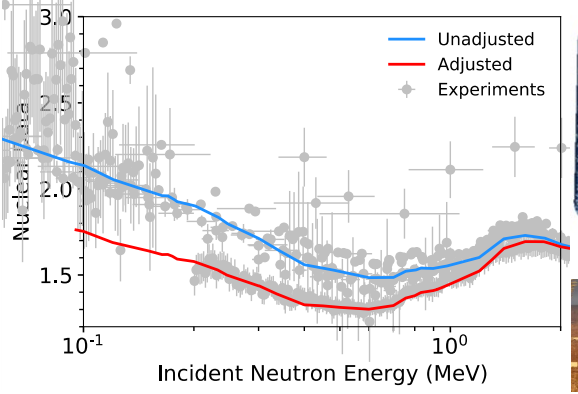

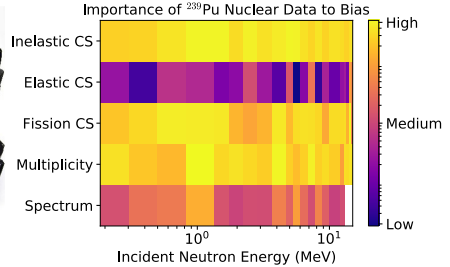

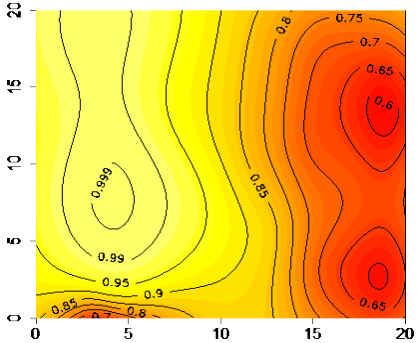

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NATIONAL LABORATORY

Delivering science and technology
to protect our nation
and promote world stability

EUCLID: Experiments Underpinned by Computational Learning for Improvements in nuclear Data

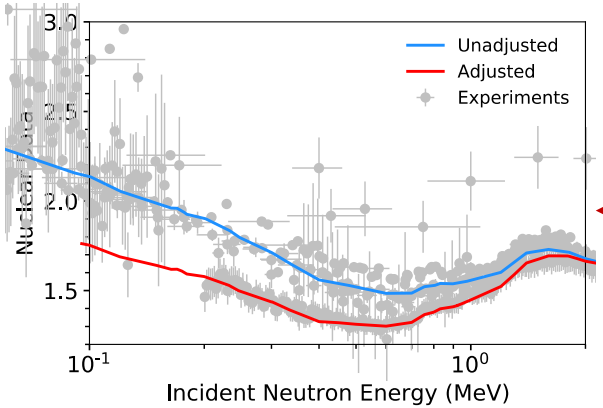
EUCLID team: J. Alwin, A. Clark, T. Cutler, M. Grosskopf, W. Haeck, M. Herman, J. Hutchinson, N. Kleedtke, J. Lamproe, R.C. Little, I. Michaud, D. Neudecker, M. Rising, T. Smith, N. Thompson, S. Vander Wiel

Feb 16 2021

EUCLID will design validation experiments optimized to resolve compensating errors & adjust nuclear data to experiments

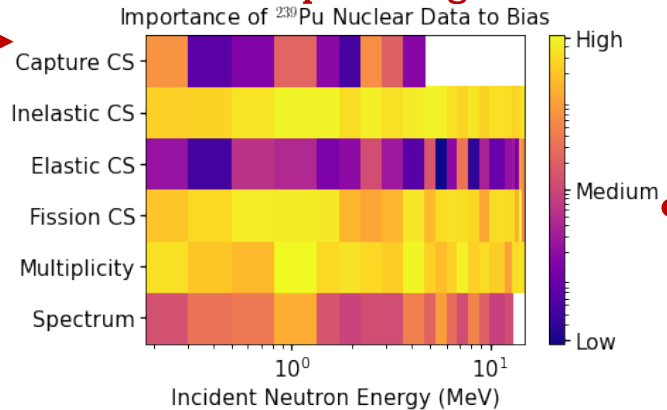
Neutron Transport Simulation (MCNP)

