NUCLEAR NONPROLIFERATION AND SECURITY

GLOBAL SECURITY DIRECTORATE

ANNUAL HIGHLIGHTS REPORT | 2020

Los Alamos NATIONAL LABORATORY

DETECT | PREVENT | SECURE | PARTNER | ENGAGE

The **Nuclear Nonproliferation and Security Program Office** within the Global Security Directorate (GS-NNS) at Los Alamos National Laboratory supports the Lab's mission of preventing efforts of proliferants to acquire, develop, or disseminate materials, technologies, equipment, and expertise necessary for nuclear weapons and improving nuclear and radiological security.

Our portfolio includes research and development, deployment activities, and policy support, primarily for the National Nuclear Security Administration's (NNSA) Defense Nuclear Nonproliferation (DNN or NA-20) office. NNS sponsors also include the U.S. Department of State and National Aeronautics and Space Administration (NASA).

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PROGRAM DIRECTORS

NINA ROSENBERG
PROGRAM DIRECTOR

"The COVID pandemic made 2020 a very challenging year. Through pivots to virtual engagements and rethinking how to conduct field campaigns, our staff's incredible dedication and creativity allowed us to accomplish more to support our national security mission than we could have imagined."

BOB SHIREY
DEPUTY PROGRAM DIRECTOR
PROGRAM MANAGER | NONPROLIFERATION R&D

"Los Alamos continues to bring a range of technical expertise, weapons knowledge, and operational capabilities to our nuclear nonproliferation and nuclear security missions. We appreciate the support and flexibilty from our NNSA sponsors and many partners for making this work possible even during a challenging year."

OFFICE TEAM

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RECOVERY PROGRAM

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NUCLEAR SMUGGLING
DETECTION AND DETERRENCE

LISA DANIELSON
NASA DISCOVERY SCIENCE
AND NEW MISSIONS

Los Alamos National Laboratory's mission is to solve national security challenges through scientific excellence.

OVERVIEW

In 2020, work for the National Nuclear Security Administration's (NNSA) Defense Nuclear Nonproliferation (DNN or NA-20) office made up 80 percent of Los Alamos National Laboratory's Global Security Nuclear Nonproliferation and Security programs portfolio. The majority of our work is aligned with DNN's mission.

NONPROLIFERATION RESEARCH & DEVELOPMENT

We conduct a broad set of research and development activities supporting nuclear proliferation detection and ground-based nuclear detonation and test detection. (For space-based detection efforts, see the Space Systems and Science section.)

- Our work in **proliferation detection** includes the development of new technical capabilities to detect and characterize foreign nuclear material production and weapons development activities, often utilizing unique testbeds and facilities in Los Alamos, Nevada, and across the complex. In July 2020, the Los Alamos-led multi-Lab Persistent DyNAMICS remote detection project had a great success in demonstrating its initial operating capability using Oak Ridge National Laboratory's (ORNL) High Flux Isotope Reactor (HFIR) as a testbed.
- As part of **nuclear detonation and test detection R&D**, Los Alamos successfully conducted eight chemical explosive tests at NNSS as part of the Multi-Domain Experiment (MDE) and the Large Surface Explosion Coupling Experiment (LSECE). These efforts, combined with ongoing modeling and analysis activities, advance U.S. capabilities for improved detection and measurement of nuclear tests.

GLOBAL MATERIAL SECURITY

- For the **Off-Site Source Recovery Program** (OSRP), Los Alamos recovers domestic transuranic and large beta and gamma sources that do not have a commercial disposal pathway. In 2020, we made significant progress in developing OSRP's Type B container operations capability. LANL's first-ever 380-B container was received at the Laboratory's facility in Carlsbad, NM, in January and a new 435-B container was received in early April.
- For the **Nuclear Smuggling Detection and Deterrence** (NSDD) program, we provide technical support for the installation and maintenance of radiation detection systems at sites all over the world, as well as support testing and evaluation of new detection equipment and techniques. In 2020, we used virtual technology to continue to make progress in this important work.
- We work with the NNSA Office of Global Material Security to improve the **security of nuclear material** globally. In February 2020, Los Alamos international nuclear security team presented on their work in emerging technologies, Nuclear Material Accounting and Control training, and counter-unmanned aerial systems (C-UAS) technologies implementation at the International Atomic Energy Agency (IAEA) International Conference on Nuclear Security: Sustaining and Strengthening Efforts, in Vienna, Austria.

NONPROLIFERATION & INTERNATIONAL ENGAGEMENT

We provide leadership and technical expertise in support of U.S. efforts to strengthen international nuclear nonproliferation and arms control.

- Under Los Alamos **international nuclear safeguards** programs, last year marked the completion of a major 10-year **Spent Fuel Nondestructive Assay (NDA)** project, which has made important contributions to the long-standing technical problem in the safeguarding of nuclear material. Also, Los Alamos teams successfully transferred several safeguards technologies to our international partners, an important way the Laboratory contributes to advancing global nonproliferation goals. In addition, we successfully pivoted to virtual engagements with the IAEA through our participation in a wide range of virtual consultancy meetings, workshops, and technical exchanges.
- We continue to work to limit the spread of sensitive materials, equipment, and technologies through DOE/NNSA-led **collaborations with international partners** to build and maintain national export control systems through training and workshops, all held virtually after mid-March 2020 due to the COVID-19 pandemic.
- As part of Los Alamos' activities in support of the NNSA Office of **Nuclear Verification**, the Laboratory together with LLNL and SNL, also delivered data to the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) Preparatory Commission to support the Regional Seismic Travel Time (RSTT) model.

MATERIAL MANAGEMENT & MINIMIZATION

We support DNN's mission to minimize and, where possible, eliminate nuclear materials.

- In the Convert Program, we continued our work on the **molybdenum-99 (Mo-99)** program to encourage the establishment of Mo-99 production without highly enriched uranium (HEU) in the United States. Laboratory researchers currently support three commercial partners: Niowave, NorthStar Medical RadioIsotopes and SHINE Medical Technologies. We also continued our efforts in **reactor conversion** by developing methods to fabricate alternative fuels that use low-enriched uranium (LEU) for several U.S. research reactors.
- The **Advanced Recovery and Integrated Extraction System (ARIES)** program is an excellent example of Los Alamos' Weapons and Global Security programs working together to achieve important nuclear security mission goals. This program is helping the nation meet its nonproliferation commitments by preparing surplus weapons-grade plutonium for final disposition. In early FY20, the program completed production of 1 metric ton of plutonium oxide. This significant achievement was recognized in a January 2020 commemoration ceremony, attended by senior DNN and Los Alamos leadership.

