

Site-Directed Research & Development Annual Report Overview FY 2020

Site-Directed Research & Development

FY 2020 Annual Report Overview

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How to read this report

The SDRD program's annual report for fiscal year 2020 consists of two parts: the program overview, which contains three major sections, Program Description, Program Accomplishments, and Program Value, and individual project report summaries published electronically on the Nevada National Security Site's website, www.nNSS.gov/pages/programs/sdrd.html. Complete technical reports for concluding projects are available from the Office of Scientific and Technical Information (OSTI) or the principal investigator.

On the cover

(front and back cover) Principal investigator Ian McKenna at the existing shock tube overpressure apparatus (STOA) at the NNSS Special Technologies Laboratory. The redesigned STOA will provide a new capability for modeling RF emissions and particulate evolution in a well-characterized environment. (inside front cover) An acoustic sensor, part of a compact wireless sensor system with an array of sensing modalities, covers infrasound through audio frequencies. (inside back cover) Area 12 photo footprints of 846 frames collected at 80% forward and side overlap for processing of a high-resolution terrain surface model.

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

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

Our 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.

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 cyberattack, 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.

In the coming years, SDRD will better align with NNSS programmatic goals by supporting strategic initiatives that will serve as a long-term S&T investment to better prepare the NNSS to support future NNSA missions as well as become more agile and able to rapidly respond to future global threats.

Moreover, the SDRD program aims to enable our ST&E workforce to innovate and advance the ST&E state of the art that will transform us into a next-generation NNSS partner with the NNSA weapon laboratories in support of their missions that is flexible enough to meet future challenges.



José Sinibaldi

*Chief Scientist
Nevada National Security Site*

■ PROGRAM DESCRIPTION

■ SDRD Program Mission, Alignment, and Objectives

History and Impact

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

The program is modeled after the Laboratory Directed Research and Development (LDRD) program, which is conducted in accordance with the guidance provided by U.S. DOE Order 413.2C 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.

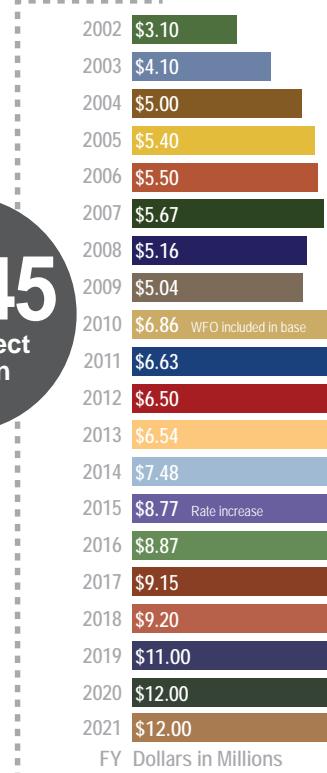
P.L. 110-161 (H.R. 2764), "The Consolidated Appropriations Act, 2008," provides that up to 4% of the NNSS site costs may be applied to the SDRD program. In addition, SDRD is an allowable cost within the NNSS management and operating contract and as such is identified in the NNSS contractor accounting 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 2021 by the senior management team.

As the illustration on this page shows, SDRD has made a significant impact in the past 20 years, providing over 120 new technologies to NNSS programs from 2008 to 2020, a high return on the investment of R&D dollars.

FY 2002 – FY 2021 NNSS Site-Directed R&D BY THE NUMBERS

~\$145
Total project
dollars in
funding



48.5%
Percent of S&T
personnel engaged

1896
Proposals

694
Projects

333
Total number of
principal investigators
with projects

124
New technologies
deployed to
programs
(FY 2008–FY 2020)

Alignment with the NNSA LDRD/SDRD Strategic Framework

The NNSA laboratories and NNSS R&D programs have five objectives as described in DOE Order 413.2C. They are to

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

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

programs address four important challenges presented in the 2018 Nuclear Posture Review, which are to

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

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

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

Mission Agility.

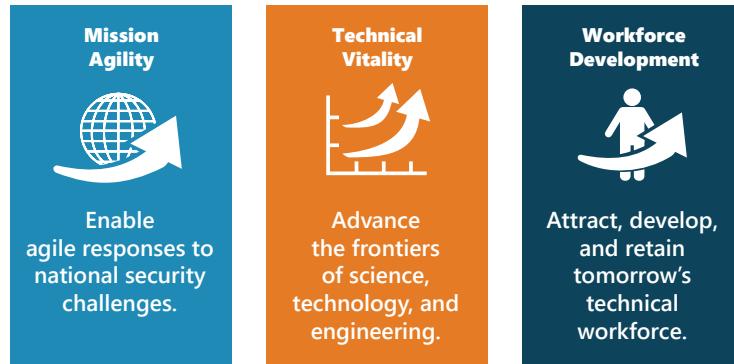
Enable agile technical responses to current and future DOE and NNSA mission challenges.

Scientific and Technical Vitality.

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

Workforce Development.

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



Mission and Objectives

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

The research projects featured on pages 9–20 are keyed to the Strategic Framework challenges as well as the three objectives, as indicated by icons.

■ SDRD Program Leadership

The senior leadership of Mission Support and Test Services, LLC (MSTS), the management and operating contractor for the NNSS, which includes the president, vice president, and senior program directors, is committed to advancing the contract's R&D goals. Working closely with senior management and the SDRD program manager, the chief scientist ensures the quality of science and technology across the company's multiple programs and missions, 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 and is responsible for all practical aspects of the program. The program manager is assisted by local representatives at each NNSS site to coordinate technical activities undertaken by local principal investigators (PIs). PIs are responsible for all aspects of technical activities on their projects. They deliver monthly updates, present quarterly reviews, submit final annual reports, and report technical outcomes post-project closure.

The SDRD program relies on an external advisory board of distinguished individuals

from academia, government, and industry to help guide and direct our investments toward the most important areas of national security science and technology. This board has been instrumental in the success of the program since it was instituted in the mid-2000s.

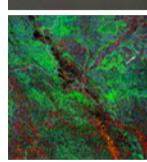
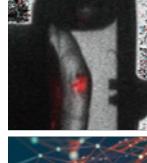
The NNSS Centers of Excellence

The NNSS Centers of Excellence (COEs) are a focused long-term technical investment to prepare the NNSS technology capabilities for future NNSA missions and to enhance our ability to respond to future global threats.

The goals and objectives for these centers 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 COEs will directly align their efforts to support our NNSA and Strategic Partnership Projects missions and will be an integral component of the SDRD program. COE leaders will be involved in shaping the program as well as integrating COE goals with defined strategic initiatives directed to SDRD proposers. More about this exciting expansion of the SDRD program will emerge in FYs 2021 and 2022.

NNSS Centers of Excellence

	Radiographic Systems Imaging and Analysis
	User-Centered Remote Testing & Operations
	Neutron Technologies and Measurements
	Accelerator Beam Science and Target Interactions
	Enabling Technologies for Autonomous Systems & Sensing
	Dynamic Experiment Diagnostics
	Communications and Computing

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

■ Strategic Opportunity and Exploratory Research Areas

As in previous years, in FY 2020 the program was divided into two principal research types, Strategic Opportunity Research (SOR) and Exploratory Research (ER). In addition, a small number of Feasibility Studies were funded.

Strategic Opportunity Research

The SOR project portfolio, first initiated in the FY 2015 proposal cycle, is 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 the SOR category fit with our strategic goals and align with broad mission objectives within our two main mission categories, stockpile stewardship and global security. Initially funded at about 10% of the 2015 SDRD budget, SDRD funds dedicated to SORs in FY 2021 will be about 25% to 30%. 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.

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. Several past successful endeavors, such as broadband laser ranging (page 24), 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 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, staff 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 subject matter experts (SMEs) to refine their ideas. This phase sparks innovation and initiates a feedback loop that extends to the invited proposal phase.



