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Evaluations of ^{238}U PFNS and minor U/ Pu isotopes

D. Neudecker, M. Devlin, F. Diaby,
W. (Cole) Fritsch, W. Haeck,
N. Gibson, T. Kawano, K.J. Kelly,
R.C. Little, A.E. Lovell, I. Stetcu,
P. Talou

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This work shows progress towards fulfilling an NCSP milestone of LANL ND1 (Nuclear Data Evaluation and Testing).

This year, we successfully completed milestones of FY24 and made progress on FY25 milestones.

Successfully completed FY24 milestones:

- ^{238}U: “Finalize prompt fission neutron spectra based on LANSCE Chi-Nu Data”.
- Minor Pu Isotopes: “Format and V&V nu-bar means and covariances”.

Made progress on FY25 milestones:

- ^{233,234,236}U: “Attempt a consistent nu-bar evaluation supported by a model code to provide better nu-bar data for minor U-isotopes”
- ^{240}Pu: “Update evaluation to include new LANSCE / Chi-Nu prompt fission neutron spectra.”

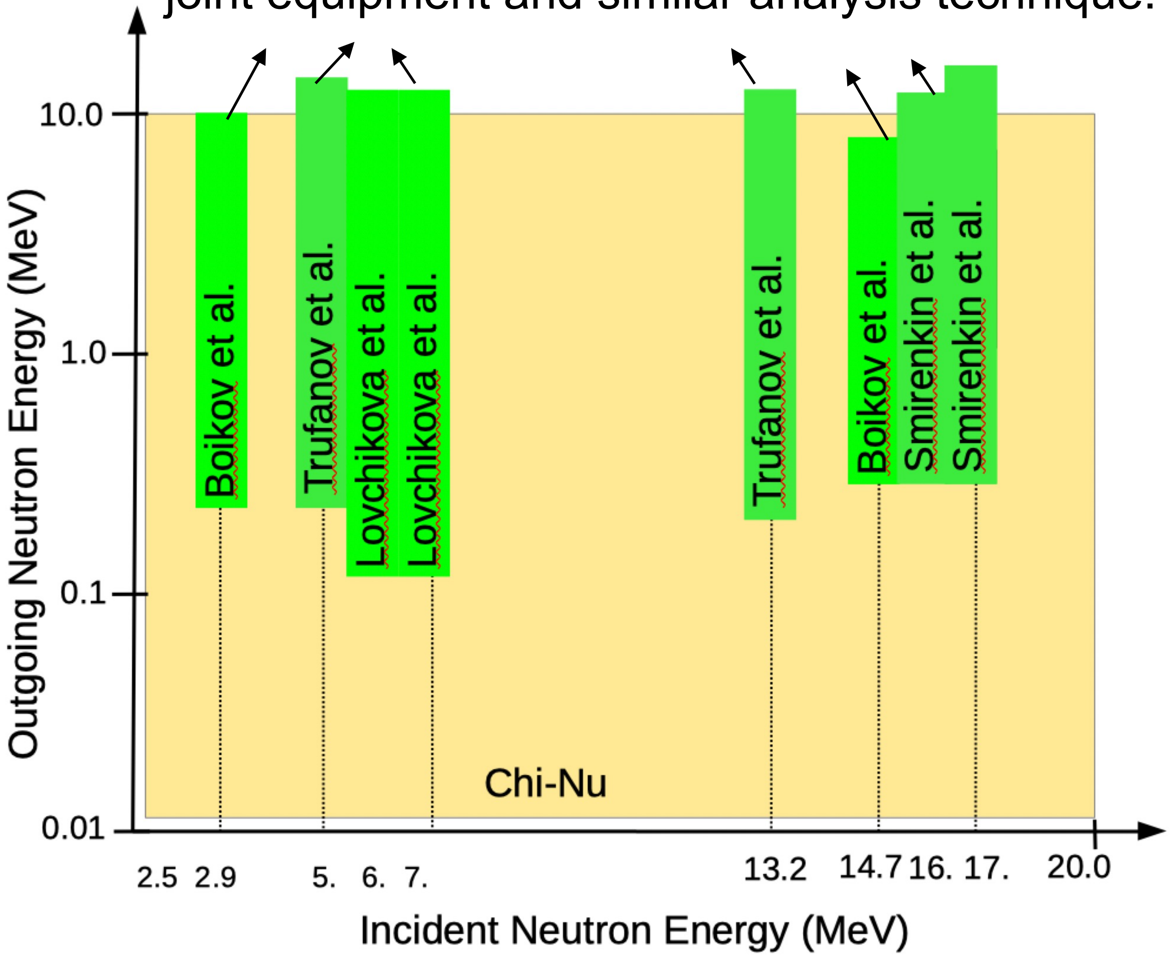
FY24 milestone: ^{238}U: "Finalize prompt fission neutron spectra based on LANSCE Chi-Nu Data".

Eval., val. & unc. documented in: Neudecker et al., LA-UR-24-25503 (2024).

New ^{238}U PFNS evaluation includes LANL/ LLNL high-precision Chi-Nu data with broad E_{inc} & E_{out} range.

