LA-UR-25-26758

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Title:	FSEN Reaction Rate Calculations in MCNP
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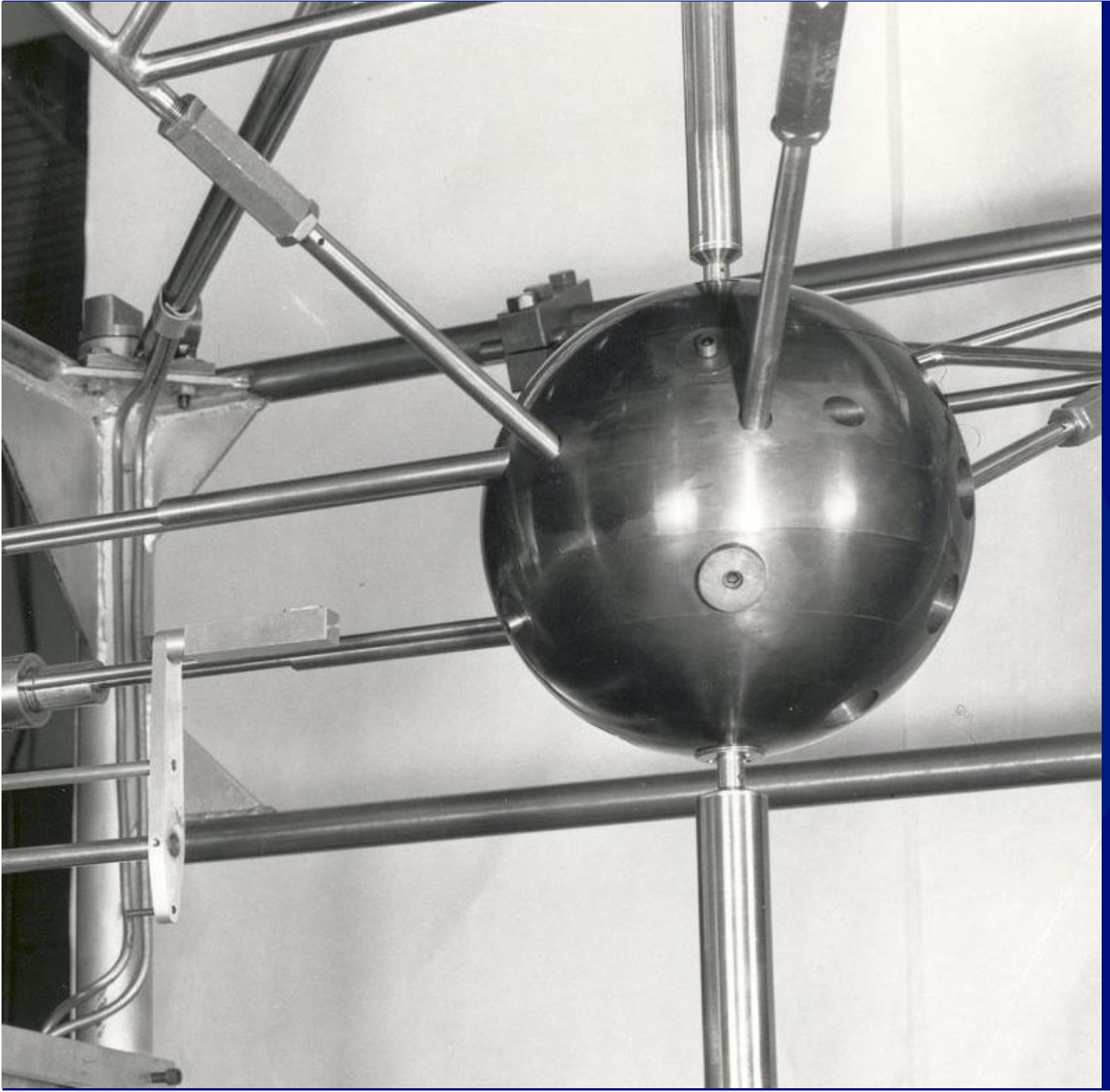
Intended for:	MCNP User Symposium 2025, 2025-07-07/2025-07-11 (Los Alamos, New Mexico, UNITED STATES)
Issued:	2025-07-14



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FSEN Reaction Rate Calculations in MCNP

