2018 RUN CYCLE REPORT

LANSCE
Los Alamos Neutron Science Center

Pulse

Los Alamos
NATIONAL LABORATORY
EST. 1943

Service to the nation

Contents

On the cover: The Los Alamos Neutron Science Center serves the nation through materials and nuclear science supporting NNSA and DOE missions. Shown are an illustration of the Chi-Nu project, which advances our understanding of nuclear criticality, and an image of a proton radiography experiment, which reveals essential data about materials under extreme conditions. The proton radiography images show a sequence of the magnetically-driven damaged surface hydro experiment examining transport and instability growth in vacuum of an initially porous surface layer of preformed tungsten particles. The particle layer breaks free from the surface, forms a cloud that amplifies initial surface imperfections, and collides with itself at the center. The data tests our understanding of complex flows and provides validation data for modern hydrodynamics codes and material models.

For more information about LANSCE, please visit lansce.lanl.gov.

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From the LANSCE User Facility Director

For more than four decades, the United States has relied on the Los Alamos Neutron Science Center (LANSCE) accelerator to deliver high-energy, high-power proton beams in support of national security science. Today the LANSCE facility is a center for materials and nuclear research supporting National Nuclear Security Administration (NNSA) and Department of Energy (DOE) missions.

During the 2018 run cycle, LANSCE operated from June 11 to December 20, delivering proton beam to 5 target stations and 16 flight paths. As a DOE user facility supporting the NNSA mission, LANSCE hosted 591 unique users and executed 141 experiments for a total of 1,996 beam experiment days. Our industrial user program continues to lead the world with 16 corporations coming to LANSCE to irradiate and validate the performance of their electronics, used in aviation and computing, against neutron upsets caused by cosmic rays. This was also the first year in which instruments in the Lujan Center were part of the Nuclear Science User Facilities, which is overseen by Idaho National Laboratory.

In this publication you will read about how LANSCE delivered critical data and material for NNSA, DOE, and the nation, while maintaining a focus on operational excellence. The scientific achievements discussed here are the result of the dedicated efforts of our workers, who aim for simultaneous excellence in operations and delivery of mission to exceed the expectations of our sponsors.

At the Proton Radiography Facility we executed 46 dynamic experiments: 38 with high explosives and 8 with a powder gun drive. These experiments provided critical data, unattainable through other means, for the directed stockpile program's life extension programs, the Office of Experimental Science within the NNSA, and the Army Research Laboratory. At the Lujan Center we executed experiments in materials science to better understand the microstructure and aging of plutonium and plutonium alloys; the properties of U-6Nb; and how advanced manufacturing methods can be adapted to produce components for NNSA missions. The unique capability to perform isotope-specific tomography of materials was exploited to better understand diffusion in nuclear fuels and advance our ability to design better nuclear reactors. The nuclear data obtained at the Lujan Center and at the Weapons Neutron Research Facility were instrumental in achieving an NNSA Level 1 milestone in advancing our understanding of nuclear criticality.

Beyond the NNSA mission, LANSCE plays important roles in the production of medical isotopes, searching for physics beyond the Standard Model, and providing a world-leading neutron irradiation capability for industry. The Isotope Production Facility at LANSCE is an important source of radioisotopes for medical imaging and is part of a critical development effort to scale up production of the α-emitting isotope actinium-225, currently undergoing clinical trials for the treatment of prostate cancer. LANSCE is home to the world's most intense source of ultracold neutrons, subatomic particles that, when cooled, move so slowly they can be "trapped" and measured. This ultracold neutron source was used to make the most precise measurement of the lifetime of the free neutron, which is important for understanding the evolution of the early universe and to search for physics beyond the Standard Model.

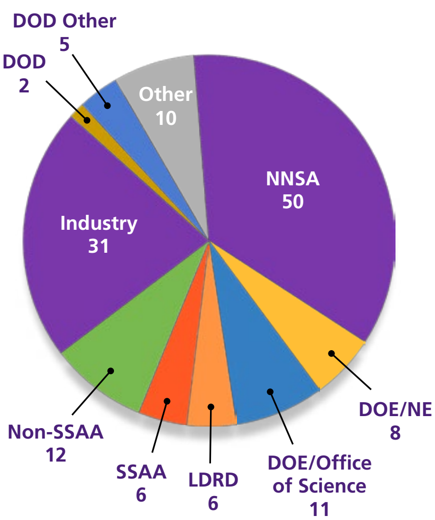
In the pages that follow you will find more detailed information on how LANSCE has served the nation and supported the national security of the United States.

LANSCE User Facility Director Gus Sinnis

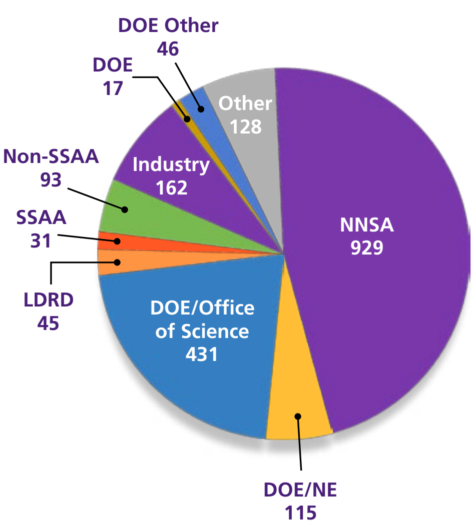
LANSCE 2018 RUN CYCLE STATISTICS

141 proposals scheduled
1,996 beam experiment days scheduled

Scheduled Proposals



Beam Experiment Days



Scattering Science Team Leader Don Brown (right) and post-doctoral researcher Maria Strantza (background) arrange a sample for residual stress measurements using SMARTS.

Materials Science at LANSCE

SMARTS, located at the Lujan Center, is optimized for studying engineering materials.

Ann Junghans (left) and Erik Watkins prepare an experiment on Asterix, a polarized neutron beam spectrometer for studies of material surfaces and interfaces.

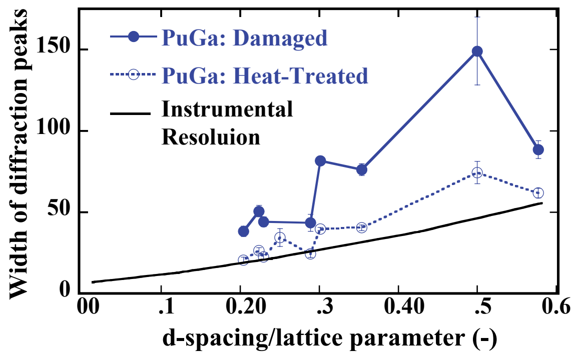
Revealing how microstructure matters

While two materials may look the same, it's what is below the surface that counts. Taking the same material and processing it in two different ways can lead to differences in the microstructure, which in turn leads to differences in the performance of the two materials. These effects are described by the "process/structure/properties/performance," or PSPP, relationship.

The materials science beamlines at the Lujan Neutron Scattering Center—SMARTS, HIPPO, Asterix, and ERNI (see sidebar, next page)—are sharply focused on understanding how the processing of materials that are of interest to the weapons program affects their microstructure, which inherently controls their properties and performance. Neutrons, with their ability to penetrate most materials to bulk depths, provide a unique window into the microstructure, enabling nondestructive, evolutionary, in situ observations under a host of extreme environments.

The manufacturability of the uranium alloy U-6Nb is a relevant example. The current stockpile uses components made from U-6Nb manufactured by a qualified wrought process that cannot currently be repeated in the United States. New manufacturing routes such as direct casting are being developed, but the critical question remains: how will the difference in processing affect the properties and how do those properties affect performance? The scientists at the Lujan Center are working to understand the PSPP relationship in U-6Nb in order to help answer that question.

