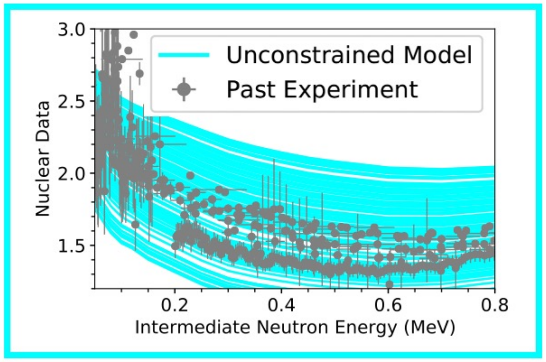
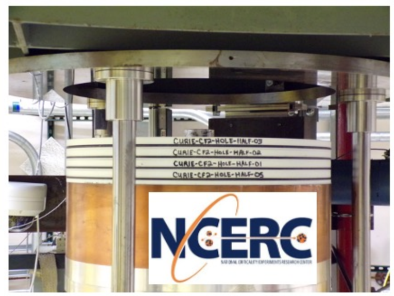
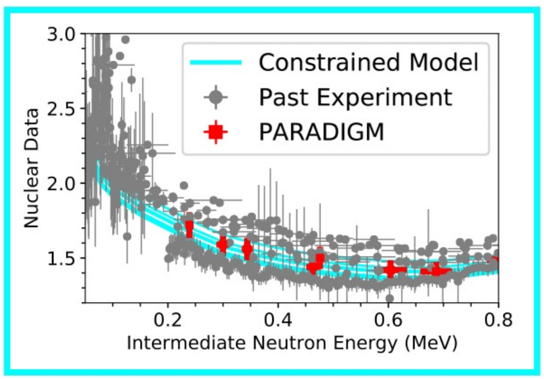


New theory and joint LANSCE & NCERC experiments lead to ...



... more precise nuclear data for applications.



Los Alamos
NATIONAL LABORATORY

PARADIGM

PARallel Approach of Differential and InteGral Measurements

LDRD

NNSA

PARADIGM: PARallel Approach of Differential and InteGral Measurements

M. Devlin, D. Neudecker, T. Cutler,

K. Amundson, P. Brain, F. Diaby, N. Gibson, M. Grosskopf, M. Herman, J. Hutchinson, T. Kawano, A. Khatiwada, N. Kleedtke, E. Leal Cidoncha, R.C. Little, A.E. Lovell, A. Stamatopoulos, S. Vander Wiel

NCSP Technical Program Review

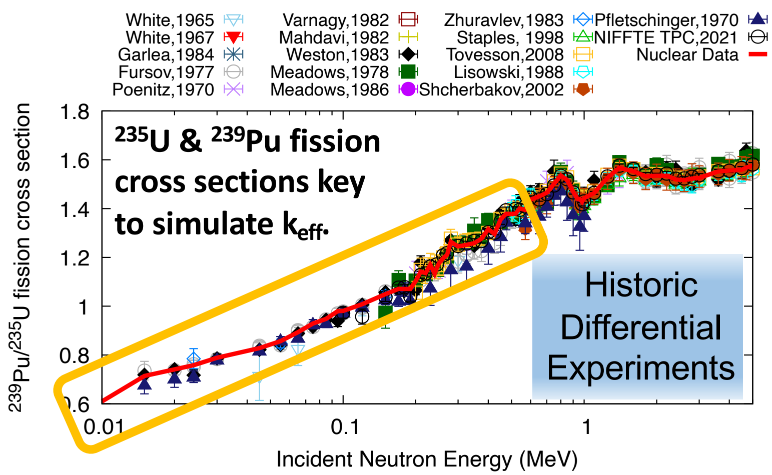
February 2024

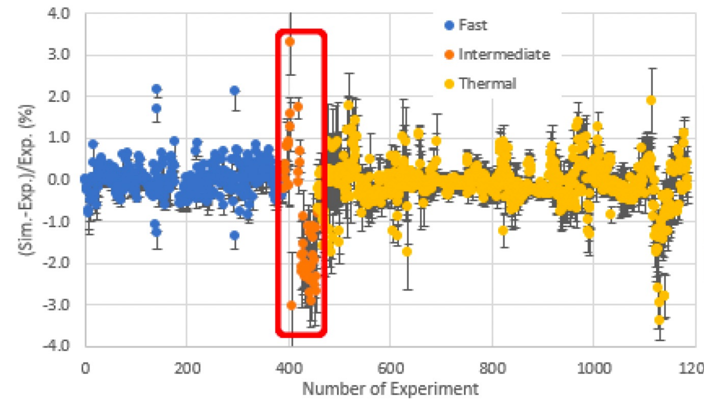
LA-UR-24-21075

PARADIGM tackles increasing accuracy and reducing unc. of intermediate energy (1-600 keV) actinide nuclear data (ND).

