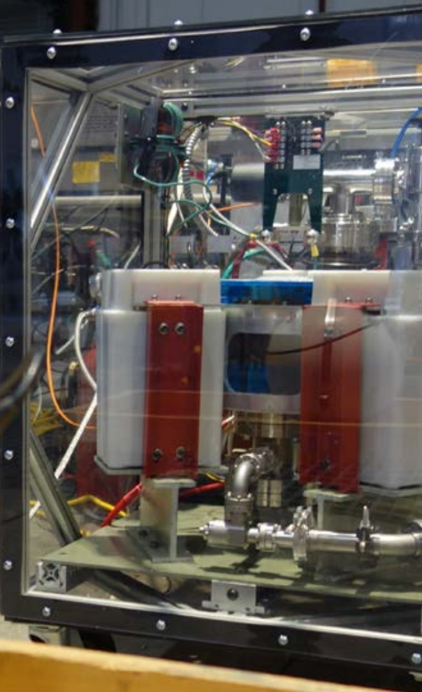
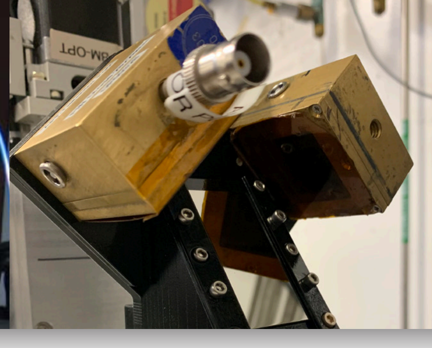
DOE/NV/03624--0780


NEVADA NATIONAL SECURITY SITE (NNSS)

FY 2019 Site-Directed Research & Development

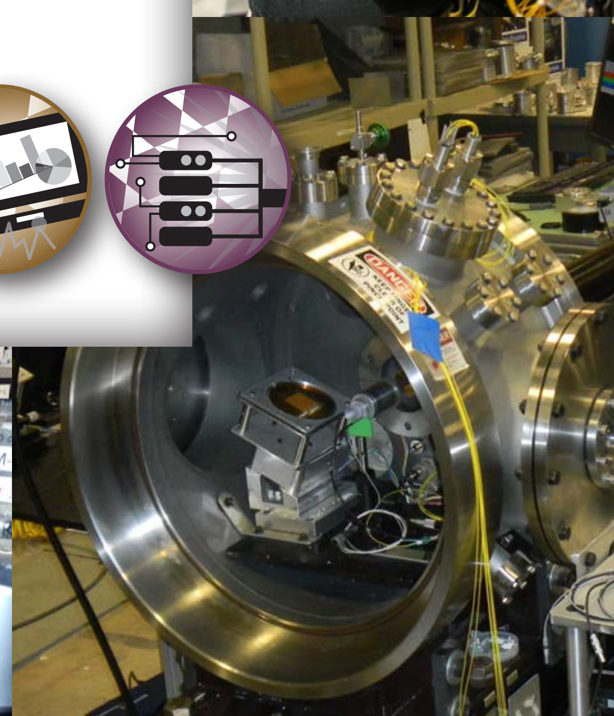
Annual Report Overview

Strategic Opportunity Research

Exploratory Research





Site-Directed Research & Development FY 2019 Annual Report Overview

Contents

Foreword, Jose Sinibaldi....1
How to read this report....2
SDRD program mission and objectives....2
SDRD program leadership....4
Types of R&D....5
Proposal cycle and project selection....6
Stockpile stewardship and global security....7
Outstanding performance....8
Project Highlights....9
Materials Studies and Techniques....10
Instruments, Detectors, and Sensors....13
Computational and Information Science....17
Photonics....20
UAS Initiative....21
SDRD program performance metrics....24
Afterword, Howard Bender....27
Acknowledgments....28
References....28

Staff

SDRD Progam Manager .... **Howard Bender**

Editors.... **Michele Vochosky, Katsura Rast**

Design and Layout.... **Katina Loo, Michele Vochosky**

Collage art, inside covers.... **Dianne Gomersall**

Web Design and Production .... **Kirsten Kellogg, Michele Vochosky, Katsura Rast**

www.nnss.gov

About the cover

(*clockwise from top left*) Falcon, a portable dense plasma focus machine; crystal and detectors used for x-ray polarization contrast measurements; installing a Merlyn, part of a wireless sensor system; Marylesa Howard, PECASE awardee; Talbot-Lau deflectometer on the gas launcher catch tank for a phase contrast imaging experiment; another view of crystal and detectors used for polarization contrast measurements at the Advanced Photon Source synchrotron; a Harris H6 hybrid hexacopter during radiation survey flights at the NNSS; Hovig Yaralian and Alan Horzewski of Unmanned Systems, Inc. ready their Harris H6 hexacopter for flight.

This work was done by Mission Support and Test Services, LLC, under Contract No. DE-NA0003624, with the U.S. Department of Energy and supported by the Site-Directed Research and Development Program. DOE/NV/03624--0780.

Publication Date: April 2020

SDRD: The key to meeting NNSA's current and future nuclear deterrence and nonproliferation mission needs

As the innovation engine for NNSS, the SDRD program utilizes the full complement of the Nuclear Security Enterprise (NSE), including its research infrastructure, high-performance computing, specialized material production, and many other capabilities, in our pursuit to solve national security challenges. Both large- and small-scale R&D and associated laboratory and user facilities are critical for us to enable scientific and technical staff to accomplish goals. Our ST&E staff working on SDRD projects partner with NSE laboratories and other institutions to fully leverage competencies that exist elsewhere, and thus we amplify our own abilities to meet NNSA mission requirements and provide solutions with far-reaching impact.

Jose Sinibaldi
Chief Scientist
Mission Support and Test Services, LLC

In the near term, the SDRD investments match NNSA Laboratory efforts to enhance the fundamental understanding of current aging nuclear weapons systems, namely through linear induction accelerator technologies, solid-state pulsed power, and fundamental and applied research in diagnostic development efforts for shock physics and high energy density science. These investments will ensure that we are positioned well for our mid-term investment to support the Enhanced Capability for Subcritical Experiments (ECSE) with advanced detectors, high-speed x-ray and neutron imaging, and advanced algorithms for data analytics. Investments in unmanned aircraft systems (UAS) and counter-UAS technologies, combined with our sensor and detector technologies, will address the security and resilience of the nation's critical infrastructure from cyber attack, electromagnetic pulses, and UAS attacks. Our long-term strategy is to leverage artificial intelligence/machine learning and quantum sensing technologies being developed at the National Laboratories and by academia in three focused areas: (1) integrating them to transform our detection and characterization capabilities for subcritical experiments; (2) enabling alternate, more sensitive ways to discover signatures that enable the detection and characterization of radiological, nuclear, chemical, biological, and explosive agents; and (3) dramatically enhancing standoff distances while concurrently applying data science at an unprecedented scale.

The SDRD program is the key enabler to meet the NNSA's current and future nuclear deterrence and nonproliferation mission requirements. The SDRD program aims to enable our ST&E workforce to innovate and advance the ST&E state of the art that will transform us into a next-generation NSE flexible enough to meet future challenges.

How To Read This Report

The Site-Directed Research and Development (SDRD) program's annual report for fiscal year (FY) 2019 consists of this overview, which describes the program, and individual project report summaries.

This overview contains information regarding the program's history and growth, leadership, project selection process, present areas of research, highlights of significant accomplishments and awards, noteworthy people, and performance metrics.

Individual reports for projects that are both continuing into FY 2020 and concluding in FY 2019 are published electronically in the form of summaries on the Nevada National Security Site's (NNSS) website, www.nnss.gov. Complete technical reports for concluding projects are also available as individual documents, published independently and submitted to U.S. Department of Energy (DOE) National Nuclear Security Administration (NNSA) and the Office of Scientific and Technical Information (OSTI). These are also available from the authors.

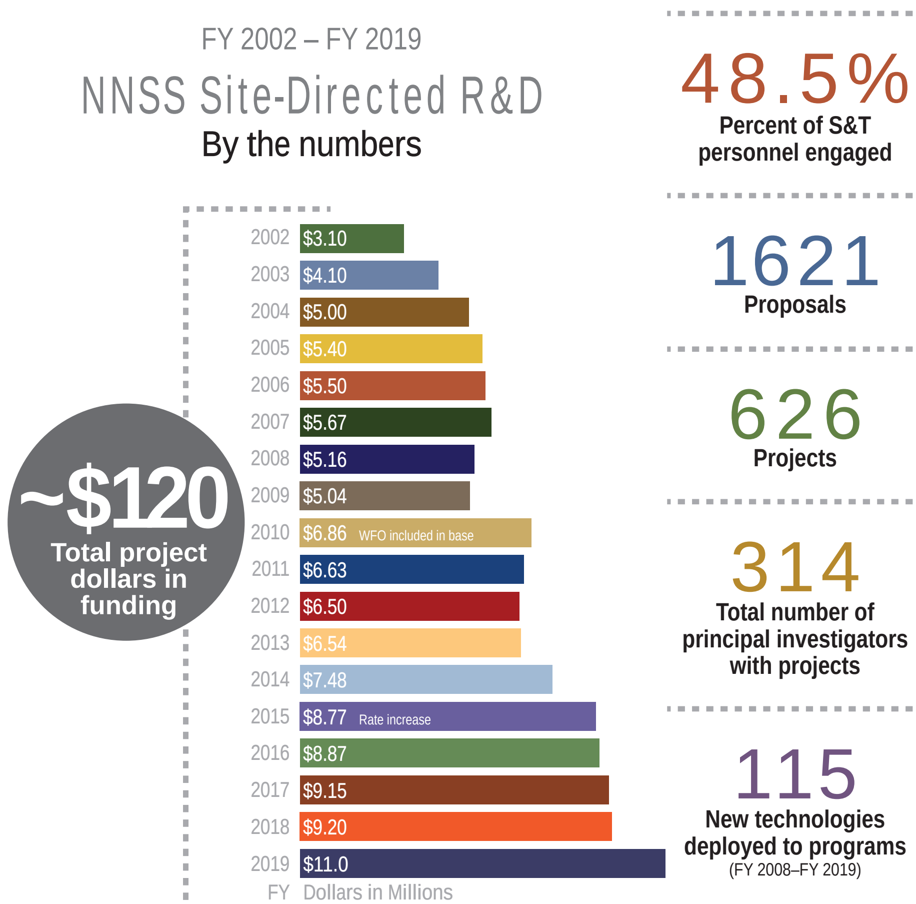
A list of all FY 2019 projects for the period of October 2018 through September 2019 is contained in this overview. Project identifiers are built as follows: site abbreviation-project number-originating year, RSLN-002-18, Remote Sensing Laboratory–Nellis, project 002, initiated in FY 2018. Several projects are highlighted in this overview for their unique, innovative achievements.

