How Integral Benchmarks Benefit Fission Product Data via Data Calibration

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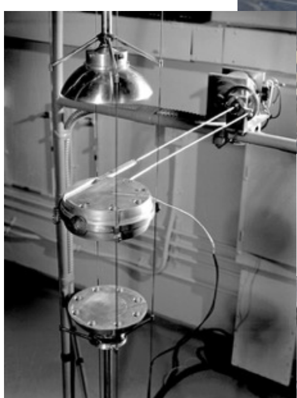
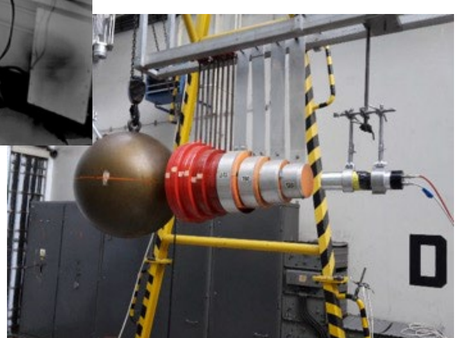
Measurements Form the Basis for Nuclear Data

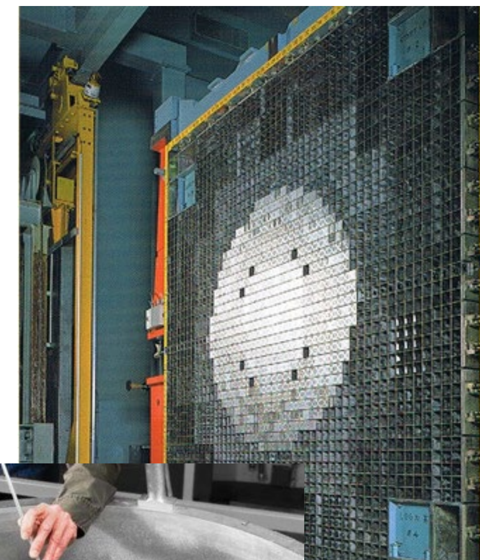
- **Integral Measurements/Benchmarks**
  - Measurements of a system that is dependent on multiple data (isotopes, reactions, energies) at once
  - May be designed to be particularly sensitive to one piece of data





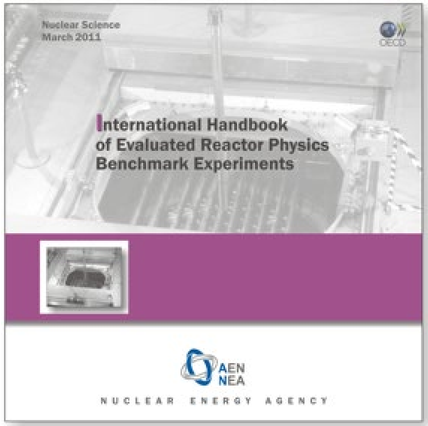
Examples:

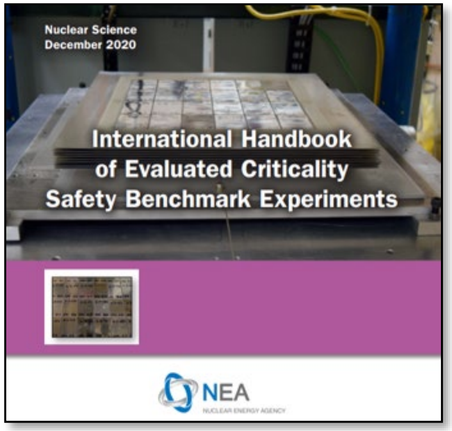
- Critical assemblies
- Subcritical assemblies
- Reactor startup experiments
- Reactor operation data
- Shielding Experiments
- Activation Experiments
- Post Irradiation Examination