Optical microscopy indicates that the microstructure of the cast material is similar to wrought material except that the prior β grain size is larger in the cast material.[1] Moreover, macroscopic mechanical testing of the cast material demonstrates that the properties are only subtly different from conventional wrought U-6Nb.[1] Work to understand the micromechanics of deformation of wrought U-6Nb has been ongoing at the Lujan Center since 1998.[2–4] Neutron diffraction measurements allow researchers to probe



The chart above demonstrates the increase in the width of the diffraction peaks in aged plutonium. The width of these peaks increases because dislocation and other defects change the nearby lattice spacing, resulting in a broader distribution of lattice spacings throughout the material. Heat treating the material removes these defects so the crystal structure is more similar to newly processed plutonium.

MATERIALS SCIENCE BEAM LINES AT THE LUJAN CENTER

Asterix: A versatile neutron reflectometer for studying surface properties and buried interfaces in materials.

ERNI: Energy-resolved neutron imaging for imaging based on isotopic differences not possible with x-rays or protons.

HIPPO: The High-Pressure-Preferred Orientation neutron time-of-flight power diffractometer used to study microstructure or phase composition and texture.

SMARTS: The Spectrometer for Materials Research at Temperature and Stress is a neutron diffractometer optimized for studying engineering materials under operating and/or processing conditions.

the microstructural response to deformation, in addition to the macroscopic response. Specifically, in situ neutron diffraction measurements on SMARTS have identified four successive, distinct, active deformation mechanisms during tension of wrought U-6Nb, each with a distinct signature in the crystallographic texture: (1) 0–0.2% strain: elasticity, (2) 0.2–4% strain: reorientation of twin-related crystallographic variants, (3) 4–8% strain: mechanical twinning, and (4) >8% strain: conventional dislocation-moderated plasticity.

In 2018, in situ neutron diffraction measurements were completed during compression and tension of cast U-6Nb, specifically for comparison to past measurements on wrought material. We were specifically looking at the reorientation of crystallographic variants in this shape-memory alloy. Like the wrought material, the cast material initially deforms elastically and then through de-twinning of the crystallographic variants. However, the secondary mechanical twin that is observed during deformation of wrought material was not observed in the cast material prior to the initiation of dislocation slip. Understanding the evolution of the active deformation mechanisms is critical for modeling the performance of components made with this complicated alloy.

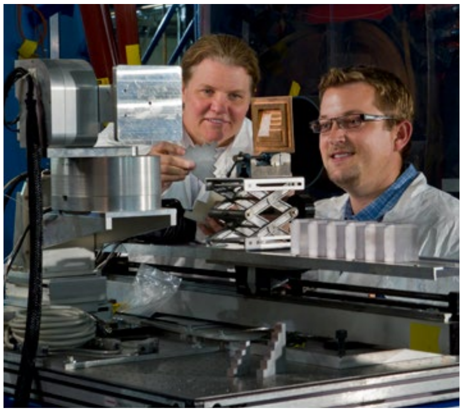
Complementing this study, multiple studies of how the microstructure of U-6Nb forms were performed. Lujan Center materials scientists are studying the microstructure of U-6Nb during quenching from the processing temperature of 800 °C using fast x-ray measurements at the Advanced Photon Source. Finally, we are using neutron reflectivity measurements on the Asterix reflectometer, coupled with x-ray measurements, to monitor the inter-diffusion of niobium and uranium nanolayers. These measurements help us understand the formation and stability of this alloy.

Plutonium, specifically Pu-2at%Ga alloy, is another material of interest whose performance is particularly sensitive to microstructure.[5,6] Phase stability and mechanical properties depend on microstructural evolution as a result of mechanical working or aging.[5–8] Work during the 2018 run cycle in collaboration with principle investigators Alice Smith and Franz Freibert focused on the microstructural evolution of Pu-2at%Ga at low temperatures using in situ neutron diffraction techniques on both SMARTS and HIPPO.

SMARTS, which offers high resolution at a slow data rate, was used to determine semiquantitative dislocation densities and lattice parameters as a function of temperature during a thermal cycle starting at 673 K (the annealing temperature), decreasing to 10 K, holding for several weeks, then returning to the annealing temperature. In contrast, HIPPO, offering a fast data rate but relatively poor resolution, was used to make measurements during thermal cycling between room temperature and 35 K. In each case, the measurements started with a two-day heat treatment at 673 K, after which the material was defect free (to our resolution). Extreme peak broadening, suggestive of an increase in dislocation density, was observed on cooling below roughly 170 K, increasing to the base measurement temperature of 10 K. Significant but incomplete recovery of the peak breadth was observed during a return to room temperature. Moreover, the lattice parameter was larger following a cooling cycle than it was after annealing. This increase in lattice parameter (strain) developed after each cooling cycle. Full recovery of the microstructure was achieved only after a repeat of a two-day 673 K heat treatment. Scientists are working to understand the source of the microstructural damage that occurs below 170 K and is evident in the diffraction pattern. The kinetics are not consistent with self-irradiation damage. Also, no evidence of low temperature phase transformation was observed, although the measurement technique would require ~5 % volume fraction to see the low temperature phase.

References
[1] R.M. Aikin Jr., C.M. Cady, S. Chen, E.K. Cerreta, G.T. Gray III, C.P. Trujillo, M.F. Lopez, D.R. Korzekwa, *Los Alamos National Laboratory*, 2009. [2] R.D. Field, D.W. Brown, D.J. Thoma, *Phil. Mag*., 85 (2005) 2593-2609. [3] D.W. Brown, M.A.M. Bourke, P.S. Dunn, R.D. Field, M.G. Stout, D.J. Thoma, *Metall. Mater. Trans. A*, 32 (2001) 2219-2228. [4] C.N. Tupper, D.W. Brown, R.D. Field, T.A. Sisneros, B. Clausen, *Metall. Mater. Trans. A*, 43A (2012) 520-530. [5] J.N. Mitchell, M. Stan, D.S. Schwartz, C.J. Boehlert, *Metall. Mater. Trans. A*, 35A (2004) 2267-2278. [6] A.C. Lawson, J.A. Roberts, B. Martinez, R.B. Von Dreele, B. Storey, H.T. Hawkins, M. Ramos, F.G. Hampel, C.C. Davis, R.A. Pereyra, J.N. Mitchell, F. Freibert, S.M. Valone, T.N. Claytor, D.A. Viskoe, F.W. Schonfeld, *Phil. Mag*., 85 (2005) 2007-2022. [7] B.W. Chung, S.R. Thompson, K.E. Lema, D.S. Hiromoto, B.B. Ebbinghaus, *J. Nuc. Matl*., 385 (2009) 91-94. [8] J.L. Robbins, *J. Nuc. Matl.*, 324 (2004) 125-133.

Proton Radiography at LANSCE



Dale Tupa (left) and Carl Wilde adjust calibration objects for the proton radiography beamline to characterize the radiography system.

Leveraging protons to diagnose materials under extreme conditions

Invented at Los Alamos, proton microscopy uses the LANSCE high-energy proton beam to image the properties and behavior of materials driven by high explosives, pulsed power, or a powder gun. The Proton Radiography Facility came about through a synergy between basic scientific research and the needs of the NNSA Defense Programs.

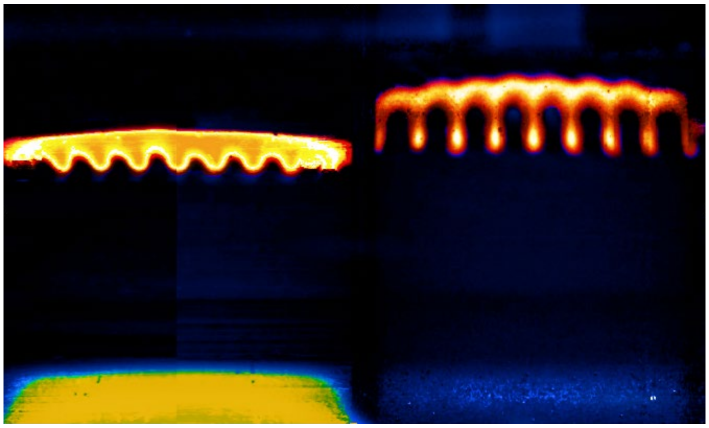
The penetrating power of high-energy protons, like that of x-rays, makes them an excellent probe of a wide range of materials. The strengths of proton radiography stem from the LANSCE accelerator's ability to produce multiple proton pulses with very flexible timing and the ability of protons to be manipulated with magnetic lenses in a direct analogy to optical systems. The latter enables researchers to build proton imaging systems that can achieve a resolution as good as 30 microns.