Experimental input

By the same group and correlated through joint equipment and similar analysis technique.

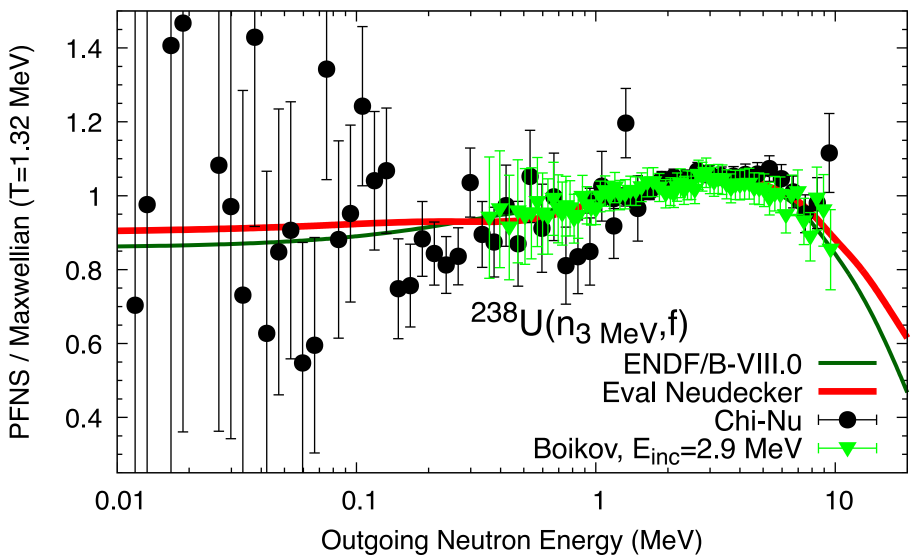


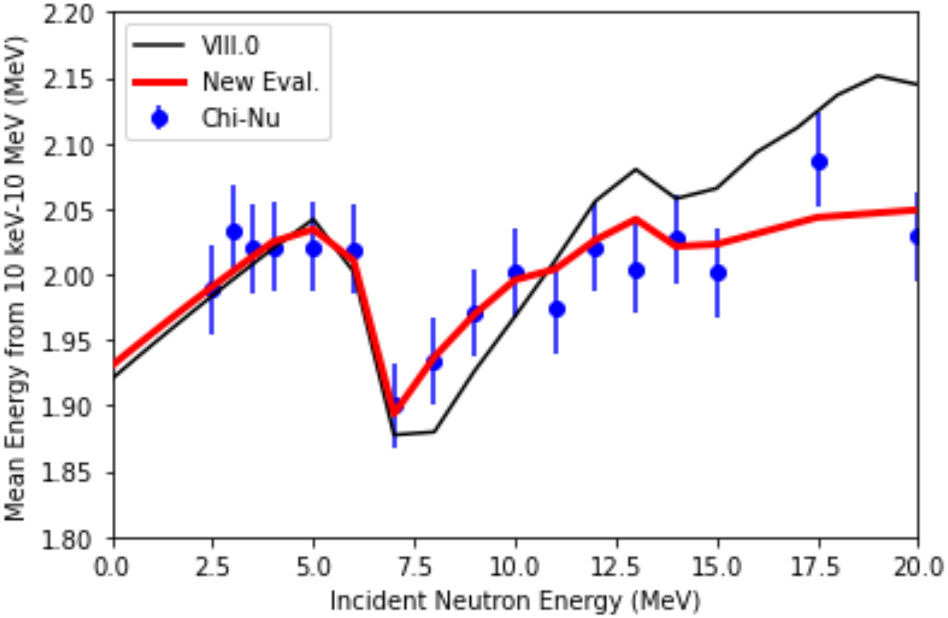
Evaluation technique: GLS in PFNS space.

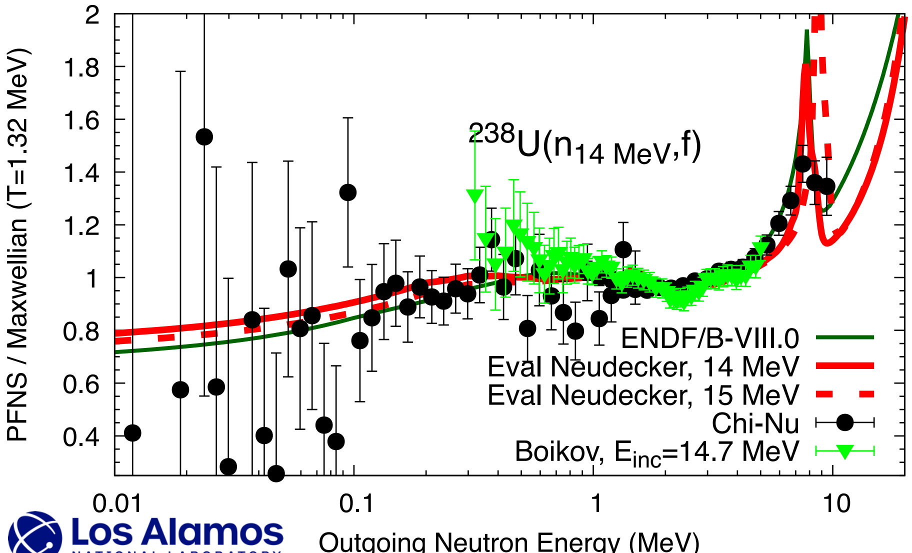
Prior: uses CoH by Toshihiko Kawano.