Validation Experiments

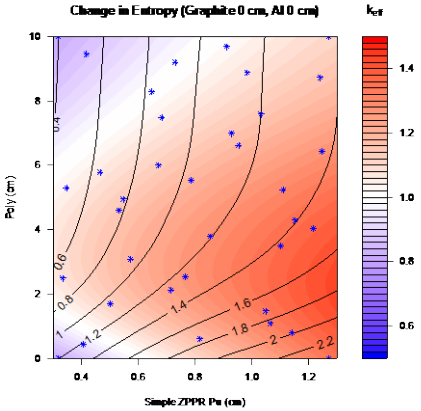


Experiment Refines Nuclear Data to Improve Simulations

ML-Augmented Search for Compensating Errors

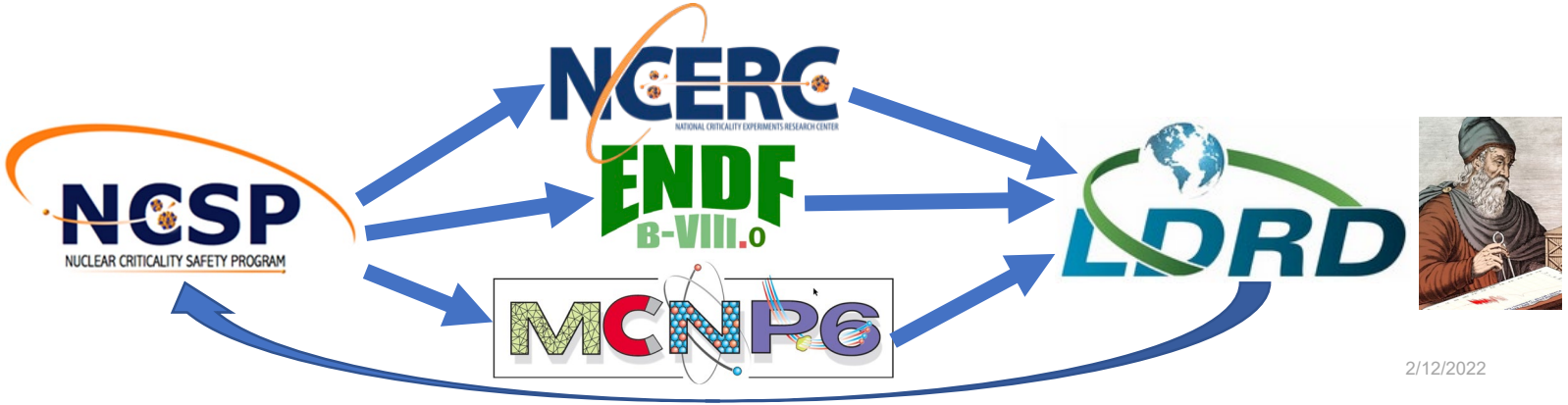


ML-Optimally Designed Experiment to Resolve Compensating Errors



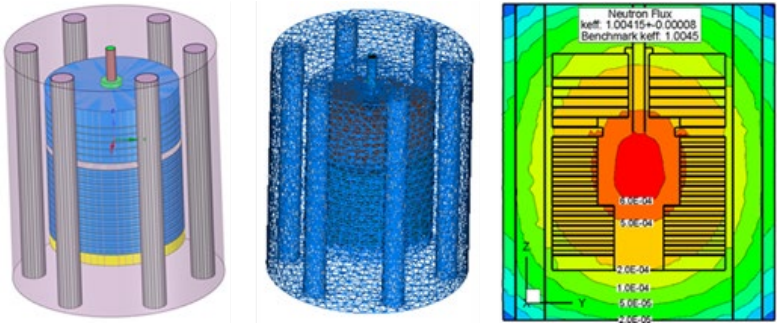
There is a symbiotic relationship between NCSP and LANL LDRD through the EUCLID project

- A big part of the success of the EUCLID proposal was due to previous work supported by NCSP (MCNP, nuclear data, and NCERC capabilities).
- And the work performed under EUCLID will similarly benefit the NCSP mission:
  - New MCNP capabilities
  - Improved nuclear data and nuclear data capabilities
  - New methodology and tools will have large impact on future NCERC experiments