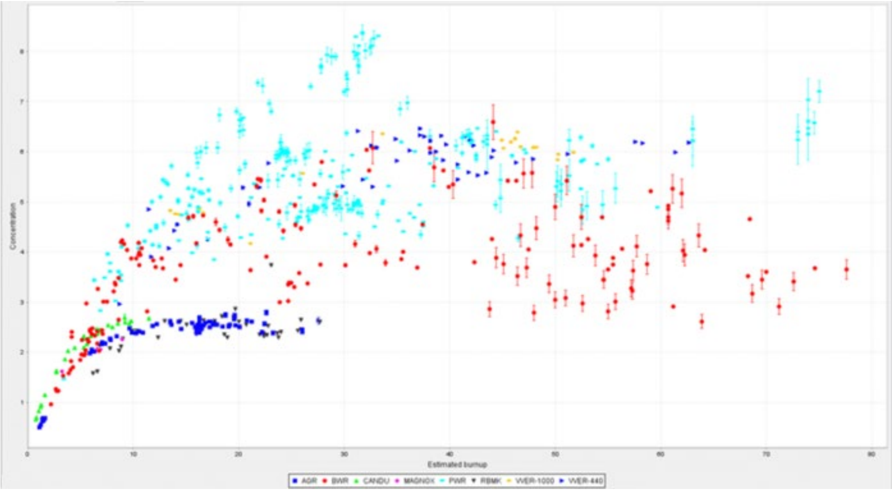


Established Integral Benchmark Handbooks

- Benchmarks are evaluated integral experiments
- **International Criticality Safety Benchmark Evaluation Project (ICSBEP)**
  - >5000 Critical, subcritical, and physics configurations
- **International Reactor Physics Evaluation Project (IRPhEP)**
  - 200 Reactor benchmarks
  - 200 Spectra benchmarks
- **Shielding Integral Benchmark Database (SINBAD)**
  - Reactor shielding (46)
  - Fusion neutronics shielding (31)
  - Accelerator shielding (23)
- **Spent Fuel Composition (SFCompo)**
  - 700 Samples



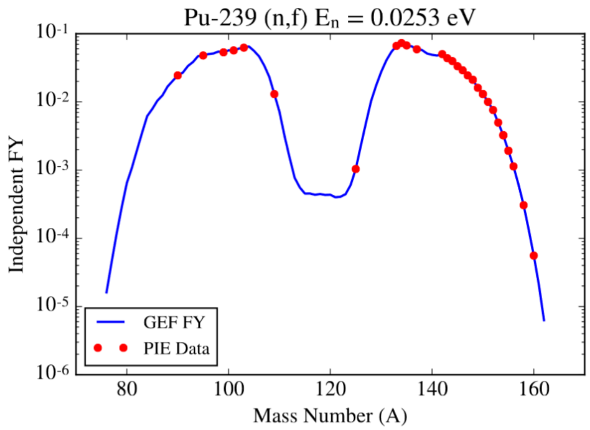




Integral Experiments Sensitive to FYs

- Experiments with benchmark data:
  - Irradiated reaction rate foils
  - Reactor kinetics (delayed neutron fraction)
  - **Post Irradiation Examinations**
  - Calorimetry of irradiate fuel

- Fuel after burnup in reactor can be examined to determine it's composition
- Concentrations of fission products & minor actinides used as integral data
- Simulation biases are large and uncertainties are large
- Sought to perform adjustment of FYs with data



Approach

- Take data from SFCOMPO database and simulate reactor fuel cycle
- Evaluate covariance matrix of fission product concentrations
- Use GEF to propagate uncertainties of model parameters
- Correct for model defects (GEF or radiation transport) and unaccounted for uncertainties
- Perform Bayesian Monte Carlo adjustment
- Verify with ENDF/unseen fuel sample/reactivity measurements