The high energy of the beam gives it a penetrating power sufficient to resolve internal details in objects of a wide variety of densities, such as lead, plutonium, uranium, or high explosives—shedding light on features under extreme conditions that are difficult to discern with x-ray imaging. The LANSCE accelerator allows multiple images to be taken

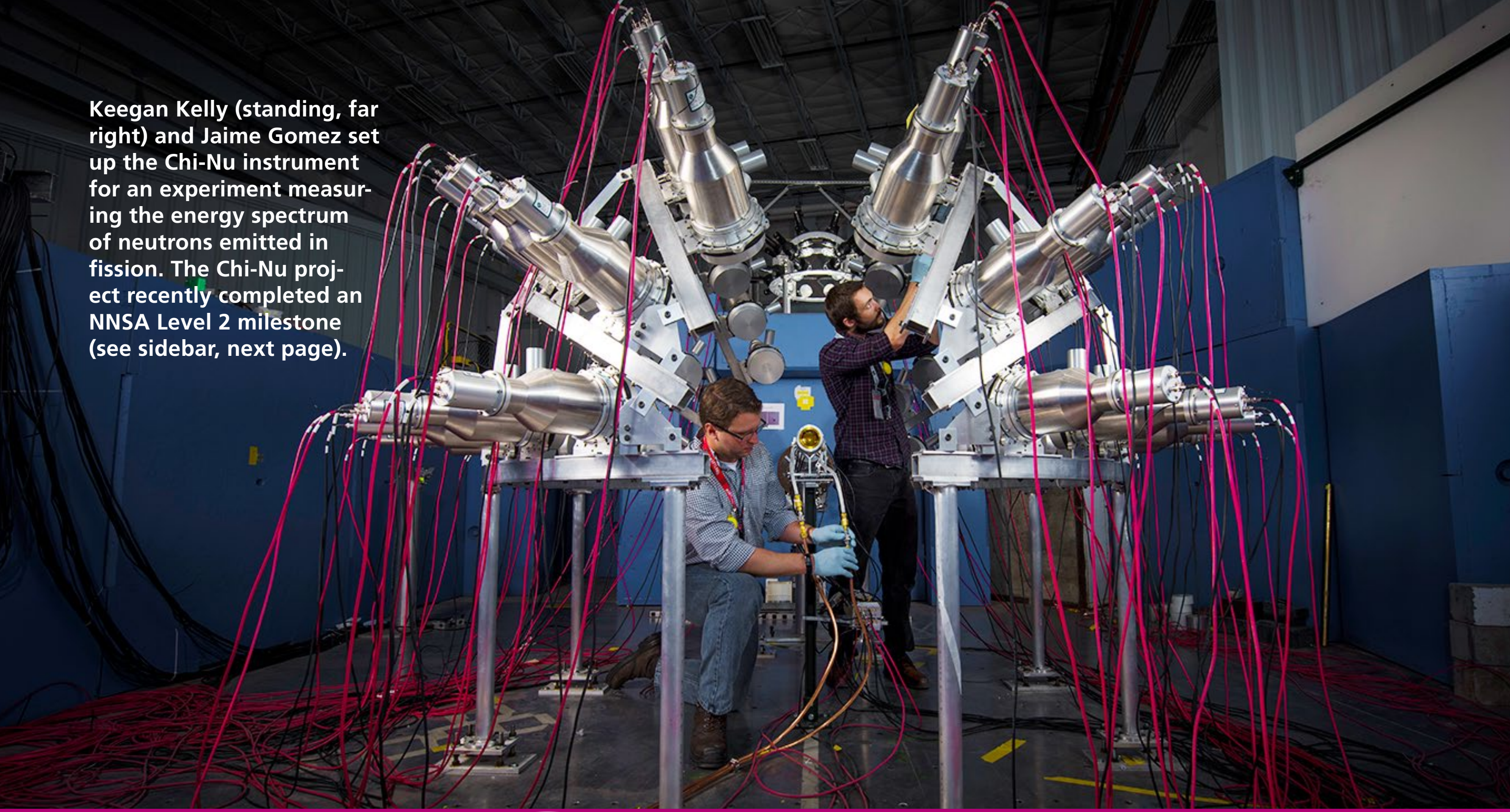
A view inside the dome of the Proton Radiography Facility, where 46 dynamic experiments were performed during the last run cycle. Half of these experiments were classified and a significant number supported the B-61 Life Extension Program and the W88-ALT370.

over a wide range of time intervals, capturing a movie of dynamic events where the frames may be as little as 100 billionths of a second apart (or arbitrarily long durations between images).

Over the past run cycle the Proton Radiography Facility performed 46 dynamic experiments. Half of these experiments were classified and a significant number of those supported the B-61 Life Extension Program and the W88-ALT370. These experiments played a crucial role in our confidence in the performance of the final systems. In addition to this work, the Army Research Lab came to LANSCE to develop advanced armor and armor penetrating projectiles. Los Alamos scientists used proton radiography to understand material strength, the burning of high explosives (both conventional and insensitive), and the onset and development of turbulence. As a DOE national user facility, the Proton Radiography Facility serves the nation and hosted scientists from Lawrence Livermore National Laboratory, the Atomic Weapons Establishment in the United Kingdom, and the Army Research Lab.



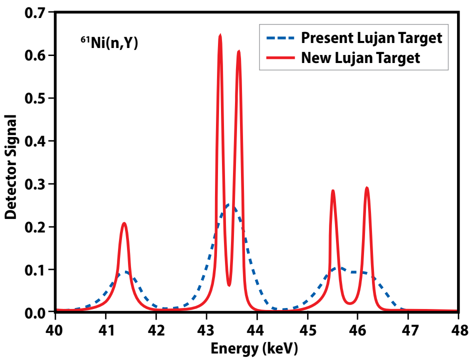
Proton radiography reveals how manufacturing and processing affect microstructure, which affects performance. Here, two copper samples, identical in size and shape but with different microstructures due to different manufacturing techniques, perform differently when tested under identical drive conditions and initial perturbations.



Keegan Kelly (standing, far right) and Jaime Gomez set up the Chi-Nu instrument for an experiment measuring the energy spectrum of neutrons emitted in fission. The Chi-Nu project recently completed an NNSA Level 2 milestone (see sidebar, next page).

Nuclear Science at LANSCE

A new Lujan Center target will be installed in 2020, in a process similar to the operation shown here.



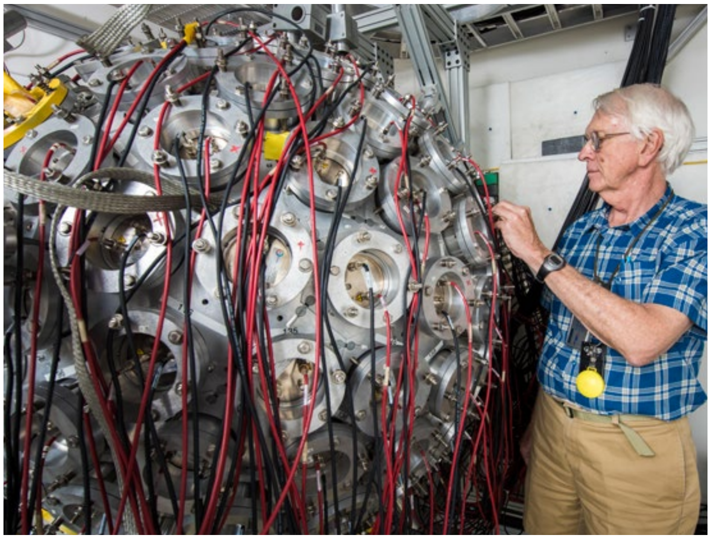
Performance improvements for the new Lujan Center target can been seen by comparing present performance, in blue, to the predicted future performance, shown in red.

