Calculation of Independent and Cumulative Fission Product Yields and Fission Spectrum with the Statistical Decay Theory

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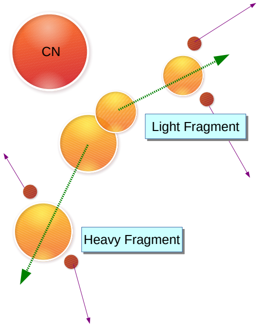
HF^{3}D: Hauser-Feshbach Fission Fragment Decay

Fully Deterministic Approach to Fission Yield and Prompt Neutrons



HF^{3}D Model Inputs

- primary fission fragments $Y(Z, A, \mathrm{TKE})$
- R_T (energy sharing) and f (spin dist.) parameters

We integrate Hauser-Feshbach outputs over

- initial population distribution $P_0(J, \Pi, E_x)$ for
- spin, parity, and fragment excitation energy

Prompt fission neutron spectrum

- convert CMS neutron spectrum into LAB
- consistent χ calculation with FPY

FF Initial Configuration for $n_{th} + {}^{235}U$

Spin and parity distribution

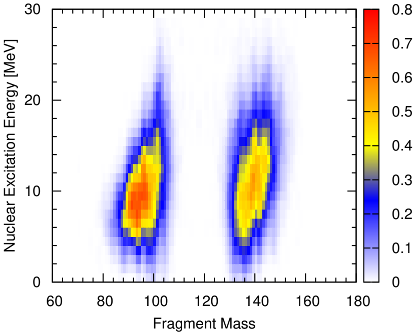
$R(J,\pi)$ from level density J distribution, with scaled $\sigma(U)$

$$R(J,\pi) = \frac{J+1/2}{2(f\sigma)^2} \exp\left\{-\frac{(J+1/2)^2}{2(f\sigma)^2}\right\}$$

Excitation energy distribution

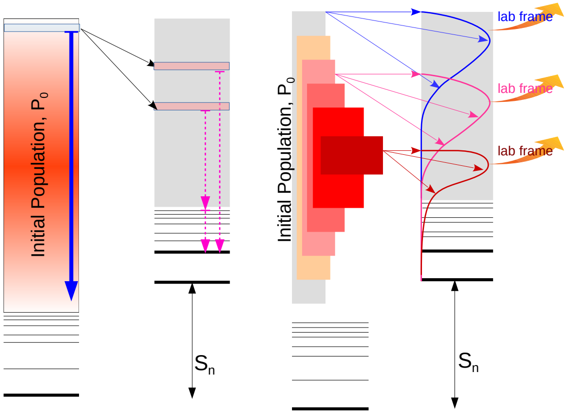
Anisothermal parameter R_T

$$R_T = \frac{T_l}{T_h} = \sqrt{\frac{U_l}{U_h}\frac{a_h(U_h)}{a_l(U_l)}}$$



$R(J,\pi)$ and R_T determine $\overline{\nu}$ and $\nu(A)$

Deterministic Statistical Decay of CN in HF^{3}D



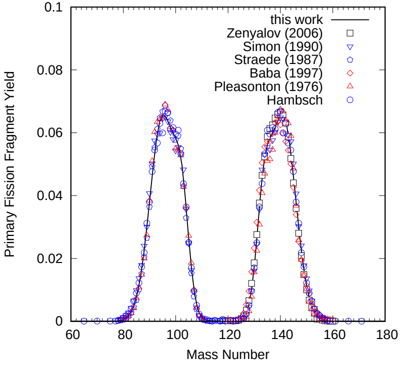
FPY case

χ case

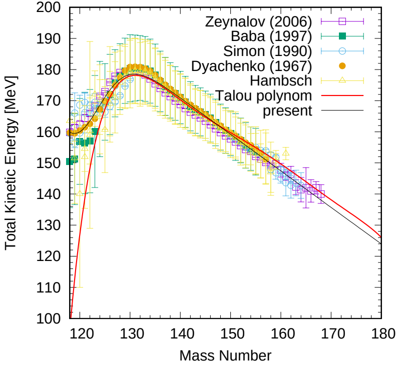
- fission fragment excitation energy discretized, $E_x(i)$
- calculate kinetic energy E_k of the fragment at each $E_x(i)$
- convert neutron energy from CMS into LAB using Feather's technique

