mated to camera architecture being developed by the NNSS to prototype a high-Z-semiconductor-based direct x-ray camera capable of recording many frames, bypassing scintillators and optics, improving sensitivity and spatial resolution, and taking advantage of previous and ongoing compact digitizer designs.

Technical Readiness Level

Start of Project: TRL 3-4 Mission research
End of Project: TRL 5+ Technology maturation

Summary of Technical Progress over the FY

Our initial technical progress was to evaluate the readiness of different NNSS camera architectures for adaptation. The Continuous Imager was determined to be too immature to be easily usable, and the Kraken digitizer was determined to be appropriate, though a fast sampling rate had to be compromised.

Technical progress during fiscal year 2025 consisted of three parallel efforts.

1. Electrical design of sensor front-end circuit.
2. Firmware redesign of existing NNSS camera electronics.
3. Manufacturing or procurement of example sensor crystal.

Effort #3 does not explicitly contribute to a stated goal but is implicitly necessary to evaluate ultimate design performance. One crystal was manufactured by an intern, but most progress on effort #3 was postponed to accommodate increased circuit board costs.

The electrical design was broken into two boards to simplify partial reuse of a previous board design from previous SDRD 23-088. The first board (amplifier board) was designed to interface with the sensor crystal, supplying high voltage (~1 kV) and coupling low-noise charge-integrating amplifiers to the crystal's electrodes. Simple small crystal-carrier boards were also designed to mate unpackaged crystals to this board. The second board (interface board) was designed to groom the output voltages of the integrating amplifiers to the correct polarity, endedness, offset, and range to be recorded by the digitizers installed on Kraken v1 digitizer boards. These boards were designed, procured, and assembled this fiscal year.

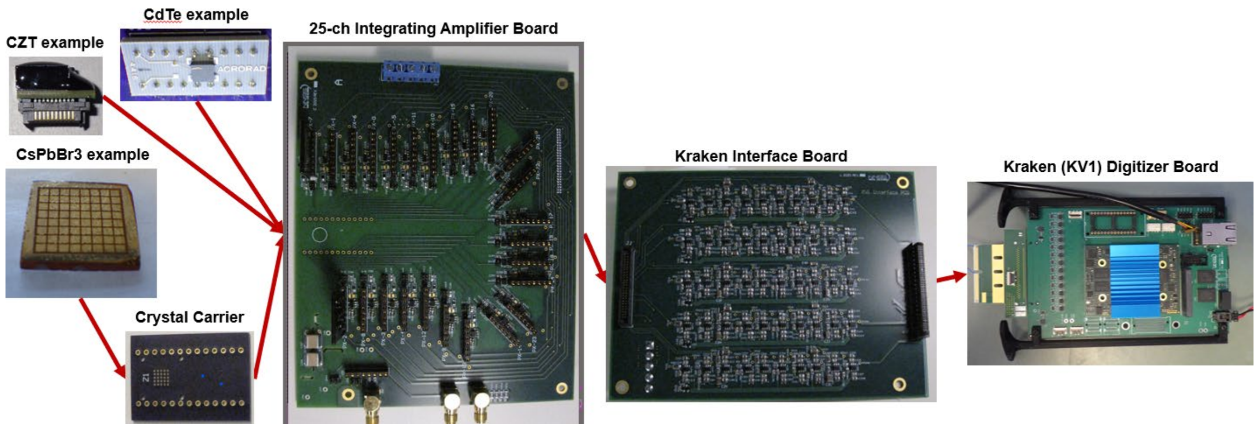

Figure 14. Board assembly.

Most firmware changes were of the Cyclone V system-on-chip field-programmable gate array located on the digitizer board. A new readout state machine was designed and written. Digital sampling was accelerated from 3 µs to 1.06 µs. Trigger walkthrough was simulated and a trigger uncertainty of 10 ns was found with 30 ns of fixed delay. Packet controller was modified and direct memory access was achieved, allowing recorded values to be read to a laptop computer.

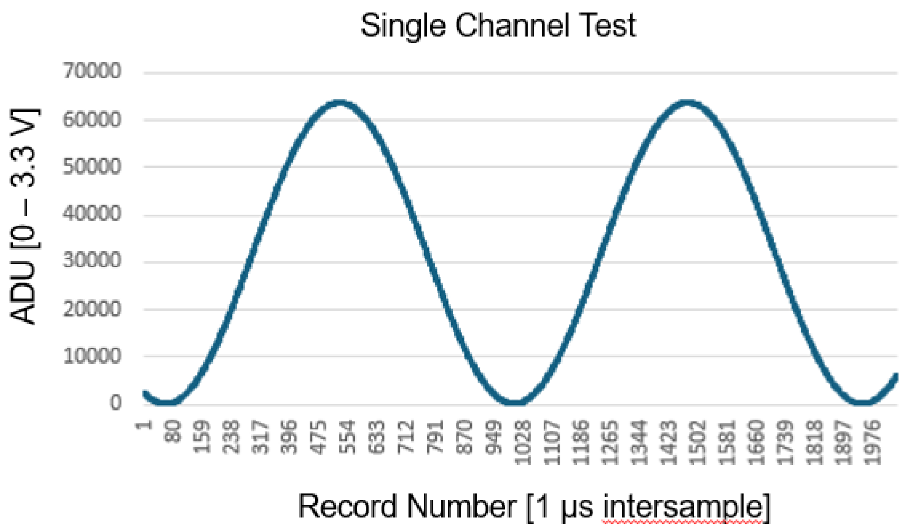

Figure 15. Readout for single channel test.

Benefits to Mission/Program

Multi-frame mid-soft radiography is needed to examine hydrodynamic and subcritical experiments on less dense material across the Nuclear Security Enterprise (NSE) and to characterize existing and new designs for explosive detonators and explosive wire systems. This project will continue recent development of directly converting framing cameras using high-Z semiconductors for high resolution imaging in the hundreds-of-keV photon range, with potential for novel imaging of physics experiments with accelerators such as the Advanced Photon Source, with portable needle-washer flash x-ray generators, or with continuous x-ray generators whose flux is historically too low for short integrations. The electronic adaptation developed may also facilitate future adaptation to other semiconductor-based sensors (e.g., infrared-sensitive or neutron-sensitive).

Portable High-Resolution MeV Neutron and X-Ray Radiography

25-114
YEAR 1 OF 3
INTERLABORATORY PROJECT
GLOBAL SECURITY
RADIOGRAPHY & ANALYSIS FOR PHOTONIC IMAGING DETECTOR SYSTEMS

Charles Leak
Los Alamos Operations
Stuart Miller[1], Ryan Roman[2], Jacob Marks[1], Luke Hovey[1], Andrew Green[1], Sean Breckling[2], Alex Long[3], Patrick Feng[4]
[1]Los Alamos Operations, [2]North Las Vegas, [3]Los Alamos National Laboratory, [4]Sandia National Laboratories

Summary

A TimePix camera (event-mode imager) is being coupled to nanoguides (fiber-optic-like structure) developed from organic glass scintillators (OGS) and paired with portable radiation-generating devices to prototype portable radiography systems. Physics-informed machine learning is being applied to differentiate between x- and gamma-ray interactions and neutron interactions to form separate images.

Our project seeks to develop a portable, high-resolution fast-neutron and X-ray imaging system that incorporates advanced and novel scintillator and imaging-sensor technology as well as machine-learning algorithms for neutron/X-ray discrimination, enabling unprecedented accuracy in detecting explosives and other concealed threats, even through thick shielding or embedded in dense materials. This system will significantly enhance national security by improving real-time detection of hazardous materials in complex and challenging environments, strengthening nuclear nonproliferation efforts and providing critical support to emergency responders.

Technical Readiness Level

Start of Project: TRL 3-4 Mission research
End of Project: TRL 3-4 Mission research

Summary of Technical Progress over the FY

This interlaboratory project has seen progress from Sandia National Laboratories (SNL), Los Alamos National Laboratory (LANL), and the NNSS. SNL manufactured a large (10x10x4 cm^3) OGS nanoguide sample, building on their previous work, and delivered it to LANL/Los Alamos Operations (LAO). LANL designed and conducted an experiment to measure the spatial and temporal response of their existing imaging lens and Timepix camera coupled to SNL's sample. The NNSS generated artificial data using a Monte-Carlo radiation transport code (Geant4) and processed this data into artificial images.

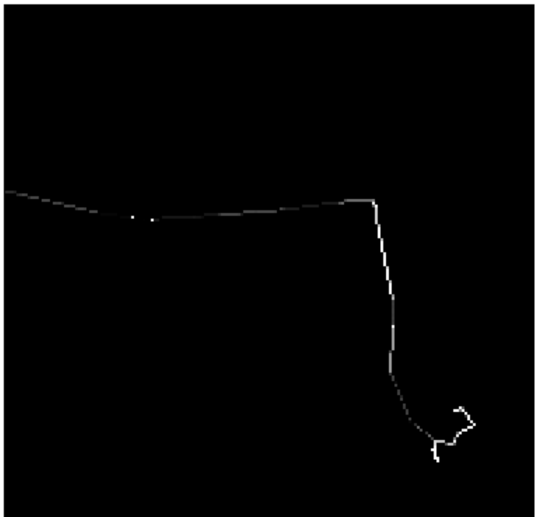

Figure 16. Example of primary photoelectron track in scintillator simulated with Monte Carlo methods and visualized as an image frame

NNSS then applied some machine-learning techniques to these artificial images and to toy data to segment and classify the events in these images.