SPACE SYSTEMS & SCIENCE

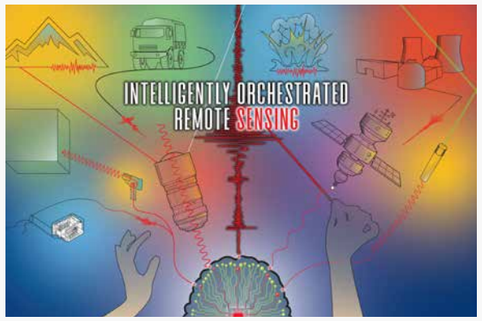
In late 2020 a new Space Systems and Science program organization was formed in an effort to improve integration and coordination of space-related research and development at Los Alamos across different GS-NNS sponsors.

- The major NNSA-sponsored activity is our ongoing support for the nation's **space-based nuclear detonation detection** capability. This year we supported the launch and activation of payloads on two new GPS satellites, and supported the integration and testing of two payloads with the Space Test Program Satellite Six (STPSat-6) and its ground systems.
- Los Alamos continued to have major roles in several current **NASA science missions**, and several more in development. This year saw the milestone launch of the Mars 2020 Perseverance rover mission, where Los Alamos is the lead institution for the SuperCam instrument and contributed to the SHERLOC instrument.
- Los Alamos also proved the ^{238}**Pu radioisotope** heat source units that power the Perseverance rover and we continue to advance the production and testing of radioisotope heater units to meet future national space needs.

NONPROLIFERATION RESEARCH & DEVELOPMENT

Our work in this area is funded by DNN R&D and includes the development of new technical capabilities to detect and characterize foreign nuclear material production and weapons development activities, often utilizing unique testbeds and facilities in Los Alamos and Nevada and in partnership with other national laboratories, as well as R&D for nuclear safeguards, emergency response, and research towards improved detection of underground nuclear tests and detonations.

PROLIFERATION DETECTION ENABLING TECHNOLOGIES



Los Alamos is leading the multi-Lab **Persistent Dynamic Nuclear Activity Monitoring through Intelligent Coordinated Sensing (Persistent DyNAMICS)** Venture project to develop improved methods for remote detection of nuclear proliferation activities. This project involves deployment of sensors and computing resources from several National Labs to be operated remotely in an integrated manner. In July 2020, this project had a great success in demonstrating the Initial Operating Capability of this system using ORNL's HFIR as a testbed.

We are also leading the **UFORCE** project, working with Lawrence Livermore National Laboratory (LLNL), Sandia National Laboratories (SNL), and the Nevada National Security Site (NNSS). The goal of this project is to develop capabilities to model proliferatio- relevant signatures in a variety of challenging environments. Los Alamos has demonstrated capabilities to model electromagnetic signals in complex environments and developed new capabilities for fast seismic modeling.

Los Alamos is working with several other National Labs on the **Multi-Informatics for Nuclear Operations Scenarios (MINOS)** Venture project, developing advanced analytic techniques to explore the potential to utilize disparate data sets from measurable phenomena associated with nuclear reactor and nuclear target processing facilities to characterize operations. The Los Alamos MINOS analytics team developed a Bayesian approach that treats a collection of sensors as a network rather than as independent measurement devices. They used their method, which provides uncertainty estimates naturally through its Bayesian framework, to estimate the location of moving radioactive sources around the HFIR and Radiochemical Engineering Development Center (REDC) at Oak Ridge National Laboratory. Because there is not enough information in the network of radiation detectors at HFIR and REDC to uniquely localize a dynamic source, many disparate source paths are equally consistent with the data. Their approach incorporates contextual constraints, such as limits on plausible movements, to rule out source paths and thus reduce the uncertainty in their estimates.

We are also working with several other National Labs to develop capabilities for the **Advanced Data Analytics for Proliferation Detection (ADAPD)** Venture project. The effort focuses on advancing the state of the art in proliferation-relevant physics-informed machine learning, process-informed machine learning, and integration of multi-phenomenology and multi-formalism modeling approaches. In 2020 ADAPD (1) demonstrated that machine-learned and human-interpretable seismic features from one explosives test can be used to detect specific activities at another test, (2) demonstrated interval-graph-based fusion of arbitrary combinations of hard and soft observables to create complex composite signatures of activities otherwise undetectable, and (3) developed forward models of the explosives testing process, including possibly-confounding alternate hypotheses, and validated against activities at NNSS.

Los Alamos recently kicked off the new project **CRASHPAD: Curating, Refining, And Synthesizing Heterogeneous Proliferation Activity Data**. This project will establish the first community-wide "data set as a testbed" for nonproliferation R&D. Through the combination of disparate data streams (e.g., remote sensing, social media, written reports), this community data set will enable cutting-edge patterns-of-life research that includes rapid and flexible prototyping, robust data fusion, and discovery of new proliferation signatures.

Los Alamos is working with Lawrence Berkeley National Laboratory (LBNL) and ORNL on the **Radiological Anomaly Detection And Identification (RADAI)** project, developing and assessing advanced radiological detection algorithms using a constructed comprehensive canonical data set. The improvements to the data simulator (Modeling Urban Scenarios and Experiment – MUSE) are focused on incorporation of details such as variable detector speeds, weather (radon), cosmic rays, a larger source catalog, and longer more flexible temporal segments that will enable algorithm benchmarking under more realistic conditions. This project leverages the ground-breaking work of the "Developing and Analyzing Competitions for the Office of Proliferation Detection" project led by Los Alamos in 2018-2020. The Los Alamos statistics team is working with the radiation experts to use adapted and innovative design of experiment methods to facilitate the canonical data set capable of comprehensive multiple criterion evaluation of new algorithms with quantitative comparisons to existing baselines. The large data set will seek to balance manageable size with the ability to explore and characterize the high dimensional input space under which the algorithms will be asked to demonstrate performance.

Initial QD-loaded composites show the material under room light (top), and a black light (bottom).

Los Alamos researchers, in collaboration with researchers from the United Kingdom, are seeking to improve performance of radiation detectors by doping traditional scintillating plastics with visible-light emissive **QDs (quantum dots)**. QDs are unique materials that down-convert electromagnetic radiation in a predictable manner that is highly dependent on the QD size. The team has successfully fabricated a QD-loaded plastic scintillator that emits red light upon exposure to a radioactive source (and ultraviolet light for testing). While these results are still preliminary, they suggest a new avenue to the next-generation scintillating radiation detectors.

