Los Alamos NATIONAL LABORATORY

LANL FPY Evaluation Report

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CSEWG, November 16, 2023

LA-UR-23-32862

Funding provided by NA-22 and supported by NCSP.
Thanks also to M. Chadwick, S. Okumura, I. Stetcu, M. Herman, and M. Mumpower, W. Haeck, N. Gibson, A. Mattera, and A. Sonzogni.

Evaluation methodology for fission product yields

- Combination of experimental data and model calculations through a Kalman filter optimization
  - Includes new experimental data, including recent effort to measure short-lived FPY and energy-dependent values
  - BeoH – LANL-developed, Hauser-Feshbach fission fragment decay code (*PRC* **103**, 014615 (2021) and references therein)
  - Updated experimental FPY data with most recent structure information and updated decay data (consistency between independent and cumulative FPY with decay data)
- Covariances are calculated consistently from the Kalman filter
- R-values are not currently included in the fitting procedure but are instead being used for validation

Optimization details

- Prompt and delayed average neutron multiplicity included in the optimization
  - Further constrains input parameters that are not well-constrained by the cumulative fission product yields
- Currently, data from EXFOR is being used, which has been nominally curated to remove some discrepant data
  - Templates of experimental uncertainties should be used
  - BNL is sending revised FPY values based on current structure data and data that is not included in EXFOR (A. Mattera), ^{238}U(n,f), ^{239}Pu(n,f) received already
  - BNL has shared updated decay data (A. Sonzogni), which has been tested in ^{239}Pu
  - Comparison against data used in previous LANL/England and Rider evaluation has to be done
- We perform a consistent optimization across all incident energies (updated from our previous piece-wise fitting)
- Currently investigating isomeric states and ratios in more detail

Fission product yield evaluations under development

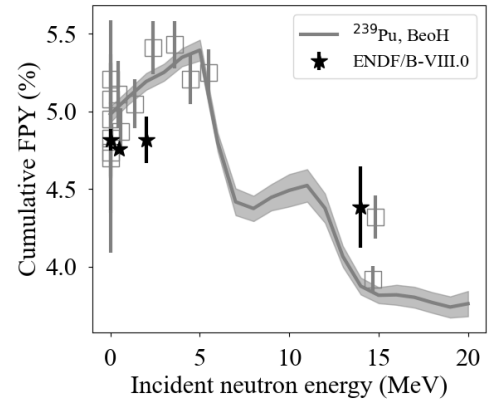
- ^{252}Cf spontaneous fission
  - Fitting has been performed
  - Covariances are calculated
- ^{235}U neutron induced fission - thermal to 20 MeV
  - Fitting has been performed up to 20 MeV
  - Covariances calculated up to 20 MeV
- ^{238}U neutron induced fission – thermal to 20 MeV
  - Fitting has been performed up to 20 MeV
  - Covariances calculated up to 20 MeV
- ^{239}Pu neutron induced fission – thermal to 20 MeV
  - Fitting has been performed up to 20 MeV
  - Covariances calculated up to 20 MeV

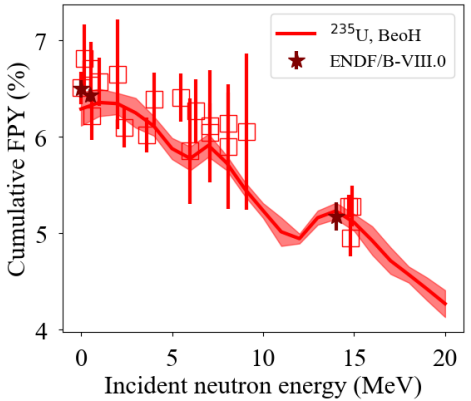
Tweaks are still being performed, especially as isomeric ratios are being studied

