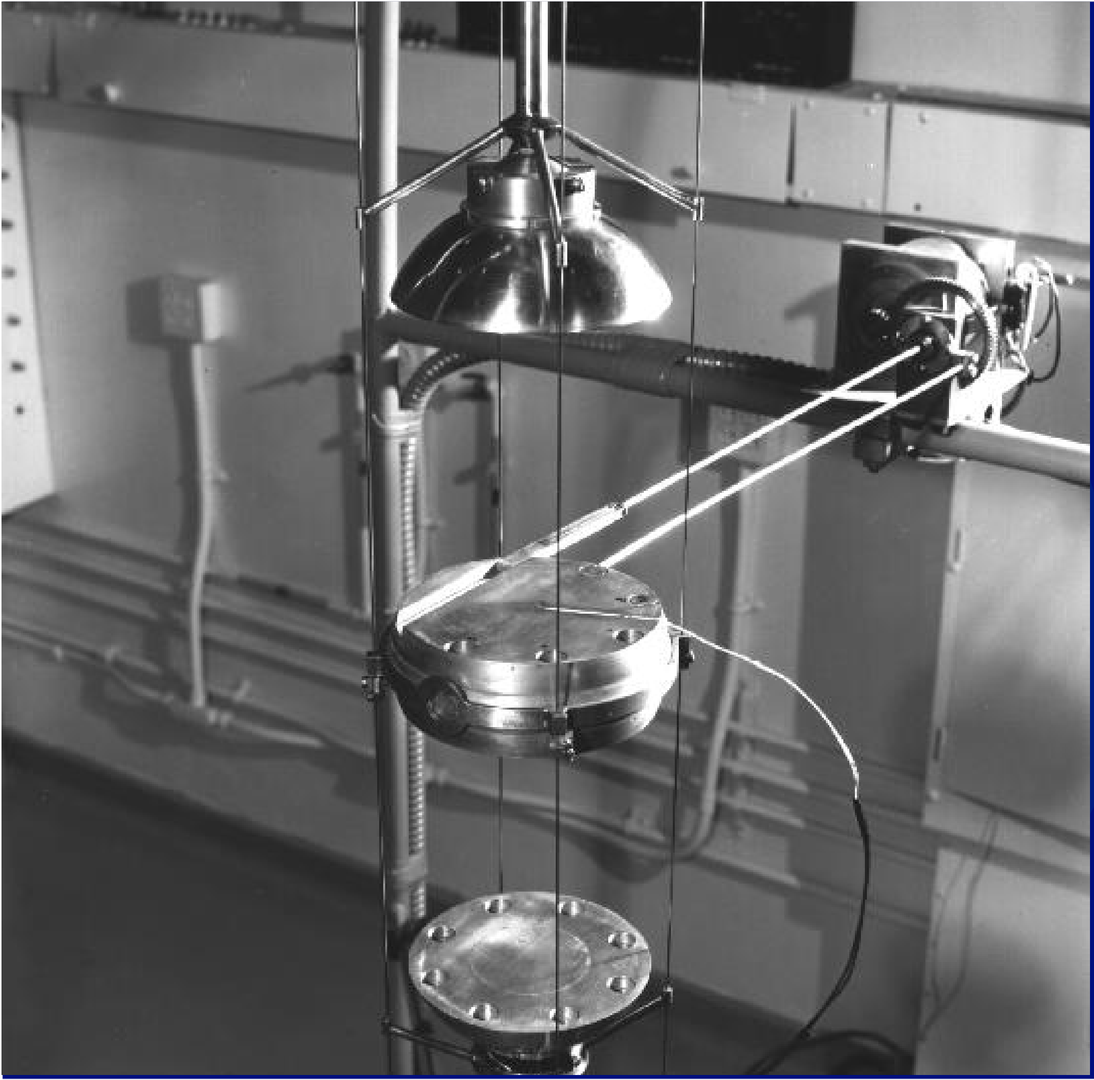

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Current and future Pu validation experiments

J. Hutchinson, T. Cutler, N. Kleedtke, G. McKenzie, I. Michaud, D. Neudecker,
K. Stolte, N. Thompson, R. Little

8/13/24: Mini CSEWG

Overview

- Historic Pu validation experiments
- Recent NCERC benchmarks
  - EUCLID
- Future experiments
  - Lilith
  - PARADIGM
  - Others