Accurate nuclear data (ND) are required for useful predictive simulations

- EUCLID will help steer where future ND improvements are needed

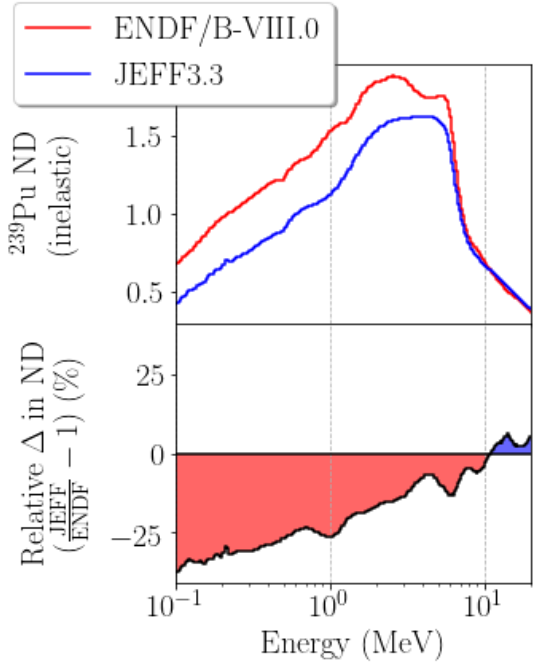


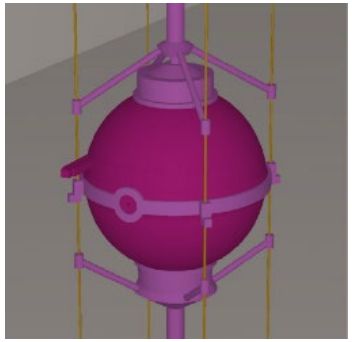
J. Spencer, J. Alwin, "Big Ten MCNP6 Unstructured Mesh Benchmark," LA-UR-19-25731 (2019).

- Nuclear reactor physics
- Nuclear critical and subcritical experiments
- Criticality safety
- Nuclear diagnostics
- Survivability
- Intrinsic radiation
- Radiography
- Nuclear weapon effects and output
- Emergency response / nuclear threat assessments
- Nuclear safeguards and nonproliferation
- Radiation detection and analysis
- Medical and health physics

Unconstrained physics spaces: We can change nuclear data widely within differential constraints and still get the same k_{eff}

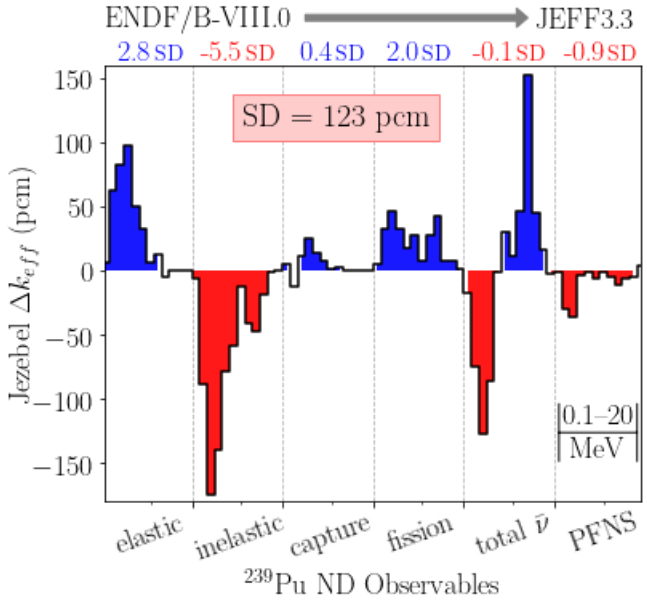
Differences in ENDF/B-VIII.0 and JEFF3.3 nuclear data represent uncertainty in the differential information.