Providing national security solutions using the full neutron spectrum

Nuclear science efforts at LANSCE that support NNSA's Office of Experimental Sciences use the high-energy neutron spectrum at the Weapons Neutron Research Facility (WNR) and the lower energy neutrons at the Lujan Center. WNR, which was used for the fission spectrum measurements discussed on the next page, looks directly at the hot neutrons. Typical neutron energies at WNR range from 1–20 MeV. These high-energy neutrons have energies similar to those created in neutron-induced fission and thermonuclear fusion. Measuring neutron reactions at these energies is important to understand the performance of the stockpile. This past year measurements made on the prompt neutrons resulting from the fission of plutonium contributed to an important Level 1 milestone related to improving our understanding of nuclear criticality.

At the Lujan Center, the neutrons produced are moderated through interactions with a cold-water bath before they are delivered to experiments. This lower energy range (1 eV–1.0 keV) is used to study neutron capture reactions in elements and isotopes of interest to both NNSA and the nuclear astrophysics community.

Understanding interactions in these three energy regimes (fusion, fission, and thermalized) plays a key role in understanding the performance of the U.S. nuclear weapons test program and our ability to use that information to predict the performance of untested designs. In addition, recent work has led to increased interest in understanding reactions from "simmering" neutrons, those with energies from 1 keV–1 MeV, exactly the gap between the WNR and the Lujan Center.



John Ullmann works on DANCE, the Detector for Advanced Neutron Capture Experiments, which captures the radiation emitted from neutron capture reactions to measure nuclear data for Office of Experimental Sciences research programs.

LANSCE is addressing this gap with a new design for the target at the Lujan Center, planned to be installed in 2020. The target performance is primarily determined by two factors: the number of neutrons produced at relevant energies and how well focused those neutrons are in time. The new target increases the number of neutrons in the intermediate energy region by as much as a factor of 10, relative to the current target. In addition, by reducing the time the neutrons spend in the water bath, the neutrons are delivered to the target stations with better focus. The net result of these effects can be seen in the data on the previous page, where features in the data that were previously obscured clearly stand out.

Several instruments at the Lujan Center will benefit from the new target, which will enhance our capability to perform measurements on radioactive isotopes. Despite the key role these isotopes play in reaction chains used to interpret past nuclear tests, many of the interaction probabilities have not been measured. The new target will expand our capability to measure neutron cross sections for many more of these as-yet unmeasured isotopes. DANCE, the Detector for Advanced Neutron Capture Experiments, measures neutron-induced reactions where the neutron is absorbed by the target, making a heavier nucleus. DANCE was built with investment from the Los Alamos Laboratory Directed Research and Development Program and is the premier instrument in the world for these types of measurements. It will directly benefit from the new target. A new instrument at the Lujan Center, DICER, the Device for Indirect Capture Experiments on Radionuclides, expands the range of radioisotopes that can be investigated by separating the radioisotope sample from the detector. By measuring the nuclear structure properties of exactly those resonance peaks whose signal is dramatically increased by the new target design, DICER will enable nuclear theorists at Los Alamos to provide reliable predictions of important nuclear cross sections.

Chi-Nu measurements obtain prompt fission neutron spectra for uranium-235 and plutonium-239

Accurate nuclear data on neutron-induced fission form the basis of criticality calculations essential for nuclear weapons and power plants. The energy spectra of neutrons produced in neutron-induced fission reactions, known as prompt fission neutron spectra (PFNS), are a significant contributor to reactivity in such systems. The NNSA supports an effort at LANSCE to improve these experimental data. This work, called the Chi-Nu project, has been seeking data from the neutron-induced fission of both uranium-235 and plutonium-239.

The project reached an NNSA Level 2 milestone when researchers at Los Alamos and Lawrence Livermore national laboratories completed PFNS measurements on neutron-induced fission of uranium-235 and plutonium-239 for incident neutrons from 1–20 MeV. They also made clear observations of two neutron spectral features from nuclear fission. These features—multi-chance fission and pre-equilibrium, pre-fission neutron emission—were either poorly understood or never before observed in the fission neutron spectrum.

Multi-chance fission implies that one or more neutrons were emitted after equilibrating with the target nucleus but prior to nuclear fission, thereby altering the identity of the nucleus undergoing fission as well as the energy spectrum of neutrons associated with the fission event. Significant differences in the probability of different multi-chance fission modes were observed between the uranium-235 and plutonium-239 systems, contrary to fission model predictions in some cases. Pre-equilibrium, pre-fission neutron emission occurs in more energetic systems and changes the emitted neutron spectrum from fission as a function of detection angle. Neither this process nor its angle dependence had been observed for the neutron-induced fission of plutonium-239 and there were sparse data on this feature for uranium-235 prior to Chi-Nu.

These results were made possible after the team developed new tools to properly interpret the measured neutron spectra. The results reduce uncertainties in calculations of fast nuclear systems, help guide future evaluations of prompt fission neutron spectrum data, and shed light on some poorly understood features of nuclear fission.

The Chi-Nu team collected data using a two-arm time-of-flight technique. Fission events were detected with a parallel-plate avalanche counter, and the time difference between fission and incoming neutron creation times yielded the incoming neutron energy. Neutrons were detected in either a lithium-6 glass or liquid scintillator detector to measure low- and high-energy neutrons. The time difference between neutron detection and fission times yielded the outgoing fission neutron energy.

Despite the differences in behavior and detection mechanisms of these two detectors, the Chi-Nu team was able to combine data from each detector type to form a single measurement of the prompt fission neutron spectra from uranium-235 and plutonium-239 spanning the largest outgoing neutron energy range ever measured in a single experiment.

Neutron Radiography and Imaging at LANSCE

Ron Nelson mounts a 62.3 million-year-old *Tetraclaenodon puercensis* skull in front of a neutron imaging setup.

Nondestructively imaging objects to reveal critical detail

Neutron radiography can generally be described as the process of probing an object's features based on the attenuation of neutrons that pass through it. Similar to other types of imaging techniques, neutron radiography is considered to be a nondestructive probe, meaning that the object is not compromised during the examination process. Additionally, the use of neutrons for imaging offers certain advantages over more conventional radiography probes, such as x-rays. Given that neutrons interact with the nucleus, rather than electrons in the case of x-rays, complex attenuation functions emerge that depend both on the energy of the incoming neutrons and the isotopic composition of the object being imaged. These dependences result in slow neutrons being heavily attenuated by light elements—such as hydrogen, boron, or lithium—while heavy materials such as tantalum, lead, or uranium are almost transparent to high-energy neutrons. As a result, neutron radiography enables researchers to image objects with complicated and wide-ranging density distributions.

At LANSCE, the 800-MeV pulsed-proton linear accelerator, when coupled with spallation neutron targets such as the 1L Target at the Lujan Center or Target 4 at the Weapons Neutron Research Facility (WNR), provides capabilities for imaging with neutrons across a broad range of energies with both traditional and unique-to-LANSCE techniques.

With the tightly pulsed nature of the protons arriving at the 1L Target, neutron radiographs can be resolved based on the energy of the neutrons (measured by their time-of-flight) traversing the object. When this technique, known as energy-resolved neutron imaging (ERNI), is applied to the epithermal energy region, isotope-specific interaction resonances in the transmission spectrum can be used to obtain isotopic densities. Furthermore, determining these isotopic quantities in a two-dimensional image over a range of sample orientations allows for a full computed tomographic reconstruction of the densities of the various isotopes.