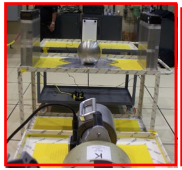
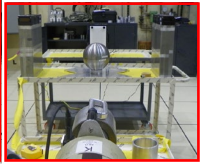
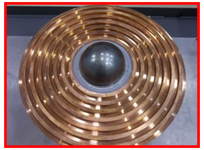
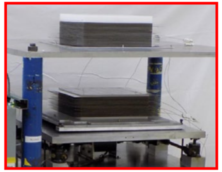
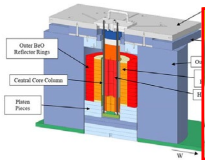
Historic Pu validation experiments

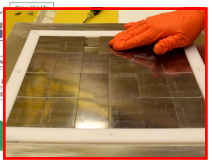
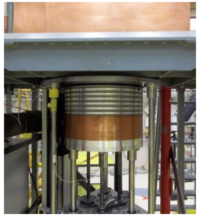
- Table at right shows benchmarks sorted in order of descending Pu239 fission sensitivity.
- Integrated over all energy, ENDF/B-VIII.0 nuclear data.
- List mostly filled with historic LANL (blue) and Russian (red) experiments.
- LANL has a history of Pu239 validation experiments.
  - We are continuing to add new experiments.

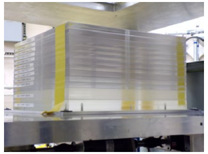
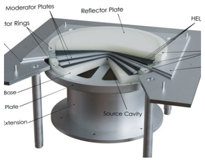
Experiment	Fission	Elastic	Inelastic	n,gamma	total nu
pu-met-fast-022-001	0.743	0.064	0.041	-0.008	0.987
pu-met-fast-025-001	0.731	0.051	0.033	-0.009	0.988
pu-met-fast-035-001	0.729	0.051	0.033	-0.009	0.988
pu-met-fast-040-001	0.729	0.048	0.033	-0.010	0.988
pu-met-fast-039-001	0.727	0.045	0.032	-0.010	0.988
pu-met-fast-001-001	0.727	0.063	0.040	-0.008	0.966
pu-met-fast-001-004	0.726	0.063	0.040	-0.008	0.966
pu-met-fast-001-002	0.726	0.062	0.040	-0.008	0.966
pu-met-fast-001-003	0.726	0.063	0.039	-0.008	0.966
pu-met-fast-023-001	0.725	0.046	0.032	-0.010	0.988
pu-met-fast-045-005	0.718	0.035	0.026	-0.014	1.000
pu-met-fast-026-001	0.718	0.039	0.022	-0.011	0.988
pu-met-fast-045-004	0.718	0.034	0.026	-0.014	1.000
pu-met-fast-045-006	0.718	0.038	0.024	-0.015	1.000
pu-met-fast-045-003	0.717	0.035	0.024	-0.014	1.000
pu-met-fast-024-001	0.716	0.048	0.038	-0.020	0.988
pu-met-fast-045-001	0.715	0.034	0.024	-0.016	1.000
pu-met-fast-045-002	0.713	0.034	0.023	-0.015	1.000
pu-met-fast-045-007	0.712	0.035	0.021	-0.017	1.000
pu-met-fast-036-001	0.710	0.042	0.037	-0.021	0.988
pu-met-fast-015-001	0.707	0.033	0.018	-0.013	0.985
pu-met-fast-009-001	0.706	0.044	0.032	-0.010	0.964
EUCLID_3x2x64	0.702	0.043	0.025	-0.011	0.965
pu-met-fast-003-103	0.701	0.039	0.018	-0.008	0.962
pu-met-fast-021-002	0.700	0.040	0.027	-0.016	0.968
pu-met-fast-005-001	0.699	0.035	0.025	-0.012	0.965
pu-met-fast-013-001	0.696	0.023	0.018	-0.019	0.986
pu-met-fast-021-001	0.696	0.042	0.028	-0.019	0.968
pu-met-fast-018-001	0.696	0.033	0.030	-0.016	0.965
pu-met-fast-014-001	0.695	0.025	0.019	-0.018	0.985
pu-met-fast-008-001	0.695	0.035	0.025	-0.012	0.955
pu-met-fast-029-001	0.690	0.059	0.036	-0.008	0.915
EUCLID_8x1x130	0.685	0.022	0.010	-0.011	0.965

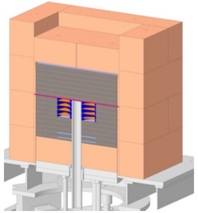
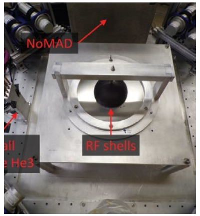
Recent NCERC benchmarks

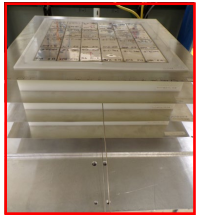
- Of the 17 ICSBEP evaluations of experiments performed at NCERC, 8 are Pu systems.
- Many of these are included in our modern validation suite.
- Fast, intermediate, and thermal systems.
- Most of the Pu benchmarks are WG Pu.
  - Some upcoming benchmarks with high Pu240.
- Subcritical BeRP experiments:
  - Still need to make validation easier for these experiments.

