The benefit of adjusting with criticality and reaction rate data

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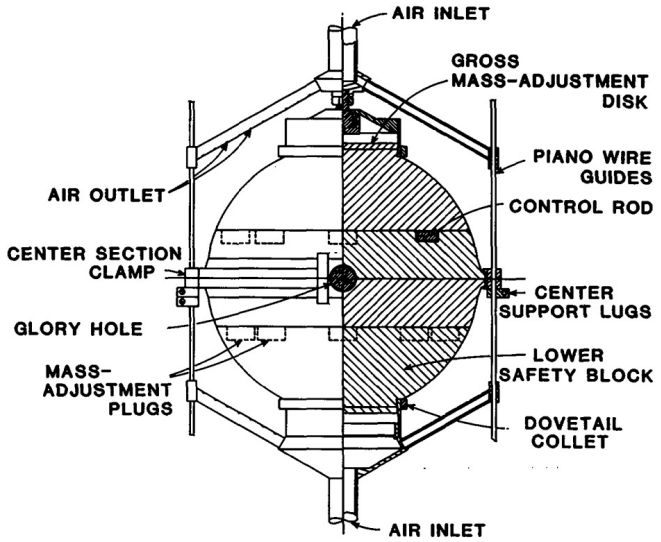
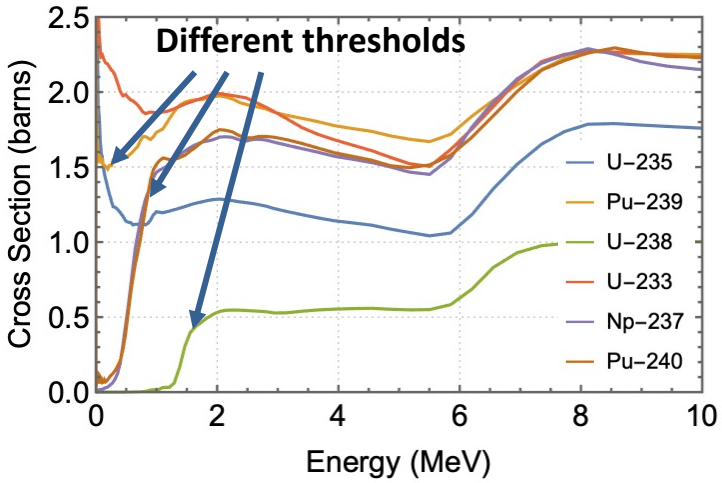
Criticality and reaction rates





- Critical assembly keff is sensitive to fission and scattering, so adjustment with keff creates correlations between those reactions.
- Assembly neutron spectrum depends on PFNS and scattering properties.
- Adjusting with fission ratios measured in critical assemblies can help constrain the fission cross section *and* assembly neutron flux.
  - keff adjustment alone does not do this.
  - These fission reaction rates are sensitive to the neutron spectrum, and are referred to as spectral indices.
  - Measurements were quick, which allowed for multiple fission chambers and foil thicknesses. (Avoided some pitfalls of differential fission ratio measurements).

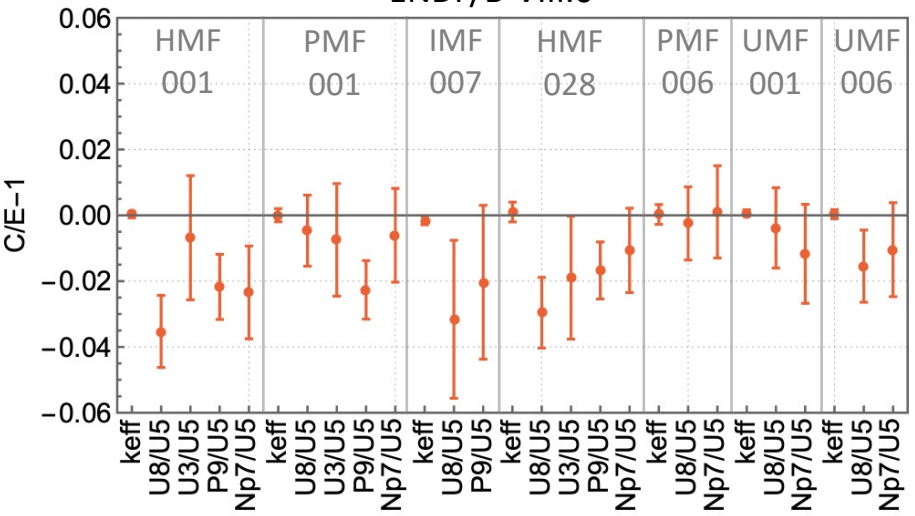
The ENDF/B-VIII.0 Spectral Indices Table