Peter Brain, J. Favorite, N. Kleedtke, M. Rising

July 7 – 11, 2025

MCNP User Symposium 2025

Los Alamos, NM, USA

LA-UR-25-XXXXX

Outline

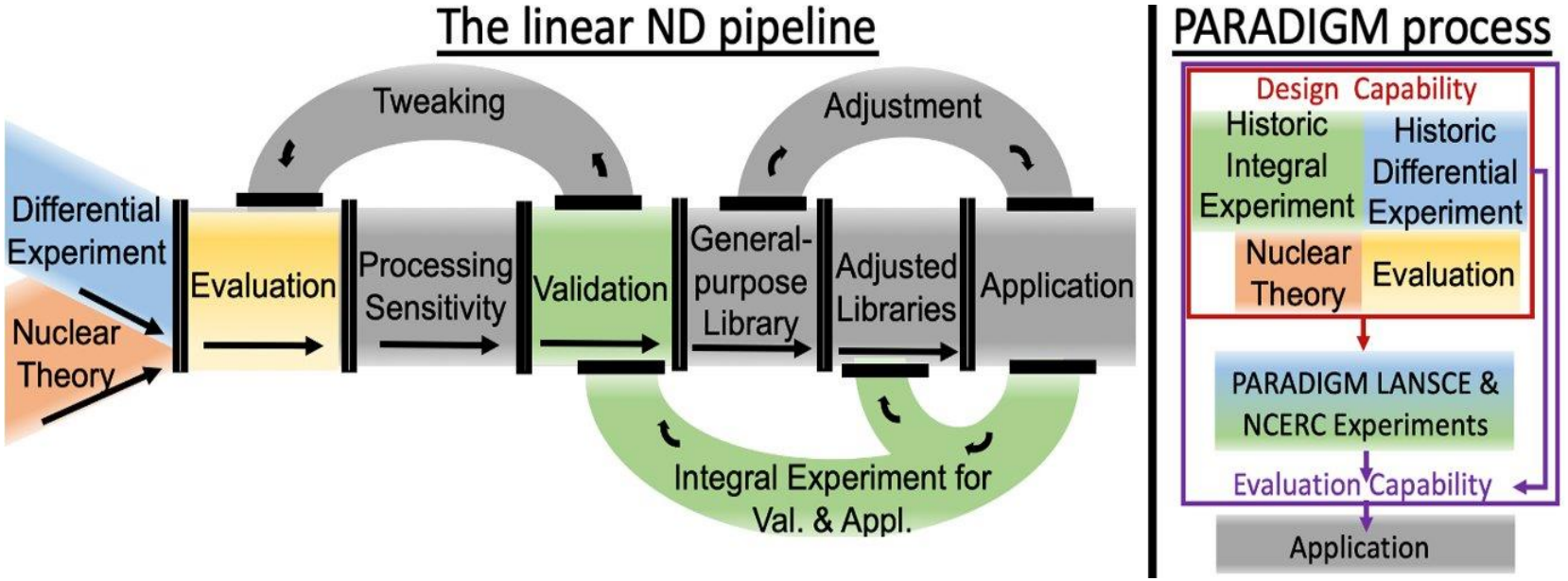
Supporting Pu operations

- PARADIGM
- Secondary measurements
- Developing Sensitivities
- Toy Problem
- Application Calculations
- Concluding Remarks

Motivation

Nuclear Data and Transport Codes need Validation

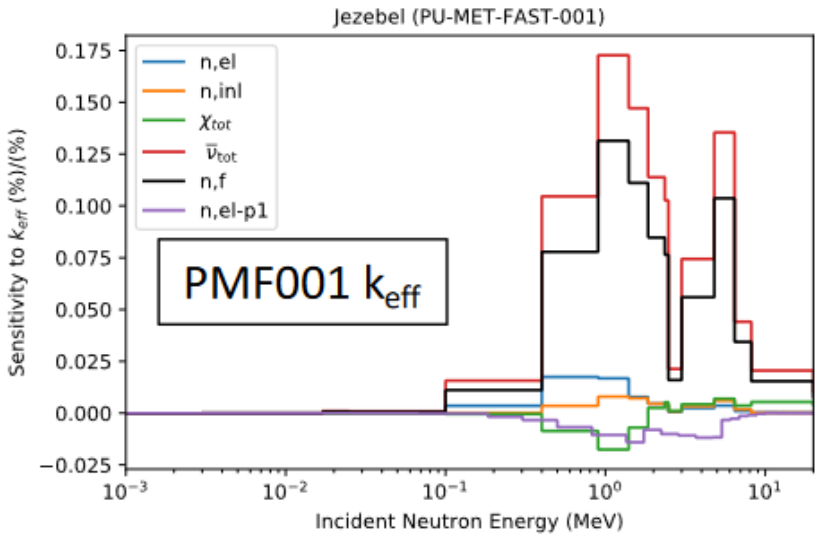
- PARallel Approach of Differential and Integral Measurement (PARADIGM) is an LDRD targeting the reduction of Pu-239 uncertainties in URR
- Part of this work are two integral experiments targeting the 1 – 600 keV region used for adjustment of cross sections