- Extended Los Alamos model as described in DN., NDS 148, 293 (2018); DN, NIMA 791, 80 (2015).
- Parametrized TKE, energy release, etc., with E_{inc}.
- Exciton model used to describe pre-equilibrium component.

New eval. PFNS gets reasonably close to Chi-Nu & other exp. PFNS. Also, close to ENDF/B-VIII.0 for E_{inc} < 6 MeV.



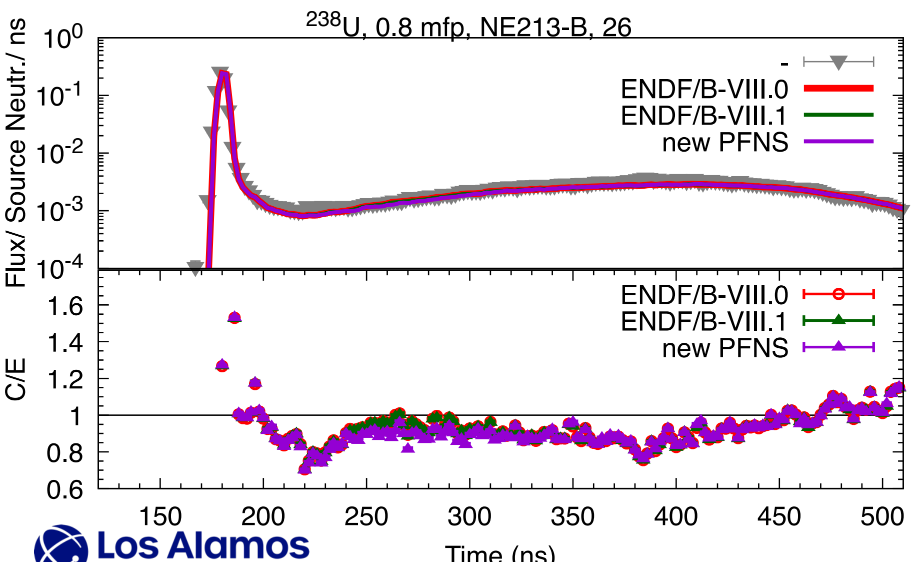


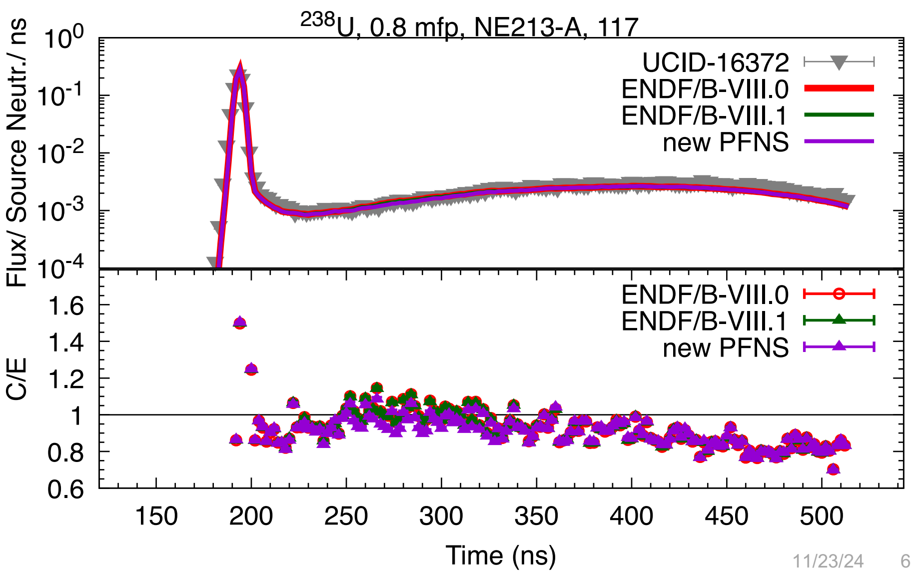


Given how close the new eval. is to VIII.0 for E_{inc} < 6 MeV, little impact on k_{eff} of ICSBEP benchmarks expected. Larger change for E_{inc} ~14 MeV could impact LLNL pulsed spheres simulations.