Model Parameter Inputs

primary fission fragment, $Y(A)$

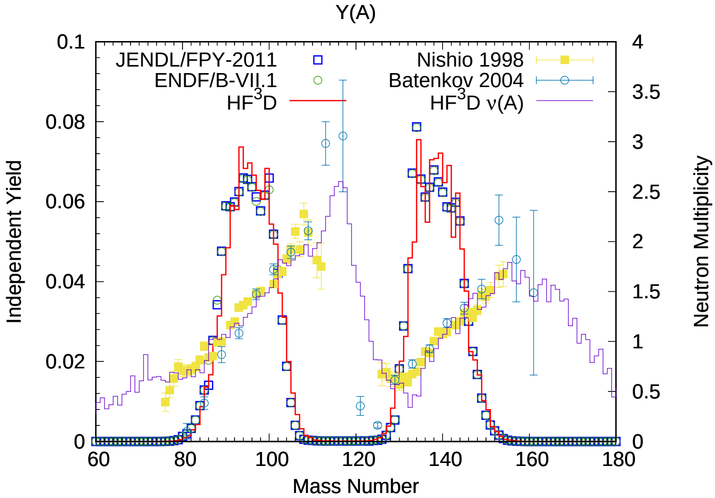


TKE(A)



- Z-distribution by Wahl's Z_p model
- $Y(Z,A)$ and TKE(Z,A) are energy-dependent up to 1st-chance fission

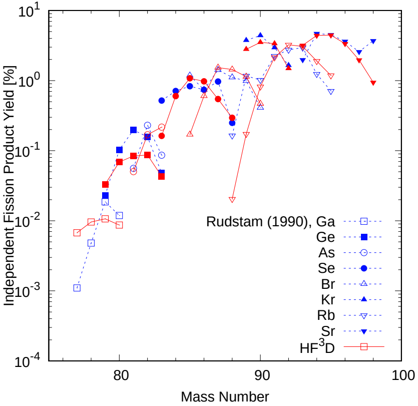
Independent Mass Yield for n_{th} + ^{235}U