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

Project Selection

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), 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 ranked results from the peer-review process, the SDRD program manager and chief scientist recommend to the MSTS president SDRD projects for approval and final selection. An annual program plan is submitted to the NNSA in mid-August for concurrence.

■ Mission Categories: 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 \$20.7M, while global security received approximately \$20.3M in funding.

The four main areas of research were established in 2009, after earlier category types were combined and simplified. From FY 2016 (SOR projects were added in FY 2015) to 2020, the distribution of projects in the portfolio in the five areas has been 11.8% SOR; 19.2% Materials Studies and Techniques; 43.3% Instruments, Detectors, and Sensors; 14.7% Computational and Information Science; and 11% Photonics. Recently, projects focusing on dynamic materials properties, remote sensing, big data analysis, and machine learning have increased, signaling the importance of these challenges to the mission.

Initially SOR projects concentrated on dynamic materials research to advance the understanding of fundamental physics questions and on developing radiation, chemical, and spectroscopic real-time sensing systems for use on UAS platforms.



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.



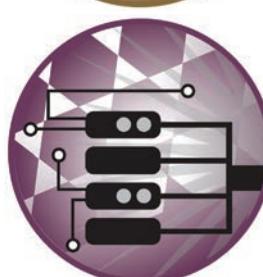
Instruments, Detectors, & Sensors

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.

In FY 2020 the SOR portfolio 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.

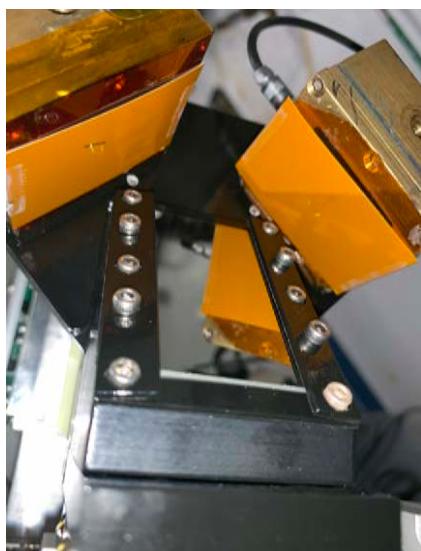
■ PROGRAM ACCOMPLISHMENTS

NNSS R&D 100s Have Roots in SDRD

Since 2010 the NNSS has won six R&D100 awards, four of which have roots in SDRD. Three additional SDRD-based submissions to the R&D 100 awards were recognized as finalists, including the most recent ICARUS.

X-ray Polarizing Beam Splitter Wins 2020 R&D 100

The NNSS' X-ray Polarizing Beam Splitter (XRPBS) was named a winner of the 2020 R&D 100 awards. The award-winning innovation recognized, the XRPBS, has the ability to separate an x-ray beam in two in order to measure each polarized beam



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



The ICARUS team; left to right are Alan Horzewski (USI), Todd Bagley (USI), Manny Manard (STL), Rusty Trainham (STL), Hovig Yaralian (USI), and Paul Guss (RSL-Nellis).

simultaneously, which will be used for diagnostics within the NNSA enterprise. Developed in partnership with Sandia National Laboratories, Argonne National Laboratory, and EcoPulse, it is the first x-ray polarizing beam splitter in existence.

"I see it as a diagnostic that will be involved with many different types of experiments and scientific research facilities," said SDRD program manager Howard Bender. "There is a continual advancement of these high-synchrotron resources."

Using Unmanned Systems (ICARUS) was an R&D 100 finalist in 2020. ICARUS equips unmanned aircraft systems with a payload of radiation, chemical, optical, LIDAR, and photographic detectors.

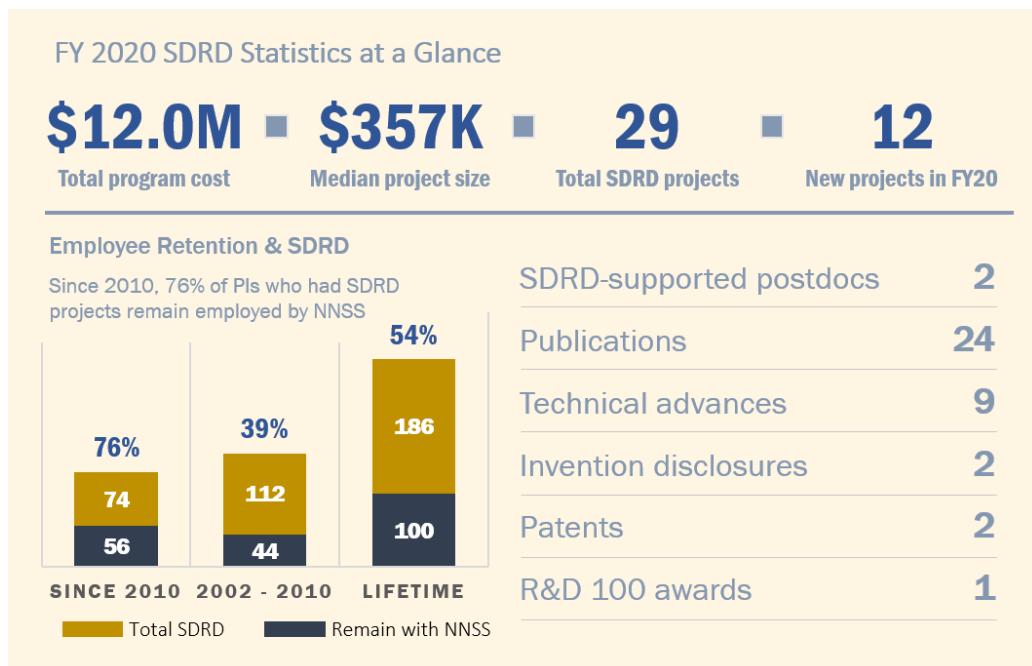
The technology, developed by the NNSS in partnership with Unmanned Systems, Inc., H3D, Inc., and Virginia Tech, can be viewed in this [video](#).

"ICARUS is an intelligent unmanned aerial autonomous system," said Howard Bender. "It provides an unmanned capability to do some of the dull, dirty, dangerous, and sometimes deep work where you don't want to send any type of human system—for example, a serious incident involving hazardous materials."

ICARUS Named 2020 R&D 100 Finalist

The Intelligent Consequence Control by Aerial Reconnoiter

■ SDRD Statistics at a Glance



■ Featured Research

SDRD projects demonstrate a high level of ingenuity and innovation each year.

Featured research projects of the R&D undertaken in FY 2020 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
- ▶ Photonics

While all projects aim to align with the challenges defined by the Strategic Framework and the three objectives of the NNSA LDRD/SDRD program, icons accompanying these research project descriptions indicate that the project was particularly strong in addressing those objectives.



PI Clare Kimblin is investigating the contributions that detonation soot make to RF and optical signatures (page 13).

Summaries of all FY 2020 projects can be found on the SDRD program pages of the NNSA.gov website. A list of all projects by area of research can be found on the inside back cover of this publication.

Materials Studies and Techniques

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.



