the Pulse
LANSCE Los Alamos Neutron Science Center
Summer 2017

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LANSCE researchers are studying enhancements in neutronic performance of the Mark-IV target design at the Lujan Center (pictured above).

Expanding research opportunities

Towards a new and improved Lujan Center neutron-production target

> *These improvements will broaden the reach of nuclear-physics experiments at the Lujan Center while simultaneously maintaining its world-class material research program.*

The neutron-production target at the Lujan Center (known as the 1L target) must be replaced periodically to ensure operational reliability—with the current Mark-III target assembly anticipated to be replaced during the Los Alamos Neutron Science Center's (LANSCE) 2020 extended maintenance period.

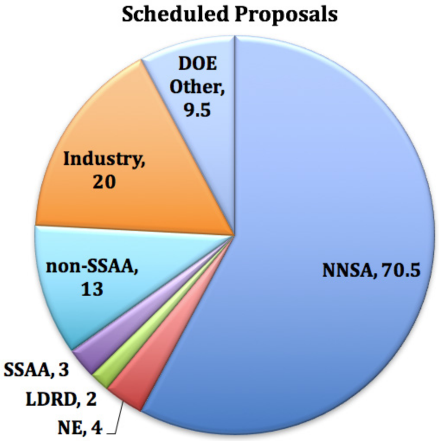
To take advantage of this necessity, a team of Los Alamos researchers is studying enhancements in neutronic performance of the replacement, the Mark-IV design. Its principal goals are to 1) increase the flux and improve the resolution for neutron energies above 1 keV for nuclear physics experiments and 2) preserve the current strong performance at thermal energies for material science.

These improvements will broaden the reach of nuclear-physics experiments at the Lujan Center while simultaneously maintaining its world-class material research program. These two main goals are, however, often at odds and drive target design in opposite directions. Fortunately, a key feature of the 1L target assembly allows researchers to circumvent this conundrum.

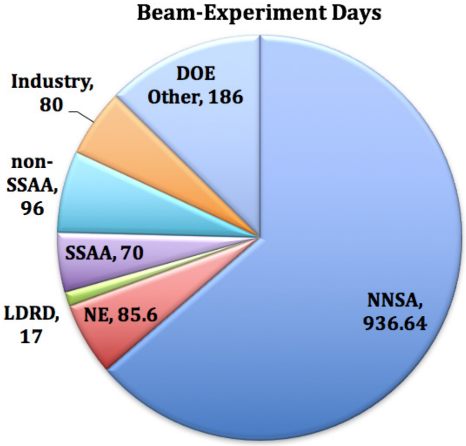
continued on page 4

From Gus's desk . . .

We had another highly successful run cycle at LANSCE. The accelerator operated at more than 85% availability, with exceptionally high availability in the last month of operations. At the three NNSA designated national user facilities (pRad, WNR, and Lujan Center), we hosted 547 unique users, ran 122 proposals, and scheduled 1,471 beam-experiment days. The graphics at right show the breakdown of proposals and beam-experiment days by sponsor. NNSA continues to be the dominant sponsor of our programs, and we continue to deliver critical data for national security missions. As of this writing we have completed the proposal review process for all three user facilities for the upcoming run cycle. Scheduling information will be sent out shortly to the successful PIs.


Scheduled Proposals

This has been a busy outage with a lot of maintenance work. We have removed the bulk of the high-resolution spectrometer from the pRad dome and performed much of the D&D of the flight paths in the Lujan Center owned by the DOE Office of Science. The Accelerator Improvement Project for the Isotope Production Facility (IPF) has been successfully completed with the replacement of the beam window and collimator with a new beam window assembly that includes an active adjustable collimator. This will enable a factor of two increase in the irradiation level of IPF targets. And please check out the June issue of *Popular Mechanics*, where the IPF team and its work are highlighted.


Beam-Experiment Days

> “*While we continue to perform outstanding science in support of our national security mission, we also strive to improve our operational excellence.*”

While we continue to perform outstanding science in support of our national security mission, we also strive to improve our operational excellence. This year we have had several incidents that highlighted weaknesses in our work control procedures. The unauthorized removal of a large roll-off bin with recyclable metals was the most serious event on the mesa and has led us to revamp our entry and exit procedures. In addition to this event, we had several instances of people working on site without proper dosimetry, training, and in one case, without the knowledge of any on-site RLM.

We have convened a learning team, held a series of all-hands meetings, and discussed the path forward with group and division managers. While there are still some details to work, the overall plan is taking shape. We will require a badge swipe for entry to TA-53 (residents may be given a residents card that indicates a badge swipe is not needed). The swipe will result in either a red or green light. A green light indicates that the person is authorized to work at TA-53. A red light indicates that the person is not authorized to work at TA-53. If a person is here for a meeting, presentation, training, car pool, etc., they may proceed to their destination. If they are here to perform other work, they must report to the Visitor Center in Building 1 prior to going to their destination. Work authorization will be given by group-level managers. We expect to complete the needed changes to the guard station this fiscal year and will implement changes to the Visitor Center next fiscal year. We will increase coverage at the Visitor Center to accommodate these changes. Our hope is that we will not significantly impact entry and egress from TA-53, and we will perform traffic studies prior to finalizing the procedures. If we encounter significant issues, we will adapt the system as needed.

While these changes will help us with work control on the mesa, no system is perfect. To ensure a safe and secure work environment takes the engagement and awareness of all of us. This has always been a great place to work and that is really because of you, the people that work on the mesa. Continue to look out for each other and let's have another great run cycle.

LANSCE User Facility Director Gus Sinnis

“We must continue to deliver. We must continue to provide results for the nation’s Stockpile Stewardship Program, solve national security science challenges, and deliver for all of our users; something I am sure the team here on the mesa can do.”

Mary

From Mary’s desk . . .

LANSCE is on good footing as we head into the next run cycle. I’m pleased to share that the President’s FY18 Budget Request includes the replacement target for the Lujan Center. This funding will enable us to design, procure, and construct the target. (For details about the target, please see the issue’s cover article). To me, this clearly shows LANSCE is viewed as essential to the nation.

But that doesn’t mean we can be complacent. We must continue to deliver. We must continue to provide results for the nation’s Stockpile Stewardship Program, solve national security science challenges, and deliver for all of our users; something I am sure the team here on the mesa can do.

Given that, I am eagerly looking forward to the next run cycle.

Associate Director Experimental Physical Sciences
Mary Hockaday

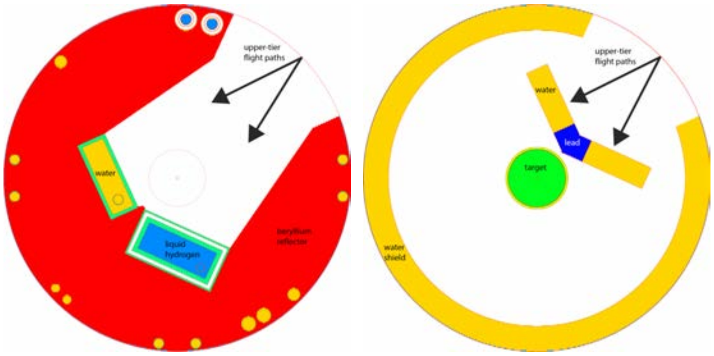


Figure 1: plane view through the upper-tier moderator suite. Left figure depicts the Mark-III design with two moderators and a large beryllium reflector. Right image shows the new configuration studied for Mark-IV design with target in the field-of-view.

Target cont.

The LANSCE accelerator proton beam is directed through the split target geometry of the Mark-III assembly. Two levels of horizontal flight paths perpendicular to the axis of the proton beam view two different tiers of the 1L target. This two-tier design naturally facilitates simultaneously optimizing the two energy regions. The basic plan is to optimize the upper and lower tiers for nuclear physics and materials science, respectively. As the flux-trap geometry of the lower tier is already well optimized for superior thermal and cold neutron performance benefiting material science experiments, the Mark-IV design effort has focused on increasing the kiloelectronvolt flux and improving the resolution of the upper tier.

Figure 1 shows a horizontal slice through the upper tier of the 1L target at the center of the beam lines. Depicted are the current Mark-III design on the left and a studied Mark-IV design on the right. There are four main changes between the Mark-III and this Mark-IV design: 1) the tungsten spallation target has been raised so that it is in the field of view of upper-tier flight paths; 2) the beryllium reflector has been removed; 3) both moderators are water; and 4) a water liner has been added to the inside surface of the outer lead reflector-shield. The first change was made to increase the flux of neutrons above 1 keV. The main purpose of the other three changes was to improve the resolution.