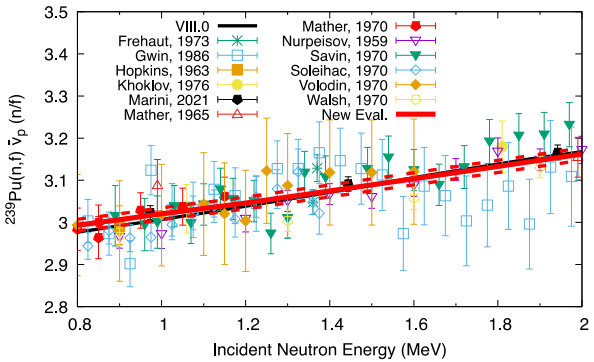
```
@@@ PU-MET-FAST-001-001 @@@
1 1 -15.61 -1        imp:n=1
2 0         1        imp:n=0

1    so   6.3849

c material 1: Plutonium
m1     94239.00c 3.7047E-02
       94240.00c 1.7512E-03
       94241.00c 1.1674E-04
       31069.00c 8.2661E-04
       31071.00c 5.4859E-04
kcode 1000000 1.0 200 4200
ksrc 0 0 0
```

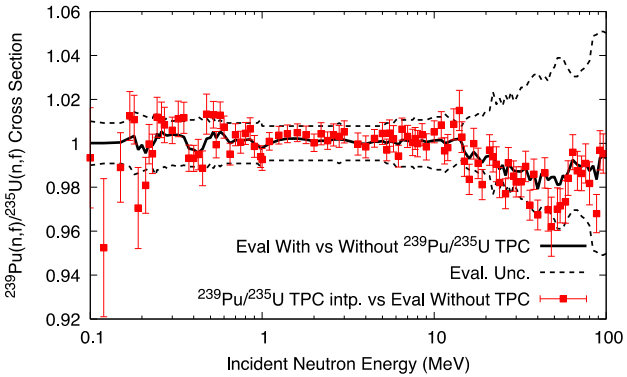
Both ENDF/B-VIII.0 and JEFF3.3 compute Jezebel k_{eff} equally well using MCNP6 but contributions per reaction differ drastically

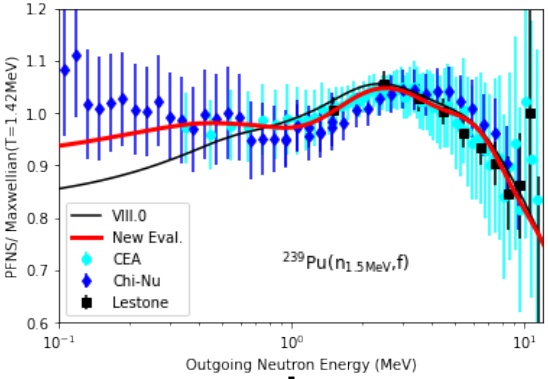


Is there enough freedom in ^{239}Pu diff. exp. data? YES
Do the changes in nuclear data impact simulations? YES

Example for freedom in differential data: Change from ENDF/B-VIII.0 to VIII.1 beta1







Change in Jezebel k_{eff}*

+ 139 pcm

-40 pcm

-121 pcm

Total change: - 22 pcm (from 1.00069 -> 1.00047) -> all good.

All of the nuclear data shown give reasonable representations of differential data and yield a realistic k_{eff} of Jezebel.

Eval. and validation work funded by NCSP, see talk of Lovell & Neudecker later today.

*Change of 220 pcm in Jezebel k_{eff} – range between prompt & delayed critical, k_{eff} unc: 123 pcm.

Measurement Types

Measurement Method	Observable			
	σ	ν	β	PFNS
Critical experiments	✓	✓		✓
Neutron Multiplication Measurements	✓	✓	✓	
Reaction rate ratios	✓	✓		✓
Pulsed Spheres	✓			
Gamma/Neutron Leakage Spectra	✓			✓
Delayed Neutron Measurements			✓	
Rossi-α	✓	✓	✓	
Reactivity Coefficient	✓		✓	

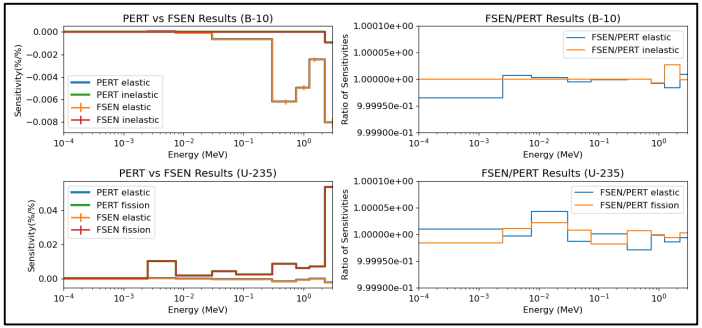
Currently we have calculated sensitivities for and gained physics understanding for all eight types of integral responses listed above.