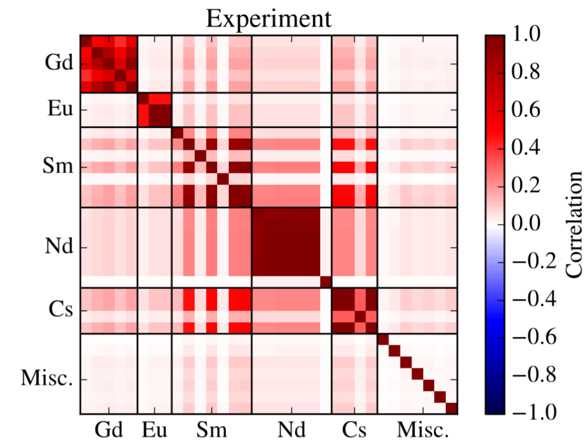


Figure: Experimental covariance matrix

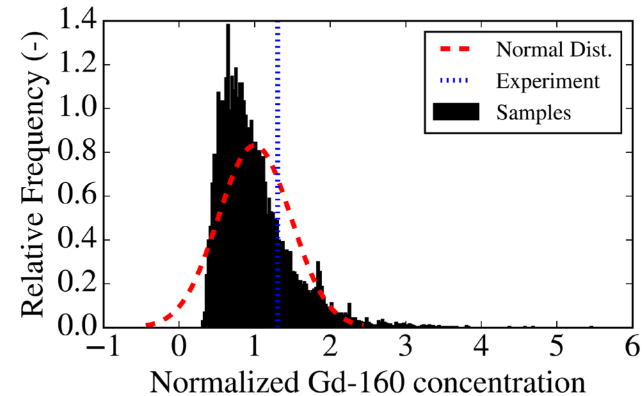


Figure: Non-Gaussian PDF of FP concentration from GEF

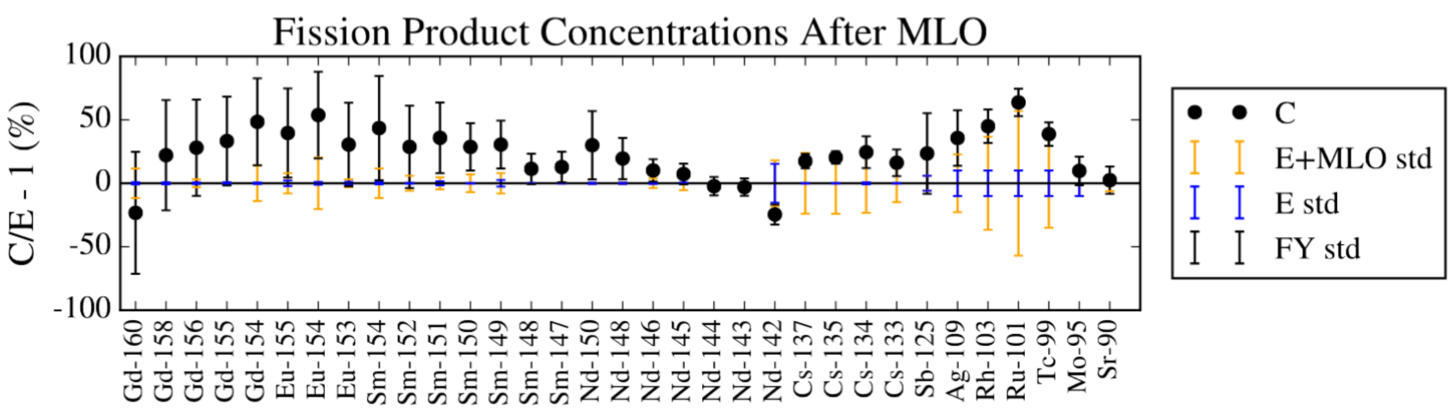
Marginal Likelihood Optimization

- Unexplained biases create large χ^2 that threatens to worsen FYs
- Add penalty hyperparameter by minimizing marginal likelihood of the data set

$$\chi^2 = (\mathbf{E} - \mathbf{C})^T (\mathbf{M_E} + \mathbf{M_C} + \mathbf{M_{extra}})^{-1} (\mathbf{E} - \mathbf{C})$$