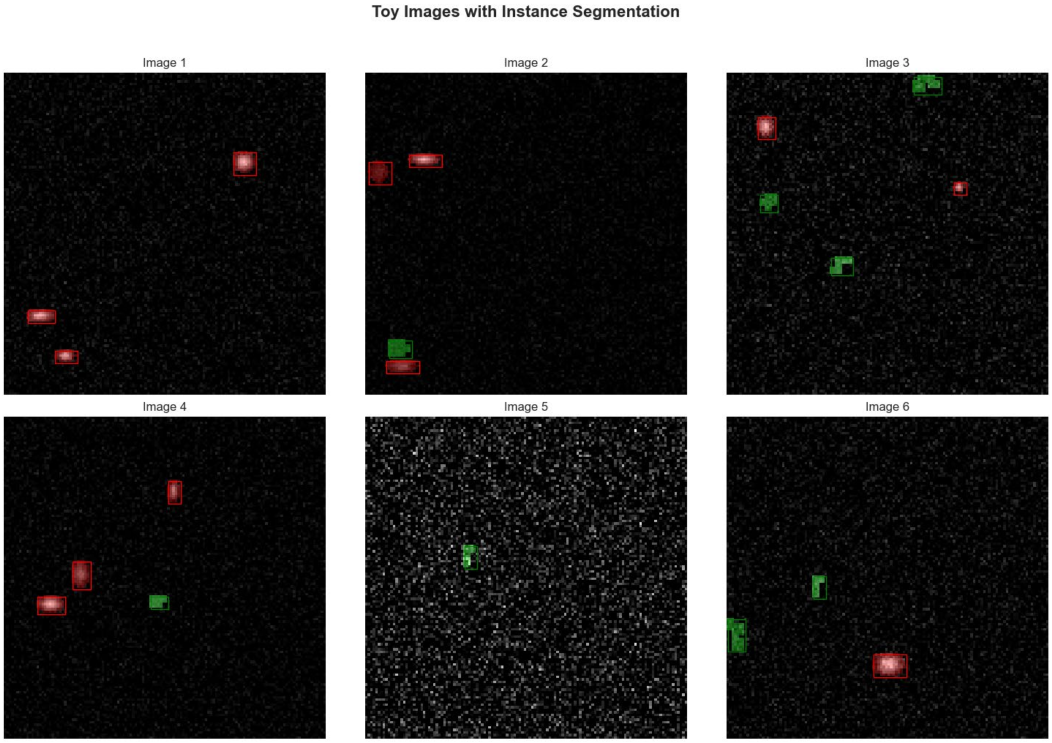

Figure 17. Segmentation and classification of events in artificial image frames.

Benefits to Mission/Program

Radiographic methods are a core capability of Department of Energy (DOE) and Department of Homeland Security (DHS) mission-relevant activities, especially stockpile stewardship, nuclear security, and emergency response. The development of nanoguide scintillators has the potential to benefit all these areas by breaking the inverse relation between efficiency and spatial resolution, relaxing requirements of source intensity. Portable neutron sources exist, but portable neutron radiographic systems are currently impractical because of weak signal and poor spatial resolution. The combination of efficient nanoguides and sensitive Timepix sensors with ultra-high resolution reconstruction techniques and event classification should enable portable neutron radiography, which is capable of imaging through heavy metals, unlike soft x radiography currently used in portable radiography systems, and should provide higher contrast of plastics, all else equal. Neutron-photon event classification may also enable elemental identification in future work. The advancements proposed herein will most improve radiography of "black boxes," but advanced versions of Timepix cameras are on the horizon while concurrent reduced cost for existing Timepix chips may enable event rates to be increased by tiling many chips. The current project is therefore an investment to enable pulse-shape discrimination, event centroiding, and other techniques also for dynamic radiography in the future (e.g. for Scorpius, pRad, or DARHT).

Study of Intense Electron Beam Target Interactions for Radiographic Applications

25-116
Year 1 of 3
Stockpile Stewardship
Radiography & Analysis for Photonic Imaging Detector Systems

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Summary

Flash x-ray radiography remains an important diagnostic for locating material position(s), amount(s) and type(s) in dynamic fundamental, focused, and integrated experiments. Understanding how the electron beam used to produce x-rays effects a target has been a problem for at least as long as the invention of the vacuum tube, only made more difficult by the need for very intense (MA), high-energy (MV) and short-pulse (ns) sources for a variety of applications. This project concentrates specifically on intense single- and multi-pulse radiographic x-ray source development.

We are enabling very broad diagnostic capabilities at the Naval Research Laboratory's (NRL) Mercury facility, a unique facility in the NA-11 arena as substantially devoted to R&D in this area. We are adding the ability to diagnose cathode (source) and anode (target) measurements to the facility. This is an addition to the existing diagnostics there (e.g., radiography, time-resolved spot diagnostic [TRSD], Aerogel Cherenkov Detector for Cygnus [ACD/C], Ross Filter Diode Array [RFDA], dosimetry, pin hole camera [PHC]) that have substantially been implemented by our team and collaborators.

We will field time-resolved 1) visible imaging and 2) soft x-ray measurements of the hydrodynamic evolution of the target during and after e-beam bombardment. Our collaborators will field complementary spectroscopic and interferometric measurements of plume composition, temperature, and density.

As Mercury has been in the Cygnus-like configuration for several years now, we start with it in that configuration. However, the machine will become reconfigured into a linear induction accelerator (LIA)-like planar target geometry that can deliver >10x the energy on target than DARHT/Scorpius. Our work will continue in that configuration.

Given the regular availability of beam-time at a source with current, voltage and pulse-length characteristics relevant to other sources in the nuclear weapons complex, this project helps to strengthen our collaborative work with pulsed-power and plasma experts at NRL. With about a 10-year track record, this collaboration provides an excellent testing ground for existing and newly

developed diagnostics and, most importantly, a superb training ground for scientists, engineers, and technicians new to working near intense sources and/or making precision radiographic measurements.

Substantially because of this, the facility is already outfitted with a very wide range of power-flow, e-beam, hard x-ray spot and spectral measurements, hydrodynamic and plasma diagnostics along with the additional soft x-ray and visible imaging this project is providing. This wealth of data is available to us to test our own simulations as well as simulations of our partners and collaborators. Specifically, as part of work with the NRL, the PI has run and continues to run moderate fidelity simulations using the Particle In Cell (PIC) package known as Chicago. These calculations show what might be expected when various parameters of the drive or diode are changed. These simulations show nothing like phenomena shown from a set of Faraday cup (FC) ion measurements already taken at Mercury. This modeling work will continue collaboratively with NRL and possibly others. (e.g., future work with Los Alamos National Laboratory (LANL) to test their material point method (MPM) hydrodynamic modeling has been discussed. Specific targets, namely combinations of Ti and Au, are excellent candidates as their material properties are established within the MPM approach at LANL.) The collaboration welcomes those who are interested in working together.

Technical Readiness Level

Start of Project: TRL 0-2 Fundamental research
End of Project: TRL 3-4 Mission research

Summary of Technical Progress over the FY

In the Cygnus configuration, our ability to measure the prompt ions, plasma plume, and hydrodynamics of the anode target are severely limited. This is simply because the end section of Cygnus was designed as the end section for a production radiographic facility, not one devoted to scientific research. To achieve our goals, we obviously needed to modify the end-section ("spool") of Mercury to enable improved diagnostic access.

The collaboration specified our desire to enable access to the A-K and pinch regions—several close-in ports for x-ray backlighting, many ports at many angles for Faraday cup ion measurements, a number of ports for our existing "60 degree" measurements, and new laser backlighting ports—but did not include cathode-viewing ports. A complete conceptual layout meeting the desires of the collaborators was completed but this, in the end, was extremely complicated with more than 3 dozen individual vacuum-tight viewing ports specified. It became clear to those involved that we needed to reduce our desires while enabling a good view of the cathode region. This re-design and a complete drawing package was finished in July and sent to the A1 shop for manufacture.

As the completed specification and design process took longer than expected, we also chose to pursue first attempts at gated visible imaging of the hydrodynamics of the target region that could be accomplished within the current diagnostic constraints. The initial look at those images suggests unexpected behavior and remains to be studied. These results will be presented at an upcoming Joint Working Group (JOWOG) at Atomic Weapons Establishment (AWE) in early FY 2026.

Benefits to Mission/Program

Our Cygnus facility remains the ultimate source for flash x-ray radiography of subcritical experiments (SCEs); our Scorpius facility is next. We have shown via trial-and-error that Cygnus' performance can be improved by nearly a factor of 2 by simple modifications to the anode (i.e., e-beam target) and cathode (i.e., e-beam source). Whether or not the target for Scorpius is optimal for its initial SCEs, like at Cygnus, it will be a multi-decadal facility for a variety of SCE types; we want better data and model constraints so that we can design and optimize x-ray production target(s) for those several decades.

The Development of Nanocrystalline Quantum Dot Scintillator Plate for Fast Neutron Imaging

25-133
YEAR 1 OF 2
STOCKPILE STEWARDSHIP
RADIOGRAPHY & ANALYSIS FOR PHOTONIC IMAGING DETECTOR SYSTEMS

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North Las Vegas
Kaleab Ayalew[1], Jesse Andrew Green[1], Alexander Barzilov[2], George Henry Peterson[2], Teodulfo Alanano[2]
[1]*North Las Vegas,* [2]*University of Nevada, Las Vegas*

Summary

Scintillator plates are essential for radiography used by the Nevada National Security Sites and its customers for both the Global Security and Stockpile Stewardship missions. Traditional scintillator plates, such as ZnS:Cu embedded in plastics, have been employed for fast neutron imaging. However, their performance is hindered by significant light scattering and prolonged afterglows lasting several minutes. Recent advances in nanomaterial engineering and quantum sensing have shown potential for creating scintillator plates with tunable emission, improved light output, and reduced afterglow to the sub-nanosecond level. These advancements could enable significantly faster, and improved energy and spatial resolution for neutron radiography.