Monte Carlo N-particle (MCNP) simulations were run to assess design performance. These simulations indicate that the flux in the 20–1000 keV range is two to five times higher in the Mark-IV design. Time profiles of the beam were also extracted from the MCNP simulations. The narrower these profiles the better the resolution and hence, performance for nuclear physics experiments. The profile width is affected both by the 1L design as well as the width of the proton pulse impinging on the target. This latter width can be varied by tuning LANSCE accelerator components.

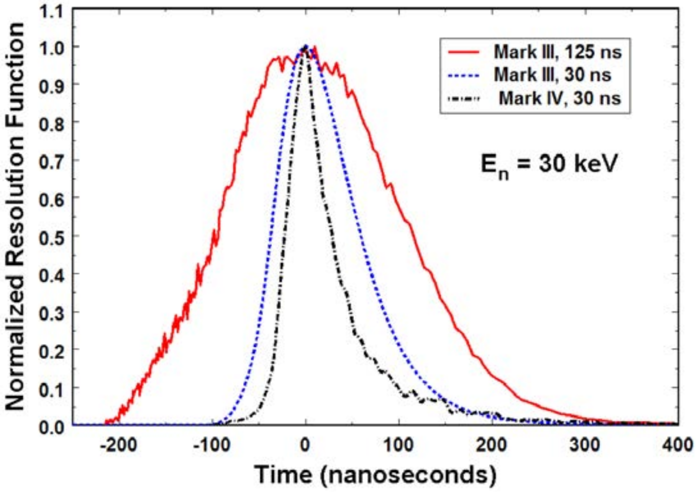


Figure 2: pulse time profiles at a neutron energy of 30 keV. See text for details.

Figure 2 shows several profiles at a neutron energy of 30 keV. The profiles have been normalized to a maximum of 1.0 and shifted so that the maximum occurs at a time of zero. The solid red profile represents the current Mark-III target with a FWHM proton pulse width of 125 ns. This is the standard operation condition of the current facility. The blue dashed profile represents the expected result from reducing the proton pulse width to 30 ns.

One might naively expect the profile width to decrease by a factor of four, reflecting the corresponding reduction of the proton pulse width. As shown in the figure, however, only about a factor of two improvement is achieved. The expected proportional reduction is not achieved because the 1L target itself is making a substantial contribution to the pulse width, even at this relatively high energy. The contribution of the 1L target also is reflected in the asymmetry of the dashed blue profile. Finally, the dot-dashed black profile is for the Mark-IV design shown in Figure 1, with a proton pulse width of 30 ns. This candidate Mark-IV design has significantly improved resolution, which is calculated to persist across a wide range of energies of interest to nuclear physics experiments.

It is important to benchmark simulations with data. To that end, the researchers measured transmission spectra through a gold sample using an apparatus being developed on Flight Path 13. Gold has many resonances that can be used to benchmark the resolution at kiloelectronvolt energies. Figure 3 shows a small portion of the data taken with proton pulse widths of 125 and 30 ns. Also shown in this figure are R-matrix calculations of the expected transmissions using the code SAMMY, which has been used for more than 40 years for these kind of analyses. SAMMY employs pulse profiles such as those shown in Figure 2 to broaden the theoretical transmission. There is good agreement between the data and the SAMMY calculations, lending confidence to the pulse profiles from the MCNP simulations.

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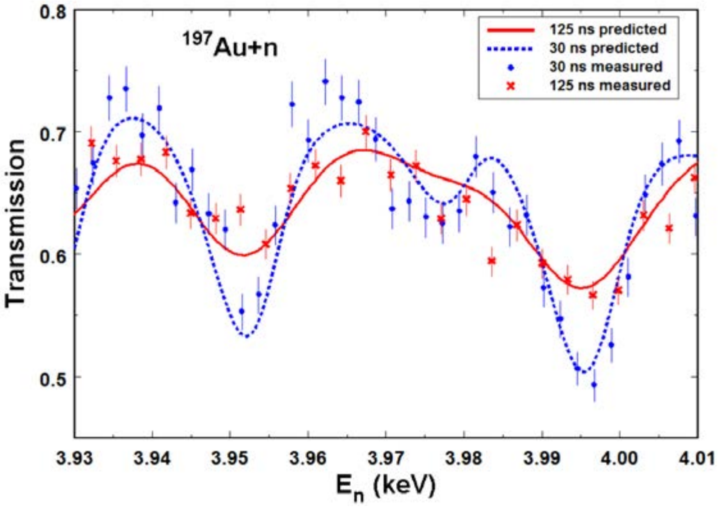

Figure 3: measured and predicted transmission though a gold sample. The data were taken on Flight Path 13 with an instrument under development. The predictions used the R-matrix program SAMMY, which broadens the theoretical transmission over the instrument resolution using time profiles such as those shown in Figure 2.

Target cont.

There is nearly infinite parameter space that could be explored in the quest to find the optimum design. It seems clear, however, that higher flux in the kiloelectronvolt region benefits from having the tungsten spallation target in the field of view or as close to this as possible, and resolution is improved by reducing the moderator size and removing as much material as possible in the target region. Even with these general guidelines there is still a wide variety of shapes and materials to explore.

Researchers include Principal Investigator P. E. Koehler (LANSCE Weapons Physics, P-27), Michael Mocko (P-27), Suzanne Nowicki (Space Science and Applications, ISR-1), John Ullmann (P-27), Don Brown (Materials Science in Radiation and Dynamics Extremes, MST-8), Bjorn Clausen (MST-8), Aaron Couture (P-27), Eron Kerstiens (Accelerator Operations, AOT-OPS), Joe O'Toole (Mechanical Design Engineering, AOT-MDE), Fredrik Tovesson (P-27), Ray Valicenti (AOT-MDE), Sven Vogel (MST-8), Erik Watkins (Materials Synthesis and Integrated Devices, MPA-11), and Stephen Wender (P-27).

These advancements were featured in talks by Koehler, Mocko, and Nowicki at the International Collaboration on Advanced Neutron Sources XXII, held recently in England.

The work, which is funded by Weapons Infrastructure, supports the Laboratory's Stockpile Stewardship and Basic Science missions and the Nuclear and Particle Futures, Science of Signatures, and Materials for the Future science pillars by providing improved nuclear data and nuclear theory of importance to these areas.

Technical contact: Paul Koehler

First demonstration of neutron phase-contrast imaging using a cold neutron source at LANSCE

Similar to x-rays, neutrons can be used to nondestructively image a variety of samples, including nuclear and high explosive components. An advantage of neutrons over x-rays—especially at lower neutron energies—is the ability to image light elements, such as hydrogen-rich polymers, organic compounds, lithium, etc., or to penetrate many materials such as aluminum and lead. In addition, higher energy neutrons can penetrate dense, thick objects of materials such as steel, uranium, or plutonium and allow the study of materials buried inside thick casings.

Because neutrons interact with the atom's nucleus rather than with the electron shell, they can also distinguish between different isotopes of the same element. Typical neutron imaging performed at nuclear reactors or spallation neutron sources, such as LANSCE, requires two-dimensional neutron detectors in which the transmitted neutrons are converted into optical or electronic signals with high spatial resolution (typically from 50–200 μm).

In the usual case, the resulting image is based on the neutron attenuation of the imaged object, showing regions of high versus low absorption. Neutron imaging becomes more challenging, however, if the studied objects have low neutron attenuation cross sections. In such cases the quantum mechanical, wave-like, neutron properties of thermal and cold neutrons can be used to advantage to perform so-called "phase-contrast" or "refraction-enhanced" neutron imaging.

In quantum mechanics, neutrons are described by de Broglie wave packets whose spatial extent (or coherency) may be large enough to show refraction and interference effects similar to what can be observed with visible laser light or highly brilliant x-rays from synchrotron sources. Differing interaction potentials of the neutron wave packets in various materials result in measurable refraction and phase shifts. With intense neutron sources and sensitive detectors, sufficiently short exposure times enable phase-sensitive neutron computed tomography that provides three-dimensional reconstructions of objects of interest (F. Pfeiffer et al., *Phys. Rev. Lett.,* **96***,* 215505, [2006]).