Intermediate actinide Nuclear Data are poor because:

- Differential experiments: scarce and uncertain due to low neutron flux.
- Nuclear theory: no reliable URR model implemented to smoothly connect RRR to fast.
- Integral experiments sensitive to this range are sparse (only 5% of ICSBEP benchmarks).





Historic Integral Experiment

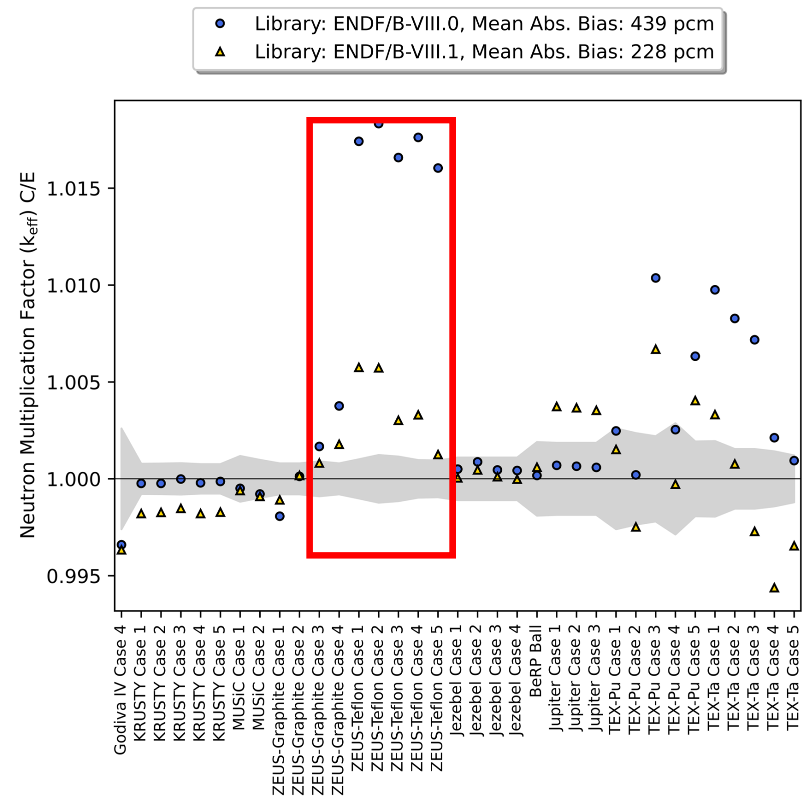
Energy Range	# Cases	Average (Sim.-Exp.)/ Exp. (%)
Fast	382	0.029
intermediate	55	-0.74
Thermal	728	-0.24

Intermediate actinide nuclear data are crucial input for the weapons program, criticality safety, etc.!

Example: Precise Zeus experiment (intermediate HEU) had C/E bias because of poorly understood reflector ND.

Zeus experiment (in ICSBEP since 2000s):

- Filled integral experiment gap in HEU intermediate ND with reliable exp. unc. of <100 pcm.
- VI.0-VIII.0: **C/E > 1000pcm & bias as funct. of EALF**.
- Large C/E partially linked to poor Cu (reflector) ND.
- New Cu differential exp. and evaluation followed.
- **20-25 years later: C/E (VIII.1beta3) ~ 500 pcm.**
- Integral exp. (IER-537, Cerberus) should validate theory and differential data for better Zeus C/E.



