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The Future of LANSCE

Physics Colloquium

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January 9, 2020

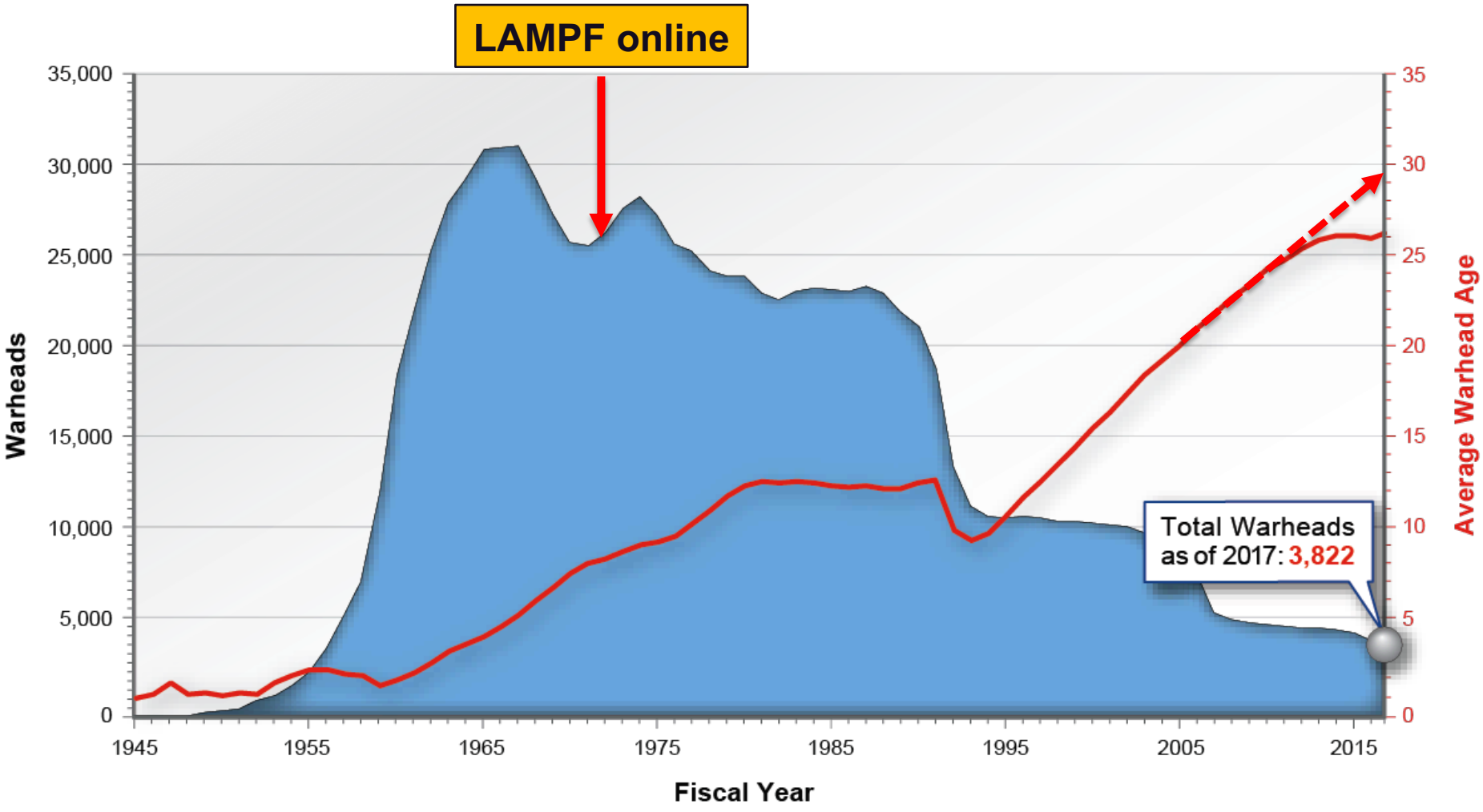
Los Alamos NATIONAL LABORATORY EST.1943

NNSA National Nuclear Security Administration
Managed by Triad National Security, LLC for the U.S. Department of Energy's NNSA

LANSCE is a NNSA Center for Materials and Nuclear Research

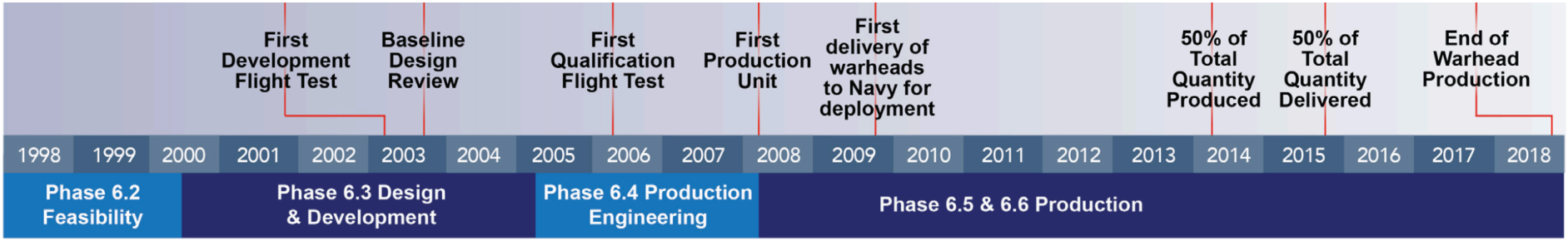
- **An aging stockpile presents unique challenges in materials and nuclear science**
- **Grand challenge of a predictive materials capability**
  - Design to manufacture
  - Born certified
- **Requires capability to study manufacture to structure relationships**
- **Requires capability to study structure to performance relationships**
- **LANSCE has the capabilities needed for this mission**
- **We leverage our capability to provide broader benefit to the Nation**
  - Production of medical isotopes
  - Industrial irradiation facility for electronics certification
  - Fundamental materials and physics research
- **LANSCE linear accelerator is nearly 50 years old. The severity of maintenance issues is increasing**
- **We must reinvest in LANSCE to ensure mission delivery into the future**
- **We must develop new capability to be responsive to changing mission needs**
  - Ultimately this will require a Dynamic Mesoscale Materials Science Capability
  - Now we must develop a pathway to MaRIE that ensures continued operation of LANSCE

The stockpile has undergone dramatic changes since LANSCE was built: 14% of weapons in service 3x older



The maintenance of an aging stockpile requires understanding the performance of aging and replacement materials

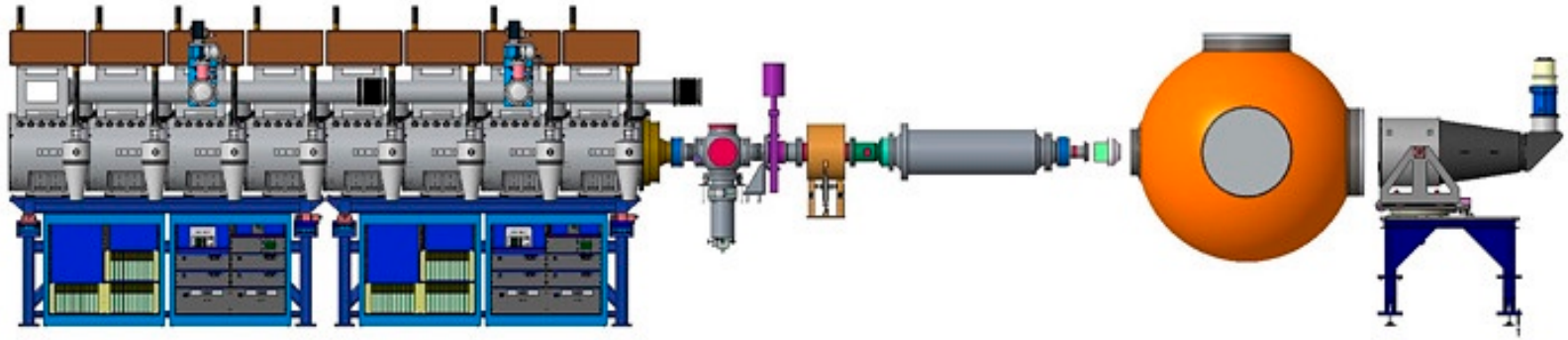
- **Life extension programs are expensive and time consuming**
  - The B61-12 LEP cost estimated at $7.6B (GAO-18-456, NNSA estimate)
  - The W80-4 LEP cost estimate is $8.0-11.6B



- **LEPs typically require material replacement and/or different manufacturing methods**
- **Neutron diffraction at the Lujan Center informs the manufacturing process**
- **Proton radiography validates performance models**
  - LANL was the production agency for the detonators on the B61-12
  - Relied on proton radiography to certify the detonators
- **Nuclear physics at WNR/Lujan will inform NDSEs**

Re-use of (and making new) plutonium pits present other challenges

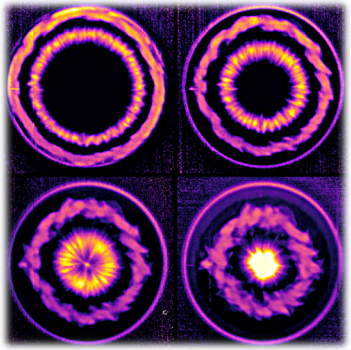
- The average age of Pu pits is now close to 30 years
- With 3800 weapons in the stockpile and a production rate of 100 ppy it will take 38 years to replenish the stockpile with new pits
- We must understand the performance of aged plutonium
- We must be able to ensure that the new pits will perform as intended
- NNSA is building the ECSE (Enhanced Capability for Subcritical Experiments) Facility, which includes NDSE (Neutron Diagnosed Subcritical Experiments) in Nevada to study plutonium performance as a function of age



- Nuclear cross section measurements at the Lujan Center and WNR will be needed by the NDSE program
- Dynamic plutonium data from pRad will be needed to validate new pits, understand the impact of aging on performance, and test new Pu alloys
- Neutron diffraction will be needed to understand strength and structure of new alloys and impacts of aging

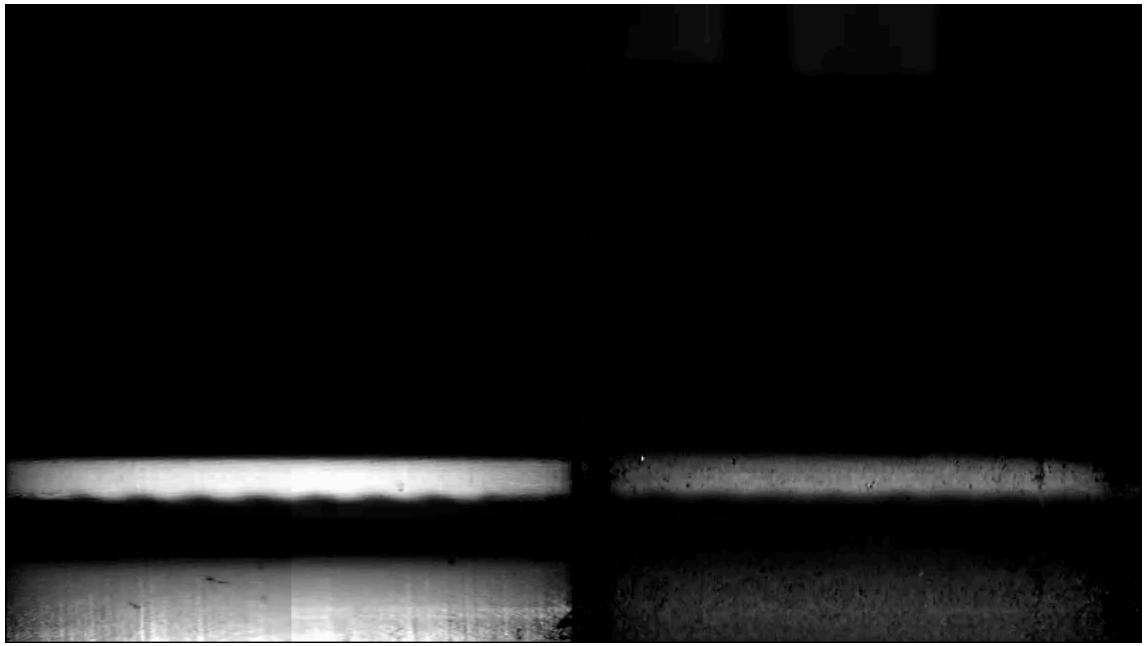
And LANSCE must keep pace

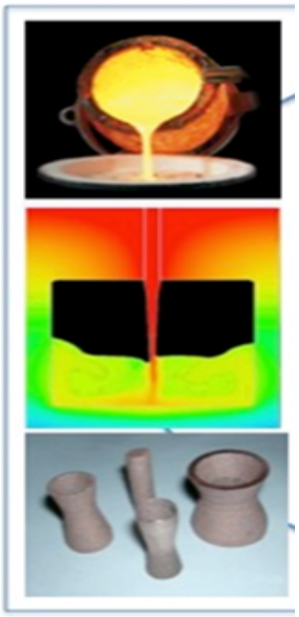
- **Dynamic plutonium capability at pRad will address:**
  - Performance of aged plutonium at relevant conditions
  - Performance of new alloys of Pu for new designs
  - Testing of coupons from new Pu pits for certification
  - SFIs
- **New Lujan Center Target will address:**
  - Nuclear cross section measurements that will be needed by the NDSE program
  - Nuclear physics ties to historical testing (radiochemical tracers)
  - Fission fragment yields for understanding waste heat generation
- **New Lujan Center neutron diffraction flight paths address:**
  - Survivability (structural changes)
  - Material aging, processing changes, and replacement (structural changes)
- **We need to ensure the long-term viability of LANSCE into the MaRIE era**