SDRD Program Mission and Objectives

History and Impact

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

The program is modeled after the Laboratory Directed Research and Development (LDRD) program, which is conducted in accordance with



the guidance provided by U.S. DOE Order 413.2C Change 1, "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 recently issued NNSA LDRD/SDRD Strategic Framework.

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 \$12M has been allotted for FY 2020 by the senior management team.

As the illustration on page 2 shows, SDRD has made a significant impact in the past 19 years, providing over 110 new technologies to NNSS programs since 2008, a high return on the investment of R&D dollars.

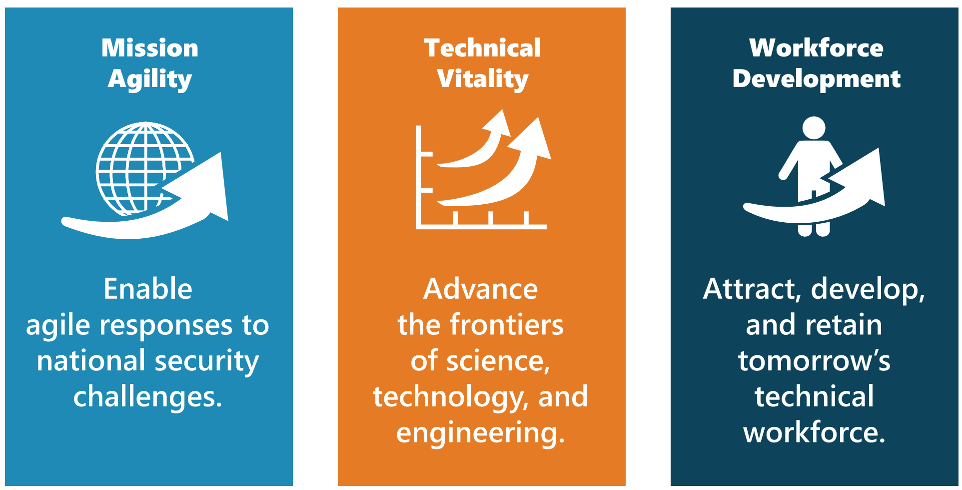
Mission and Objectives

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.

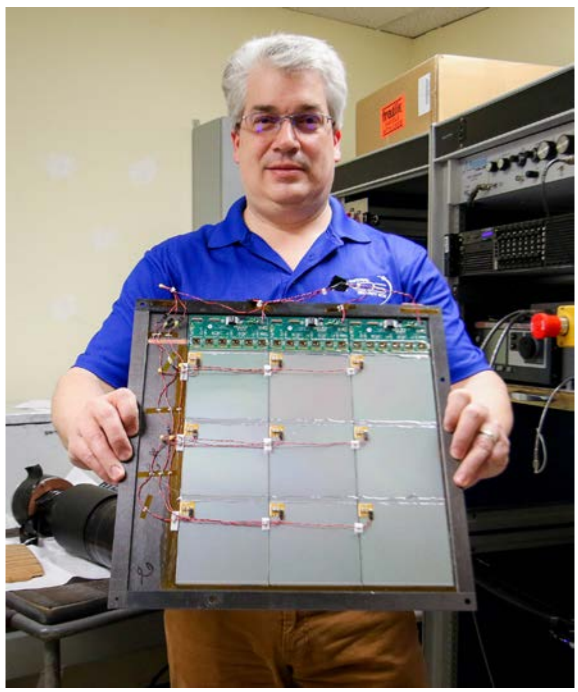
Workforce Development. Recruit, retain, and develop tomorrow's technical workforce in essential areas of expertise critical to mission delivery.



SDRD Program Leadership

The senior leadership of the management and operating contractor LLC of the NNSS, which includes the president, vice president, and senior program directors, is committed to advancing the contract’s R&D goals. Working closely with senior management and the SDRD program manager, the chief scientist ensures the quality of science and technology across the company’s multiple programs and missions, advocating translation of research products through technology readiness levels, and planning and directing new scientific concepts and technologies to provide solutions to identified issues to fulfill our mission to the nuclear security enterprise.

The SDRD program manager is a single point of contact for SDRD program management and is responsible for all practical aspects of the program. Among his duties are developing and overseeing the project selection process, identifying and communicating technology development priorities, overseeing the technical review teams, implementing each year’s program, and ensuring that the SDRD program abides by Congressional and NNSA-mandated financial guidelines. He is assisted by subject matter experts (SMEs) for technical proposal review, site representatives, and an external advisory board.



PI Andrew Green holds one plane of silicon cosmic muon microstrip detectors, which have been integrated with their readout electronics. For each detector column, three 10 cm sensors are wire-bonded in series to effectively make ~30 cm sensors. The microstrips cannot be seen individually, but they run vertically in the photo. The project won a 2018 R&D 100 award. The project began as an SDRD based on ideas to improve muon detection technology for global security applications, and it was co-developed with Fermi Lab.

The NNSS comprises a headquarters in Nevada and several outlying locations, or sites; therefore, the SDRD program relies on local site representatives to coordinate the technical activities of SDRD projects at their respective sites and ensure operational support to principal investigators (PIs). They help PIs identify potential safety-related issues prior to initiation of activities and communicate programmatic requirements to the PIs. They also help identify and resolve issues associated with financial performance and resource allocation.

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. Board members review our strategic plans and program structure, periodically assess the overall effectiveness of the program, and review individual projects to ensure highest standards for our R&D.

Types of R&D

There are two principal elements of SDRD, Strategic Opportunity Research (SOR) and Exploratory Research (ER).

Strategic Opportunity Research

SOR projects, initiated in FY 2015, are closely aligned with long-term mission strategy and corporate vision. In many ways, SOR is similar to directed research at the NNSA national laboratories. SDRD SOR challenges are bold, game-changing concepts with the potential for tremendous transformational impact to the NNSS and to the security of our nation. Ideas to solve these challenges require breakthrough advances in science, engineering, and technology. Typically the projects funded in this category fit with our strategic goals and align with broad mission objectives within our two main mission categories, stockpile science and global security. Initially funded at about 10% of the 2015 SDRD budget, SDRD funds dedicated to SORs in FY 2020 will be about 25%. Since 2015, SOR projects have researched unmanned aircraft system (UAS) sensor platforms, dynamic materials science, seismic hazard analysis methods, many aspects of neutron generation and imaging, and advanced algorithms for wireless sensor networks, among others.

Broad Site Announcement: Meeting Future Key Mission Needs

Each year a Broad Site Announcement (BSA) is issued with the call for proposals. The BSA is specifically intended to stimulate ideas and innovations on the cutting edge of science and technology. This short list of strategic initiatives targets research areas in a manner similar to the national laboratories grand challenges. Projects responding to the BSA, if funded, are likely to be SOR projects. Strategic efforts are providing foundational emphasis on forward-looking needs and coupling efficiently with long-term visionary goals. As always, SDRD desires to be "ahead of our time by design" and urges SDRD innovations to intersect future and evolving missions with the most impact possible.

Strategic opportunity research offers bold, innovative solutions to achieve mission goals.

Exploratory Research

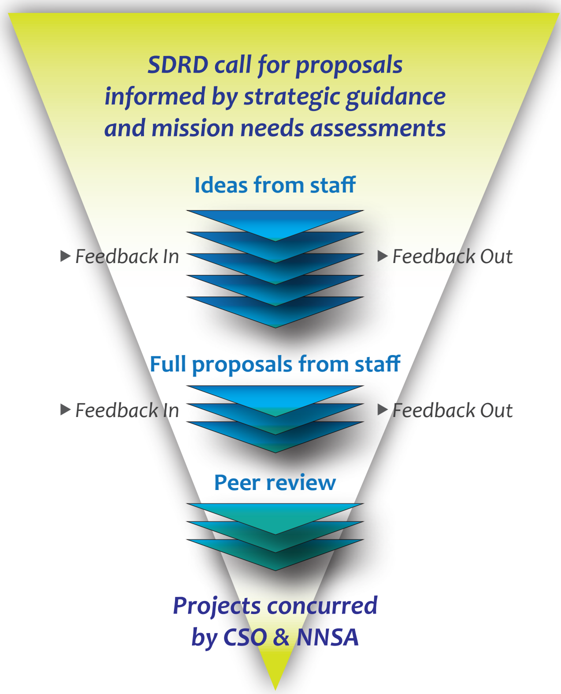
Our ER element is also similar in model to other exploratory research at many national laboratories, both NNSA and the DOE Office of Science. This element of our program continues to make up the bulk of our portfolio (70% to 75%) and seeks to obtain new knowledge, innovate advanced techniques, and develop new capabilities in all areas relevant to our national security mission. This area of research covers a rather broad base, and the "NNSS Technology Needs Assessment for R&D," updated annually and available to proposers, is its guiding document.

Feasibility Studies

Several investigative feasibility studies are funded each fiscal year. These brief (3 to 6 months, usually under $100K) research projects 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.

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 in a peer-review process. Proposers are guided by mission needs and other strategic guidance to provide unique solutions to existing and emerging problems. Furthermore, proposers are encouraged to accept higher levels of R&D risk that could nonetheless result in high-reward technological advances that are of immediate benefit to naturally risk-averse programmatic projects.



Call for Proposals

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

In the pre-proposal phase, PIs are encouraged to submit ideas in a standardized, succinct format (one page) that presents the proposed project's essence and impact. In addition, during the pre-proposal phase, proposers are encouraged to obtain feedback from SMEs to refine their ideas. This phase sparks innovation and initiates a feedback loop that extends to the invited proposal phase. Our goal each year is to receive as many staff-generated ideas as possible.

Guidance for proposers is provided in two major documents, the BSA, described above, and the "NNSS Technology Needs Assessment for R&D." Updated annually, the assessment helps proposers identify and address technology gaps in existing and emerging technologies. The feedback loop also provides specific, useful guidance.

Project Selection

The SDRD SME subcommittees (currently there are two—stockpile science and technology and global security) made of peers evaluate the pre-proposals, determining how well the pre-proposal addresses the core questions contained in the short pre-proposal form, which is based on the Heilmeier approach to R&D. Additional criteria considered in the evaluation of pre-proposals include alignment with NNSS strategic priorities, focus area(s) targeted, alignment with emerging missions, and development of capability. Individual pre-proposals are evaluated with a reduced-weighted scoring matrix (low, medium, high). The scores are then compiled and a ranking is determined.

