Relevant Nuclear Databases

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Utilized Databases

- ENDF/B
  - The Evaluated Nuclear Data File begun in 1966, and run by the American lead Cross Section Evaluation Working Group (CSEWG).
  - Decay Data Sublibrary contains spectrum data concerning nuclear decays for over 3800 materials (radioisotopes both in ground state and metastable isomers).
  - Current published version: VIII.0
    D.A. Brown, et al., Nucl.Data Sheets **148**, 1 (2018)
  - Fission Yield Sublibrary provides independent and cumulative fission yields.
  - Decay Data Sublibrary provides decay radiation spectra for all radiation types.

Image: CSEWG 2019 Group Photo (Last in-person meeting).

Utilized Databases

- JEFF
    - The Joint Evaluated Fission and Fusion File (JEFF) is an evaluated library produced via an European lead collaboration of Nuclear Energy Agency Data Bank participating countries.
    - Current published version: 3.3

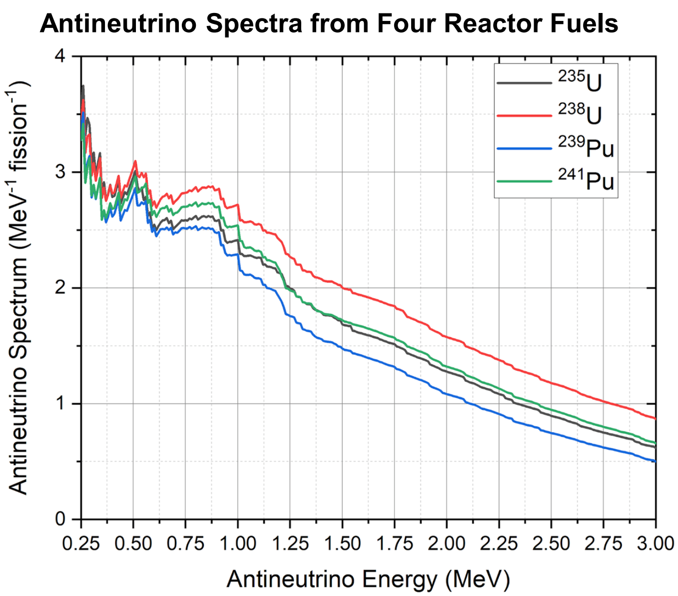
      Plompen, A.J.M., Cabellos, O., De Saint Jean, C. *et al.* The joint evaluated fission and fusion nuclear data library, JEFF-3.3. Eur. Phys. J. A **56**, 181 (2020)
    - JEFF library contains a decay data, and fission yield sublibraries.
    - Provides us with Cumulative Fission Yield Data.

Unutilized Sublibraries within Databases

ENDF/B and JEFF are used to calculate Electron and Neutrino Spectra via the Summation Method.

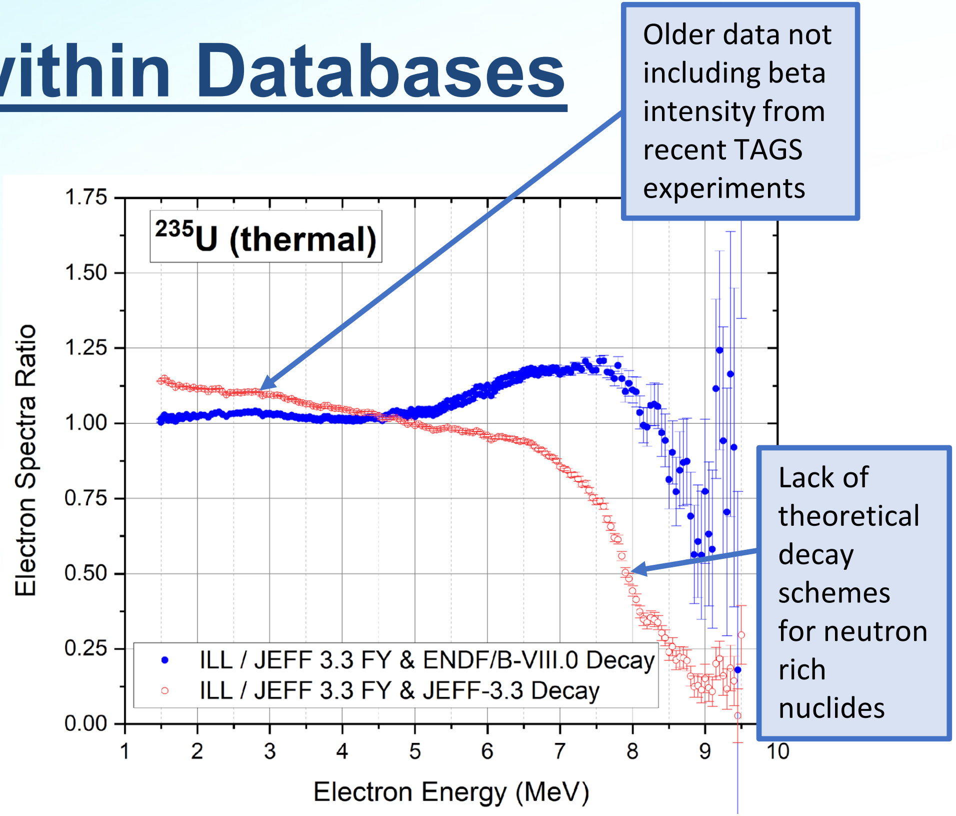
$$\text{Summation Spectra} = \sum CFY_j(\sum I_{\beta jk} S_{jk})$$