We have investigated and began synthesis of three such quantum dot materials: $MAPbBr_3$, $MAPbI_3$, and PEA_2PbI_4. Tailoring the emission wavelength of these quantum dot materials has been explored using several published approaches with success. However, ageing and environmental effects have posed a not-so-unique challenge in the synthesis of these materials. The developments made and lessons learned will be leveraged to create, characterize, and employ the next generation of scintillator plates for fast neutron imaging in the final year of this project.

Technical Readiness Level

Start of Project: TRL 0-2 Fundamental research
End of Project: TRL 3-4 Mission research

Summary of Technical Progress over the FY

We performed an extensive literature review to identify novel and existing materials that exhibited favorable performance characteristics for fast neutron radiography and imaging applications. The identified materials were, $MAPbBr_3$, $MAPbI_3$, and PEA_2PbI_4.

Geant4 simulations were performed with these three materials to predict how each would respond in energy and time to a uniform distribution of neutrons from 100 keV to 15 MeV. It was discerned that PEA_2PbI_4 was the most sensitive to this spectrum of neutrons yielding a higher energy deposition per interaction than the other two materials. Simulations of varying quantum dot concentration in a polymethyl methacrylate (PMMA) matrix and subsequent time performance for each material under neutron irradiation are underway.

MAPbBr3, MAPbI3, and PEA2PbI4 quantum dots were synthesized by our collaborators at the University of Nevada, Las Vegas (UNLV). It was readily noticeable that the materials utilizing iodine were sensitive to environmental conditions. Without an inert atmosphere to perform the synthesis, the MAPbI3 and PEA2PbI4 quantum dots were not stable and did not persist. The MAPbBr3 quantum dots were much more stable under atmospheric conditions. Tuning of the MAPbBr3 emission spectrum was explored with some success as shown in Figure 1. However, the MAPbBr3 quantum dots did show effects of ageing where their color or brightness would change as a function of hours to days. Several published approaches to stabilizing the quantum dots while enhancing the tunability are currently being investigated by UNLV which will continue into FY26 Q1.

The developments and lessons learned gleaned from the first year of this project will be implemented so to attain a stable and tunable quantum dot material in FY26 Q1 followed closely by characterization measurements of each material. These measurements will include scintillator decay time, light yield, transmission spectrum, absorption spectrum, emission spectrum, XRD, and SEM/particle size measurement. The integration of the quantum dots into a polymer matrix scintillator plate is planned for Q2.

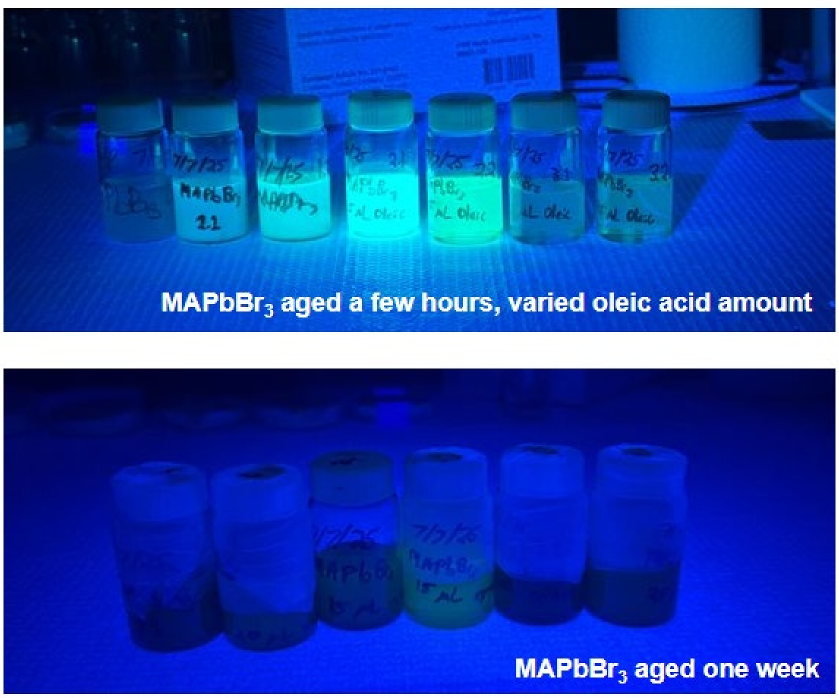

Figure 18. First batch of MAPbBr3 quantum dots to investigate tuning of emission wavelength by means of varied oleic acid amounts; subsequently observed was the effects of ageing on the quantum dots

Benefits to Mission/Program

The 2025 Technology Needs Assessment identified the development of new detector materials for X-ray and neutron radiography systems as one of the priority research and development needs. Furthermore, the report highlighted the importance of quantum sensing as another research priority. The project aims to address both identified needs and is anticipated to contribute to the development of the next generation of sensors and detectors utilized by the NNSS and its customers across the US Department of Energy complex. Lastly, programs such as Neutron-Diagnosed Subcritical Experiments, and Global Security-Defense Nuclear Nonproliferation are potential near-term customers of the developments.

Exploration of 3D Printed Ultrafast and Bright Scintillator Materials

25-135
YEAR 1 OF 2
STOCKPILE STEWARDSHIP
RADIOGRAPHY & ANALYSIS FOR PHOTONIC IMAGING DETECTOR SYSTEMS

Kaleab Ayalew
North Las Vegas
Adam Wolverton[1], Robert Buckles[1], Jim Tinsley[2], Justin Neubauer[1], Alexander Barzilov[3], Kayvaan Adrangi[3]
[1]North Las Vegas, [2]Special Technologies Laboratory, [3]University of Nevada, Las Vegas

Summary

The enduring requirements of the Stockpile Stewardship experimentation mission, both at the Nevada National Security Sites (NNSS) and throughout the broader Department of Energy complex, necessitate the development of scintillator materials possessing both ultra-fast response times and high brightness. Existing commercially available scintillators, however, present inherent limitations, often forcing a compromise between these two critical performance characteristics. Consequently, this project is dedicated to a comprehensive exploration of the scintillator materials landscape, specifically targeting the creation of novel ultra-fast and high-brightness materials. The core strategy involves focusing on nanocrystalline composite scintillators, a class of materials promising enhanced performance attributes. Furthermore, the project leverages advanced additive manufacturing techniques, which enables rapid production of these novel materials and facilitate their efficient optimization through iterative design and testing cycles. This integrated approach seeks to overcome long-standing material science challenges and fulfill the critical needs of national security applications.

Technical Readiness Level

Start of Project: TRL 0-2 Fundamental research
End of Project: TRL 3-4 Mission research

Summary of Technical Progress over the FY

At the outset of the project, an extensive literature study was conducted to identify promising pathways for achieving sub-nanosecond decay in scintillator materials. This research revealed two primary avenues: nanocrystal composite scintillators and fluoride nanocrystal (NC)-based scintillators utilizing core-valence transfer.

For the nanocrystal composite pathway, the approach leverages the quantum confinement effects of NCs to achieve intrinsically ultrafast emission and high quantum yields, effectively decoupling the traditional speed-brightness trade-off. Progress has been made, including the successful demonstration of 3D printing NC-containing scintillators. Initial samples, specifically 3D printed plastic samples incorporating CdSe/ZnS NCs, have shown promising results. However, to fully realize the potential of these materials, higher nanomaterial loading is required, which will be a focus for the upcoming year. Additionally, future optimization will involve investigating the 3D printable polymer host. While commercially available Form labs clear photo resin is currently used, plans are in place to develop an optimized photo resin more compatible with NC materials.

Concurrently, research into fluoride NCs has concentrated on exploiting core-valence band transfer mechanisms. A key finding from the literature review indicates that reducing the size of fluoride NCs, such as BaF2, can significantly mitigate or eliminate their typically slow luminescence component, thereby achieving faster response times. As a result, three candidate materials (BaF2, LiF, TlF) have been identified for further research. The team at the University of Nevada Las Vegas has been actively synthesizing these selected materials. Early characterization tests suggest successful material synthesis; however, continuous work is underway to refine the synthesis procedures to meet the stringent purity and quality requirements of this project.

A crucial project achievement is the development of in-house scintillator characterization tools. Systems capable of measuring light yield, scintillator decay constants, and UV-vis spectroscopy have been established. This capability provides essential feedback for material optimization and facilitates rapid iteration in the development process.

Benefits to Mission/Program

The development of advanced scintillator materials offers substantial benefits for the NNSS and National Nuclear Security Administration missions. The successful discovery of optimized ultra-fast and bright scintillators could directly enhance diagnostic capabilities for subcritical experiments, allowing for more precise temporal resolution and higher fidelity data acquisition across multiple high-value experiments. This improved performance is crucial for accurately characterizing dynamic processes within complex experimental setups, thereby refining our understanding of materials at extreme conditions.

Presentations & Accolades

"Recent development in quantum enabled scintillators," 4th annual NNSS Prompt Radiation Detection and Imaging workshop, May 15, 2025, Las Vegas, Nevada.