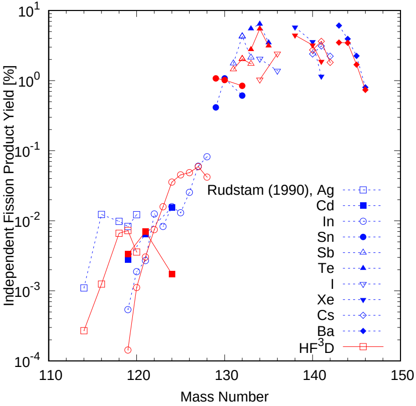
$\bar{\nu} = 2.38$

Some Selected Independent FPYs for $n_{th} + {}^{235}U$

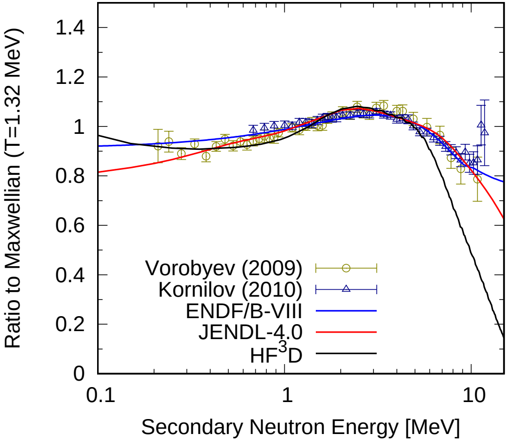
Light FPs



Heavy FPs



Prompt Fission Neutron Spectrum for n_{th} + ^{235}U

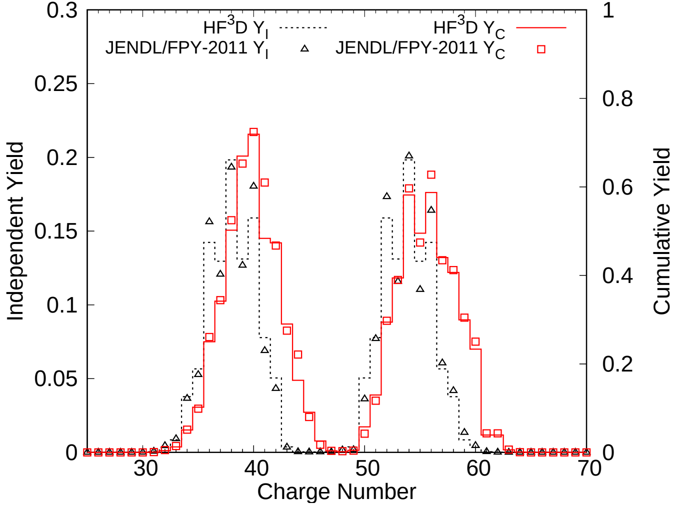


- Shape below 1 MeV different from Madland-Nix model
- HF^{3}D result drops quickly above 5 MeV
  - already seen in our past Monte Carlo works

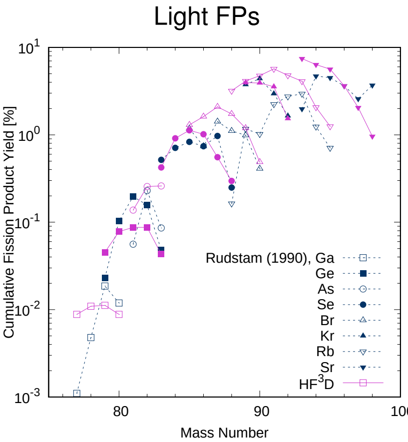
    Becker, PRC **87**, 014617 (2013)

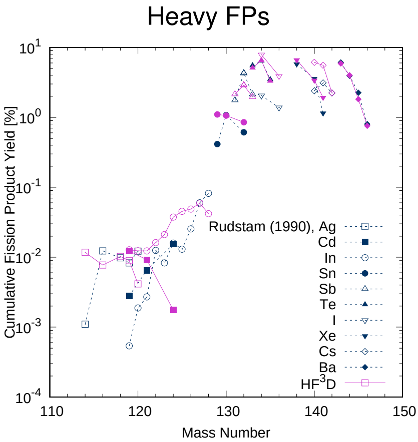
    Kawano, NPA **913**, 51 (2013)

