Evaluation of Energy Dependent Fission Product Yields

T. Kawano, LANL

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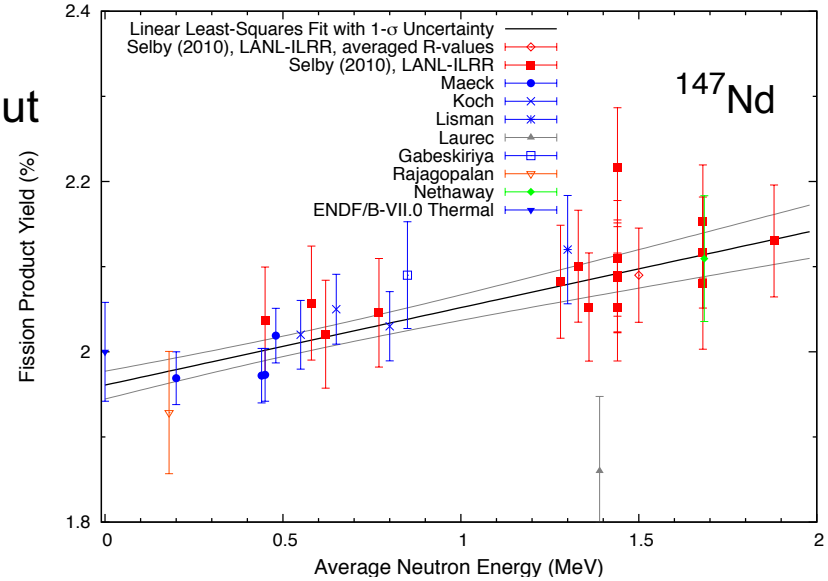
Objectives

- ENDF Fission Product Yield (FPY) library produced in 1990's, and limited upgrade made by Chadwick and Kawano to take account of energy-dependence
- Revival of the FPY evaluation effort
  - Demands for more accurate FPY data rapidly increasing, especially better representation of energy dependence of FPY
  - New theoretical modeling for the fission, prompt and delayed decay processes available
  - New experimental data, not only the FPY data but also relevant observable for the fission phenomena, also available
  - Recognition of importance of new FPY data by international nuclear data communities
    - IAEA will start a new international cooperative research project (CRP)

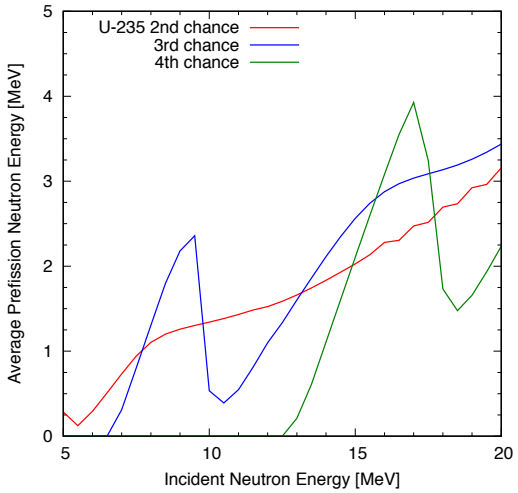


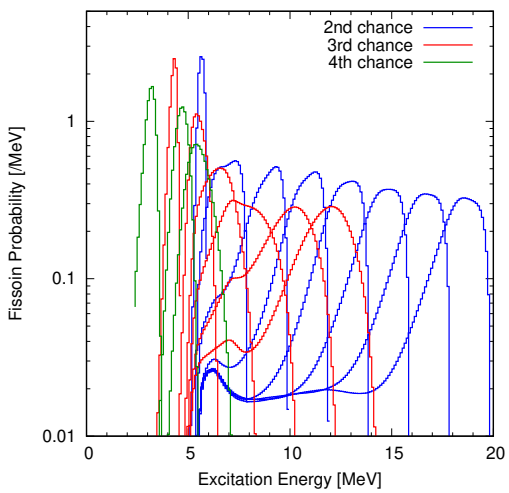
Energy-Dependent FPY Project Funded by NA22