Typically, about 50% of the pre-proposals are promoted to invited proposals. An integrated SME and advisory-level committee evaluates invited proposals using well-benchmarked and well-established criteria that include technical merit/innovation, program applicability, probability of achieving R&D objectives, benefit/return on investment, enhancement of critical skills and capabilities, and leverage/interaction with other federal agencies, universities, and industries.

Based on the results of the technical screening and evaluation and available budget, senior NNSS contractor management approves the final selection of SDRD investments for the next fiscal year. An annual program plan is submitted to the NNSA in mid-August for concurrence.

Stockpile Stewardship and Global Security

The SDRD portfolio falls into two primary mission categories, stockpile stewardship and global security, and is further divided into four major areas of research:

- **Materials studies and techniques**
- **Instruments, detectors, and sensors**
- **Computational and information science**
- **Photonics**

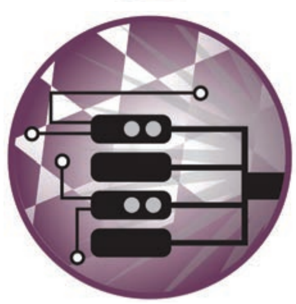
Historically, PIs have submitted a nearly equal number of ideas addressing stockpile stewardship and global security issues, although global security garners slightly more proposals. Dollars awarded over the past five years to stockpile stewardship were approximately $20.3M, while global security received approximately $19.9M in funding.

The four main areas of research were established in 2009, after earlier category types were combined and simplified. From 2015, when SOR projects were added, to 2019, the distribution of projects in the portfolio within the five areas has been 8% SOR; 20% Materials Studies and Techniques; 42% Instruments, Detectors, and Sensors; 17% Computational and Information Science; and 13% Photonics. In the past two years, projects focusing on dynamic materials

Materials Studies and Techniques
Science and engineering studies to understand the fundamental characteristics of materials in the extremes and inform equation of state and phase dynamics, material ejecta and spall, material strength and damage, and other properties.

Instruments, Detectors, and Sensors
Research and development of detector and sensor systems for complex diagnostic applications and global security, anticipating the needs of the NNSA labs for emerging experiment protocols and global security missions.

Computational and Information Science
Theoretical investigations and practical schemes to manipulate and analyze big data through algorithm development, modeling, simulations, and the use of novel cutting-edge computing technologies.



Photonics
Study, design, and development of light-emitting and transmitting systems such as lasers, fiber-optics, and optics suitable for a wide range of NNSA mission applications, ranging from material science to telecommunications.

properties, remote sensing, big data analysis, and machine learning have increased, signaling the importance of these challenges to the mission.

From 2015 to 2019 the majority of SOR projects funded concentrated on dynamic materials research to advance the understanding of fundamental physics questions. The remainder focused on developing radiation, chemical, and spectroscopic real-time sensing systems for use on UAS platforms. In 2020 the SOR portfolio has expanded—in addition to materials studies, new projects include research into underground event monitoring and seismic activity, supporting the NNSA laboratories in validation and verification for high-performance computing, and advanced neutron source development for future applications.

Outstanding Performance: Awards and Recognition

Marylesa Howard, PECASE Awardee

Marylesa Howard, an NNSS scientist and mathematician active in the SDRD program, received a Presidential Early Career Award for Scientists and Engineers (PECASE) in 2019. It is the highest honor bestowed by the U.S. government to scientists and engineers in the early stages of their careers.

"I see this as being much bigger than me," Howard said. "This is also about the NNSS being recognized for the powerful research enabled here. I came to the NNSS for a job, but what I've found here is much more than a job. It is a mission I'm proud to serve, groundbreaking research to which I can contribute, and a sense of belonging among the people with whom I work. This is an absolute honor, one of which I would have never dreamed."

"I came to the NNSS for a job, but what I've found here is ... a mission I'm proud to serve."

Recently she led a team that developed a new approach to image segmentation, where an automated method quantitatively determines which parts of an image correspond to different objects in a street scene, different materials in an x-ray image, or different components of an item on an assembly line. She invented the first statistical method that allows a user to characterize parts of an image, but then automatically characterizes the rest of the image, even with the ability to correct any mistakes made by the user. Her invention has been incorporated into a software tool that has been copyrighted and licensed to Sandia National Laboratories, Los Alamos National Laboratory, Lawrence Livermore National Laboratory, and many universities.

R&D 100 Finalist: Falcon Portable Dense Plasma Focus

Falcon, a portable pulsed neutron source developed by Senior Engineer Brady Gall and his team in NNSS' Nevada Operations, was selected as an R&D 100 Award finalist for 2019. The annual R&D 100 Awards recognize exceptional engineering and science accomplishments that will have significant impact in the scientific community.

Falcon is a compact, transportable pulsed power machine that produces very short, high-yield neutron pulses (1×10^8 neutrons per pulse). Falcon is a safe, cost-effective, portable, dense plasma focus solution for detecting and locating concealed special nuclear materials, and is also useful in explosive detection, materials research, and industrial applications. See page 13 for a summary of the project.

The three-year R&D effort, funded by NNSS' SDRD program, involved teaming with Sandia National Laboratories; Lawrence Livermore National Laboratory; Los Alamos National Laboratory; University of Nevada, Las Vegas; Powder River Geophysical; Alameda Applied Sciences; and Sigma Science/Keystone Global Engineering and Technology, Inc.

Project Highlights

Selected highlights of the R&D accomplished in FY 2019 by the SDRD program are presented on the following pages for each of our four major areas of research: Materials Studies and Techniques; Instruments, Detectors, and Sensors; Computational and Information Science; and Photonics. In addition to these highlights, all FY 2019 projects are listed by research area. Summaries of all FY 2019 projects can be found on www.nnss.gov under the Programs/SDRD tab.

SDRD projects demonstrate a high level of ingenuity and innovation each year. In FY 2019 new R&D projects explored a vast range of topics. For example, a materials study project examined what the collapse of a gas bubble caused by a shock wave propagating in an explosive can reveal about detonation. And an instruments, detectors, and sensors project began a 3-year effort to explore a new nondestructive assay approach to verifying spent fuel casks as they enter geo-repositories.

Some projects concluded in FY 2019. Among these is a photonics project that has used recent developments in phase contrast imaging to accurately measure density profiles of two or more materials in a dynamic experiment. In the area of computational and information science, a PI applied various machine learning techniques, including those that have proved useful in the image processing community, to create new algorithms to identify targeted isotopics to address the lack of automated identification algorithms available for gamma ray spectroscopy.

Finally, we present a long-term highlight about our unmanned aircraft system (UAS) initiative, which began in FY 2015 and has continued with great success. This effort has grown steadily since we acquired our first UAS in FY 2015; in FY 2019 we have accomplished several beyond visible line of sight missions, demonstrating an operational level of technical readiness.

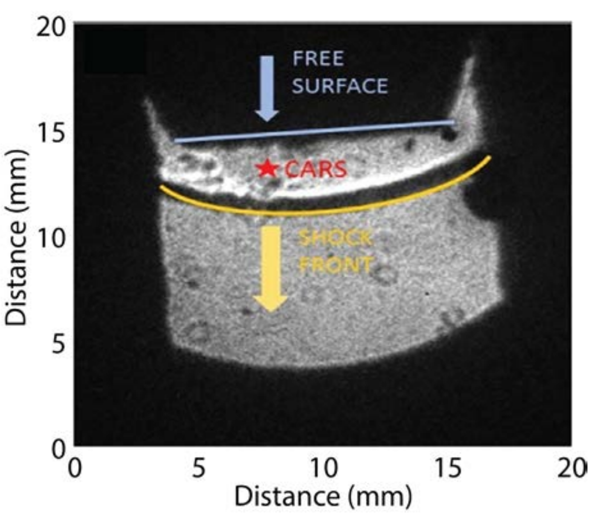
Materials Studies and Techniques Highlights

Over its history, the SDRD program has put a high priority on Materials Studies and Techniques research. Understanding material properties through complex modeling and experimentation addresses gaps that exist in the fundamental knowledge of how materials behave under extreme conditions.

Using CARS to Determine the Dynamic Temperature of Ejecta Particles Reacting with Surrounding Gas in a Shock Compression Experiment, J. Mance (STL-042-19, 2-year project)

Using coherent anti-Stokes Raman spectroscopy (CARS) as an alternative to pyrometry to measure gas temperatures and support recent and future pyrometry measurements until a conclusion can be drawn about the nature of the proposed chemical reactions.

We are using a CARS system to make temperature measurements in shock waves driven by high explosives in deuterium and hydrogen gases. We also developed a unique Schlieren imaging system that enabled us to capture images of the gas shock waves and measure their velocity. The Schlieren images revealed that the shock wave velocity decreases as the wave propagates, and the CARS measurements reveal that the temperature also decreases, results that agree with models we prepared using the hydrodynamic code CTH. This work quantifies the extent to which shock waves in these type of experiments deviate from ideal "normal" shock waves where the gas velocity always travels normal to a planar shock front. In a normal 1-D gas shock, expansion occurs in only one direction, and the gas velocity, pressure, and temperature remain constant as the shock wave propagates. Under these ideal conditions, the properties of the shock wave can be inferred through a measurement of the velocity of the free surface behind the shock wave, which is often measured with photonic Doppler velocimetry. However, in practice

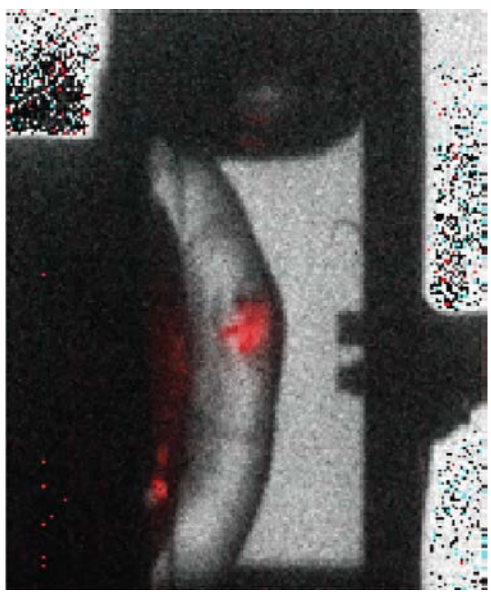


A Schlieren image of the shock wave showing the shock front, the free surface behind it, and the position where the CARS lasers measured temperature.