At LANSCE, the Lujan Center's Asterix and SPEAR beamlines provide so-called "cold neutrons" (neutrons with de Broglie wavelengths of ~5-15 Å) that are especially suitable for performing phase-contrast imaging. Preliminary experiments performed by Jaroslaw (Jarek) Majewski (Center for Integrated Nanotechnology, MPA-CINT) and Erik Watkins (Materials Synthesis and Integrated Devices, MPA-11), with the help and support of Adrian Losko (Materials Science in Radiation and Dynamics Extremes, MST-8), Ron Nelson (LANSCE Weapons Physics, P-27), David Montgomery

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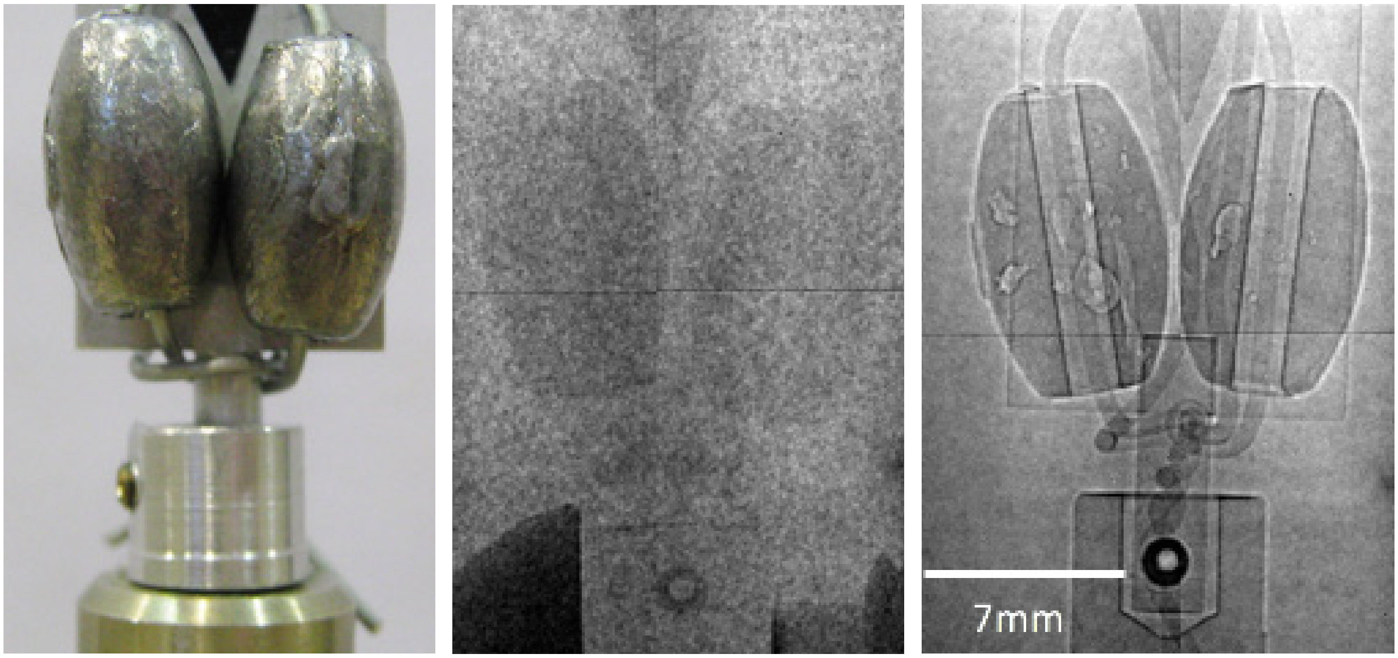


Figure 1 (left): photo of lead sinkers held together with aluminum wires. Figure 2 (center): cold neutron attenuation image of nearly transparent lead and aluminum. Figure 3 (right): cold neutron phase contrast image clearly shows the lead and aluminum outlines.

First cont.

(Plasma Physics, P-24), and Kyle Ramos (HE Science and Technology, M-7), demonstrated that neutron phase-contrast conditions can be realized using the high flux and highly coherent cold neutron beams produced at the 1L target at LANSCE.

The investigated sample (Figure 1) consisted of lead fishing weights suspended by an aluminum wire on a thin aluminum plate. Both lead and aluminum have very low neutron attenuation, with greater than 98% transmission through 1 cm of lead and 96% through 1 cm of aluminum. Figure 2 shows a conventional attenuation radiograph using cold neutrons. The lead and aluminum pieces are difficult to see. Figure 3 shows a cold neutron radiograph where the phase contrast is visible at the interfaces as white and black shades produced by refraction and interference of neutron wave packets.

The ability to perform phase-contrast imaging, as well as cold neutron attenuation radiography at LANSCE, has important applications to issues that arise in explosives fabrication, as well as other programmatic and research areas.

Cold neutron imaging is ideal for materials science studies—for example, examining welds and properties of material bonds, revealing hydrogen distributions and processes occurring in fuel cells, looking at interfaces between materials, and studying issues in the application of adhesives that are often difficult or impossible to study with other techniques. In particular, the new phase-contrast imaging capability can image interior features of solid objects—for example, defects or cracks in low atomic number organic materials and can detect these features inside difficult to penetrate (with x-rays) metal casings.

Cold neutron attenuation imaging and dark-field imaging techniques can be applied using the same flight path and detectors. In addition, the thermal and high-energy neutron beams at LANSCE are available and have been developed to image items requiring greater penetrating power.

This work, which supports the Laboratory's weapons and fundamental science missions, was funded by W76 Stockpile Stewardship, C1 and C2 programs, and benefited from use of equipment and expertise from Enhanced Surveillance.

The work supports the Materials for the Future, Science of Signatures, and Nuclear and Particle Futures science pillars, and can benefit from the Integrating Information, Science and Technology for Prediction science pillar through improved computed tomography reconstruction and analysis algorithms for large and multi-probe data sets.

Researchers include Jarek Majewski (MPA-CINT and Molecular Biophysics Cluster, National Science Foundation, Virginia), Erik Watkins (MPA-11), Adrian Losko (MST-8), Ron Nelson (P-27), David Montgomery (P-24), Kyle Ramos (M-7), Sven Vogel (MST-8), and James Hunter (Applied Engineering Technology, AET-6).

Technical contacts: Erik Watkins and Jarek Majewski

Neutron scattering investigations at LANSCE provide insight into properties of novel nuclear fuels

Thorium, with uranium, is one of only two significantly radioactive elements that occur naturally in large quantities in the Earth's crust. Weakly radioactive, thorium is three to four times more abundant than uranium and its chemical compounds have many applications independent of its radioactive nature.

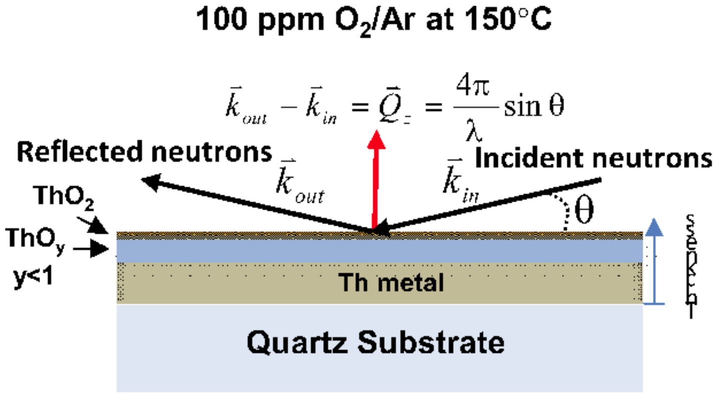
Known as a chemical catalyst, thorium, for example, can improve creep resistance in magnesium alloys and the high-temperature strength of tungsten welding electrodes. It also can improve the light-emitting properties of portable gas lights commonly used during camping trips.

Los Alamos researchers and colleagues used the neutron reflectometry capabilities of LANSCE to better evaluate this versatile element for use as an advanced nuclear fuel.

Thorium (^{232}Th) itself is not fissile. However, it is "fertile" and upon absorbing a neutron will transmute to ^{233}U, which is an excellent fissile fuel with considerable advantages, including safety and proliferation resistance due to reduction of plutonium and minor actinides in the spent light water reactor's fuel stockpiles. However, both simplest forms of thorium considered–the metal or the dioxide–have significant disadvantages. For example, because of poor heat conductivity and the chemical inertness of ThO_2, it is difficult to use it as fuel elements and chemically post-process spent ThO_2-based fuels. Therefore, production and characterization of new thorium-based materials, especially oxides, for nuclear fuels are of great importance.

In "Formation of solid thorium monoxide at near-ambient conditions as observed by neutron reflectometry and interpreted by screened hybrid functional calculations," a group of researchers led by David Allred (Brigham Young University), Kirk Rector (Physical Chemistry and Applied Spectroscopy, C-PCS) and Jaroslaw (Jarek) Majewski (Center for Integrated Nanotechnologies, MPA-CINT) provided evidence that kinetically-favored solid-phase ThO can be preferentially generated as a majority phase under the thermodynamically-favored ThO_2 top layer at conditions close to ambient. ThO is advantageous over common ThO_2 phase due to its higher thermal conductivity, which could make it more suitable as nuclear fuel elements.