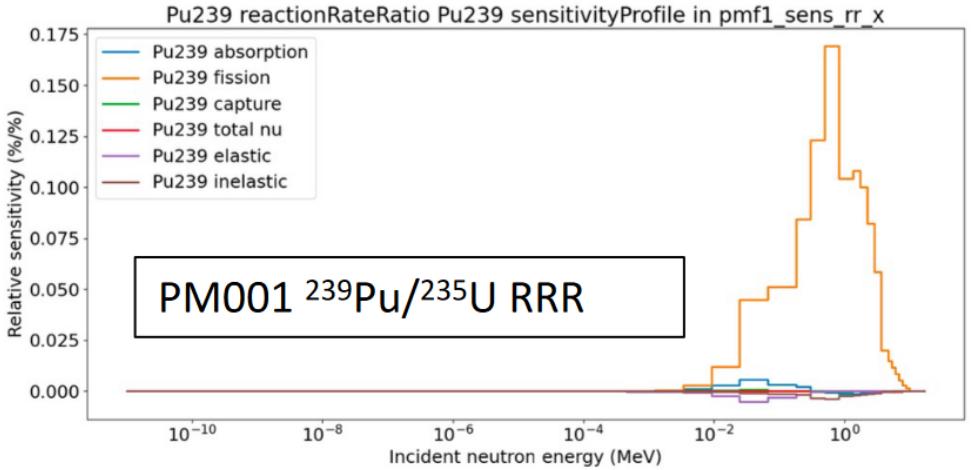


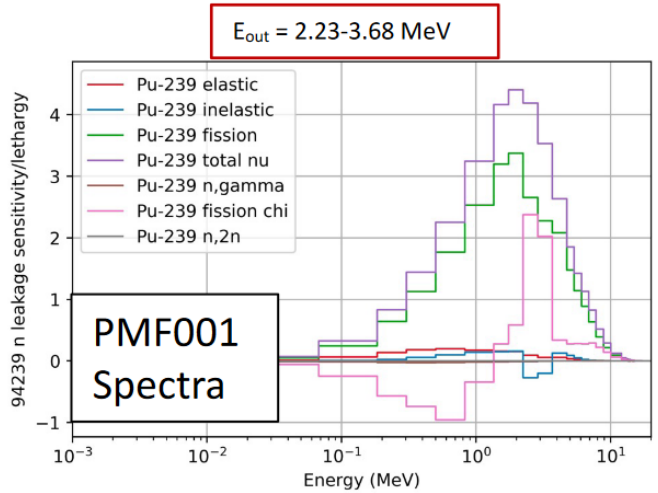
Secondary Measurements

Sensitivity Comparison

- Reaction rate ratios (RRR) and neutron leakage measurements offer highly sensitive measurements that are orthogonal to Keff
- Measurements are done in both a delayed critical and subcritical state



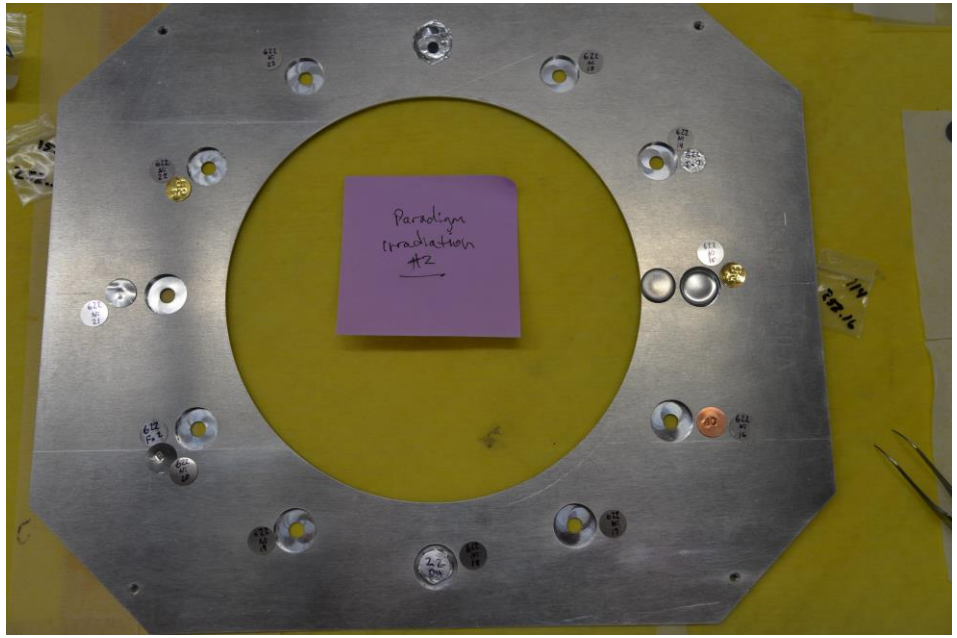




Secondary Measurements

PARADIGM Experiment

- Utilized MC-15 neutron noise, Bonner sphere leakage, and activation/fission foil irradiations for both critical configurations