- *Dynamic Measurements of the Structural Evolution of Material Defects at the Mesoscale, M. Howard*
- *Equation of State Properties of Additively Manufactured Metals, M. Matthes*
- *Fast Temperature Measurements Using Dispersive Time-Domain Spectroscopy, E. Larson*
- *Imaging of Bubble Collapse Effects in Optically Transparent High Explosive as a Method to Study the Detonation Process, D. Turley*
- *Lattice Dynamics of Shock-Induced Phase Transformations, D. Morgan*
- *Measurement of Second Shock Ejecta with Asymmetric Groove Shapes and Sweeping Shock Waves, B. La Lone*
- *Strategic Studies in Dynamic Material Response of Weapons-Relevant Materials, R. Hixson and S. Thomas (SOR)*
- *Strength of Shock-Induced Instabilities, J. Scharff*
- *Using CARS to Determine the Dynamic Temperature of Ejecta Particles Reacting with Surrounding Gas in a Shock Compression Experiment, J. Mance*

we find that knowledge of the free surface velocity is not sufficient to determine the properties of the shock wave as it evolves. While 1-D normal shock wave equations cannot always be used to predict the time evolution of the shocked gas, we find that an instantaneous measurement of temperature or gas shock velocity can be inserted into these equations to determine the other thermodynamic properties of the gas at that moment. This suggests that the instantaneous relationships between pressure, temperature, and velocity from the simple 1-D normal gas shock equations hold true even when the system has evolved beyond what is predicted from initial conditions. In practice then, a single measurement of at least one of these parameters at the time of interest is sufficient to characterize the system.

Mission Impact: The properties of material ejected from the free surface of a shocked metal is of significant importance to the stockpile stewardship community. Although much work has been done to determine the properties of ejecta produced in a vacuum, knowledge of the transport and breakup of ejecta particles in pressurized gas has remained largely unexplored until more recently. In much of the recent work on ejecta, parameters such as temperature, pressure, and velocity of the gas are not directly measured. In particular, much of this work has been carried out using high explosives to drive shock waves, which can result in curved or expanding shock fronts that decelerate and cool during propagation. It is important to understand the dynamic properties of shock waves in the gas surrounding the ejecta in order to draw conclusions about the nature of the transport properties of the ejecta itself.



Combined framing camera and infrared images following the collapse of a helium bubble in nitromethane. The highest radiance (temperature) in the infrared image is located at the region of the collapsed bubble and the presumed onset to detonation.

Imaging of Bubble Collapse Effects in Optically Transparent High Explosive as a Method to Study the Detonation Process, D. Turley (STL-017-19, 2-year project)

By investigating the collapse of a gas bubble caused by a shock wave propagating in an explosive, we are probing the early stages of the initiation process and furthering our understanding of explosive detonation.

Polymer-bonded explosives (PBX) are a mixture of explosive granules and binder material characterized by zones of porosity and impedance mismatch. The pores are tens to hundreds of microns in size. Given this heterogeneity, localized temperature impulses (hot spots) may occur during detonation due to void collapse and complex wave interactions. Hot spots can affect the rate at which some chemical reactions occur during the onset of detonation, but the detailed role of hot spots during initiation, deflagration, and detonation is still not well understood. Our goal is to investigate effects of hot spots on detonation mechanisms in simple explosives and apply experimental results to detonation simulation models. Because PBX are optically opaque, we selected a transparent liquid explosive, nitromethane, for our studies. This year we measured bubble collapse using a visible light high-speed imaging camera and the associated hot spot with a gated infrared camera. The first method gave information about shock wave formation and the bubble collapse as the shock propagates in the compressed liquid as well as the unique shapes formed at the onset of detonation. The second method allowed us to estimate the temperature impulse resulting from the collapse of a helium bubble and the subsequent temperature rise in the early stages of the detonation process.

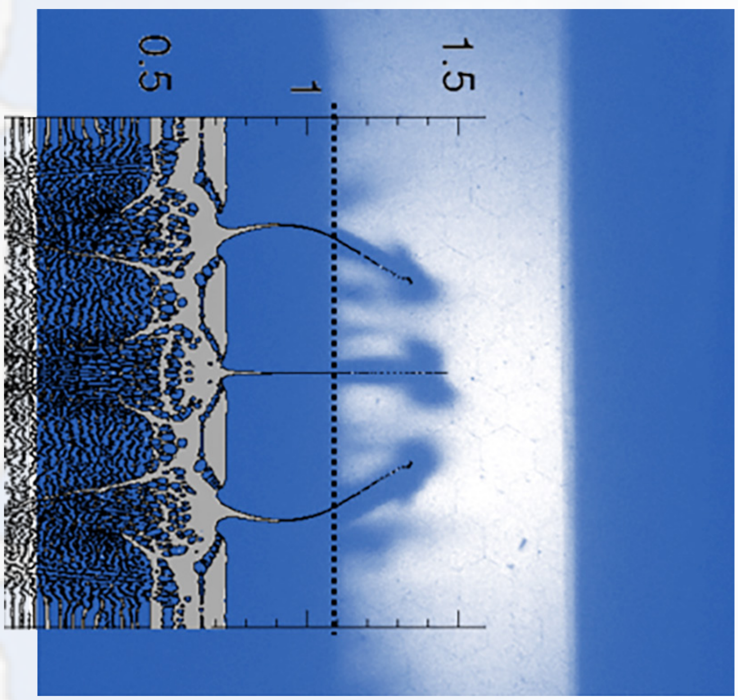
For example, with a bubble diameter of 1 mm and a shock velocity on the order of 5 mm/μs, we resolved a bubble collapsing using an integration time of 100 ns per frame with on the order of 100-micron spatial resolution. Interframe times (on the order of 300 ns) were adjusted to cover the relevant timeframes of bubble collapse and the development and propagation of the shock and detonation waves. We also studied the spectroscopic properties of light emitted from the collapsed bubble. Our initial measurements indicate a distinct difference in the spectral content emitted during the bubble collapse versus the onset of detonation—emission from the bubble collapse is lower in signal and shifted to shorter wavelengths than the emission associated with chemical reaction at the onset of detonation.

Mission Impact: Hydrodynamic codes can model the localized energy increase caused by collapse of a void in an explosive and can provide insight into the mechanisms of detonation, such as hot spot formation. Dynamic visible and infrared imaging of detonation waves and hot spots can contribute to the understanding of wave dynamics and the fundamentals of the detonation process. Such measurements could be extremely useful in the understanding of the high-explosive detonation burn process. Further understanding and control of hot spot densities can help tailor designs for high-explosive detonation sensitivity and improve the predictive capability for sensitivity and initiation characteristics.

Measurement of Second Shock Ejecta with Asymmetric Groove Shapes and Sweeping Shock Waves, B. La Lone (STL-036-19, 1-year project)

Through microscale models and dynamic compression experiments, we investigated ejecta-ejecta collisions sourced in unconventional ways when two or more shock waves are present. Ejecta collisions can lead to particle breakup and increased temperatures, both of which effect ejecta transport, which is an area of great interest to the weapons laboratories.

One mechanism that we explored for potential ejecta collisions was asymmetric groove shapes that lead to non-surface-normal ejecta trajectories. We performed a powder gun experiment with a tin target that was prepared with asymmetric grooves and diagnosed with a fast framing camera. The experiment results were consistent with what we expected from our microscale models in that the ejecta trajectories were indeed not normal



Dynamic image of the shocked tin target having asymmetric grooves (shaded dark blue). The calculated density output from a CTH microscale model (grayscale) is overlaid on ejecta (mushroom-shaped structures). The ruled scale is in centimeters. The dashed line indicates the front of some light ejecta that source from the tin surface itself and obscure the view of anything behind it.

to the surface. This discovery conflicts with some commonly held theories that ejecta always travel normal to the surface or normal to the shock wave. Large asymmetric grooves may not be expected to exist on a machined surface; however, they could form from instability growth of defects and machining marks during the first shock breakout at a surface and be present when a second shock wave arrives. The other mechanism explored was the collision of second shock ejecta with first shock ejecta when the surface melts on first shock and significant first shock ejecta is present. Results from prior experiments suggest that such collisions should not occur because both first and second shock ejecta travel normal to the surface and in interleaving rows. However, the prior gun experiments used supported (square shaped) first and second shock waves. Our models suggested that ejecta collisions should occur if the first shock wave has a triangle-shaped pressure versus position profile (Taylor wave). The triangle wave leads to subsurface cavitation that breaks the symmetry of the original groove shapes and enables non-normal trajectories of the second shock ejecta. However, throughout the course of this work we learned that the second shock recompression of the cavitation layer itself leads to significant ejecta production and heating and would likely swamp any effect due to first and second shock collisions. The latter effect, resulting from recompression of a cavitated liquid, is an area of intense interest at the Los Alamos National Laboratory (LANL) and Lawrence Livermore National Laboratory. In 2019, concurrent with this SDRD project, LANL undertook a programmatic effort to diagnose similar ejecta collisions where the ejecta were sourced from different explosive packages at various angles, and with LANL we are not only assessing temperature increases but also quantifying ejected masses in two-wave experiments with and without cavitation.

Mission Impact: The manner in which ejecta are transported in gases strongly depends on individual ejecta particle size; therefore, understanding the particle breakup process is central to ejecta science. Second shock ejecta production, being investigated by the weapons labs, is the basis of two upcoming series of subcritical experiments. However, because the grooves are symmetric (mirror symmetry), and the shock wave is normal to the surface, second shock ejecta collisions are less likely to occur. But machine finishes can have saw tooth–shaped grooves that break the symmetry and cause the ejecta to travel at an angle to the surface normal, and sweeping shock waves can also break the mirror symmetry. Both of these conditions can make ejecta collisions more likely but have not been investigated under second shock conditions.

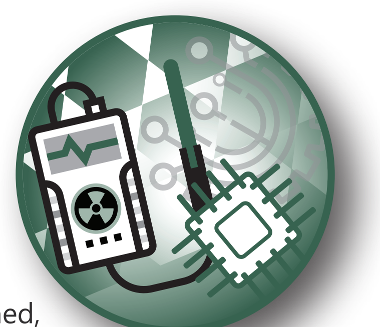
Instruments, Detectors, and Sensors Highlights

Instruments, Detectors, and Sensors has always been a major area of R&D for the NNSS, producing a high percentage of technologies that have successfully transferred to programs, such as multiplexed photonic Doppler velocimetry (MPDV) and SOR research on UASs for radiation detection.