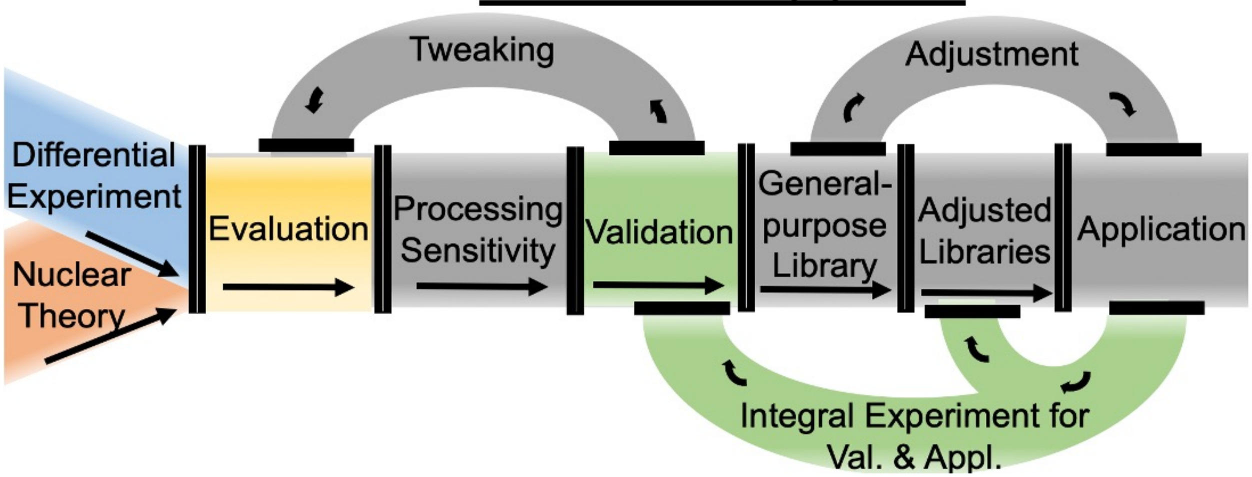
If differential AND integral experiment exp. AND theory were developed simultaneously, the Zeus issue could have been resolved in < 5 years.

Thanks to N. Kleedtke

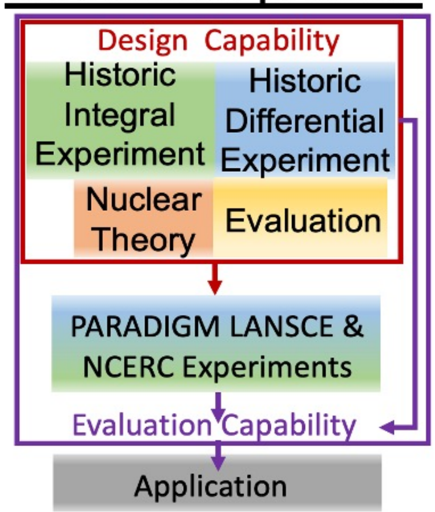
PARADIGM tackles reducing actinide intermediate ND uncertainty by simultaneous improvements to several parts of the ND pipeline.

- **Theory team:** implements model to evaluate intermediate-energy ND.
- **LANSCE team:** provides high-precision differential data leveraging higher intermediate neutron flux at LANSCE.
- **NCERC team:** executes integral exp. with ND improved by LANSCE data & theory.
- **Evaluation & ML team:** selects LANSCE/ NCERC exp. to best improve actinide ND.