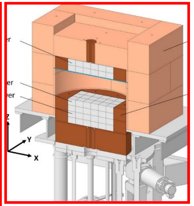
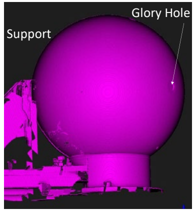






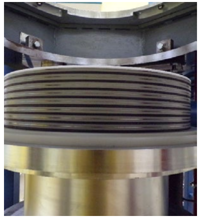



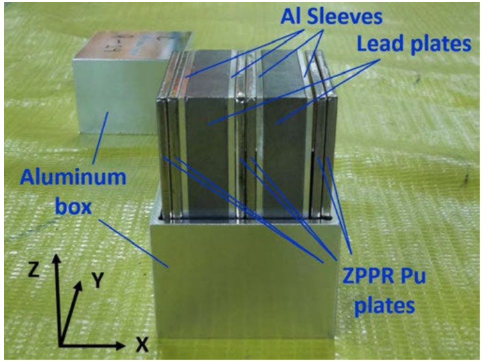


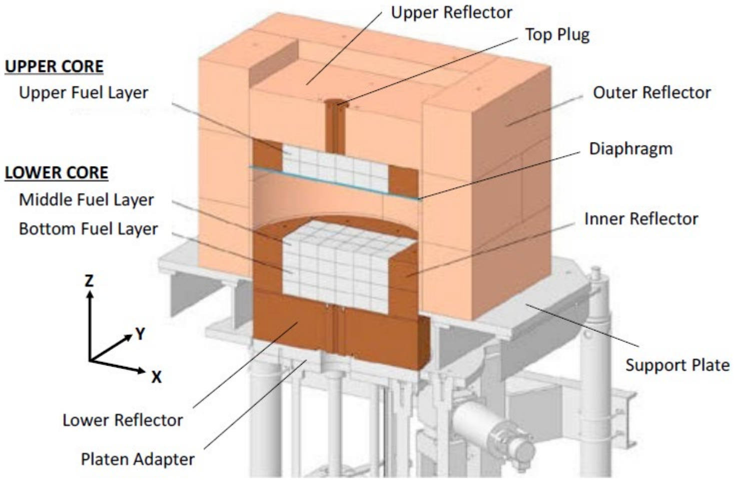



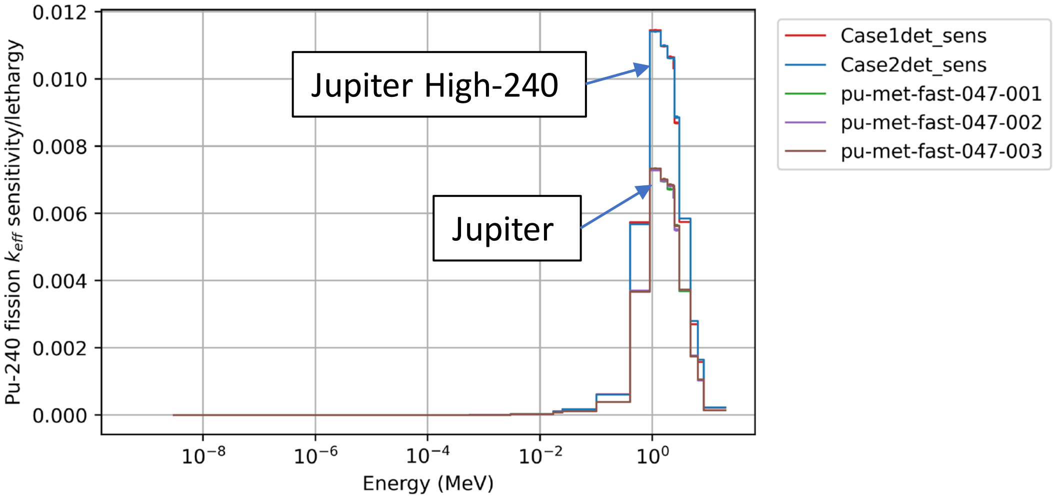


Jupiter High-240 experiment

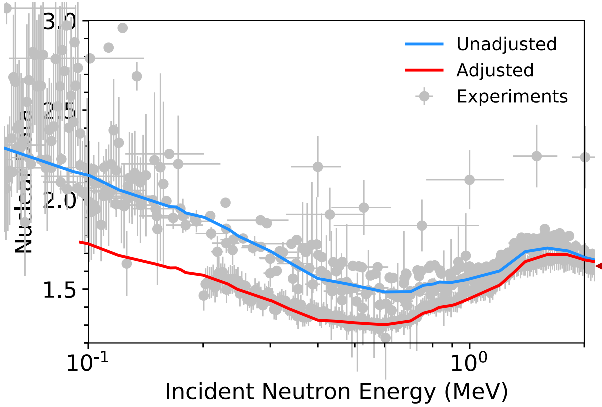
- Collaboration with JAEA to help validate Accelerator Driven Systems (ADS).
- Similar to the WG Pu Jupiter experiments.