CFY_j : Cumulative fission yield of a fission product.
$I_{\beta jk}$: Beta decay intensity.
S_{jk} : Nuclear level to nuclear level antineutrino spectra.



Unutilized Sublibraries within Databases

- JEFF Decay
  - Does not include theoretical neutron rich nuclide decay spectra.
  - Does not include beta intensities from recent TAGs experiments.
- ENDF/B Fission Yields
  - Contains anomalous cumulative yields values and uncertainties.



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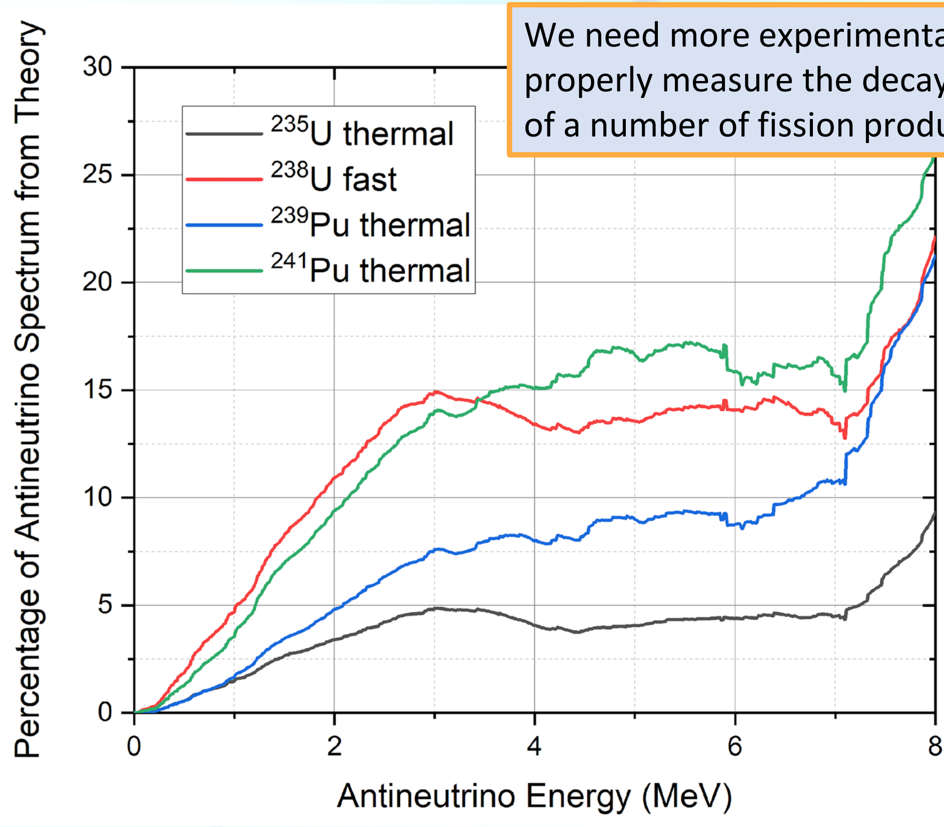
Reliance on theory in ENDF/B-VIII.0 Decay Data

We need more experimental work to properly measure the decay scheme of a number of fission products.