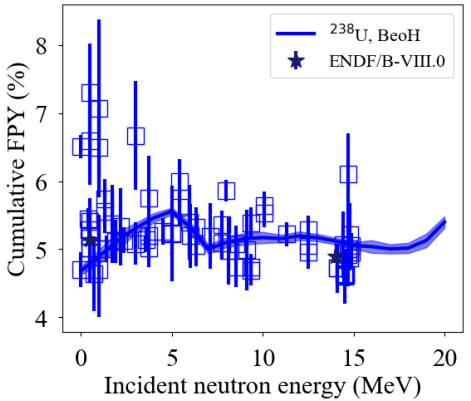
ENDF files have been created with uncertainties; new covariance format is being pushed off until after 8.1 is released

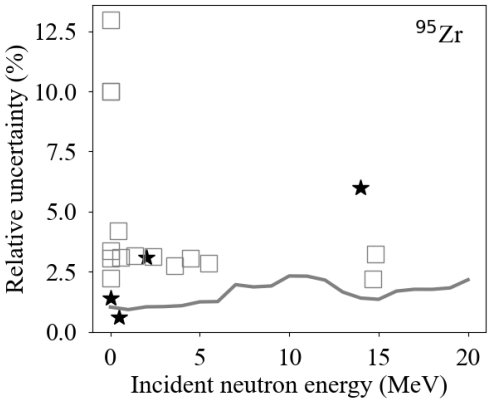
Uncertainties shown here are still preliminary

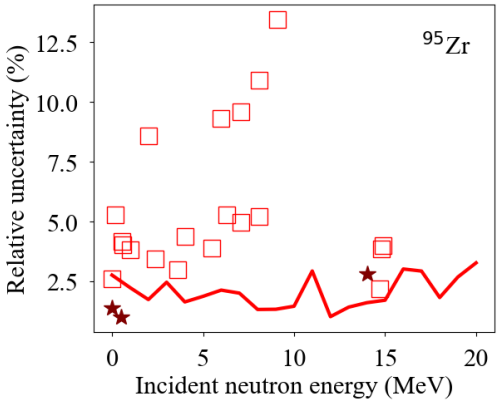
Cumulative FPYs for ^{95}Zr from the major actinides