Developing Sensitivities

Options for calculating sensitivities

- XSn→ Make ACE files with perturbed cross section and run the MCNP with each perturbed ACE
- FSEN → Adjoin weighting method available in beta version of MCNP6.3
- PERT → Performs Taylor series expansion for 1^{st} and 2^{nd} order sensitivities to a given perturbation.
- SENSMG → Available in PARTISN, need low fidelity models to perform sensitivities with, fine for many applications

Developing Sensitivities

Options for calculating sensitivities

- XSn→ Will always give the correct answer, perturbation size matters (uncertainties could be large), will take the longest
- FSEN → Time limitation on HPC for 12 hrs., few validation cases
- PERT → Will give 1st and 2nd order answer, some limitations on perturbation size and starts adding to run time with lots of pert.
- SENSMG → Fast and exact answer, need cylindrical/spherical models

  FSEN, Manual Pert., and PERT all give the same answer on lower multiplication (keff < 0.95) for flux tallies relative to Pu-239 –

  J. Lamproe et al. “Preliminary verification of the MCNP perturbation and fixed-source tally sensitivity tools” Ann. of Nuc. Eng., Vol 194, 2023.

Developing Sensitivities

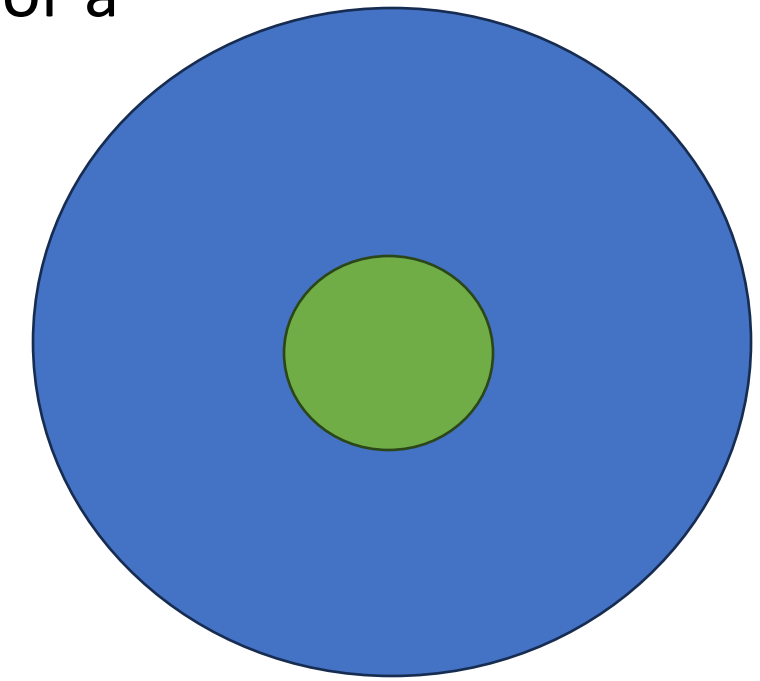
Options for calculating sensitivities

- What happens when we start performing RRR sensitivities for high, near-infinite multiplication?

Toy Problem

Reaction Rate Ratios for Modified Jezebel

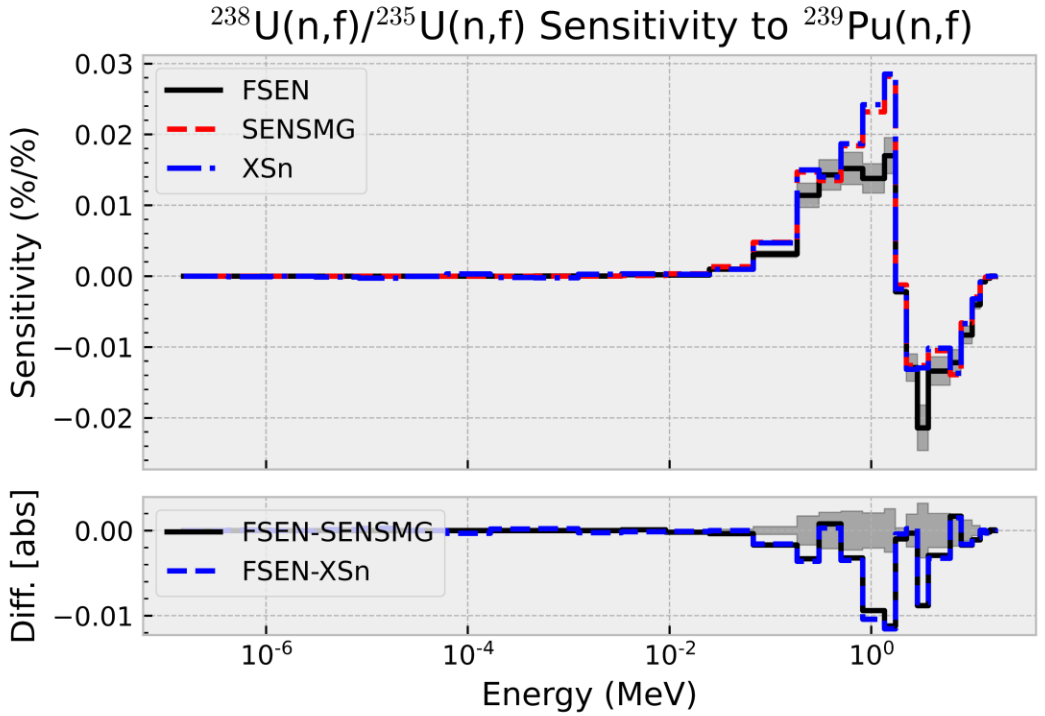
- Jezebel with the inner ½” diameter swapped out for a 50 a/t% HEU sphere (50/50 U8-U5)
- Look at the U8, U5, Average Flux, with respect to various cross sections
- Compare against manual pert. and SENSMG
- FSEN has radius shrunk slightly so M=100 to prevent infinite runtime.