Nucleus	$T_{1/2}$ (s)	$Q_{\beta-}$ (keV)	CFY	% total IBD
~~^{103}Nb~~	~~1.5~~	~~5,932~~	~~2.165×10^{-2}~~	~~0.65~~
^{103}Zr	1.3	7,213	4.484×10^{-3}	0.36
^{104}Nb	4.9	8,531	4.357×10^{-3}	0.32
^{101}Y	0.45	8,105	3.007×10^{-3}	0.31
~~^{104m}Nb~~	~~0.94~~	~~8,531~~	~~3.331×10^{-3}~~	~~0.24~~
~~^{88}Se~~	~~1.5~~	~~6,832~~	~~2.716×10^{-3}~~	~~0.21~~
^{142}Xe	1.2	5,285	6.886×10^{-3}	0.20
^{94}Kr	0.21	7,215	1.802×10^{-3}	0.15
^{139}I	2.3	7,174	7.554×10^{-3}	0.15
^{105}Nb	2.9	7,422	2.414×10^{-3}	0.14

TABLE I. The ~~10~~ 7 largest contributors to the IBD antineutrino yield generated in the thermal neutron fission of ^{235}U for which only incomplete decay data is available, thus necessitating theoretical calculations to obtain the radiation spectra. The table includes their rounded values of half-lives, β-Q-values and cumulative fission yields, ordered by their percentile contribution to the total IBD yield.

R. Lorek, A.A. Sonzogni, A. Mattera and E.A. McCutchan, TBP.

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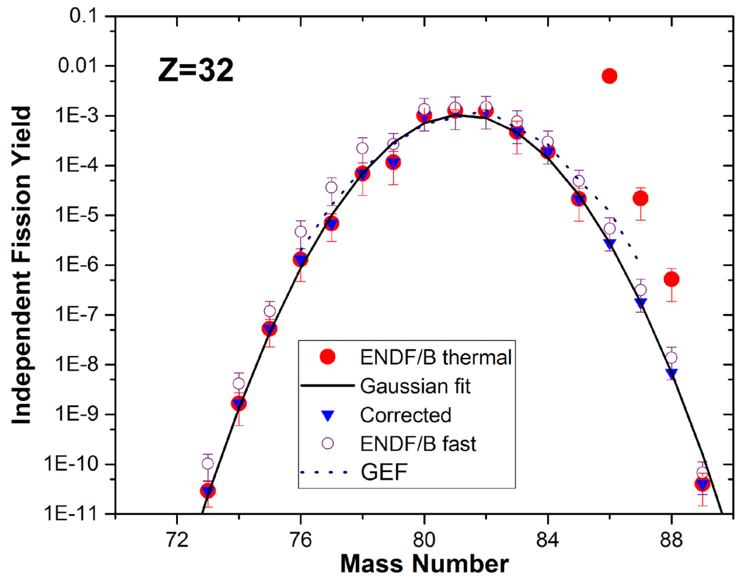
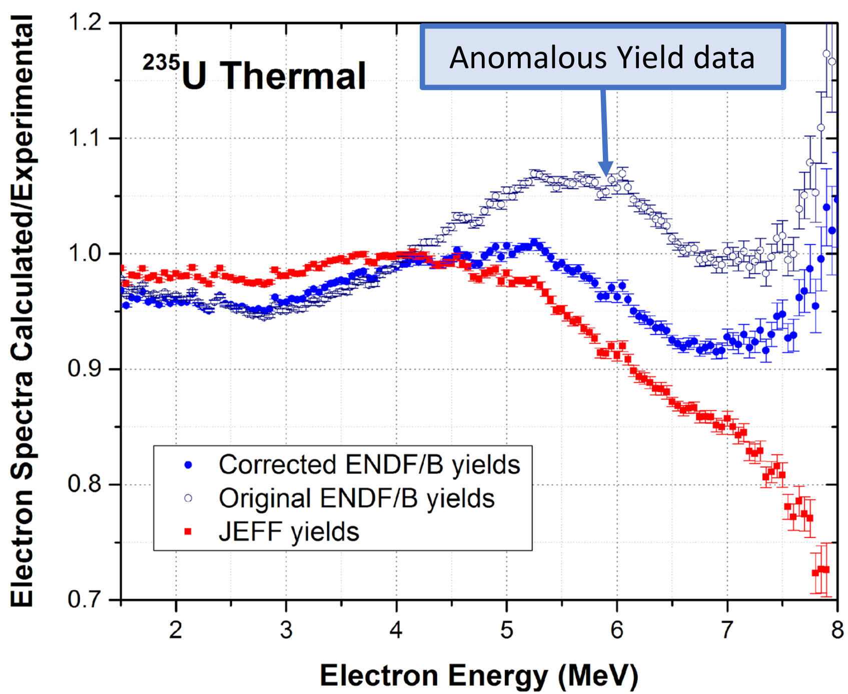
ENDF/B-VIII.0 Fission Yield Anomalies