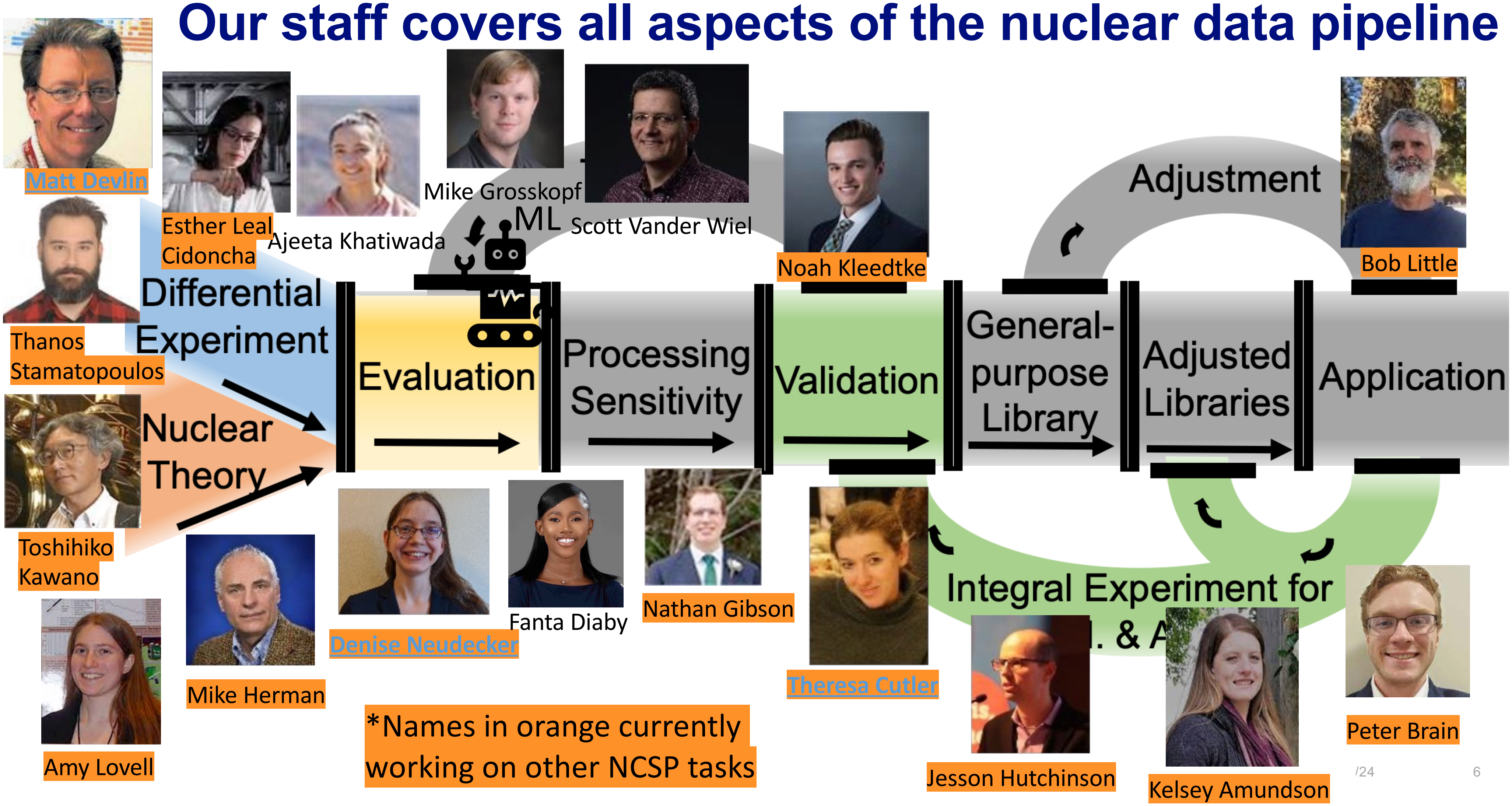
The linear ND pipeline



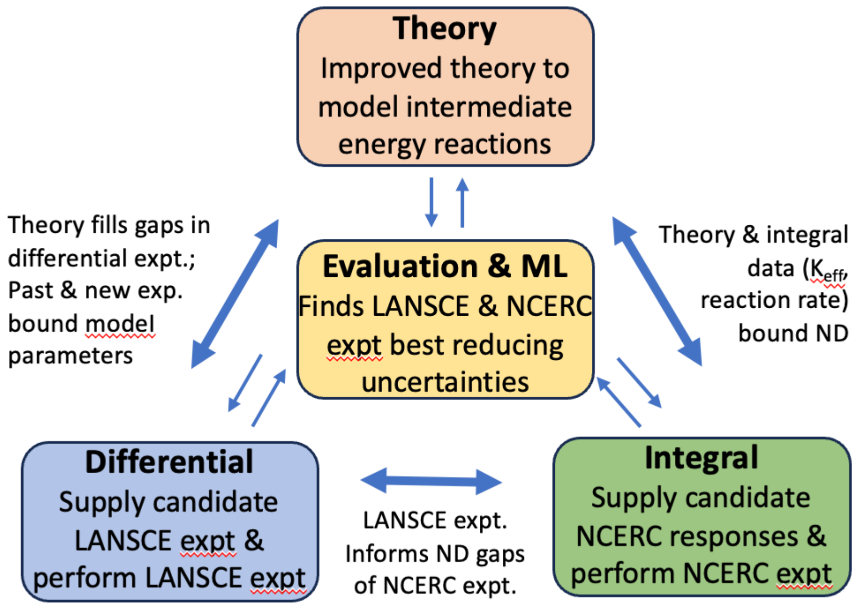
PARADIGM process



Our staff covers all aspects of the nuclear data pipeline



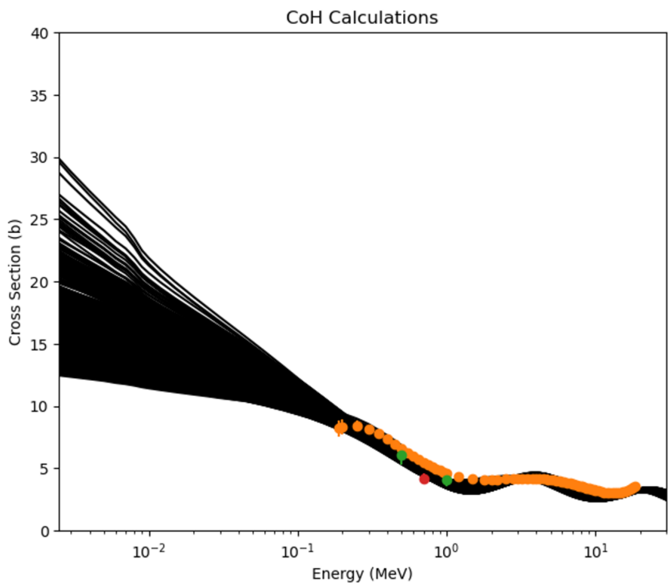
Here is an example how PARADIGM experiments could be selected using theory and Machine Learning (ML)



Current status:

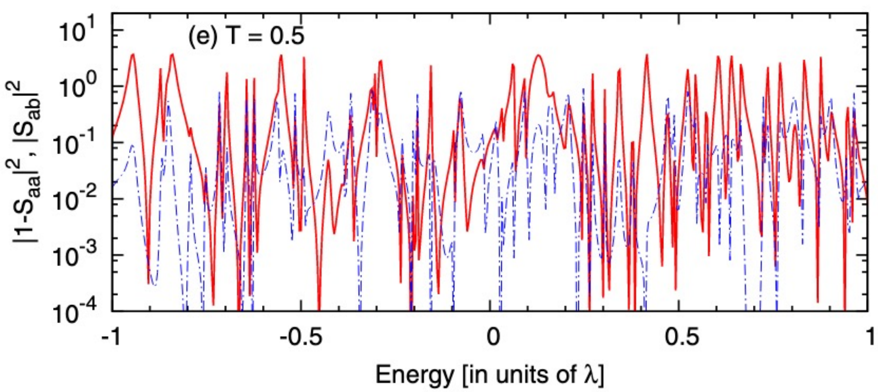
- We down-selected that PARADIGM has the best potential to significantly reduce intermediate ^{239}Pu ND unc.
- Critical Assembly design options and materials are being selected for consideration in the ML exercise.
- We are producing theory curves and LANSCE candidate files for the fuel and potential reflector/ interstitial materials as well as do UQ for historic differential exp.

Theory Improvement: Random Matrix Theory in the Unresolved Resonance Region (URR) will be expanded



Statistical random matrix theory is used to calculate statistical properties of nuclei, such as the Γ distribution and the average level spacing, which is based on the Gaussian Orthonormal Ensemble (GOE), shown above for elastic (red) and inelastic (blue) scattering

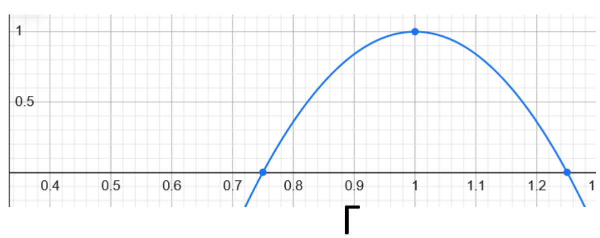
Kawano, Talou, and Weidenmüller, *PRC* **92**, 044617 (2015)