Toy Problem

Looking at Sensitivities with perturbation not in RRR

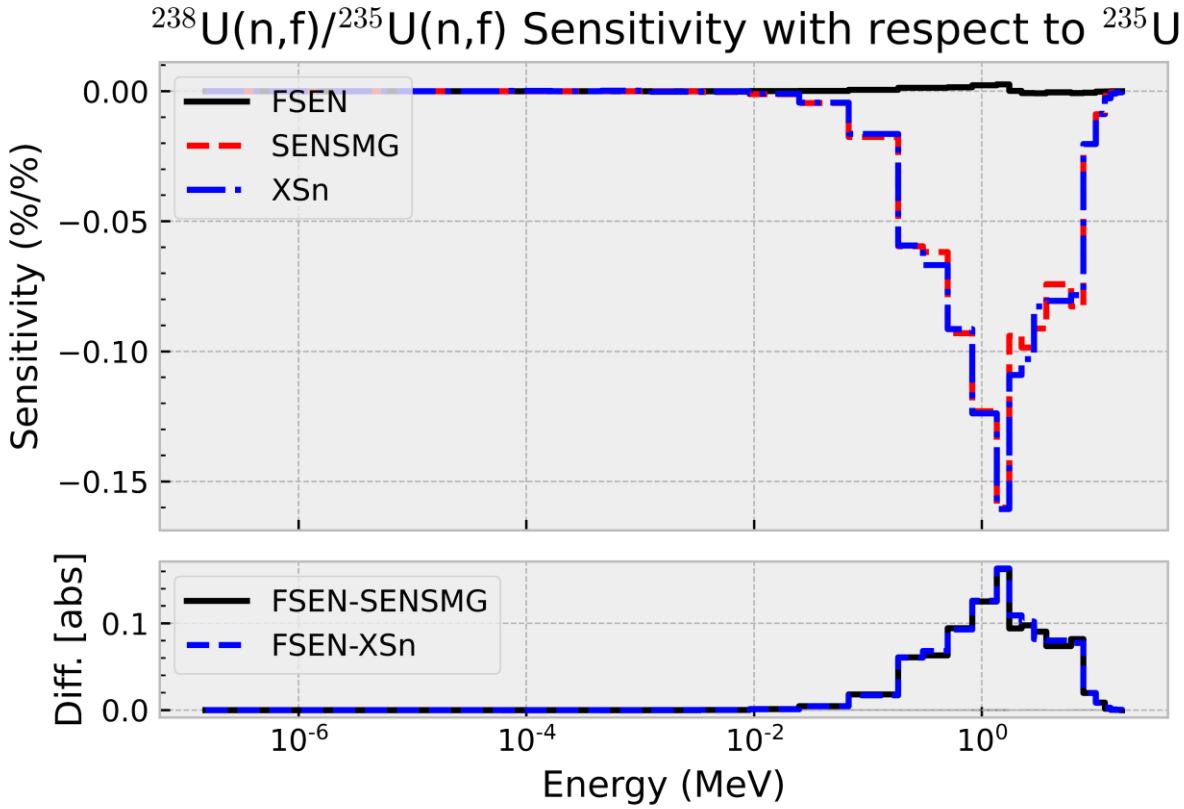
- FSEN will calculate close to what is predicted
- Combination of both statistics and multiplication



Toy Problem

Looking at Sensitivities with perturbation in RRR

- FSEN will not calculate close to what is predicted.
- Cause: FSEN doesn't affect the tally multiplier for xs of interest (but there is a way around)



FSEN Capability

Sensitivity to Reaction Rate Ratio

- Two components in RRR, the change in the flux that and the change in cross section.

$$S^g_{R,x} = \left(\frac{\sigma^g_x}{R_1}\int_V dV \frac{\partial \Sigma^g_1(r)}{\partial \sigma^g_x}\phi^g(r) - \frac{\sigma^g_x}{R_2}\int_V dV \frac{\partial \Sigma^g_2(r)}{\partial \sigma^g_x}\phi^g(r)\right) + \left(\frac{\sigma^g_x}{R_1}\int_V dV \Sigma^g_1(r)\frac{\partial \phi^g(r)}{\partial \sigma^g_x} - \frac{\sigma^g_x}{R_2}\int_V dV \Sigma^g_2(r)\frac{\partial \phi^g(r)}{\partial \sigma^g_x}\right)$$