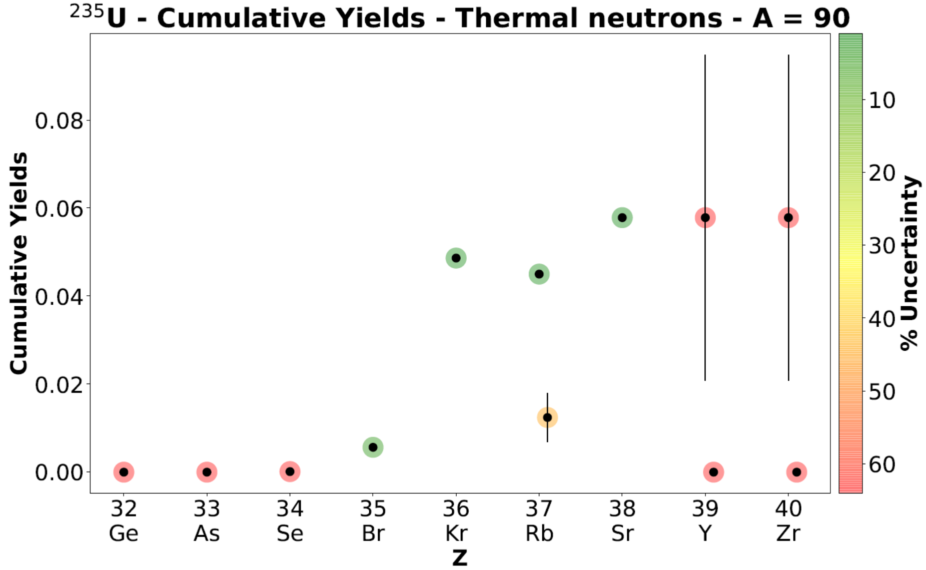




- Anomalous yields for some neutron rich nuclides, ex. Z=32.
- Also, lack of compatibility with current decay data.

A.A. Sonzogni, E.A. McCutchan, T.D. Johnson, and P. Dimitriou, PRL **116**, 132502 (2016)

ENDF/B-VIII.0 Fission Yield Anomalies



Library	^{235}U	^{238}U	^{239}Pu	^{241}Pu
JEFF-3.3	-173.155 ± 0.076	-173.047 ± 0.298	-173.585 ± 0.115	-173.523 ± 0.240
ENDF/B-VIII.0	-173.125 ± 0.943	-173.225 ± 0.585	-173.676 ± 0.417	-173.552 ± 0.410
ENDF/B-VIII.0 Mod.	-173.137 ± 0.039	-173.218 ± 0.081	-173.694 ± 0.073	-173.547 ± 0.092
Kopeikin [8] (England & Rider)	-173.43 ± 0.05	-173.39 ± 0.10	-173.87 ± 0.07	-173.82 ± 0.10

Table 1. Y and ΔY values, calculated with Eqn. 21.