Wide-Field Coded Aperture Neutron Imaging by High-Resolution Tungsten Additive Manufacturing

25-152
YEAR 1 OF 2
STOCKPILE STEWARDSHIP
RADIOGRAPHY & ANALYSIS FOR PHOTONIC IMAGING DETECTOR SYSTEMS

Robert Buckles
North Las Vegas
Andrew Green, Zach Wolff, Danny Sorenson
North Las Vegas

Summary

Neutron imaging has been a fundamental diagnostic for the inertial confinement fusion (ICF) campaign and is emerging as a necessary aspect for the Stockpile Stewardship mission, particularly for neutron-diagnosed subcritical experiments (NDSE). Neutron Radiography is listed as a secondary milestone for the upcoming Excalibur series of NDSE experiments, and we believe it is a challenging task for the expected flux. We have successfully designed and constructed a 3D-printed thick metal coded aperture that alleviates the flux restriction, while also allowing high resolution and mitigates transmissive/scattered contrast. We succeeded at coarse resolution trials with 1MeV x-rays at the end of FY25 and will now proceed with high resolution trials in tungsten on deuterium-tritium and broadband neutron sources by mid-year FY26, culminating in the trial print designed for in-vessel Excalibur shots.

Technical Readiness Level

Start of Project: TRL 3-4 Mission research
End of Project: TRL 5+ Technology maturation

Summary of Technical Progress over the FY

We have successfully established a uniform design for any experimental condition of size, distance, and number of resolution elements, a realistically achievable design with 3D metal printing, and holds to the methodology of Modified Uniformly Redundant Arrays (MURA). One particular complexity was the mathematically ideal slots/holes with unsupported sides, and we extended the concept to include finite thin walls. We have simulated these designs in both Monte Carlo N-Particle code (MCNP) and Geant4 and conclude that they meet all the functional rigor of classical MURAs and behave essentially perfectly in the mathematical ideal of the MURA context. We have also succeeded at designing and manufacturing MURAs as 3D printed constructs and successfully tested a stainless-steel MURA with MeV x-rays.

Benefits to Mission/Program

Neutron Radiography is listed as a secondary milestone for the upcoming Excalibur series of NDSE experiments, and we believe it is a challenging task for the expected flux. Radiography has a decent chance, while pinhole imaging seems impossible without a significant change in methodology. High resolution imaging of neutron sources and neutron-irradiated/fission objects generally requires significant flux, on the order of 10^{17} neutrons with a classical fine pinhole technique, and yet we attempt to do so with much smaller sources, on the order of 10^{12} or less. The coded aperture approach can achieve this by having a vast multitude of such pinholes, about 10^{5}, arranged in an encoded pattern allowing extraction of the simultaneous overlapping images. The technique was developed in the 1970s for observation of astronomical gamma sources (dark stars) yet applies to any particle. The challenge however is to observe near-field sources; so near that the pinholes must have a common focus at a few centimeters, rather than parallel channels at infinity. We are the first to have successfully demonstrated a working near/wide-field design, both in simulation and experiment. We expect FY26 work to actually image Zeus neutron distribution and prepare a design/print for Excalibur in-vessel fission imaging.

Presentations & Accolades

We presented our design mid-year at the Prompt Radiation Detection and Imaging workshop, and plan to present experimental fabrications and testing at the JOWOG 32HDT workshop in October.

Technology & Research in Artificial Intelligence for Nuclear Security

25-016	*Computational Fluid Dynamic Simulations for Critical Infrastructure (CFD-SCI)*	Sean Breckling
25-051	*One-Time Waveforms with Low Spectral Signature*	Corey Heitzman
25-052	*Data Fusion: Reconstructing 3D Hydrodynamic Scenes Utilizing Both Radiography and Momentum Diagnostics*	Jordan Pillow
25-055	*Background Subtraction and Noise Reduction via Machine Learning*	Clifford Watkins
25-117	*Cloud-Based Meta-Analysis with Adaptive Learning for Massive Sensor Networks*	Carson Schuetze
25-200	*Feasibility Study for Internal ML Compute Infrastructure at NNSS*	Nicholas Eisenberg

Computational Fluid Dynamic Simulations for Critical Infrastructure (CFD-SCI)

25-016
YEAR 3 OF 3
GLOBAL SECURITY
TECHNOLOGY & RESEARCH IN ARTIFICIAL INTELLIGENCE FOR NUCLEAR SECURITY

Sean Breckling
North Las Vegas
Cliff Watkins, Paige Brady[1], Caleb Monoran[2], Jorge Reyes[3], Jacob Murri, Hayden Schaeffer[4] *[1]NNSS-Special Technologies Laboratory, [2]NNSS-North Las Vegas, [3]Virginia Polytechnic University, [4]University of California, Los Angeles*

Summary

The challenge: Computing 3D simulations of incompressible fluid flows is a famously difficult endeavor. In settings with strong variations in temperature or potential forces, if the practitioner under-resolves important regions of the domain, the entire simulation may become unstable, losing all physical relevance. There are a number of proven and practical techniques to address this issue, but few have been as successful as Proper Orthogonal Decomposition (POD)-based reduced order modelling (ROM). While these methods have received significant and growing academic attention since 2012, they tend to be inflexible when simulating flow settings that were not included in their training data.

Introducing model reduction methods to a user-driven digital twin of a user facility necessitates the ability to automatically and correctly account for changes in the flow domain. Under normal circumstances, if a digital twin user decides to open a facility door, or move a large crate, the associated fluid model would require a new 3D mesh. However, if a POD-ROM has not been pre-trained on that specific 3D state, a digital twin would need to compute a full-order model to produce physically relevant results. This scenario is wholly impractical.

We have developed a technique that allows for digital twin users to adjust the computational flow domain more freely, without the necessity of a complete numerical simulation. This is done by developing several small POD-ROMs around important objects found in the digital twin and supplanting them into a larger numerical model. Given that the bulk of the computational cost of a fluid simulation is found near objects / boundaries, if these regions can be modelled by a surrogate, the total computational cost of the simulation drops significantly. If the user moves, or changes the state of one of these objects, the larger model can accommodate, producing an accurate 3D flow at a substantially lower computational cost.

Attempting this naively, using popular numerical methods, will fail in all but the simplest scenarios due to forcing / traction mismatches at the false internal boundaries that surround our surrogates. We have overcome this problem in several ways, chief among which is through a combination of discontinuous Galerkin, Brezzi finite elements, and the Petrov-Galerkin method.

Technical Readiness Level

TRL 3-4 Mission research
TRL 5+ Technology maturation

Summary of Technical Progress over the FY

In 2024 we developed a model reduction methodology for incompressible flow regimes common to user facilities. For 2025, much of that work was continued under the SET/Osiris program, leaving the lower TRL work for this project. Among the studies conducted under this program this year, the main research efforts developed techniques to parameterize a key class of reduced-order modelling methodologies: Dynamic Mode Decomposition (DMD). These developments would allow users to rapidly estimate internal flow features in settings never directly realized numerically.

In addition to the model-parameterization efforts, our partners at UCLA implemented a novel new technique to optimally incorporate discrete time-dependent temperature sensor data directly into numerical flow simulations. The result is a new capability that allows the modeler to accurately solve for a time-dependent continuum of flow quantities (velocity, temperature, and pressure) as highly under-determined inverse problem.

Benefits to Mission/Program

The NNSS sought to develop skillsets among technical staff in computational fluid dynamics related to Defense Nuclear Nonproliferation (DNN) and Strategic Intelligence Partnership Project (SIPP) sensing operations and test beds. To that end, new tools and techniques were developed that have been absorbed into a variety of programmatic efforts- namely the SET/Osiris project.

Publications

Advanced drafts and preprints:

1. *"Inferring velocity from temperature measurements in buoyancy-driven flow with nonlinear continuous data assimilation,"* Murri, J., Schaeffer, H., Watkins, C., Breckling, S. (Draft pending submission before end of CY2025.)
2. *"Regularizing the Linearly Extrapolated BDF2 Scheme for Incompressible Flows with Time Relaxation,"* Breckling, S., Reyes, J., Sheilds, S., Watkins, C., Finite Elements in Analysis and Design, (Submitted July 2025, Reviewed October 2025, Acceptance pending finalization)
3. *"Data-Driven Parameter Domain Decomposition for Robust Digital Twins of Nonlinear Thermo-fluid Systems,"* Breckling, S., Watkins, C., Brady, P., Monoran, C., Reyes, C. (Advanced draft pending public release and submission to the journal Computers & Fluids)

Publications:

4. *"An extension of the 3D Lorenz model under the Gay–Lussac approximation,"* C. Monoran, Watkins, C., Breckling, S., Chaos 1 September 2025; 35 (9): 093116. https://pubs.aip.org/aip/cha/article/35/9/093116/3361663
5. *"A note on the long-time stability of pressure solutions to the 2D Navier Stokes equations,"* Breckling, S., Fiordilino, J., Reyes, J., Shields, S., 2024;478, Applied Mathematics and Computation, https://doi.org/10.1016/j.amc.2024.128839

Presentations & Accolades

Records of Invention (NNSS)

1. *"Submerged Surrogate Fluid Models for Digital Twins,"* S. Breckling, C. Watkins, J. Murri.

Accepted, Post-Closeout Conference Talks

1. "Data-Driven Parameter Domain Decomposition for Robust Digital Twins of Nonlinear Thermofluid Systems," AMS Special Session: Recent Advancements in Numerical Methods for Fluid Dynamics, Joint Mathematics Meeting (JMM) 2026, S. Breckling.
2. *"Exploring Continuous Data Assimilation Algorithms for Reconstructing Flow from Temperature Measurements,"* American Physical Society Division of Fluid Dynamics (DFD25)– J. Murri.