Strategic Studies in Dynamic Material Response of Weapons-Relevant Materials, S. Thomas (LAO-015-18, 3-year SOR project)

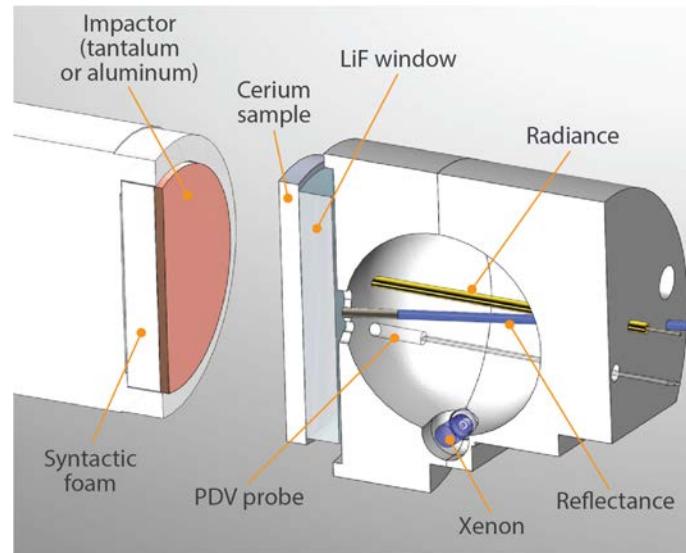
We examined material properties such as crystal anisotropy, temperature, pressure, and phase state (solid or liquid) in metals subjected to extreme conditions during shock wave experiments.



This research explored some key outstanding shock physics issues with regard to certain stockpile materials. We explored dynamic phase changes, namely large-volume, low-stress solid-solid transitions and the melting and resolidification transitions in a surrogate material, cerium. We developed and tested techniques to conduct necessary experiments and obtained shock temperature, stress, and dynamic emissivity measurements for cerium shocked from 8.4 to 23.5 GPa.

The isentropic shock release temperature as a function of release stress was also determined. In addition, we sought to learn how anisotropies in single-crystal metals (iron for this study) affect the polycrystalline averages of the shock speeds and compressive and spall strengths of metals with moderate crystalline anisotropy. The shock speeds in the three principal orientations of cubic single-crystal iron samples were measured and compared to those of polycrystalline iron to determine differences in shock Hugoniot between each orientation and the polycrystalline value.

Mission Impact: The equation of state (EOS) of a metal is the thermodynamic surface that describes its pressure-volume-energy relationship. For a metal with phase changes, this is a multiphase EOS, a grand challenge focus for the weapons program. Our information about cerium metal may contribute significantly to the Advanced Simulation and Computing program. Physics theory and modeling will benefit the most, as our data will allow theorists to build better physics models.



Experimental geometry for combined radiance/reflectance/photonic Doppler velocimetry (PDV) diagnostics. Hugoniot temperatures and isentropic release path temperatures of cerium samples were measured for shock stress values between 8.4 and 23.5 GPa.

Such models are essential for refining computational predictions, and especially for improving the fidelity of large-scale weapons simulations.

We have developed a new method and used it to make temperature measurements and map out portions of the phase diagram of shocked cerium. These measurements will help theorists construct higher-fidelity multiphase EOSs for cerium and eventually for plutonium. Details of the melting transition have been measured and first experiments done to carefully look at the refreezing process. This is likely to be applied to ongoing special nuclear material experiments. Single-crystal metal research done in this project will help develop mesoscale physics models that describe the dynamic response of relevant metals.

Publications include "High-pressure melt curve of shock-compressed tin measured using pyrometry and reflectance techniques," *J. Appl. Phys.* **126**, 225103 and "Wave speeds in single-crystal and polycrystalline copper," *Int. J. Impact Eng.* **139**, 103506.

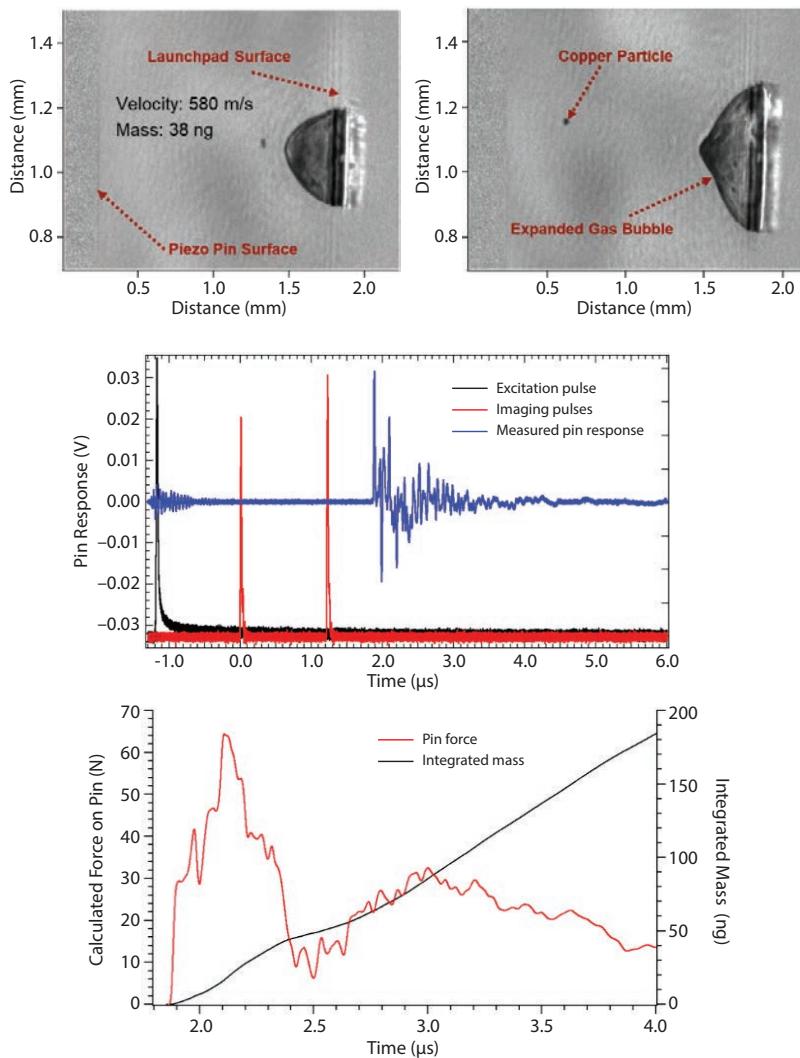
Laser-Induced Particle Impact Test (LIPIT) and Micro-Pin Investigation of Ejecta/Surface Interactions, M. Staska (STL-025-20, 2-year project)

This project uses a laser-induced particle impact test platform to study individual micron-scale particle impacts on current piezo pin designs and is also developing advanced pin designs in an effort to determine particle size distributions by resolving single-particle impacts.



We have set up and successfully fielded a laser-induced particle impact test (LIPIT) platform to study individual micron-scale particle impacts. This platform was developed by MIT ([Hassani-](#)

[Gangaraj 2018](#)) and consists of an excitation laser that is focused onto a "launchpad" consisting of a glass substrate with a metallic ablation layer and a poly-film layer. We sparsely distribute metallic



(top) Shadowgraph images of an expanded gas bubble launching a copper particle into a piezoelectric pin surface (time separation between images is 1.2 μ s), (middle) raw data, and (bottom) a plot of the calculated force on the pin due to the particle strike and the resultant integrated mass. Our data analysis correctly predicted a mass of ~ 40 ng prior to the ringing (before 2.5 μ s).

particles of a known diameter on the launchpad. The excitation laser pulse is then focused and aligned with a single particle. Adjusting the power of this excitation laser pulse, we can control the rapid expansion of the poly-film layer (due to the ablation of the metallic layer) and therefore the launch velocity of the particle.



We then perform particle imaging velocimetry using two laser pulses to determine the velocity of the particle. Shadowgraphy images are used to calculate the particle velocity. With these known values of mass (diameter and density) and velocity, we can calculate the momentum of the single particle to compare with the pin response.