Difficult to see that most values are low when reading table

Assembly	Quantity	U238f/U235f	Np237f/U235f	U233f/U235f	Pu239f/U235f
Godiva	Calc	0.1583	0.8318	1.5793	1.3846
(HMF001)	Exp-B	0.1643 ±0.0018	0.8516±0.012		1.4152 ± 0.014
	Exp-A	0.1642 ±0.0018	0.837 ±0.013	1.59±0.03	1.402±0.025
	Calc/Exp	C/E=0.9636	C/E=0.9767	C/E=0.9933	C/E=0.9784
Jezebel	Calc	0.2121	0.9770	1.5560	1.4273
(PMF001)	Exp-B	0.2133 ±0.0023	0.9835 ±0.014		1.4609 ± 0.013
	Exp-A	0.2137 ±0.0023	0.962 ±0.016	1.578 ±0.027	1.448 ±0.029
	Calc/Exp	C/E=0.9943	C/E=0.9934	C/E=0.9924	C/E=0.9770
Big-10	Calc	0.0358			1.170
(IMF007)	Exp	0.0375 ±0.0009			1.198 ± 0.028
	Calc/Exp	C/E=0.954			C/E=0.977
Jezebel-23	Calc	0.2121	0.9851		
(UMF001)	Exp-B	0.2131 ±0.0026	0.9970 ±0.015		
	Exp-A	0.2131 ±0.0023	0.977 ±0.016		
	Calc/Exp	C/E=0.9951	C/E=0.988		
Flattop-25	Calc	0.1451	0.7735	1.5664	1.3622
(HMF028)	Exp-B	0.1492 ±0.0016	0.7804 ±0.01	1.608 ±0.003	1.3847 ±0.012
	Exp-A	0.149 ±0.002	0.76 ±0.01	1.60 ±0.003	1.37 ±0.02
	Calc/Exp	C/E=0.9722	C/E=0.9911	C/E=0.9741	C/E=0.9837
Flattop-Pu	Calc	0.1801	0.8593		
(PMF006)	Exp-B	0.1799 ±0.002	0.8561 ±0.012		
	Exp-A	0.180 ±0.003	0.84 ±0.01		
	Calc/Exp	C/E=1.0011	C/E=1.0037		
Flattop-23	Calc	0.1892	0.9030		
(UMF006)	Exp-B	0.1916 ±0.0021	0.9103 ±0.013		
	Exp-A	0.191 ±0.003	0.89 ±0.01		
	Calc/Exp	C/E=0.9876	C/E=0.9920		