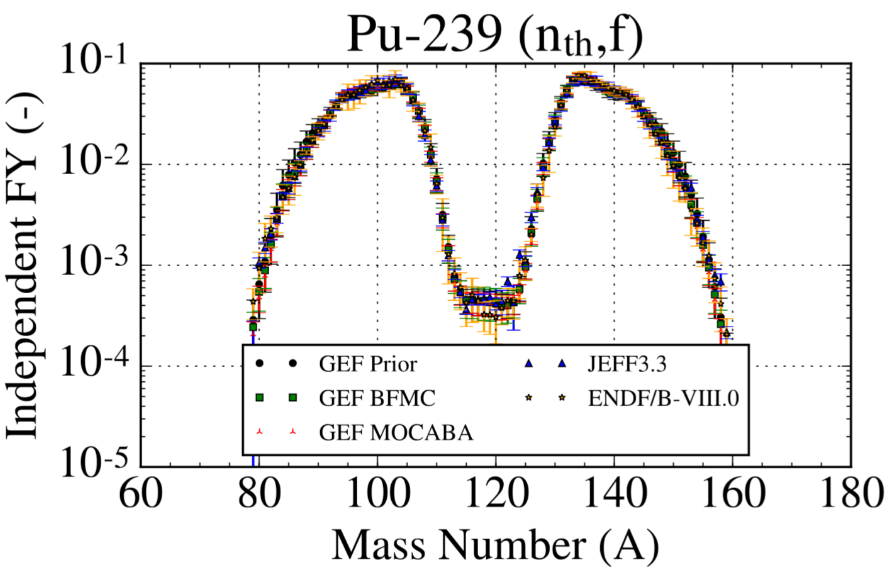
$$L = \frac{e^{-\chi^2/2}}{\sqrt{(2\pi)^N \det(\mathbf{M_E} + \mathbf{M_C} + \mathbf{M_{extra}})}}$$

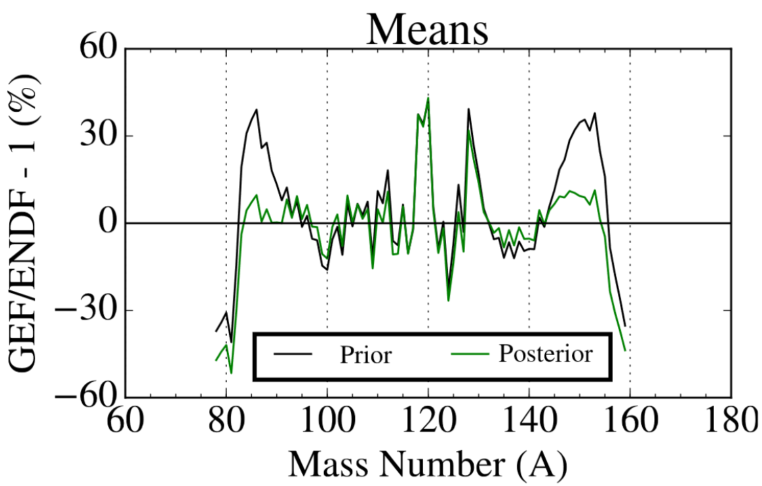
$$\min\left[\frac{1}{2}(N * \log(2\pi) + \det(\mathbf{M_E} + \mathbf{M_C} + \mathbf{M_{extra}}) + \chi^2)\right]$$