Anomalous large uncertainties for a number of stable or very long-lived fission products, for instance ^{90}Y and ^{90}Zr, resulting in large uncertainties in the parameter ***Y*** needed to calculate total energy released in fission.

$$Y = \sum C Y_k M_k,$$

A. Mattera and A.A. Sonzogni, BNL-220804-2021-INRE Report (2020).

Updates

Updates:
- ENDF/B-VII.0 contained no TAGS in β spectrums.
- Current version (VIII.0) released on February 2018
- Version VIII.1 in progress with ~435 materials updated so far.
- Updates are made as peer-reviewed published data becomes available.

NA22 is funding new fission yield sublibrary via a multi-lab effort.
(PI: Toshihiko Kawano (LANL))

Desired Improvements

In brief; the decay emission spectra is described as...

$$S(E_e) = NW(W^2\text{-}1)^{½}(W\text{-}W_o)^2 \text{ x } F(Z_k,W) \text{ x } C_L(W) \text{ x } C_{fs}(W) \text{ x } C_s(Z_k,W) \text{ x } C_{WM}(W) \text{ x } C_r(Zk,W) \text{ x } C_{exp}(W)$$

Shape Factor represents an experimental correction and is dependant upon the chosen Fermi Function ($F(Z_k,W)$).

Shape Factor may have a significant impact on the antineutrino spectra.
See, *First-forbidden transitions in reactor antineutrino spectra,* L. Hayen, *et al*., PRC 99, 031301 (2019)

A new database format is needed to store the Shape Factor.

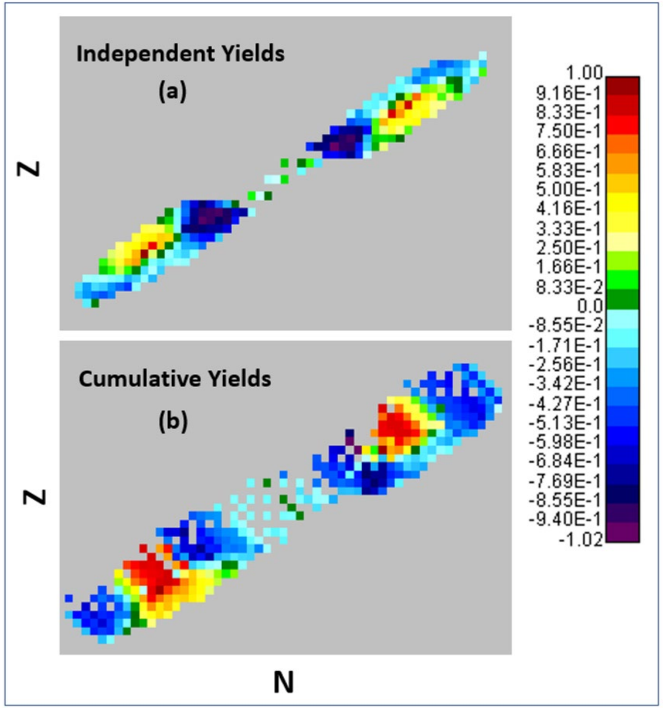
- If measured, must be stored.
- If stored, must fit within the current database.

Desired Improvements

In order to properly quantify uncertainty in calculations cumulative fission yield correlations must be stored within database format.

$$\Delta^2 S = \sum \Delta^2 C_j S_j + C_j \Delta^2 S_j + \sum S_j S_k \mathit{Cor}(C_j C_k) \Delta C_j \Delta C_k$$

Plot illustrates independent and cumulative fission yield correlation matrices.