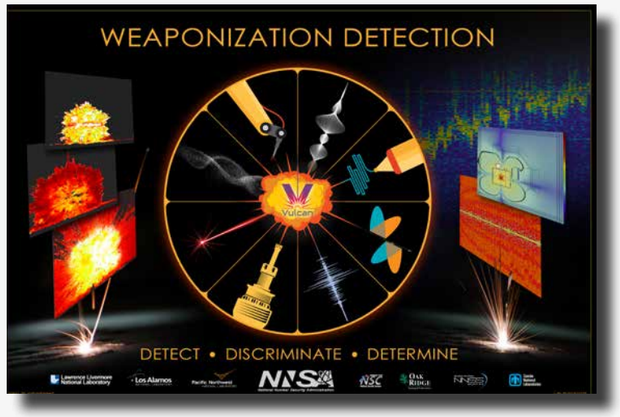
MATERIAL PRODUCTION DETECTION & MONITORING

Los Alamos works with several other National Labs on a project to enhance detection and characterization of undeclared irradiation activities. The **Reactor Venture** project seeks to measure the isotopic and elemental compositions of small samples, and using data analytic techniques and high-fidelity reactor modeling, correlate the results back to parameters of interest in the system. One of the goals of research in FY20 was to relate measurements at different positions within a pressurized water reactor (PWR) BR3 fuel rod obtained from Belgium to both expected results based upon gamma scans of the rod and/or simulated results for the core. Both the newly developed microchemistry technique for measuring small samples with ICP-MS techniques and the in situ method Secondary Ion Mass Spectrometry (SIMS) measured 10 x 10 x 10 µm cubes from focused ion beam (FIB) samples cut by Idaho National Laboratory (INL).

Los Alamos has developed a unique signature analysis capability called **Los Alamos Maximum Likelihood Pipeline (LAMP)**. LAMP models the underlying probability distribution of time series data more accurately than previous methods, enabling robust detection at a constant false alarm rate (this is similar to having an uncertainty estimate). LAMP has been deployed next to the sensor, for data reduction and real-time detection. It has also been deployed on high performance computing and cloud computing platforms to characterize signatures in large volume historical archives. Los Alamos recently released a significant update to the LAMP signal analysis capability. The update enables automated detection of several new families of signatures that can provide additional insight into activities within facilities. LAMP has been made available to other National Labs and government agencies and it continues to find new applications and use cases.

Our **Disparate Data Integration for Improved Safeguards Verification** project aims to develop automated methods and approaches for pattern-of-life analysis to support nuclear facility monitoring and verification for cooperative safeguards applications. Various machine-learning approaches are explored for automatically integrating disparate data streams representative of existing IAEA safeguards information. The project is using the Laboratory's Category 3 nuclear facility at TA-66 that serves as a safeguards training site as a testbed for implementation and exploration of multiple different data streams and deliberate scenarios mimicking long-term as well as abrupt diversion of nuclear material.

WEAPONS DEVELOPMENT DETECTION



Los Alamos along with several other National Labs contributed to the **Vulcan** Venture project that builds upon capabilities developed through prior ventures (**HERTZ** and **Helios**) to develop a science-based modeling capability for multi-phenomenological signatures of weapon manufacturing and high explosive (HE) detective testing. The team continued to develop capabilities in detection and characterization of weapon component manufacturing during focused experiments at Los Alamos' Sigma facility and will continue such experiments in 2021. The full capability will be demonstrated during a summer 2021 field campaign, also at Sigma. The team is also currently continuing to improve advanced multiphysics codes, particle transport and combustion codes, and electromagnetic propagation codes as well as design and manufacture test articles for high explosive tests at NNSS in the near future.

Los Alamos also started several new multi-laboratory projects. The first, **Multi-Phenomenological Signatures Characterization for Emerging High Explosive Hydrodynamic Tests (HEHT) Capabilities**, is a collaboration between Los Alamos, LLNL, Sandia, and NNSS to develop a multi-modal detection and characterization capability to monitor sub-critical and HEHT testing activities for nonproliferation research purposes. This project will develop and test new multi-modal diagnostics and analysis techniques in close cooperation with NNSA's Defense Programs. Targeted test and infrastructure development monitoring opportunities will be primarily located at NNSS. Similar to **Vulcan**, this project will continue to advance multiphysics and propagation codes. The second project, **Particulates for the Discrimination of Detonation Events**, is a collaboration with multiple National Labs to research the generation of particulate formation during detonation events to determine potential methods for discriminating signatures of HEHT from conventional munitions. Detonation and thermochemical models, hydrodynamic simulations, and combustion and phase models will be developed and validated to better track conditions that produce particulates at timescales useful for collection. Results from this project will also support other projects within the portfolio, and large-scale tests developed for programs such as **Vulcan** will be used to validate models developed.

UNIVERSITY CONSORTIA

Los Alamos is an active member of the three DNN-funded university consortia: the **Nuclear Science and Security Consortium (NSSC)**, the **Consortium for Monitoring and Treaty Verification (MTV)**, and the **Consortium for Enabling Technologies and Innovation (ETI)**. Despite the COVID-19 pandemic, members of the consortia and Laboratory points of contact showed incredible resiliency as we adapted to a virtual environment for interacting with students and faculty members and continued to develop new relationships.

In summer 2020, we conducted our fourth Keepin Nonproliferation Science Summer Program. This program gave 14 university consortia students representing nine different universities the opportunity to spend eight virtual weeks performing research and participating in lectures to provide broad exposure to the nonproliferation mission space.

Work at the National Criticality Experiments Research Center (NCERC) has resumed operations, and a measurement campaign involving multiple universities is in the planning stages for 2021.

EMERGENCY RESPONSE RESEARCH & DEVELOPMENT

Los Alamos supports the development and demonstration of advanced diagnostics for emergency response, as well as the underlying research on materials and HE behavior that allows for more accurate and timely information for emergency responders to nuclear incidents.

High Explosives Science Thermal Validation Test: Various stages of assembly and explosive dissasembly.

Los Alamos leads the **Emergency Response R&D High Explosives Science** Venture project. The project had a very productive year, addressing knowledge gaps in threat explosives by integrating the work of three national laboratories in identification, characterization, performance, and thermal and mechanical response. The explosives studied span a range of proportions of constituents, enabling the building of detailed models of the behavior of a class of explosives.

The **Materials Threat Science** Venture project seeks to understand the dynamic behavior of relevant materials. The team successfully integrated the work of four National Labs and four regimes of material characterization. Los Alamos used a combination of focused science experiments in order to develop material models, as well as providing material samples for experiments at other laboratories.

NUCLEAR FORENSICS RESEARCH & DEVELOPMENT

A highlight of the DNN R&D Forensics program is the development of six exciting new projects. This expansion reflects a new consensus within the Interagency that places primary responsibility for Forensics R&D within the NNSA with significantly increased investment.

Four new projects focus on problems in Pre-detonation Nuclear Forensics. Two of these projects are led by Los Alamos, including the flagship **Intentional Forensics Venture** and the multi-laboratory **Morphologic Signatures** project. The Intentional Forensics Venture project will pursue an integrated R&D program to design, implement, and test new concepts in intentionally-introduced taggants to identify nuclear materials that might be found outside of institutional control at any point during the nuclear fuel cycle. The Morphologic Signatures project will measure morphologic signatures and apply statistical modeling to infer provenance and recent history of unknown nuclear materials. In addition, Los Alamos is a participating laboratory in two key materials production and processing test beds: The **Uranium Test Bed** (ORNL) and the **Plutonium Test Bed** (Pacific Northwest National Laboratory, PNNL).