Utilizing LIPIT, we can launch single particles of a known momentum into a target of choice. In FY 2020 we studied the response of a single, simple piezoelectric pin. Because we are able to launch single particles with a known momentum, we can then calculate the piezoelectric coefficient (a value that is typically assumed in most dynamic use cases) from the recorded pin response. We discovered that standard piezoelectric pins can have an acoustic ringing (as shown in the blue curve in the middle plot on page 11) due to the mechanical dimensions/characteristics of the active piezoelectric disc. This was unexpected, as current pin analysis does not account for such ringing. Preventing this ringdown in the pin via surface patterning or impedance matching and optimizing the analysis will allow us to resolve single particle strikes with piezoelectric pins.

Mission Impact: The national labs are currently conducting significant research into ejecta formation and transport. Central to many ejecta transport models is understanding the particle size distribution. Current methods such as holography require high-power lasers and vessel windows, or are based on assumptions that may not fit all experimental requirements. Piezoelectric pins are vastly simpler, and the research we are conducting could lead to the development of a new, versatile ejecta diagnostic to dynamically determine particle size distributions.

■ Instruments, Detectors, and Sensors

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.

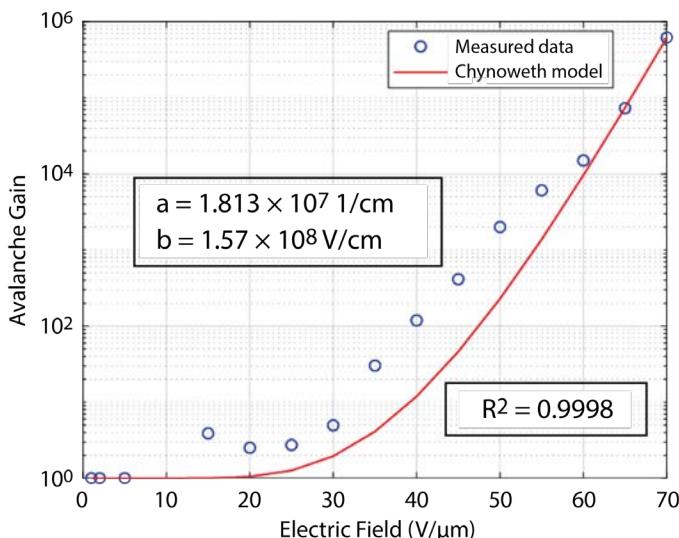
Multi-layered Avalanche Diamond Detector for Fast Neutron Applications, A. Guckes (NLV-003-20, 2-year project)

The project will design and fabricate a novel multi-layered

avalanche diamond (MAD) detector leveraging the intrinsic avalanche and atomic properties of single-crystal chemical vapor deposition (scCVD) diamond to yield a novel fast neutron detector with inherent gain, improved detection efficiency compared to a single layer, and small footprint. Such a device can provide an inherently low-noise, high-fidelity, current mode measurement of a pulsed neutron source.



Single-layer 10 μm thick scCVD diamond detector



Avalanche gain as a function of applied electric field measured with the same detector exposed to 14.1 MeV neutrons from an MP320 neutron generator.

Based on our efforts, we predict a multi-layered scCVD diamond avalanche device with several vertically stacked layers can maintain geometrical gain similar to a photomultiplier tube and will provide an increased signal-to-noise ratio and flexibility in fielding the detector farther from the source. The avalanche effect is electron-hole multiplication achieved by increasing the electric field within the scCVD diamond high enough such that secondary electrons created from radiation interactions in the diamond can be kinetically accelerated beyond the band gap energy before colliding/scattering within the lattice. Fields of 30 V/μm and greater have been observed to demonstrate avalanche gain in diamond radiation detectors. Electrons at avalanche speeds have enough energy to transit a thin metal layer and can be transported between stacked layers to continue producing compounded secondaries resulting in multiplicative gain.

Working closely with Applied Diamond, Inc., we developed two thin-layered scCVD diamond detectors, one 5 and one 10 μm thick. DC current measurements with an electrometer were performed with these detectors exposed to 14.1 MeV neutrons produced by an MP320 Thermo Fisher neutron generator. The bias voltage applied to each detector was increased

with the aim to observe charge multiplication while avoiding a hard breakdown. As shown in the figure, distinct charge multiplication was observed at electric fields greater than 30 V/μm.



Mission Impact: Emphasis on the advancement of neutron detection technologies was made at the most recent NNSS Neutron Detector System Workshop and noted in the FY 2021 *NNSS Technology Assessment for R&D*. High gamma ray rejection and intrinsic detection efficiency were called out as requirements important to the success of high-flux neutron source experiments across the DOE complex including neutron-diagnosed subcritical experiments at the NNSS. The MAD detector will meet these requirements and provide a low-noise, high-fidelity, current mode measurement of the neutron source term. It will also enable neutron time-of-flight measurements on such experiments and contribute to spectroscopy capabilities for the global security mission.

An invention disclosure was filed for this innovation. Our modeling effort is described in "Geant4 and MCNP6.2 modeling of fast-neutron detectors based on single-crystal chemical vapor deposition diamond," [Proc. SPIE 11494: 1149417](#).

Dynamic Sub-Micron Particulate Behavior in Turbulent Media, C. Kimblin (STL-008-20, 2-year project)

We are building a capability to support modeling of radio frequency (RF) emissions and particulate evolution with known particulates in a well-characterized environment. This capability included developing a revised design of the shock tube overpressure apparatus (STOA) in a new anechoic chamber at the NNSS Special Technologies Laboratory, associated diagnostics, and software.

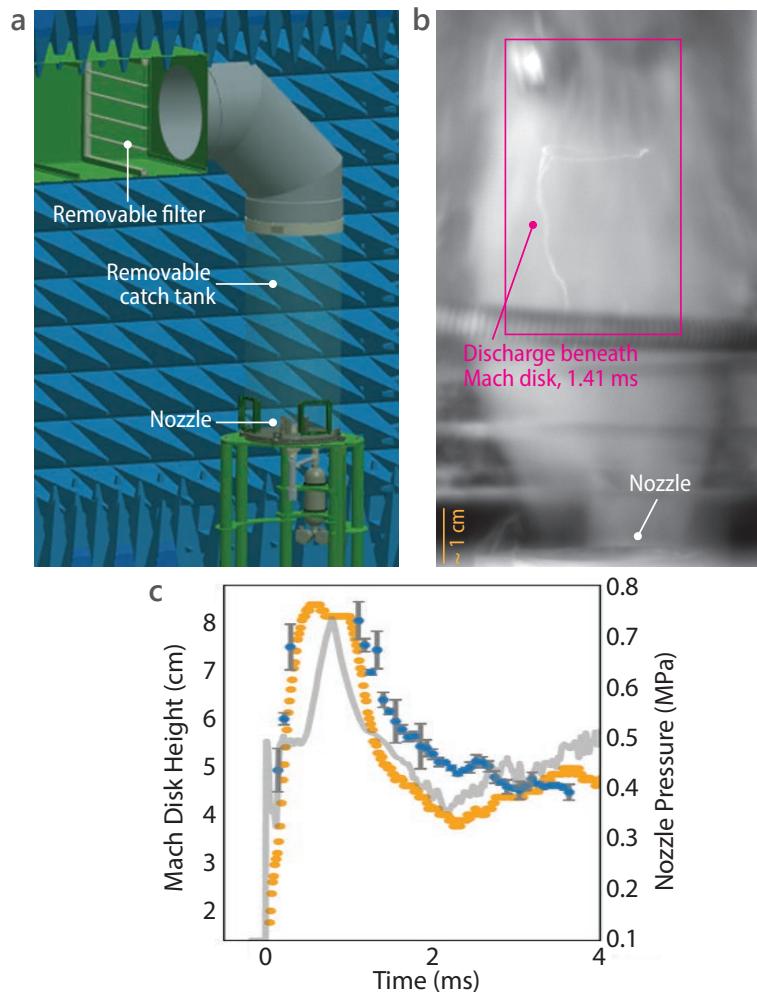




We are motivated by the need for consistent access to a stand-alone shock

tube system in a dedicated anechoic chamber and a desire to understand the contributions that detonation soot makes to RF and optical signatures. We are particularly focused on reducing contamination from previously released particulates in the anechoic chamber and shock tube itself. This focus has led us to devise mechanisms for simpler cleaning between shots; we are also proposing in-nozzle detonation soot delivery systems that will position small sample quantities above the nozzle/vent, rather than below the rupture disk. The latter will also reduce particulate-to-wall interactions. A new nozzle design was selected, and diagnostic improvements were made in preparation for FY 2021 tests. To improve analysis of RF and optical shock tube data, MATLAB code was written and used to analyze previously collected data. This analysis supported Lawrence Livermore National Laboratory models of hydrodynamic and electrostatic behavior of particulates in shock waves.