- Performed at NCERC in 2019.
- ICSBEP evaluation currently underway.



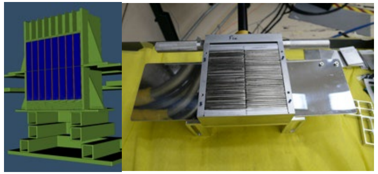




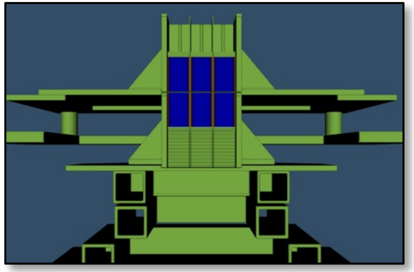
EUCLID designed validation experiments optimized to reduce ^{239}Pu compensating errors & adjusted nuclear data to experiments



Experiment Refines Nuclear Data to Improve Simulations



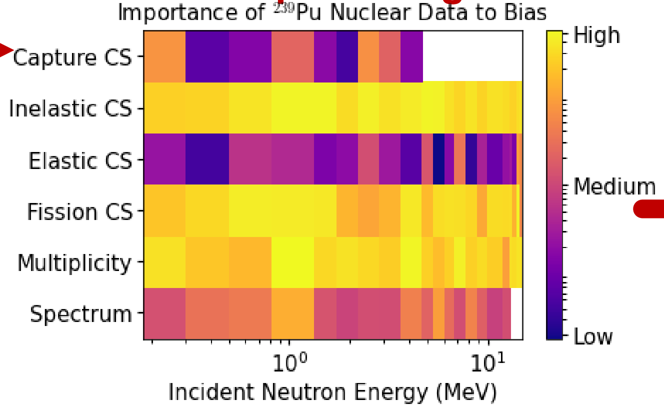
Neutron Transport Simulation (MCNP)