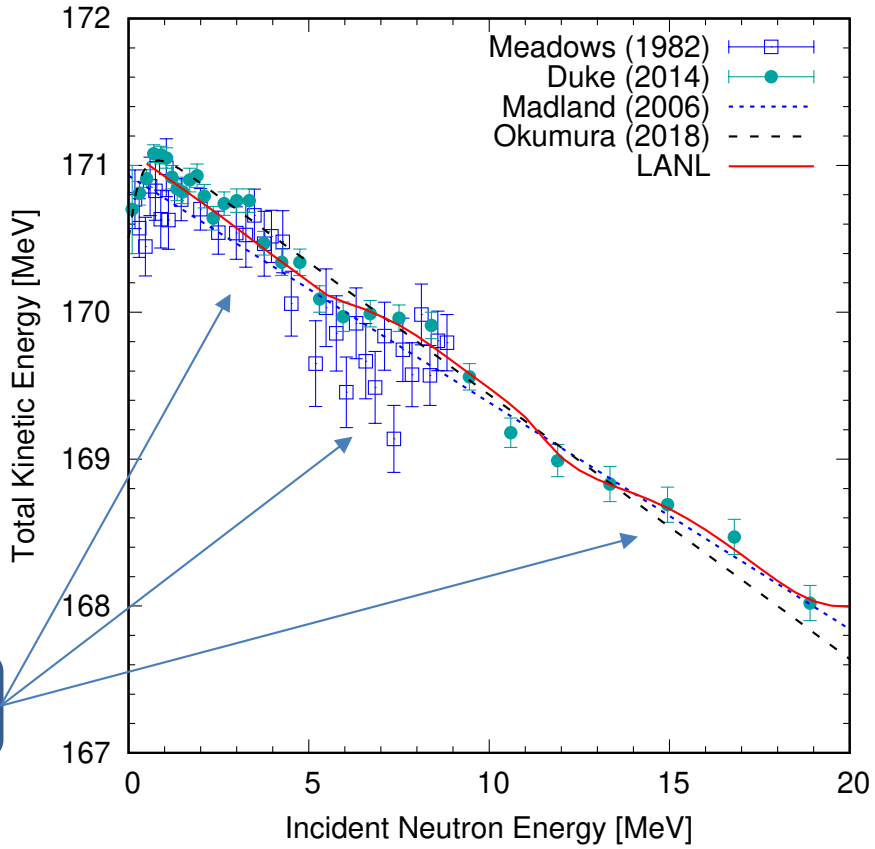
- Joint effort by 5 laboratories
  - LANL (leading lab) develops FPY models and produce the final FPY data files
  - BNL complies experimental FPY data and produces a set of recommended FPY values, performs FPY data validation calculations
  - LBNL performs measurements of energy-integrated and differential CNAA (Cyclical Neutron Activation Analysis) using the intense neutron source by the LBNL cyclotron, and data interpretation by the FIER code
  - PNNL develops a new Bragg curve based fission TPC (Time Projection Chamber) analysis in collaboration with LANL and LLNL (see Duke's talk)
  - LLNL develops theories and methods to calculate primary fission fragment yields, and performs FREYA calculations for prompt decay

Project Status and Recent Highlights, LANL

- Extending FPY model up to higher energies
  - Inclusion of multi-chance fission by the LANL Hauser-Feshbach code CoH_3
  - Extract required quantities, fission probabilities, average energy of pre-fission neutrons, probabilities of fission at each excitation energy, and calculate TKE at each excitation energies