Enhanced understanding of materials is critical for future stockpile certification

Copper Coupons

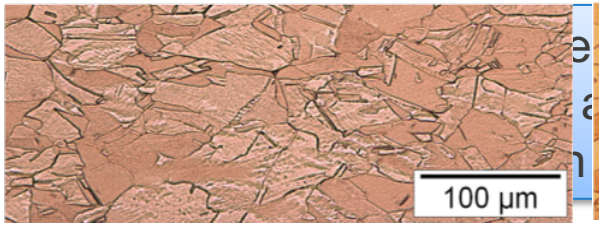




casting

STS environment and survivability

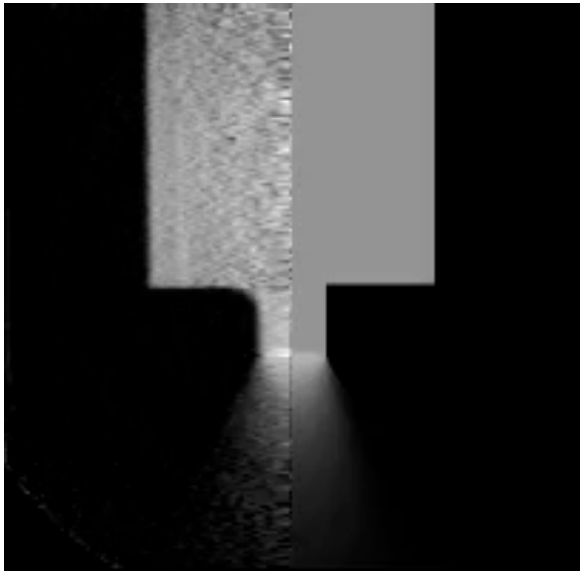
Cold rolled

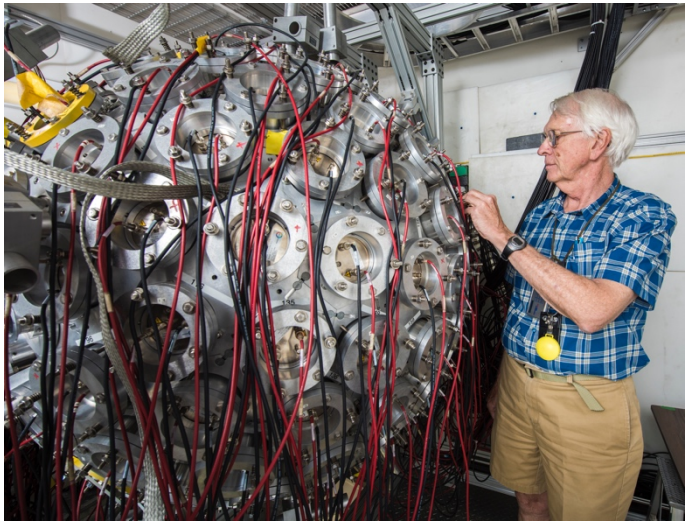


Annealed

Additional Mission Requirements

- **pRad: Dynamic performance testing for stockpile sustainment and future deterrent**
  - SFIs (feature driven hydrodynamics)
  - LEPs and new designs (high explosives, initiators, detonators, STS variations)
  - Pu at pRad will fill a gap in NNSA's capability (focused experiments – ***GAP*** – subcrits)
- **Lujan and WNR: Nuclear science data for stockpile and global security**
  - Weapons: performance and survivability (fission)
  - Production: criticality and waste management
  - Radiography of mock stockpile canned sub-assemblies
  - Nuclear forensics for global threats (fission and neutron capture)





The proton radiography facility is responsive to emerging stockpile issues

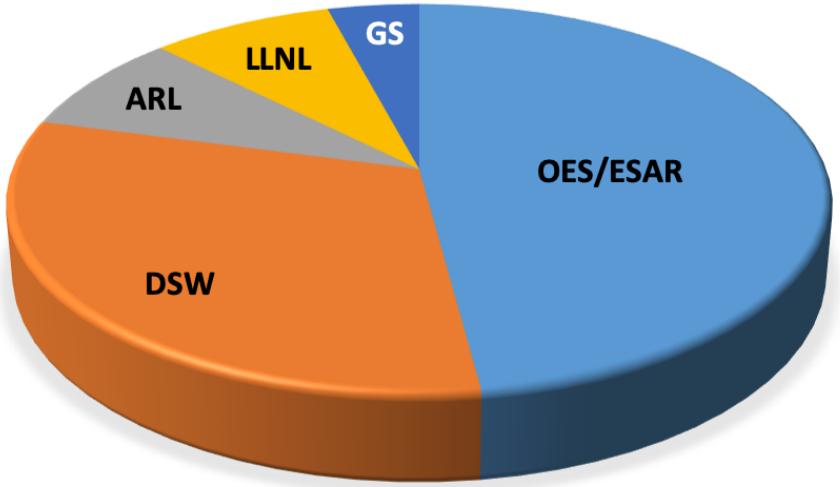
- **Delivers data vital to stockpile certification:**
  - High explosive performance through STS temperature range,
  - Material failure and ejecta production and transport
  - Instability growth
  - Feature driven hydrodynamics
  - Validation of subcritical experiments (Bacchus, Barolo, Red Sage)
- **Re-establishing plutonium capability fills a gap for NNSA missions**
  - Performance of: new alloys, new manufacturing and processing, aging

pRad experiments are used for stockpile certification and to improve predictive code capabilities

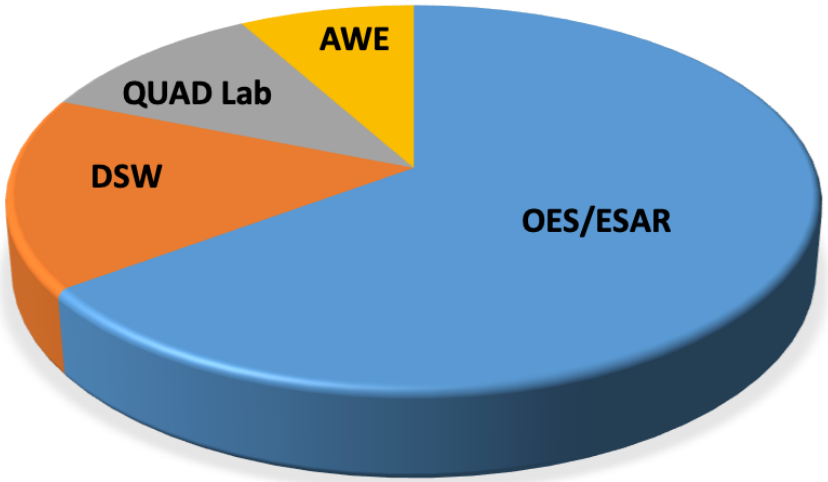
- 6 LT63 experiments for the B61 tested a use control element under different conditions, including various temperatures. The data validate models that are used to predict performance beyond STS conditions and improve our understanding of explosive behavior under extreme conditions.
- 8 recent FIT-3 pRad experiments were fired supporting the W88 ALT 370 CHE-R project. The data were used for detonator qualification and to validate the baseline hydrodynamic and HE initiation model. The data is also being used to validate reactive burn models to be used in future updates to the primary baseline model.

pRad
PROTON RADIOGRAPHY

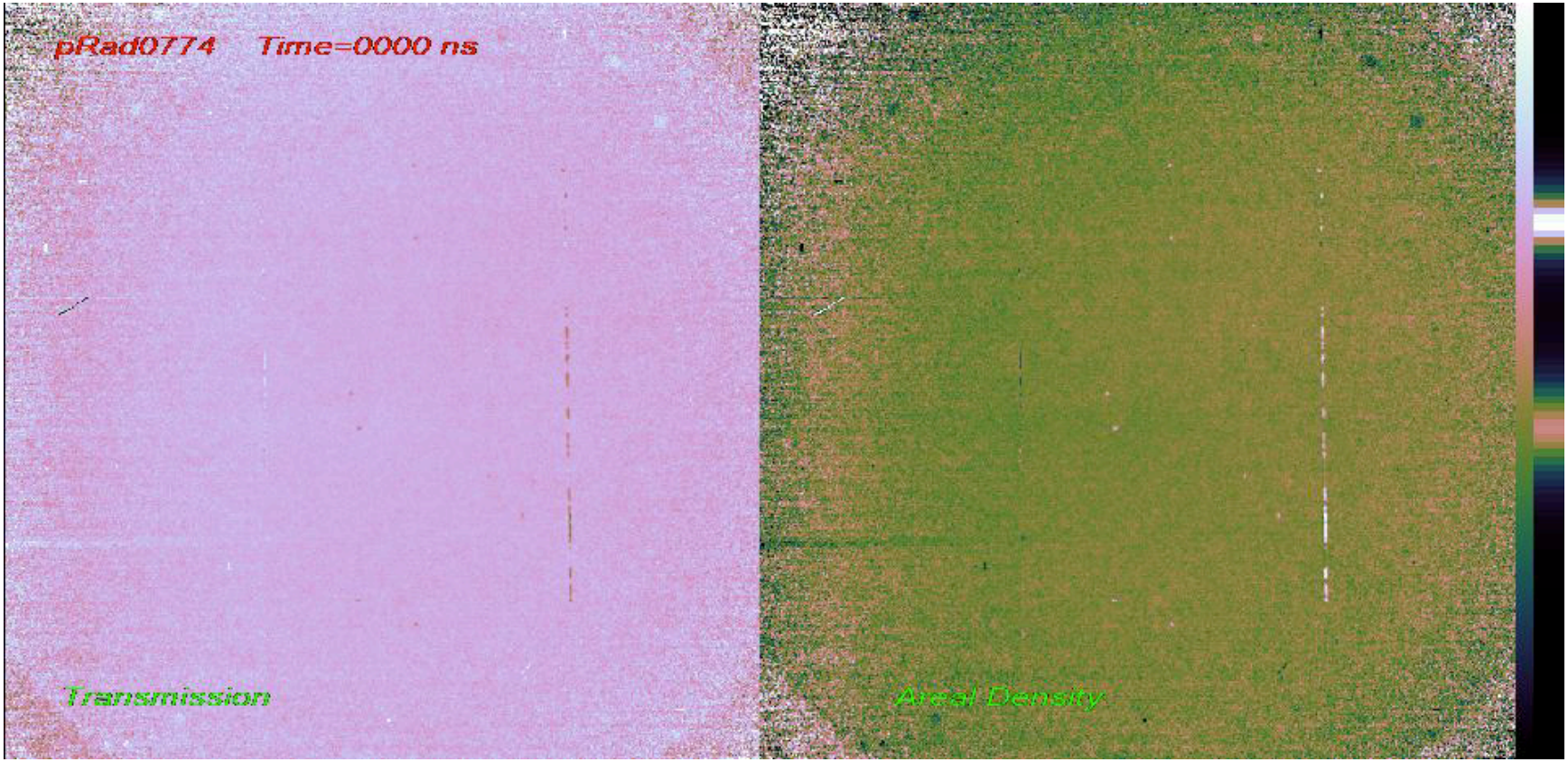
PRAD USAGE 2018 (48 SHOTS)



PRAD USAGE 2019 (37 SHOTS)