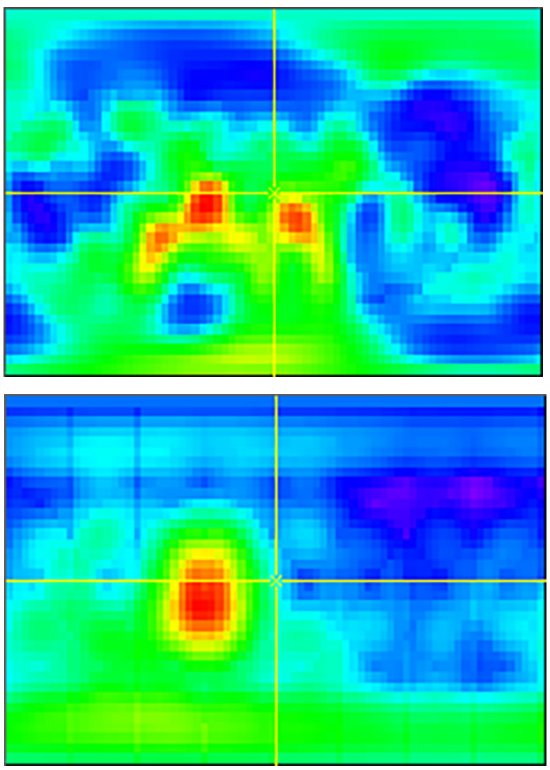
Man-Portable Dense Plasma Focus for Neutron Interrogation Applications, B. Gall (NLV-009-17, 3-year project) R&D 100 Finalist 2019 **(see page 9)**

A dense plasma focus portable design to generate sufficient neutron flux to be relevant for neutron interrogation applications.

Over the last three years, Falcon, a portable, high-output dense plasma focus (DPF) system, was



designed, constructed, and tested in support of defense nuclear nonproliferation applications. Leveraging recent advances in portable DPF technology and our expertise in large-scale DPF systems at the NNSS, this work culminated in an experimental series to measure active fission products from nuclear materials using signal from Falcon in a multi-lab collaboration with teams from the NNSS and the three NNSA laboratories. Falcon has a simple interface, operates on low voltage, has an easily replaceable plasma chamber, and can be integrated into robotic delivery platforms. We are continuing to reduce the size of the portable DPF system by shrinking the control system down to PCB components and by eliminating the vacuum chamber, enabling a truly field-compatible form factor. Finally, the fusion fuel can be readily converted to a deuterium-tritium mix to provide up to an 80 times increase in neutron production at the enhanced neutron energy of 14.1 MeV. In FY 2019 tests, this DPF system had an average neutron yield of 5.84 × 10^7 neutrons per pulse with a repetition rate of 30 seconds, providing a time average neutron yield of 1.95 × 10^6 neutrons per second, which is approximately two times higher than the required output to accomplish portable active interrogation missions. This portable DPF was an R&D 100 finalist in 2019.



Sample testing results for depleted uranium (20 shots, 97 neutron pairs, 6.9 neutrons/minute) show a neutron hot spot roughly where a target was expected.

Mission Impact: This effort signifies several milestone achievements, not only within this SDRD project itself, but within the broader nuclear security enterprise, delivering a novel active interrogation tool to the NNSS and its partners. This achievement augments our nation's ability to protect against the threat of clandestine nuclear material by providing an effective, easily transportable instrument to detect special nuclear material in a variety

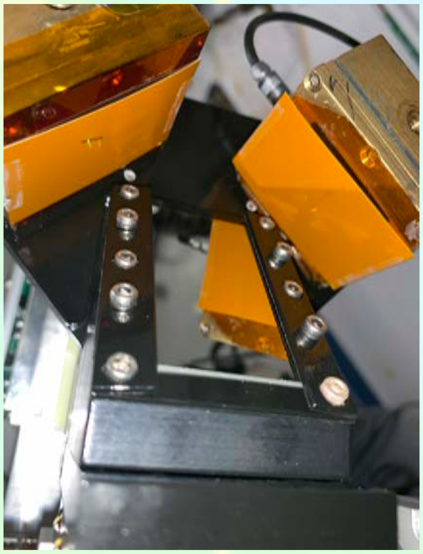
- *Cognitive Hybrid Radio Waveforms for High-Reliability Secure Wireless Communications, S. Koppenjan*
- *Compact Heterodyne Spectrometer for LWIR Detection of Gases from WMD Proliferation Activities, D. Baldwin*
- *Drone Video Platform–Collision Avoidance, Situational Awareness, and Communications, R. Trainham*
- *Dual Comb Spectroscopy for Definitive Identification of Gas at Speeds Faster than Turbulence Effects, D. Baldwin*
- *Gas-Phase Ion-Neutral Interactions of Cerium Ions with Deuterium, M. Manard*
- *High-Fidelity Dynamic Neutron Imaging and Radiography for Subcritical Experiments and Other Applications, A. Durand (SOR)*
- *Man-Portable Dense Plasma Focus for Neutron Interrogation Applications, B. Gall*
- *Millimeter Wave Imaging Diagnostic for High-Explosive Fireball Characterization, I. McKenna*
- *Multi-Modal, Multi-Energy Approach for Neutron Interrogation of Spent Fuel, P. Guss*
- *A Semiconductor-Based High-Yield X-Ray Photocathode, E. Dutra (R&D 100 Winner 2017)*
- *Single-Crystal X-Ray Spectropolarimeter, R. Presura*

of key settings such as border crossings, ports of entry, combat and emergency response scenarios, and urban environments.

Single-Crystal X-Ray Spectropolarimeter, R. Presura (SO-003-18, 2-year project)

A polarizing x-ray spectrometer for applications such as a diagnostic for magnetic fields and electron beams in high energy density plasmas.

This work was motivated by the need to perform measurements of important quantities in difficult experimental conditions, such as the axial magnetic field at stagnation in magnetized liner inertial fusion loads. X-ray spectropolarimetry is a non-perturbative diagnostics technique suitable for measuring intense electron beams and strong magnetic fields in hot, dense plasmas. To improve the accuracy of measurements achievable with this technique, we investigated the possibility of measuring both components of linear polarization simultaneously using a single crystal. Over two years we systematically evaluated combinations of crystal planes and x-ray emission lines to find matches with acceptable integrated reflectivity and high polarization contrast, and we procured crystals suitable for analyzing the emission of high energy density plasmas. We designed and built a simplified spectropolarimetric setup for characterizing polarization-splitting crystals on Manson and synchrotron sources. For the first time, we demonstrated experimentally that crystals with cubic symmetry can be used as polarizing beam splitters. We also found that the polarization-splitting planes in cubic crystals can be accessed in two crystal orientations, a property that can be used to decrease the clutter in polarized spectra. In parallel, we developed a crystal reflectivity ray-tracing code that will eventually be incorporated into instrument modeling codes, which will help us interpret the spectra and design spectroscopic and spectropolarimetric instruments. Our work will continue beyond SDRD, as some Sandia National Laboratories (SNL) collaborators asked us to continue the code development and to use it to design upgrades to SNL x-ray spectroscopic instrumentation.



Crystal and detectors in the setup used for polarization contrast measurements at the Advanced Photon Source synchrotron.

Our research is presented in M. S. Wallace, R. Presura, S. Haque, I. Pohl, P. Lake, and M. Wu, "Cubic crystals in an x-ray polarization-splitting geometry," *Rev. Sci. Instrum.* **91:** 023105 (2020).

Mission Impact: The path toward this application has provided collateral success opportunities. By measurements on a Manson source and a synchrotron, we have confirmed experimentally for the first time that crystals with cubic symmetry present polarization-splitting properties, as previously predicted theoretically. The Manson source measurements coupled with ray-tracing modeling revealed that the polarization-splitting planes in cubic crystals can be accessed in a second orientation different from that initially predicted by theory. Choosing one of the orientations permits control over the number of unintended reflections in spectra. Single-crystal x-ray spectropolarimetry has been pursued as a diagnostic for magnetic fields and electron beams in high energy density plasmas. A potential application of intense interest is the measurement of axial magnetic field at stagnation in MagLIF utilizing Zeeman splitting. Feasibility analysis shows that this is a very demanding diagnostic for the parameters of MagLIF plasmas because measuring this small

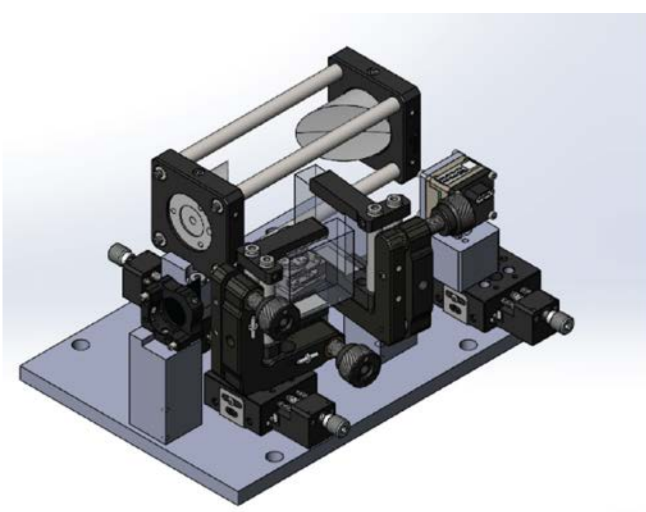
effect requires instrumental resolving power at the very limit of what is achievable with practical crystals and the system setup options.

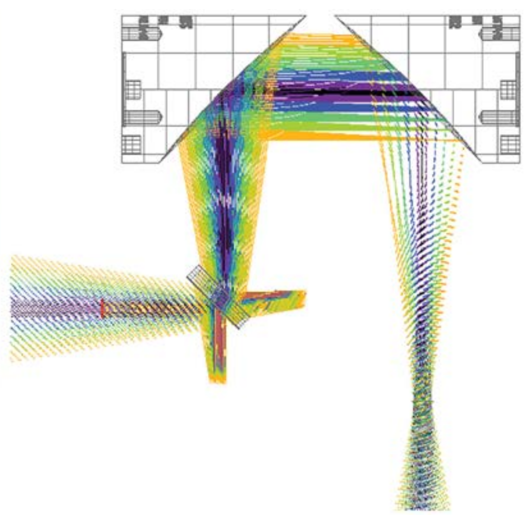
Compact Heterodyne Spectrometer for LWIR Detection of Gases from WMD Proliferation Activities, D. Baldwin (STL-003-19, 2-year project)

A highly portable spatial heterodyne spectrometer to be a compact, rugged, low-power, passive, long-wave infrared sensing instrument for close proximity detection and identification of fugitive gas releases. These releases are invaluable signatures for identifying the proliferation of weapons of mass destruction.

This research began in FY 2019. A portable device, the spatial heterodyne spectrometer (SHS), will collect broadband spectral information that can be used to detect and unambiguously identify fugitive gases from weapons proliferation activities. In FY 2019, we designed and assembled a compact SHS for long-wave infrared (LWIR) wavelengths. The SHS records the Fourier spectrum from 7.5 to 12 µm with approximately 4 cm^{-1} resolution and has no moving parts. The optical system is approximately 110 × 160 × 75 mm and weighs 0.8 kg. The finished SHS will meet size, weight, and power requirements that make it compatible as a handheld detector or suitable for small UAS or other flight platforms, as well as transport to remote, hard-to-get-to locations. In FY 2020 we will develop custom optical and mechanical construction methods to reduce the size and weight of the SHS while incorporating a more sensitive LWIR array detector. We will be investigating detector materials such as mercury-cadmium-telluride or the recently developed strained-layer superlattice LWIR array detector. Our project will develop an internal capability to 3-D print custom mirrors that meet design requirements for size and performance rather than relying on commercially available optics and mounts.