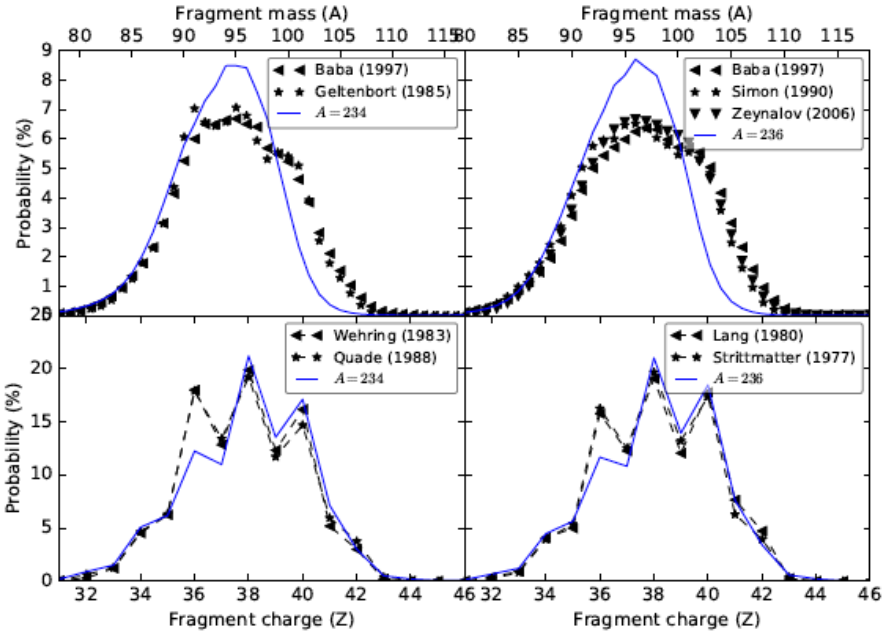


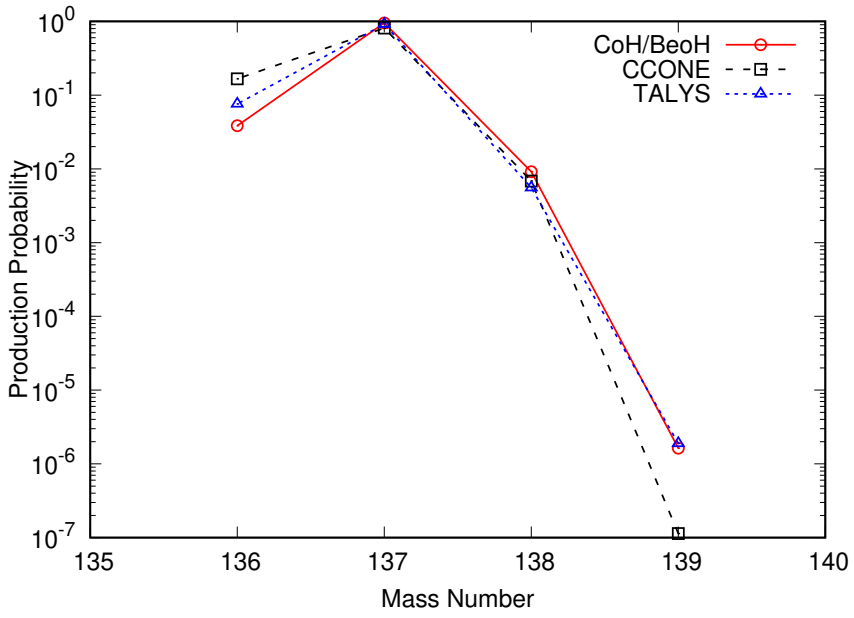


Apply Okumura model [JNST 55, 1009 (2018)] to each fissioning CN

Project Status and Recent Highlights, LANL (cont'd)

- Better modeling for fission fragment configurations
  - number projection method by Verriere [PRC100, 024612 (2019)]
- Maintaining international FPY evaluation network
  - survey missing experimental data in EXFOR by BNL and IAEA [INDC(NDS)-0793 (2019)]
  - preparatory FPY evaluation meetings at IAEA in Aug. 2019 and Jan. 2020 [IAEA-NDS-230]
    - enhanced capabilities in TALYS (IAEA) and CCONE (JAEA) to produce FPY