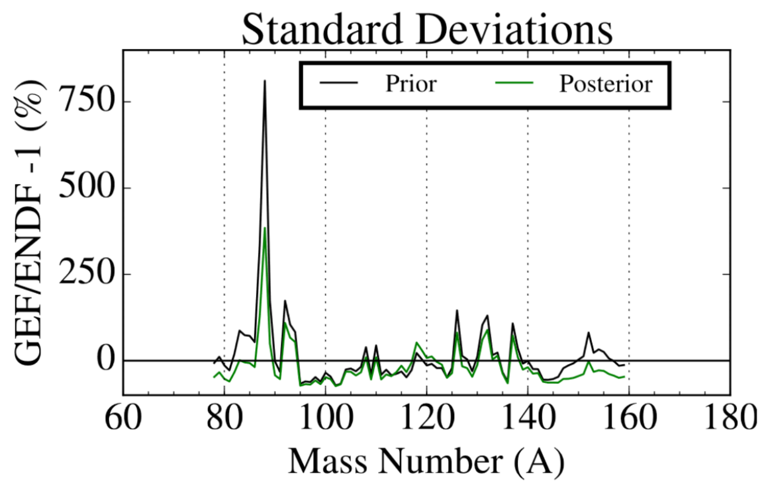


6

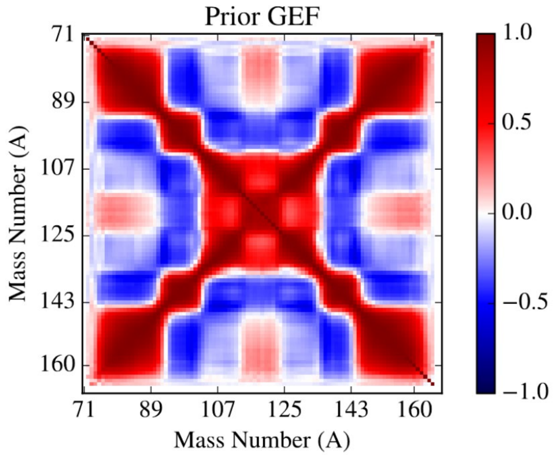
Adjusted FYs

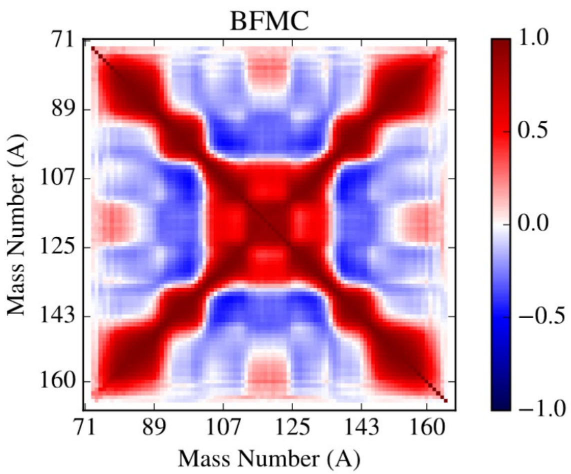


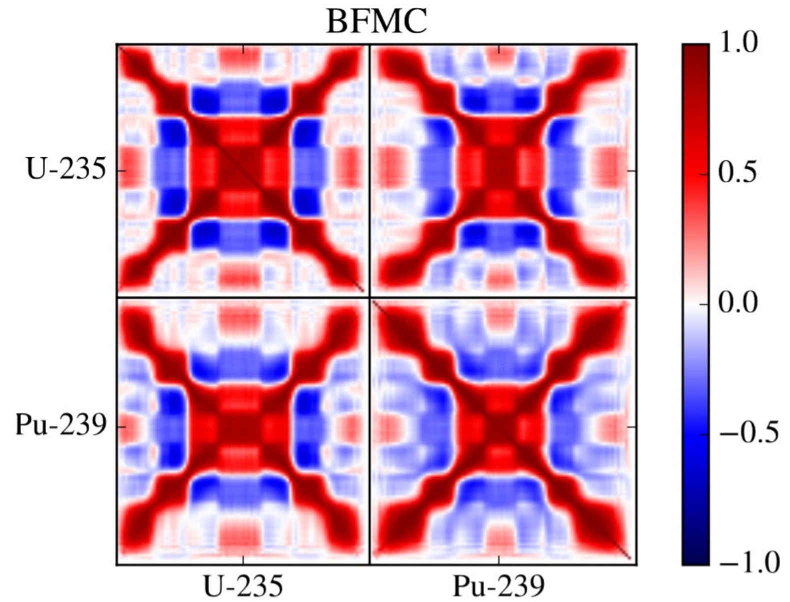




Adjusted Covariances

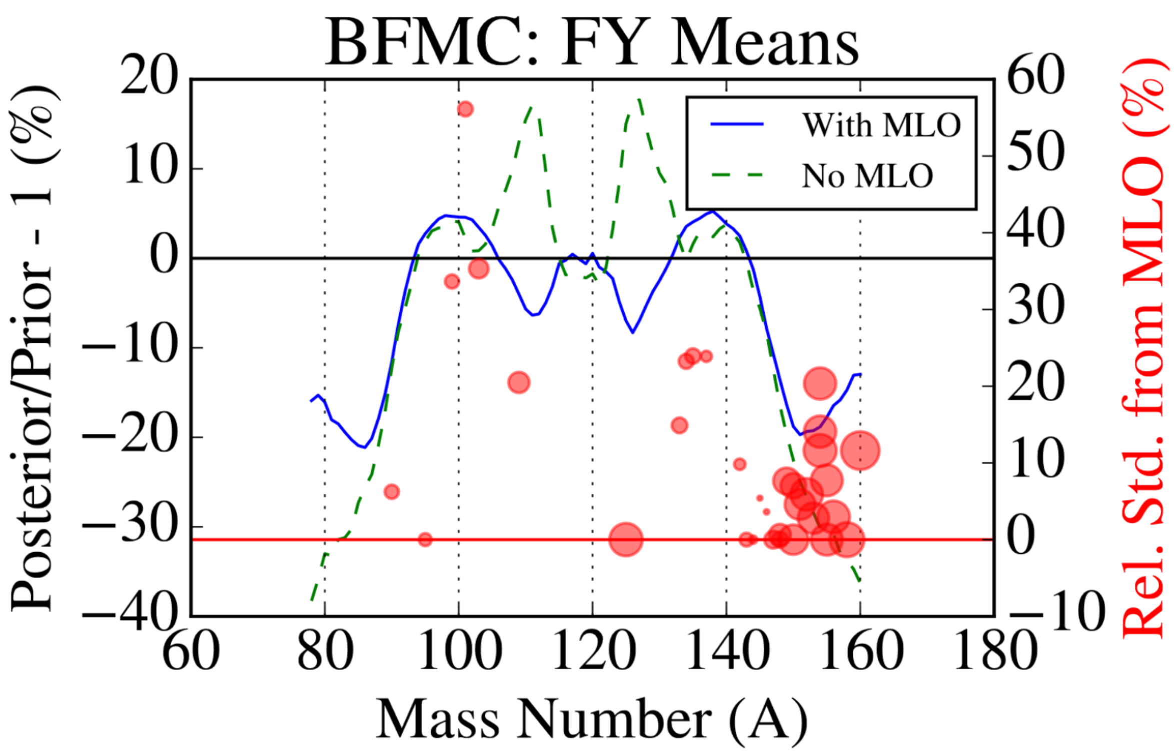






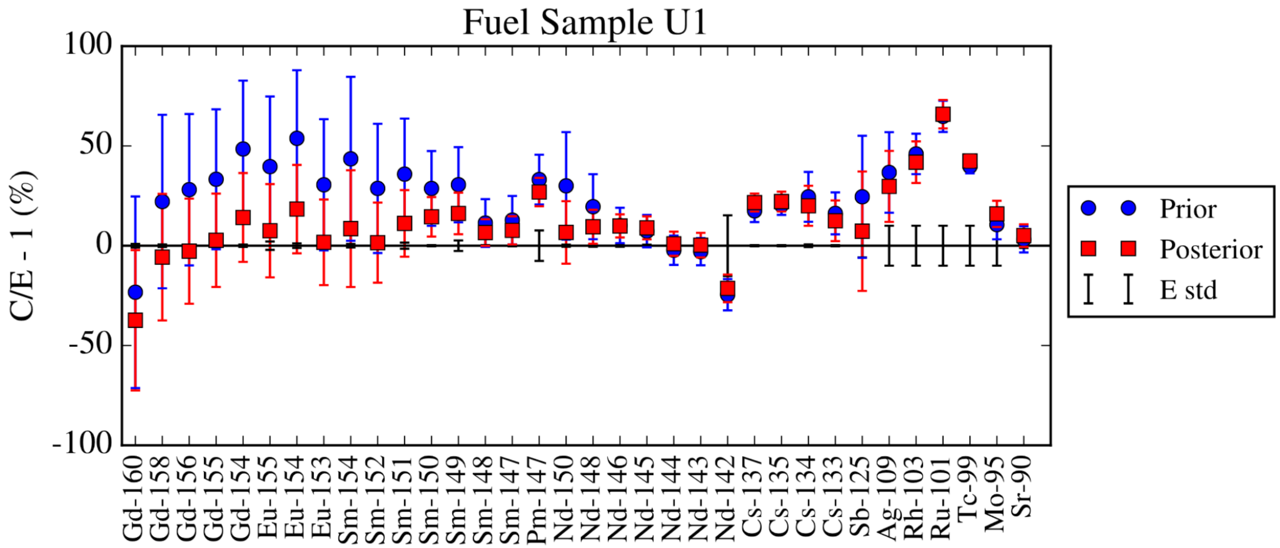
8

MLO Importance



Posterior Concentrations