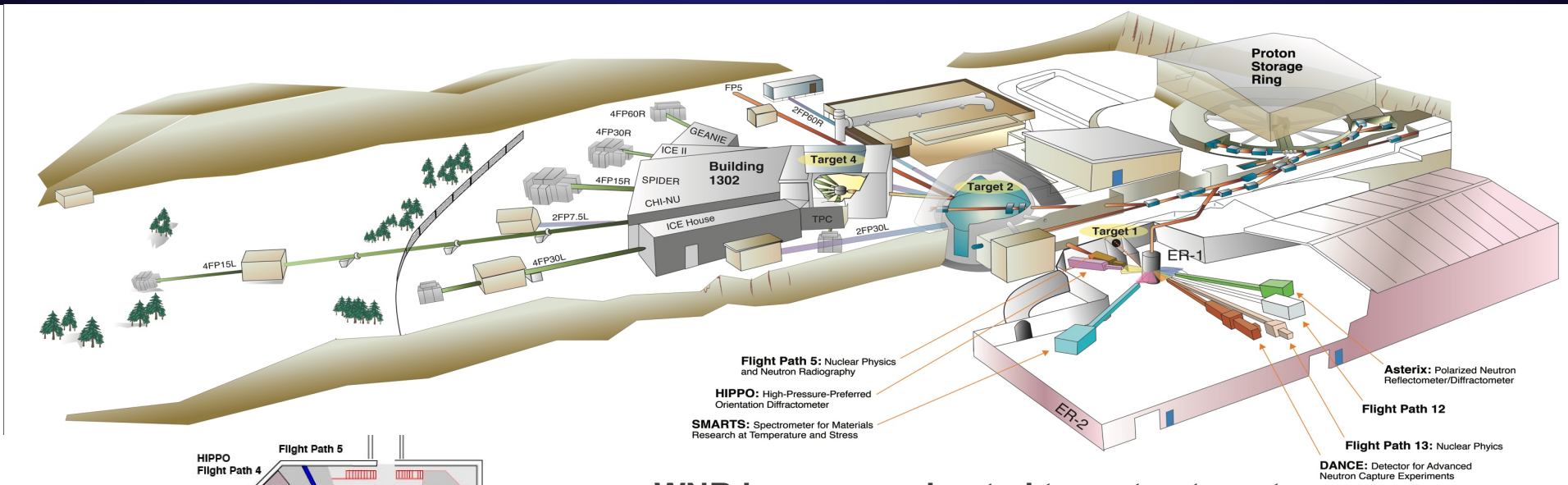


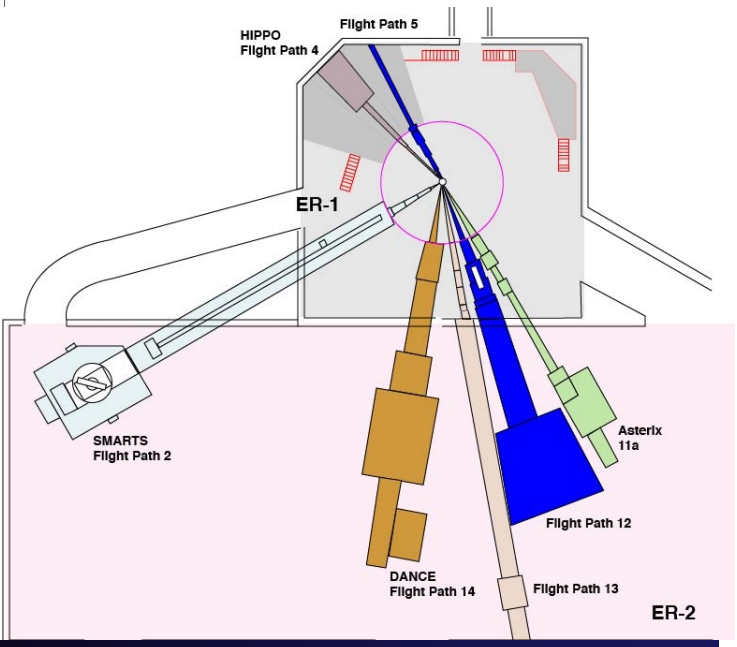
pRad Hedonist: 4 detonators on corners of 9501 slab (50 g) create colliding waves at center



Shots designed to test the EOS for HE detonation products. Measured: Burn front speed, density changes, and shape of colliding shock waves. Pressure reached 1.6 Mbar at center.

Thirteen neutron flight paths at LANSCE enable diverse array of nuclear and materials science experiments

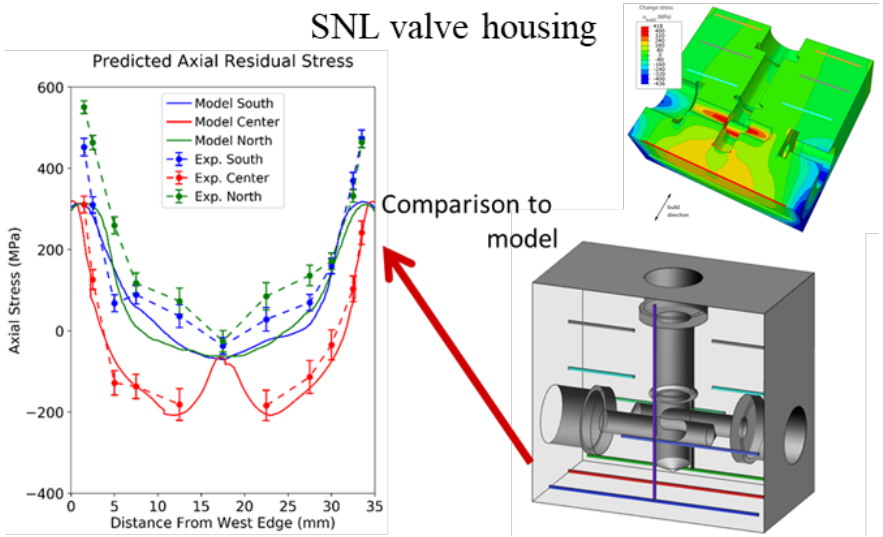


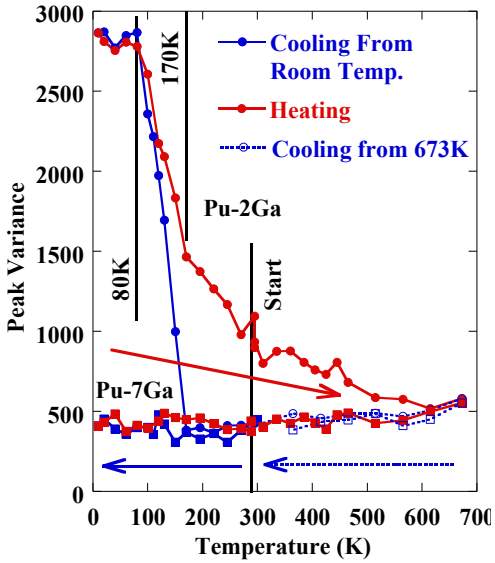


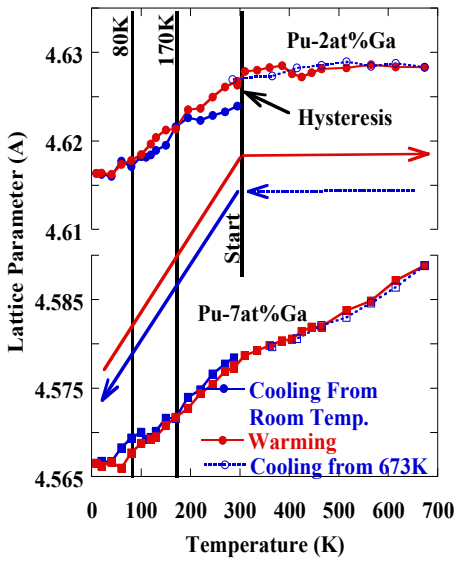
- **WNR is an unmoderated tungsten target**
  - Fission and fusion relevant nuclear cross sections
  - High-energy neutron radiography
  - Industrial irradiation program
- **Lujan Center has a moderated target**
  - SMARTS & HIPPO: neutron diffraction
  - ASTERIX: Neutron reflectometry
  - FP-5 energy resolved neutron radiography
  - DANCE and FP-12: Nuclear physics
- **Authorization basis suited to NNSA needs**
  - Classified experiments
  - 150 PEG at a flight path(380 PEG total)
  - 12g TNT equivalent at a flight path

Material science at the Lujan Center focuses on developing a predictive manufacturing capability

- **Multi-lab (LANL, LLNL, SNL, NSCKS) effort to develop improved models for additively manufactured components**
  - High-fidelity process models can enable process-based qualification of components
  - Neutron diffraction measures residual stresses throughout components.
- **Understanding how PuGa alloy composition affects properties**
  - Defects in the microstructure control the mechanical properties and influences phase boundaries
  - Large differences in defect production and hysteresis observed as a function of %Ga
  - Used to develop microstructure/phase aware strength models needed to predict manufacturing and performance of PuGa alloys

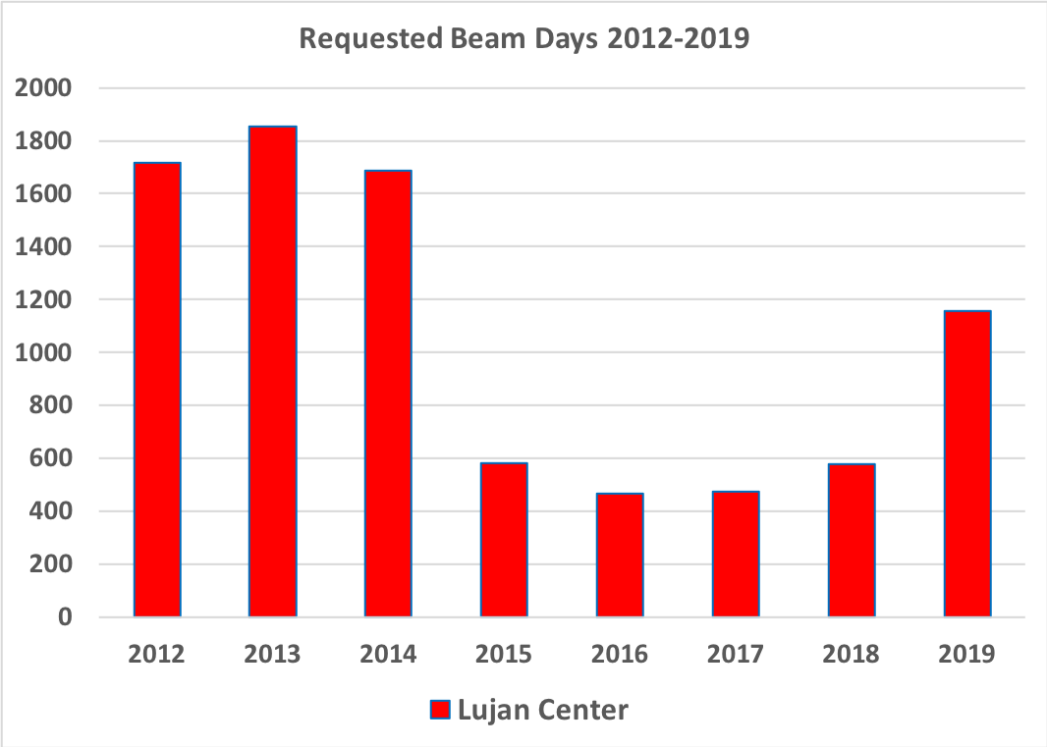


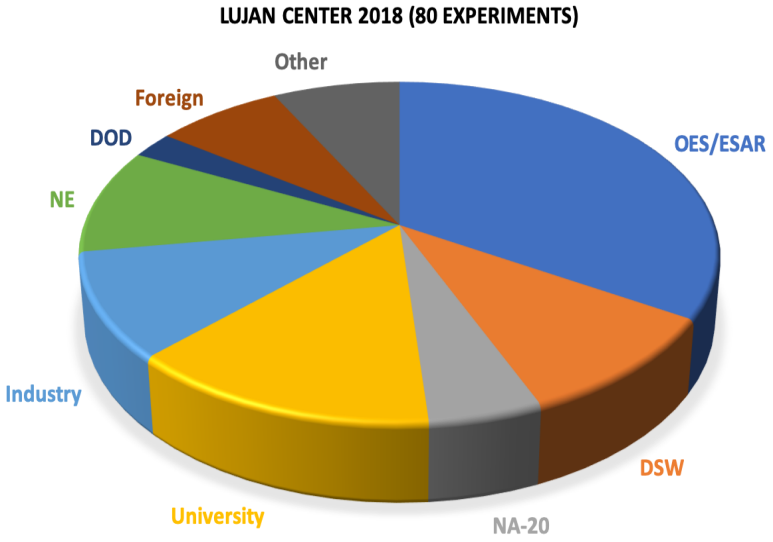


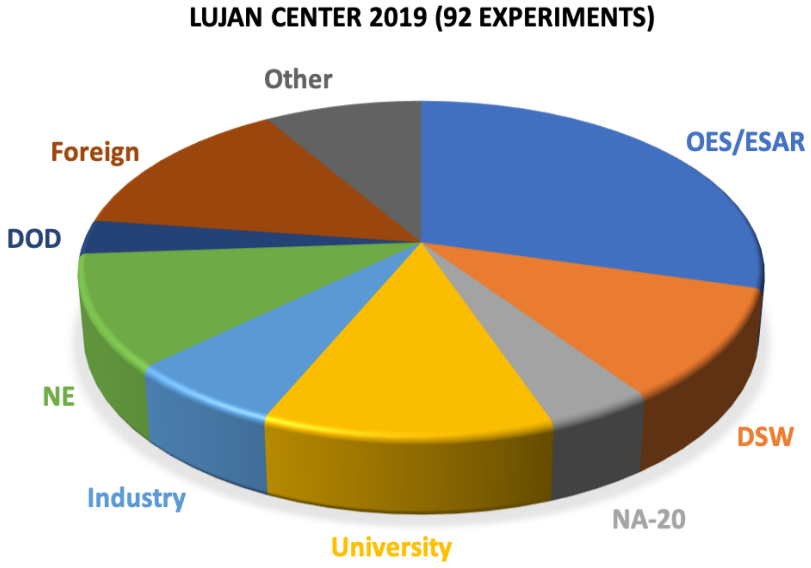


Material science at the Lujan Center is saturated, a new beam line is needed to keep up with growing demand

A beam line dedicated to 3-dimensional stress and texture measurements would significantly increase throughput and impact of Lujan Center on NNSA mission