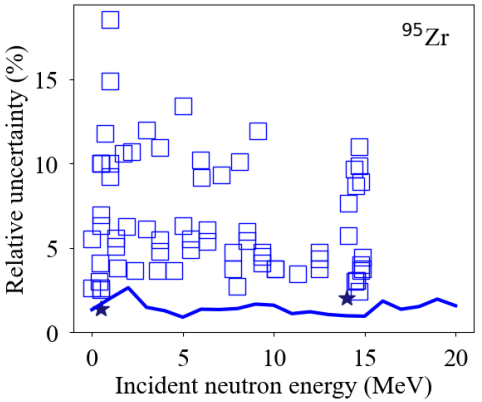




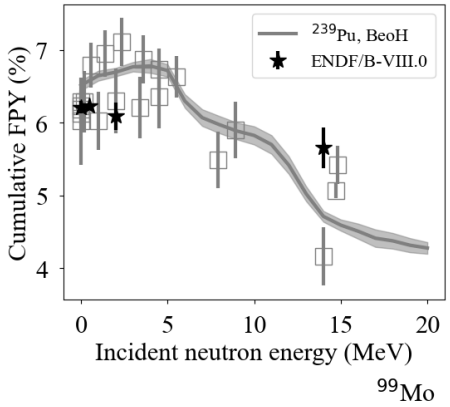


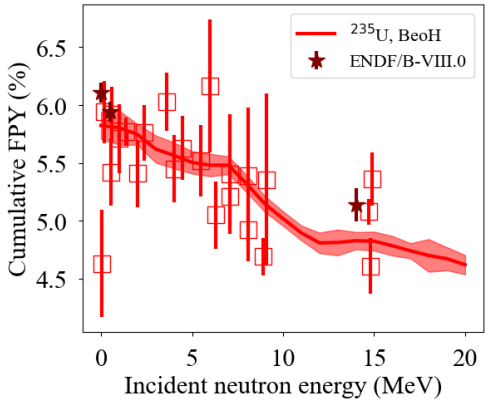


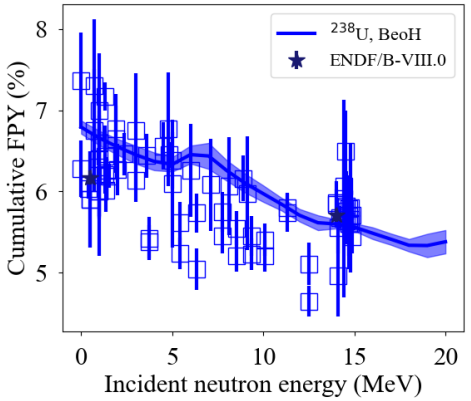


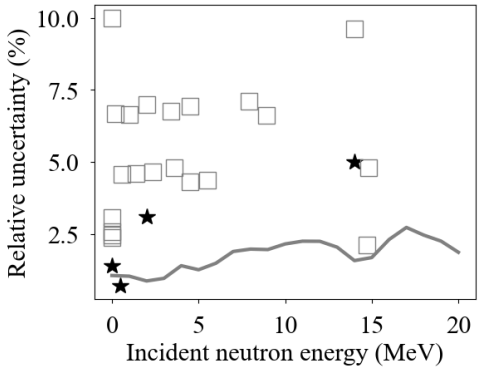


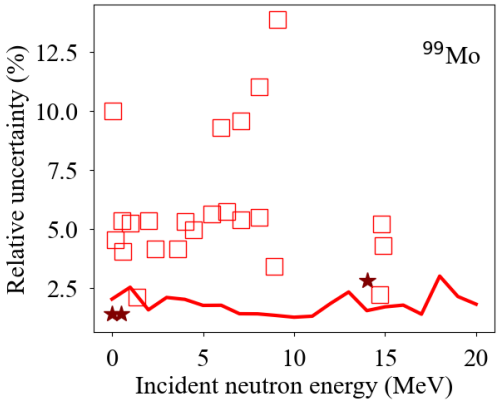
Cumulative FPYs for ^{99}Mo from the major actinides

