

Covariances for the Fission Product Yield Re- evaluation

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Current status of fission product yield covariances

- Uncertainties but not correlations are currently included in ENDF! (For both independent and cumulative fission product yields.)
 - There is also no format for the FPY covariances.
- The NA-22 funded re-evaluation project of the FPYs will include generating covariances.
 - New modeling capabilities (e.g., the LANL-developed, deterministic, Hauser-Feshbach code BeoH) and experimental measurements make it a prime time to perform this re-evaluation.
 - Previous ENDF evaluations were based solely on experimental data and conservation/summation rules.

A.E. Lovell, T. Kawano, *et al.*, *PRC* **103**, 014615 (2021)

S. Okumura, T. Kawano, *et al.*, arXiv:2102.01015 [nucl-th] 1 Feb 2021, in press *JNST*, LA-UR-21-20820

Model calculations and optimizations are used to produce covariances between fission products

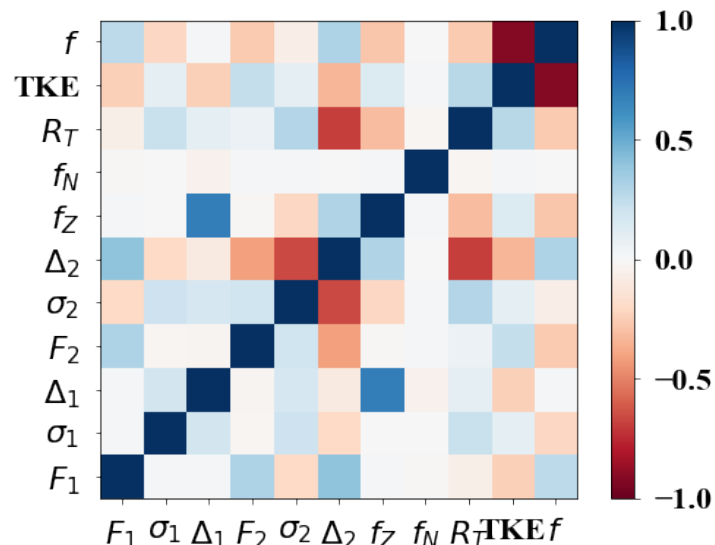
Parameter and observable covariances are straightforward to calculate using a Kalman filter optimization (input of model parameters and baseline calculations plus experimental values and covariances)

Updated parameter values

$$\mathbf{x}_1 = \mathbf{x}_0 + \mathbb{P}\mathbb{C}^T\mathbb{V}^{-1}(\phi - f(\mathbf{x}_0))$$

Updated parameter covariances

$$\mathbb{P} = (\mathbb{X}^{-1} + \mathbb{C}^T\mathbb{V}^{-1}\mathbb{C})^{-1}$$

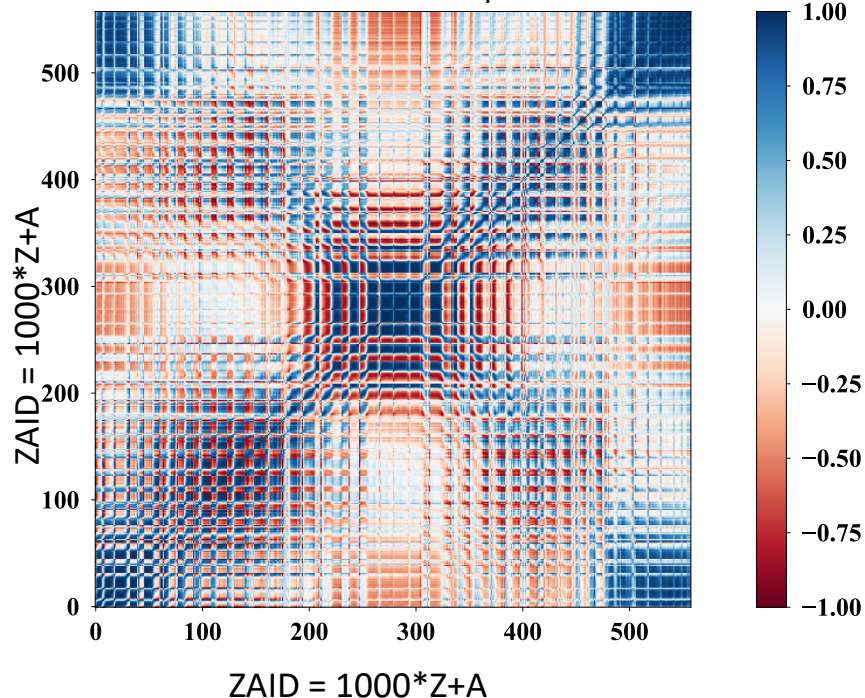


Observable covariances are calculated from parameter covariances and model sensitivities