Project Status and Recent Highlights, BNL

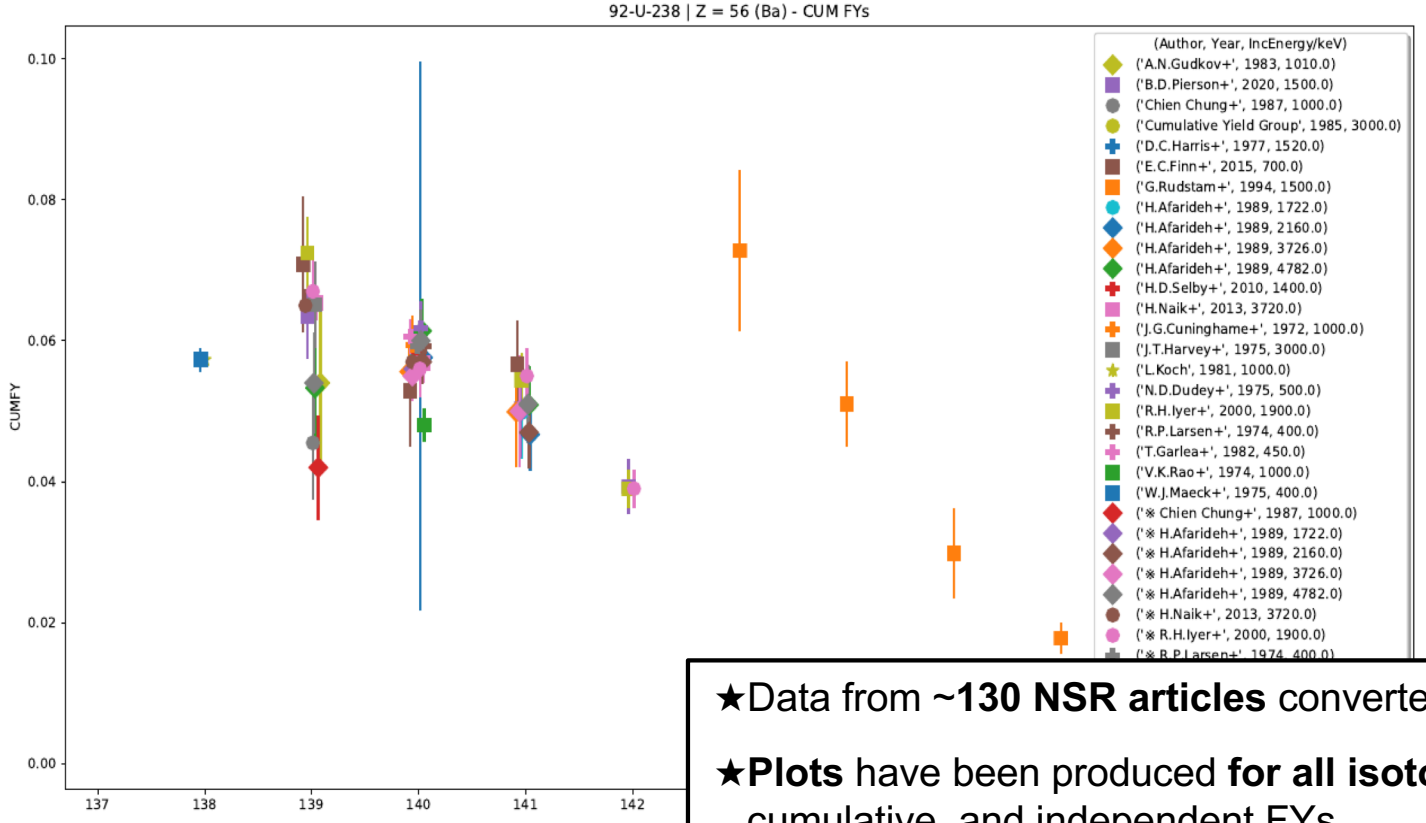
EXFOR Compilations	Neutron-induced	Charged particle-induced	Gamma-induced
Old articles	53	56	6
New articles	18	1	7

- Number of Fission Yield articles added to **NSR**: 283
- Compilation of all ^{238}U neutron-induced data is nearly complete
- Corrections of ^{238}U fission yields to account for more precise decay data is about 50% complete
- JSON format developed in cooperation with the IAEA (V. Zerkin)
- Plots generated for comparison of measured data

BNL team: Andrea Mattera, Libby McCutchan, Boris Pritychenko, Alejandro Sonzogni, JoAnn Totans, Matteo Vorabbi, Olena Gritzvay, Stanislav Hlavac

Project Status and Recent Highlights, BNL (cont'd)

^{238}U | Z = 56 (Ba) | cumulative FYs



★Data from **~130 NSR articles** converted to new *JSON* format

★**Plots** have been produced **for all isotopes** showing available cumulative and independent FYs.