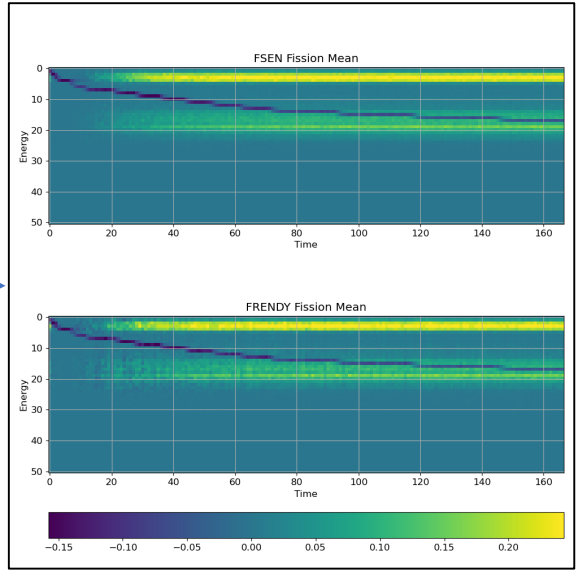
Different measurement types give complimentary data which we will use to constrain nuclear data.

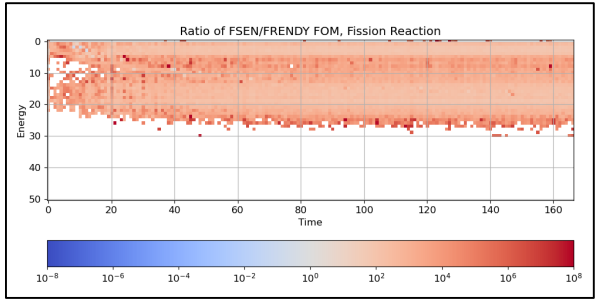
MCNP Fixed Source Sensitivities

- New fixed-source sensitivity capability in MCNP6 is under development
- Performing extensive verification to provide a robust and accurate capability
  - Comparison between FSEN and PERT
- Comparison between FSEN and central difference
  - Verification of FSEN using FRENDY results

LLNL Pulsed Sphere of 0.7 MFP Pu



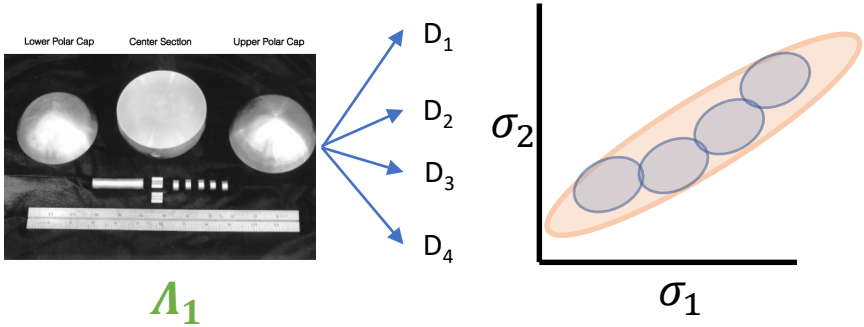


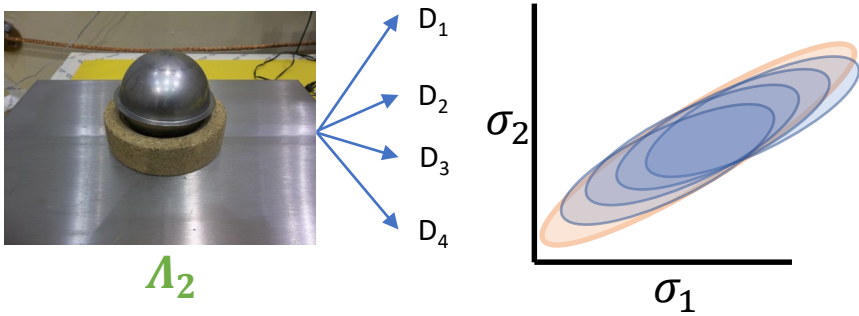


Average efficiency gain for fission is 700,000 x.

How do we design an experiment to optimally reduce unconstrained physics spaces?