Two new projects focus on data assessments and on analytical operations supporting Post-detonation Nuclear Forensics. Los Alamos leads the new **Device Assessment** project in partnership with LLNL and SNL. This project aims to improve the sophistication and timeliness of post-detonation device assessments through design code and tool development, machine-learning techniques, and advanced statistical methods. An ambitious new effort called the **Rapid Response Research (R3) Venture** project has also been started. The primary goal of this Venture is to improve timeliness of forensic response. The Venture is organized along three technical thrusts including interpretation of fireball dynamics and chemistry, improvements in screening and triage analyses, and fixed-laboratory capabilities.

DETECTING AND CHARACTERIZING UNDERGROUND NUCLEAR TESTS AND DETONATIONS

In 2020, Los Alamos successfully conducted eight chemical explosive tests at NNSS as part of the Multi-Domain Experiment (MDE) and the Large Surface Explosion Coupling Experiment (LSECE).

Los Alamos, through multi-laboratory research collaborations, continues to develop the scientific understanding needed to address key challenges in confidently detecting and assessing underground nuclear tests, globally. The major focus of this research—largely through the **Low Yield Nuclear Monitoring (LYNM)** program—is advancing predictive, physics-based models of detonation signatures that track radiative (e.g., seismic, acoustic, and electromagnetic) and material (i.e., radionuclides) emissions from underground nuclear explosions from origin to the point of release, propagation, and potential detection. These end-to-end models are the basis for effective exploitation of multiple phenomenology signatures—e.g., through the **Ground-based Nuclear Detonation Detection (GNDD)** program—to increase detection sensitivity, decrease background false alarms, and reduce uncertainties in reporting assessments. An important aspect of this work is the validation of physical models against both historical underground nuclear tests and large-scale (non-nuclear) field experiments designed expressly for model validation.

The Bradbury Science Museum completed the installation of a new exhibit featuring Los Alamos research on ground-based nuclear explosion monitoring. Its grand opening in 2020 was postponed due to the pandemic and the Laboratory is eagerly anticipating a debut to the public in the near future.

The LYNM program continued to develop a large new experimental testbed at NNSS called **Physics Experiment 1 (PE1)**. The PE1 field campaign will consist of a series of chemical explosions in the vicinity of historic NNSS underground nuclear tests, observed by a suite of multi-physics sensors. Preliminary design of this testbed concluded in 2020, with Los Alamos leading in several areas including design, fielding, and operations of chemical HE and electromagnetic sources, and design of diagnostic sensors. The HE and sensor design maturation process included successful fielding and execution in partnership with Mission Support & Test Services (MSTS) of six surface HE tests at NNSS as part of the **Multi-Domain Experiment (MDE)** series. The MDE campaign also exercised a new triggering, timing, and firing capability as well as multi-physics sensors from several laboratories. In 2020 Los Alamos also successfully designed, fielded, and executed (with LLNL and MSTS) two additional surface HE tests as part of the Department of Defense (DoD)-supported **Large Surface Explosion Coupling Experiment (LSECE)** conducted near the site of the former Phase II **Source Physics Experiment (SPE).** The large team supporting SPE Phase II activities received a Los Alamos National Laboratory Distinguished Performance Award in 2020 for their 2019 accomplishments in executing the final experiments of the test series.

GLOBAL MATERIAL SECURITY

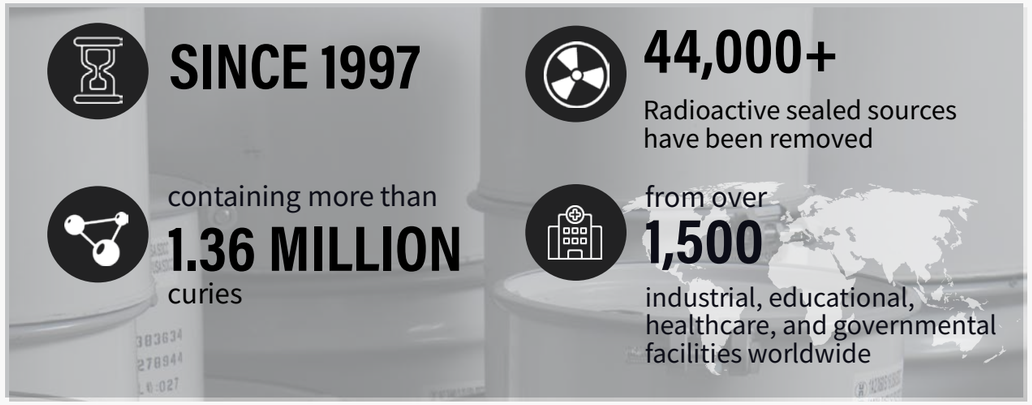
INTERNATIONAL NUCLEAR SECURITY

In 2020, Los Alamos participated in multiple virtual technical exchanges on **counter unmanned aerial systems (C-UAS)** with the Belgian Federal Agency for Nuclear Control. The audience for this exchange included representatives of the Belgian Federal Police and the Belgian National Crisis Center. Topics included U.S. and Belgian C-UAS polices, law enforcement interaction on C-UAS, and the experience using jamming/interference for C-UAS. Planning is underway for future virtual engagements.

We also partnered with Sandia to develop a nuclear security program to educate the next generation of nuclear security experts. These experts, once finished with the program, will be able to immediately contribute to the important mission of securing nuclear material and facilities both domestically and abroad. The development of these courses contributes to the larger curriculum, which will enable students to earn a graduate certificate/ Master's degree in Nuclear Security from University of New Mexico.

Los Alamos experts presented on several initiatives at the 2020 IAEA International Conference on Nuclear Security: Sustaining and Strengthening Efforts, in Vienna, Austria. Topics included emerging threats, nuclear material accountancy and control (NMAC) training, countering unmanned aerial systems, and radiological security.

OFF-SITE SOURCE RECOVERY PROGRAM



For the **Off-Site Source Recovery Program (OSRP)**, Los Alamos recovers domestic transuranic and large beta and gamma sources that do not have a commercial disposal pathway. In January 2020, the Laboratory's first-ever 380-B Type B container was received at Los Alamos' facility in Carlsbad, New Mexico. It was followed in April by a new 435-B container. These NNSA-owned Type B containers will be used to expand transportation options that do not require removing high-activity sources from the device shielding. This packaging method, termed "overpacking," provides for safer and more secure transportation of disused radioactive sources.

We also assist in the repatriation of U.S.-origin sources from other countries. For more than twenty years, we have worked to remove radioactive sealed sources from industrial, educational, healthcare, and government facilities worldwide. In FY20, despite the COVID-19 pandemic, Los Alamos OSRP recovered nearly 1,000 disused sealed radioactive sources within the U.S. and 158 sources from Mexico.