Bad 0.2% uncertainty exists in ICSBEP handbook too

ENDF/B-VIII.0

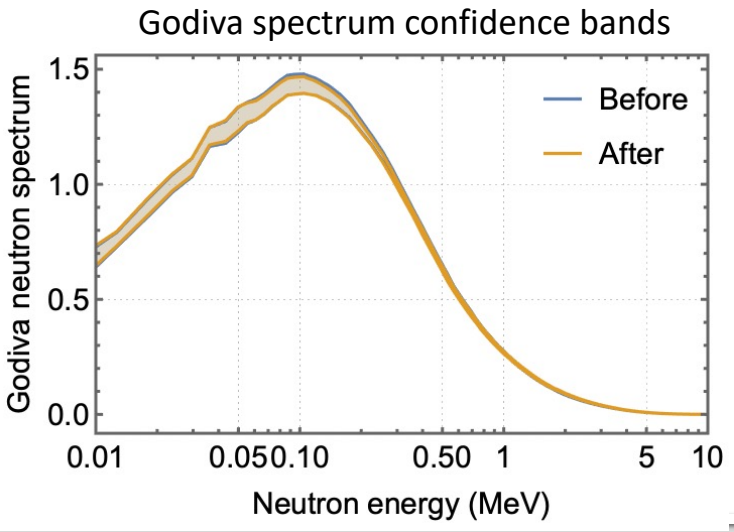


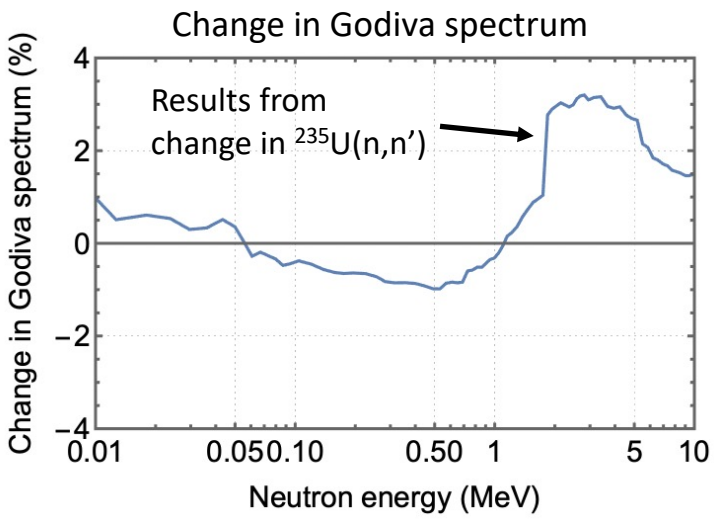
- Assembly letters indicate main actinide.
- For many assemblies, reaction rates systematically low by ~2%; all are ratios to ^{235}U(n,f).
- This raises questions about validation of ENDF/B-VIII.0 major actinides.

D. A. Brown et al., Nuclear Data Sheets **148**, 1 (2018).

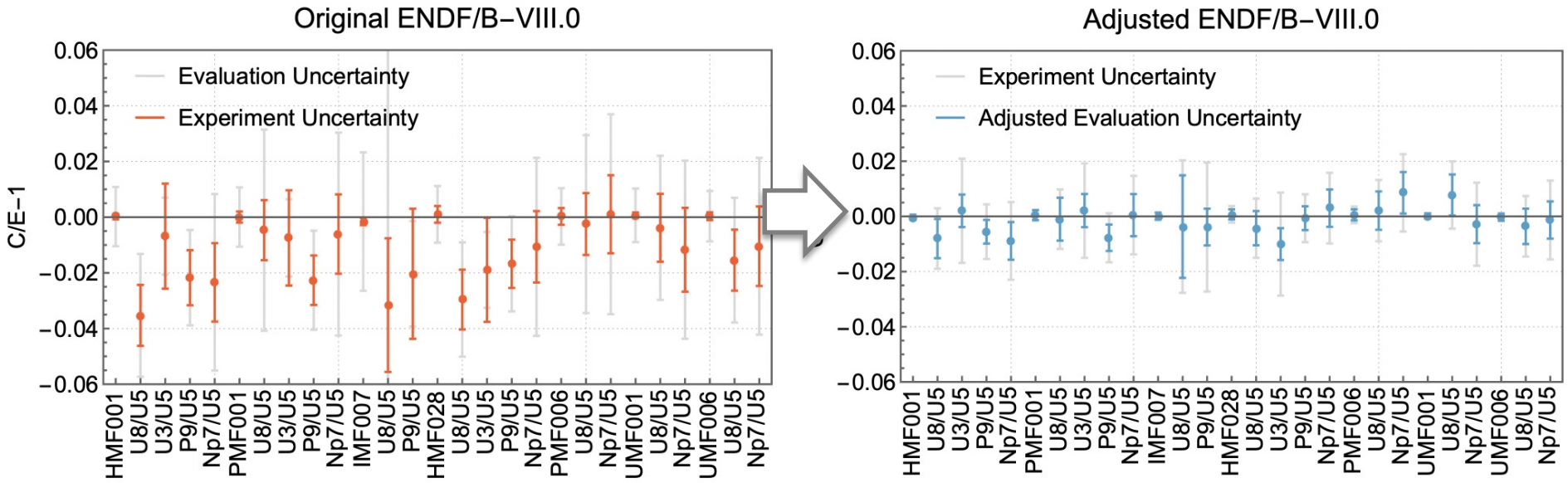
Adjustment method

- There are several methods for adjustment, but we have used a hybrid of Monte Carlo sampling and sensitivity analysis for the regression (GLS).
  - Monte Carlo sample phases are decorrelated, which requires covariance rank + 1 samples.
  - Sensitivity vectors found in joint evaluation/integral model covariance matrix.
  - Variations include PFNS covariance, but currently not elastic angular or inelastic spectral covariances.
- Assembly and foil nuclear data varied together, to account for uncertainty in assembly neutron spectrum.