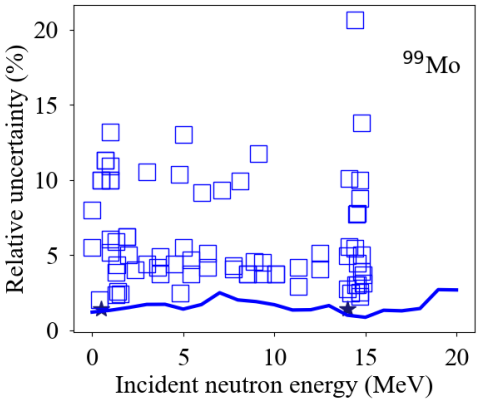




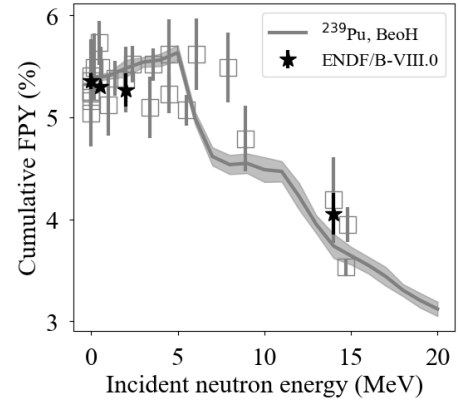


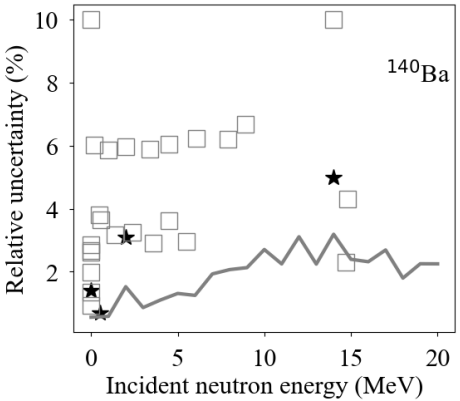


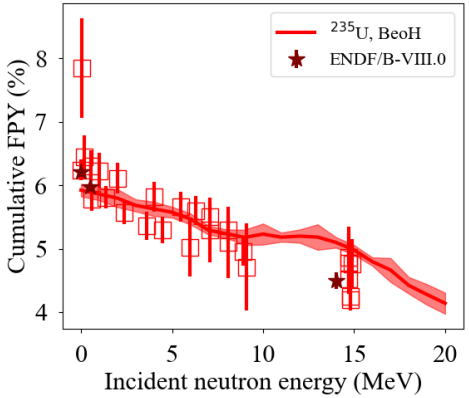


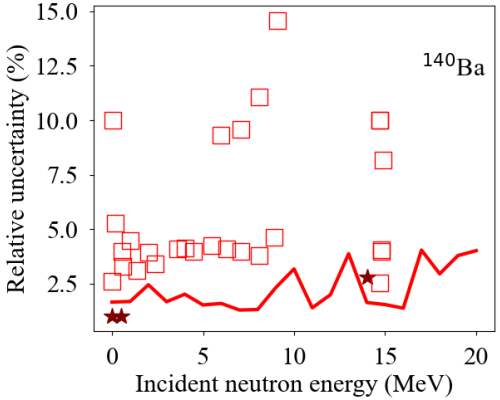


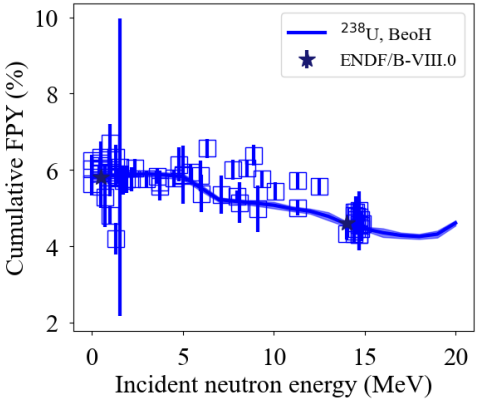
Cumulative FPYs for ^{140}Ba from the major actinides