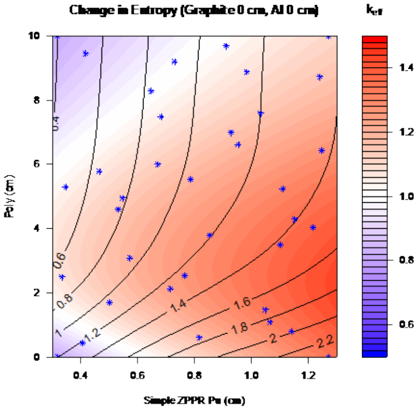


Validation Experiments

ML-Optimally Designed Experiment to Resolve Compensating Errors

ML-Augmented Search for Compensating Errors



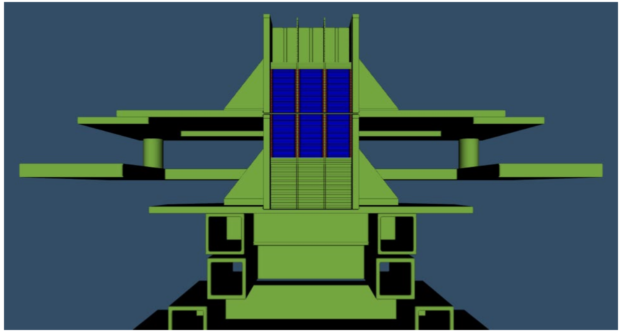


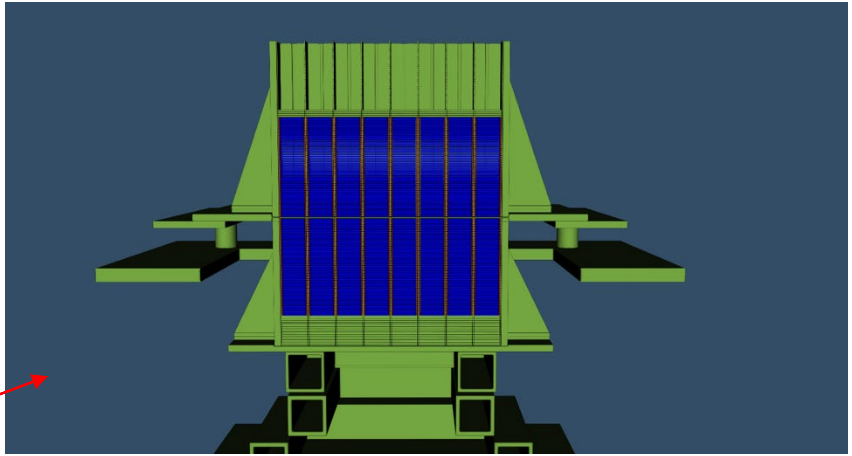
Experiment Optimization

- Results of the D-Optimality analysis led us to two configurations:

3 X 2 (Low Mass/Cube)
Critical with 384 ZPPR plates (41 kg Pu)

8 X 1 (High Mass/Slab reactor)
Critical with 1033 ZPPR plates (109 kg Pu)



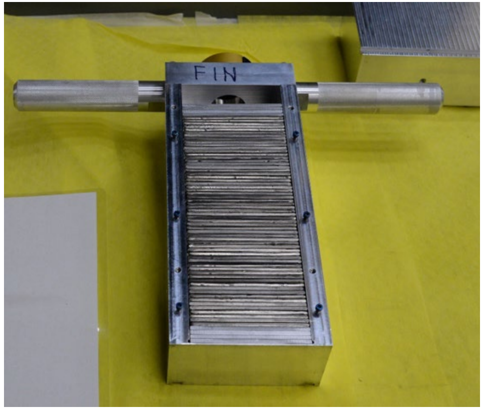


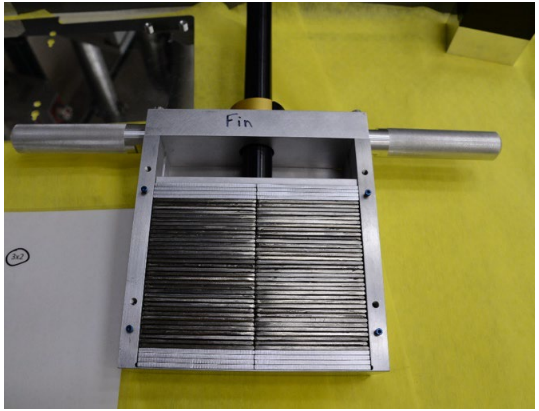
8x1 H/"D" ratio is 5.4

- Both utilize WG Plutonium-Aluminum No-Nickel (PANN) ZPPR plates as fuel
- Non-nuclear components can be used for future experiments as well

Experiment execution

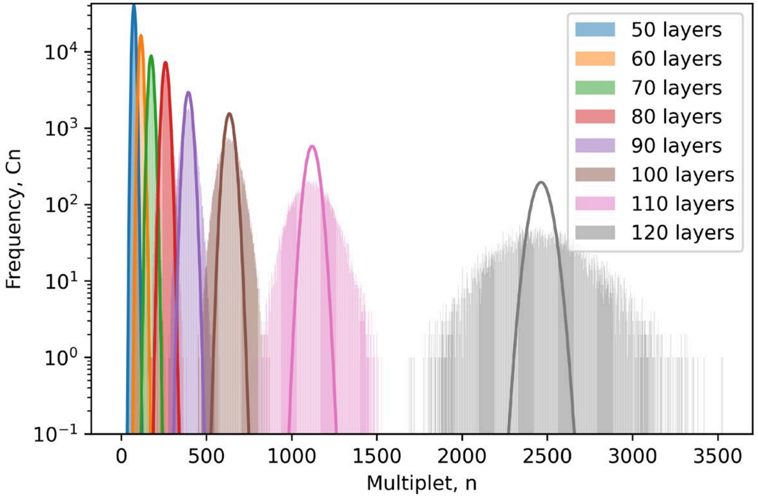
- 7 weeks at NCERC: Nov 28 2022 - Jan 26 2023
- The most Plutonium ever used in an NCERC Experiment