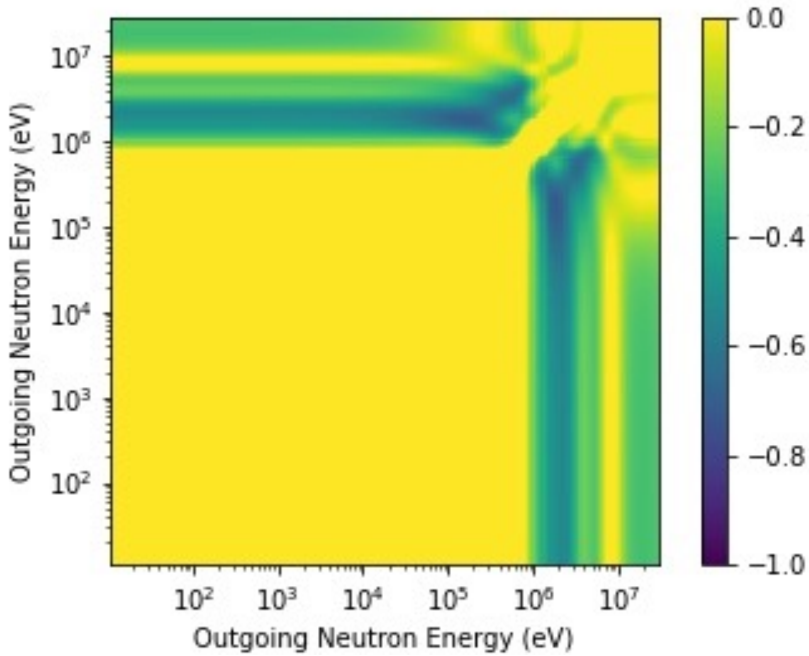
Crit changes (reflector with high ^{238}U %) are within 1-2 sigma of MC statistics. LPS improved after valley within exp. unc.

Assembly	C/E VIII.0	C/E VIII.1beta3	C/E VIII.1beta3+PFNS
Flattop-Pu (PMF006)	0.99970	0.99989	1.00009 Within 2s unc.
Flattop-U (HMF028)	1.00093	1.00065	1.00073 Within 1s unc.
BigTen (IMF007d)	0.99954	1.00011	1.00034 Within 2s unc.





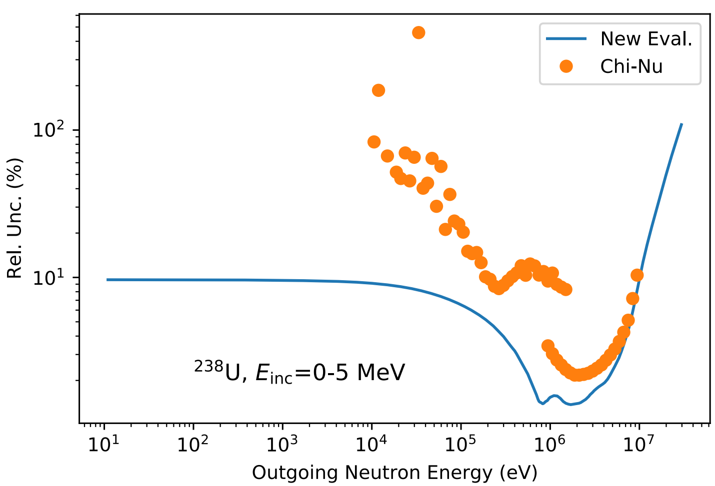
Covariances were provided in 4 E_{inc} bins.
Evaluated data were submitted to IX.0/VIII.2β0 for testing.



Mean energy uncertainties derived from the evaluated covariances.

E_{inc}-group	Mean Energy Uncertainty (keV)
0–5	19.3
5–9	23.5
9–12	20
12–20	21.5

PFNS mean energy uncertainties for ^{238}U are now comparable to ^{235}U and ^{239}Pu PFNS mean energy uncertainties due to Chi-Nu high-precision data.



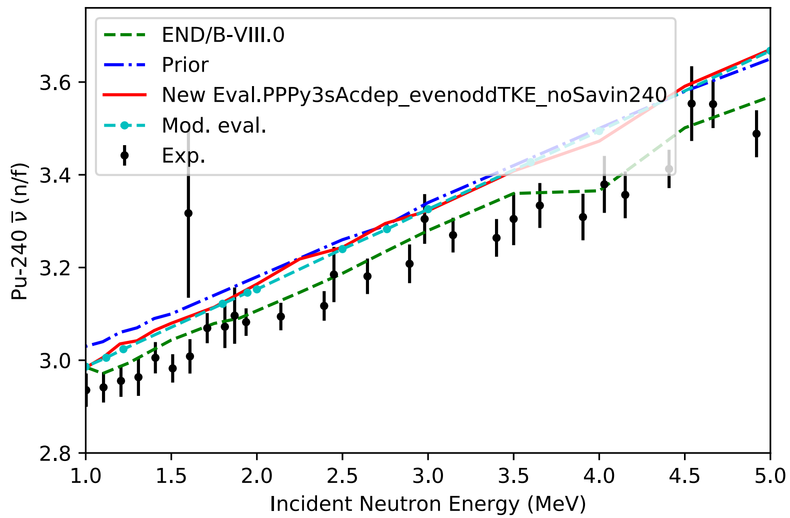
New experiments from the CEA/ NNSA collaboration might further decrease evaluated uncertainties.