- Intuition: what data would lead to the most constrained nuclear data uncertainties of anything in the design space?
  - How could we do it:
    - Simulate experimental data D with sampled ND
    - Fit the adjustment model
    - Quantify the resulting size of nuclear data uncertainty
    - Choose design that most decreases posterior uncertainty
- **D-optimality criteria:** Minimizing the determinant of the expected covariance matrix will minimize the volume of the ND credible region
  - Under normal, linear, and non-regularized assumptions, the above intuition is captured by this criteria

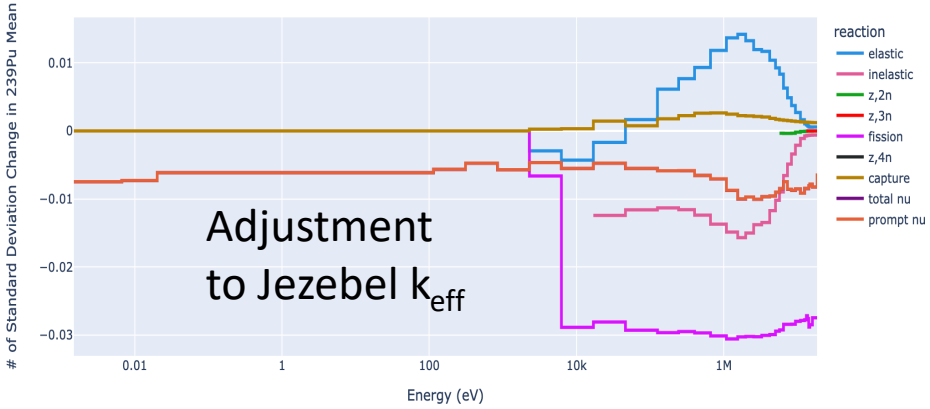


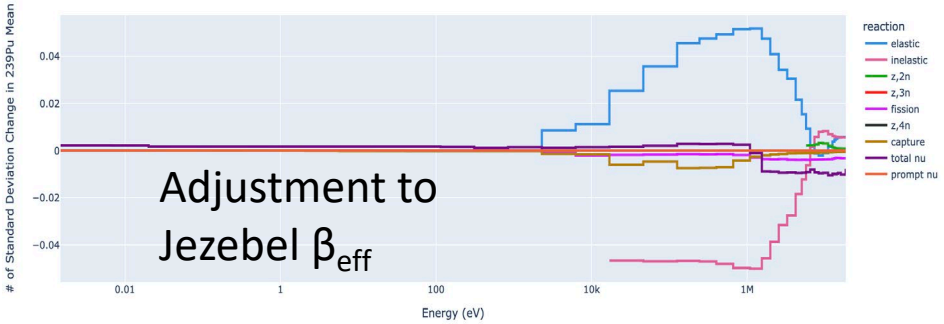


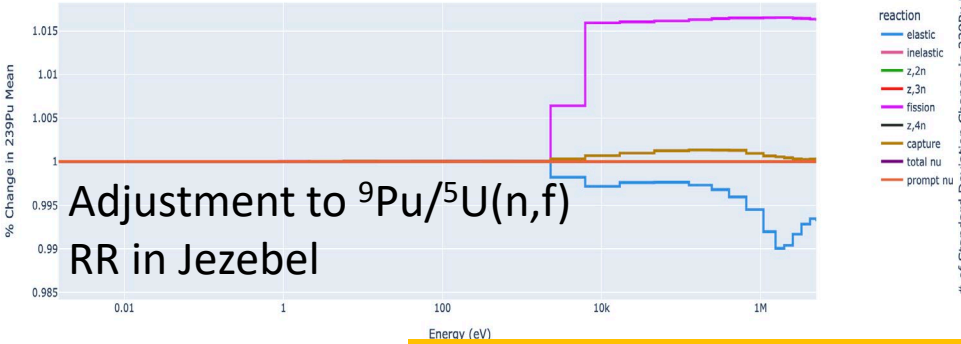
EUCLID has developed a Conditional D-optimality criteria to focus on the targeted subset of all ND reactions