The neutron reflectometry (NR) capabilities at LANSCE were used to follow slow oxidation process in the thorium samples. NR is known as a non-contact, nondestructive, high-resolution analytical technique with superb ability to detect even minute amounts of elements like oxygen or hydrogen for precise characterization of chemical speciation. Their work describes how the NR method was extended as a time-resolved (i.e., dynamic), in situ tool to identify the presence, stoichiometry, and growth rate of subsurface oxides layers under controlled conditions. To aid in interpretation of the experimental observations, screened hybrid-functional calculations were performed on various hypothetical thorium-oxygen structures. The conditions that produce the ThO phase may be useful in fabricating bulk materials, perhaps, beginning with submicron-sized thorium powders oxidized in a fluidized bed.



A schematic of neutron scattering experimental setup. The intensity of the reflected neutrons is recorded as a function of the value of the momentum transfer vector *Qz*. The analysis of the intensity distribution provides precise measure of the chemical speciation along the depth of the sample.

Financial support of this work, which supports the Laboratory's Energy Security mission and Materials for the Future science pillar, was provided by the U.S. Department of Energy through Los Alamos's Laboratory Directed Research and Development program. This work benefited from the use of the time-of-flight neutron reflectometer (SPEAR) at the Manual Lujan Neutron Scattering Center at LANSCE, which was funded by the DOE Office of Basic Energy Sciences at the time the data was collected and Los Alamos National Laboratory under DOE contract DE-AC52-06NA25396. The researchers acknowledge the contributions of Michael Whitehead in the experimental setup.

Reference: "Formation of solid thorium monoxide at near-ambient conditions as observed by neutron reflectometry and interpreted by screened hybrid functional calculations," by Heming He (Chemistry Division, now China Nuclear Power Technology Research Institute), Jaroslaw Majewski (MPA-CINT, University of California, Davis), David D. Allred (Brigham Young University), Peng Wang (MPA-CINT, now Intel Corp.), Xiaodong Wen (Chinese Academy of Sciences), and Kirk D. Rector (C-PCS), *Journal of Nuclear Materials,* **487** (2017).

Technical contacts: Kirk Rector and Jarek Majewski

High Performance Computing group tests Trinity computers at LANSCE/WNR Ice House

The ability of Los Alamos to perform its defense program mission depends on calculations that are performed on super computers. Los Alamos has traditionally had some of the latest and most powerful computers in the world to simulate a wide range of situations, including the detonation of nuclear explosives, climate change on earth, and the creation of stars in the galaxy.

Super computers contain billions of bits and thousands of processors. One of the greatest threats to calculations performed on these machines comes from small subatomic particles called neutrons. These neutrons are produced when naturally occurring cosmic rays (mostly high-energy protons) strike the atmosphere and cause nuclear reactions with the elements of air producing neutrons. These neutrons can travel long distances to sea level and hit the semiconductor devices inside super computers. When these neutrons hit semiconductors, they produce charged particles that deposit charge in sensitive volumes of the semiconductor and cause a wide range of failures including single and multiple bit flips, latchups, etc. Because there are so many transistors in super computers, they can be very susceptible to these radiation effects. The exact nature and frequency of these failures are difficult to predict. To determine how sensitive these computers are and how often they can fail, a group from the High Performance Computing (HPC) section of Los Alamos tested modules of the newest super computer, the Trinity machine, at the Weapons Neutron Research Facility's (WNR) high-energy neutron source at LANSCE. The WNR high-energy neutron source produces a neutron spectrum very similar to the neutron spectrum produced by cosmic rays hitting the atmosphere. Computer modules can be placed in the neutron beam and the failure rate in any particular environment can be determined by scaling the neutron intensity.

In December 2016, during the LANSCE run cycle, a HPC team led by Sean Blanchard (HPC-Design, HPC-DES) assembled a group to study the effects of neutrons on elements of the Trinity machine. As part of the experiment, they studied how the new Knights Landing (KNL) processors and the associated high bandwidth memory behave under the effects of neutrons when running applications similar to the ones used by HPC Division during Trinity phase 2 acceptance tests.

This study is important for understanding the susceptibility of advanced architectures, such as the Trinity system (www.lanl.gov/projects/trinity/), especially as it relates to past experiences with the Q machine where high susceptibility led to a heavy operational burden. The intent is to correlate errors found during acceptance testing and normal operation of Trinity to cosmic ray damage. In the future, researchers plan to use the F-SEFI fault injector to look for correlations between faults found during beam testing, acceptance testing, and a known set of simulated hardware failures. They expect results in 2017.

Above, the newest super computer at Los Alamos: Trinity

Below, radiation is hard on computer components. Thirty minutes into testing, this Knight's Landing node had a hardware failure and, despite several attempts at recovery, never successfully booted again.

Above, the beam testing collaboration team: (from left) Daniel Oliveira (Universida de Federal do Rio Grande do Sul, Brazil), Sean Kauffman (University of Waterloo, Canada), Paolo Rech (Universida de Federal do Rio Grande do Sul, Brazil), Fritz Previlon, (Northeastern University), and Sean Blanchard (LANL). Rech, Oliveira, and Previlon were testing the latest Nvidia components; Kauffman components from JPL/NASA; Blanchard was testing Trinity components.

The experiment team includes Sean Blanchard (HPC-DES), Paolo Rech (Universidade Federal do Rio Grande do Sul), and David Kaeli (Northeastern University).

This work, funded by the Advanced Simulation and Computing program, supports the Laboratory's Stockpile Stewardship mission and Information, Science and Technology for Prediction science pillar by helping to ensure that calculations performed in pursuit of the mission are reliably performed. Reference: D.A.G. Oliveira, L.L. Pilla, M. Hanzich, V.F. Neto, C. Lunardi, J. M. Cela, P.O.A. Navaux, L. Carro, and P. Rech, "Radiation-Induced Error Criticality in Modern HPC Parallel Accelerators," presented at the 23rd International Symposium on High- Performance Computer Architecture (HPCA 2017), Austin, TX, USA, 2017.

Technical contact: Sean Blanchard

Characterization and application of a laser-driven intense pulsed neutron source using Trident

A team of Los Alamos researchers supported a final campaign to use the Trident laser to produce neutrons, contributing their multidisciplinary expertise to assess experimentally if laser-driven neutron sources can be useful for MaRIE. Neutrons provide a radiographic probe that is complementary to x-rays and protons and can address imaging challenges not amenable to those beams. MaRIE is the Laboratory's proposed experimental facility for the study of matter-radiation interactions in extremes. The team's efforts characterize the Laboratory's responsiveness, flexibility, and ability to apply diverse expertise where needed to perform successful complex experiments.

Campaign Principal Investigator and then-Los Alamos Neutron Science Center Rosen Scholar Markus Roth (Technical University (TU) Darmstadt, Germany), his team (Annika Kleinschmidt, Alexandra Tebartz, Victor Schanz, Gabriel Schaumann), and the Trident-based team (Cort Gautier, Randy Johnson, Russ Mortensen, Tom Shimada, Sasi Palaniyappan, and Glen Wurden (all Plasma Physics, P-24); Andrea Favalli (Safeguards Science and Technology, NEN-1) were joined by Sven Vogel (Materials Science in Radiation and Dynamics Extremes, MST-8), Ron Nelson (LANSCE Weapons Physics, P-27), Michelle Espy and James Hunter (both Applied Engineering Technology, AET-6), and Adrian Losko (University of California, Berkeley, postdoctoral affiliate in MST-8). Scientists from Tel Aviv University (Ishay Pomarantz, Itay Kishon) and Dresden HZDR (Anna Ferrari, Fondazione Cnao, and Alejandro Garcia-Laso) completed the international team and explored novel neutron detectors. Targets and neutron time of flight detectors were provided by TU Darmstadt and NEN-1.

The staff from MST-8, P-27, and AET-6 set up detectors at Trident that were developed and that are used at LANSCE, aiming to characterize the laser-driven neutrons and demonstrate various applications. Vogel provided three detector panels from the HIPPO (High-Pressure-Preferred Orientation) diffractometer to attempt to collect thermal diffraction spectra. Losko installed the Flight Path 5 thermal/epithermal neutron time-of-flight imaging detector to collect data for neutron absorption resonances and Bragg-edges. Nelson, Espy, and Hunter provided a high-energy neutron imaging detector. All of these detector systems are normally used at LANSCE beam lines and added substantial value to the Trident campaign. Such specialized detector systems would be otherwise unavailable. The neutron source was moderated for many of the shots to assess the ability to produce thermal and epithermal neutrons.