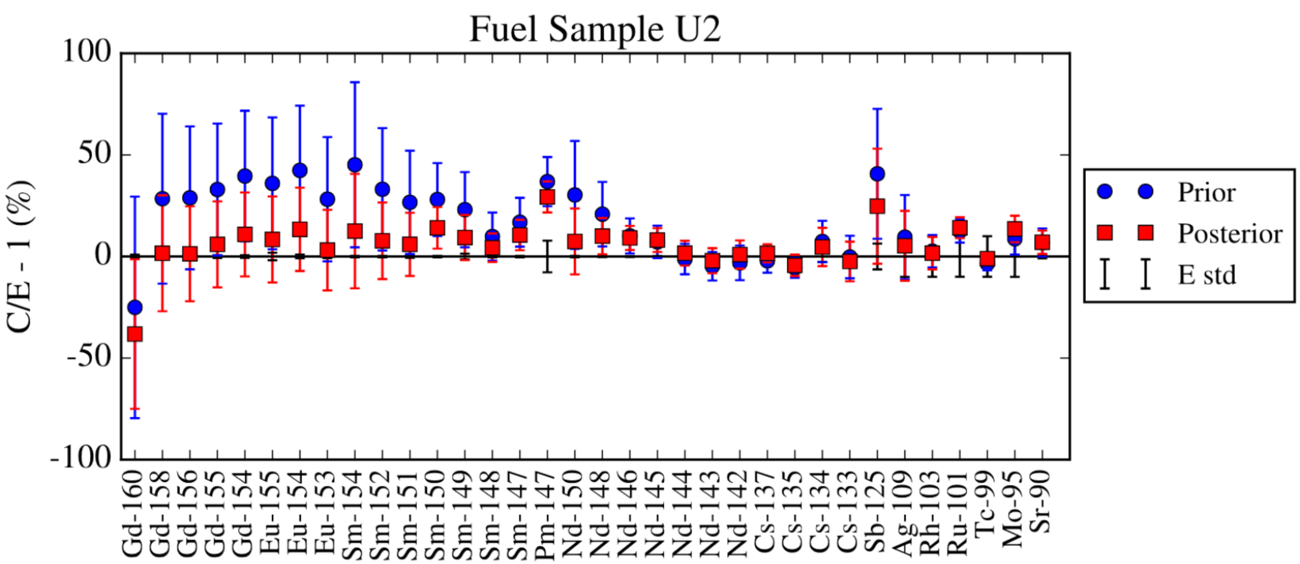
	Prior	Posterior
Average absolute bias	26%	15%
Average relative standard deviation	21%	9%



10

Unseen Fuel Sample

	Prior	Posterior
Average absolute bias	19%	9%
Average relative standard deviation	19%	14%



Ideal Integral Experiment to Test FYPs

- Current benchmarks unlikely to have characterization needed for high quality calibration
- Well characterized neutron source (fast burst critical assembly, research reactor irradiation well)
- Well characterized fissile target (foil, fission chamber)
- High precision fission product analysis (chemical dissolution and mass spectrometry)
- Detailed computational model with evaluated uncertainties that affect fission product production