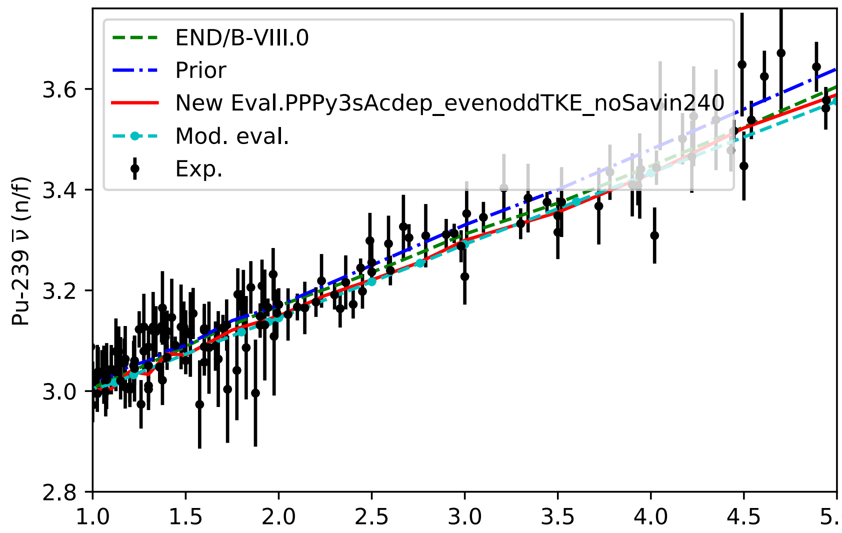
Eval., val. & unc. documented in: DN et al., LA-UR-24-25503 (2024).

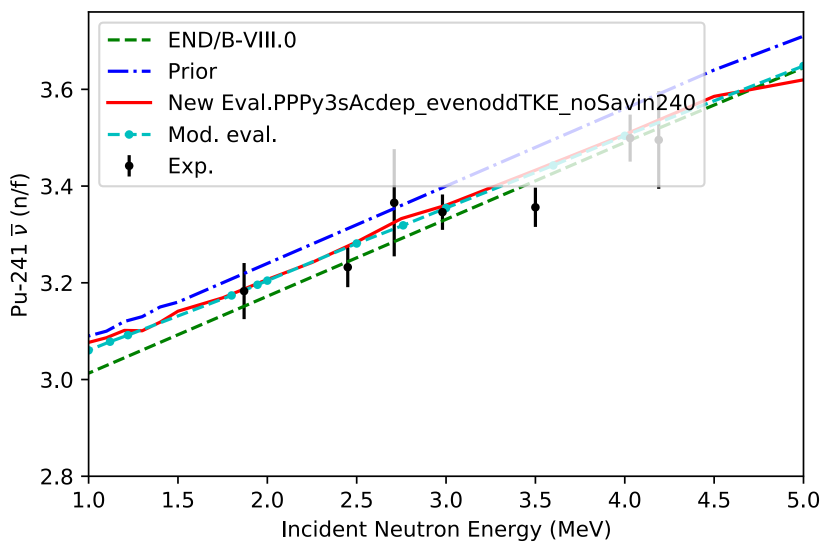
FY24 milestone: Minor Pu Isotopes: “Format and V&V nu-bar means and covariances”.

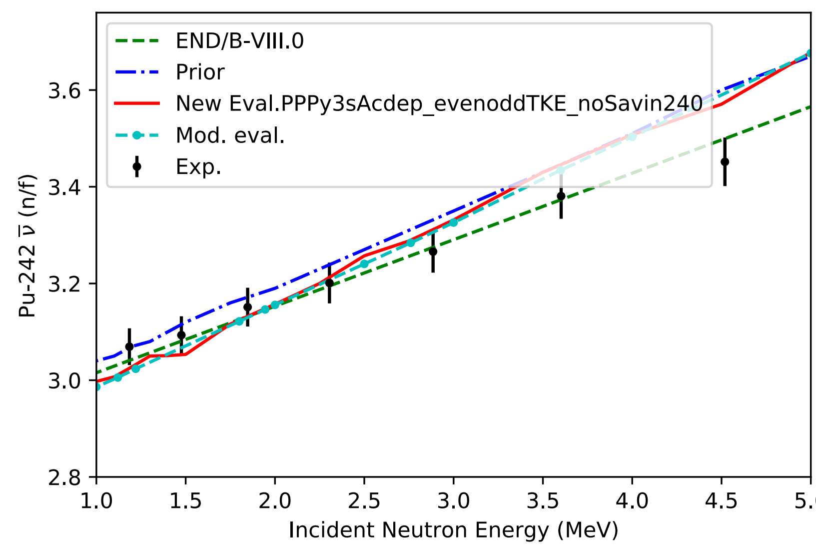
Modeling progress & impact on evaluation documented by A. Lovell et al., LA-UR-24-29825 (2024).
Validation, uncertainty quantification & formatting documented by D. Neudecker et al., LA-UR-24-29634 (2024).

We evaluated consistent $^{238\text{-}242}$Pu prompt fission neutron multiplicities using model correlations introduced by CGMF.