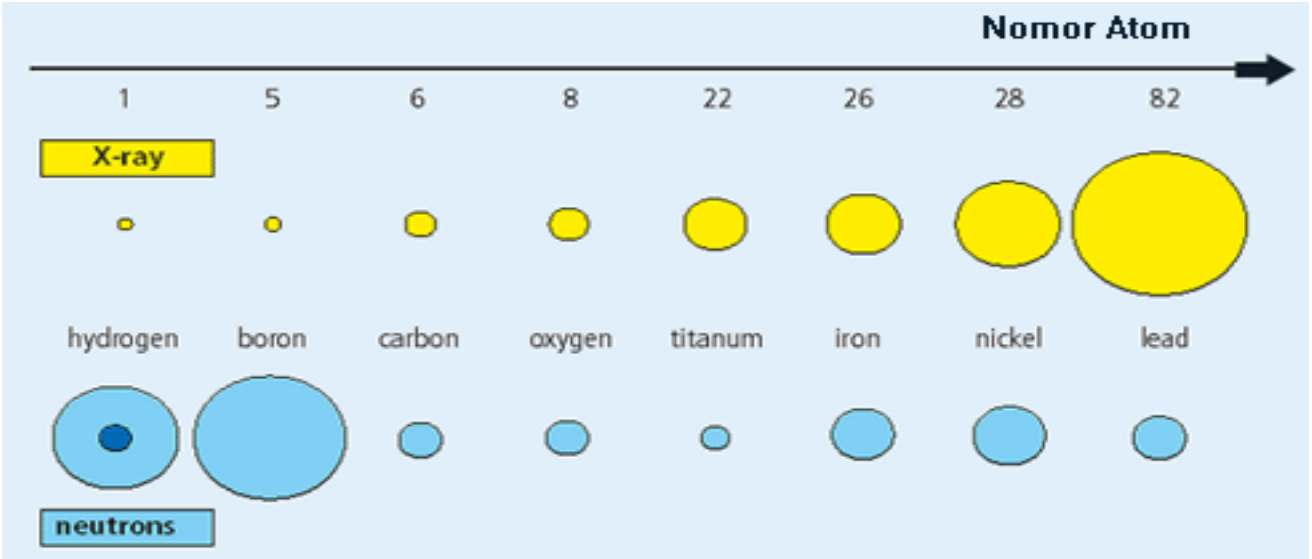






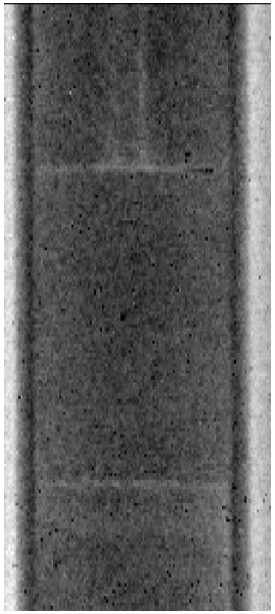
LANSCE is a center of excellence for neutron radiography

- **Neutron radiography is complementary to x-ray radiography**
  - Nuclear cross section vs. electron density
  - Can image hydrogen through lead
- **LANSCE supported an assessment of neutron imaging for surveillance Assessed capability vs. energy using TOF imaging**

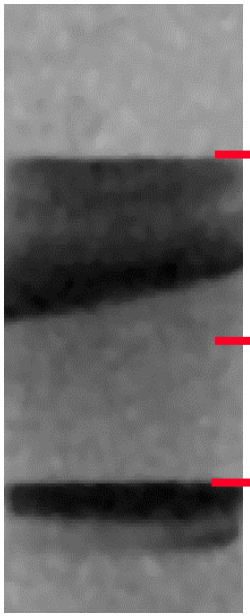


Isotopically specific neutron imaging is a unique capability of LANSCE

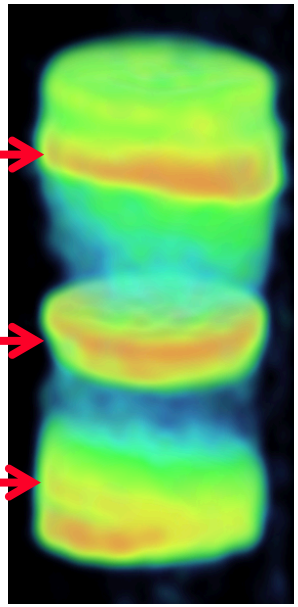
- Each nucleus has a unique neutron absorption spectrum
- Using time-of-flight we can select a narrow energy range and therefore a specific element or isotope



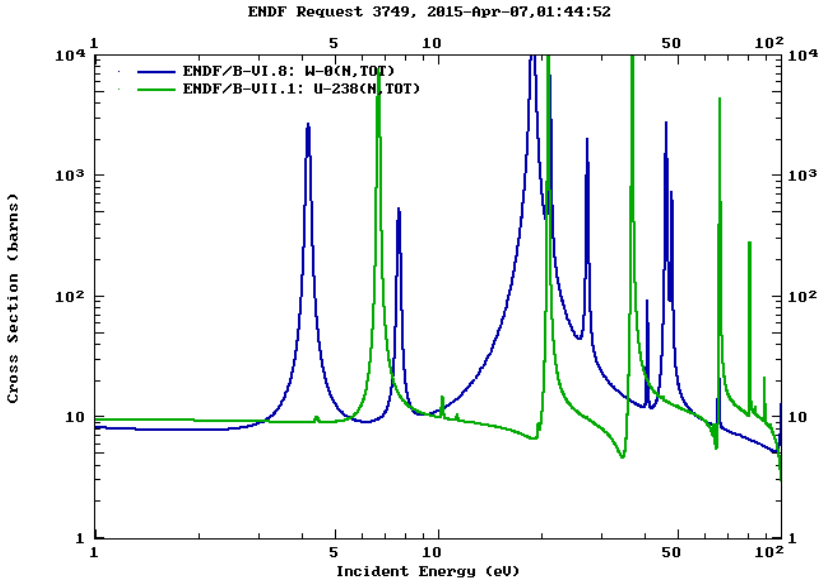
Thermal neutron image



Tungsten only by energy selection



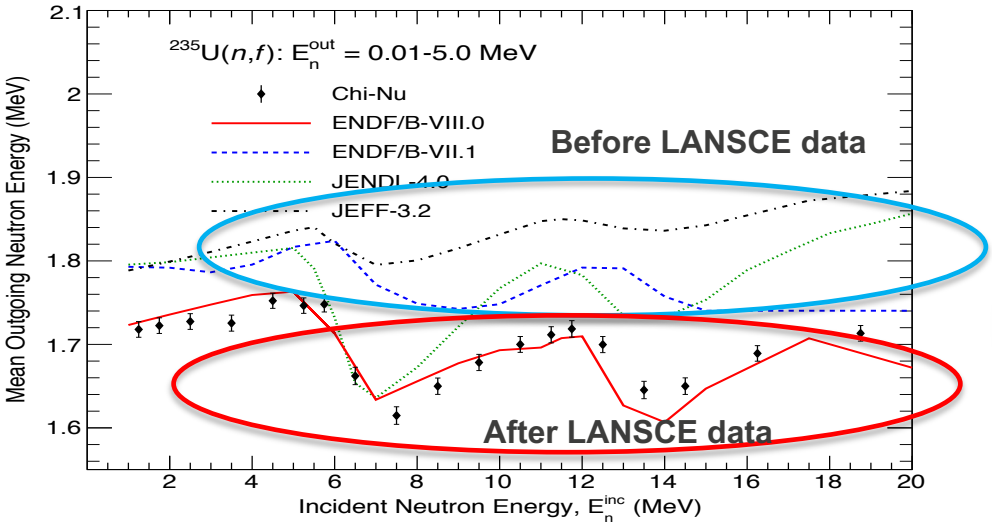
3-D reconstruction Tungsten

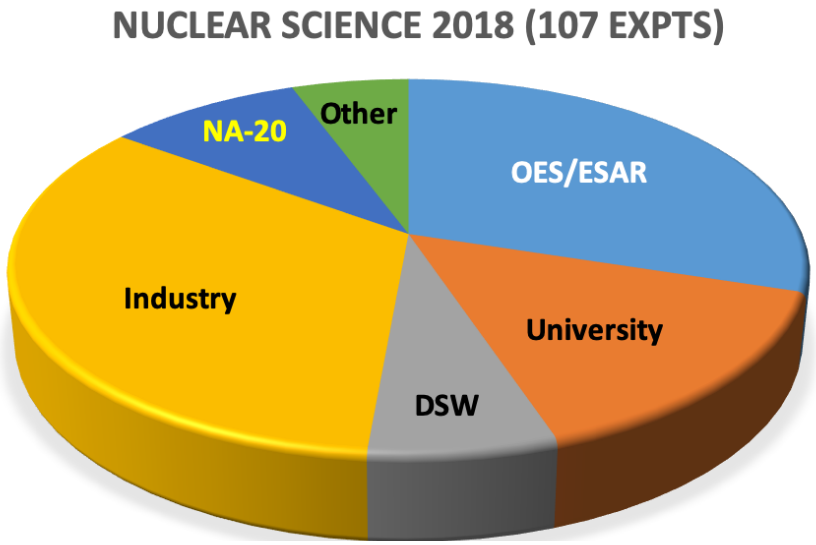


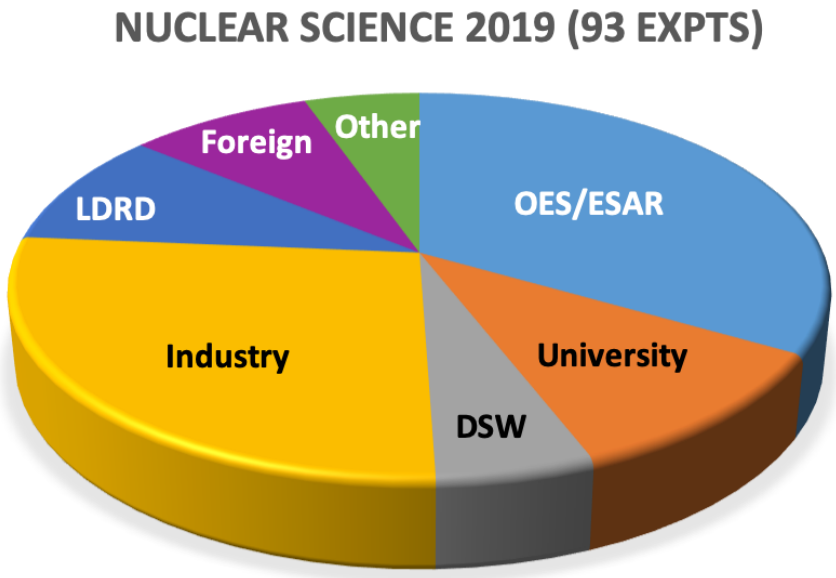
Enables quantitative measurements of isotopic density in nuclear fuels
Can measure fuel burn up, material diffusion, contamination, and damage

Nuclear science at LANSCE measures the breadth of neutron-induced reactions of interest to NNSA

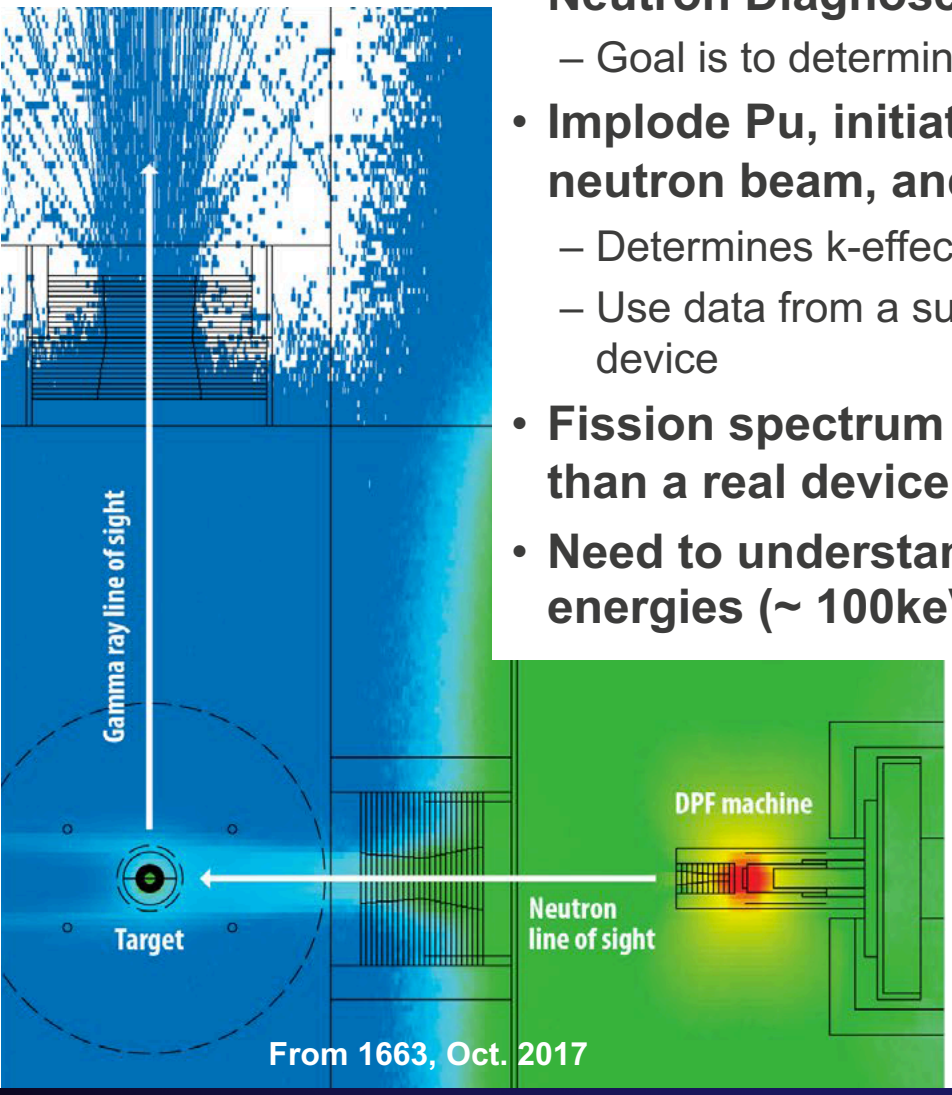
- **LANSCE data has had a significant impact on ENDF/B-VIII and a L1 milestone on criticality**
  - Total fission cross section Pu and U @ TPC
  - Prompt fission neutron spectrum of Pu and U @ Chi-Nu
  - Neutron capture on Pu, U, and Am @ DANSCE
  - Strong collaborations with LLNL, CEA, and SSAA
- **Future focus on fission fragment yields**
  - reactor decay heat
  - waste management
  - nuclear survivability
  - Basic science (reactor antineutrino anomaly)
- **Future focus on keV-MeV neutron cross sections**