References

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Model Parameter Adjustments

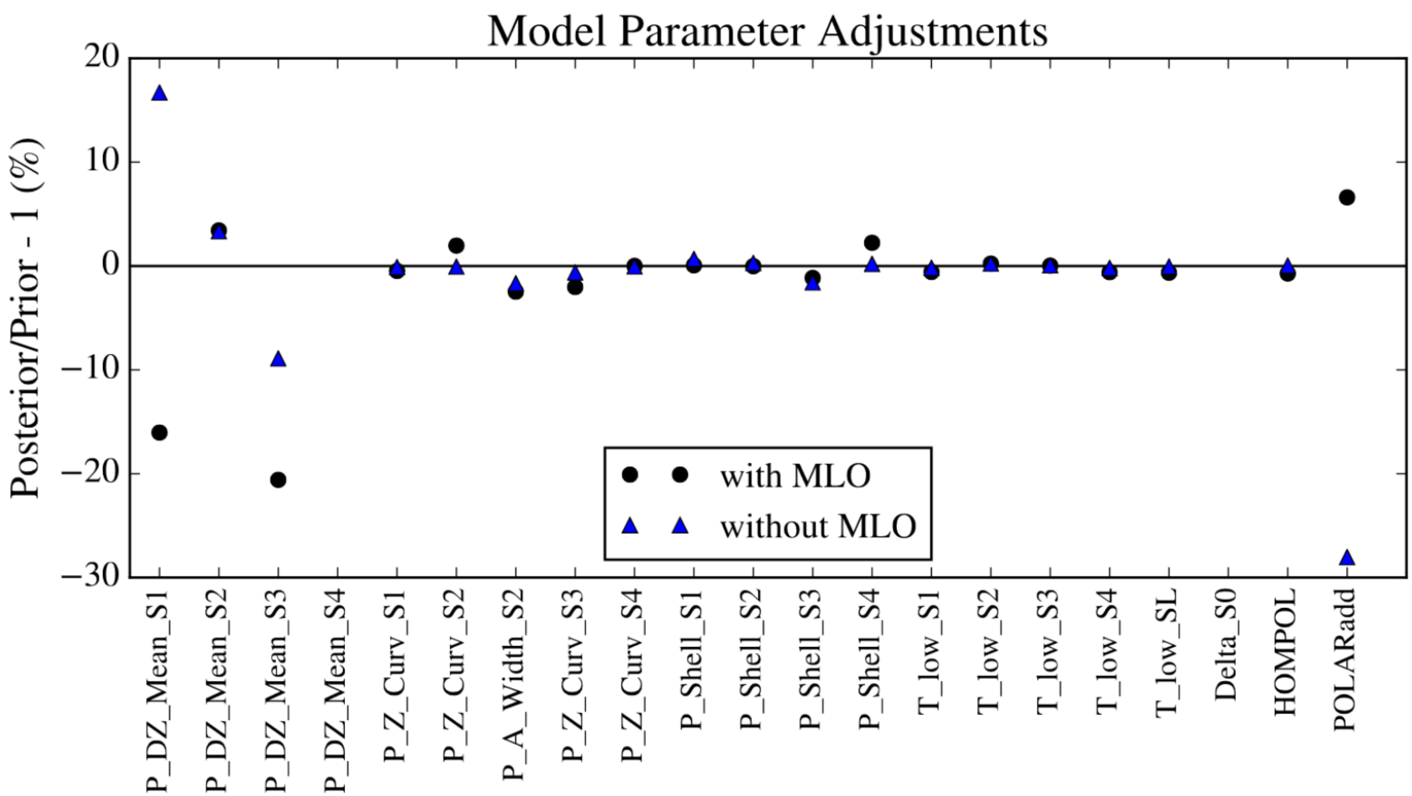

Figure: Adjustments to 21 model parameters, with and without MLO.

Non-Gaussian FPYs