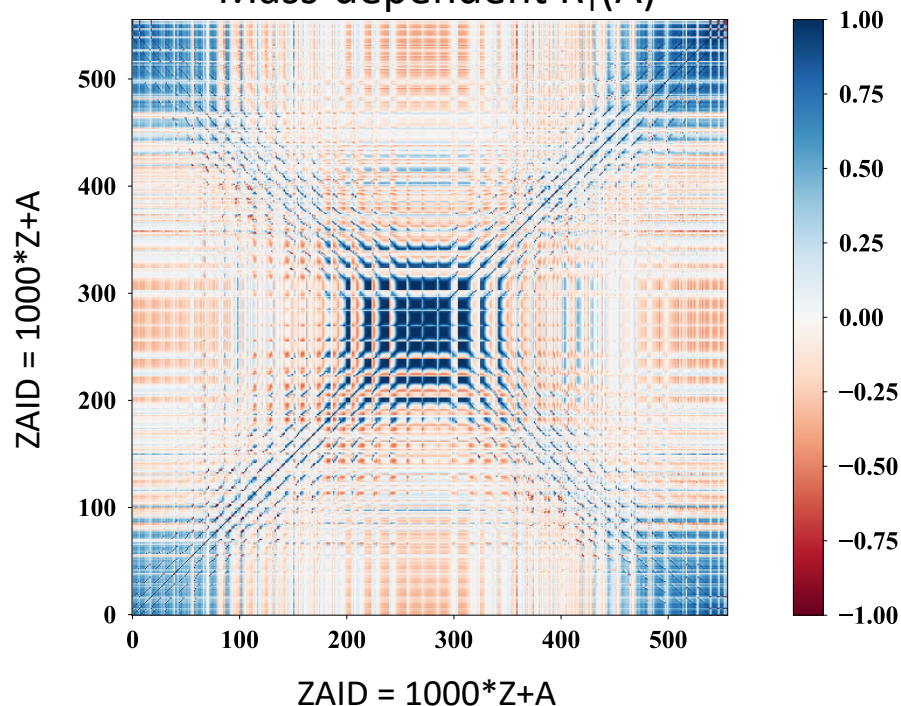
$$\mathbb{F} = \mathbb{C}\mathbb{P}\mathbb{C}^T$$