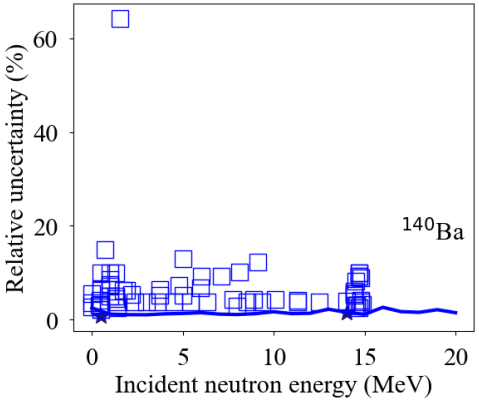




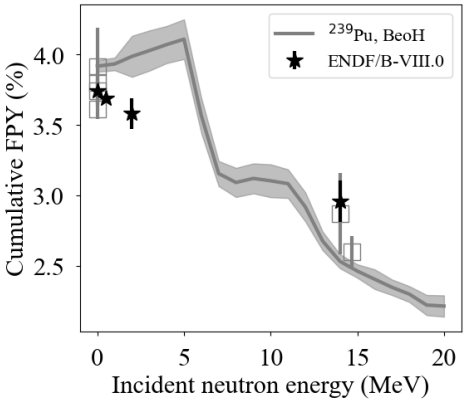


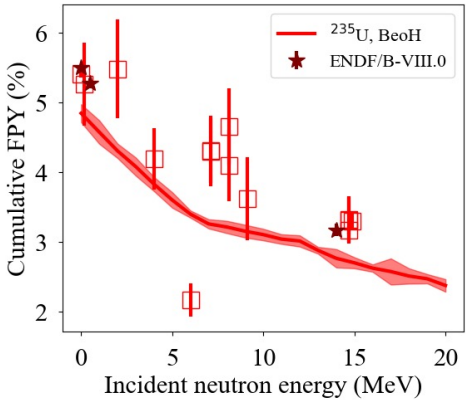


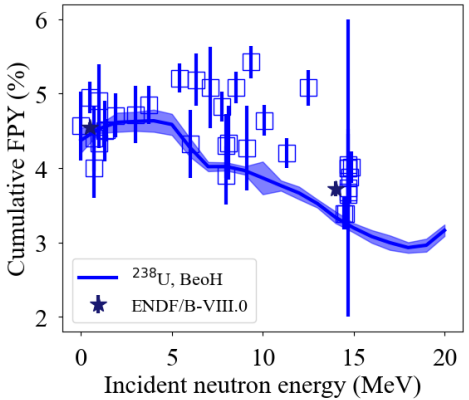


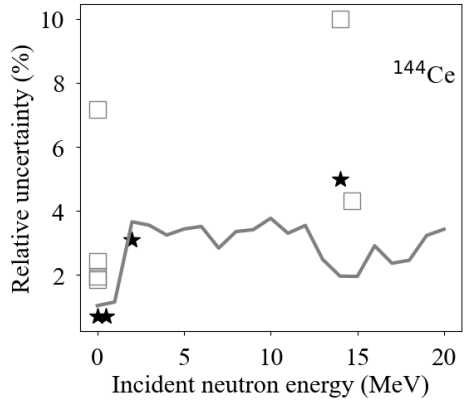


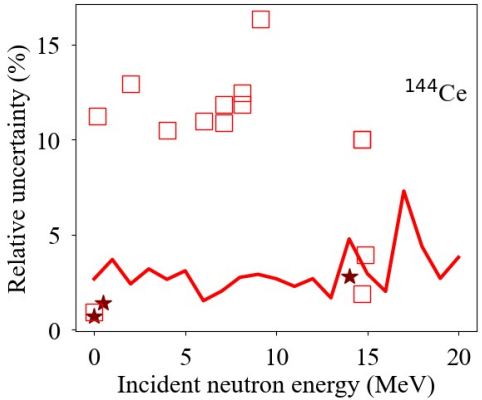
Cumulative FPYs for ^{144}Ce from the major actinides