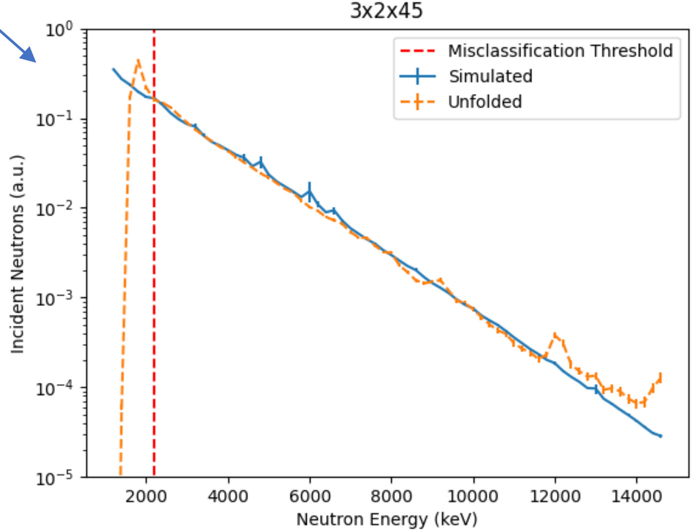




Measurement Responses

- Six responses were measured for each configuration:
  - Critical: ICNC 2023
  - Subcritical (neutron noise): ANE
  - Neutron leakage spectra: NIM A and APS 2023
  - Rossi-α: future work
  - Reactivity coefficients: ICNC 2023
  - Reaction rate ratios: NSE





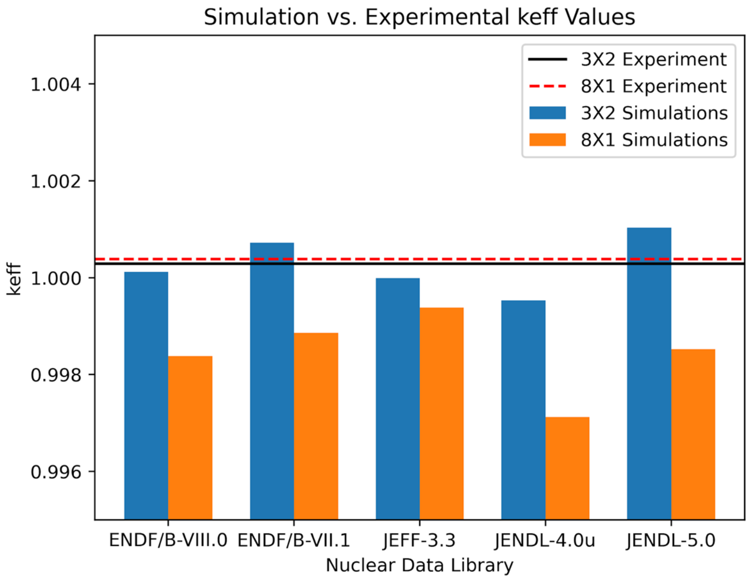
Calculated k_{eff} is mostly below experiment and varies with ^{239}Pu library by 10s to 100s of pcm

3x2 exp: 1.00029 +/- 0.00200

Library	keff	keff unc	C-E (pcm)
ENDF/B-VIII.0	1.00012	0.00003	-17
ENDF/B-VII.1	1.00072	0.00003	43
JEFF-3.3	0.99999	0.00003	-30
JENDL-4.0u	0.99953	0.00003	-76
JENDL-5.0	1.00103	0.00003	74
Pu9VIII1beta1-11c	0.9991	0.00003	-119
Pu9LANL10172022-10c	1.00011	0.00003	-18
e81b2	0.99992	0.00003	-37

8x1 exp: 1.00038 +/- 0.00300

Library	keff	keff unc	C-E (pcm)
ENDF/B-VIII.0	0.99838	0.00003	-200
ENDF/B-VII.1	0.99886	0.00003	-152
JEFF-3.3	0.99938	0.00003	-100
JENDL-4.0u	0.99712	0.00003	-326
JENDL-5.0	0.99852	0.00003	-186
Pu9VIII1beta1-11c	0.99757	0.00003	-281
Pu9LANL10172022-10c	0.99802	0.00003	-236
e81b2	0.99815	0.00003	-223