Mission Impact: Models are required for improved discrimination of signatures associated with hydrodynamic tests related to weapons development vs. other types of high-explosive test activities. Field experiments do not allow



(a) STOA design in anechoic chamber (ducting to exterior not shown). (b) Image of ring-shaped and vertical discharge constrained by standing shock wave (Mach disk). (c) Mach disk height above nozzle in experiment (blue) vs. Lawrence Livermore National Laboratory simulation (yellow-orange), and nozzle pressure (gray).

for direct viewing of aspects of shock-contained particulate clouds, are costly, and separation of innumerate variables from observed signatures is difficult. This work provides a lab-scale platform, diagnostics, and software to reproduce, record, and allow for analysis of essential hydrodynamic and electrostatic phenomena. It will improve insight into, and provide direct validation of, shock phenomena models associated with high-explosive

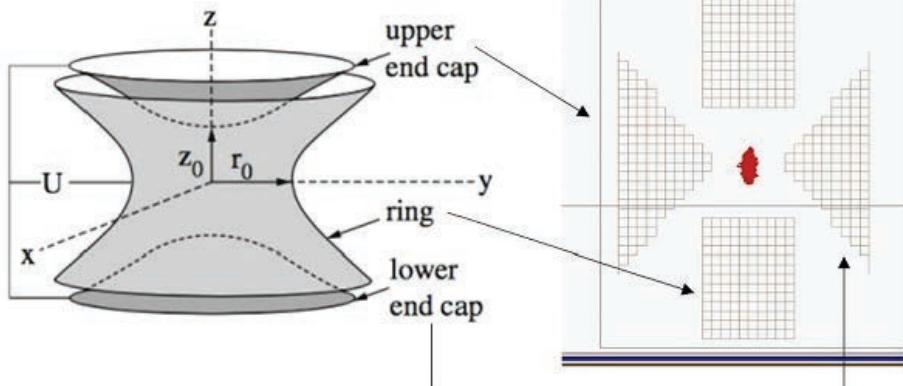
tests. FY 2021 controlled tests with carbonaceous detonation soots will help to further identify and validate underlying physics mechanisms associated with electromagnetic emissions and particulate generation. This project will also provide a platform for fine-tuning high-explosive field diagnostics so that correlated optical signatures, higher frequency emissions, and electric field might be measured in the field.

Micro-Ion Traps for Real-Time Chemical Analysis in Harsh Environments, M. Manard (STL-002-20, 3-year project)

This project will design, build, and test a proof-of-concept prototype utilizing small Paul-type (radio-frequency field) ion traps that will provide mass spectral analysis of chemical species to be used specifically for making measurements remotely in harsh environments.



a



(a) A schematic representation of a Paul-type ion trap. (b) A Simion 8 simulation showing a 2D cross section of ion confinement in a micro-ion trap. Here, $z_0 = 200 \mu\text{m}$, $P = 20 \text{ Torr}$, and the RF frequency = 50 MHz. The red trace at the center of the trap is the motion of ion cloud inside the trap.

Our goal is to design, build, and test a proof-of-concept prototype using Paul-type (RF field) ion traps that have trapping regions measuring hundreds of microns to provide mass spectral analysis of chemical species in the field. The unit is being designed for remote operation in harsh environments, such as on unmanned aircraft systems (UASs). Thus, the system is being designed to meet the weight and power operational requirements

of small quadcopter platforms that have been used as part of several previous UAS/chemical sensing tests. A maximum weight of 750 g and power draw less than 3 W are two specifications. We will also attempt to exceed the sensitivity of the nonspecific, real-time chemical sensors previously flown on UASs; thus, a sensitivity of less than 1 ppm is targeted.

Ion trajectory simulations (Simion 8) were performed. These simulations are used to theoretically determine

applied to the ring electrode. This result is consistent with observations

made as part of our previous efforts and with those reported in the literature, which indicate the RF frequency must increase as the trap volume decreases. 50 MHz is a reasonable requirement and renders trap size reduction feasible. RF amplitudes required to confine ions in a micro-trap are similar to those applied to a standard trap (100–400 VP). Simulations also indicate that trapping can be performed at elevated pressures of up to 20 Torr (figure (b)). Operating in this pressure regime provides the benefit of greatly reducing the system's vacuum requirements. The simulation was experimentally verified using an existing laboratory instrument that contains an ion trap with a z_0 equal to 2 cm and an applied RF frequency of 1.33 MHz. Although the pre-existing device is larger than the trap modeled in the simulation, the experiment confirms that trapping at a pressure of 20 Torr is possible. In FY 2021 we will use the knowledge acquired from these simulations and initial experimentation to begin building and testing a prototype system.



the feasibility of confining ions on a submillimeter size scale and the parameters this would require. Accordingly, the simulations suggested efficient ion confinement can be obtained for trapping regions measuring 200 μm from the center of the trap to either end cap (z_0 as defined in the figure (a)). In order to maintain trapping efficiency at these sizes, an RF frequency of approximately 50 MHz must be

Mission Impact:

The development of small, field-portable systems for chemical detection and identification is of interest to



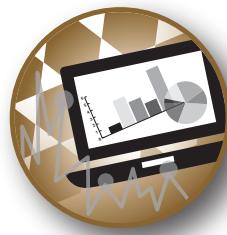
multiple government agencies. In particular, inexpensive instruments capable of providing real-time chemical analysis with reasonable sensitivity and selectivity

in remote and/or harsh environments, such as on a UAS, are desired. A device capable of providing analytical specificity in the field and transmitting the data back to the operator would be a significant improvement for certain operational scenarios. Onboard data processing with wireless communication

capabilities would allow the system to be used in hazardous conditions where chemical analysis is required. Additionally, a design concept that relies on low-cost components would potentially make it disposable in situations where the system could not be recovered.

■ Computational and Information Science

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 2020 two projects in this R&D area are making significant contributions as SOR projects (one is featured below) focused on seismic response and node-level processing of sensor data from distributed networks.