Figure 1 shows a fast neutron radiograph of various objects, selected to assess resolution and discriminate contributions from neutron and gamma radiation. The radiograph was taken with a single Trident laser pulse producing neutrons and gammas. Initial analysis of attenuation by a six-step polyethylene wedge, which attenuates neutrons far more than gamma rays, indicates that the image originates predominantly from neutrons. The line pair gauge, which was not well aligned, showed resolution better than 2 mm. Both the detector configuration and the geometry can be optimized for better resolution in future work. The picture quality was surprising to the team, surpassing previous results acquired at Trident (Roth et al., *PRL* **110**, 044802 [2013]), and may already be sufficient for some applications. The high penetrating power of energetic neutrons has been demonstrated

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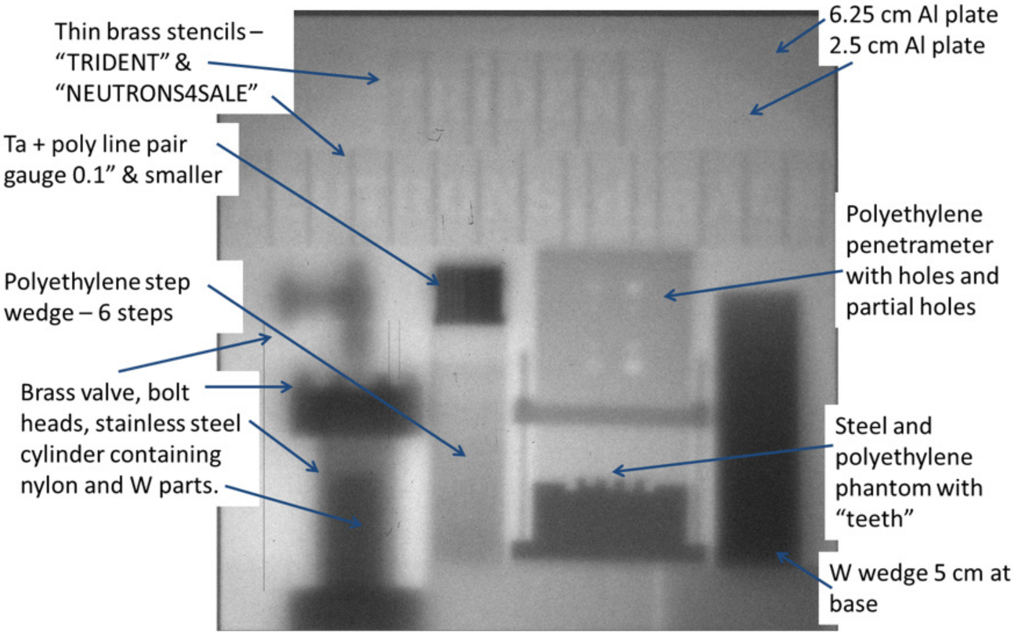


Figure 1: radiograph from a single Trident shot viewing several objects. The objects chosen for this test reveal the resolution as well as the fraction of neutron versus gamma radiation detected by the imaging system. Initial analysis, e.g., of the image of the polyethylene step wedge, indicates that the detected signal originates predominantly from neutrons. The spatial resolution can be improved with changes in both the neutron converter screen in the detector and the geometry. The line pair gauge shows better than 2-mm resolution for this proof-of-principle measurement.

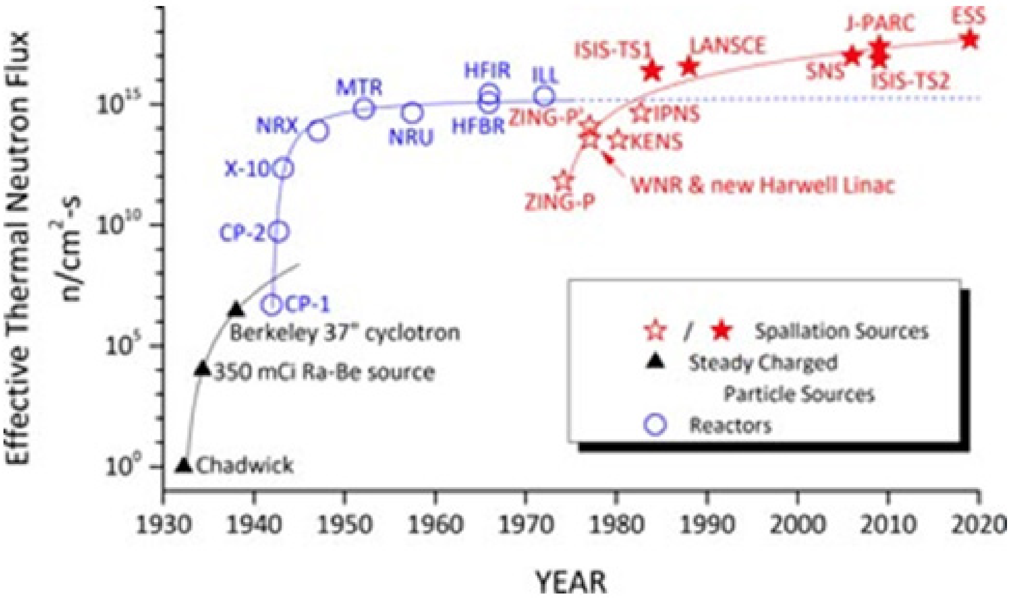


Figure 2, top: evolution of neutron flux at various neutron sources over time (from: Mason et al., *MRS Bull*. 28, 923 [2003]). The 10^{10} neutrons/sr achieved per pulse at Trident are on par with the ZING-P spallation source, which paved the way to the Intense Pulse Neutron Source, ISIS, and LANSCE only a decade later.

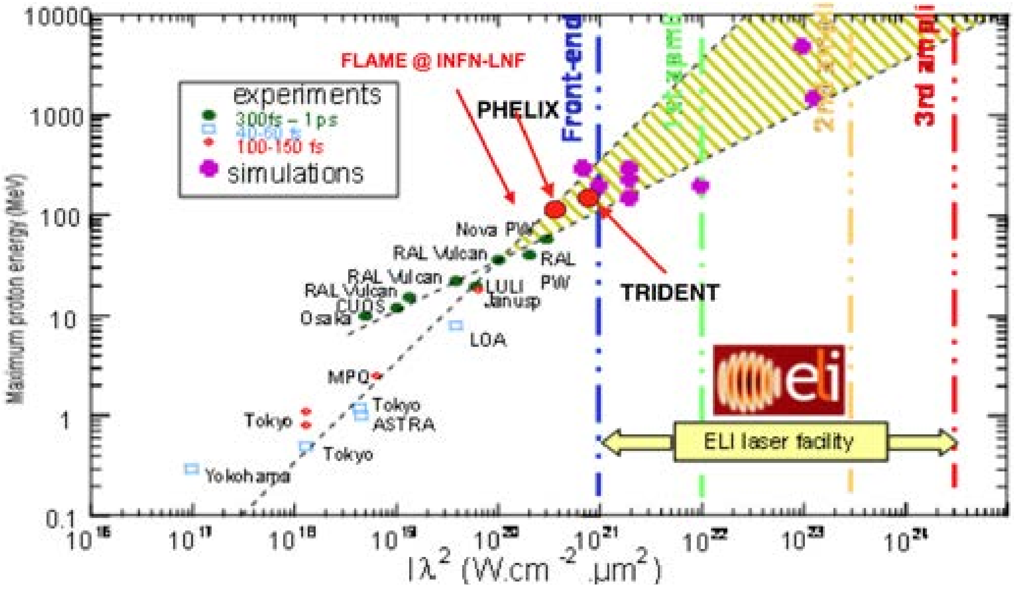


Figure 2, bottom: laser power and the resulting proton energy of past and current laser sources as well as the predicted proton energy for the European Extreme Light Infrastructure (ELI), currently under construction in Europe. When the ELI facility in Prague becomes available in a few years, proton energies exceeding the 800-MeV LANSCE accelerator will be possible. The investment cost for the ELI facility in Prague is €278 million, including four high intensity laser sources. For comparison, the investment cost for the linear accelerator of the Spallation Neutron Source at Oak Ridge National Laboratory exceeded $1 billion.

Trident cont.

at LANSCE, and laser driven sources show the potential for compact energetic neutron sources.