Taken from J. Favorite, “SENSMG: First-Order Sensitivities of Neutron Reaction Rates,Reaction-Rate Ratios, Leakage, k eff, and α Using PARTISN” Nucl. Sci. and Eng., Vol. 192, Pgs. 80–114, Oct. 2018

FSEN Capability

Sensitivity to Reaction Rate Ratio

- If the cross section we are taking the sensitivity to is not in the RRR, the first half drops out

$$S^g_{R,x} = \left(\frac{\sigma^g_x}{R_1}\int_V dV \frac{\partial \Sigma^g_1(r)}{\partial \sigma^g_x}\phi^g(r) - \frac{\sigma^g_x}{R_2}\int_V dV \frac{\partial \Sigma^g_2(r)}{\partial \sigma^g_x}\phi^g(r)\right) + \left(\frac{\sigma^g_x}{R_1}\int_V dV \Sigma^g_1(r)\frac{\partial \phi^g(r)}{\partial \sigma^g_x} - \frac{\sigma^g_x}{R_2}\int_V dV \Sigma^g_2(r)\frac{\partial \phi^g(r)}{\partial \sigma^g_x}\right)$$

0

FSEN Capability

Sensitivity to Reaction Rate Ratio

- However, if it is in the RRR, then only one part of the first half drops out
- The derivative of the macroscopic cross section w.r.t. the microscopic is 1

$$S^g_{R,x} = \left(\frac{\sigma^g_x}{R_1}\int_V dV \frac{\partial \Sigma^g_1(r)}{\partial \sigma^g_x}\phi^g(r) - \frac{\sigma^g_x}{R_2}\int_V dV \frac{\partial \Sigma^g_2(r)}{\partial \sigma^g_x}\phi^g(r)\right) + \left(\frac{\sigma^g_x}{R_1}\int_V dV \Sigma^g_1(r)\frac{\partial \phi^g(r)}{\partial \sigma^g_x} - \frac{\sigma^g_x}{R_2}\int_V dV \Sigma^g_2(r)\frac{\partial \phi^g(r)}{\partial \sigma^g_x}\right)$$