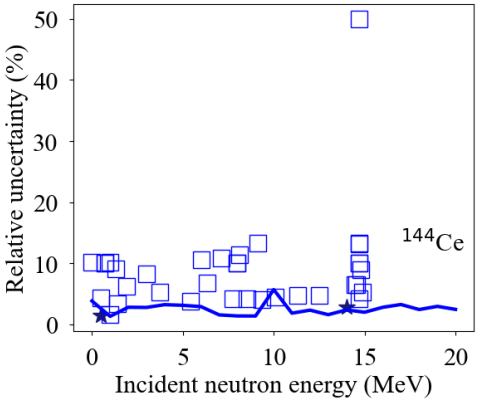




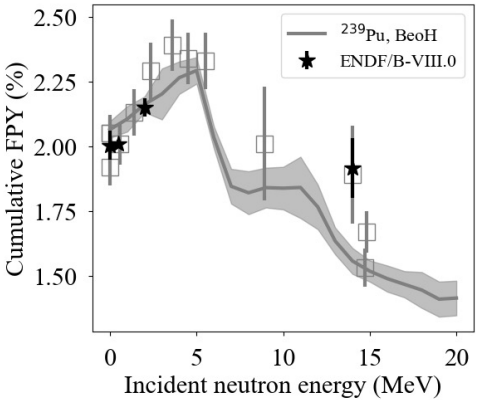


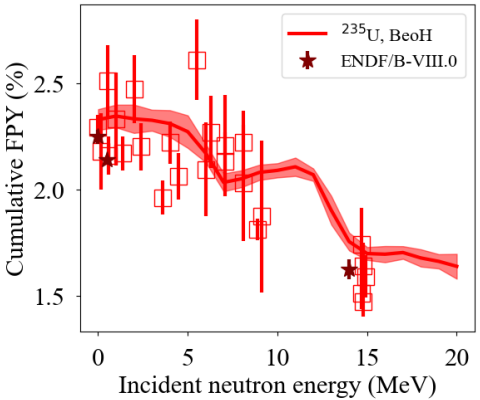


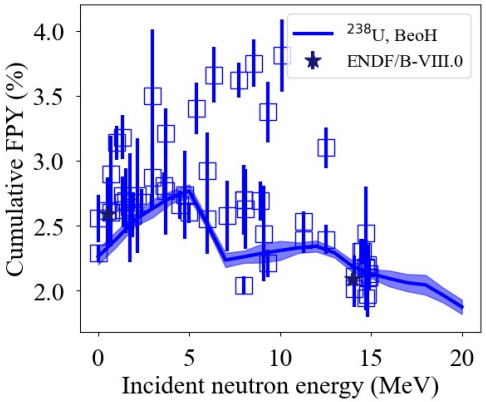


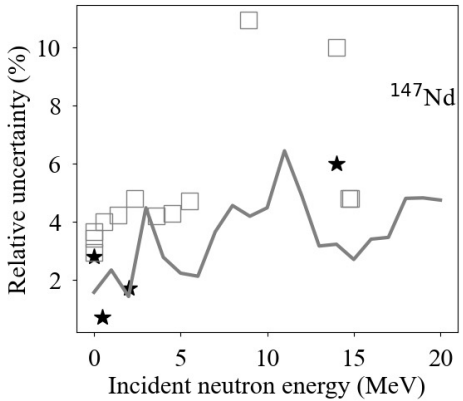


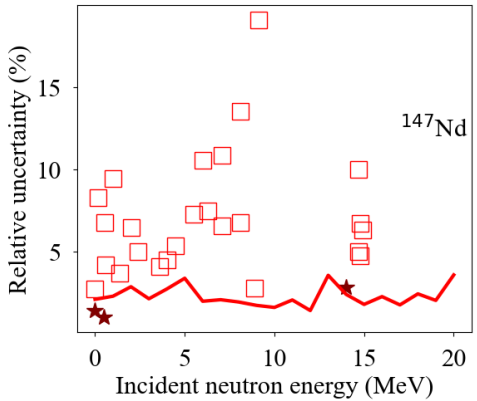
Cumulative FPYs for ^{147}Nd from the major actinides