LANSCE nuclear science will be key to the NDSE program

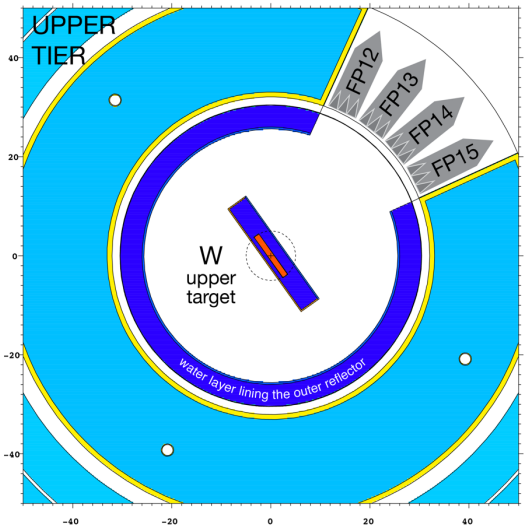


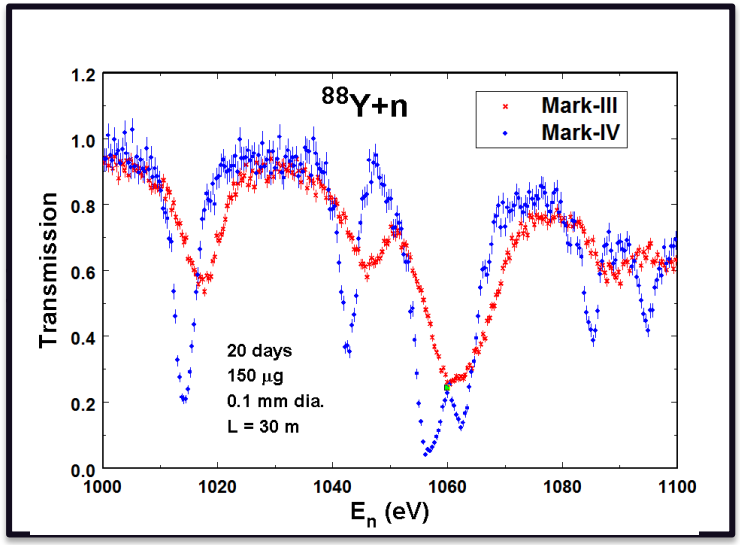
- **Neutron Diagnosed Sub-critical Experiments**
  - Goal is to determine the impact of aging on plutonium compressibility
- **Implode Pu, initiate fission reactions with an intense neutron beam, and measure decay the gamma rays**
  - Determines k-effective for the device
  - Use data from a sub-critical device to infer performance of a real device
- **Fission spectrum of sub-critical device is lower in energy than a real device**
- **Need to understand neutron cross sections at these energies (~ 100keV – 1 MeV)**

The new Target at the Lujan Center will dramatically increase our ability to measure cross sections in this energy range

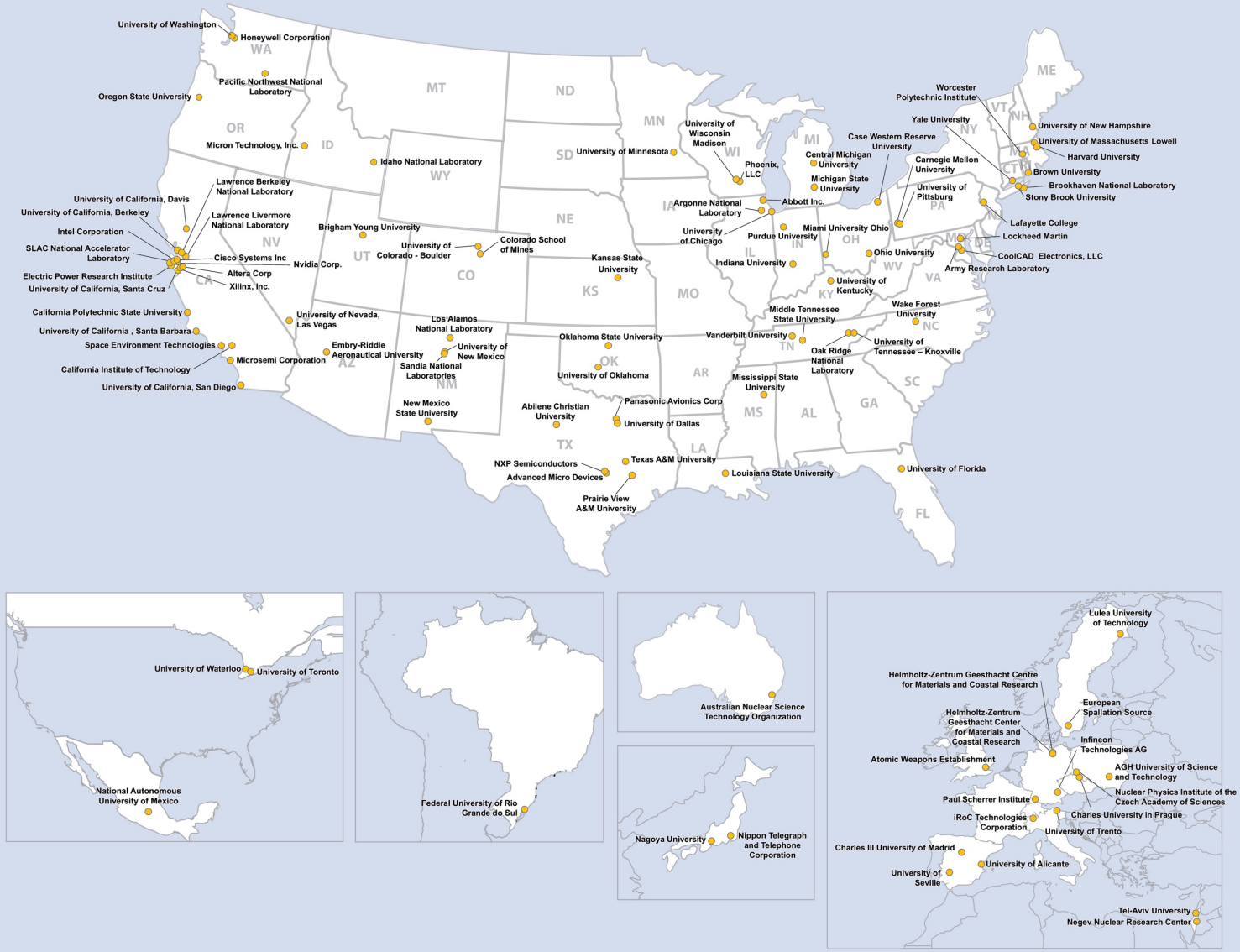
The new Lujan Center target will improve our understanding of radiochemical tracers in historic nuclear tests

- Neutron cross sections of tracer elements have large uncertainties
- Measurements on radioactive isotopes are needed to constrain neutron cross sections
- Increase flux and improve resolution in keV to MeV band
- The new target at the Lujan center will improve our ability to measure these cross sections by up to 3 orders of magnitude





The LANSCE User program attracts researchers from around the world

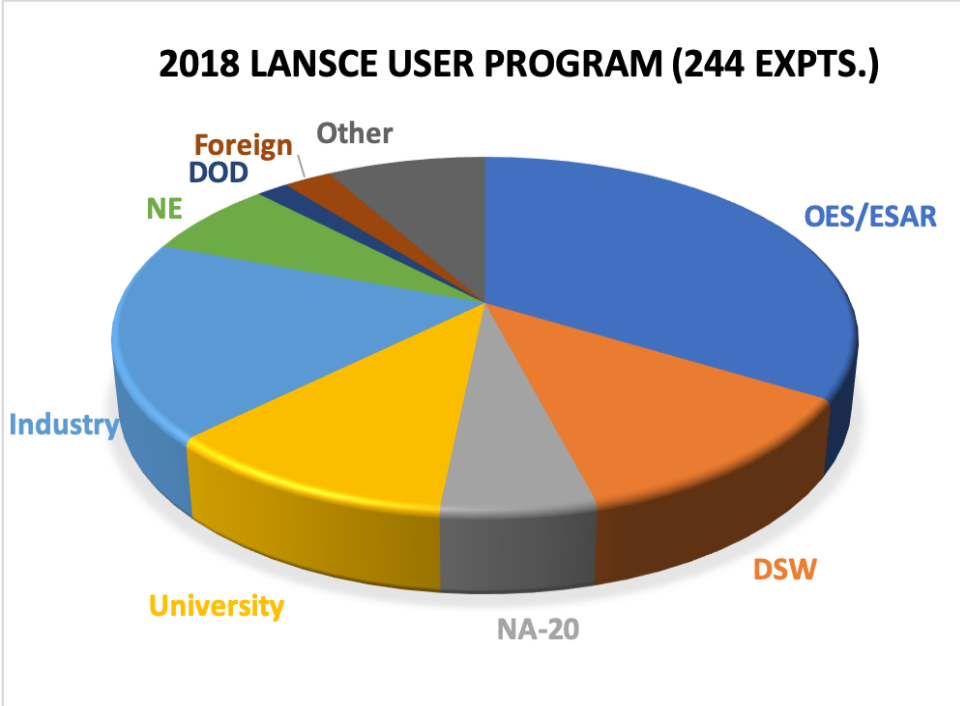


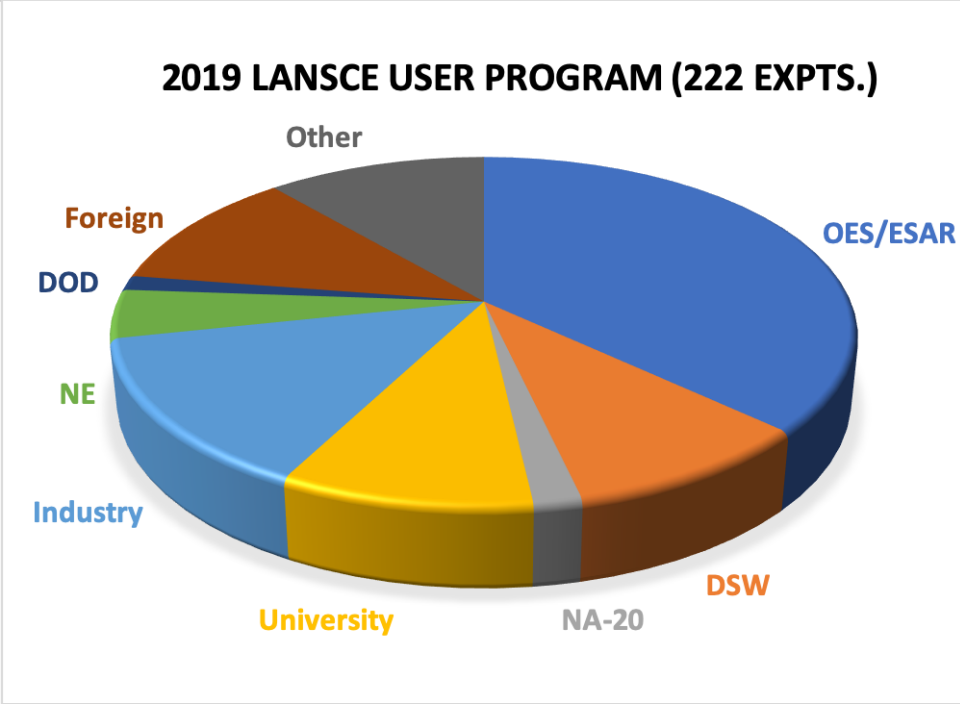
591 users
101 institutions
16 countries

The LANSCE User program serves a broad range of sponsors

pRad, Lujan Center, and WNR

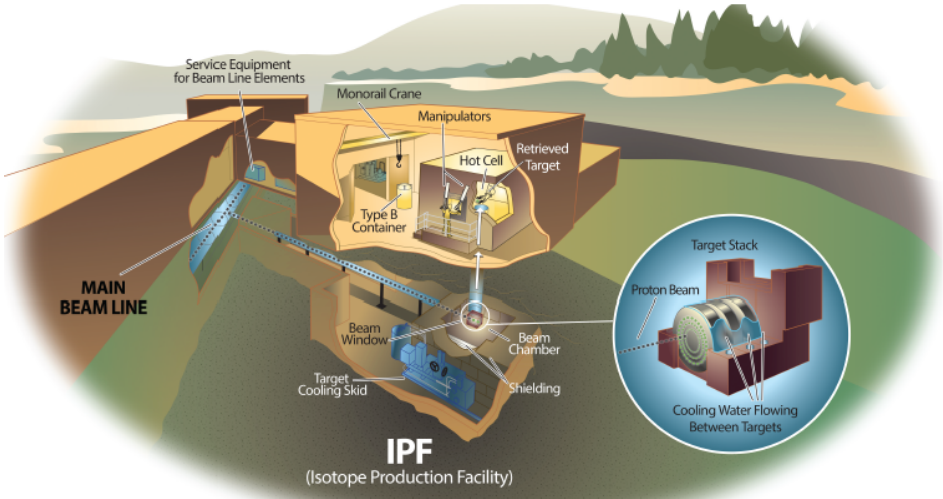
1,628 beam-experiment days scheduled in 2018