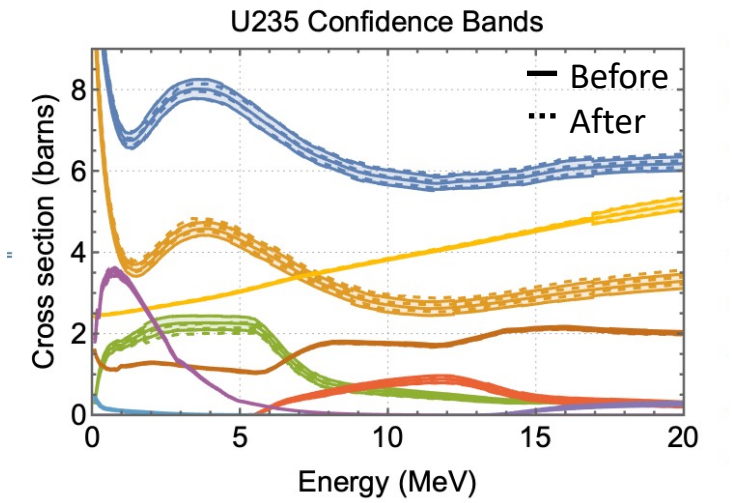


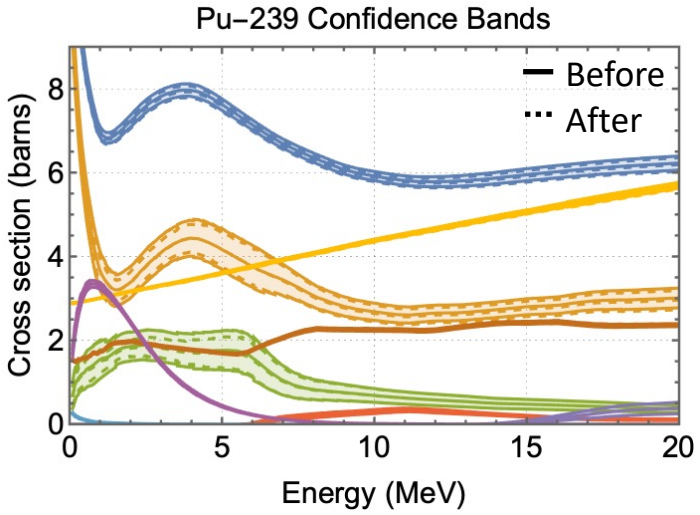
Impact of adjustment on integral data

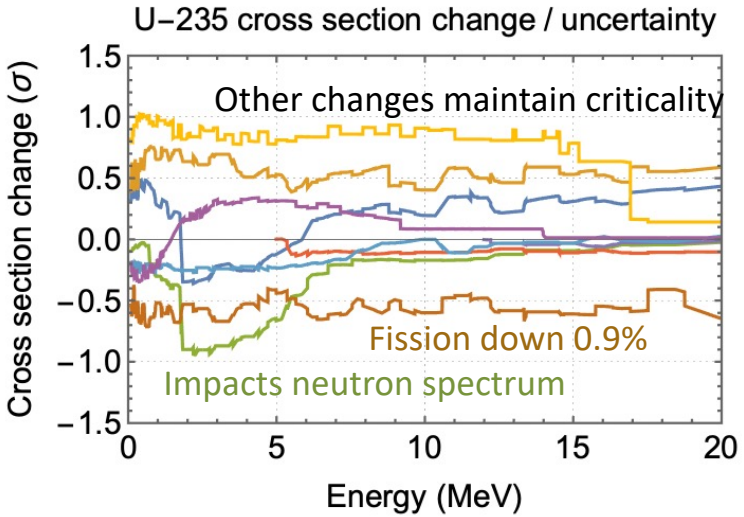


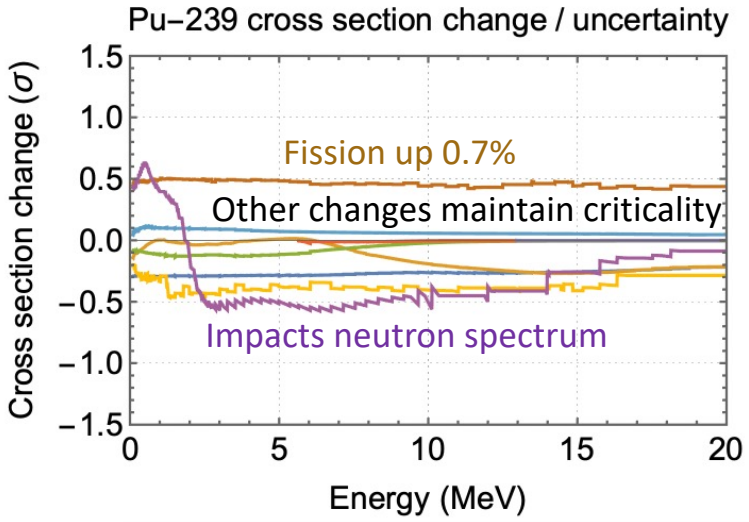
- Adjustment includes keff and reaction rates, so resulting evaluation consistent with both.
- The collection of integral data from the ENDF spectral indices table is statistically significant enough to cause substantial changes in differential evaluation.
- Some ^{252}Cf(sf) data supports the changes on the following slides, but there is not as much data available.

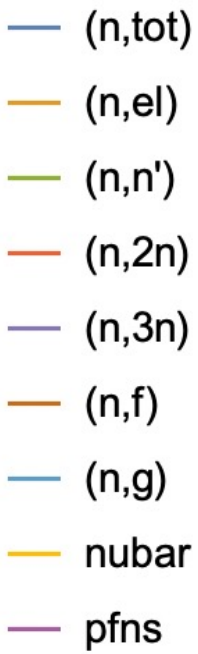
Adjustment impact on ^{235}U and ^{239}Pu differential data