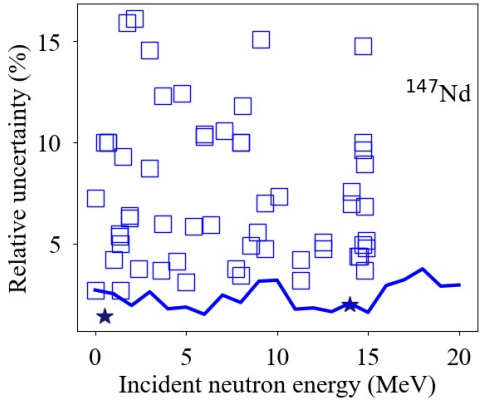






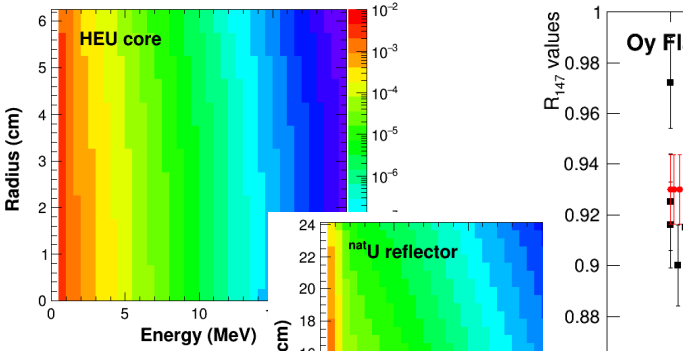


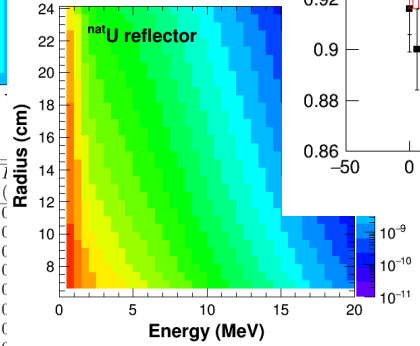




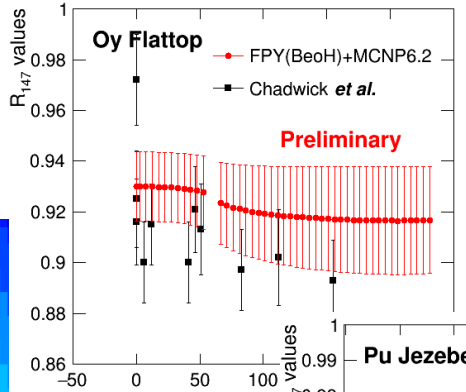
A process has been set up to validate select cumulative FPYs with critical assemblies

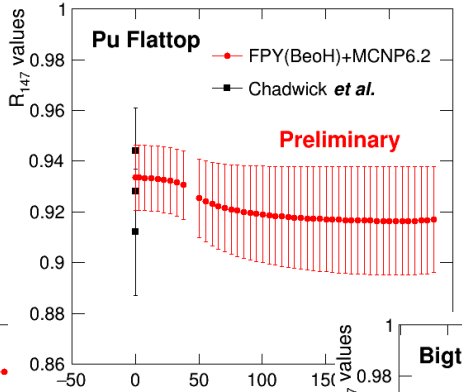
Correlations are not yet included in the uncertainty calculations

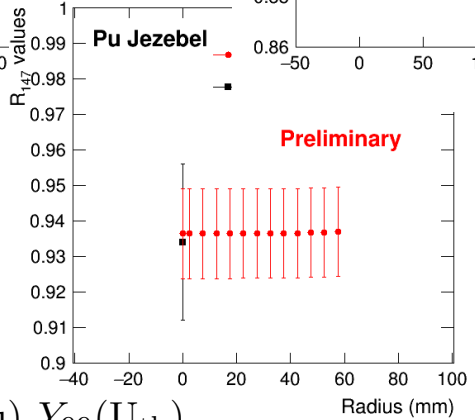


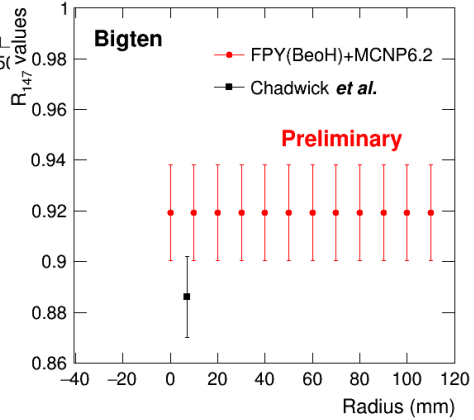


Critical Assembly	$\langle E \rangle$ (MeV)		
Oy Flattop, 155mm	0.45		
Oy Flattop, 112mm	0.58		
Bigten, 7mm	0.62		
Oy Flattop, 83mm	0.77		
Oy Flattop, 51mm	1.28		
Oy Flattop, 46mm	1.33		
Oy Flattop, 41mm	1.36		
Oy Flattop, 12mm	1.44		
Oy Flattop, 6mm	1.44	0.896 ± 3.3%	0.900 ± 1.78%
Oy Flattop, center	1.44	0.968 ± 3.3%	0.972 ± 1.89%
Oy Flattop, center	1.44	0.929 ± 2.7%	0.925 ± 2.04%
Oy Flattop, center	1.44	0.899 ± 2.7%	0.916 ± 1.88%
Pu Flattop, center	1.68	0.895 ± 2.7%	0.912 ± 2.70%
Pu Flattop, center	1.68	0.927 ± 2.7%	0.944 ± 1.78%
Pu Flattop, center	1.68	--	0.928 ± 1.77%
Pu Jezebel, center	1.88	0.927 ± 3.3%	0.934 ± 2.32%
Average R-value			0.916 ± 0.8%