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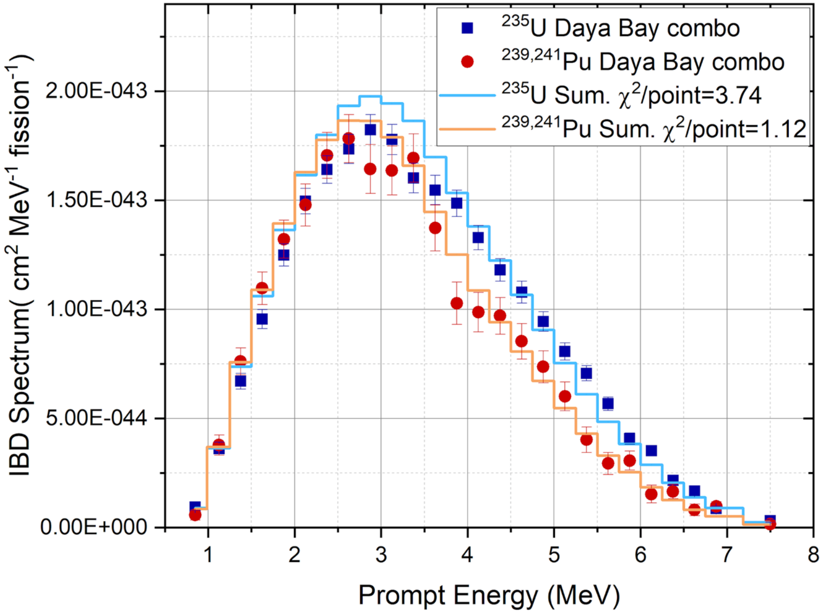
Application to Antineutrino Spectra

IBD Yields as a function of prompt positron energy.



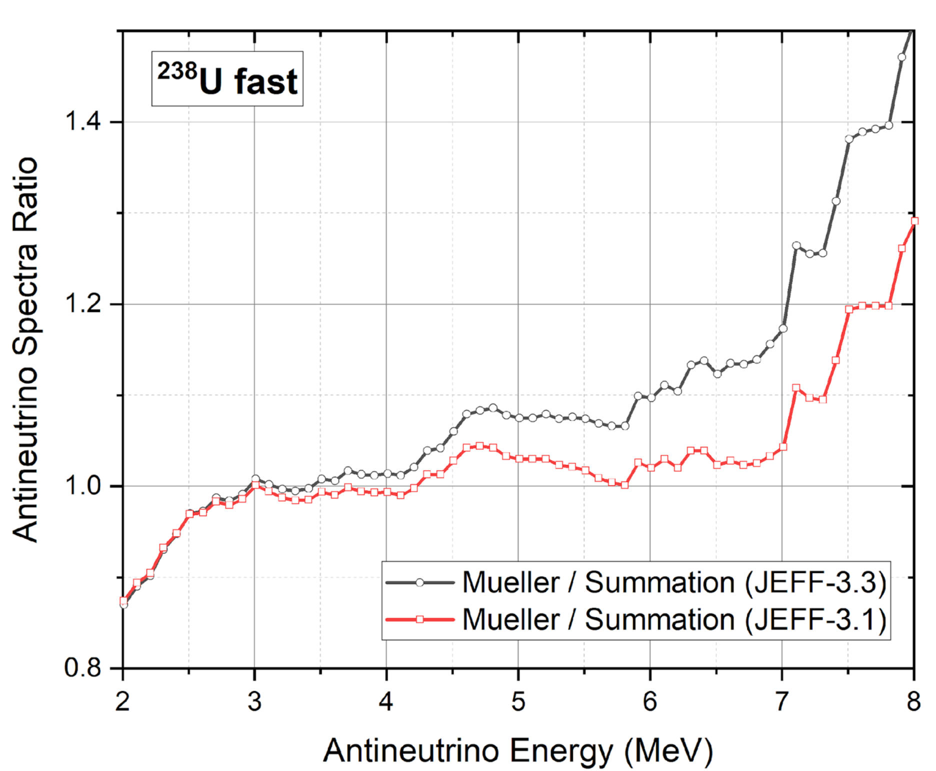
Daya Bay Data from: D. Adey, et al. PRL **123**, 111801 (2019).

Summation from ENDF/B-VIII.1 decay data and JEFF-3.3 Cumulative Yields.

Daya Bay deduced antineutrino spectra for ^{235}U and ^{239}Pu.

Database Summation does not agree with deduced spectra.

Application to ^{238}U antineutrino spectrum



The new JEFF-3.3 fission yields produce a 238U antineutrino spectrum that is different from JEFF-3.1 and from the Mueller model.

Mueller model used an earlier version of JEFF.

More TAGS data has become available since this earlier version.

Difference is based on fission yield data (decay data taken from ENDF/B-VIII.1).

Conclusion

Full current ENDF/B sublibraries available on Gitlab: https://git.nndc.bnl.gov/
(Account required for access)

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