Using the LANSCE thermal/epithermal energy-resolved imaging detector, resonances from an indium foil were visible in single pulses. This may allow measurement of the temperature in bulk materials from resonance broadening, as demonstrated at the ~1,000 times more intense LANSCE neutron source a decade ago (Yuan et al, *PRL* **94**, 125504 [2005]) This technique can provide a unique diagnostic tool for MaRIE.

Based on initial results, using intense short laser pulses to accelerate ions to energies sufficient for fast neutron production can provide focused, short pulse (<60 ns depending on time-of-flight) neutrons for applications. Such sources complement and may someday replace or even surpass large, expensive accelerators such as the LANSCE linear accelerator (LINAC). At present, the >10^{10} neutrons/steradian generated in each pulse with Trident are equal to the number of neutrons produced with the first neutron spallation source ZING-P at Argonne National Laboratory in the 1970s, which enabled construction of production neutron sources at the Intense Pulse Neutron Source (IPNS), LANSCE, and ISIS (England) only a decade later (Figure 2, left: note that all these sources operate at 10-50 Hz and flux is given per second). Because lasers are much more compact than linear accelerators and require less energy, this could eventually allow a compact pulsed neutron source to be deployed on a truck. The forward-directed emission of neutrons reduces the radiation shielding needed for an installation, and the short pulse enables flash neutron radiography.

continued on next page

Trident cont.

Because the investment cost of lasers is at least one order of magnitude lower than a LINAC, several lasers could be combined to make a neutron source of higher emittance than even today's most powerful neutron sources. The potential to combine several synchronized laser-driven neutron producing targets into a single intense neutron source could circumvent thermal problems of present neutron sources, enabling new neutron production target designs.

Figure 2 shows the laser power of past and present intense laser sources and the resulting proton energies as well the proton energies for future laser sources. The Extreme Light Infrastructure facility under construction in Europe is predicted to provide laser power that will accelerate protons to energies exceeding that of the LANSCE 800-MeV linear accelerator, shifting the neutron production into the regime of spallation, where ~20 neutrons per proton are produced (the neutron production mechanisms achieved with the energies at Trident produce one neutron per proton or deuteron). For MaRIE, several intense laser-driven neutron sources could generate sub-microsecond spaced neutron pulses to characterize different sample volumes at different times during a dynamic event, providing temperature and microstructure information from neutron absorption resonance broadening and Bragg-edges, respectively.

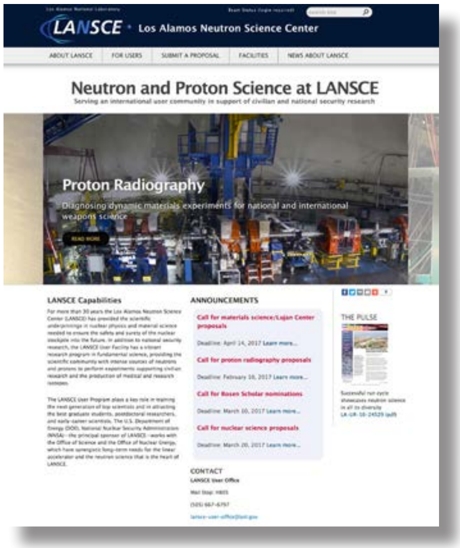
In the past decade, some of the physical effects occurring during the interaction of the laser pulse with the target material, which boost neutron production, were theoretically predicted in computer simulations on the Laboratory's Roadrunner super computer and subsequently experimentally verified at Trident. The one-of-a-kind combination of experimental and theoretical laser and laser-plasma expertise, plus the neutron expertise existing at LANSCE, makes Los Alamos a unique place to develop laser-driven pulsed neutron sources from proof-of-principle to applications.

The MST-8, P-27, and AET-6 work was funded as part of an initiative to assess if laser-driven neutron sources can be used for MaRIE. Development of neutron imaging detectors was funded by Enhanced Surveillance, Nuclear Energy, and a Laboratory capability development grant. After the announcement of the closure of the Trident laser at Los Alamos, one last campaign was conducted in early 2017 to further explore the imaging characteristics of a laser-driven high-energy gamma radiography source discovered during the campaign described in this article. The activities for laser-based neutron production will continue at Trident's new home at the Texas Petawatt Facility as well as laser sources in Europe, such as the German PHELIX laser system or the soon-to-be opened European Extreme Light Infrastructure facility in Prague.

Technical contact: Sven Vogel

New LANSCE website launches

Find what you need to get beam time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Serving an international user community in support of civilian and national security research

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LANSCE Capabilities

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Deadline: March 10, 2017 Learn more...

Call for nuclear science proposals

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CONTACT

THE PULSE

Visit lansce.lanl.gov.

Users will find a newly redesigned LANSCE website at lansce.lanl.gov. Organized for their needs first and foremost, the site features five tabs with drop-down menus for straightforward navigation.

"About LANSCE" provides an overview of the national user facility. Under "For Users" researchers will find a step-by-step guide of actions to take before arriving, upon arriving, and departing LANSCE; beam schedule details; and user group information. Scientists seeking to obtain LANSCE beam time will find the information they need under "Submit a Proposal." The "Facilities" tab provides specifics about the exceptional capabilities and instruments available at LANSCE and "News About LANSCE" highlights the latest scientific and technical accomplishments by our staff and visiting scientists. Feedback on the site is welcome. Please send comments to adeps_comm@lanl.gov.

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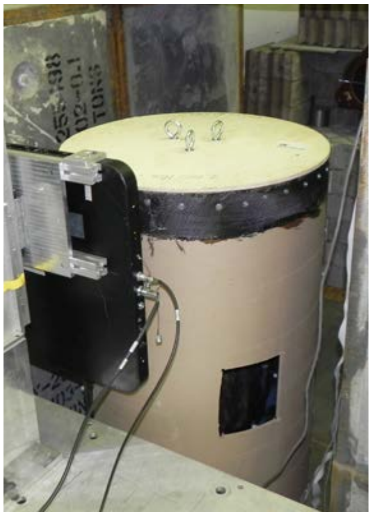
Using LANSCE to gain insight into a dinosaur's skull

Paleontologists began using x-ray computed tomography (CT) imaging to study the internal details of fossilized plants and animals about 30 years ago. These studies reveal valuable new information from which researchers can learn about the structure, functioning, and evolution of organisms now long extinct, without damaging or destroying the fossils in the process. In a collaborative effort between Los Alamos (LANL), the New Mexico Museum of Natural History and Science (NMMNHS) in Albuquerque, and the University of New Mexico (UNM), researchers have used unique imaging capabilities at LANL to expose the inner structures of the fossil skull of a tyrannosauroid dinosaur, *Bistahieversor sealeyi* (Sealey's Badlands Destroyer). Known as the "Bisti Beast" and usually on display at the museum, the fossil was found in 1996 in the Four Corners area of New Mexico called the Bisti Badlands, located in the Bisti/De-Na-Zin Wilderness Area near Farmington. The fossil is 74 million years old and lived about 8 million years before its most famous cousin *Tyrannosaurus rex*.

Above: A high-energy neutron radiograph (left) of the section within the red rectangle in the photo of the skull. The neutron image has good contrast and resolution that indicate that the neutron CT scan, once reconstructed will provide further insight into the internal features of the fossil.

The team was comprised of Tom Williamson (curator, NMMNHS), Kat Schroeder (UNM), Steve Brusatte (University of Edinburgh, Scotland), James Hunter, Michelle Espy and Cort Gautier (Applied Engineering Technology, AET-6), Ron Nelson (LANSCE Weapons Physics, P-27), and Sven Vogel and Adrian Losko (Materials Science in Radiation and Dynamics Extremes, MST-8).

To support the fragile skull during positioning and rotations, a special carbon-fiber "clamshell" was constructed and mounted in a fiberboard drum. The skull remained in the drum during its stay at LANL, so the only viewing was via x-rays and neutrons. The possibility of long-term radioactive activation of the skull by neutrons was shown not to be an issue by using a bone fragment from the fossil in a test irradiation and by monitoring the skull after a short irradiation at LANSCE.



Right: The skull in the drum in front of the special high-energy neutron imager (black) in the shielding of the 60R cave at LANSCE. The barrel is mounted on a rotation stage. The square opening in the barrel's side allowed close-up radiation surveys of the skull.

Michelle Espy, James Hunter, John Stearns, Ron Nelson, Tom Williamson, and Kat Schroeder with the drum containing the fossil in front of the microtron x-ray source at LANL.