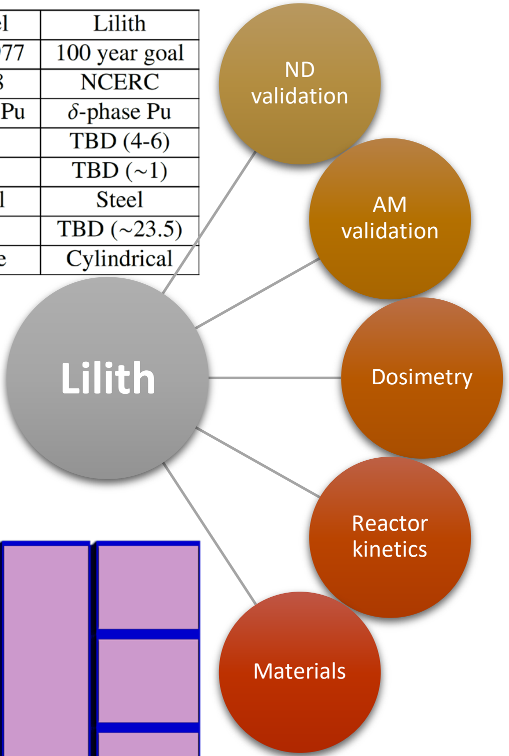


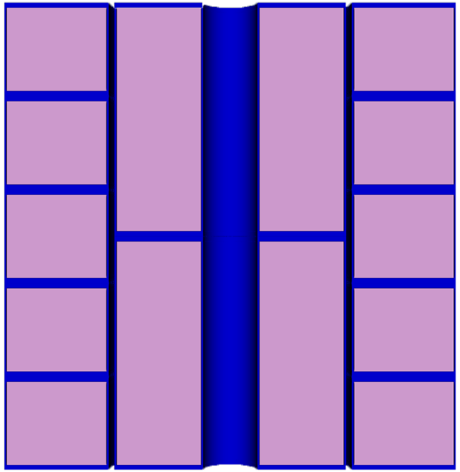
Results when switching Pu239 nuclear data (all other nuclides are ENDF/B-VIII.0)

Future experiments: Lilith

Parameter	Jezebel	Lilith
Lifespan	1954-1977	100 year goal
Location	TA-18	NCERC
Nuclear material	δ-phase Pu	δ-phase Pu
Pu240 wt.%	4.3	TBD (4-6)
Ga wt.%	1.02	TBD (~1)
Cladding/canning material	Nickel	Steel
Pu mass (kg)	17.1	TBD (~23.5)
Geometry	Sphere	Cylindrical

- Much more than just a "Jezebel replacement"
- New enduring Pu assembly
  - Design goal of 100 years of operation
- Ability to change part of the Pu fuel
- Will become the "default experiment" for Pu239 nuclear data validation
- Benchmark can be updated over time as new technologies become available
- Can be used to measure changes over long periods of time
- Would provide new clean Pu assembly for spectral indices, reactor kinetics parameters, etc.

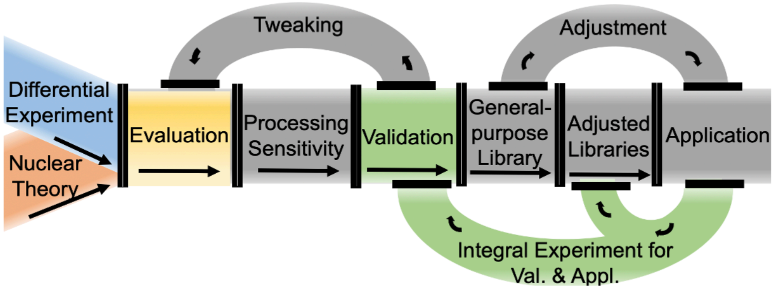




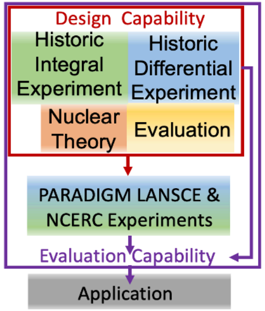
Future experiments: PARADIGM

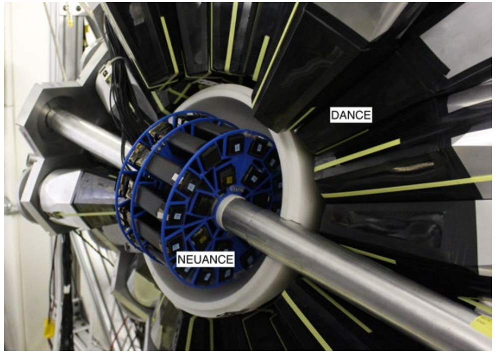
- Reduce Pu-239 nuclear data uncertainty in the intermediate region
  - And reduce the timeline of the pipeline
- Design differential (LANSCE) and integral experiments (NCERC) simultaneously using machine learning (see Christi Thompson talk)
  - Differential, integral, and theory in single optimized process
- Two validation experiments targeting Pu239 uncertainty reduction for:
  - 1-30 keV
  - 30-600 keV
- More sensitive to Pu239 fission in these energies than any existing experiments
- Additional responses (beyond k_{eff}) will be measured