Conference Talks

1. *"Improved Long Time Accuracy for Fluid Models using EMAC Formulation,"* Theoretical Analysis and Numerical Methods of PDEs and Data-Driven Models, 10th SIAM Annual Meeting of the Central States Section (SIAM-CSS), J. Reyes.
2. *"On Capturing non-Boussinesq Physics with Incompressible Natural Convection Models,"* The 9th SIAM Central States Section Annual Meeting, S. Breckling.
3. *"At the intersection of Reduced Order Modelling and Discrete Loss Minimization: Can complicated, high-Re incompressible flow models become edge computable?"* American Physical Society Division of Fluid Dynamics (DFD24), S. Breckling.
4. *"Submerged Reduced-Order Models for Incompressible Flow around Obstacles",* American Physical Society Division of Fluid Dynamics (DFD24), J. Murri.
5. "*Regularized Reduced Order Modelling for Turbulent Flow,"* Minisymposium 13: Recent Advances in Efficient and Robust Numerical Techniques for Partial Differential Equations and their Applications, 8th Annual SIAM Annual Meeting of the Central States Section (SIAM-CSS), J. Reyes.

Accepted, Post-Closeout Posters

1. *"Data-Driven Parameter Domain Decomposition for Robust Digital Twins of Nonlinear Thermo-fluid Systems,"* 2025 LDRD Annual Meeting (JLab), S. Breckling.

Posters

1. "An Extension of the 3D Lorenz Model under the Gay-Lussac Approximation," American Physical Society Division of Fluid Dynamics (DFD24), C. Monoran.
2. "Long-Time Stability of Pressure Solutions to the 2D Incompressible Navier Stokes Equations" UNLV Computational & Data Science Day, University of Nevada Las Vegas, 2023, J. Reyes.

One-Time Waveforms with Low Spectral Signature

25-051
YEAR 1 OF 3
GLOBAL SECURITY
TECHNOLOGY & RESEARCH IN ARTIFICIAL INTELLIGENCE FOR NUCLEAR SECURITY

Corey Heitzman
Special Technologies Laboratory
Peter Buglewicz
Special Technologies Laboratory

Summary

This project will research methods to generate unique, one-time use radio waveforms with low spectral signatures to establish ultra secure communication links. The system will achieve a transmit/receive functionality with unique generated and decoupled randomized time parameters along with physical adjustments to radio signals.

Technical Readiness Level

Start of Project: TRL 3-4 Mission research
End of Project: TRL 5+ Technology maturation

Summary of Technical Progress over the FY

During FY25, a preliminary codebook architecture was designed and implemented that demonstrated low probability of intercept and low probability of detect characteristics. Transmitted waveforms are encoded with a randomly selected modulation scheme and a randomly selected set of parameters (e.g. spectral footprint, amplitude, etc.). The current model implements binary phase shift keying, quadrature phase shift keying, and eight phase shift keying modulation schemes. Open air transmission is simulated using a channel model which adds timing offset, voltage offset, phase offset, and Gaussian white noise. Additional channel models that provided greater realism through simulating other physical phenomena likely encountered were researched as well for future testing purposes. Further improvements can be made to improve the depth of the model's complexity and to validate the reliability of the syncing between the transmitter and receiver. Collaborators were brought under contract and aligned with project mission objectives at a joint technical exchange hosted at the University of North Las Vegas (UNLV). UNLV collaborators designed and provided a preliminary spectrum sensing algorithm which provides a printout of regions of spectrum that surpass an automatically determined background threshold level. This algorithm will aid in future development and testing of the limited use waveform model. Feedback from potential customers indicated that additional scope was required to generate interest and increase novelty. Project team decided that creating a prototype device to provide the context normally provided to fielded instruments by GPS will provide project with sufficient additional scope and novelty to interest potential customers.

Benefits to Mission/Program

The US Department of Energy has stringent requirements for wireless security system use. MASINT [measurement and signal intelligence] sensors and devices require a secure communication link.

Ideally this link would be non-detectable and non-repeatable for absolute security confidence. Current radio technology, while robust, does not achieve the full user requirements. Digitally encrypted recorded waveforms are at risk of future compromise given advancements with artificial intelligence/machine learning (AI/ML). Custom waveform solutions would greatly benefit the National Nuclear Security Administration and Strategic Partnership Project sponsors. In addition, solutions proposed will be applicable to future commercial or private 5G networks deployed at the Nevada National Security Sites (NNSS) allowing high confidence of sensitive data transfer.

Data Fusion: Reconstructing 3D Hydrodynamic Scenes Utilizing Both Radiography and Momentum Diagnostics

25-052
YEAR 2 OF 2
STOCKPILE STEWARDSHIP
TECHNOLOGY & RESEARCH IN ARTIFICIAL INTELLIGENCE FOR NUCLEAR SECURITY

Jordan Pillow
North Las Vegas

SEE CUI REPORT.

Background Subtraction and Noise Reduction via Machine Learning

25-055
YEAR 1 OF 3
STOCKPILE STEWARDSHIP
TECHNOLOGY & RESEARCH IN ARTIFICIAL INTELLIGENCE FOR NUCLEAR SECURITY

Clifford Watkins
Special Technologies Laboratory
Paige Brady[1], Matt Swan[2], Michael Mortenson [2], Jesse Adams [2], Nick Eisenberg [2]
[1]*Special Technologies Laboratory,* [2] *North Las Vegas*

Summary

Comparison of real signals to forward models are hampered by the backgrounds and noise present in the real data, which are absent in the clean models. This project creates a background and noise subtraction neural network to perform high quality signal extractions, and would be applicable to a wide array of modalities, including radiography, interferometry, hyper-spectral data, gamma spectroscopy, etc.

Technical Readiness Level

Start of Project: TRL 3-4 Mission research
End of Project: TRL 3-4 Mission research

Summary of Technical Progress over the FY

During fiscal year 2025, the team was able to accomplish all stated goals. The first of these was unarguably the most important—a survey of scientific and engineering staff about the data they use and how they imagine using it. This led to a change in the complexion of the end goal of the project from a one-stop portal for data, to example scripts and data science techniques. Following on from this the team was able to begin a portfolio of relevant datatypes with machine learning (ML) methods that increase signal capture to include: 1) gamma spectroscopy for nuclide detection, 2) pushbroom sensor smoothing and machine noise removal using hyperspectral sensors, and 3) wavelet transforms of audio data to detect vehicle signatures.

Benefits to Mission/Program

Separating a signal from a background is necessary in virtually every domain of work performed by the Nevada National Security Sites (NNSS). Whether it be to compare real signals with forward models, or isolate small signals from large backgrounds, this ML-enabled method can be adapted to a wide range of data modalities. It will increase analysis opportunities, by providing clear signals that were not possible to extract using conventional means and improve confidence in that analysis.

Cloud-Based Meta-Analysis with Adaptive Learning for Massive Sensor Networks

25-117
Year 2 of 3
Global Security
Technology & Research in Artificial Intelligence for Nuclear Security

Carson Schuetze
Remote Sensing Laboratory
Matthew Swan[1], Noah Blair[2], Arnulfo Gonzalez[1]
[1]*North Las Vegas,* [2]*Remote Sensing Laboratory*

Summary

This project will advance the efficiency of the nuclear search mission by migrating real-time analysis to a cloud-based architecture, enabling adaptive learning and statistical meta-analysis to be performed on the aggregation of data from all systems, sensors, and algorithms, across space and time.

Technical Readiness Level

Start of Project (FY24): TRL 0-2 Fundamental research
End of Project (FY26): TRL 5+ Technology maturation

Summary of Technical Progress over the FY

Alarming

We investigated how readings from a figure of merit (FOM) could be utilized to detect subthreshold sources. First, we developed simulation software and simulated an ideal FOM, possessing a known probability density distribution with no source present. Then, we compared the performance of parametric and nonparametric techniques such as the Kolmogorov-Smirnov (KS) test (Figure 19), Mahalanobis distance, and bootstrapping. The KS test is highly versatile, though it performs poorly with a small sample size. Bootstrapping is useful when the test statistic is unknown.

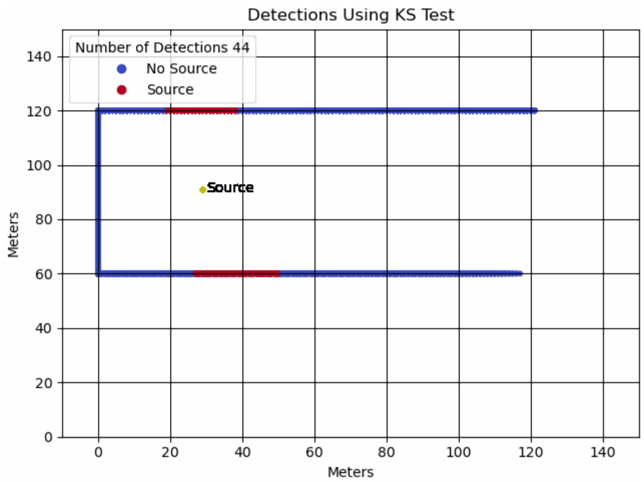

Figure 19. KS test source detections – under the existing method, no detect would occur.

Finally, we conducted an experiment at the Remote Sensing Laboratory (RSL) to test these methods with real data (Figure 20). More work should be done to ensure the false alarm rate (FAR) is not increasing over the current standard when performing meta-analysis.

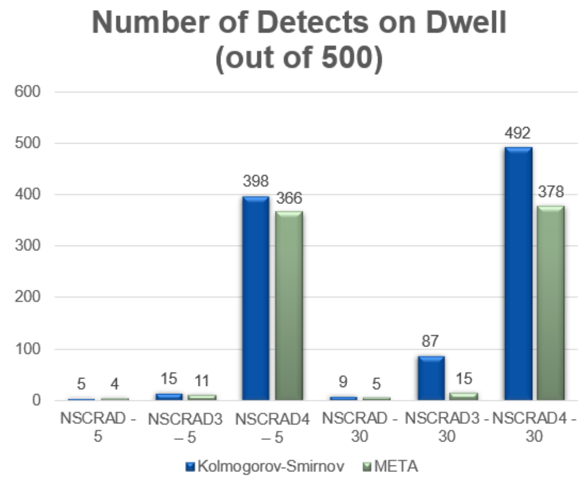

Figure 20. Experiment results show improvement over existing methods.