The 40-inch length required acquiring and combining multiple images, and the thickness of the mineralized skull required higher energy x-rays than those typically available in order to adequately penetrate the skull. The high-energy (6-MeV) x-ray imaging used x-rays produced by a microtron electron accelerator operated by the nondestructive evaluation group (AET-6). A newly developed high-energy neutron imaging technique, using neutrons produced by the 800-MeV proton accelerator at LANSCE, was employed to provide an alternate view inside the skull. The neutrons

continued on next page

From left, James Hunter, Tom Williamson, and Michelle Espy look over the fossil at the New Mexico Museum of Natural History and Science to plan the packaging and imaging work before moving it to Los Alamos National Laboratory. The lower jaw was not imaged.

Using cont.

interact with the nuclei rather than the electrons of the sample, and thus have different elemental sensitivity. This provides complementary information to that obtained with x-rays. Initial viewing of the CT slices show exciting results with preservation of soft tissues including nerves and blood vessels in the fossil as well as unerupted teeth, the brain cavity, internal structure in some bones, sinus cavities, and other anatomical structures.

The Bisti Beast skull is the largest object to date for which full high-resolution neutron and x-ray CT scans have been performed at LANL and required innovations both to image the entire skull and to handle the image reconstruction from the resulting large data sets. This work advances the state of the art in imaging capabilities at LANL and is already proving useful in imaging larger programmatic items. In addition, the open nature of this data is facilitating collaborative dual x-ray/neutron data analysis development.

Neutron CT imaging of a 62-million-year-old mammal skull has also been performed and demonstrated the utility of neutrons versus x-rays for fossils with heavy metal minerals incorporated in them. Future work is planned on a variety of smaller fossils using both x-rays and neutrons.

Los Alamos National Laboratory has a wide variety of imaging capabilities. Because studies of fossils are both challenging and provide scientific information, collaborations with academic institutions can be very fruitful and lead to development of new laboratory capabilities that benefit LANL programs as well as provide valuable community relations. In recognition of these factors, the present work has been funded by LANL capability development funds from Applied Engineering Technology Division and from NNSA Science Programs, and through a grant to UNM/NM Museum of Natural History staff through the New Mexico Consortium.

Technical contact: Ron Nelson

Nuclear reaction measurements at LANSCE: towards better calculations of nuclear criticality

Criticality is an important concept in nuclear technologies. In a nuclear reactor, energy is released when the nucleus of an actinide is split into two smaller nuclei, a process known as fission. When this occurs, neutrons are emitted from the highly excited fission products, which in turn can induce more fission reactions, and a chain reaction is started. Criticality refers to the neutron balance in the system; if the production rate and loss rate of neutrons are identical, the system is self-sustaining and critical. If, on the other hand, the production rate is higher than the loss rate, the system is said to be super-critical. An example of a device that goes super-critical is the primary in a nuclear weapon.

To accurately calculate criticality in a device, one needs to know the basic nuclear reaction data that describes the chain reaction. This is reflected in the *Integrated Plutonium Science and Research Strategy* (LA-UR-13-24336) developed jointly by Los Alamos National Laboratory and Lawrence Livermore National Laboratory. One of the objectives in this strategy is to “Expand our capabilities in detection, measurement, and analysis of actinides,” and calls out the need to improve the fidelity of nuclear data for plutonium. Additionally, sensitivity studies performed about a decade ago for the weapons program demonstrated the need to reduce uncertainties in the prompt fission neutron spectrum (PFNS) and fission cross section for plutonium in order to calculate criticality with the desired precision.

This was the starting point for two large experimental efforts at LANSCE: the Chi-Nu collaboration that measures PFNS and the TPC collaboration that is addressing the fission cross section. In the 2016 LANSCE run cycle, the two projects made major advances towards delivering precise nuclear data for plutonium in support of the Primary Assessment Technologies (Science Campaign 1), which is part of the Weapons Program. The experiments are performed at the Weapons Neutron Research Facility (WNR) at LANSCE, where an 800-MeV proton beam impinges on a tungsten spallation target to produce fast neutrons. The neutron time-of-flight technique is used to determine the incident neutron energy, which allows for energy-differential nuclear data to be measured. This information is used by evaluators to generate files for nuclear data libraries such as ENDF, which in turn becomes input for radiation transport codes such as MCNP. The libraries are benchmarked using critical assembly experiments, which tell the reactor and weapons communities how well our understanding of nuclear reactions reproduce criticality for various critical systems. These benchmarks sometimes hint at problems with the latest library, which then prompts new measurements of microscopic nuclear data.

continued on next page

Figure 1 (right): the prompt fission neutron spectrum (PFNS) for neutron-induced fission of ^{235}U with incident neutrons from 2-3 MeV measured by the Chi-Nu project, compared to the ENDF/B-VII.1 evaluated database values.

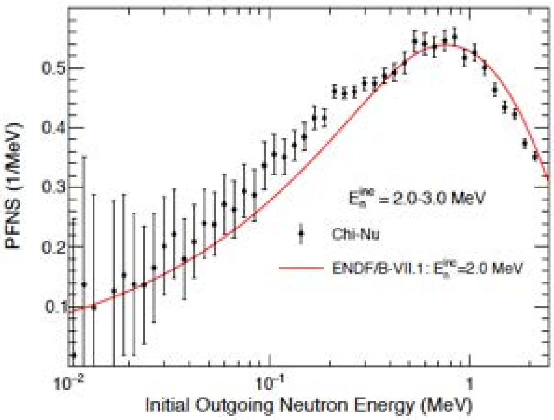
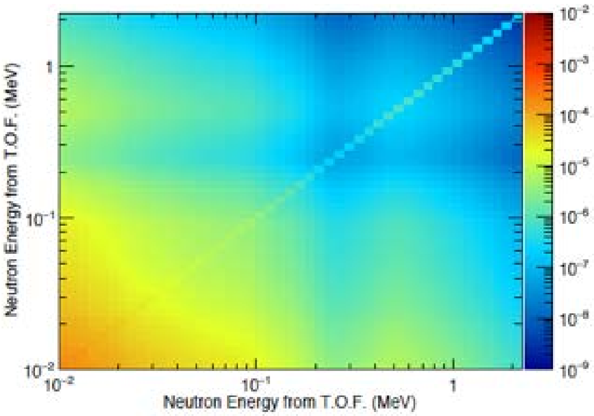


Figure 2 (far right): the covariance matrix for these data, showing the correlations in the uncertainties in this measurement.



Nuclear cont.

The Chi-Nu collaboration is performing the most precise measurement of the prompt fission neutron spectrum to date. The high precision is achieved both through improved experimental techniques and advances in modeling and simulation of the experimental setup. The energy spectrum of neutrons emitted in fission can be approximated by a Maxwellian distribution with an average of 2 MeV. Due to experimental challenges, it is difficult to reliably measure the prompt neutrons with energies lower than about 0.5 MeV, but those neutrons are still relatively important for calculating criticality. The Chi-Nu instrument is two different detector arrays—one for detecting the low-energy neutrons in the PNFS, the other for detecting higher-energy neutrons. The two arrays are complementary and by combining measurements with each of them, the PFNS can be accurately reconstructed.

To measure the prompt fission neutron spectrum as a function of incident neutron energy, a double time-of-flight approach is used. When a pulse of protons strikes the spallation target and neutrons are generated, a timing signal is sent to the experiment, starting a clock. In the center of the Chi-Nu array is a parallel-plate avalanche counter (PPAC) loaded with actinide samples. When a neutron from the spallation target induces fission in one of the samples it gets registered by the PPAC, which stops the clock for the incident neutron. This provides the first time-of-flight, which is used to determine the energy of the incident neutron. The second time-of-flight is started by the PPAC, registering a fission reaction, and stopped when a neutron emitted in that fission reaction hits the Chi-Nu array. This provides the energy for the outgoing fission neutron in that reaction. In this manner, the so-called “Chi-Nu matrix” can be determined, which is a matrix of incident versus outgoing neutron energies.

The time projection chamber (TPC) instrument for fission cross section measurements uses samples with thin deposits of actinides, which are irradiated with neutrons from the WNR spallation target. In this case, however, the samples are loaded into a TPC, rather than the PPAC used for Chi-Nu. Time projection chambers were first developed in the late 1970s for particle physics experiments. TPCs allow researchers to track particles inside the active volume of the instrument and is often used to track hundreds or even thousands of particles created in high-energy beam interactions with fixed targets or in beam-beam collision. The fission TPC is smaller than its predecessors, with a diameter of only 20 cm and is typically only required to track two ions in any one physics event: the two collinear fission fragments emitted in neutron-induced fission. By taking advantage of the information about the fragment tracks, it is possible to reduce the uncertainties in the cross-section measurements from 3-5% obtained using conventional techniques to around 1%.