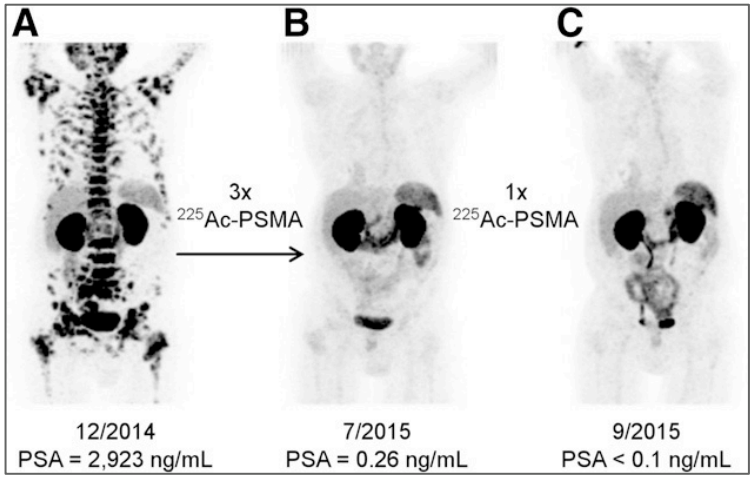




Medical isotopes produced at LANSCE serve the needs of 30,000 patients per month and enable future cancer therapies

- **LANSCE produces 60% of the 82Sr supply for PET scanners in the US**
  - 30,000 patients /month impacted
- **We are researching the production of Ac-225**
  - Used for targeted alpha therapy
  - Short path length of alpha particles leaves surrounding tissue alive
  - Need on site separation capability





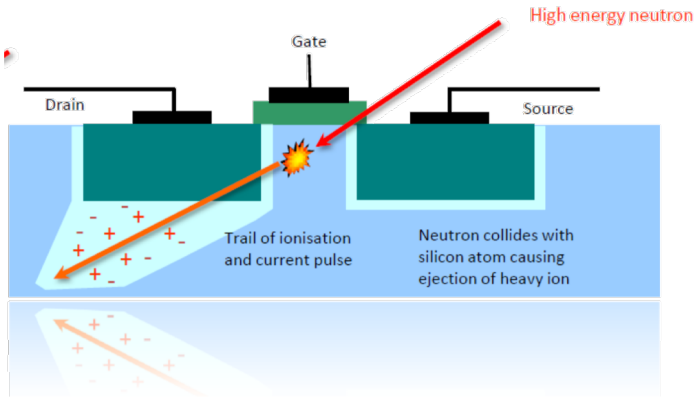
Treatment of metastatic prostate cancer with Ac-225.
C. Kratochwil, J. Nuc. Med, v57, 2016 p1971


Shipping container

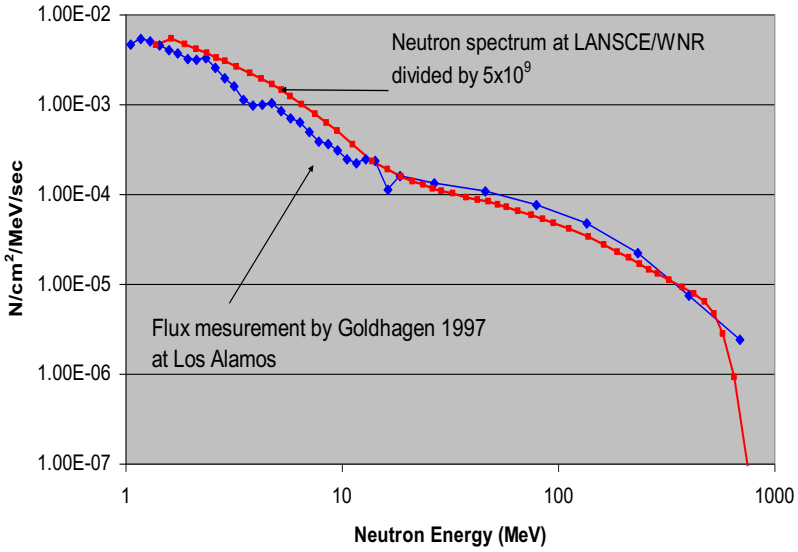

TA-48 Hotcells

Neutron irradiation is critical for the defense and civilian applications

- LANSCE is THE facility for electronics testing and certification
- Avionics, high-performance computing, self-driving vehicles, weapons' tailkits
- ISIS just opened ChipIR facility in the UK
- ORNL is proposing a 3rd target station
- Industry relies on LANSCE for reliable beam delivery – currently the only U.S. facility

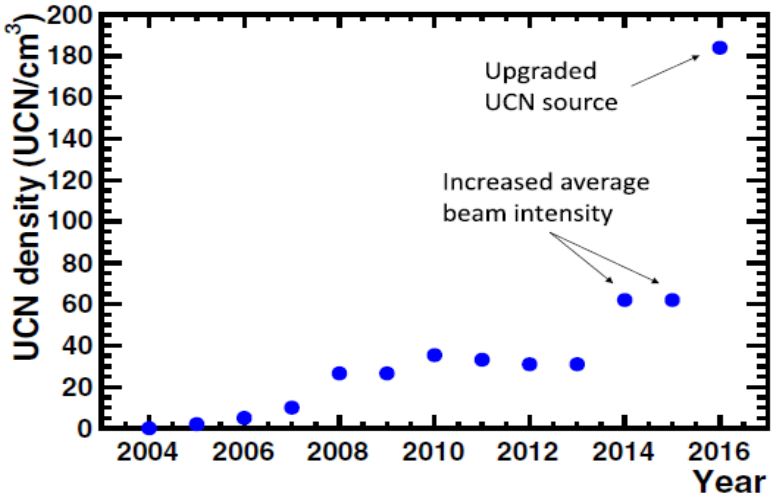


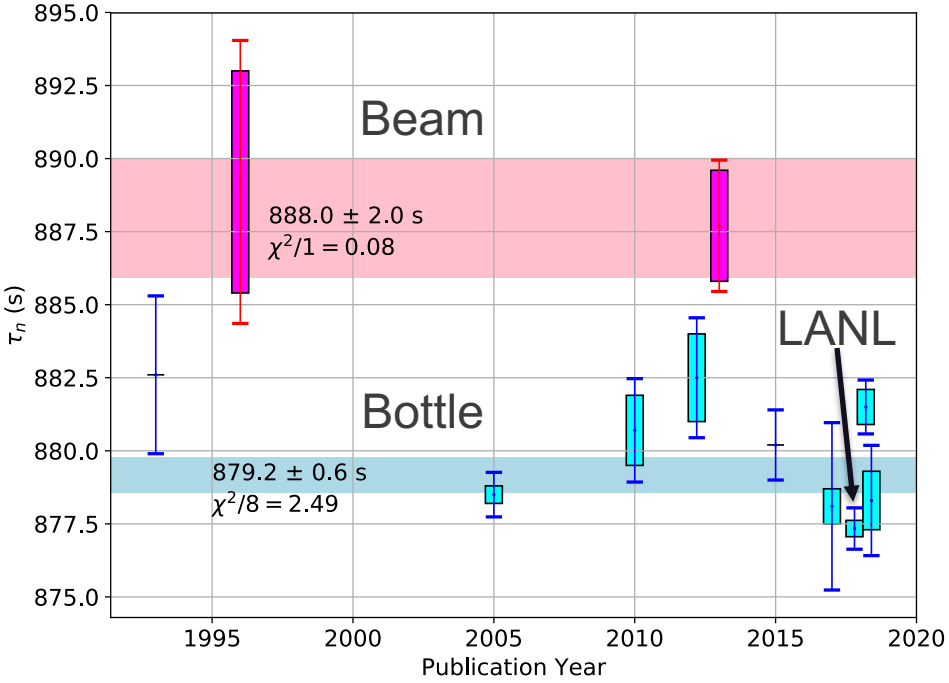
Neutron Flux at Los Alamos and LANSCE/WNR

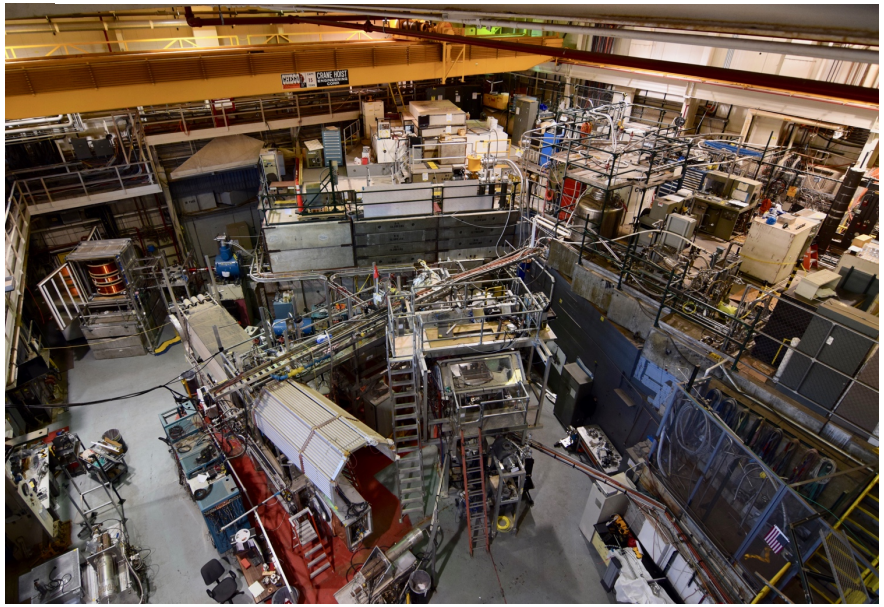


Ultra-cold neutrons can probe fundamental symmetries of nature

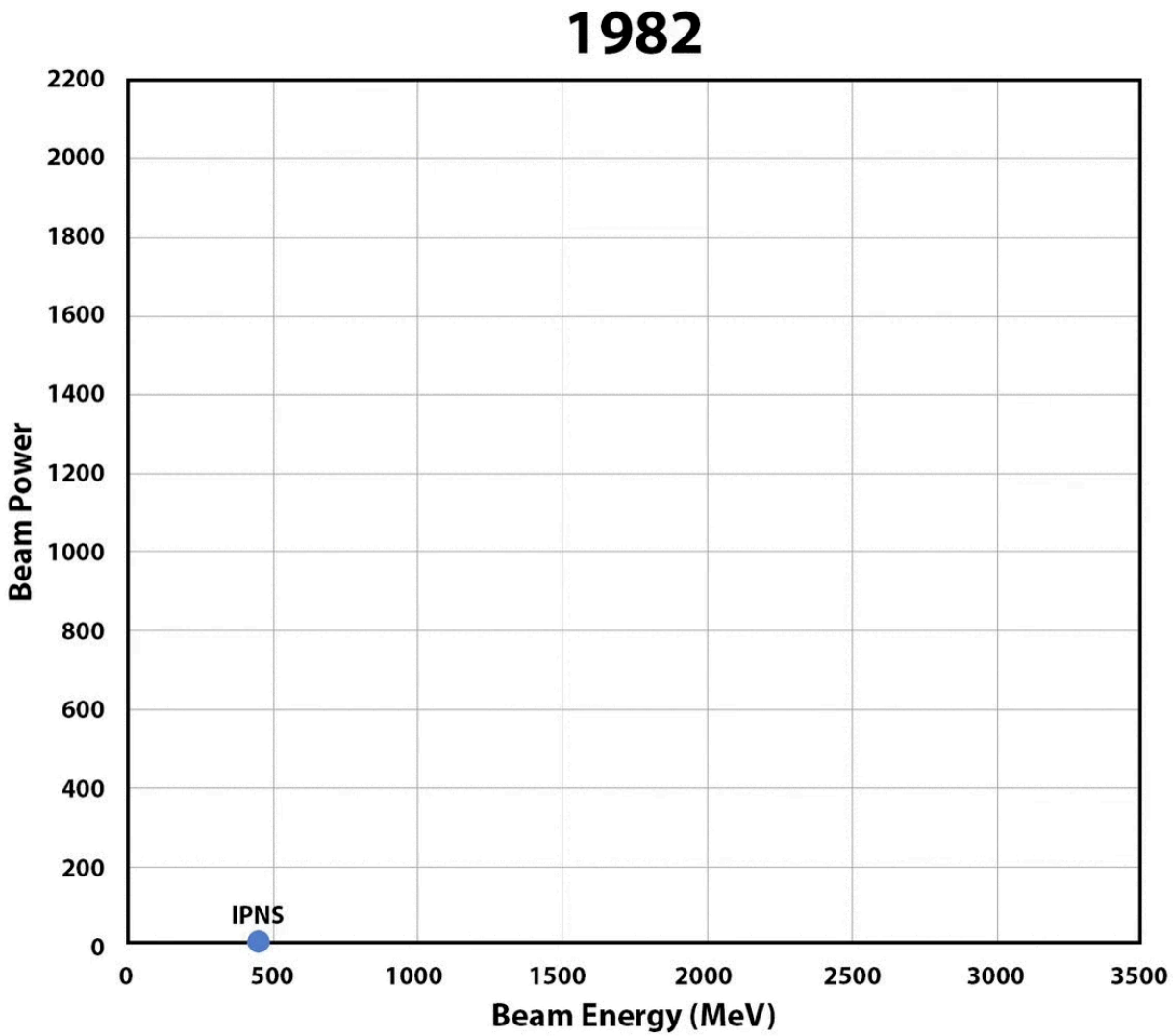
- **LANSCE has the most intense source of ultra-cold neutrons**
- **We have published the world's most precise measurement of the neutron lifetime (*Science* May 6, 2018)**
- **Developing experiment to detect non-β decay of neutrons**