0 or 1

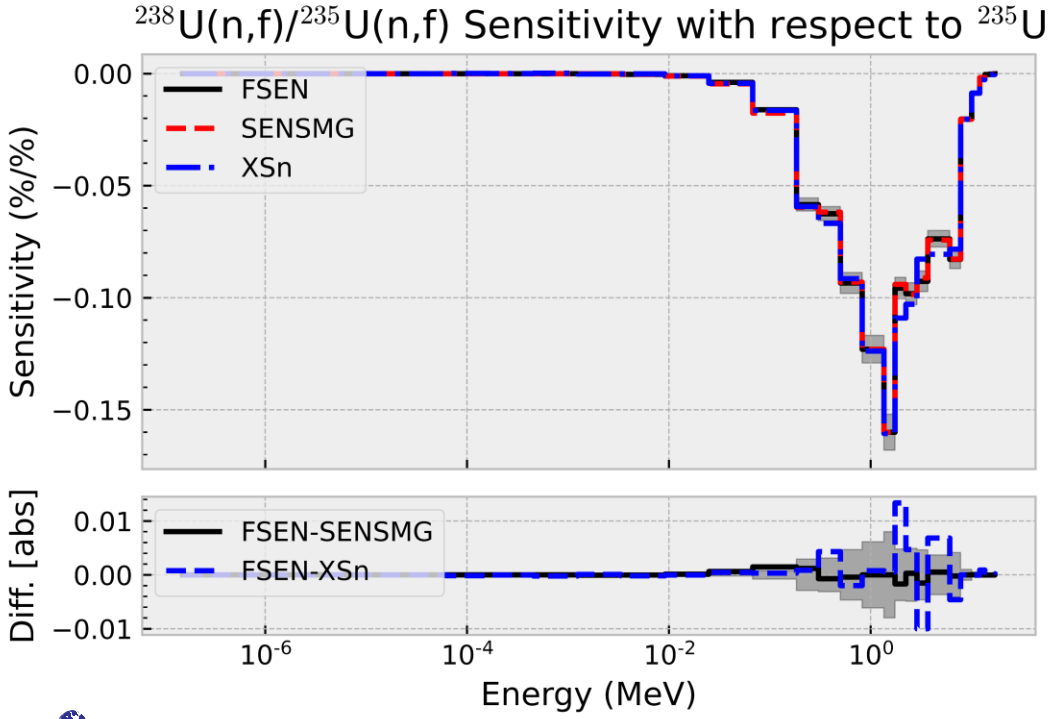
0 or 1

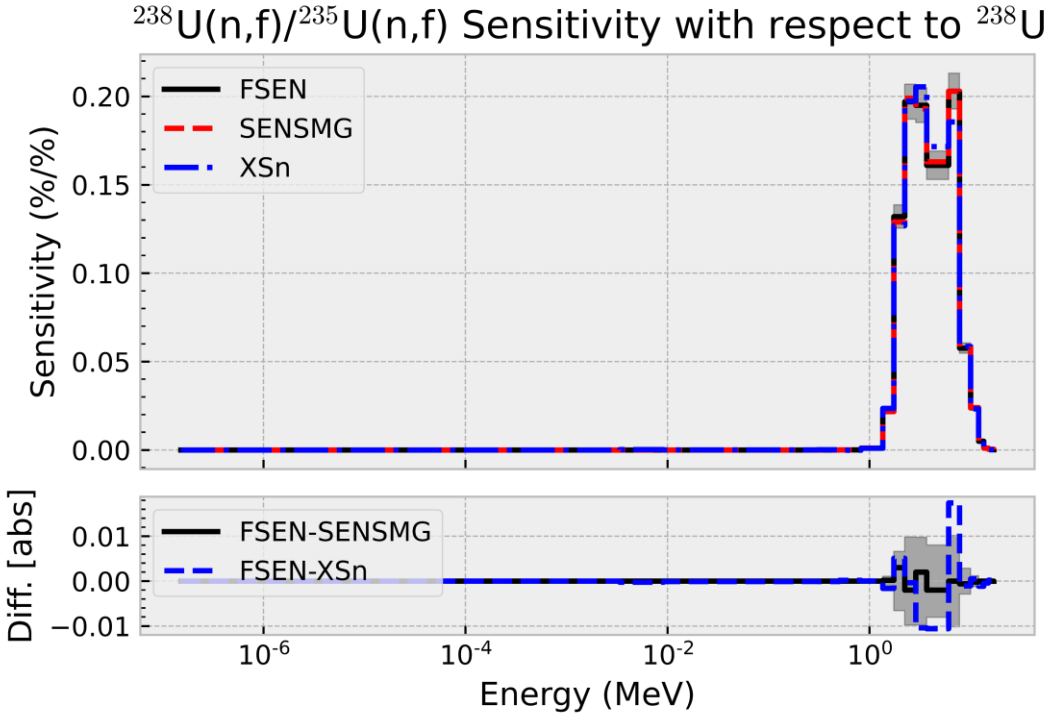
- Then all you need to do is calculate the energy dependent contributions to the reaction rate.

Toy Problem

Looking at Sensitivities with perturbation in RRR

- FSEN predicted + partial reaction rate contributions returns XSn and SENSMG results



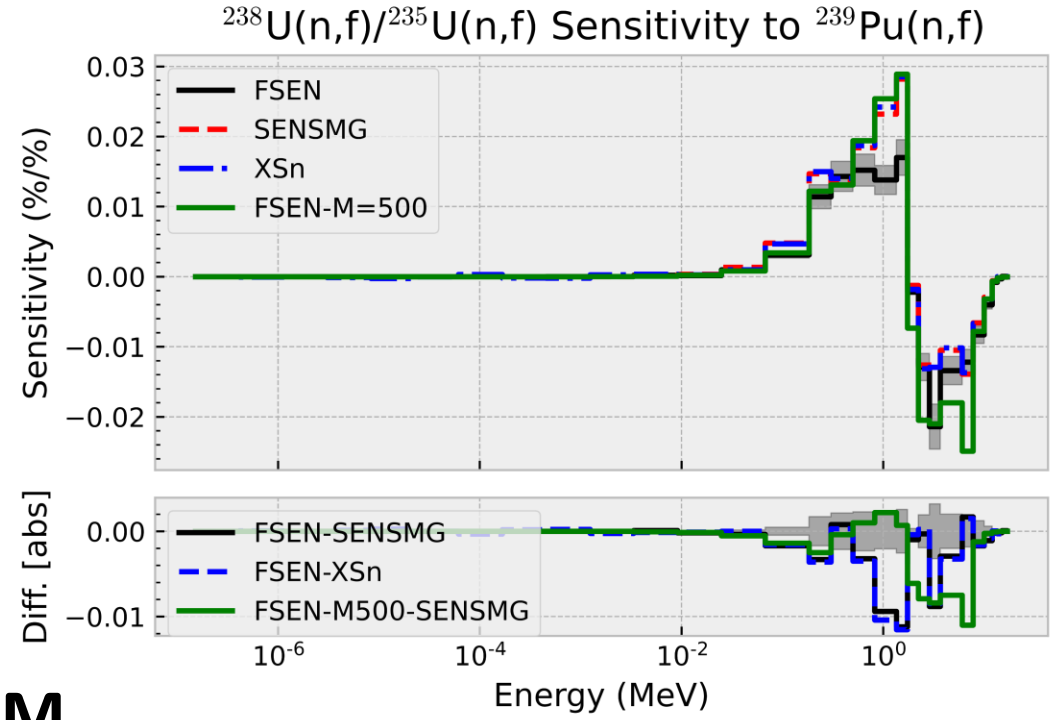


Future Work

Accounting for Multiplication

- Indirect (flux) driven sensitivity changes as a function of system multiplication
- Looking into various multiplications as how this impacts the indirect sensitivity