Additional neutron imaging capabilities at the Lujan Center include thermal (cold) neutron imaging on the Asterix beam line. This beam line can measure surface properties and buried interfaces. Using techniques such as phase contrast imaging on Asterix, the hydrogen distribution in materials, which is difficult to study using other probes, can be examined.

Fast (E_n > 1 MeV) neutrons can penetrate materials that are too dense for high-energy x-rays. Using the unmoderated fast spallation neutrons from Target 4 at the WNR, fast neutron imaging is performed on Flight Path 60 Right (4FP-60R). The figure below shows an example of such imaging performed on a 74.5 million-year-old tyrannosauroid dinosaur (*Bistahieversor sealeyi*) collected from northwestern New Mexico.

Using multiple fast neutron radiographs stitched together to cover the entire skull, scientist are able to observe features in the anatomy that may be preserved inside the skull, such as nascent teeth in the jaw, the cranial endocast or braincase, sinuses, and pathways of blood vessels and nerves.

Optical image of a 74.5 million-year-old tyrannosauroid dinosaur (*Bistahieversor sealeyi*) with an overlay of several fast neutron radiographs stitched together to show the internal structure of the neck region. Looking at the neutron radiographs, the occipital condyle inside the skull can be directly observed.

The Industrial Program at LANSCE

LANSCE user Bharat Bhuva (left) and Steve Wender set up an electronic device test in the ICE House.

Serving the semiconductor electronics community

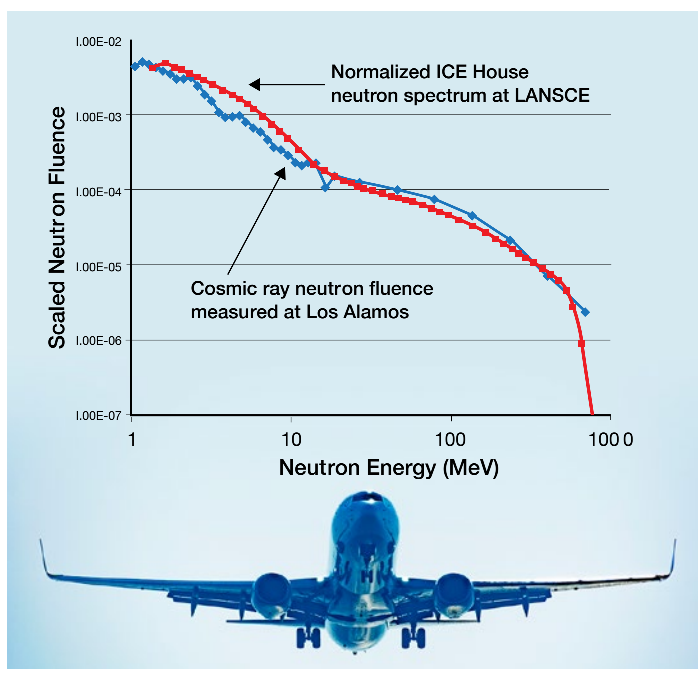
Semiconductor devices are ubiquitous in modern society. They enable cell phones and other communications devices. They are in control systems of all modern equipment, including airplanes, cars, and other machinery. They are in medical devices and diagnostic equipment. All modern business and financial systems use computers, which rely on semiconductor devices. Even washers, dryers, and dishwashers use semiconductor devices. It would be hard to imagine life without transistors and integrated circuits. In 2015, it was estimated that there were almost 170 billion transistors for every man, woman, and child on the planet.

The use of these semiconductor devices is not without concerns. The greatest failure mode of these devices comes from neutrons produced in the atmosphere by naturally occurring cosmic radiation. When cosmic rays (mostly multi-GeV protons) strike the atmosphere, nuclear reactions occur with the nitrogen and oxygen in the air and produce energetic particles. Neutrons, because they are uncharged, can travel long distances and reach places where people and semiconductor devices exist. These cosmic-ray neutrons interact with the silicon in the semiconductor devices and produce charged particles, which in turn deposit charge near the sensitive volumes of transistors and cause failures. These failures range from "flipping a bit" but leaving the device operational to actually causing the device to fail. Such failure modes are called "single-event effects" (SEEs) because they are caused by a single neutron.

The high-energy neutron source at the LANSCE Weapons Neutron Research Facility (WNR) provides a neutron spectrum very similar to the neutron spectrum produced by cosmic rays. This allows companies to test their devices and predict the failure rate in a real-world environment. The ability to measure these failure rates is critical in producing safe and reliable products.

Two flight paths at WNR are used for these tests: Irradiation of Chips and Electronics (ICE) House and ICE-II. This run cycle, there were 25 proposals from industry users (99 days) and 14 proposals from university and other Laboratory proposals to use these flight paths. These proposals came from semiconductor manufacturers, computer companies, avionics, medical, and high-performance computing businesses, and others. Approximately 147 unique users were involved in these ICE House measurements.

This run cycle we began developing a capability to study proton-induced SEEs at Target 2. Protons are a particular threat for satellites in earth orbit, so are of concern to the defense, global security, and satellite communications communities. We also developed the capability to measure SEEs due to thermal neutrons. Thermal neutrons have become a concern for the avionics community as boron-10 has begun to be introduced into modern semiconductors. Boron-10 has a very high neutron capture cross section for thermal neutrons and subsequently emits a gamma ray, which can cause SEEs. This is a concern because materials present on airplanes, mainly jet fuel, will thermalize the high-energy cosmic-ray neutrons, dramatically increasing the likelihood that they will be absorbed by the boron-10 present in the avionics' semiconductors. The neutron intensity at 35,000 feet above sea level is roughly 300 times greater than at sea level, further increasing the threat to aircraft.



The neutron spectrum at the ICE House is similar to that of neutrons produced in the atmosphere by cosmic rays, but with a neutron flux a million times higher, depending on altitude. This large flux allows testing of semiconductor devices at greatly accelerated rates.

Isotope Production
at LANSCE

Dave Reass (left) and Eva Birnbaum in the IPF. The IPF uses the LANSCE accelerator to produce isotopes for medical imaging, fundamental nuclear physics, national security, environmental science, and industrial applications.

Meeting the need for isotopes in short supply

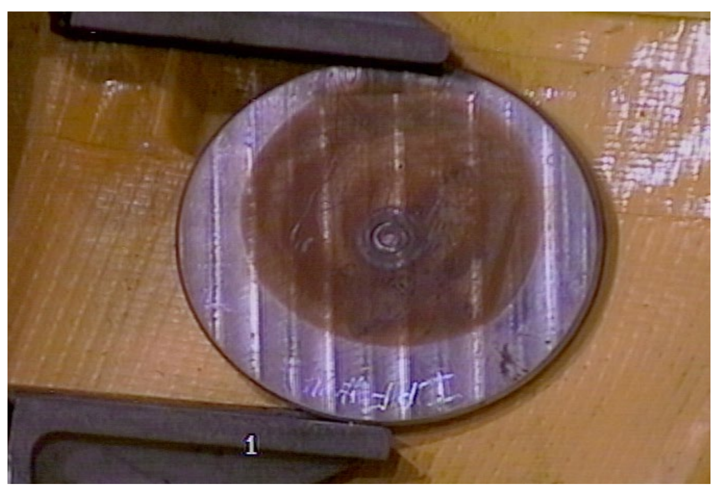
Los Alamos National Laboratory has produced radioactive isotopes for medicine and research since the mid-1970s, when targets were first irradiated using the 800-MeV proton beam from what was then known as the Los Alamos Meson Physics Facility. Today, the Los Alamos Isotope Program, using the capabilities of LANSCE and its Isotope Production Facility (IPF), supplies a wide range of radioisotopes for clinical and industrial use and to scientists all over the world to support diverse research activities. Throughout its history, the Los Alamos program has been a leader in developing and producing new and unique isotopes for research and development.