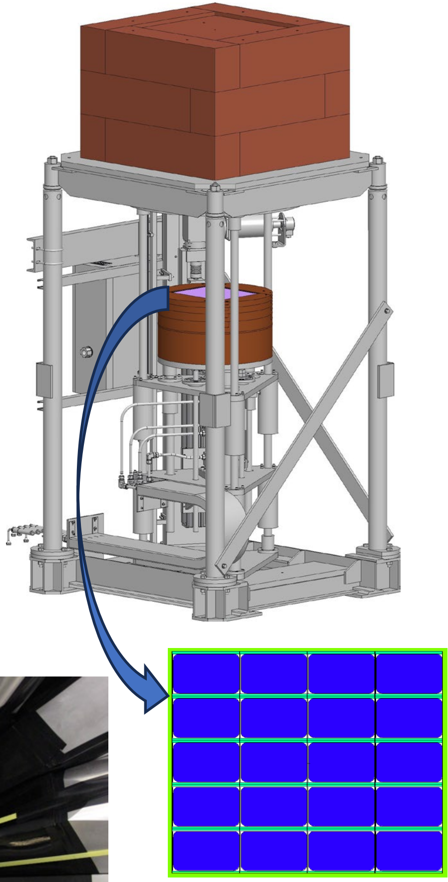
The linear ND pipeline



PARADIGM process

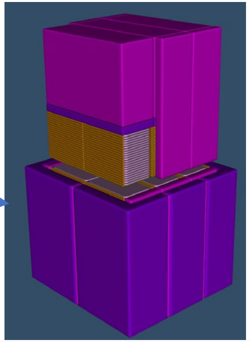




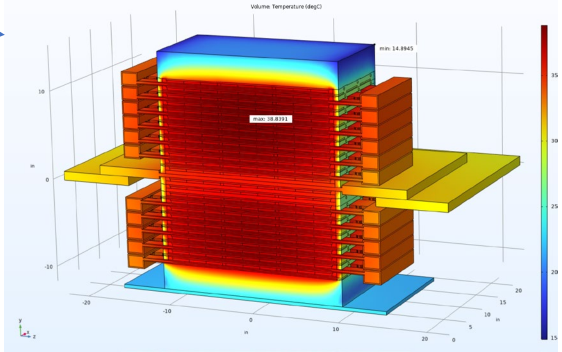


Future experiments: other

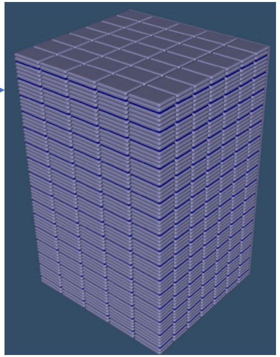
- IER 607: Thales
  - Tantalum reflection
  - Validation for Ta for Pu processing



- IER 296: TEX Mox
  - Mox fuel with high Pu240
  - Validation for Mox operations in France



- Flattop Pu
  - Updated evaluation
  - General Pu validation and basis for other experiments
- IER 551: EUROPA
  - Intermediate energy Pu (WG and elevated Pu240)
  - Complementary to PARADIGM and TEX experiments

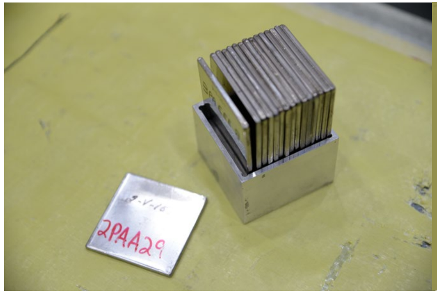


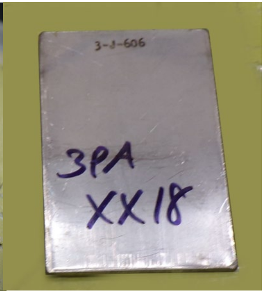
Lessons learned and challenges

- Some lessons learned along the way:
  - AI/ML can be very useful in experiment design
  - Measurement of additional responses can help further constrain nuclear data
  - Integral experiments should be designed in parallel to differential experiments (PARADIGM approach)
  - Performing benchmark evaluation directly after experiment completion is both cost effective and results in better benchmarks
- Some challenges:
  - Funding of benchmark evaluations is similar to the TRL “valley of death”. Outside of NCSP, we have had challenges securing funding
  - Documentation for other responses of historical experiments is lacking
  - “New” material is hard to acquire

Conclusions

- Recent and planned NCERC experiments provide rich opportunities for validation of Pu nuclear data
- Including k_{eff} benchmarks as well as many other responses
- Very interested in future Pu validation
  - Pu239 and Pu240
  - Fast
  - Intermediate
  - All reactions
- Interested in collaboration with CSEWG regarding new validation experiments





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