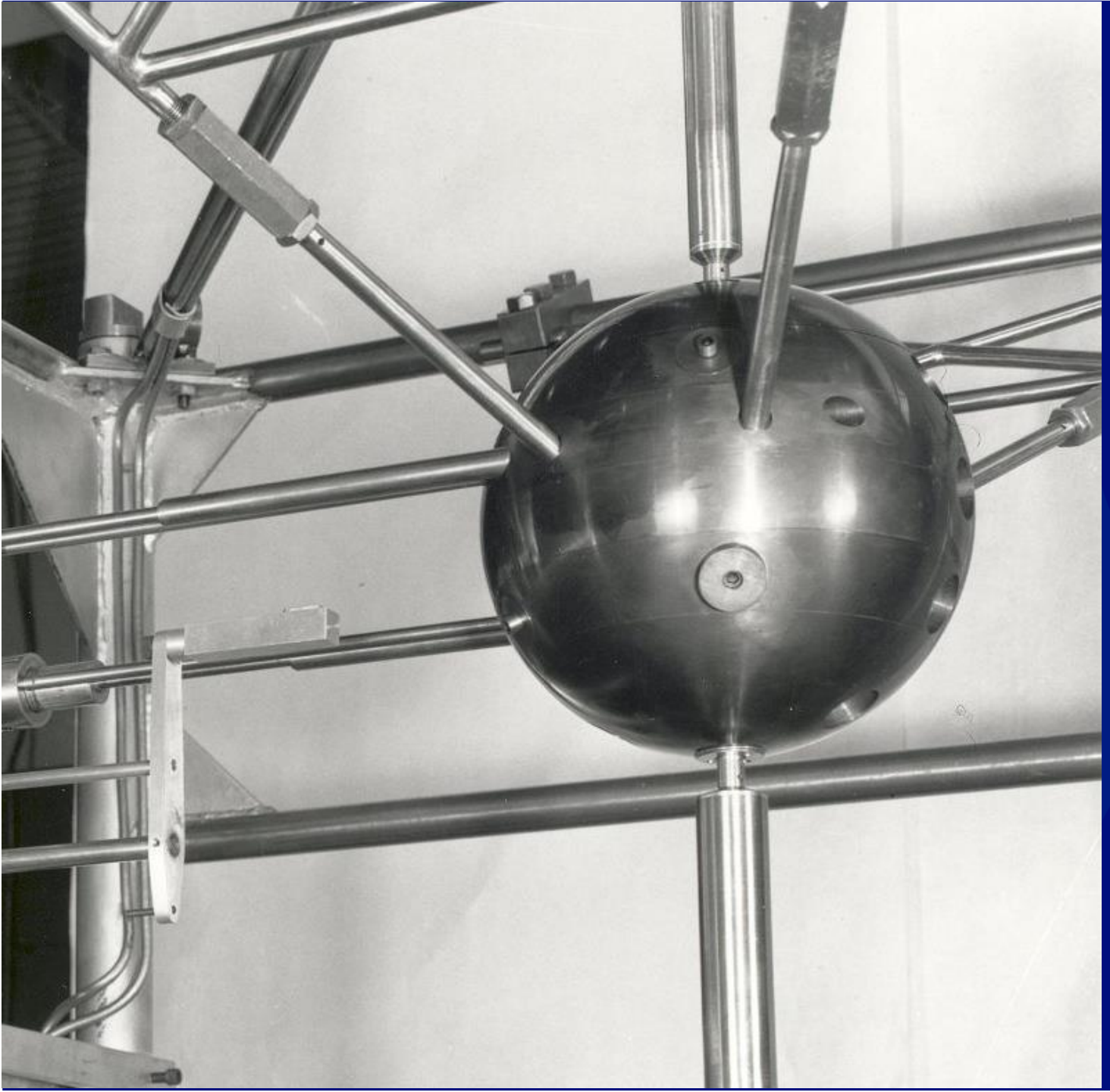
- **Apply these to generating sensitivity matrices for ND adjustment of PARADIGM**



Conclusions

FSEN Time

- FSEN provides an opportunity to quickly calculate sensitivities to orthogonal measurements during integral experiments
- Toy problem has been deployed to expand on verification of FSEN for reaction rate ratios
- While there is decent agreement, further investigation must be done on multiplication's impact on sensitivity vector.



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