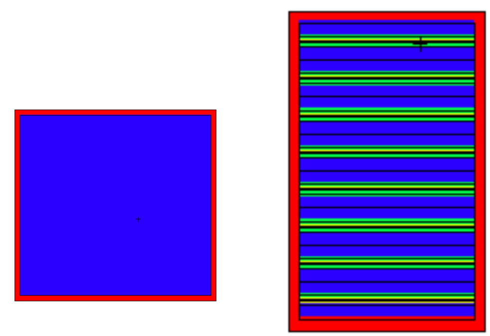


Currently, we use the Hauser-Feshbach statistical theory to calculate average cross sections in the URR (right) to provide samples of possible measurement values, which do provide structure in the URR

Initial integral experiment design uses genetic algorithm to be optimized for intermediate Pu Nuclear Data

- Designed using machine learning (genetic algorithm)
- Geometries: rectangular-planar (CWS-style)
- Maximize sensitivity to two portions of the intermediate energy range
  - 1 to 30 keV [URR]
  - 30 to 600 keV [connection to fast energy range and theory]
- Narrowed list of reflector and interstitial components based on nuclear data uncertainty and material availability
  - Interstitial: boron, boron carbide, alumina, graphite (and combinations of any two of these)
  - Reflector: copper, graphite, natural uranium, lead
- Objective function for optimization code:
  - $R_f * S_f * \Gamma$
    - $\Gamma = -16*(k_{eff}-1)^2+1$

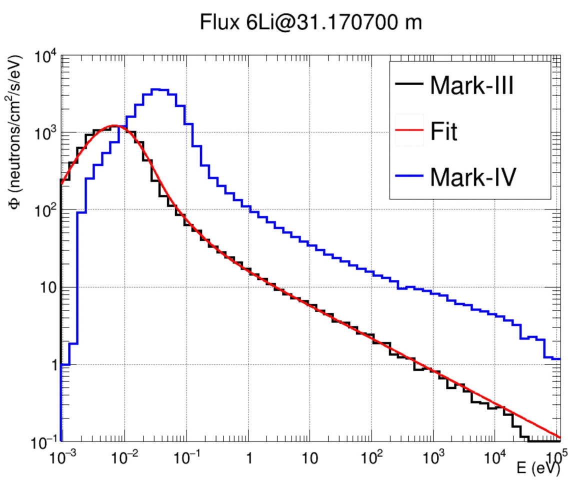


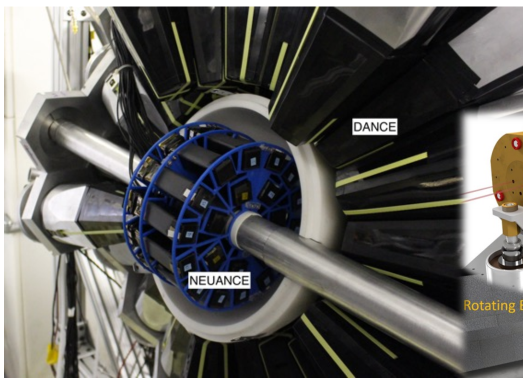


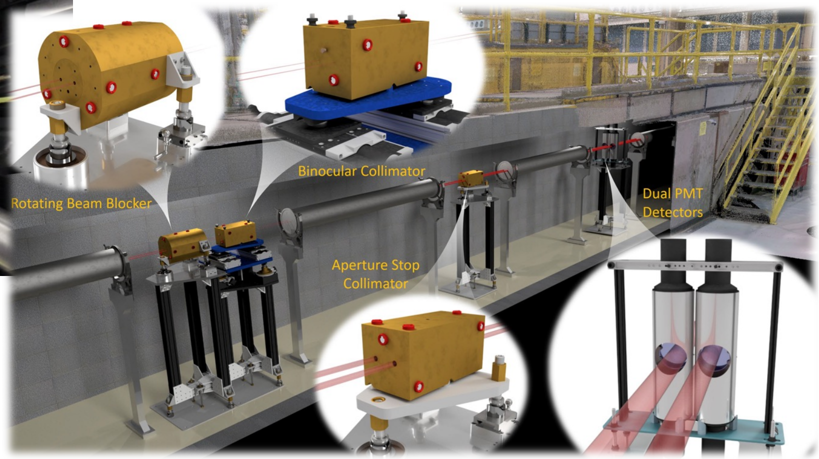
LANSCE capabilities

Instrument	Observable	Detectors
Chi-Nu	PFNS	22 ^{6}Li-glass & 54 liquid scintillators
CoGNAC	(n,n) cs & ang. distr.	70 CLYC (^{6}Li enriched)
DANCE	(n,γ) cross section	160 BaF_2 scintillators
NEUANCE	(n,n_f) cross section	Stilbene crystals
DICER	Neutron transmission	^{6}Li-glass scint. & LAPPD imaging array
LENZ	(n,z) cs & ang. distr.	Double-sided silicon strip detectors