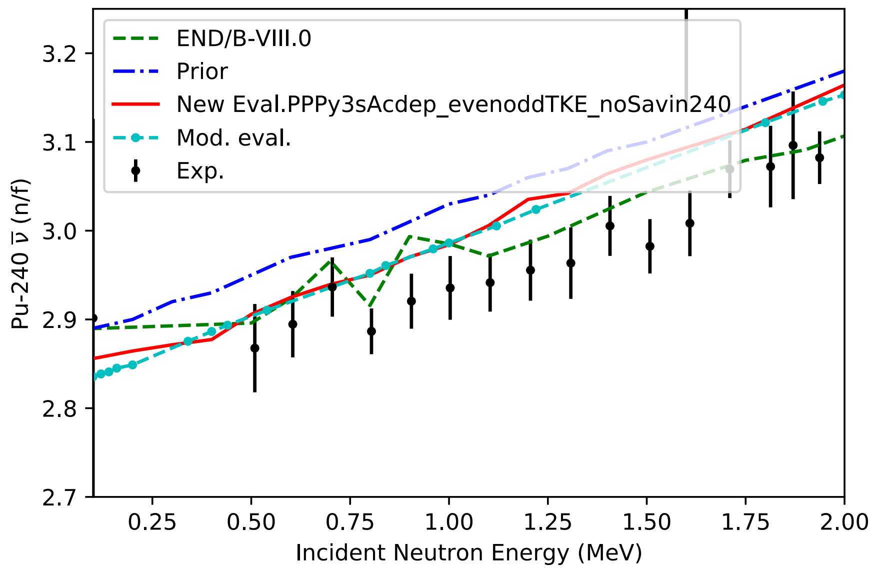


Modeling & eval. documented in AL, LA-UR-24-29825 (2024).

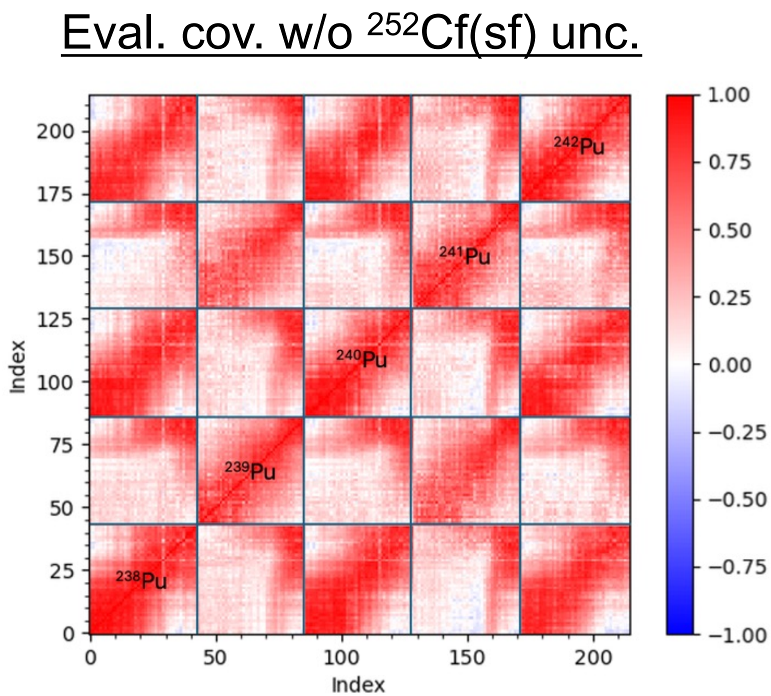
Validation with new evaluated $^{238,240\text{-}242}$Pu ν_p led to only modest changes in k_{eff}.

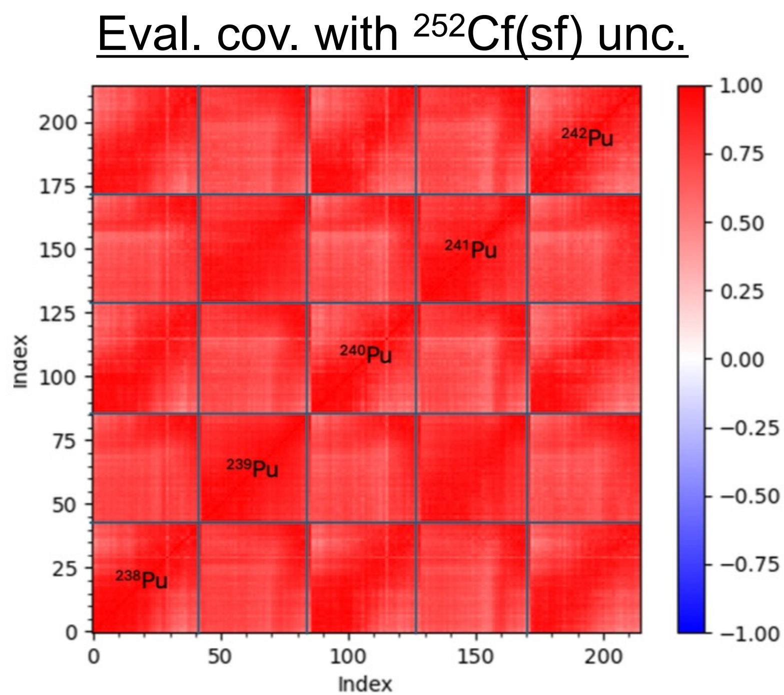
Crit Name	Exp.	VIII.1β_4	^{238}Pu	^{240}Pu	^{241}Pu	^{242}Pu	$^{238,240-242}$Pu
Jezebel	1.0	0.99934(8)	-	0.99948(8)	0.99937(8)	-	0.99941(8)
Dirty Jezebel	1.0	1.00075(8)	-	1.00087(8)	1.00100(8)	1.00089(9)	1.00076(8)
Jupiter-001	1.0	1.00368(4)	1.00371(3)	1.00371(4)	1.00371(2)	1.00371(2)	1.00372(2)
Jupiter-002	1.0	1.00346(4)	1.00349(2)	1.00346(5)	1.00344(2)	1.00345(2)	1.00345(3)
EUCLID 3x2	1.0	0.99997(6)	0.99990(6)	0.99982(6)	0.99988(6)	0.99987(6)	0.99994(6)
EUCLID 8x1	1.0	0.99814(7)	0.99819(7)	0.99817(7)	0.99815(7)	0.99814(7)	0.99815(7)