The Los Alamos OSRP team plays an important role in NNSA's efforts to encourage licensees to replace radiological devices with nonradioisotopic alternatives. The Cesium Irradiator Replacement Project (CIRP) is a cost-sharing program that assists qualified sites with the purchase price of a new nonradioisotopic device, and sponsors OSRP to remove the old cesium irradiator at no charge. This past year, we recovered nearly 40 irradiators in conjunction with CIRP.

During FY20, the Los Alamos OSRP team has collaborated closely with the Mobile Loading Source Recovery Team (MLSRT), based in Carlsbad, NM, to develop OSRP's Type B container operations capability. These activities included procedure development; equipment design, testing, and fabrication; and personnel training and qualification. Although delayed by the COVID-19 pandemic, the initial use of the 380-B is anticipated for 2021, with the 435-B following later in the year.

Los Alamos continues to contribute technical expertise and oversight to the ongoing remediation of the University of Washington Harborview Research and Training building in Seattle following the 2019 source breach incident. In May 2020, Los Alamos completed the "Release of Cesium-137 Corrective Action Plan" (CAP), written in response to the source breach incident a year earlier. The CAP outlines actions to respond to the findings of an investigation report of this incident. Following forensic inspection at PNNL, the breached source was safely delivered to a secure storage facility in October 2020 in preparation for disposal, utilizing packaging and transportation expertise of OSRP personnel from both Los Alamos and INL.

The 380-B is transported on a dedicated trailer oufitted with custom work platforms, lid stands, and impact limiter stands. The new container will be put into operation in 2021.

NUCLEAR SMUGGLING DETECTION & DETERRENCE

The Office of **Nuclear Smuggling Detection and Deterrence (NSDD)** works with international partners to strengthen capabilities to deter, detect, and investigate the smuggling of nuclear and radiological materials by providing the expertise and tools needed to respond to smuggling events.

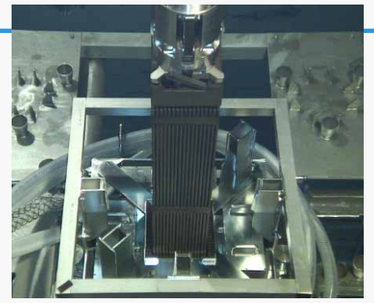
In 2020, Los Alamos provided scientific and engineering expertise in support of the design, installation, operation, and maintenance of radiation detection systems at sites in 70+ countries around the world. Los Alamos staff also contributed to a variety of consultancy meetings, technical meetings and coordinated research projects for the IAEA. Along with adapting to COVID and temporarily converting a large portion of these activities to a virtual setting, Los Alamos experts developed and contributed to curriculum development and programmatic baseline documents. We added the "Spectral Flavor of the Month," a new monthly expert support/reachback exercise, which has been very successful. In addition, the Science and Engineering Team (SET) started testing Pedestrian Portal Monitors as a market survey evaluation of new and dual use monitors for application on the NSDD Program.

The Los Alamos NSDD Investigations Team supported a wide range of capability and capacity-building activities in countries and regions expressing an interest in nuclear forensics engagement. Additionally, collaborative efforts in the areas of radiochronometry, particle morphology and stable isotope measurements were pursued with more than half a dozen countries. The COVID situation had a significant impact on travel through much of the year. Fortunately, much of the technical work could continue at each respective lab, and communication and engagement was completed using virtual technology so progress on these collaborative efforts was able to advance.

NONPROLIFERATION & INTERNATIONAL ENGAGEMENT

NUCLEAR SAFEGUARDS

Los Alamos continues to be at the forefront of international nuclear safeguards technologies and instrumentation development and related training. This past year marked the completion of the large 10-year **Spent Fuel Nondestructive Assay (NDA)** project. This project has made important contributions to the long-standing technical problem in the safeguarding of nuclear material–the direct assay of the Pu content in spent commercial light water reactor (LWR) fuel assemblies. As the type of access required for these spent fuel measurements was difficult to attain solely in the U.S., the measurements occurred at international facilities in other countries, including Japan, Republic of Korea, and most recently Sweden. The LANL team supporting this Spent Fuel NDA project received a LANL Distinguished Performance Award in 2020 for their 2019 accomplishments in completing this 10-year Spent Fuel NDA project.



Spent fuel assembly being inserted into the Differential Die-away Self Interrogation instrument built at LANL for characterization

Transferring technology to our international partners is an important way the Laboratory contributes to the safeguarding of global nuclear material. LANL Safeguards Technology teams received three **Joule Awards** from DNN's Office of Nonproliferation and Arms Control in recognition of our success in this area.

- Matt Newell and team were recognized for designing and building a new data acquisition instrument for the IAEA for use in gamma measurements in scintillator applications. This instrument, the Unattended Single Channel Analyzer (USCA), completes a suite of instruments that provide the most needed functions for unattended safeguards applications and joins the Unattended Multiplicity Shift Register and the Unattended Dual Current Monitor instruments that were delivered to the IAEA in previous years.
- Todd Williamson and Travis Tenner led the LANL contingent of a SRNL-PNNL-LANL project team recognized for producing and delivering a set of U particle reference material to IAEA with specified size, chemical contents and isotopic compositions in support of the IAEA Network of Analytical Laboratory (NWAL) Environmental Sample Laboratory quality control program.
- Heather Nordquist led a team that successfully transferred a new version of Deming software to the Joint Research Centre (JRC) in Ispra, Italy, to support their training obligations. Deming calibration fitting software is used with IAEA Neutron Coincidence Counting (INCC) software.

In addition, the **Los Alamos International Safeguards Engagement Program (INSEP)** team led by Andrea Favalli and Martyn Swinhoe developed and transferred a fast neutron collar safeguards instrument to EURATOM, to enable reduced measurement times in fresh Gd-loaded BWR (boiling water reactor) assembly verification. The team also developed an improved poison rod correction for the Uranium Neutron Coincidence Collar (UNCL) fresh fuel measurements in Brazil, which resulted in reduction of error of assay by an order of magnitude.

Characterization with Los Alamos fuel materials of the new detector system/fast neutron collar for fresh BWR fuel assemblies

NUCLEAR VERIFICATION

This past year, Los Alamos seismologists, together with colleagues at LLNL and Sandia, delivered data to the **Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO)** Preparatory Commission to support the **Regional Seismic Travel Time (RSTT)** model. "This model helps the CTBTO develop global verification data reports to monitor test ban treaty compliance. This is a great example of U.S. technical leadership helping the world," said Dr. Brent Park, former NNSA Deputy Administrator for Defense Nuclear Nonproliferation. "If you have a more accurate seismic event location, you can use the other tools in your toolbox to determine whether or not a suspicious event was a clandestine nuclear test."