Time-Based Clustering

We began to answer the question: "How far back in time can we cluster points?" The spatial-statistics method (Figure 21) says that points can be clustered under two conditions: (1) Apply Principal Component Analysis (PCA) to cluster 1 to determine an ellipse region – if 80% of the points in cluster 2 fall within the region, the spatial criteria is met; (2) Apply two-sample KS test to determine if clusters came from the same distribution – if p-value > FAR, the statistics criteria is met. Other methods were explored and will be tested for validation in FY26.

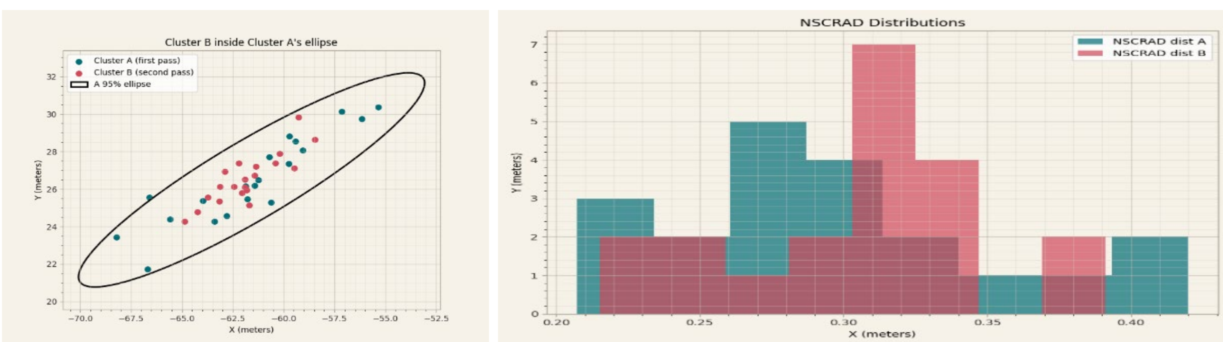

Figure 21. Left – Condition 1; Right – Condition 2

Machine Learning

The North Virginia Array project (PI: Chris Burt) demonstrated the utility of a convolutional neural network (CNN) to classify radioactive sources. We believe this work can be modified for this project. We tested the CNN on one simulated and one real dataset (Figure 22). More work to come in FY26.

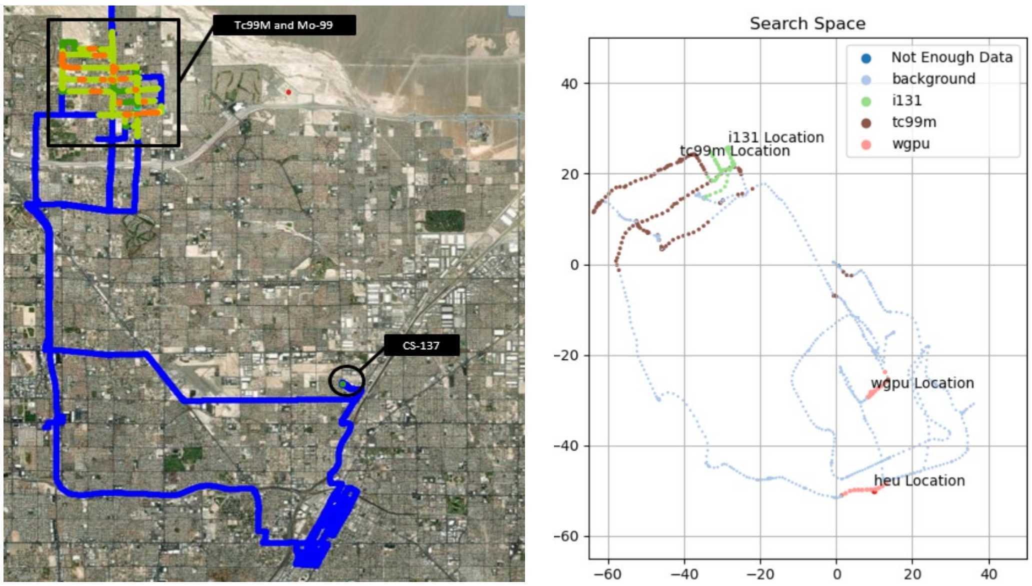

Figure 22. CNN results over simulated (left) and real data (right).

Benefits to Mission/Program

Personnel

Before the kickoff of this project, there was little interaction between the nuclear search scientists at RSL and the data scientists at North Las Vegas (NLV), though their skillsets are highly complementary. One of the biggest benefits of this project has been bringing together NLV and RSL scientists. Since the inception of the project, almost all NLV data scientists are now involved in at least one RSL project – greatly increasing the efficiency and robustness of the scientific methods to answer radiological questions, as well as increasing the camaraderie throughout the company from early- to late-career scientists.

Mission

The edge-based sensor analytics paradigm routinely misses subtle radiation anomalies which do not trigger alarms, suffers from a pervasive lack of context that curtails performance, and requires intensive analyst oversight which scales linearly with the number of sensors. During real-world events, human analysts become overwhelmed and exhausted. This mission is in desperate need of contextual analytics, autonomous adjudication, and anomaly prioritization. At the conclusion of year 2 of 3 of this project, we have proven that meta-analysis is both possible and effective in advancing the efficacy of the nuclear search mission. At the conclusion of this project in FY26, our methods will be integrated into field operations and will provide relief from the aforementioned deficiencies in the current modus operandi.

Feasibility Study for Internal ML Compute Infrastructure at NNSS

25-200
FEASIBILITY STUDY
GLOBAL SECURITY
TECHNOLOGY & RESEARCH IN ARTIFICIAL INTELLIGENCE FOR NUCLEAR SECURITY

Nicholas Eisenberg
North Las Vegas

Summary

This one-year feasibility study was to investigate the possibility of developing a shared compute resource within the NTSOPs network. To have this be successful, there needs to be input and coordination from Information Technology (IT), Infrastructure and Engineering, Networking and Cyber Security and this study was to see how feasible internal shared compute could be with the aforementioned teams. Nevada National Security Sites (NNSS) IT support is almost entirely focused on the Windows operating system, and this currently is the biggest hurdle as all scientific compute happens on Unix and Unix-like infrastructure. The project ended in somewhat of a successful state and we proved that internal shared compute within the NTSOPs network is "possible." However, what this project discovered was our current Linux infrastructure and engineering staff lack the support needed from other teams and the dedicated hours needed so that they could assist in this endeavor.

Technical Readiness Level

Start of Project: 4
End of Project: 4

Summary of Technical Progress over the FY

The following are notable accomplishments of this study:

1. Proved that an internal shared Linux resource is possible within the NTSOPs network.
2. Purchased a powerful server with two Nvidia RTX 6000 Pro GPUs [graphics processing units].
3. Developed python software, that is installable with pip and JFrog, that facilitates the training of neural networks on a high-performance computing (HPC) system that easily allows the user to train on multiple nodes and multiple GPUs.

Benefits to Mission/Program

Machine learning workflows have become a staple to almost all scientific projects within the NNSS. Therefore, there is a growing need for compute resources to facilitate the training of these models. Currently, the NNSS only has a shared CPU [central processing unit] compute resource, which is the Athena HPC located at Los Alamos Operations (LAO), but a GPU compute server is also needed as machine learning models are almost always trained on the GPU rather than on the CPU. Because of the need of GPU compute, some of the scientists have used the Lawrence Livermore National Laboratory HPC Matrix server, however this compute server is off our network. Moreover, getting access to Matrix is not necessarily easy. Because of this, developing our own internal GPU compute resource is necessary to ensure success of all current and future machine learning projects. It should be noted that this is also not a dichotomy and access to LLNL should always be considered an option for the future. But without access to internal compute options, NNSS scientists and engineers will continue to be faced with timely roadblocks, which in return delays deliverables and hinders the success of our mission work.

User-Centered Remote Testing & Operations

25-007	*Fundamental Experiments for Detonation Signature Modeling*	Clare Kimblin
25-021	*Collection and Analysis of NFC Signature Gases with Metal-Organic Framework Solids*	Mark Morey
25-034	*Surface Gas Sampling Payload for Autonomous Underwater Vehicles*	Kevin Lee
25-076	*Optical Remote Sensing for Facility Monitoring: An Integrated Approach to Modeling, Simulation, and Sensors*	Saketh Ayyalasomayajula
25-091	*Advancing NNSS Geological Modeling Capabilities*	Devon Smith
25-095	*Spatial Spectral Observations from Near and Far*	Michael Howard
25-120	*Feasibility of Reoccupying Historic Testbeds for Future Experiments*	Ian Bortins
25-142	*Improving Infrasound Propagation Analysis with Ambient Noise Level Retrievals*	Melissa Wright
25-181	*Improving Nodal Seismic Collections by Enabling Data Telemetry for Dense Arrays*	Reagan Turley

Fundamental Experiments for Detonation Signature Modeling

25-007
Year 3 of 3
Global Security
User-Centered Remote Testing & Operations

Clare Kimblin
Special Technologies Laboratory

See CUI report.

Collection and Analysis of NFC Signature Gases with Metal-Organic Framework Solids

25-021
YEAR 1 OF 3
GLOBAL SECURITY
USER-CENTERED REMOTE TESTING & OPERATIONS

Mark Morey
Special Technologies Laboratory

SEE CUI REPORT.