- $^{238,240\text{-}242}$Pu nu adopted > 0.1 MeV.
- ^{240}Pu nu change has less impact on dirty Jezebel than large ^{241,242}Pu nu changes because of structures in ^{240}Pu below 1 MeV that we average through.
- Change in k_{eff} using consistent $^{238,240\text{-}242}$Pu nu small.
- Validation documented in DN, LA-UR-24-29634 (2024).



Strongly correlated cov. driven by high standard ^{252}Cf(sf) nu-bar unc. Cross-isotope cor. important if >20% minor isotopes.





- Considering cross-isotope covariances versus neglecting them has little impact for most k_{eff} unc. estimates because mostly ^{239}Pu in Pu fuels.
- Dirty Jezebel (20% ^{240}Pu, 3% ^{241}Pu) k_{eff} unc. with cross-correlation is 443 pcm unc. versus 374 pcm without.
- We should consider cross-isotope cov. for ^{233,235,238}U nu-bar!!
- UQ & formatting documented in DN, LA-UR-24-29634 (2024).

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FY25 milestone: ^{233,234,236}U: "Attempt a consistent nu-bar evaluation supported by a model code to provide better nu-bar data for minor U-isotopes"

Work documented in W. Fritsch, LA-UR-24-29315 (2024).

Summer student W. (Cole) Fritsch (UTK) helped us make significant progress on ^{232,234,236}U exp. UQ and modeling.

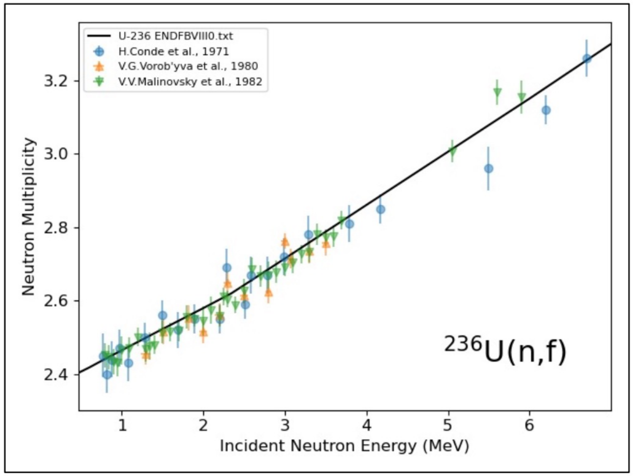
- Cole did detailed uncertainty estimate for all accepted ^{232,234,236}U nu-bar data using ARIADNE code and templates of expected measurement uncertainties (DN, EPJ N 9, 30 (2023) , https://doi.org/10.1051/epjn/2023016)

Table 4: Experimental $\overline{\nu}$ measurements adopted for the minor uranium isotopes evaluation.

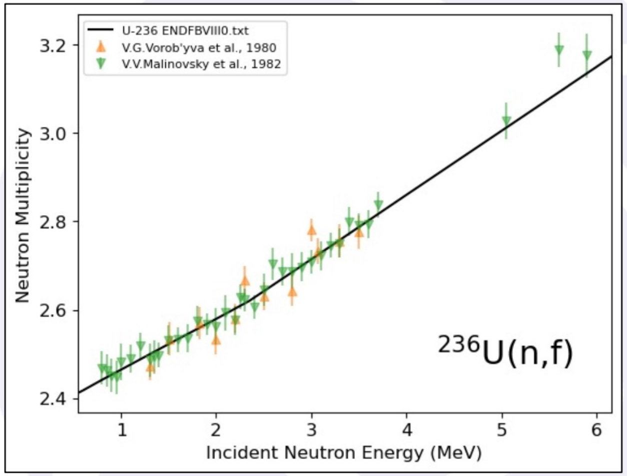
Observable	EXFOR no.	First Author & Year	Monitor	E_{inc} (MeV)
^{232}U(n,f) $\overline{\nu}_p$	10125.009	Jaffey, 1970	^{233}U, ^{235}U $\overline{\nu}_p$	thermal
^{234}U(n,f) $\overline{\nu}_p$	21135.005	Mather, 1965	^{252}Cf $\overline{\nu}_p$	1–4 MeV
^{233}U(n,f) $\overline{\nu}_p$	21135.003, 21135.004	Mather, 1965	^{252}Cf $\overline{\nu}_p$	thermal–4 MeV
^{236}U(n,f) $\overline{\nu}_p$	20037.002	Conde, 1971	^{252}Cf $\overline{\nu}_p$	0.77–6.7 MeV
^{236}U(n,f) $\overline{\nu}_p$	40612.002	Vorobyeva, 1980	^{252}Cf $\overline{\nu}_p$	1.3–3.5 MeV
^{236}U(n,f) $\overline{\nu}_p$	40660.002	Malinovsky, 1982	^{252}Cf $\overline{\nu}_p$	0.8–5.9 MeV