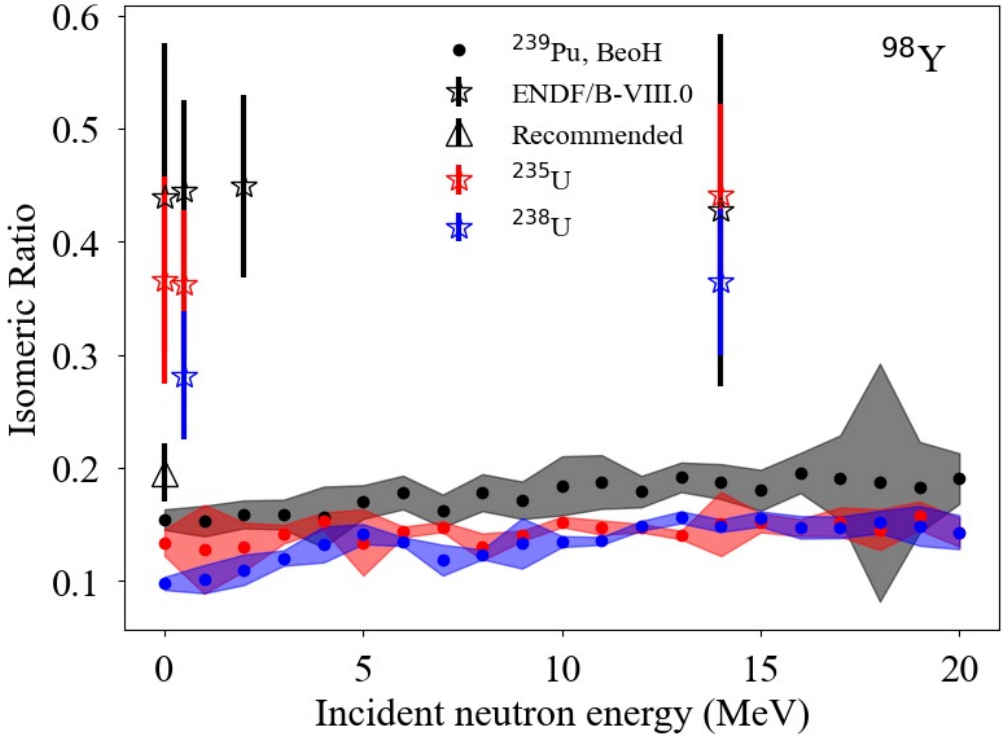


$$R_{147} = \frac{Y_{147}(\mathrm{Pu})}{Y_{147}(\mathrm{U_{th}})} \frac{Y_{99}(\mathrm{U_{th}})}{Y_{99}(\mathrm{Pu})}$$

Calculations and figures by G. Rusev (LANL)

M.B. Chadwick, et al., NDS 111, 2923 (2010)

Investigation of isomeric ratios is underway



Our calculated isomeric ratios are often lower than evaluations/data; however, there are indications that the Madland-England treatment is over-simplified. Differences between theory and data can point to needed nuclear structure information.

"Recommended": C.J. Sears, *et al., NDS* **173**, 118 (2021)

Conclusions and path forward

- Independent and cumulative FPYs are being re-evaluated, with covariances, for ^{252}Cf(sf), ^{235,238}U(n,f), and ^{239}Pu(n,f)
- Adjusting of BeoH pre-neutron emission mass distributions (input parametrization) underway to account for stiffness in the model that currently doesn't consistently calculate important FPYs
- Parameter and nuclear structure investigations in progress to better compare to isomeric ratios (discussions ongoing with LLNL, A. Tonchev and collaborators)
- Continuing work on calculating R values from critical assemblies beyond R_{147}
- Preliminary calculations for ^{233,234,236}U have been performed