The TPC is a gas-filled detector with a central cathode plane where the actinide sample is placed. On each side of the gas volume is a MicroMEGAS detector with 3,000 individual pixels. As fission fragments are emitted from the sample they lose energy through ionizing collisions in the gas, and the resulting charge is drifted through an electric field towards the MicroMEGAS. The pixilation of the readout plane provides a two-dimensional projection of the track, and by including the drift time information, the full three-dimensional track can be reconstructed. In fact, not only does the TPC provide the particle track but also the specific energy loss along this track. That information is then used to significantly improve the particle identification compared to conventional ionization chambers, which reduces the uncertainty associated with misidentification of fission events when calculating the final reaction cross section.

The 2016 run cycle saw major advances towards the final results on nuclear data for ^{239}Pu. In previous years, measurements of the prompt fission neutron spectrum and fission cross section of uranium were performed. The reason to start with uranium is that it has a longer lifetime than plutonium, and its nuclear data is better known, thus making for a good benchmark of the techniques used. Some example results for the uranium fission cross section and PFNS are shown in Figures 1 and 2 where the experimental

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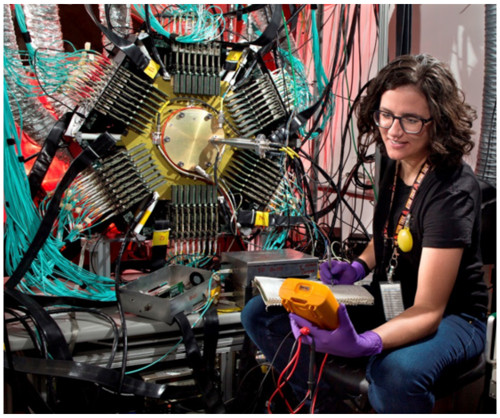
The time projection chamber is used for high-precision cross-section measurements. Attached to the detector are 192 optical fibers that send digitized signals from almost 6000 channels to the data acquisition computer.



Nuclear cont.

data is compared to the evaluation files from the ENDF/B-VII library of nuclear data. The data collected on plutonium in 2016 is being analyzed and will be presented at milestone review at the end of FY2017.

The work on nuclear data for criticality is scheduled to continue through the next few years. The TPC is switching towards a plutonium fission cross section relative to neutron scattering on hydrogen, which is the most accurate standard available for this type of measurement and which enables researchers to reach the target 1% uncertainty level. Chi-Nu will use the high-energy array to improve understanding of the part of the PFNS that is above 2 MeV. Furthermore, a new instrument, LENZ (Low-energy n,z), has been developed and commissioned to measure another type of nuclear reaction, namely neutron-induced light charged-particle emission, some of which is also relevant for criticality. This new instrument is measuring the neutron-induced alpha-particle emission from oxygen, which is highly relevant for so-called “solution critical benchmarks.” Therefore, this type of research will continue to be an integral part of nuclear science at LANSCE in the future.

Isolating microstructural effects on observed strength of additively manufactured stainless steel

Recent measurements taken at SMARTS, the spectrometer for materials research at temperature and stress, provide a better understanding of how different additively manufactured (AM) microstructural features can be controlled to produce predictable properties.

The quasi-static mechanical strength of AM materials often exceeds that of traditionally wrought counterparts. The AM process results in a distinct microstructure in 304L steel, including unique grain morphology, high dislocation density, and ferrite content—all of which affect the strength. Through precise measurements, researchers can provide a recipe to design microstructure-aware process models that enable science-based qualification of AM components.

In situ heat treatment measurements completed on SMARTS, a technology located at the Lujan Neutron Scattering Center and uses neutron diffraction to probe metals and structural materials, showed that the dislocation density decreases at 700 °C, while the ferrite persists until 950 °C.

Electron backscatter diffraction completed at Sandia National Laboratories (SNL) showed that the unique grain morphology persists until ~1200 °C. Five samples were created by tailored heat treatments to eliminate individual portions of the microstructure.

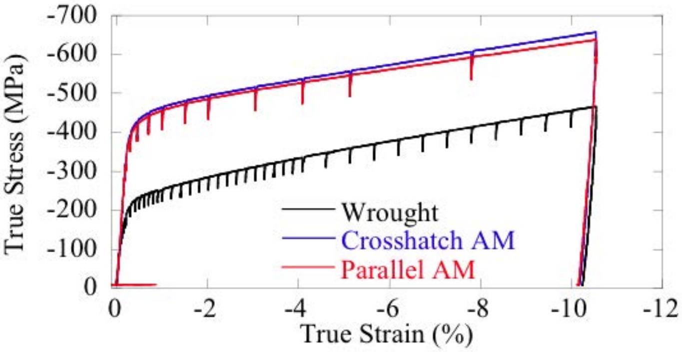
In 2017 in situ deformation measurements will be completed to isolate the effect of each microstructural feature on the strength of the material, boosting understanding of the relationship between process, structure, and properties. The measurements will show how different microstructural features associated with AM can be controlled to produce predictable properties, in support of the Laboratory’s vision of controlled functionality in materials.

The Lujan Center at LANSCE provides unique hardware and software capabilities for rapid bulk microstructural characterization to accelerate qualification of AM materials. These results are an example of decades of experience with large datasets that provide the foundation for data analysis of MaRIE experiments in material discovery. MaRIE is the Laboratory’s proposed experimental facility for Matter-Radiation Interactions in Extremes.

The research was funded by the C1 and C2 Science Campaigns (LANL program managers Ray Tolar and Dana Dattelbaum, respectively). Material provided by Sandia National Laboratories. Researchers include Reeju Pokharel, Bjorn Clausen, and Don Brown (Materials Science in Radiation and Dynamics Extremes, MST-8); and Dave Adams and Paul Specht (SNL).

Reference: submitted to *Metallurgical and Materials Transactions A.*

Technical contact: Don Brown



Observed strength differential between AM and wrought material.

Innovation Academy for Women of the Americas recently toured LANSCE.

International Academy for Women of the Americas tours LANSCE

Nearly 30 members of the Innovation Academy for Women of the Americas, a first-of-its-kind program bringing together undergraduate student women from New Mexico and Mexico majoring in the fields of science, technology, engineering, mathematics, or architecture (STEM+A), recently toured LANSCE.

The tour was part of their course of intensive research, career mentoring, and leadership training at The Academy, a partnership between the University of New Mexico, Universidad La Salle México, and Universidad Autónoma de Yucatán. The Academy is supported by a grant from 100,000 Strong in the Americas, a public-private collaboration of the White House, U.S. Department of State, Partners of the Americas, and NAFSA: Association of International Educators.

Los Alamos hosts were Eva Birnbaum (Science Program Office-Office of Science, SPO-SC) and Anna Llobet (Neutron Science and Technology, P-23), who was the keynote speaker at the program's closing ceremony in Albuquerque in June.

The group met with Los Alamos researchers as they toured LANSCE's Isotope Production and Proton Radiography facilities and learned about astrophysics and Los Alamos contributions to the High-Altitude Water Cherenkov Observatory (HAWC). HAWC, located at 13,500 feet on the slopes of Mexico's Sierra Negra, is a joint collaboration between the United States and Mexico (www.lanl.gov/discover/news-release-archive/2015/March/03.20-hawk-obsevratory-universes-most-energetic-phenomena.php).

> “*The tour was part of their month's-long course of intensive research, career mentoring, and leadership training at The Academy, a partnership between the University of New Mexico, Universidad La Salle México, and Universidad Autónoma de Yucatán.*”

The day included a lunch-time discussion with Birnbaum, Llobet, Mary Hockaday (Experimental Physical Sciences, ADEPS), Verena Geppert-Kleinrath (P-23), Ann Junghans (Engineered Materials, MST-7), Rex Hjelm (Materials Science in Radiation and Dynamics Extremes, MST-8), Ann Junghans (Engineered Materials, MST-7) and Andrea Albert (P-23).

The Academy aims to increase bidirectional student mobility between the United States, Mexico, and the Americas through an innovative academic and career development program for underrepresented, minority, and indigenous women in the STEM+A fields; increase the preparedness and representation of women in STEM+A higher-level research and senior leadership roles in the workforce; provide support for women in the STEM+A fields through ongoing web-based forums and mentorship designed to provide encouragement and individualized, meaningful guidance; and discover and leverage ways institutions can collaborate in the STEM+A field over long periods of time.

Technical contact: Anna Llobet