Independent/Cumulative FPY Charge Distributions

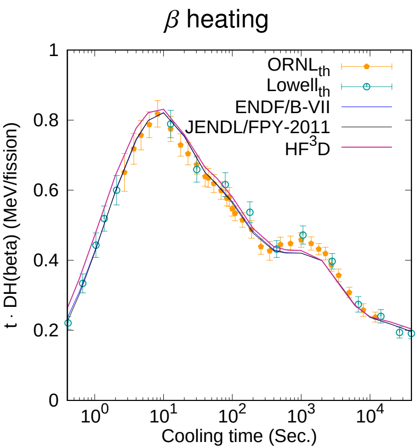


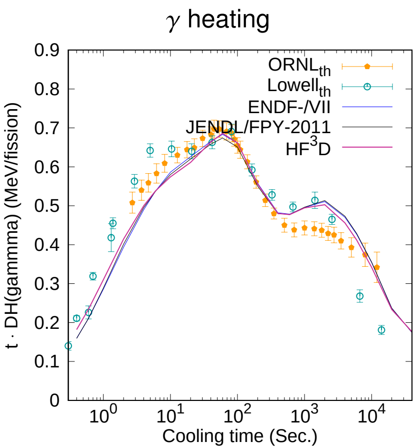
Some Selected Cumulative FPYs





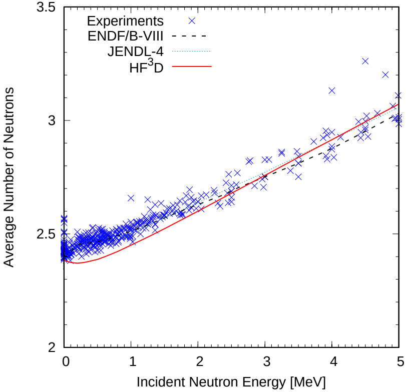
Calculated Decay Heat



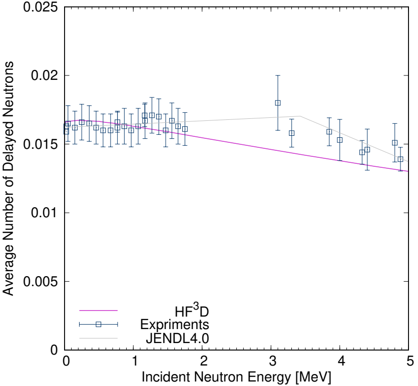


Prompt and Delayed Neutron Multiplicities

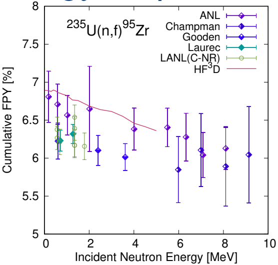
prompt neutron

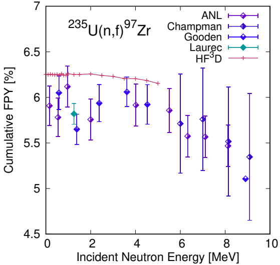


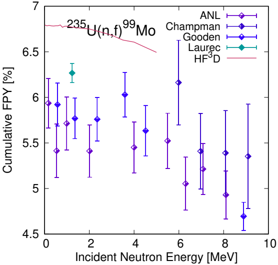
β-delayed neutron

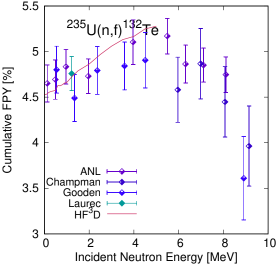


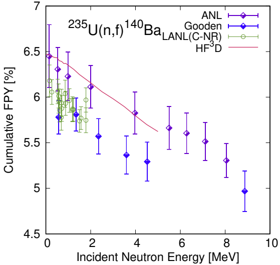
Energy-Dependent Cumulative FPYs

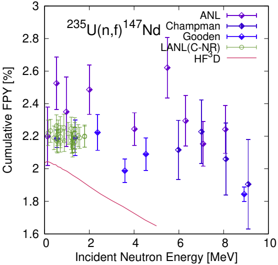












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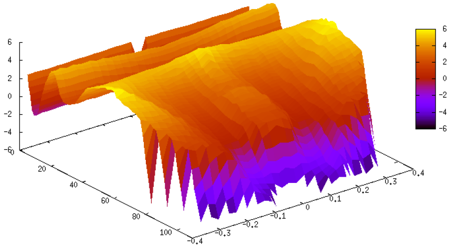
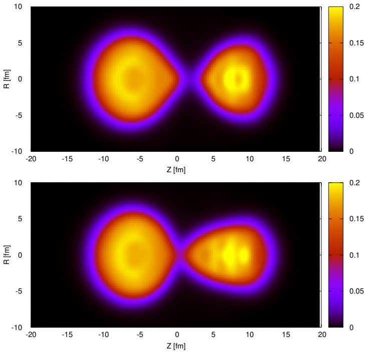
Micro/Macro Approach to Primary FF Yield

potential energy surface of ^{236}U



density distribution



These data will be produced by the FIRE collaboration, and will be employed as the energy-dependent primary fission fragment distribution

Toward New FPY Data Library, Experimental Data

Construction of Experimental Database

- Review some personal FPY databases (England, Mills, Katakura)
- Include recent FPY data, which were not given in these databases
- Prepare a common experimental FPY database
- Also compile other data, such as TKE, mass yield, etc, for parameter tuning

International Cooperation

- Workshop on Fission Product Yield Experimental Data
  - Los Alamos, NM, Aug. 20 – 23 (2018)
  - LANL (chair), IAEA (co-chair), BNL, JAEA, and KAERI
- IAEA Consultants' Meeting on Fission Product Yield Experimental Database
  - tentative date/place May 2018 in Tokyo
- IAEA Fission Product Yield CRP

Toward New FPY Data Library, Model and Evaluation

Application of the Hauser-Feshbach theory to the fission fragment decay process

- The HF^3D model produces independent fission product yields as well as prompt fission neutron spectrum in a consistent manner
- Capable to produce energy-dependent FPYs
- Current model is limited to n+^{235}U up to the second chance fission

S. Okumura et al. J. Nucl. Sci. Tech. **55**, 1009 (2018)

Extension and Optimization

- Prepare model parameter inputs for other fissioning systems (partly done by the CGMF team at LANL)
- Include multi-chance fission
- Theoretical prediction for primary fission fragment yields
- Large scale parameter optimization to produce the final evaluation