Mission Impact: LWIR sensors have proven valuable in detecting and imaging gas releases, including unintended fugitive emissions from chemical processes. While their small profile makes them amenable to portability and unique placement, their reliance on nonspecific spectral signatures such as a single absorption feature or chemical or physical adsorption means that they are better at identifying and detecting a material in a controlled environment than in an uncontrolled environment





A compact LWIR SHS was designed and assembled from commercially available components. Its performance was modeled, and the assembled system was compared to the model. (left) SolidWorks render of the SHS using commercial mounts and optics; (right) ray tracing model of the SHS with rays at 7-, 8-, 9-, and 10-micron wavelengths.

where many confounding conditions may be encountered. Our SHS will address this issue by being small and lightweight enough for portable and field applications while also covering a spectral range large enough for specific chemical identification. The SHS will greatly enhance our capability to perform highly specific chemical identification in a variety of field settings.

Computational and Information Science Highlights

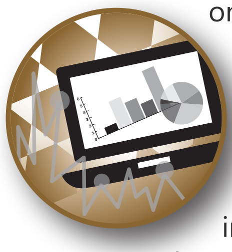
Computational and Information Science research has grown significantly over the last two decades as the need for data analysis tools and possibilities in artificial intelligence have expanded. The field of machine learning has likewise grown exponentially in recent years. In FY 2019 two projects in this R&D area are making significant contributions as SOR projects focused on seismic response and node-level processing of sensor data from distributed networks.

A Spectral Evaluation of the Application of Super-Resolution to Commercial Satellite Imagery, J. Turk (STL-010-18, 3-year project)

We are using spectral machine learning techniques to exploit millions of pixels from labeled hyperspectral imagery, the result of which will be improved target detection and image classification.

The challenges of material identification in hyperspectral or multispectral imagery are well suited for analysis by a machine learning model: the data are noisy and high-dimensional, but the task (target or anomaly detection) is well constrained. We are demonstrating how machine learning techniques can enhance traditional image analyses. In FY 2019 we sought to improve target detection in spectral imagery by using a novel training dataset, an extensive ground-truth hyperspectral image treated as individual pixels. This gave us millions of labeled data points from which to select training data for a neural network to improve target detection in spectral imagery. We successfully trained adaptive algorithms to classify the pixels according to the material present by using a 1-D convolutional neural network (CNN) and ignoring the spatial relationship between pixels. The resulting classification images maintained accuracies of ~80%, which is consistent with the expected upper bound possible due to noise and spectral variances in the data. Where the material of interest had few data points (as few as 20) available to train a neural network, we exploited transfer learning to achieve high accuracy of ≥70%. We also examined the benefits of transfer learning for materials with

- *Advanced Characterization of Spatial Aspects of Image System Blur, D. Frayer*
- *Algorithm Development for Targeted Isotopics, E. T. Moore*
- *Dynamic Test Prediction and Characterization through Modeling-Informed, Multi-Source Data Fusion, M. Howard*
- *High-Performance Computational Modeling of Strong Ground Motion for Seismic Response Analysis with Implications for High-Hazard and/or Nuclear Facilities and Critical Infrastructure at the NNSS, J. Bonner (SOR)*
- *Improved Tomographic and Altitude Corrections for AMS Data, D. Haber*
- *Phenomenology and Node-Level Processing of MASINT Sensor Data across Distributed Sensor Networks, E. K. Miller (SOR)*
- *A Spectral Evaluation of the Application of Super-Resolution to Commercial Satellite Imagery, J. Turk*



only a small number of sample data. As this work continues, we will develop innovative convolutional methods for processing of higher-order data, incorporating spatial data in a 3-D CNN architecture (e.g., hyperspectral imagery, which has an *x*-dimension, a *y*-dimension, and hundreds of *z*-dimensions).

Mission Impact: Adaptive algorithm approaches (machine learning) are becoming useful in the field of hyperspectral image analysis. The NA-22 program office, Strategic Partnership Project (SPP) and Strategic Intelligence Partnership Program (SIPP) customers have identified the need for modern and robust analysis techniques such as machine learning to extract more information from existing data. Of particular interest are data streams, including multimodal and time-series data. Our research creates methods for classifying pixels in hyperspectral imagery with an emphasis on real-world mission considerations, such as mixed signals and small datasets.

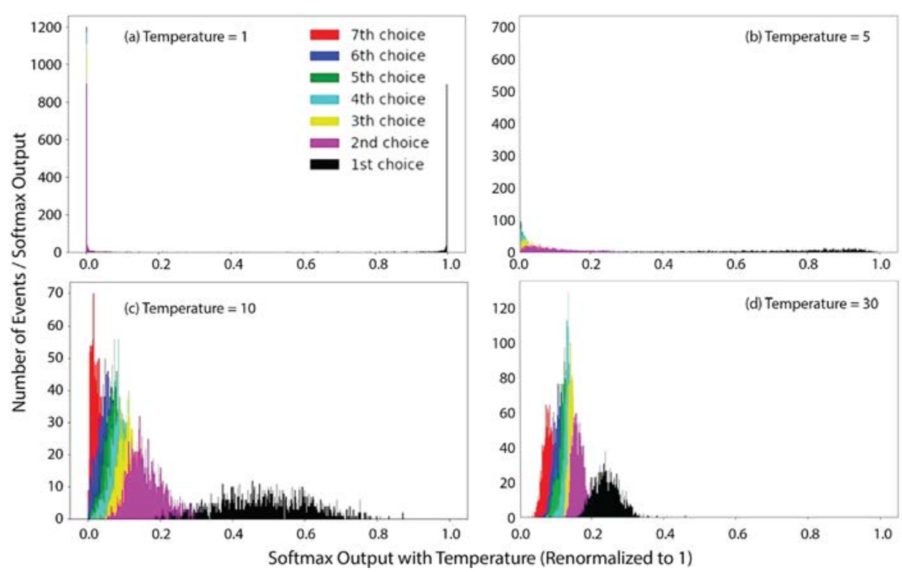
The codebase for this work was published onto an open Bitbucket repository; technology abstract, MSTS No. 19-S-10 Hyperspectral Classification with Machine Learning, an Open Bitbucket Repository.

Algorithm Development for Targeted Isotopics, E. T. Moore (RSLA-002-17, 3-year project)

New algorithms we are developing to identify targeted isotopics are filling a technology gap by supplying automated identification algorithms for gamma ray spectroscopy.

The models and weights of prior-trained convolutional neural networks created for automated isotopic classification of time-sequenced gamma ray spectra were used for providing source domain knowledge as training on new domains of potential interest. This prior training was done solely with modeled spectral data. In this work we transferred the knowledge gained to a new domain of solely measured data and successfully demonstrated that we can combine simulated data with measured data to create widely applicable methods. Our findings could be used to design for engineering better fielded algorithms for automated identification. Modeled source spectra should be injected onto measured backgrounds for this purpose. Some of the better-known deep neural models we drew from were VGG, AlexNet, ResNet, and Inception. It has been shown that knowledge can be "distilled" from deep networks by careful consideration of outcomes that the machine classifies as low but non-zero probability classifications (Hinton 2014). The techniques presented demonstrate that we can successfully combine simulated data with measured data to create widely applicable and robust methods; this approach should be leveraged to engineer more robust fielded algorithms for automated identification.

Mission Impact: Accurate and fast spectral identification of nuisance alarms has been a shortfall in detection operations for many years—especially in the domain of low statistics (short-source encounters). Remote analysis of complex feeds is time-consuming and resource intensive, and even brief delays in communicating



The temperature-softened softmax outputs for a variety of temperatures for the same sample of test data. The setting Temperature = 1 implies no softening.

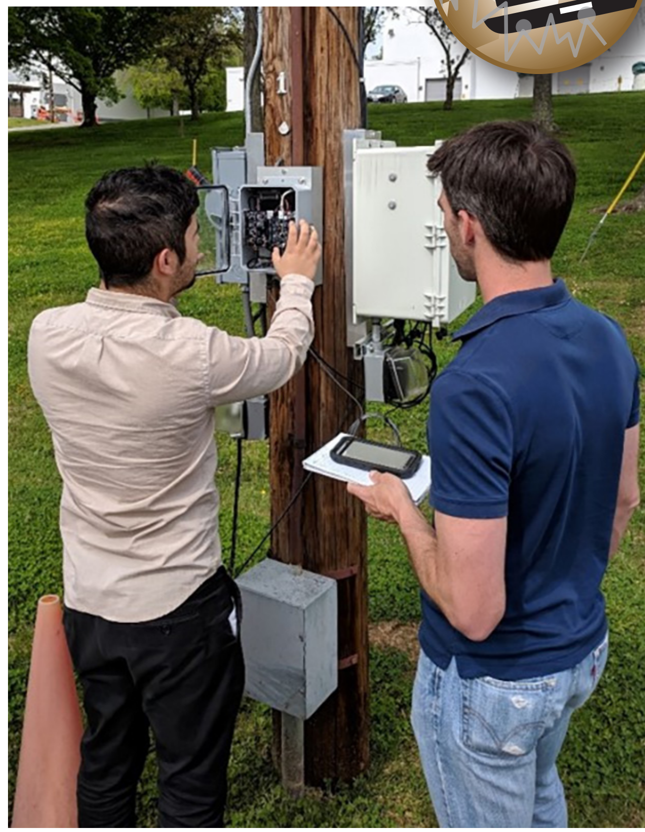
desired collection targets can jeopardize time-sensitive cueing of high-value assets. Compact, low-power sensor arrays capable of node-level data processing with limited node-to-node communication present an opportunity to improve cueing and reduce the likelihood of detection during RF data transmission.

Phenomenology and Node-Level Processing of MASINT Sensor Data across Distributed Sensor Networks, E. K. Miller (STL-016-19, 3-year project)

Compact wireless sensor systems with an array of sensing modalities are being explored to detect changes in daily routines to provide cueing via a lower-cost platform that can be widely deployed.

This SOR project is collecting multi-sensor measurements of mission-relevant phenomenology and developing artificially intelligent algorithms and low-power processor hardware capable of running the algorithms. We are developing a methodology to detect and monitor daily activities at a suspected proliferation site to determine indirectly what activities occurring in the facility bear upon nonproliferation agreements.