Surface Gas Sampling Payload for Autonomous Underwater Vehicles

25-034
YEAR 3 OF 3
GLOBAL SECURITY
USER-CENTERED REMOTE TESTING & OPERATIONS

Kevin Lee
Special Technologies Laboratory

Summary

With 71% of Earth's surface covered in water, surface gas collection from autonomous underwater vehicles (AUVs) is an underdeveloped technology. By combining existing methods of gas sampling with existing AUVs, there is a possibility to discreetly sample gases of high interest to the nuclear nonproliferation community. The solution will be to develop a low-SWaP (size, weight, and power) air sampling payload consisting of a positive displacement pump, situational awareness sensors, and an embedded processor. The challenge will be to autonomously control this system at the sea/air interface in real-world open water conditions.

Technical Readiness Level

Start of Project: TRL 0-2 Fundamental research
End of Project: TRL 5-6 Mission prototype

Summary of Technical Progress over the FY

Designed, developed, and field tested a modular surface gas air sampler in oceanwater this FY. Using the knowledge gained from computer aided physics-based modelling in FY 2023 and the science bay module's exterior prototype design, fabricated, and field tested in freshwater in FY 2024, the project successfully created a new in-house automated collection methodology to sample surface gas in the ocean with a mechanical snorkel, electronics controller board, and automation software.

The mechanical design of the snorkel and its actuation was revised from FY 2024's freshwater test. Ultimately this led to a less heavy design and a smaller surface area, which greatly benefited the AUV's capability to smoothly traverse while submerged at the surface.

Benefits to Mission/Program

See FY 2023 classified proposal.

Optical Remote Sensing for Facility Monitoring: An Integrated Approach to Modeling, Simulation, and Sensors

25-076
YEAR 2 OF 3
GLOBAL SECURITY
USER-CENTERED REMOTE TESTING & OPERATIONS

Saketh Ayyalasomayajula
Special Technologies Laboratory
Milton Smith[1], Byron Eng[2], Michael Howard[3], Ian Bortins[4]
[1]Chrysalis Systems, [2]Rochester Institute of Technology, [3]Remote Sensing Laboratories, [4]Special Technologies Laboratory

Summary

This integrated ground-based/airborne simulation/acquisition capability will be essential for our remote observation of NNSS testbeds, the development of new algorithms and pattern-of-life analysis techniques for facility characterization.

Technical Readiness Level

Start of Project: TRL 3-4 Mission research
End of Project: TRL 3-4 Mission research

Summary of Technical Progress over the FY

In Q1, STL successfully integrated and conducted a first light of the ground-based hyperspectral sensor with numerous collections against industrial gases of interest. Additionally, a MATLAB algorithm developed by Chrysalis Systems was utilized to process hyperspectral data from the sensor in real-time and provide confidence intervals for target identification based on pre-determined libraries. Benchtop integration of the airborne sensor at the Remote Sensing Laboratory, Nellis (RSL-N) occurred during Q2/Q3 after lengthy hardware debugging with Lawrence Livermore National Laboratory (LLNL) support and necessitated new gyro-stabilized mounts for future flight operations in FY26.

Synthetic airborne long-wave infrared (LWIR) hyperspectral imagery was generated in DIRSIG (a physics based synthetic image generation software) over the course of Q3-Q4, with the Rochester Institute of Technology (RIT) collaborating with Special Technologies Laboratory (STL) on simulating an airborne sensor with similar specifications to the operational sensors. A final DIRSIG simulation of a sensor against a mock Nevada National Security Sites (NNSS) scene (STL's 226 facility) with gas calibration targets and a methane plume was sent by RIT as a validation of the simulation capability to characterize a known facility with gas effluents. Q2-Q4 also saw various collections of data on solid arrays (metal compounds) and various gases (methane, R134a, ammonia) using the ground-based sensor system at STL's 226 Laser range to create a broader dataset for calibration/object identification development work by Chrysalis. A novel sub-space calibration technique paired with refined autoencoders was developed by Chrysalis and implemented at STL for better identification of gases and sharper denoising of images in real-time.

Later in Q4 saw a field collect conducted at RIT in conjunction with numerous commercial entities, government labs, and academia to collect hyperspectral data against various calibrations, solid and gas targets with varying sensor types/modalities (drones, aircraft, hand-held). This was to primarily build a more diverse set of visible and near infrared (VNIR)/short wave infrared (SWIR) data in varying geographic/weather localities for the autoencoders to better classify broader hyperspectral data, independent of sensor type. Ongoing work initially began in Q4 by North Las Vegas collaborators to convert large portions of Chrysalis's sub-space calibration and object classification algorithms from MATLAB to Python for computing and integration ease.

Benefits to Mission/Program

The NNSS is responsible for numerous test-beds integral to research and development efforts in the defense nuclear nonproliferation arena. This integrated ground-based/airborne simulation & acquisition capability will be essential for our remote observation of NNSS testbeds, the development of new remote sensing algorithms and sensor simulation techniques in DIRSIG, and pattern-of-life analysis techniques for facility characterization. Moreover, this capability in combination with emerging computational techniques including autoencoders and sub-space calibrations will allow for greater precision in prediction/object classification of hyperspectral datasets. A successful end-to-end optical capability will be readily extendable to other remote sensing modalities such as synthetic aperture radar.

Advancing NNSS Geological Modeling Capabilities

25-091
YEAR 1 OF 3
GLOBAL SECURITY
USER-CENTERED REMOTE TESTING & OPERATIONS

Devon Smith
Nevada National Security Site
Eric Eckert, Justin Reppart, Michelle Scalise, Matthew Dietel
Nevada National Security Site

Summary

This work advances NNSS capabilities by developing and testing a geologic model for a complex geologic setting with limited subsurface data availability. Applying this work to a foreign testbed addresses a gap in global treaty monitoring capabilities, laying the foundation for more accurate event detections using foreign testbed geologic models.

Technical Readiness Level

Start of Project: TRL 3-4 Mission research
End of Project: TRL 5+ Technology maturation

Summary of Technical Progress over the FY

To investigate capabilities, an alternative Yucca Flat Geologic Framework Model (GFM) was constructed by stripping thousands of subsurface controls points from a preexisting dataset, mostly derived from drilling over 900 boreholes in the basin. After overcoming several challenges with basin thickness, fault geometry, and lack of control for intrusive volcanic stocks, an alternative GFM was created.

The GFM construction itself revealed software limitations, particularly with modeling the intrusive volcanic stocks present in northern Nevada National Security Site (NNSS), valuable insight to the future of this project as we transition to modeling the Korean Peninsula which is dominated by similar types of rocks.

To assess potential impacts caused by the alternative geometry, the GFM was used to create a 3D property model which was leveraged to model seismic wave propagation. Synthetic seismic waveforms were modeled from the source location of a previous experiment, SPE-5, which is part of the Source Physics Experiment. SPE-5 was located within an intrusive volcanic stock known as the Climax stock which lies at the northern extent of Yucca Flat.

Modeling waveforms from the SPE-5 event using a poorly constrained geologic model revealed impacts to wave trapping time and complex scattering, however, the synthetic waveforms did show similar travel times of the phase arrivals.

Q4 focused on preparation for the South Korea (DPRK) geologic modeling work. The GFM extents were determined using the locations of international seismic stations bordering DPRK and then a topographic file was obtained for the region. NNSS geologists collaborated with the US Geological Survey to compile geologic data for the region, laying the groundwork for FY26 efforts.

Benefits to Mission/Program

Adapting our GFM technology to a more complicated geologic province advances the NNSS and national capabilities. Overcoming challenges with model uncertainty through event simulation modeling improves our current understanding of limitations of our NNSS GFMs. Adapting our GFM technology to a foreign testbed will enhance our ability to detect small or deeply buried explosions by helping to predict instrument placement. Previous efforts within the Low Yield Nuclear Monitoring (LYNM) and Source Physics Experiment (SPE) projects have shown that high quality geologic models are essential for creating forward models which can accurately simulate wave propagation. Such models have many applications including determining optimal instrument placement which is essential in an environment where access issues may constrain the number of seismic stations that can be deployed. This project serves as a critical first step by demonstrating and testing this capability.

Spatial Spectral Observations from Near and Far

25-095
Year 3 of 3
Global Security
User-Centered Remote Testing & Operations

Michael Howard
Remote Sensing Laboratories
Carson Schuetze, Heather Howard
Remote Sensing Laboratories

Summary

Investigate the spatial and spectral signatures of surface materials that characterize the experimental design and proliferation intention of activities associated with preparing and utilizing vertical emplacement shafts used for underground weapons testing.

Technical Readiness Level

Start of Project: TRL 1 Fundamental research
End of Project: TRL 4 Mission research

Summary of Technical Progress over the FY

FY25 had many challenges due to aircraft availability preventing the capture of drilling activities at the Rock Valley Direct Comparison (RVDC) testbed at multiple points in the drilling process. Hardware failures also delayed ground collection activities and data processing. However, the research was able to move forward to produce results that validate the hypothesis of mineral detection associated with lithology at depth at a vertical drill site. To do this, the team pursued the development of in-scene simulations of the RVDC site using borehole spectra of Test Well F (TWF). The in-scene simulations allowed us to develop algorithms for interpreting spectral observables related to the extraction of subsurface materials deposited in the vicinity of a drilling operation. The TWF ground spectral resolution was resampled to the airborne hyperspectral instrument optical response. The resampled TWF data matched the actual scene of the hyper-spectral imaging (HSI) data collected in FY23 and could be used as artificial cuttings for detection simulations. The first simulation is shown in Figure 23 where the artificial cuttings pile was emplaced in the southeast corner of the drilling pad for 4 depths and the spectral signatures are compared to the actual drill pad surface. The four spectra from TWF that were injected into the HSI scene were readily detected because of the spectral contrast of surface pixels with the below ground pixels.