NUCLEAR CONTROLS - ENGAGEMENT WITH INTERNATIONAL PARTNERS

As part of our support of international strategic trade controls outreach objectives, Los Alamos staff apply comprehensive expert knowledge of nuclear and weapons of mass destruction-related export controls to help build the capacity of foreign partners to regulate strategic trade and to deter, detect, and interdict illicit transfers. Los Alamos has been organizing or supporting up to a dozen bilateral, regional, or multilateral export control engagements per year since 2005 for countries at all stages of nonproliferation development.

As an example, our **International Nonproliferation Export Control Program (INECP)** team has partnered closely over the years with Malaysia's Strategic Trade Secretariat and has been instrumental in helping Malaysia develop one of the strongest strategic trade control systems in South East Asia. Due to the COVID-19 pandemic, our training with Malaysia this past year went virtual and the Los Alamos INECP team successsfully navigated this new instructional environment.

STATE DEPARTMENT

Our portfolio supports U.S. State Department activities closely aligned with our work for DNN. This includes work funded by its Program of Technical Support to Agency Safeguards (POTAS), Export Control and Related Border Security Program (EXBS), the Biosecurity Engagement Program, and the Key Verification Assets Fund (V-Fund).

The IAEA's Department of Safeguards is looking to modernize and replace outdated hardware with the latest safeguards technologies developed at LANL. Los Alamos has been developing modern electronics hardware to both improve existing capabilities and to replace obsolete safeguards equipment. The IAEA recognizes that the new hardware under development at Los Alamos has potential applications, especially for use in **Unattended Monitoring Systems (UMS)** for safeguards.

The IAEA requested the assistance of the United States to procure several recently developed safeguards instruments. Included in this set of instruments were updated **Neutron Pulse Simulators (NPS)** to replace or augment the ten Los Alamos-designed NPS units already in use at the IAEA. The NPS produces both random and correlated pulse streams simulating real neutron detector system responses. The timing between pulses is statistically sampled from distributions that are calculated in real time. Use of the NPS allows the IAEA to perform tests on, and training with, time correlation neutron data acquisition systems without the need for Special Nuclear Material (SNM), thus providing a safer and simpler training and testing platform. Four of the final five NPS units were completed in 2020, and shipped to the Agency. This delivery has completed the production and delivery of 24 newly developed safeguards instruments to the IAEA.

NPS units ready to be shipped to the IAEA

MATERIAL MANAGEMENT & MINIMIZATION

MO-99 PRODUCTION WITHOUT HEU

Laboratory researchers are supporting commercial partners (Niowave, NorthStar Medical Radioisotopes, and SHINE Medical Technologies) to develop technologies and methods for the reliable production of the medical isotope Mo-99 without using HEU.

The NorthStar Medical Radioisotopes approach uses enriched molybdenum targets in an accelerator to produce Mo-99. In addition to general design support as problems arise in the plant layout evolution, current Laboratory activities include shielding and activation analysis, disk holder design and insertion studies, experimental studies on beam heating effects on target structural integrity, and target window cooling experiments over the range of manufacturer tolerances. Long-duration testing of the blower system that provides the cooling for the targets also continues from previous years.

SHINE Medical Technologies is developing an accelerator-driven, LEU solution-based method to produce Mo-99 as a fission product. We have been supporting SHINE with cutting-edge coupled neutronics and fluid dynamics calculations for a solution reactor system. In order to estimate real-time operating conditions and parameters, Los Alamos is developing a solution reactor transient simulator based on previously developed transient system modeling tools for solution reactor applications. This simulator will allow SHINE operators to gain experience with startup and shutdown events by displaying parameters such as average fuel temperature, reactivity, power, etc.

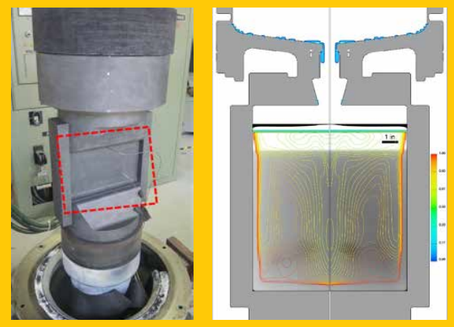
Flow visualization experiment of the Niowave molten lead-bismuth electron to neutron converter for Mo-99 production

For Niowave, Los Alamos is leveraging decades of experience with material at the lead-bismuth eutectic, a region where an alloy of lead and bismuth will melt at a significantly lower temperature than either material alone. As liquid lead-bismuth flows in front of an accelerator beam, electrons will produce neutrons as they interact with the lead. Niowave plans to use the neutrons to generate fission in a subcritical array of LEU. Our initial work focuses on analysis of the flow of material in the current design.

NEW FUEL REACTOR CONVERSIONS

Los Alamos supports the Fuel Fabrication Pillar efforts in reactor conversion by developing methods to fabricate monolithic LEU-Mo fuels for U.S. research reactors. The new LEU fuel will replace existing HEU fuels used by U.S. High Performance Power Research Reactors (USHPRR), including the Advanced Test Reactor, the Missouri University Research Reactor, National Bureau of Standards Reactor, and the Massachusetts Institute of Technology Reactor. Los Alamos is focused on improvements in two areas of fuel fabrication: casting and hot isostatic pressing.

As production of U-10Mo fuel plates ramps up over the next several years, the quality of cast high-assay LEU U-10Mo feedstock material becomes more critically important for the USHPRR program. (U-10Mo is uranium alloyed with ten weight percent molybdenum.) Higher accuracy process modeling has been identified as critical to decisions related to new mold designs. Instrumented castings, radiography data, and simulations can be combined (as in the accompanying figure) to directly correlate process conditions with defects such as porosity. Modern software for casting simulations goes through validation of their numerical models in such a way that the underlying algorithms are not a major source of error. Instead, material properties and accurate knowledge of boundary conditions becomes the main source of inconsistency. Los Alamos has been measuring fundamental properties during the solidification of U-10Mo to improve the accuracy of models for the casting process. The measurements reduce uncertainties in fundamental material properties that lead to inaccurate simulation results. In the past year, the we have verified solidus and liquidus information for alloy compositions near U-10Mo, determined the enthalpy of fusion for alloy compositions near U-10Mo, and measured thermal diffusivity of U-10Mo from room temperature to the melting point.



Graphite mold stack (left) prepared for uranium casting and corresponding radiographic image (right) of uranium casting with superimposed solidification isolines from simulations indicating where defects such as porosity occur.

ARIES PROGRAM

The **ARIES Program** at Los Alamos supports the disassembly of plutonium components and their conversion to oxide for ultimate disposal. In January 2020, the program celebrated an important milestone of processing and preparing 1 metric ton of plutonium oxide for final disposition.

The ARIES program overcame significant challenges in FY20, including infrastructure outages and COVID impacts, to complete the conversion, packaging, and NDA of all 8 production runs—successfully completing our FY20 revised production milestone. Additionally, the program successfully completed 7 of 8 Level 2 Milestones on time, and the final Level 2 Milestone before the end of the FY. This required significant coordination and effort from numerous disciplines, particularly once telecommuting was implemented at the onset of the COVID outbreak.