As a first step in this development, we designed Merlyn, an instrument made from off-the-shelf hardware that collects data from a suite of sensors and stores and/or transmits these data for processing offline. Merlyn can collect representative sensor data about vehicles and other activities of interest for the purpose of training artificial intelligence (AI) algorithms to detect and classify relevant activities at the edge of the network. The development of Merlyn has enabled us to collect large volumes of data and transfer them to desktop computer systems to support AI algorithm development. The use of off-the-shelf hardware has minimized development time and costs so that sensor data were available early in the project. Our current emphases are collecting and curating the necessary data and co-developing algorithms that utilize the state-of-the-art tools that are compatible with low-power embedded processors.



A Merlyn demonstration installation.

Mission Impact: This work leverages developments in AI tools and low-power processing to develop cutting-edge computing strategies for sensor data to reduce the data transmission requirements in deployed systems. The NNSS has been actively involved in nonproliferation technologies over the years through NA-22 and other programs. This effort brings together existing expertise in AI, low-power electronic design, and field data collection to ensure the continued participation of NNSS teams in important, multiyear efforts to leverage cutting-edge technology for national security missions.

Photonics Highlight

Photonics explores new methods to generate and manipulate light across a wide spectrum, utilizing lasers, electro-optics, and chip-scale devices for specialized applications. Past successes in interferometry, photon conversion devices, and the like have established several core competencies at the NNSS, including advanced diagnostics such as ultra-high frame rate cameras and x-ray phase contrast imaging. Bridging fundamental and applied science has been a hallmark in this area with innovative approaches aimed at difficult R&D challenges.

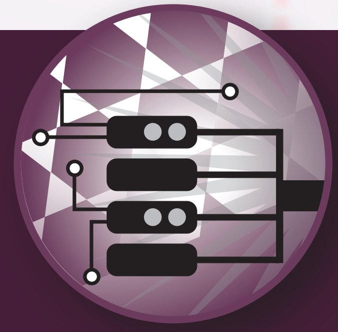
X-Ray Phase Contrast Imaging for Dynamic Material Mix Experiments, D. Clayton (LAO-003-17, 3-year project)

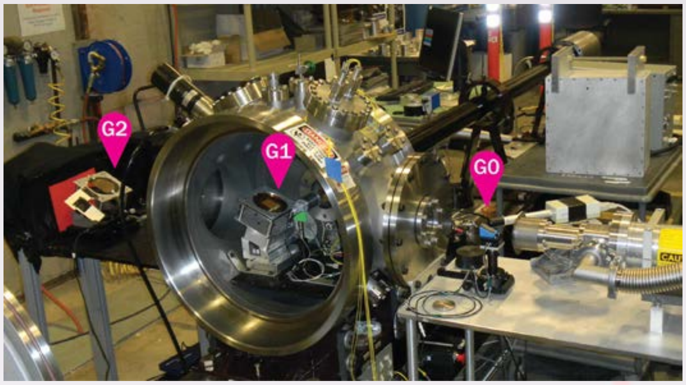
A flash x-ray tube to enable diagnosis of dynamic mixing experiments.

X-ray phase contrast imaging (PCI) with transmission gratings for density profile measurements was developed and tested for dynamic experimental applications. Advances in x-ray transmission gratings spawned Talbot-Lau x-ray deflectometry (TXD) PCI diagnostics, which use compact, incoherent x-ray sources to measure x-ray refraction and ultrasmall-angle scattering. The ultimate goal of this project was to map out the parameter space in which TXD has the sensitivity and resolution to accurately measure density profiles of one or more materials. A Talbot-Lau deflectometer consists of three transmission gratings with equal, micron-scale slit spacing (Pfeiffer 2006). In the instrument, spatially coherent, monochromatic light passes through a diffraction grating, forming images of the grating at periodic distances; this principle is called the Talbot effect. This project addressed the challenges posed by measuring electron density profiles of two mixed elements from a single-image, low spatial resolution system. Dynamic experiments were performed on a gas launcher, and initial results were promising. Near the end of this project we designed and built a new deflectometer for detonator experiments to test new techniques to improve the sensitivity and reliability of the diagnostic.

Mission Impact: TXD can provide NNSS with a capability to study several important, unsolved problems of interest within the weapons physics community, typically involving the mixing of materials or the need to measure the density of low-Z elements surrounded by high-Z material. TXD will enable PCI of dynamic experiments when using a synchrotron or similar facility is not feasible due to costs or hazards. Most experiments simply use x-ray radiography to measure density profiles and do not measure material mix. Various research groups at LANL have expressed interest in fielding the diagnostic, including pRad for mixing experiments, C Division for measuring shock waves in insensitive high explosives within aluminum shells, and Dual-Axis Radiographic Hydrodynamic Test (DARHT) Facility for measuring a large range of densities within plasma plumes created when the electron beam strikes the metal bremsstrahlung target.

► *X-Ray Phase Contrast Imaging for Dynamic Material Mix Experiments, D. Clayton*





The setup of the Talbot-Lau deflectometer on the gas launcher catch tank. Gratings G0 and G2 are x-ray amplitude gratings, and G1 is an x-ray phase grating.

The SDRD Program UAS Initiative: A Long-Term Success for Global Security

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. Unmanned aircraft system (UAS) technology—commonly known as drone technology—is an emerging technology with an immense potential for a wide range of applications, and as such is an area of long-term strategic importance that provides us with special opportunities to innovate and expand the bounds of knowledge in areas relevant to our national security missions.

2015: Drone Initiative Begins

The SDRD program began funding UAS research projects in FY 2015. The first project sponsored by the SDRD program UAS initiative was a three-year investigation into the use of multiple UASs for remote contour mapping of a nuclear radiation field. In FY 2015, the project team acquired two fixed-wing Sandstorm UASs; prepared a real-time radiation data acquisition, storage, and transmission system; conducted preliminary field trials; and initiated the process of incorporating algorithms to improve real-time data analysis (Guss 2016).

FY 2016–2017: 249 Training and Data Collection Flights

In FY 2016, the team acquired five additional UASs, continued to look into advanced data processing algorithms, and initiated a comprehensive UAS remote sensing operations program using the acquired seven UAS platforms (McCall 2017). In FY 2017, the concluding year of the project, the team continued testing and sensor integration with greater emphasis on increasingly more realistic scenarios (Malchow 2018). A total of 249 UAS training and data collection flights were conducted, and autonomous flight was achieved on several platforms.

The Sandstorm fixed-wing UAS from USI is shown with a chemical sensor pod mounted to the belly and the air sampling tube and VOC sensor chip mounted below the left wing.

FY 2017–2019: Detector Development, Aircraft Integration, and Flights in Realistic Scenarios

In FY 2017, the SDRD program funded another UAS research project that aimed at developing a modular situational awareness and communications infrastructure required to support autonomous UAS mission needs (Frayer 2018). This effort was carried on the following year but with a new scope that focused on detector payload development, aircraft integration, and flight testing (Trainham 2019a). The project team successfully developed and flight tested a variety of detectors for aerial measurements from both fixed-wing and rotary-wing UAS platforms. This work was done in parallel with a separate but complementary SDRD project that investigated techniques and algorithms for handling, analyzing, and communicating aerial sensor data in real time or near real time (Trainham 2019b). Because measurements made in the air are invariably noisier than benchtop measurements, the project team focused on exploring techniques and algorithms that help clean up noisy data.

The SDRD program continued to support UAS research in FY 2019 to build on the progress made in the previous years. Four aerial radiological survey missions were undertaken in FY 2019 at different locations and at different times (Trainham 2020). The project team focused mainly on conducting fully autonomous beyond visual line of sight (BVLOS) flights using different combinations of UAS platforms, detectors, and techniques. While the team made considerable progress and gained much practical experience by attempting these flights, issues with real-time communications for flight control and data feeds remain a challenge and require further investigation.

The Virginia Tech hexacopter carries the Apollo detector and the Raspberry Pi in the pod mounted beneath it, and the 2×2 NaI detector is mounted beneath the pod. This photo was taken in April 2018 at an exercise in Idaho.

FY 2019: Flights Over Sedan and Baneberry Craters

Ongoing support from the SDRD program is essential for UAS research at the NNSS to progress and succeed. The SDRD program is currently supporting a project that looks into the ability of a small UAS to fly into and assess difficult areas during national emergency situations. Difficult areas are those that may be too challenging or hazardous for manned aircraft to approach, such as high contamination areas, tunnels, and other confined spaces or GPS-denied locations.

In December 2019, the project team traveled to the NNSS to conduct a small UAS radiation detection, measurement, and mapping mission. A high-efficiency gamma imager, the Apollo detector from 3HD, was attached to a small UAS and flown over the Sedan and Baneberry craters at the NNSS.

In March 2020, the team revisited the Sedan and Baneberry craters to obtain more measurements. During this visit, the team also traveled to the Palanquin crater to collect additional survey and imaging data.

More activities are planned for FY 2020, including a tunnel navigation and mapping mission at the Camp Roberts California Army National Guard training site. Successful completion of these activities will help demonstrate how UAS technology can be leveraged in support of our national security missions, particularly in the area of emergency response and consequence management.

Collaborations and Partnerships

Several collaborations resulting from this initiative will continue. Among these are NNSS team members from the Special Technologies Laboratory and the Remote Sensing Laboratory–Nellis who have extensive experience in designing radiation and chemical detector systems for the Aerial Measuring System (AMS); unmanned aircraft used include hexacopters and fixed-wing Sandstorms developed and operated by Unmanned Systems, Inc. (USI); and we have also formed a solid relationship with Unmanned Systems Laboratory of Virginia Tech (Va Tech) who have also supplied additional drones for our surveys. H3D Corporation has provided cutting-edge gamma imagers such as the Apollo.

Photographed left to right are Alan Horzewski (USI), Todd Bagley (USI), Manny Manard (STL), Rusty Trainham (STL), Hovig Yaralian (USI), and Paul Guss (RSL–Nellis).

SDRD Program Performance Metrics

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

Invention Disclosures and Patents

Invention disclosures are the first step in our intellectual property pursuit and are often followed by patent applications when deemed appropriate. SDRD has generated well over half of all inventions disclosed company-wide since FY 2002. Since FY 2015 about one-third of our projects generate new invention disclosures, which is a reasonably high ratio given that projects can vary widely from basic concept, low technical readiness to much higher more applied development efforts. In fact, our programs benefit from a high rate of technology utilization precisely due to this diverse project mix.