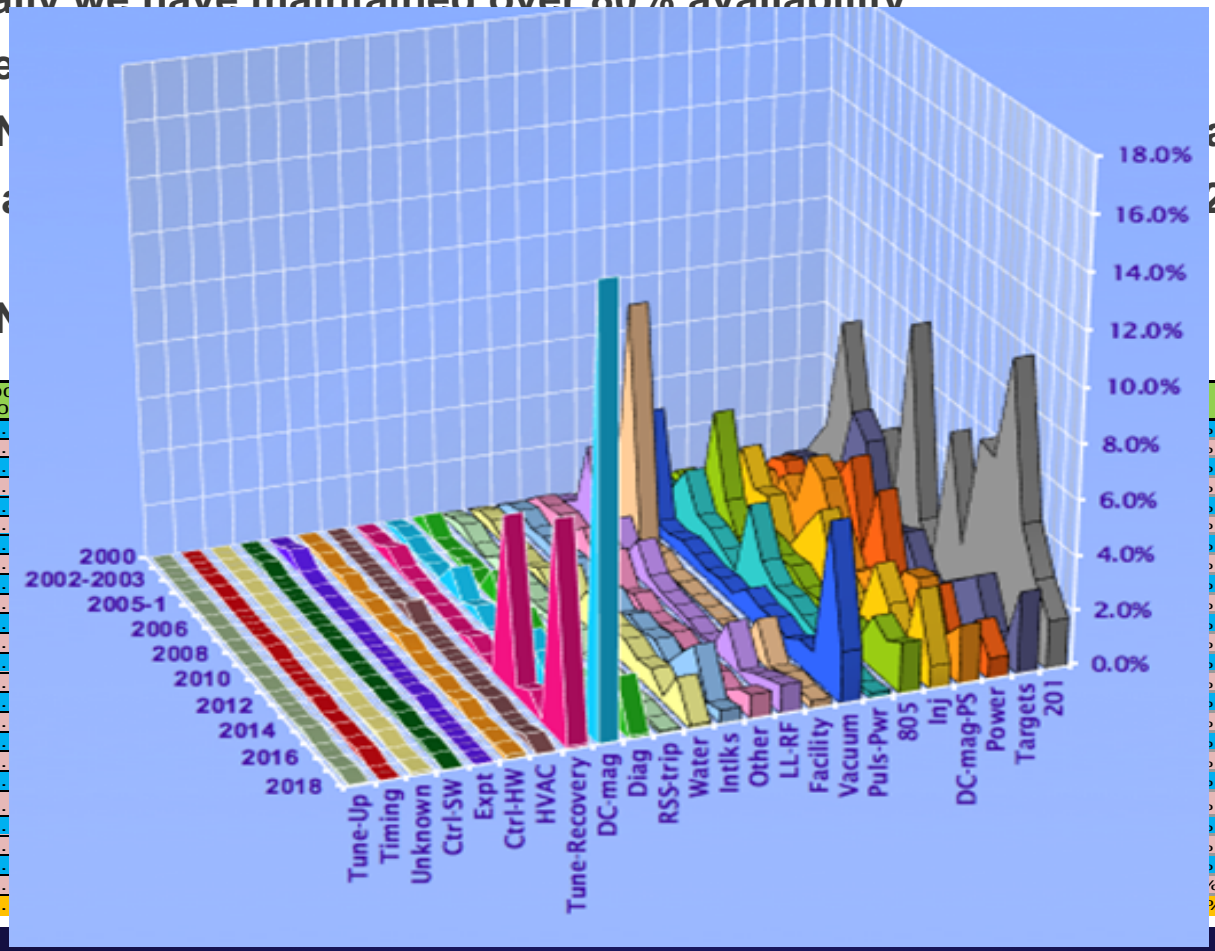


LANL's accelerator capability has deteriorated. Significant investment is needed to reinvigorate this critical capability.



An aging accelerator presents unique challenges

- **LANSCE has an antiquated controls and diagnostic system – a mixture of 1970s and newer technologies (including Vax computers)**
  - Limited ability to track down machine tuning problems has led to extensive startup delays
- **Historically we have maintained over 80% availability**
- **Past 3 ye**
- **2017 LAN** **and tune beam**
- **2018 Luja** **2017 beam losses**
- **2019 LAN**



System	2001	200 20			2016	2017	2018
Tune-Up	0.0%	0.			0.00%	0.14%	0.04%
Timing	0.0%	0.			0.17%	0.01%	0.01%
Unknown	0.0%	0.			0.01%	0.07%	0.12%
Ctrl-SW	0.0%	0.			0.15%	0.12%	0.01%
HVAC	0.0%	0.			0.00%	0.27%	0.00%
Expt	0.2%	0.			0.00%	0.00%	0.01%
Ctrl-HW	0.1%	0.			0.09%	[illegible]	0.18%
Tune-Recover	0.1%	0.			0.16%	7.76%	[illegible]
DC-mag	0.2%	0.			0.32%	[illegible]	16.15%
Diag	0.5%	0.			0.00%	1.83%	0.12%
RSS-trip	0.3%	0.			0.17%	0.12%	0.12%
Water	0.4%	0.			0.24%	1.43%	0.15%
Intlks	0.5%	0.			1.94%	0.31%	0.50%
Other	0.6%	0.			0.09%	0.64%	0.89%
LL-RF	0.3%	0.			0.53%	0.80%	1.06%
Facility	0.0%	0.			0.36%	0.28%	0.29%
Vacuum	0.4%	1.			0.97%	6.18%	1.90%
Puls-Pwr	0.8%	0.			0.20%	0.10%	0.20%
805	0.8%	0.			1.93%	1.49%	1.86%
Inj	0.3%	0.			0.09%	3.20%	0.84%
DC-mag-PS	1.0%	1.			0.34%	1.35%	2.17%
Power	0.1%	1.			0.05%	1.71%	0.77%
Targets	0.8%	1.			0.55%	0.61%	3.02%
201	1.1%	2.			4.45%	2.84%	1.78%
	8.6%	13.			12.8%	31.5%	32.3%

We are developing a proposal to ensure LANSCE continues to deliver for mission

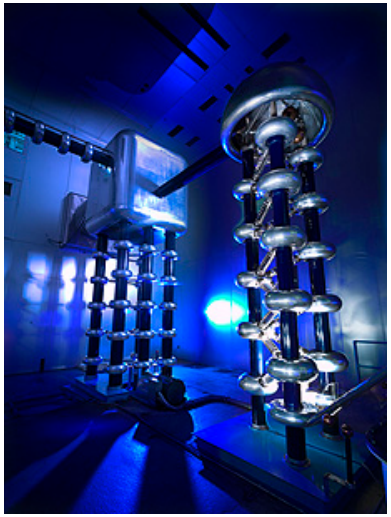
- **With DMMSC timing uncertain we must maintain capability of LANSCE for stockpile certification**
- **Replace front-end accelerating structures for reliable dynamic plutonium experiments and set the stage for future capability enhancements**
  - Replace Cockroft-Walton (C-W) structure and Drift-Tube linac (DTL)
  - LANSCE and PSI have the last operating C-Ws in the world (invented in 1932)
  - The DTL is showing signs of aging
- **Modern radio-frequency quadrupoles (RFQ) system were first demonstrated at LANL (1980) and are now used world-wide**

One of two C-W systems at LANSCE. The C-Ws accelerate H+ and H- ions to 750 keV (1 C-W for each ion species)

Fermilab Today

August 21, 2012

So long, Cockcroft-Walton



After 40 years operation, Fermilab's iconic Cockcroft-Walton generators will be decommissioned tomorrow morning. *Photo: Reidar Hahn*

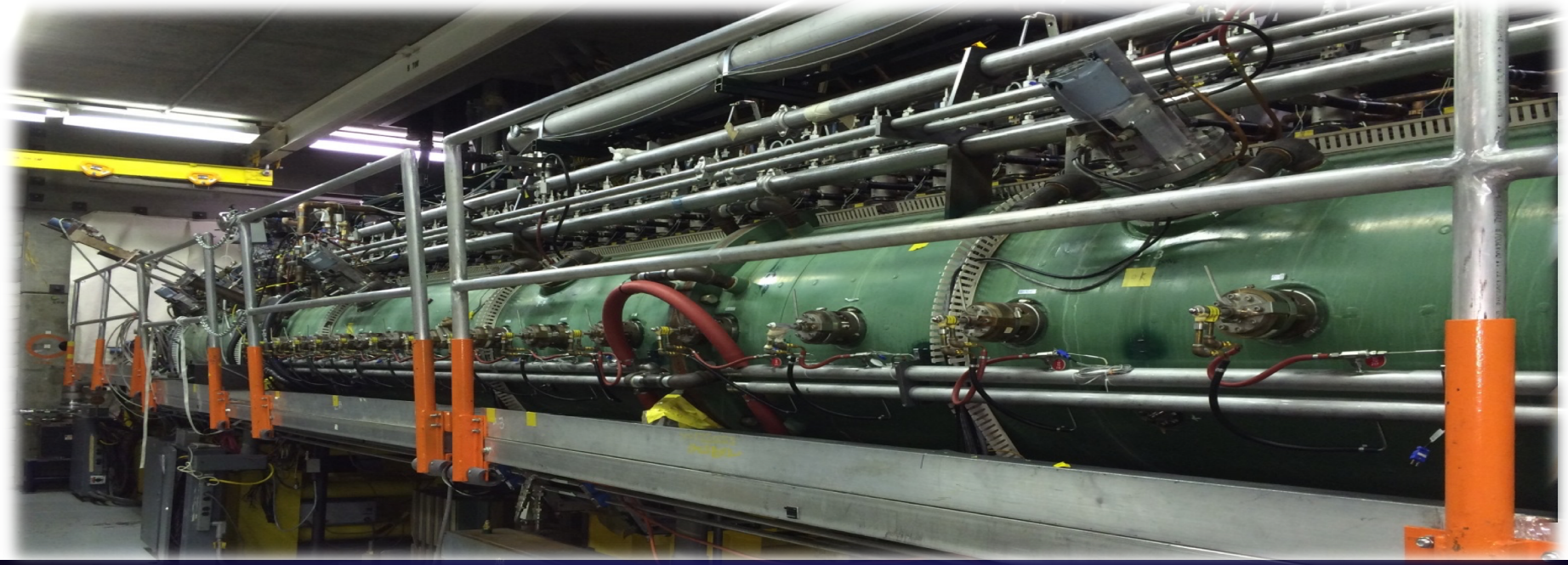
Fermilab has had many different accelerators in its four-decade history. From the Linac to the Tevatron to the Main Injector, every one of them has been powered by a Cockcroft-Walton generator. That ends tomorrow, when the generators send out their last beam.

"It's like an old car," he said. "After 40 years, maintaining it becomes more and more difficult." The new RFQ systems

However, most particle accelerators today use radio-frequency quadrupole systems that are more efficient than Cockcroft-Walton generators. Fermilab and Los Alamos National Laboratory were, until now, the only two major laboratories in the world still operating them. At the end of the current accelerator complex shutdown, Fermilab's accelerators will run on RFQ systems.

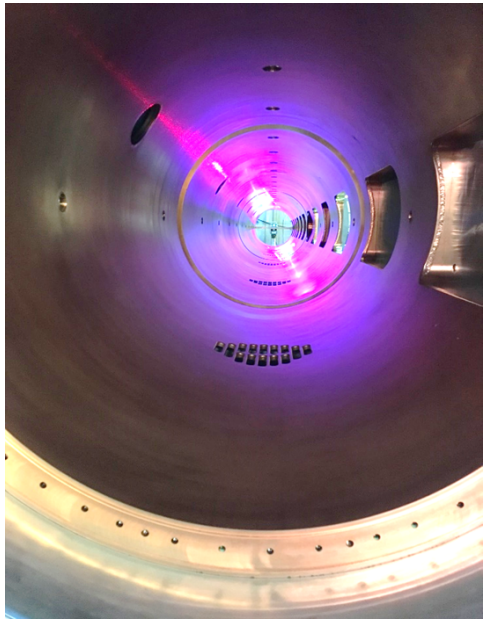
An aging accelerator presents unique challenges

- The drift-tube linac (DTL) simultaneously accelerates H+ and H- ions from 750 keV to 100 MeV
- The structures are 50 years old. Double walled steel tanks (cooling channels btwn the layers) with a 1/8” copper cladding
- 2 MWatts of RF power is dissipated in each module, with ~few kAmps of current
- Grates were welded into the tanks for access to vacuum pumps (about 15 such grates in total)
- One of the welds failed – confined space, radiation hazard, fire hazard, respiratory hazard and copper welding is extremely difficult. Repair completed; ~ two months of downtime.