- LANSCE has a range of instruments and capabilities
- Both the Lujan Center and WNR are available
- Lujan Center flux for nuclear instruments has recently been improved – Mark IV Lujan target

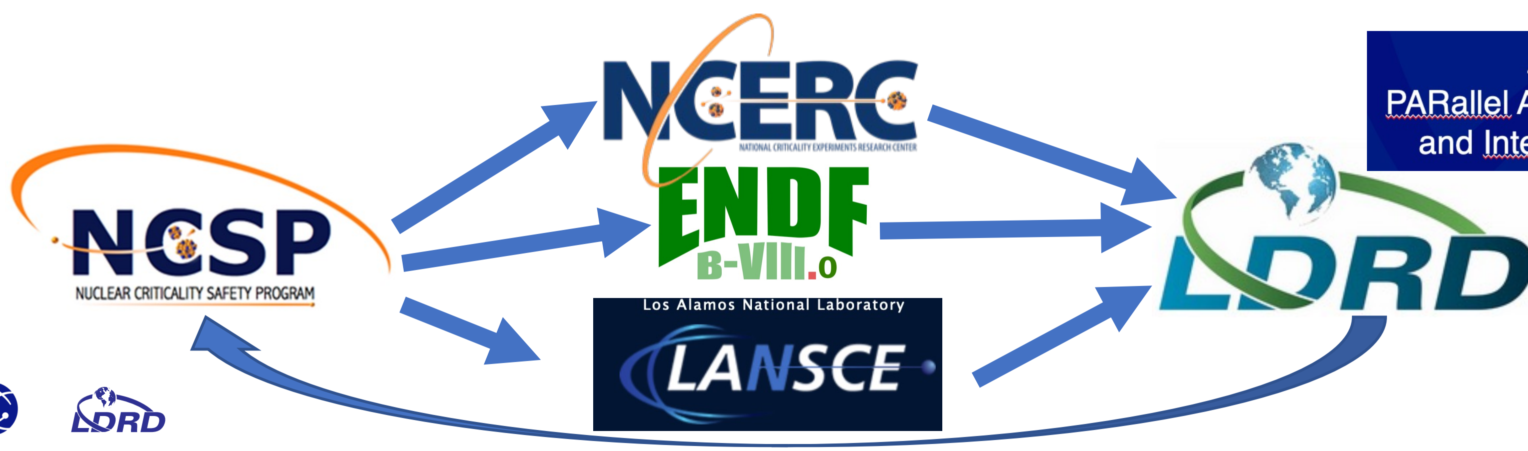






NCSP will benefit from the LANL LDRD PARADIGM project, while PARADIGM builds on NCSP capabilities.

- Builds upon NCSP-supported capabilities in evaluation/ theory, differential exp. and integral exp.
- PARADIGM exp. selection process will be blueprint to decrease ND unc. for applications. NCSP supports all ND areas and would thus strongly benefit.
- Cutting down time to reduce ND unc. for applications to 3 years!
- Studies intermediate Pu ND also of interest for NCSP.
- Connects theory, ND, LANSCE and NCERC scientists.



PARADIGM
PARallel Approach of Differential and InteGral Measurements

Acknowledgments

Research reported in this publication was supported by the U.S. Department of Energy LDRD program at Los Alamos National Laboratory.

Back up

Current Status

- **Actinide: Plutonium!**
  - All other data is tied to this
- Total energy range: 1 keV to 5 MeV
  - Integral experiment energy range: 1 – 30 keV; 30 – 600 keV
  - Differential energy range will be based upon theory and final design materials
- Differential experiment
  - Compiling data for use in machine learning tool (building upon integral experiment suite from EUCLID project)
- Theory
  - Testing methods
- Integral experiment (the main focus thus far)
  - Plutonium: ZPPR plates
  - Reflector: copper or graphite
  - Interstitial material: alumina, likely in combination with graphite or B_4C