Since its inception in 2004, the IPF has delivered on its primary mission—to produce strontium-82 (Sr-82) and germanium-68 (Ge-68) for medical imaging. The 100-MeV proton beam delivered to the IPF is well suited for the large-scale production of these isotopes. Isotopes are produced by bombarding targets with a high-current proton beam and then using radiochemical techniques to separate the desired product from the target material. The Sr-82 produced at the IPF during the 2018 run cycle resulted in an estimated 200,000 patient cardiac scans. The Ge-68 produced at the IPF is shipped to companies manufacturing Ge-68/gallium-68 (Ga-68) generators. These generators supply short-lived Ga-68 used to image cancers and other diseases.

Looking forward, the IPF's mission is adapting to meet the United States' need for new isotopes supporting the emerging field of targeted therapy for the treatment of a variety of cancers. The Los Alamos Isotope Program is scaling up production of the therapeutic isotope actinium-225, a relatively short-lived α-emitting isotope currently being tested in clinical trials. It is also performing proof-of-concept irradiations to produce antimony-119 and rhodium-103m, Auger-emitting isotopes that are in early, pre-clinical research stages, and silver-111g, a β-emitting isotope also in early research stages. The goal is to make available a suite of new isotopes that can be used to expand the toolkit for the treatment of cancers and other diseases.

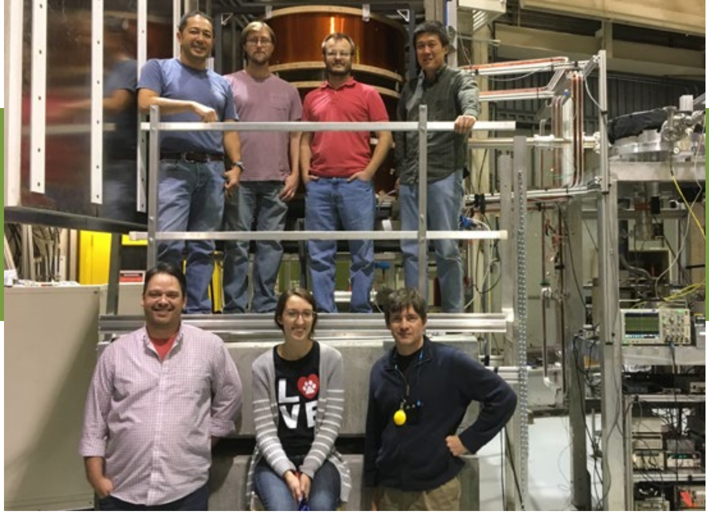
The IPF is also actively engaged in addressing the U.S. need for systematic measurement of proton-induced production cross sections in the energy range below 200 MeV. The next measurement campaign will measure cross sections for the production of selenium-72 (a promising parent isotope for positron emission tomography [PET] medical imaging). The large-scale production capability of the IPF is also being leveraged to produce unstable targets for other needed nuclear data experiments.

To support these new isotope production and nuclear data focus areas, the IPF team recently commissioned a novel beam window assembly and an associated suite of new diagnostics, as well as a complex beam raster system. The improved window assembly simultaneously supports enhanced isotope production with demonstrated beam currents as high as 350 microamps and research irradiations conducted with measured beam currents as low as 0.1 microamps. The new window assembly employs a one-of-a-kind adjustable graphite collimator that permits irradiation of targets ranging from 1.4 –2.3 inches in diameter—allowing a single target station to serve both large-scale production and small-scale research needs. The IPF will continue to supply needed isotopes as part of the DOE Isotope Program.



A thorium target irradiated at the Isotope Production Facility at 250 microamps, generating ~ 125 mCi of actinium-225 at the end of bombardment. This is the highest proton current used for generating actinium-225 and is an important step towards Ci-scale production.

Fundamental Physics at LANSCE



The prototype LANL nEDM apparatus with some of the scientists working on the experiment. Top row, from left: Takeyasu Ito, Steven Clayton, Ryan Dadisman, Brad Plaster. Bottom row, from left: Robert Pattie, Alina Aleksandrova, Josh Long.

Making basic nuclear and particle physics discoveries

LANSCE operates a source of ultracold neutrons (UCNs). UCNs are very slow neutrons with typical velocities up to several meters per second. They can be stored for hundreds of seconds or longer in a bottle made of suitable materials or permanent magnets, providing an ideal tool for precision measurements of their properties. The LANSCE Ultracold Neutron Facility is one of the brightest UCN sources in the world and is the only operating source in the United States.

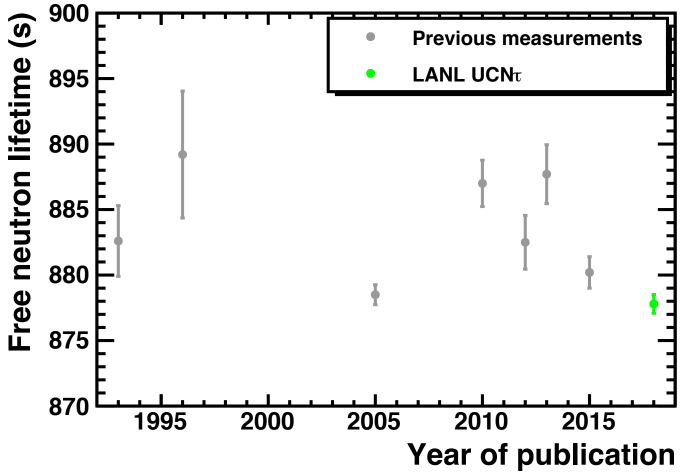
At LANSCE, UCNs are produced by moderating and cooling spallation neutrons produced by striking proton pulses from the LANSCE accelerator onto a tungsten target. The LANSCE accelerator makes it possible to run the Ultracold Neutron Facility in an ideal fashion by directing a proton pulse to the UCN source every 5–10 seconds.

The Ultracold Neutron Facility, which began operation almost 20 years ago, hosts two major efforts, the UCNτ and LANL nEDM experiments, along with various other efforts. The UCNτ experiment measures the lifetime of the free neutron. This is an important input parameter for the description of the processes that took place in the early universe in which different light elements were synthesized. It is also important in testing the consistency of the Standard Model of particle physics. Inconsistency would imply new particles and/or interactions that cannot be described by the Standard Model. Although extremely successful, the Standard Model is known to be incomplete. One of the major efforts in particle and nuclear physics is directed to making it complete. The UCNτ experiment confines UCNs using gravity and magnetic fields. This completely eliminates the loss of UCNs due to material interactions, which introduced large systematic uncertainty in many of the previous experiments.