More than 30 employees including current ARIES staff, other LANL staff and retirees received certificates of achievement for their contribution to ARIES at the January 2020 ARIES 1 MT milestone celebration. Commemorative coins were made with the message “Reducing the global nuclear danger” on one side and “ARIES Oxide Production – 1 MT in the cans – 2009-2019” on the other.

The program also focused on several key projects in FY20. Calorimetry measurements obtained from standards on the ARIES NDA table in December 2020 are currently being evaluated. Certification of the NDA table will enable ARIES to conduct NDA measurements on the operating floor, thereby alleviating demands on the basement NDA lab that is used by all Weapons and Global Security programs using PF-4, the Los Alamos Plutonium Facility. Several efforts targeting increased storage capacity were also completed in FY20, including completion of a Level 3 Criticality Safety Evaluation Document for increased criticality limits of in-line storage gloveboxes; removal of a power supply from the basement to provide space for new safes; and development of a new vault insert design to increase storage capacity along three walls in the vault by a factor of four. Storage efficiencies gained by this project will provide sufficient capacity for ARIES product until 2028 and effectively de-conflict ARIES storage demands from other PF-4 programs. Additionally, procedure revisions required to implement the new product specification included in the Surplus Plutonium Disposition Plutonium Dioxide Powder Interface Control Document were completed during FY20.

SPACE SYSTEMS & SCIENCE

In an effort to improve integration and coordination amongst GS-NNS and broader space-related research and development activities across different sponsors, a new space-focused program organization was formed in late 2020. The Space Science and Systems (S3) program includes a broad suite of activities ranging from fundamental R&D in astrophysics and space science to complete space systems for civilian and national security applications.

SPACE-BASED NUCLEAR DETONATION DETECTION

Los Alamos continues to be a principal provider of science and technology for the space-based **U.S. Nuclear Detonation (NUDET) Detection System (USNDS)**. This enduring and evolving system, jointly developed and sustained by NNSA and DoD, provides critical national security capability to detect and report global nuclear detonations above the ground—including those at high altitude and in near-Earth space that might threaten U.S. reliance on space-based services. Los Alamos designs, develops, produces, and supports multi-phenomenology sensing payloads for satellites in Global Positioning System (GPS) and geostationary (GEO) constellations, as well as associated ground-based analysis and processing technology needed to operate the system.

As part of this enterprise, Los Alamos continued to support Global Burst Detector (GBD) payloads produced and delivered in previous years for deployment on GPS Block III satellites. In 2020 Los Alamos supported the successful launch of two such satellites, GPS-III 03 and GPS-III 04, including successful deployment of the GBD payloads they carry. Design of next-generation GBD payloads also continued this year, with hardware and software designs for the Los Alamos Electromagnetic Pulse (EMP) sensor and Hard Radiation Sensor (HRS) subsystems being in the process of qualification for the hazards of space flight and high-reliability operation through rigorous testing of flight-like payloads. These next-generation GBD payloads are slated for deployment on GPS-III follow-on satellites (GPS-IIIF) starting about 2025.

The GPS-III 03 (left; 30 Jun) and GPS-III 04 (right; 5 Nov) spacecraft were launched in 2020, each deploying a Global Burst Detector payload. *(Photos: SpaceX)*

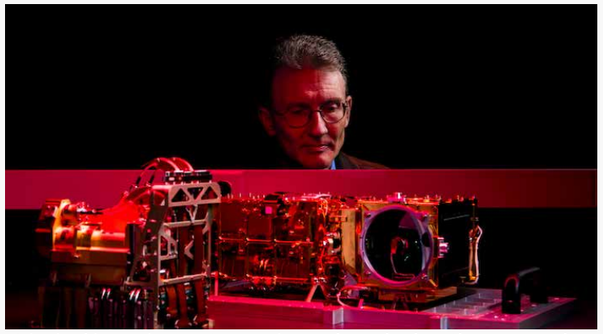
For the USNDS GEO constellation, Los Alamos continued to support and develop current and future **Space and Atmospheric Burst Reporting System (SABRS)** payloads. These payloads replace the legacy neutron, gamma-ray, and charged particle sensors fielded on Defense Support Program satellites in the 1970s through the 1990s, and complement the optical, radio frequency, X-ray, and particle sensors fielded on GPS satellites. Throughout 2020, Los Alamos continuously supported integration and testing of the third SABRS payload (SABRS-3) with its host satellite, the U.S. Air Force Space Test Program (STP) Satellite 6 (STPSat-6). This satellite also hosts seven other U.S. Government experimental payloads, including the Space and Endo-Atmospheric NUDET Surveillance Experimentation and Risk Reduction (SENSER) payload—an NNSA-sponsored experiment suite developed by Los Alamos and Sandia to demonstrate and evaluate new technologies for potential use in future USNDS. The STPSat-6 satellite is scheduled for launch in Summer 2021. The large, multidisciplinary team supporting STPSat-6 activities received a Los Alamos National Laboratory Distinguished Performance Award in 2020 for successfully completing and delivering the SABRS-3 and SENSER payloads in 2019.

Integration and testing of the STPSat-6 satellite, including the SABRS-3 and SENSER payloads, was conducted throughout 2020. *(Photo: Northrup Grumman)*

NASA SCIENCE AND INSTRUMENTATION

Los Alamos is involved in several operating NASA space science missions where we provided key contributions, including the ChemCam materials spectrometer instrument on the **Mars Curiosity rover** (since 2011), the energetic particle instrument on the **Magnetospheric Multiscale Mission** (since 2015), the plasma instrument on the **Advanced Composition Explorer** (since 1997), the energetic neutral atom imager on the **Interstellar Boundary Explorer** mission (since 2008), and the on-board processing software on the **Swift** gamma-ray burst observatory (since 2004).

One of this past year's most significant accomplishments was the launch of the Mars 2020 mission, where Los Alamos provided key contributions to the **SuperCam** (an update to ChemCam) and **SHERLOC** instruments that ride on the Perseverance rover. These instruments were in development since before 2014, and will use Laser Induced Breakdown Spectroscopy to remotely measure the chemical composition of Martian surface materials. Following launch, the Los Alamos instrument teams participated in several test and operational readiness planning activities as the spacecraft was en route to Mars. Landing is eagerly anticipated on Feb. 18, 2021, followed by Perseverance deployment and science operations.



Principal investigator Roger Wiens takes a look at the mast and body units that make up SuperCam.