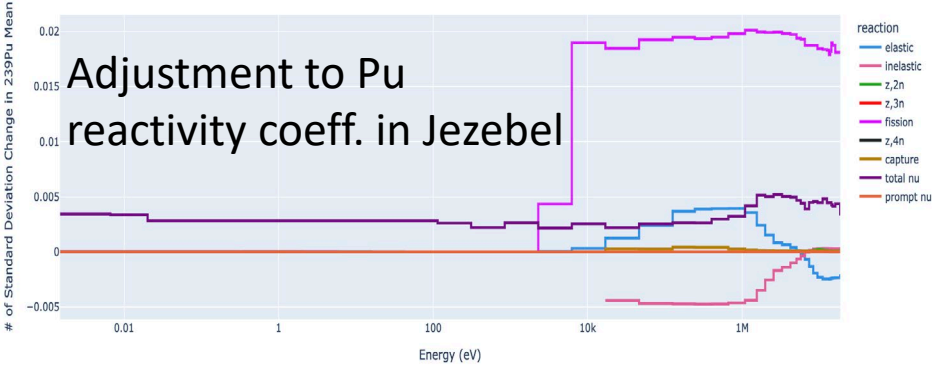
Currently designing an experiment at NCERC focused on Pu239 reactions.

EUCLID has developed a LANL-internal applet for visualizing the effect of adjusting to multiple response types.





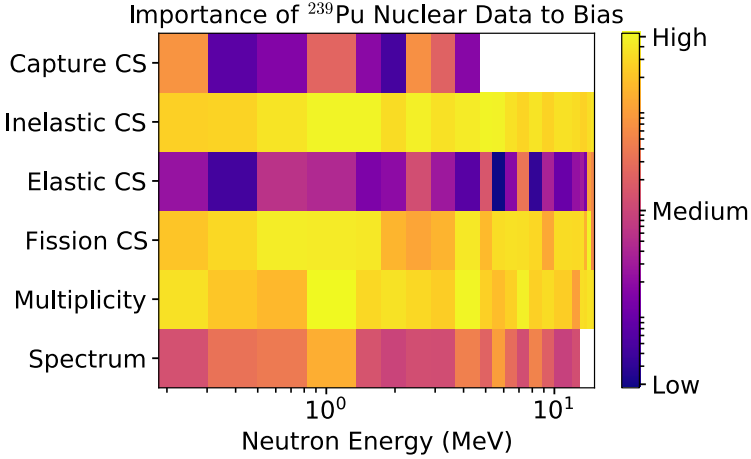




Currently 5 response types, 6,500 experiment observations, and 40,000 ND (2,000+ used for adjustment).

EUCLID benefits to the NCSP community

- Right now:
  - RAFIEKI is being used for large-scale ND validation.
- Future:
  - New sensitivities from existing validation experiments: will likely be shared through NEA.
  - FSEN capability to be released in a future version of MCNP (not 6.3).
  - Web-based adjustment tool will eventually be released to the public.
  - FAUST/Crater updates.
  - New experiments will be useful for ND validation (and will likely have positive impact on crit safety applications).
  - Increased efficiency in experiment design.
  - New adjusted ND will also likely be useful to the ND community.

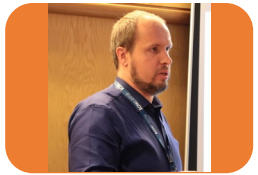


Team

Experiments Underpinned by Computational Learning for Improvements in nuclear Data

- PI/Co-PIs in blue.
- Program Representative in red.

Nuclear Data



Wim Haeck

Michal Herman

Robert Little

Denise Neudecker

Simulations

Jennifer Alwin

Alexander Clark

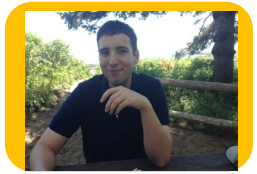
Juliann Lamproe

Michael Rising

Machine Learning

Michael Grosskopf

Noah Kleedtke



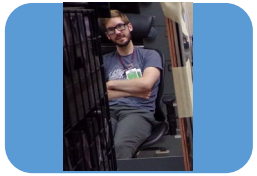
Isaac Michaud

Scott Vander Wiel

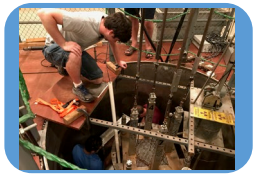
Experiments

Theresa Cutler

Jesson Hutchinson



Travis Smith



Nicholas Thompson

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