- Started modeling for consistent minor U prior using CGMF.
- Work documented in W. Fritsch, LA-UR-24-29315 (2024).

Straight from EXFOR



After Experimental UQ



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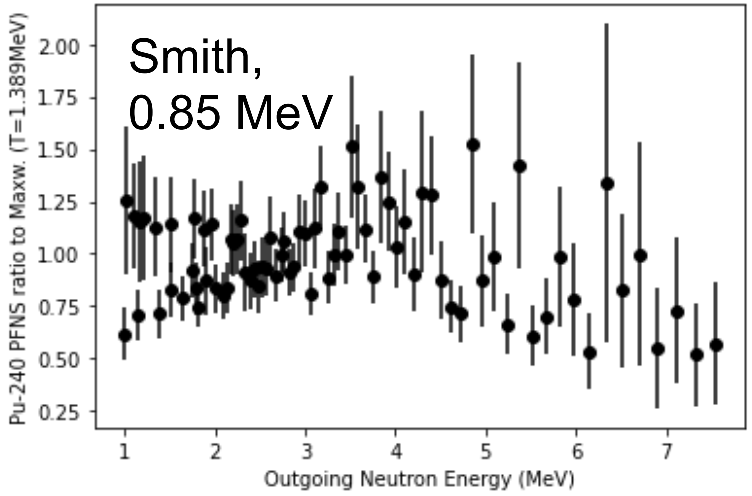
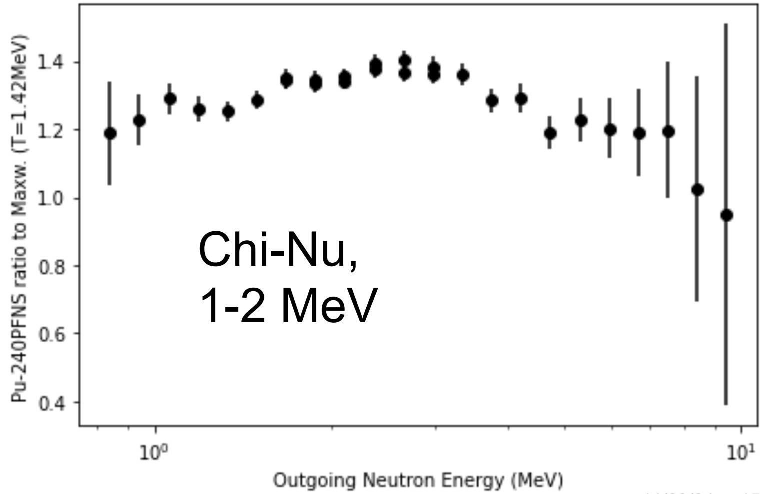
FY25 milestone: ^{240}Pu: "Update evaluation to include new LANSCE / Chi-Nu prompt fission neutron spectra."

Started ^{240}Pu PFNS evaluation by analyzing the experimental database: Only accepted data set is Chi-Nu

- Only other ^{240}Pu n-induced PFNS (Ein= 0.85 MeV) by Smith et al. were analyzed and had no red flags in the documentation, but data have high scatter and highly unphysical trends.
- NCSP-paid LANL/ LLNL Chi-Nu data documented in: K. Kelly, PRC, 2024 featured by APS! https://doi.org/10.1103/PhysRevC.109.064611
- Chi-Nu data cover broad E_{inc} and E_{out} range with high precision and will allow us to provide a much better informed PFNS evaluation!





Summary:

- New evaluated ^{238}U PFNS make use of LANL/LLNL Chi-Nu high-precision experimental data and is now part of IX.0/ VIII.2beta0!
- Evaluated, V&Ved and formatted consistent $^{238-242}$Pu nu-bar. Need to reevaluate ^{252}Cf(sf) nu-bar unc.
- Work underway for ^{240}Pu PFNS eval. Using high-precision NCSP-paid Chi-Nu data that for the first time give reliable exp.!!
- Already work made towards consistent $^{232-236}$U nu-bar evaluation thanks to summer student Cole Fritsch.

To-Do:

- ^{240}Pu PFNS modeling and evaluation.
- ^{233}U nu-bar exp. UQ.
- $^{232-236}$U nu-bar modeling and evaluation.
- Exploring how to use PFUNS data for ^{235}U PFNS with Ionel Stetcu and Jesson Hutchinson.

Thank you for your attention!

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