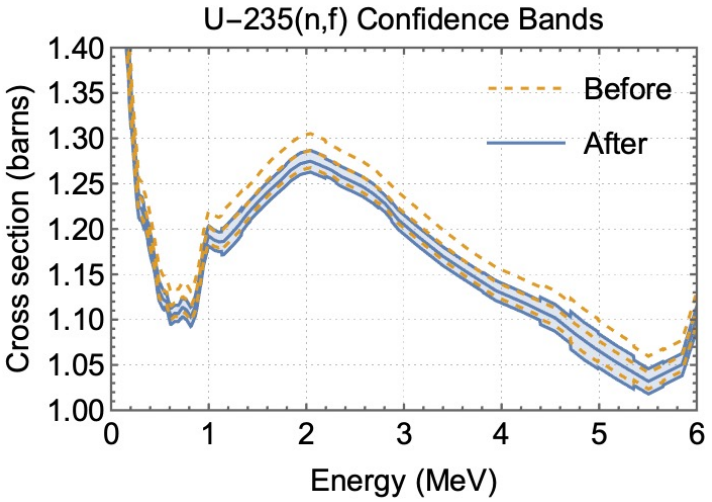


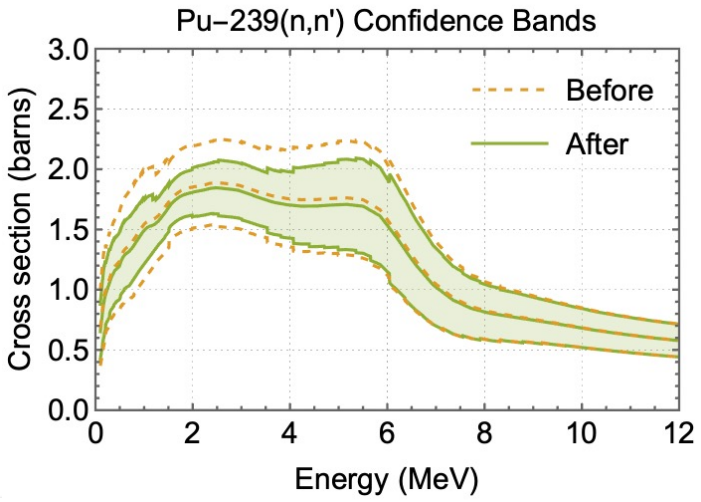




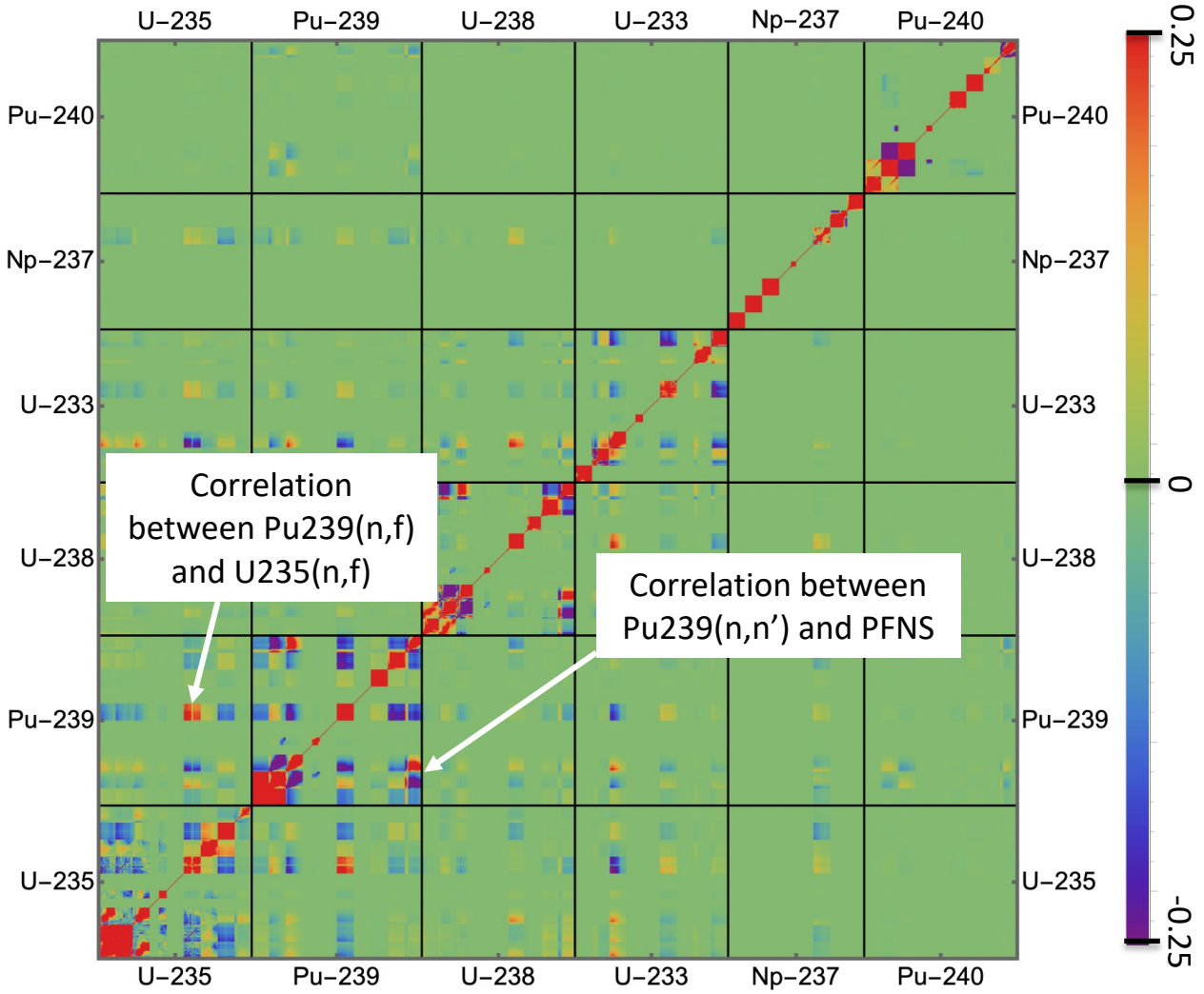
Benefits of adjusting with keff and reaction rates

- Adjustment can help address spectral indices validation issue.
- Adjusted fission and inelastic scattering uncertainties are reduced, resulting from combination of fission data, spectral sensitivity, and criticality data.
- Impact not sensitive to keff uncertainty; just as significant when all are set to 0.3%.
- Allowing adjustment with integral data could lead to novel and impactful future experiments.