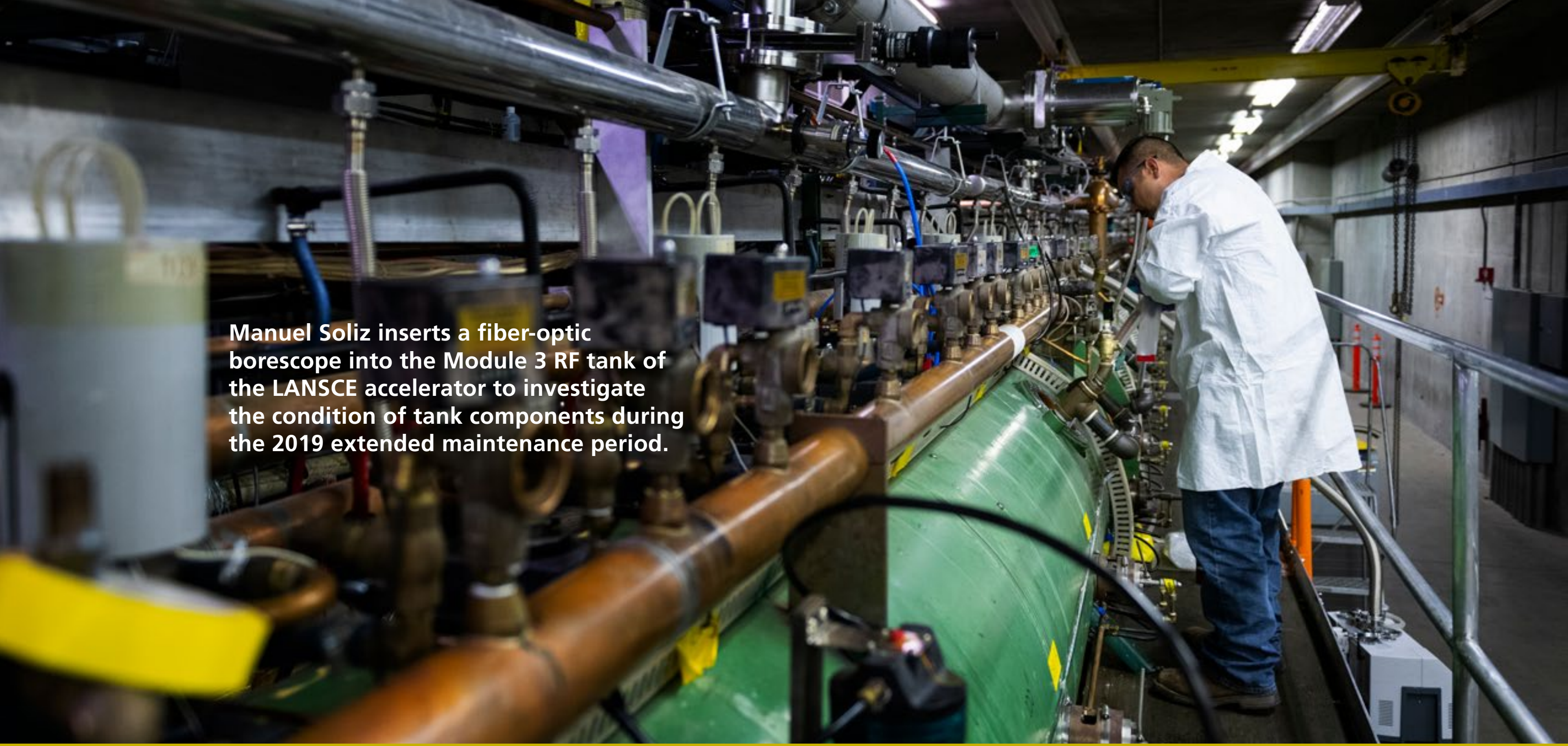
In 2018, the UCNτ collaboration reported a measurement of the free neutron lifetime with an uncertainty of 0.8 s, the most precise determination to date. Our goal is to reduce the uncertainty to 0.3 s, where the uncertainty contribution to the Standard Model consistency test from the neutron lifetime is less than the theoretical uncertainty. During the 2018 LANSCE run cycle, the collaboration took an important first step by upgrading the apparatus and performing detailed studies of major remaining systematic effects.

The goal of the LANL nEDM experiment is to search for the neutron's permanent electric dipole moment, a measure of the separation of positive and negative charges inside the neutron. A non-zero nEDM, if observed, would be a clear indication that there are phenomena that cannot be described by the Standard Model. There is a strong motivation for looking for a signal of nEDM, as it could help solve the mystery of why the universe has so much more matter than antimatter, a question that the Standard Model cannot answer. The goal of the LANL nEDM collaboration is to build the experiment in the next two years. During the 2018 run cycle, the collaboration performed a proof-of-concept measurement using a prototype apparatus.

Most of the experiments hosted at the Ultracold Neutron Facility are collaborative efforts with university researchers that attract young scientists, many of whom decide to come to Los Alamos National Laboratory as postdoctoral researchers or staff members and work in other areas of the Laboratory. Thus, the LANSCE UCN source functions as a pipeline for young talent in addition to producing world-class science.



Comparison of the recent UCNτ result and the recent previous measurements. The measured free neutron lifetimes are plotted against their years of publication



Manuel Soliz inserts a fiber-optic borescope into the Module 3 RF tank of the LANSCE accelerator to investigate the condition of tank components during the 2019 extended maintenance period.

The LANSCE Accelerator

Phil Torrez makes adjustments to the new digital LLRF system at Module 3 of the LANSCE accelerator.

Enabling scientific advances through operational efficiencies

The 800-MeV, one-kilometer-long linear accelerator (linac) is the backbone of LANSCE, delivering protons to support the Lab's national security science mission. In preparation for the 2019 run cycle, Accelerator Operations and Technology Division (AOT) staff are repairing and upgrading systems, with numerous improvements nearing completion.

Starting at the accelerator's "front end," AOT scientists, engineers, and technicians, who are system experts on ion sources and accelerator injection systems, have improved the H^- ion source. The ion source takes hydrogen gas and converts it into a stream of negatively-charged hydrogen ions. This stream of charged ions can then be accelerated to high speeds by electric fields. Benefits of these improvements include a longer and more reliable source lifetime and increases in the amount of peak beam current that the source produces, benefitting all of the H^- experimental facilities (the Weapons Neutron Research Facility, the Lujan Center, the Ultracold Neutron Facility, and the Proton Radiography Facility). Lab staff are also collaborating with researchers at the Spallation Neutron Source at Oak Ridge National Laboratory to develop the next generation of the LANSCE ion source, one capable of even longer lifetimes at higher currents.

In the linac itself, electrical engineers and technicians from AOT's Radio Frequency Engineering group are taking the antiquated low-level radio frequency (LLRF) control systems based on analog electronics and replacing them with modern, digital LLRF systems. The systems—located in the 201-MHz section of the linac, which takes the particle beams from the injection system and uses high-power RF electric fields to accelerate them to 100-million-electron-volts of energy (42% the speed of light)—have operated under normal production conditions for two years. This new system was tested in numerous modules at the front end of the 805-MHz section of the linac during the 2018 run cycle. Further testing and commissioning of the system will continue on the

805-MHz system while the infrastructure needed for these systems is installed throughout the rest of the 805-MHz linac over the course of the next few years.

During the course of the accelerator's 46-year-operation, performance issues and degradation are a reality that must be diagnosed and addressed. An important example is the RF structure for Module 3 of the drift tube linac, which has undergone a significant increase in electrical arc-downs within the tank. As a result, accelerator performance has been affected to the extent that the available beam repetition rate had to be reduced. Teams within AOT have made it a high priority to investigate the cause of this performance issue, making use of scheduled machine intervention periods during operations and dedicated testing during the first part of the 2019 extended maintenance period. This investigation is ongoing.

AOT is responsible for the target systems at the Lujan Center and the Weapons Neutron Research Facility. The active Target Moderator Reflector System (TMRS) at Lujan will be at end-of-life and replaced by a newly designed system by 2020. Procurement and fabrication are under way. Tungsten is at the heart of the TMRS, and when it is struck by a high-energy beam of protons, neutrons come off the tungsten in a process known as spallation. The moderators slow the neutron beams to an energy range that is suitable for the experiments conducted at the Lujan Center.

AOT staff continue to implement improvements and upgrades to the accelerator that make the machine more reliable and make better use of the available proton beam. As an example, the Proton Radiography and Ultracold Neutron facilities share a particle beam line. Until 2019, the Ultracold Neutron Facility could not operate while personnel were within the proton radiography dome preparing for a shot. During the 2018 extended maintenance period, additional shielding was installed that allows the Ultracold Neutron Facility to operate while personnel are present within the dome. This has resulted in increased available beam time to the Ultracold Neutron Facility.

AOT tracks accelerator reliability and uses the information to assess system performance. Beam downtimes are automatically detected by the accelerator logging system and documented by the operations staff. AOT is also developing a more detailed, division-wide maintenance analytics process, starting with a risk registry currently undergoing refinement.

As part of the process to investigate and optimize the performance of the LANSCE accelerator, AOT has made use of increased machine intervention/studies periods. During these periods we investigate machine issues, make progress on upgrade activities requiring beam, and optimize the performance of the machine. Investigations into the Module 3 arc-downs and unusually high beam spill levels in the proton storage ring were conducted during machine intervention/studies periods. Digital LLRF work and beam energy measurement improvements that required beam on were also scheduled for these periods. Information from these activities goes into extended maintenance period planning. AOT staff continue to improve outage planning to make the best use of the time available during these maintenance periods. Organizational changes have been implemented to make improvements in such areas as operations physics support of start-up, tune-recovery activities, and H^- source performance and reliability.