	FY15	FY16	FY17	FY18	FY19
Number of projects	28	27	30	28	28
Invention disclosures	6	5	4	2	4
	21%	**19%**	**13%**	**7%**	**14%**

Technology Transfer

Approximately 1 in 3 SDRD projects produce technology that is subsequently adopted by a direct NNSS program. The ratio of needs addressed to total projects is also indicative of a trend that aligns efforts strategically with the NNSS mission. In addition, a number of projects, but still a small percentage, are targeting emerging fields and new initiatives intended to incorporate higher risk; these projects explore opportunities for enhanced mission outside of traditional NNSS areas of expertise. The program strives to effectively contribute new technology into key programmatic efforts as quickly as possible. New strategic efforts are also providing greater emphasis on forward-looking needs efficiently coupled with long-term visionary goals.

	FY15	FY16	FY17	FY18	FY19
Number of projects	28	27	30	28	28
Technology adopted by programs	6	5	4	2	11
	21%	**19%**	**13%**	**7%**	**39%**

Technology Needs Addressed

The NNSS Technology Needs Assessment document includes guidance regarding technology gaps and challenges facing mission areas. Our directed research emphasis areas this year targeted key investment needs, including nuclear security, information security/assurance, high energy density physics diagnostics, integrated experiments, advanced analysis, and safeguarded energy. The "NNSS Technology Needs Assessment for R&D" is developed from a broad base of input from the national security complex, including laboratories, NNSA, and other external agencies, and it is updated annually. In addition to the assessment, at the beginning of each year's proposal call, we issue a Broad Site Announcement (BSA), which contains detailed information on strategic initiatives in our directed research areas.

	FY15	FY16	FY17	FY18	FY19
Number of projects	28	27	30	28	28
Gap or need addressed	10	10	13	11	14
	36%	**37%**	**43%**	**39%**	**50%**
"Emerging Area and Special Opportunity" effort	5	3	5	6	3
	21%	**19%**	**13%**	**7%**	**39%**

Publications

Publications are another indicator of R&D output and provide an archival record of the investments made, which are then available to the broader scientific and technical community. We place a strong emphasis on high-quality, high-impact journal publications. We generally expect about half of all SDRD projects will publish in a given year. An increase in follow-on and co-authored publications has been noted, and future prospects for enhanced publishing look promising.

	FY15	FY16	FY17	FY18	FY19
Journal Publications	7	7	8	8	10

Postdocs and Interns

The SDRD program welcomed its first postdoctoral PI in 2015. Since then it has attracted eight postdocs and interns. The contribution of these early-career scientists is significant. The program continues to enjoy the contributions of this group, having retained six, converting most to full-time staff.

Our commitment to mission agility, technical vitality, and workforce development remains strong

Since its beginning in 2002, the SDRD program has been at the forefront of innovation for the Nevada National Security Site. The principal investigators whose projects made up the FY 2019 R&D portfolio consist of distinguished scientists and engineers and early-career and mid-career professionals who are pushing the boundaries of technology to solve mission-relevant problems. This rich mix of curiosity and talent was the foundation of a vibrant, inspired FY 2019 year.

Howard Bender III
SDRD Program Manager
Mission Support and Test Services, LLC

As we prepared this annual report, the world came face-to-face with a global pandemic that boldly illustrates our commitment to the three objectives of the program: mission agility, scientific and technical vitality, and workforce development. As we face the future, it is even more crucial that our coming decades of research rise to new levels. A key component of our success rests on our ability to attract, grow, and sustain the 21st century's technical workforce in areas essential to mission. To this end, the SDRD program is a platform for researchers who desire to pursue ideas that will become solutions to future mission challenges. Strong investment in workforce development will ensure the program's vitality and the nation's progress and security.

April 2020

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 goes out to Michele Vochosky, assisted by editor Katsura Rast, for technical communications and compiling, editing, and publishing this report; to Katina Loo for providing document design; to Leslie Esquibel, Emma Gurr, and Sally Matthews for project management and cost accounting efforts; to Michael Baldonado, Shaun Galey, and Newell Ramsey for information system support; to Eduardo Morales for financial data reporting; to Larry Franks, Rob Hixson, and Lynn Veeser for technical guidance and support; and to our SDRD site representatives and technical review committee: Jesse Bonner, Frank Cverna, Eric Dutra, Daniel Frayer, Rick Freeman, Brady Gall, Paul Guss, Marylesa Howard, Brandon La Lone, Mary O'Neill, Alex Plionis, Patrick Sawyer, Jerry Stevens, and Rusty Trainham. And, finally, special thanks again goes to members of our external advisory board, Larry Franks, Carl Ekdahl, Damon Giovanielli, Ralph James, Paul Rockett, Maurice Sheppard, Ralph Schneider, and Gerry Yonas, who graciously give their time and provide ongoing, valuable recommendations.

References

Frayer, D., M. D. O'Neill, M. Mavroleon, C. Hollabaugh, J. Lawson, R. Trainham, S. Fall. 2018. "Drone video platform—Collision avoidance, situational awareness, and communications." In *FY 2017 Site-Directed Research and Development Annual Report*, 69–77. Las Vegas, Nevada: National Security Technologies, LLC.

Guss, P., et al. 2016. "Multiple unmanned aircraft system for remote contour mapping of a nuclear radiation field." In *FY 2015 Site-Directed Research and Development Annual Report*, 1–13. Las Vegas, Nevada: National Security Technologies, LLC.

Hinton, G., O. Vinyals, J. Dean. 2014. "Distilling the knowledge in a neural network." Presentation presented at the NIPS 2014 Deep Learning and Representation Learning Workshop, Montreal, Canada, December 2014.

Malchow, R. et al. 2018. "Multiple unmanned aircraft system for remote contour mapping of a nuclear radiation field." In *FY 2017 Site-Directed Research and Development Annual Report*, 9–17. Las Vegas, Nevada: National Security Technologies, LLC.

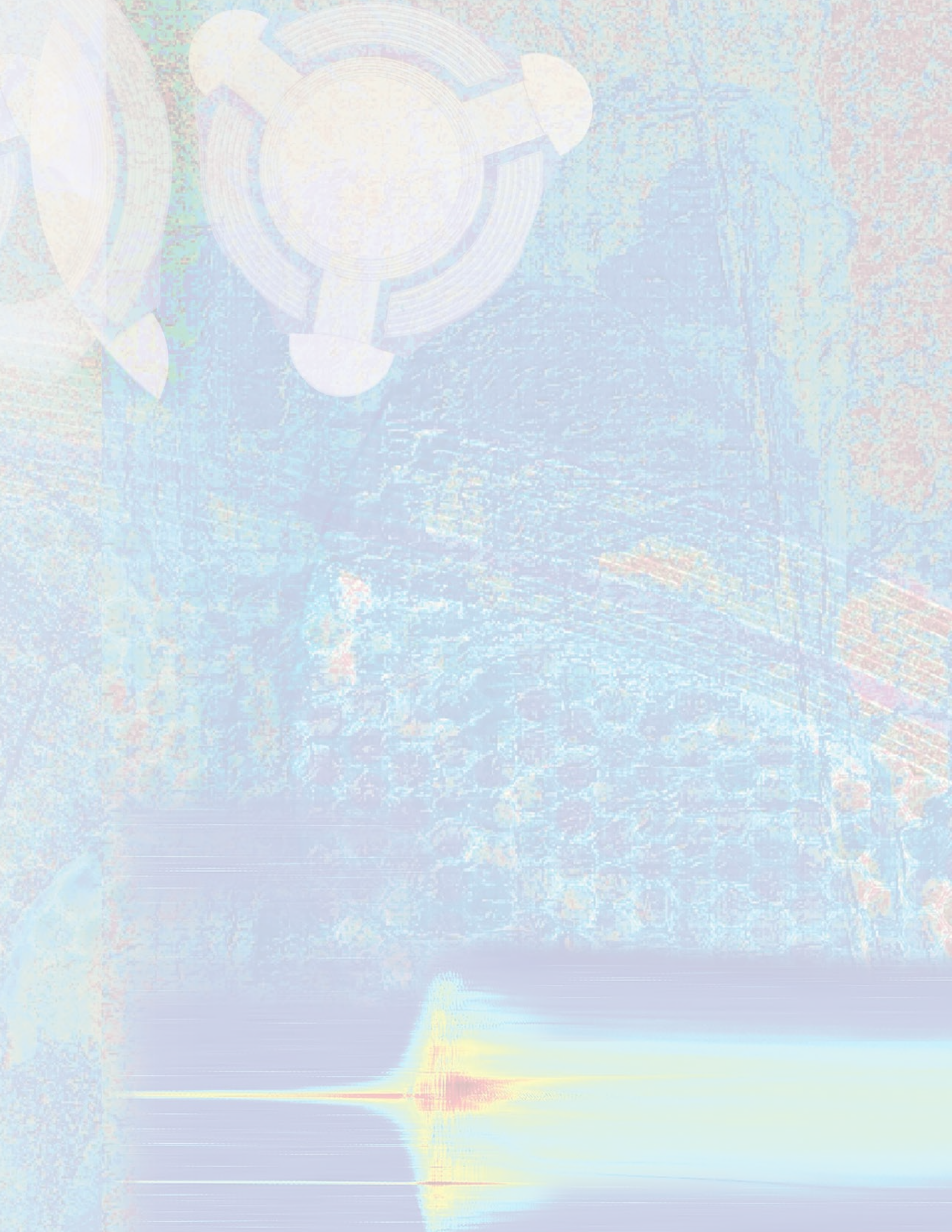
McCall, K., et al. 2017. "Multiple unmanned aircraft system for remote contour mapping of a nuclear radiation field." In *FY 2016 Site-Directed Research and Development Annual Report*, 11–22. Las Vegas, Nevada: National Security Technologies, LLC.

Pfeiffer, F., T. Weitkamp, O. Bunk, C. David. 2006. "Phase retrieval and differential phase-contrast imaging with low-brilliance X-ray sources." *Nat. Phys.* **2**: 258–261.

Trainham, R., P. Guss, M. Manard, T. Keenan, E. Bravo, W. Kaye, K. Kochersberger. 2020. "Drone video platform—Collision avoidance, situational awareness, and communications." Las Vegas, Nevada: Mission Support and Test Services, LLC.

Trainham, R., P. Guss, M. J. Manard, L. McLean, W. Kaye, K. Kochersberger. 2019a. "Drone video platform—Collision avoidance, situational awareness, and communications." In *FY 2018 Site-Directed Research and Development Annual Report*, 17–37. Las Vegas, Nevada: Mission Support and Test Services, LLC.

Trainham, R., P. Guss, M. J. Manard, L. McLean, W. Kaye, K. Kochersberger. 2019b. "Dynamic algorithms for aerial measurements." In *FY 2018 Site-Directed Research and Development Annual Report*, 193–200. Las Vegas, Nevada: Mission Support and Test Services, LLC.




SDRD
SITE-DIRECTED RESEARCH & DEVELOPMENT