Adjusted correlations between isotopes



Reaction order from lower left to upper right:

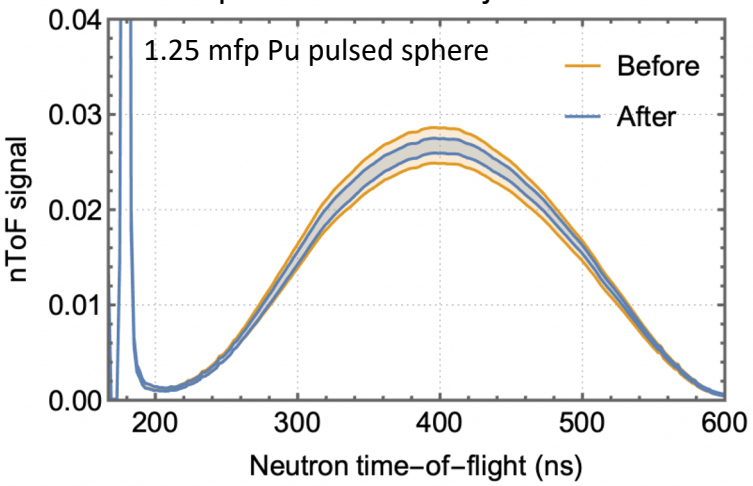
- (n,tot)
- (n,el)
- (n,n')
- (n,2n)
- (n,3n)
- (n,f)
- (n,g)
- nubar
- pfns

Adjustment with pulsed spheres

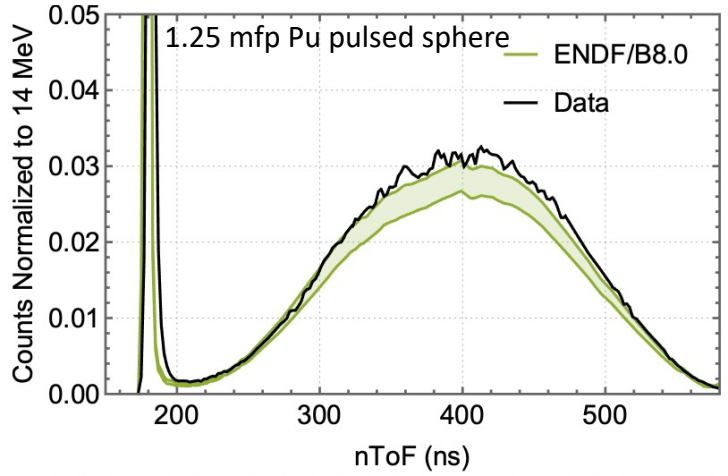
- Spectral indices can impact modeled pulsed sphere nToF spectra.
- Pulsed spheres have more resolved measurements of neutron spectra but would require covariance matrix for nToF spectrum.
- Simulations of neutron detector have shown threshold variability between measurements which would need to be accounted for in covariance matrix.

Adjusting to just two points with Pu pulsed sphere nToF spectra has a big impact on ^{239}Pu(n,n') and PFNS

Spectral indices adjustment



Agreement with new detector threshold



Path to adjustment

- **Adjustment would require evaluated integral data with realistic covariances.**
  - The single bad data point from the ENDF/B-VIII.0 spectral indices table would have doubled the impact on ^{235}U(n,f).
  - Criticality and spectral indices seem like a good starting point, but smaller number of assembly materials preferred.
- **Cross validation would help identify deficiencies of adjusted libraries.**
  - Adjusting with subsets of data and validating with data left out would help users understand appropriate uses and shortcomings of these adjusted libraries.
- **Pulsed spheres may be more sensitive to scattering uncertainties than reaction rates**
  - Adjustment with pulsed sphere spectra complicated and covariance matrix not provided with data.