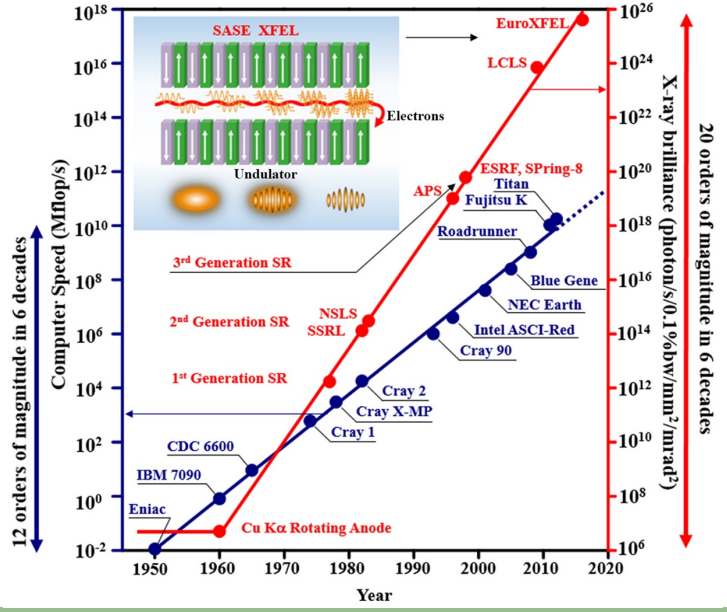
ISIS is replacing their drift-tube linac in 2020

- ISIS DTL has a mixed lineage: 2 tanks from the 1950's & two from the 1970's
- Fearing issues similar to those we have suffered they are replacing their DTL system in 2020
- It took 10 years for them to re-discover how to construct a DTL module
- Cost is estimated to be <$10M per tank

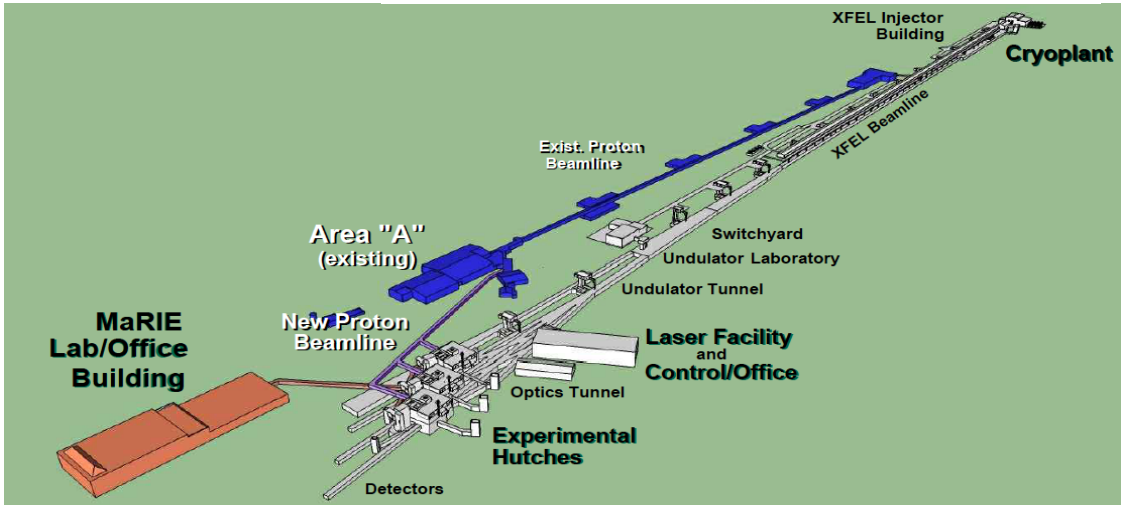


The future of stockpile stewardship will require a MaRIE-like capability

- A coherent, high-brightness XFEL can probe dynamic mesoscale material behavior at nano-second timescales
- MaRIE would provide this capability by building a 12-GeV electron linac feeding a 42 keV XFEL
- Protons would provide a secondary diagnostic
- This could drive the need for a higher-energy proton capability for spatial resolution comparable to that of MaRIE

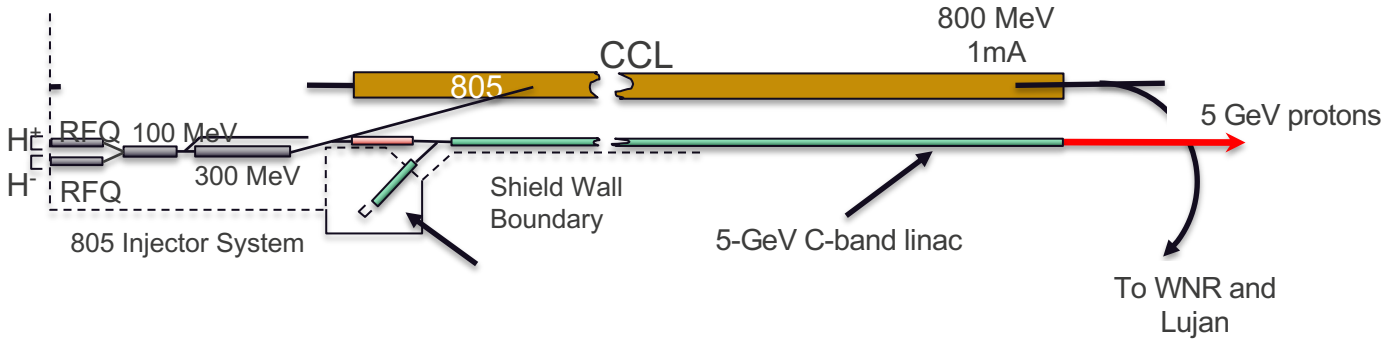


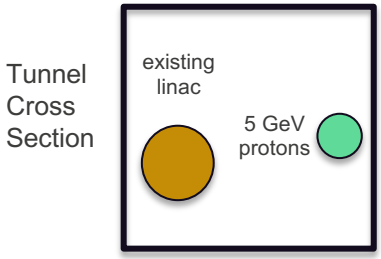
The reference design locates the electron linac on the north side of the LANSCE mesa, leveraging our existing capabilities.



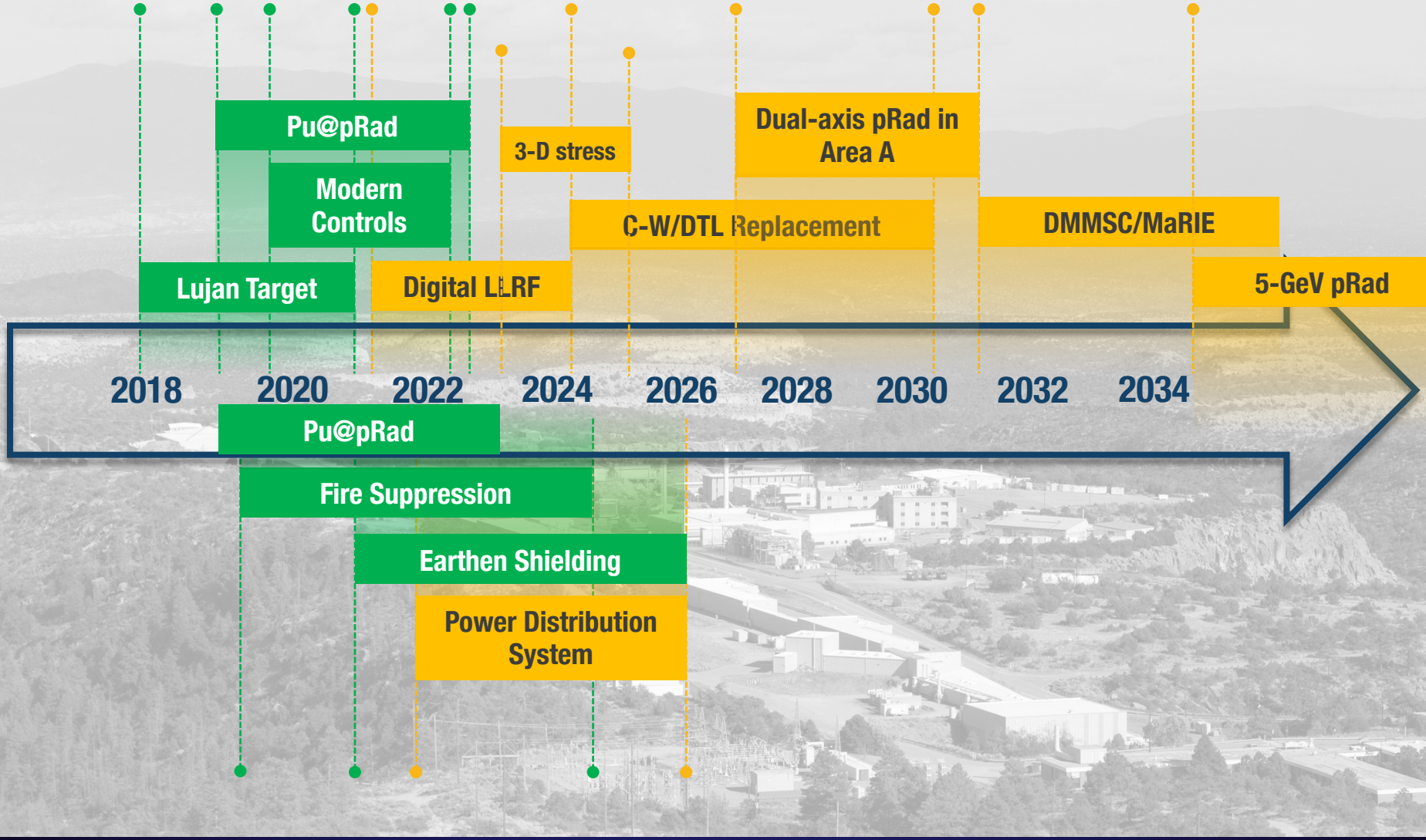
A 20-year vision for LANSCE

- **With a modern, reliable front-end and modern diagnostics and control systems we can continue to deliver on mission need and think about future capability improvements**
  - *Dynamic plutonium operations at pRad*
  - *Second dual-axis pRad firing site in Area A*
- **Modern accelerating cavities based on C-band technologies have achieved 30 MeV/meter accelerating gradients**
- **Current C-band technology would enable a 5-GeV pRad capability to be built within the existing linac tunnel**
  - This would result in ~10 micron spatial resolution, comparable to that of MaRIE





Possible Timeline for LANSCE upgrades

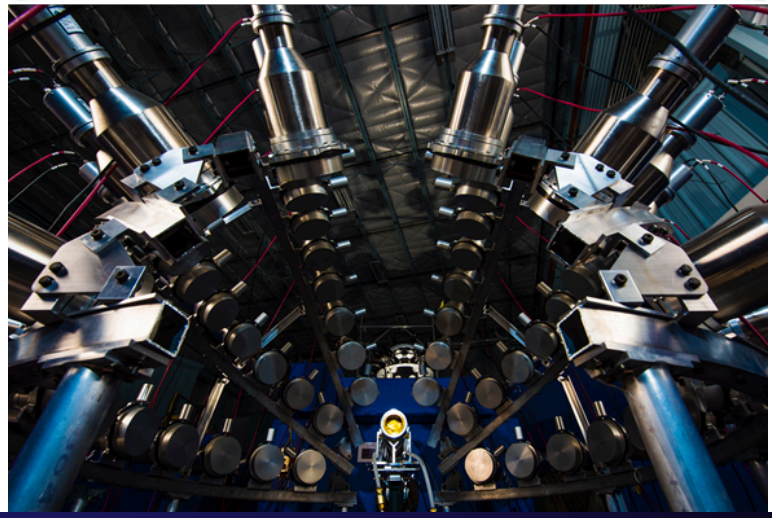


Construction of a new front-end has many benefits

- **Ensure availability of LANSCE for continued mission delivery**
- **Rebuild LANSCE's accelerator capability on relatively small but advanced accelerator project**
  - Design and build a modern, working accelerator
  - LANSCE staff have not engaged in such an activity since the LEDA project
- **Build credibility with sponsors that we are capable of designing, constructing, and operating a modern accelerator**
  - Builds confidence in our ability to deliver DMMSC
- **Build a solid basis for future enhancements (planned and prospective)**
  - Plutonium at pRad
  - New Lujan Center target for nuclear and material science
  - Material science capability including additional flight path for 3-d stress and texture
  - Production of medical isotopes
  - Continued delivery for growing neutron irradiation program
- **Set the stage for continued development of the mesa and the realization of MaRIE**

Summary

- LANSCE Plays a critical and expanding role in the certification of an evolving stockpile
- There is a growing understanding of the importance of LANSCE within NNSA
- We must continue to focus on the needs of our customer
- We must continue to develop capability to ensure that we deliver for the future mission
- We have developed a 20-year strategic vision for LANSCE that will ensure our continued importance to NNSA
- MaRIE will be the culmination of critical investments over the coming decades



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