Covariances depend on the model parameters included in the optimization

Constant R_T

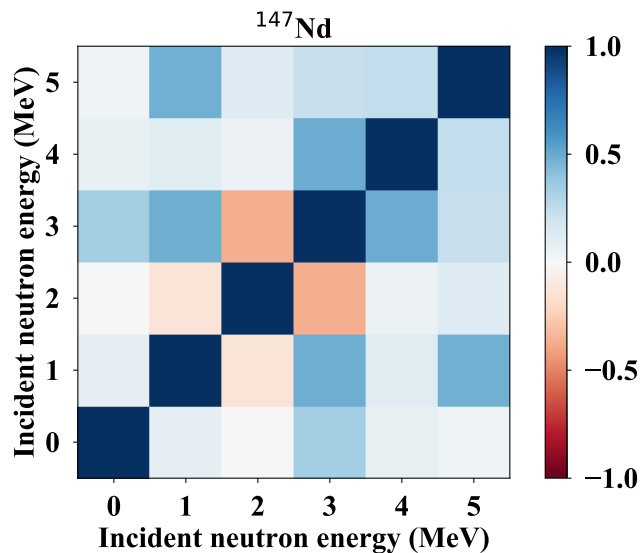


Mass-dependent $R_T(A)$

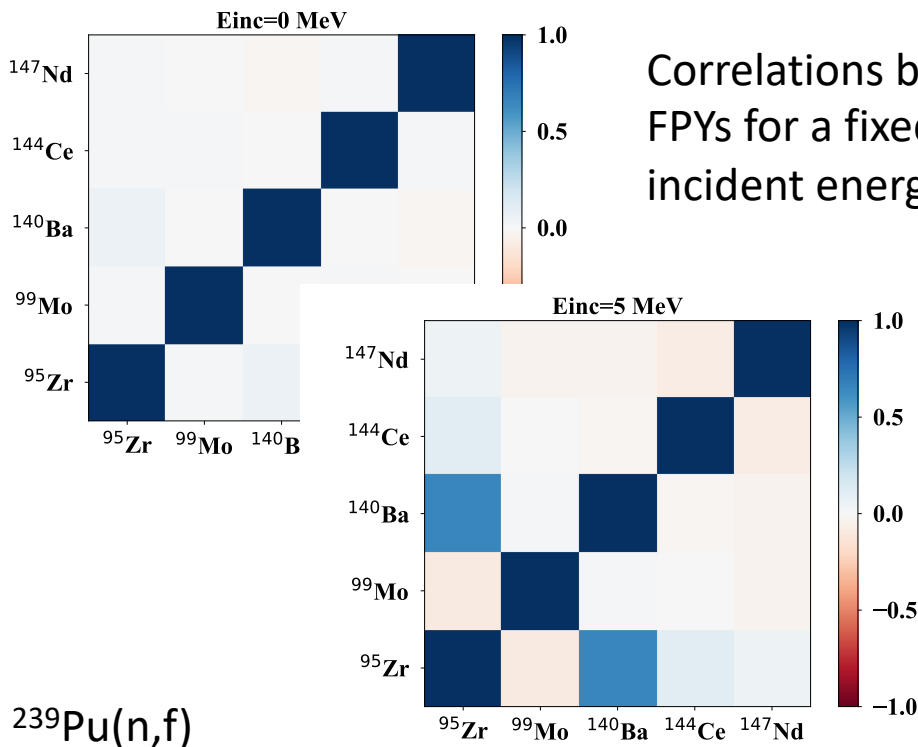


Covariances can be calculated between pairs of FPYs and incident energies

Cross-energy correlations for a single cumulative FPY

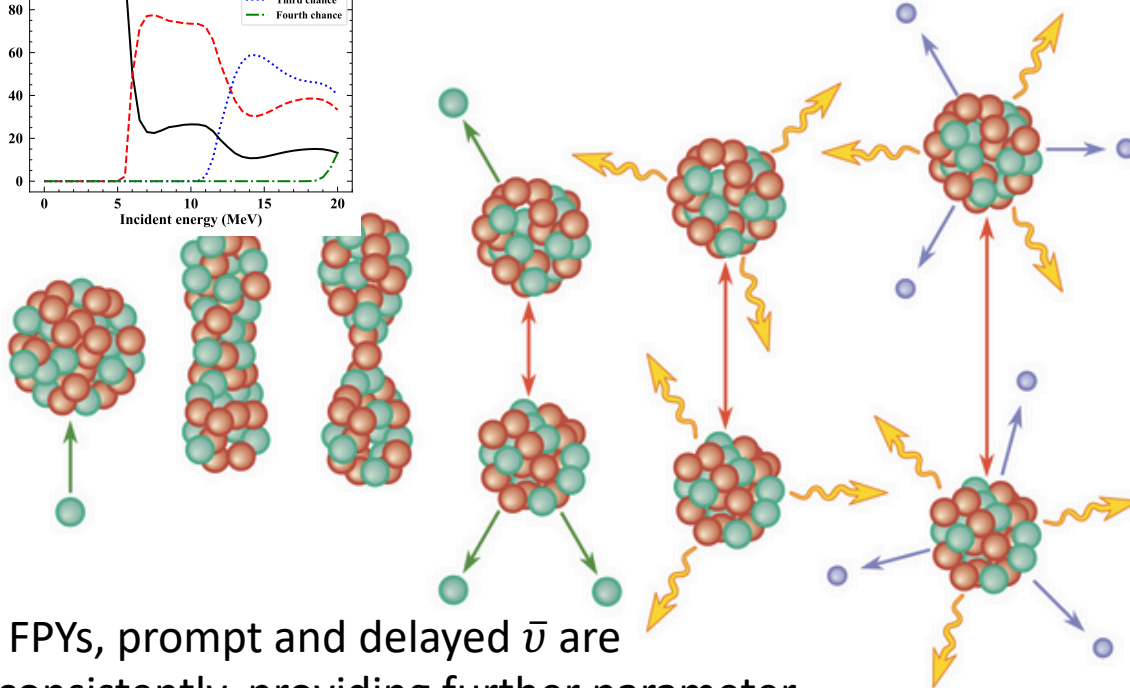
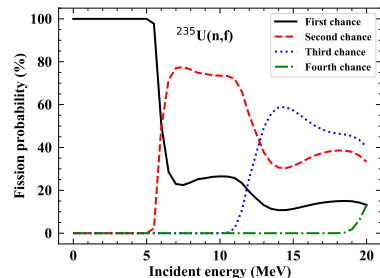


Correlations between FPYs for a fixed incident energy



Future work: cross-observable correlations are accessible, along with cross-target correlations

Multi-chance fission input correlates compound nuclei along an isotopic chain (e.g. fission barriers for ^{236}U , ^{235}U , ^{234}U , ^{233}U enter $^{235}\text{U}(n,f)$ calculations up to 20 MeV)



Along with FPYs, prompt and delayed $\bar{\nu}$ are calculated consistently, providing further parameter constraints

Summary and comments

- Covariances between fission product yields will be available in ENDF as a part of the FPY re-evaluation, based on model calculations (provides a connection to decay data as well as all conservation rules included explicitly).
- The format of these covariances is not determined, and there is probably room for a compact format due to the lack of correlations between many FPYs.
- Are energy-dependent correlations important/useful?
- How can we validate these new covariances?