Los Alamos is developing new instrumentation for several upcoming NASA space missions in collaboration with national and international partners. The **Interstellar Mapping and Acceleration Probe (IMAP)** mission, which is in the preliminary design phase working towards 2025 launch, includes two Los Alamos instruments: the high-energy Neutral Atom Imager and the solar wind electron instrument. Development also continues on the Los Alamos **Nano-satellite Atmospheric Chemistry Hyperspectral Observation System (NACHOS)** mission, which features a miniaturized hyperspectral imaging instrument that will fly on an orbiting CubeSat platform for Earth science observations. Designs for both the satellite and imager underwent qualification in 2020 on track for launch in 2021 or 2022. We continue to develop the **Beam Plasma Interactions Experiment (BeamPIE)** as part of ongoing space accelerator technology development efforts. This mission is preparing an electron beam accelerator and a sensor suite to fly in a coordinated 2022 launch of two suborbital rockets that will investigate how low-frequency radio waves affect energetic charged particles in the Earth's magnetosphere.

Los Alamos is also pursuing research towards potential future NASA missions. These include the **LargE Area gamma-ray burst Polarimeter (LEAP)** for the International Space Station, the **Black hole Coded Aperture Telescope (BlackCAT)** CubeSat mission for high-energy astrophysics, and the **Venus Elemental and Mineralogical Camera (VEMCam)** for a future Venus surface landing mission. In addition to space flight hardware projects, Los Alamos continues to maintain an extensive portfolio of smaller-scale NASA R&D projects. These projects span a broad range of science and technology including earth science, space weather, astrophysics, planetary and lunar exploration, and bioscience.

SPACE RADIOISOTOPE POWER SYSTEMS

Los Alamos continues to be the nation's sole provider of flight-qualified ^{238}Pu heat sources for space-based radioisotope power systems. In 2020, Los Alamos heat sources were deployed on the Mars 2020 mission as the core of the Perseverance rover's multi-mission radioisotope thermoelectric generator (MMRTG) power system (a mutli-institution DOE/NASA partnership project). Looking forward, we are working to establish a constant rate of heat source production to meet future national space needs, including re-building critical elements of unique Los Alamos production processes and infrastructure.

AWARDS & STAFF RECOGNITION

SECRETARY OF ENERGY HONOR AWARDS

Three 2019 Secretary of Energy Honor Awards were presented to Los Alamos National Laboratory teams.

The **Source Physics Experiment (SPE), Phase II, Dry Alluvium Geology (DAG) Team** was recognized for concluding ten years of chemical explosion testing experiments that advanced the science of nuclear explosion monitoring, and for providing value to the Nation's nuclear explosion monitoring mission for decades to come.

The multi-Laboratory **Spent Fuel Nondestructive Assay (NDA) Project Team,** together with international partners, made key technical and programmatic contributions to the important nuclear safeguards challenge of characterizing commercial spent fuel assemblies by researching 14 possible techniques, then building, field testing, and analyzing results from a series of major nondestructive assay instruments through measurement campaigns at foreign partner facilities.

The **Seattle Response and Recovery and Cs-137 Joint Investigation Teams** were recognized for successful emergency response, recovery, stabilization, and investigation of the breached radioactive source event at the University of Washington's Harborview Research and Training Facility.

JOULE AWARDS

Los Alamos National Laboratory Safeguards Technology teams received three DOE/NNSA **Joule Awards** presented by DNN's Office of Nonproliferation and Arms Control. The award is given for the successful transfer of technologies to the IAEA and/or other international partners. (See p. 16 for details.)

LOS ALAMOS NATIONAL LABORATORY GLOBAL SECURITY MEDAL

Philip K. "Phil" Tubesing was the 2020 awardee of the prestigious Los Alamos Global Security Medal, which recognizes the exceptional achievements of active or recently retired employees who have made significant contributions to the Laboratory's global security mission.

"Phil's leadership and technical expertise in weapons and nuclear nonproliferation have had a tremendous impact on the Laboratory's global security work," said Thom Mason, Laboratory director. "He is not only a technical expert on actinide processes, but he has consistently demonstrated a unique ability to apply his expertise to a variety of global security programs at the national and international levels."

LOS ALAMOS NATIONAL LABORATORY FELLOW PRIZE

The Laboratory Director appoints a few people each year to the rank of Fellow in recognition of sustained outstanding contributions and exceptional promise for continued professional achievement. One of the seven scientists and engineers to receive this honor in 2020 was **Vania Jordanova**, an expert in space physics and space weather. Jordanova is a recognized international authority on "geomagnetic storms," when vast amounts of energy are transferred from the solar wind into the near-Earth space environment (the magnetosphere).

SCIENTIFIC COMMUNITY AWARDS

American Chemical Society (ACS) Fellow

Laboratory chemist **Ning Xu** was selected as a member of the 2020 class of ACS Fellows. Xu, who just began a Technical Advisor assignment with NNSA's Office of International Nuclear Safeguards, was recognized for her sustained contributions to actinide analytical chemistry in support of national nuclear defense, technical nuclear forensics, nuclear material safeguards, and deep space exploration.

American Physical Society (APS) Fellow

Andrea Favalli was elected a 2020 APS Fellow. Favalli, from the Laboratory's Nuclear Nonproliferation and Engineering Division, was recognized for his outstanding application of the methods and underlying science of nuclear physics to the crucial issues of nuclear safeguards and security.

American Statistical Association (ASA) Fellow

Kary Myers was selected as a 2020 ASA Fellow. Myers was recognized for her creative leadership, innovative development, and application of statistical methods for high-impact collaborations, statistical outreach to the broader scientific community, and outstanding service to the statistics profession. Myers leads the Data Science portfolio for our DNN R&D program.

American Nuclear Society (ANS) Fellow

Evelyn Mullen, chief operating officer for the Laboratory's Global Security organization, was named an ANS Fellow in 2020 for her leadership in nuclear national security and ensuring the nation's experimental capability in nuclear criticality.

R&D 100 AWARDS

OrganiCam is the first camera for noncontact, nondestructive biodetection in remote environments and space. It supports applications in threat detection and is relevant for future NASA planetary missions. Los Alamos led the joint entry with the University of Hawai'i. Roger Wiens of Los Alamos (see photo on p. 21) and Anupam Misra of the University of Hawai'i directed the team.

Amanzi–ATS is a powerful and agile simulation tool for comprehensive environmental system analyses and has been used to analyze pristine local watersheds in the Western United States, effects of wildfire damage on watersheds, subsurface contaminant transport at legacy waste sites and the effect of a warming climate on the Arctic tundra. It has applications in modeling subsurface flow and transport relevant for detection and measurement of underground nuclear tests. Los Alamos led the development of this software along with co-developers ORNL, LBNL, and PNNL.

Cluster Integrity, Exception Resolution, and Reclustering Algorithm (CIERRA) is the first and only software that routinely identifies the most extraordinary and unpredictable type of lightning and it enables researchers to study the precursors to megaflashes and develop predictive tools for them. In addition to providing an important public safety tool, it supports space-based nuclear explosion monitoring through enhanced understanding of extreme lightning events that are a source of background for optical and radio frequency sensors. Los Alamos led the initiative with co-developer, University of Maryland.

NUCLEAR NONPROLIFERATION AND SECURITY

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