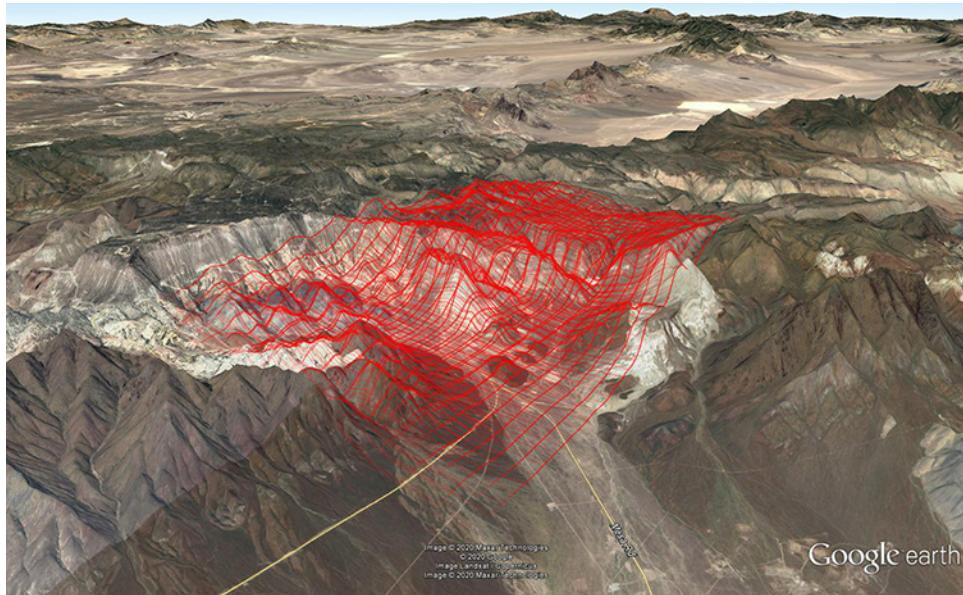


Enhancing Deep Cavity Detection Using Orthogonal Measurement Techniques, C. Zeiler (NLV-030-20, 3-year SOR project)

This research is integrating the orthogonal measurement of airborne thermal imaging and seismic surveying to improve the sensitivity of thermal inertia mapping of the surface above an underground facility.



The ability to detect and characterize an underground facility is a critical gap in our national capability. Modern mining techniques can reduce key signatures of tunneling, and only shallow tunneling has been effectively detected and characterized. To go deeper we need to merge the capabilities of multiple measurement techniques. In this project we are using geophysical parameters to enhance a heat flow model that



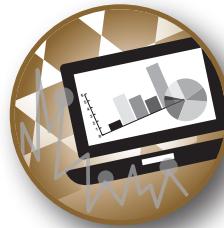
Area 12 photo footprints of 846 frames collected at 80% forward and side overlap for processing of a high-resolution terrain surface model. Image data were collected September 15 and 16, 2020, from an altitude of 4440 feet above ground level, resulting in an image pixel size of 12.5 cm (5 inches).

predicts times when the surficial thermal signature of a tunnel has the highest contrast with the host material. Supplementing surface temperature simulations with geophysical parameters obtained independently will enable better-targeted thermal imaging to detect and characterize underground facilities.

The primary focus of our research in FY 2020 was to demonstrate the feasibility of detecting deep tunnels embedded in bedrock using thermal imaging through a generalized heat flow model of reasonably representative site characteristics. A basic 1D model (advanced to basic 2D and 3D subsurface geometries in MATLAB) that solves the surface heat balance and subsurface heat flow established that the proposed testbed could be used to test the utility of thermal imaging in detecting the presence of subsurface voids. Portions of the existing and planned tunnel complexes are predicted to be detectable with current thermal imaging technologies. A photo survey of Area 12 was conducted to develop a digital surface model of the terrain (see figure). In FY 2021 we will increase the complexity of the model to include three dimensions, the actual surface elevation, construction drawings and plans, the geologic framework model defining geologic composition and structure in three dimensions, thermal characteristics of the host geology, and local weather, radiance, and ground temperature data collected over an annual cycle.

Mission Impact: A capability of remote measurements that enables the characterization of underground structures with reliable estimates of size and scope is needed to meet national requirements. The recent event in North Korean nuclear test facilities highlights that no conclusive evidence was shown to characterize the structural condition of the underground facility, other than that the entrances to the facility were dismantled. This research directly supports the Office of Defense Nuclear Nonproliferation (DNN) mission in "Remote Detection of Underground Facilities" and leverages the testbed development of which DNN has invested.

4-D Aggregate Deconvolution for Aerial Measurements, A. Guild-Bingham (RSLN-026-20, 2-year project)



We are inverting geospatial-radiological data from aerial measurements in aggregate in order to produce an estimate of ground deposition patterns directly through application of first principle physics.



Current ways of obtaining radiological data using the Aerial Measuring System (AMS) are significantly limiting in that they operate pointwise on data and rely on simple exponential fits to project the signal to the ground. These correlation coefficients are empirically determined. Despite being reliably accurate, they underutilize the available spectral data and ignore the large amount of correlation present between nearby measurements. These methods derive considerably less information from the measurements than what is theoretically possible and require extensive empirical calibration.

We implemented a prototype application capable of estimating isotopic concentrations directly from aerial radiological measurements applied to a single energy group or detector channel. Several variants of a deconvolution algorithm were applied and tested for both gross count data and isotopic extraction data derived from aerial measurement.

The deconvolution approaches were first developed for image reconstruction. However, our approach replaced the standard image processing point spread function with a model derived from an analytical gamma radiation transport and Monte Carlo detector response functions. The methodology can easily be adapted to include higher-fidelity transport models from codes like RadDetect (developed by the Remote Sensing Laboratory) or national laboratory-developed tools like MCNP and GADRAS.

Deconvolution of a radiation transport problem can be quite computationally expensive. For example, a simple aerial survey consisting of 250 km



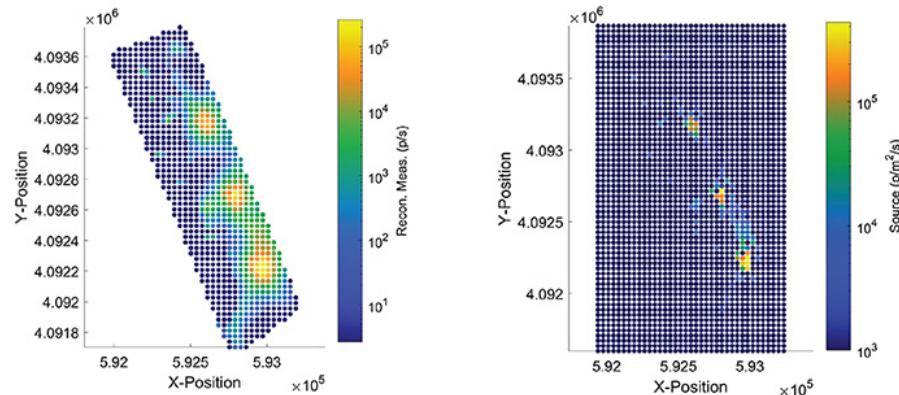
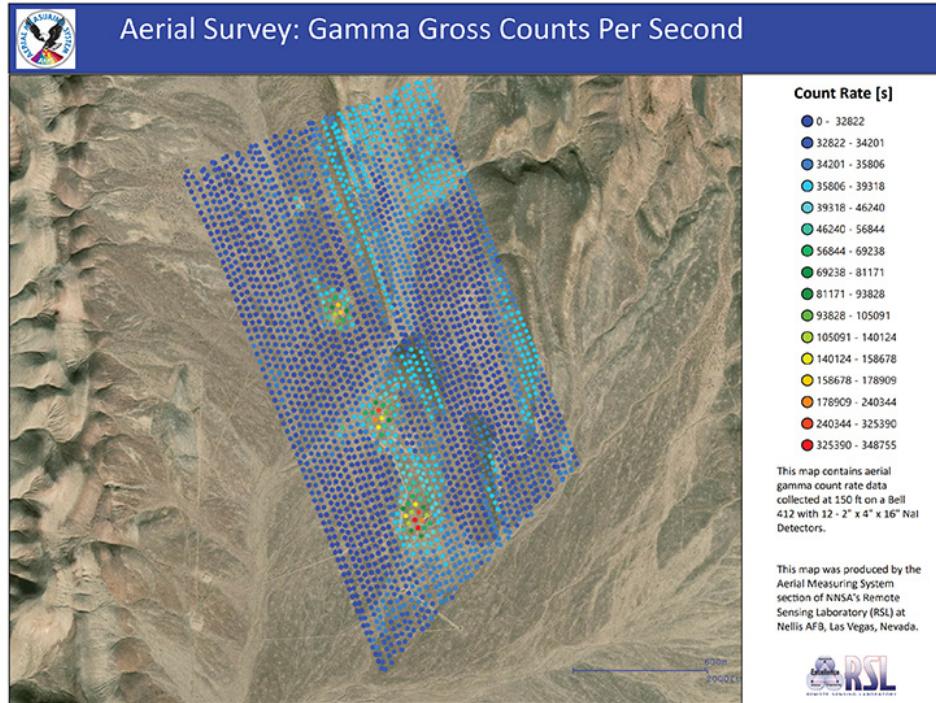
would yield 10^4 measurements. A discretized interpolated mesh of these measurements might result in 10^6 cells and 10^3 energy bins per spectra.