In the third quarter the aircraft became available and both HSI and photos were collected. These collections allow one observation of the RVDC drilling in operation. In addition, core and cuttings from three legacy boreholes were measured with handheld spectrometers, supported by X-ray fluorescence (XRF) and photo documentation. However, this data could not be processed until late in the fourth quarter and could not be used in the intended artificial neural network analysis within the limited time remaining in the FY.

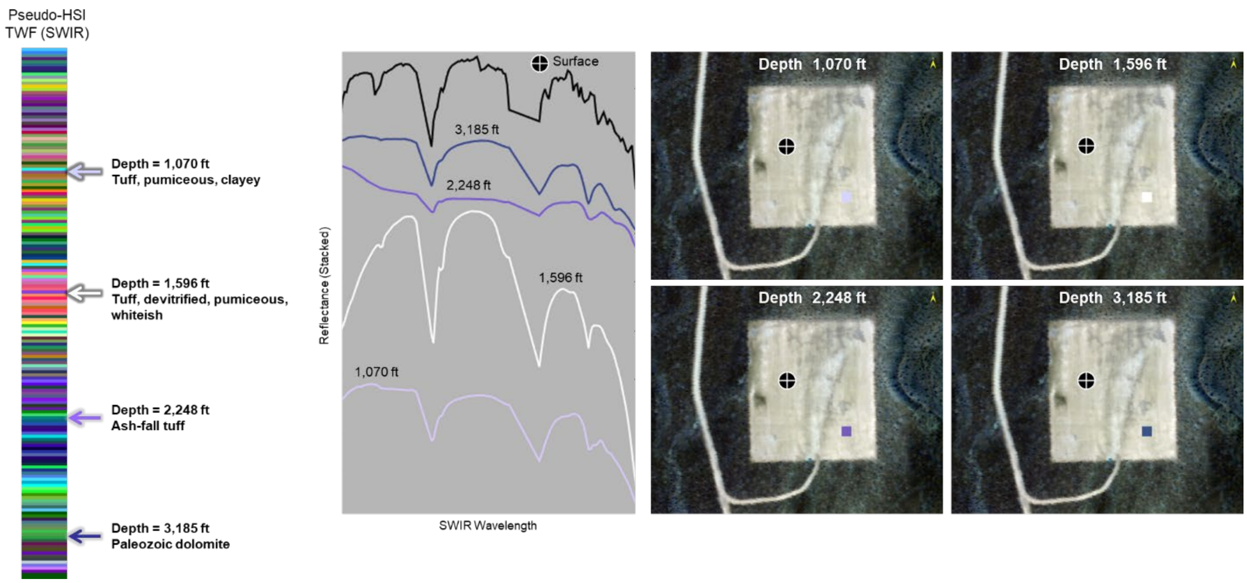

Figure 23: Simulation of drill cuttings from different depths as they are deposited on the drill pad surface showing spectral separability from surrounding surface materials.

Benefits to Mission/Program

Early detection and characterization of an underground weapons testing program is critical intelligence for the formation of national nuclear proliferation policy. This ability is subject to denied access, requiring remote detection. Optical remote sensing is the primary method that can overcome access limitations and provide long-distance detection and characterization. This research benefits Defense Nuclear Nonproliferation (DNN) and the greater nonproliferation community by defining the utility of spatial and spectral signatures for both current and future sensor architectures. The research fills knowledge gaps which limit the ability to identify and characterize vertical drilling related to underground nuclear weapons testing.

Feasibility of Reoccupying Historic Testbeds for Future Experiments

25-120
YEAR 3 OF 3
GLOBAL SECURITY
USER-CENTERED REMOTE TESTING & OPERATIONS

Ian Bortins
Special Technologies Laboratory

SEE CUI REPORT.

Improving Infrasound Propagation Analysis with Ambient Noise Level Retrievals

25-142
YEAR 1 OF 3
GLOBAL SECURITY
USER-CENTERED REMOTE TESTING & OPERATIONS

Melissa Wright
Nevada National Security Site
Gary Walker[1], Daniel Bowman[2]
[1]Remote Sensing Laboratory, [2]Pacific Northwest National Laboratory

Summary

Nuclear explosions or other energetic phenomena can create low frequency acoustic waves capable of traveling global distances, making them a key signature for the International Monitoring System (IMS) and other forensic efforts. The temperature and wind structure of the atmosphere determines how these waves propagate and therefore has a strong impact on their detectability. However, extant atmospheric models have difficulty resolving the acoustic propagation environment at local scales (e.g., close to a monitoring station, or over a small region of interest such as a city). The goal of this project is to use a multi-year acoustic dataset collected in Las Vegas, Nevada to show that the properties of the acoustic background itself can be used to determine atmospheric structure. In turn, this allows for greater resolution of the atmospheric structure that impacts acoustic propagation. Initial results using a machine learning technique reveal that correlations are present between ambient infrasound signals and a ground-based meteorological station, supporting the idea that this technique can be successful in the field.

Technical Readiness Level

Start of Project: TRL 0-2 Fundamental research
End of Project: TRL 3-4 Mission research

Summary of Technical Progress over the FY

This study has the advantage of leveraging a previously collected dataset. After the organization, formatting, and addressing any gaps of the leveraged dataset, model development began. This is a complex process that will continue next year; however, in the meantime, a machine learning technique was utilized to take an initial look at the dataset to identify correlations. The infrasound dataset was broken into 15-minute intervals, and the power spectral density (PSD) was calculated for each to obtain the signal across frequency space. The PSD was then divided into frequency bands. The bands were combined with time information and meteorology measurements to create a data table of over 88,000 observations. The table was used in a linear regression machine learning model, which included a K-fold cross-validation technique to prevent overfitting, to predict ground-based meteorology.

The results of the initial machine learning process revealed clear correlations with atmospheric parameters relevant to acoustics. Wind speed reached a Root Mean Square Error (RMSE) of 1.14, which is a measure of the accuracy of the model, with over 93% of the modeled results within 3 mph of the recorded weather station values. Wind direction was processed using directional components and revealed that over 92% of the data was within 30 degrees, although this may be related to site specific effects rather than a broader trend. The temperature and relative humidity results were not as clear; however, despite the smaller impact on infrasound, there is still a correlation present, and improvements can be made in a full regression model. Infrasound measurements were also collected during the implosion of the Tropicana Hotel on the Las Vegas Strip. This acoustic data is in the early stages of analysis for use as a benchmark.

Benefits to Mission/Program

The results of this analysis will improve signal detection and locational assessments for global prompt diagnostics. Once the model is developed and tested, it will be re-examined using lower resolution datasets that are more readily available in remote locations. This will allow the technique to be applied to other infrasound stations, such as the IMS, for nuclear forensics with an understanding of the potential errors given the atmospheric data sources used within the model. This technique can also be used to assist in localized emergency response by applying the developed noise-based model to allow for a calibrated first response and initial forensics. Lastly, these analysis methods will also be used to make advancements to the NNSS infrasound propagation model by adding the capability to assimilate atmospheric data, which will increase its accuracy and utility for future work. Future analysis efforts can include a focus on yield determination improvements once the atmospheric components have been accurately incorporated.

Presentations & Accolades

Poster Presentation at the Seismological Society of America Annual Meeting in Baltimore Maryland, April 2025.

Improving Nodal Seismic Collections by Enabling Data Telemetry for Dense Arrays

25-181
FEASIBILITY STUDY
GLOBAL SECURITY
USER-CENTERED REMOTE TESTING & OPERATIONS

Reagan Turley
Nevada National Security Site
Eric Eckert[1], Daniel Hardy[2]
[1]North Las Vegas, [2]Nevada National Security Site

Summary

The Nevada National Security Sites (NNSS) has recorded seismic signals using nodal seismic systems onsite for over decade. The current system will need to be replaced over the next 5–10 years. Purely commercial off the shelf systems (COTS) developed for use in the oil and gas industry support some operational needs but do not fully satisfy the requirements for Defense Nuclear Nonproliferation (DNN) projects. We procured seven DiGOS DATA-CUBE³ data recorders and used them to develop field kits, which may be a viable replacement.

Technical Readiness Level

Start of Project: 3
End of Project: 4

Summary of Technical Progress over the FY

This feasibility study has demonstrated proof of concept for usings DiGOS DATA-CUBE³ systems built into NNSS-developed field kits. We showed how we can use the system to collect high quality seismic data and that using the BATMAN mesh networking protocol enables us to communicate with individual units as needed for command and control without deploying additional networking equipment. Finally, the effort demonstrated that using this instrumentation at the same operational cadence as the Large Array for Seismic Sensing and Observation (LASSO) will require us to write additional software to automate field deployments and concentrate data at a single head node.

Benefits to Mission/Program

LASSO will need to be replaced over the next 5–10 years to continue satisfying National Nuclear Security Administration (NNSA) geophysical data collection needs. Market research has shown that the nodal systems currently being produced by the oil and gas industry are a poor match for our needs. Most oil and gas nodal systems are focused on single component (vertical only) seismic instruments and lack the capability to harvest data remotely and in real time. Thus, any future system we purchase will need to be customized using software and field kits developed at the NNSS. This will be viewed as higher risk than a purely commercial off-the-shelf (COTS) solution, even if the COTS solution is inferior. Purchasing DATA-CUBE³ systems under a Site-Directed Research and Development (SDRD) feasibility study has allowed us to demonstrate that developing field kits using the DiGOS DATA-CUBE³ may offer a viable path forward.

SDRD

SITE-DIRECTED RESEARCH & DEVELOPMENT