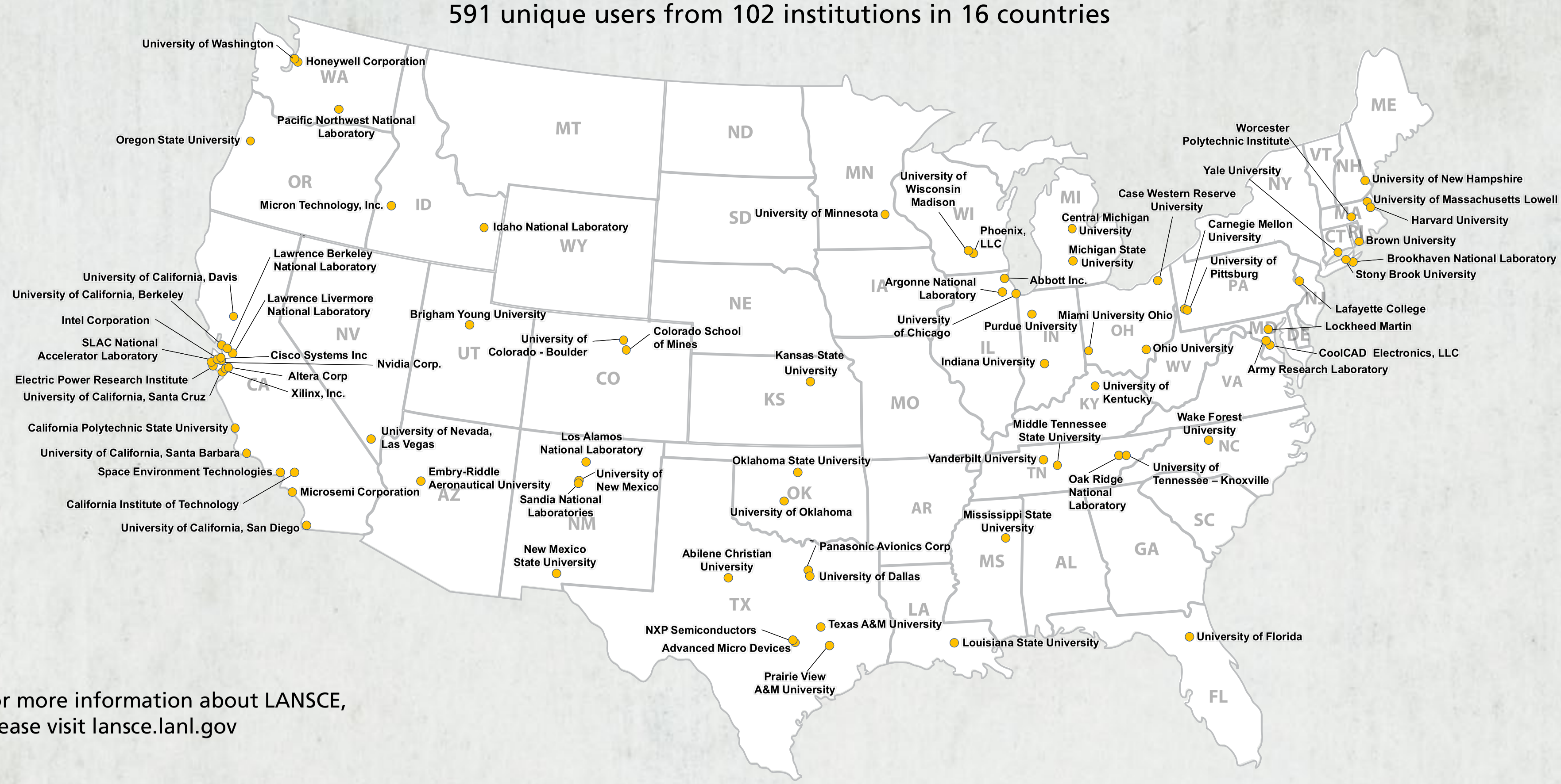
The accelerator capability needed to maintain, operate, and improve the performance of LANSCE and DARHT gives Los Alamos the skill set required to address emerging national security needs. DARHT is the Dual-Axis Radiographic Hydrodynamic Test Facility, the world's most powerful x-ray machine, which is used to analyze mock-ups of nuclear weapons.

As an example, AOT is supporting the Neutral Particle Beam Program, a multi-lab effort with much of the work centered at LANSCE. AOT is also involved in the development of the Scorpius accelerator for the Enhanced Capabilities for Subcritical Experiments (ECSE) Program. ECSE will enable scientists to better understand the behavior of plutonium when it is subjected to extreme pressure from explosively driven shocks, which is key to NNSA's science-based Stockpile Stewardship Program. Finally, LANSCE is a potential site for the Dynamic Mesoscale Materials Science Capability (DMMSC), which DOE has determined to be a mission need. DMMSC will require a state-of-the-art accelerator capability to be successful. Such a capability would allow researchers the ability to control the production and performance of materials at the mesoscale and realize transformational advances in materials behavior, response, and fabrication.

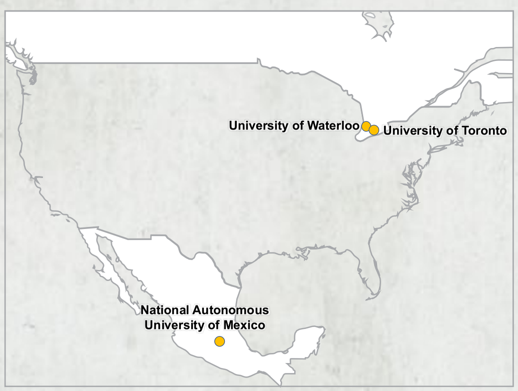
Operators Rodney McCrady and Mark McMillen team up to tune and operate the LANSCE linear proton accelerator.

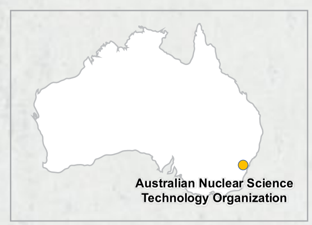
2018 LANSCE Run Cycle User Institutions

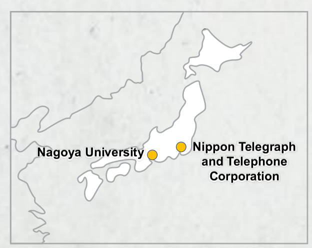
591 unique users from 102 institutions in 16 countries

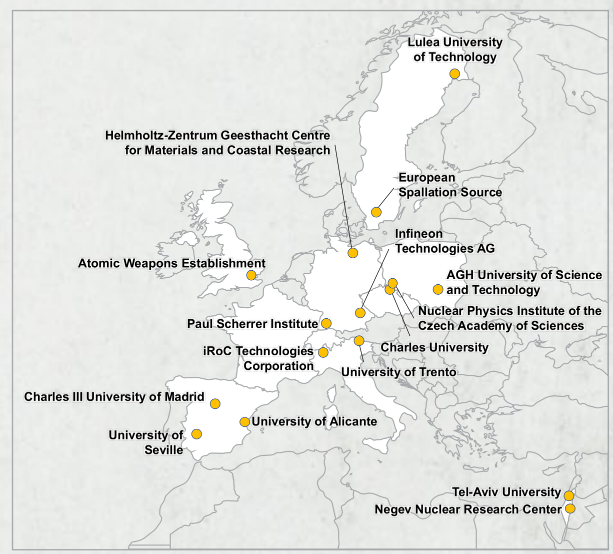


For more information about LANSCE, please visit lansce.lanl.gov









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NNSA National Nuclear Security Administration

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