Deconvolution may require 10^3 to 10^8 iterations to converge, resulting in $>10^{22}$ floating point operation. Therefore, dimensionality reduction methods and acceleration techniques are crucial to successful implementation on a personal computer.

Initial investigation in spatial domain decomposition, energy domain decomposition, and GPU acceleration began this year and will continue in FY 2021 with the goal of reducing the spectral deconvolution algorithm to a calculation solvable by a desktop computer.

Mission Impact:

Aerial detection is the primary tool for rapid characterization of large-scale radiological releases and is vital to the accurate and timely scene characterization that is required to inform public health and safety actions. Improvements to processing aerial data and alleviating the requirement for empirical correction could prove instrumental in aiding public health and safety decisions in a nuclear/radiological release emergency.



(top) Aerial measurement with deconvolution solution for (bottom left) ^{241}Am at Area 11 on the NNSS. (bottom right) The estimate of ground concentrations is based on a detector response function model in RadDetect 1.2.

Photonics

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 NNSA, 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.

High-Energy Neutron Production in a Laser-Generated High-Density Plasma, J. Tinsley (STL-012-20, 2-year project)

We will demonstrate a short-pulse neutron source that produces high-energy neutrons with high flux using a novel approach that will lead to more compact neutron sources operating at a much higher repetition rate and neutron average fluxes.



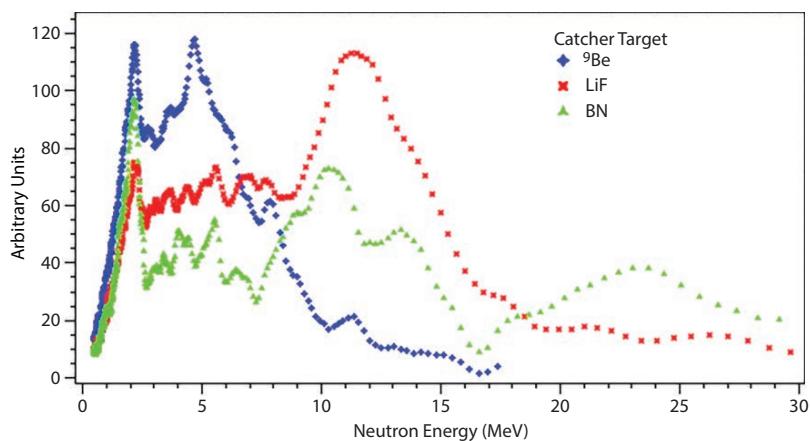
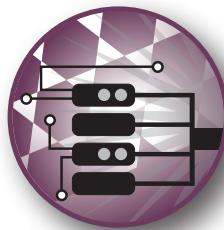
Earlier, we teamed with Colorado State University to generate a high-energy deuterium plasma that generates deuterium-deuterium (DD) (2.45 MeV) neutrons (Tinsley 2018). The laser intensity is now such that the deuteron emission is focused in a tight beam along the axis of

the target nanowires. This beam can be directed on a secondary target whose interaction with the energetic deuterons produces neutrons with energies from 10 to 15 MeV, which is near the energy of neutrons generated by the deuterium-tritium (DT) generators (14.1 MeV) that are coming online in the complex.

In FY 2020, we demonstrated that this so-called pitcher-catcher target scheme can incorporate our novel nanowire laser targets to generate a useful neutron flux in the target energy range (see figure). With a lithium fluoride (LiF) secondary target,

measured a significant neutron flux at energies between 20 and 26 MeV, although at a lower intensity. In FY 2021, we plan to use improved diagnostics and better optimized target geometries to optimize the neutron flux generated. In addition, modifications to the laser end station will be tested toward this end.

Mission Impact: This project addresses the need for the testing and calibration of neutron detectors and imagers



Compilations of energy spectra on three different "catcher" targets. Each spectrum is comprised of a number of laser shots on the same target to average out statistical variations. The peaks at about 2.4 MeV are the result of DD fusions that take place in the deuterated polyethylene (CD₂) nanowire target itself. The vertical scales have been adjusted to fit on the same plot.

we have measured an average of $\sim 5.5 \times 10^6$ neutrons/steradian; this corresponds to $\sim 7 \times 10^7$ neutrons into 4π . We have also taken data using beryllium (⁹Be) and boron nitride (BN) catcher targets. Using the latter, we have

for subcritical experiments, for high energy density physics experiments at facilities such as the Sandia Z machine and the National Ignition Facility, and for threat reduction applications. The end product of this project

is a blueprint for a neutron source that has lower infrastructure costs than present sources and which can be used to develop, test, and calibrate neutron detectors and diagnostics. This will enable users to have better access, and at a lower cost, to a neutron diagnostic source than is currently available. This benefits users throughout the national security complex.

Reference

Tinsley, J., A. Curtis, J. Rocca. 2018. "Laser-generated ultra-high-energy-density plasma for fast neutron pulse production and neutron diagnostic development." In *FY 2017 Site-Directed Research and Development Annual Report*, 213–218. Las Vegas, Nevada: Mission Support and Test Services, LLC.

■ PROGRAM VALUE

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

■ SDRD Program Performance Metrics

Invention Disclosures and Patents

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

	FY16	FY17	FY18	FY19	FY20
Number of projects	27	30	28	28	29
Invention disclosures and patents	5	4	2	4	4
	19%	13%	7%	14%	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. 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.

	FY16	FY17	FY18	FY19	FY20
Number of projects	27	30	28	28	29
Technology adopted by programs	5	4	2	11	9
	19%	13%	7%	39%	31%

Technology Needs Addressed

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

	FY16	FY17	FY18	FY19	FY20
Number of projects	27	30	28	28	29
Gap or need addressed	10	13	11	14	12
	37%	43%	39%	50%	41%
"Emerging Area and Special Opportunity" effort*	3	5	6	3	6
	19%	13%	7%	39%	21%

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

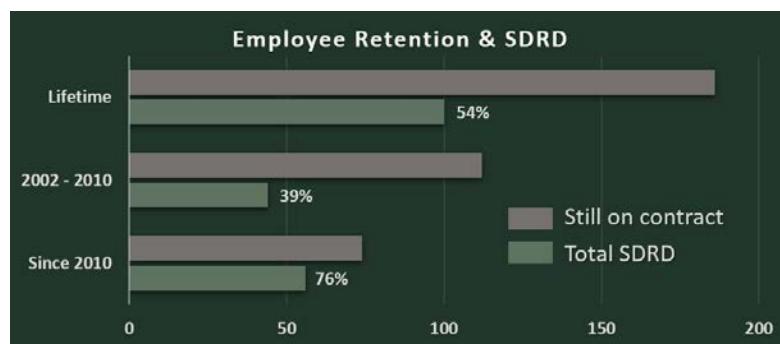
Publications

Publications are another indicator of R&D output and provide an archival record of the investments made, which are then available to the broader scientific and technical community. We place a strong emphasis on high-quality, high-impact journal publications and were very pleased to see a significant increase in this area in FY 2020.

	FY16	FY17	FY18	FY19	FY20
Journal publications	7	8	8	10	24

Postdocs and Interns

The SDRD program welcomed its first postdoctoral PI in 2015. Since then it has attracted numerous postdocs and interns. The contribution of these early-career scientists is significant. The program continues to enjoy the contributions of this group, having converting most to full-time staff. Since 2010, 76% of staff who participated in the SDRD program remain in the workforce, and from 2002 until the present 54% have been retained.



■ Leveraging R&D: The Long-Term Impact of the SDRD Program

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

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

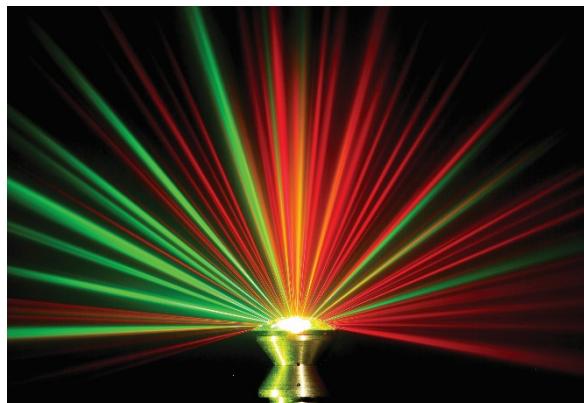


Multiplexed Photonic Doppler Velocimetry

The SDRD program began investigating multiplexed photonic Doppler velocimetry (MPDV) concepts in FY 2010. When this investigation began, its scope was limited, focusing simply on finding "a better way to do optical velocimetry." That initial effort quickly expanded, however, and soon an accelerated effort to develop MPDV into a key enabling technology for future stockpile stewardship experiments began.

A team of NNSS scientists, in collaboration with researchers from Lawrence Livermore National Laboratory (LLNL) and Los Alamos National Laboratory (LANL), set out to address the challenge of developing a better, faster, and more economical way to gather a large amount of detailed data on the reliability of the U.S. nuclear weapons stockpile without nuclear explosion testing.

By the time FY 2011 ended, the MPDV development team had built a demonstration system and completed proof-of-concept experiments. In 2012, the Gen-1 MPDV system was completed and fielded on the Gemini experimental series at U1a at NNSS. The 128-channel Gen-1 MPDV system allowed researchers to collect more high-fidelity data from a single integrated experiment than all of the previous comparable experiments combined, and the resulting data from these experiments have changed the way the nuclear weapons community views large-scale experiments within the science-based stockpile stewardship strategy.



An advanced fisheye optical probe, developed under programmatic funding, was used with MPDV for dynamic material experiments. Innovative probe designs developed by NNSS engineers have contributed significantly to the success of MPDV.



The MPDV development, assembly, and fielding team photographed with the 128-channel Gen-1 MPDV system fielded on the Gemini experimental series (circa February 2012). The MPDV system won a 2012 R&D 100 award.



The achievements attained by the MPDV development team led to several awards, including an R&D 100 award in 2012.

The technology grew and capability expanded rapidly due to significant programmatic efforts that followed. The Gen-2 MPDV system was developed in 2013 and was fielded at the Dual-Axis Radiographic Hydrodynamic Test (DARHT) facility at LANL as well as at Site 300 at LLNL. Efforts to improve the design and performance of MPDV systems and components continued, and in August 2014, the MPDV diagnostic was used on the Leda experiment at U1a. The Leda experiment was completed with 100 percent data return and paved the way for the follow-on experiment series, Lyra.

The Gen-3 MPDV system was fielded for the first time on Orpheus, the first experiment in the Lyra series executed in September 2015 at U1a; the

resulting data showed a large increase in signal-to-noise ratio over the Gen-1 system fielded on the Gemini series. The system was also fielded on the remaining experiments in the Lyra series, Eurydice and Vega, which took place at U1a in March and December 2017, respectively. These experiments demonstrated the MPDV's capability to gather shock physics data in unprecedented detail.

The innovation and development of MPDV has provided experimenters with a powerful diagnostic tool that is capable of collecting data crucial to furthering our understanding of weapons physics and advancing the science-based Stockpile Stewardship Program. The MPDV has brought about a paradigm shift in shock physics diagnostics, and the MPDV technology will continue to play an important role in upcoming and future stockpile science experiments.

Broadband Laser Ranging

Broadband laser ranging (BLR), another key optical diagnostic for current and future stockpile stewardship experiments, also has its roots in the SDRD program. BLR measures the precise position of a rapidly moving surface, and it is complementary to PDV because PDV data do not always yield complete information about the material position. Independent position measurements made with BLR complement velocity data from PDV. BLR is also compatible with PDV in that BLR and PDV can be fielded together and share the same probes pointed at the same target.

The work began as a one-year feasibility study in spring 2014 when scientists at NNSS Special Technologies Laboratory began investigating a BLR technique for use in an optical distance measurement system for dynamic experiments. By summer 2014, they had finished building a prototype BLR system and began fielding it on small-scale experiments. The study yielded encouraging results.

As a result, in 2015, a

BLR R&D team consisting of researchers from NNSS, LLNL, LANL, and Sandia was formed and began designing and building a BLR system suitable for larger-scale experiments.

In December 2015, a 2-channel BLR diagnostic system built jointly by NNSS and LLNL scientists was successfully fielded on a hydrodynamic test at LLNL Site 300. In 2016, a LANL-built BLR system and an NNSS-built BLR system were fielded on the Silverleaf

experiments, a series of four experiments conducted at LANL in preparation for the Nightshade experimental series of the Red Sage campaign at U1a. The



The first BLR prototype system ever fielded on a dynamic experiment, with PI Brandon La Lone (NNSS)



The 48-point BLR system installed at LLNL's Site 300. Pictured from left to right: Daniel Perry (LLNL), Vu Tran (NNSS), and Corey Bennett (LLNL).

to obtain orders of magnitude more distance measurements than was possible with traditional electrical pins.

In 2020, a 16-point BLR system was fielded on the Red Sage campaign experimental series at U1a and on the 3687 experiment at the DARHT facility. More recently a 48-point BLR system was installed at Site 300 at LLNL (see figure). We anticipate that BLR systems will continue to grow and expand, playing an increasingly important role as one of the main diagnostic tools for stockpile science research.

SDRD

Programmatic

■ Growing SDRD: Facing future challenges with innovation

As the SDRD program emerges from a challenging year of limitations and restrictions imposed by the world-wide pandemic, SDRD is positioned for a stimulating future.



Howard Bender III
SDRD Program Manager
Nevada National Security Site

In FY 2020, the SDRD program began to transition, looking further into the future than it has since its beginning in 2002, as it incorporates the nascent NNSS Centers of Excellence.

As the Centers of Excellence quickly mature, our principal investigators and their teams will be challenged to take on strategic initiatives in focused areas that are the foundations of future technologies, the technologies of decades to come. This calculated leap forward is propelling the program into an exciting new era and next level of innovation and expansion that will benefit all facets of our national security mission.

April 2021

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 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 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.

FY 2020 SDRD Projects

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

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

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

Advanced High-Performance Computational Modeling of the Seismic Response of High-Hazard and/or Nuclear Facilities and Critical Infrastructure at the NNSS, C. Zeiler (NLV-015-19)

Cognitive Hybrid Radio Waveforms for High-Reliability, Secure Wireless Communications, S. Koppenjan (STL-013-19)

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

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

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

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

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

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

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

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

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

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

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

Improvised Chemical Device Source Term Determinations (ICD-STD), J. Di Benedetto (STL-038-18), unpublished summary

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

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

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

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

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

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

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

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

Strategic Studies in Dynamic Material Response of Weapons-Relevant Materials, S. Thomas (LAO-015-18)

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

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

Wrap Around PDV for Measuring the Impactor Velocity History in High-Hazard Plate Impact Experiments, B. La Lone (STL-037-20)

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