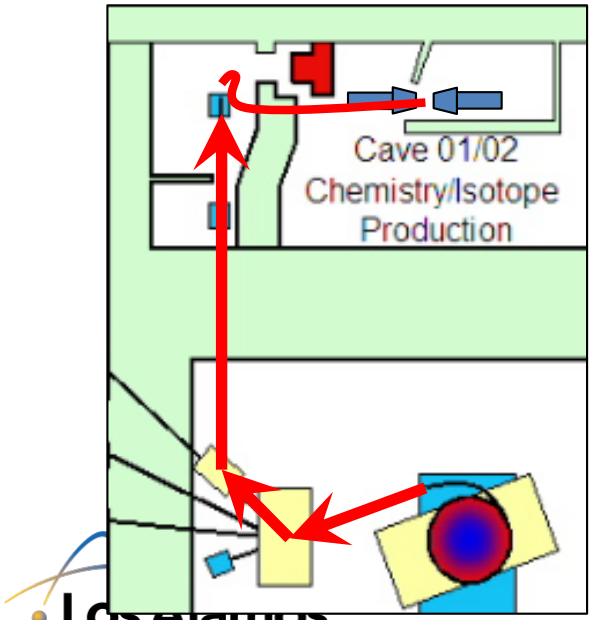
★19 **entries** (out of 40 with decay data in the reference) already **corrected using up-to-date decay data**.

★Additional NSR entries for ^{238}U(n_{14MeV},f) identified and collected

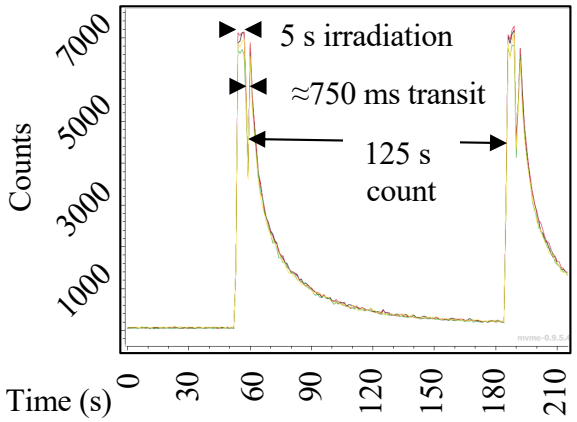
The Berkeley Group is measuring independent fission yields via cyclical neutron activation analysis

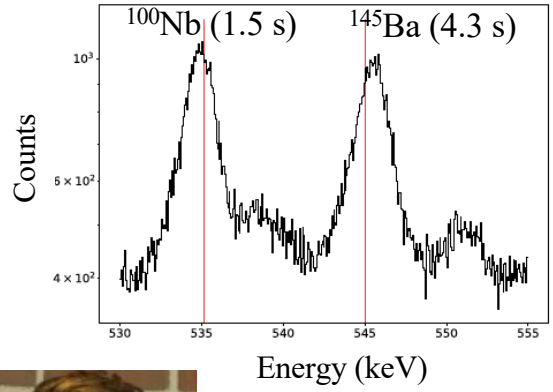
Fast Loading & Unloading Facility for Fission Yields (FLUFFY)

- $^{238,235}U + Al_2O_3$ irradiated using d-breakup and Li(p,n) neutrons at the 88-Inch cyclotron to determine FPY relative to $^{27}Al(n,\alpha)^{24}Na$
- 5 s irrad. + 125 s counts
- γ-spec compared to FIER*



Cyclical Irradiation



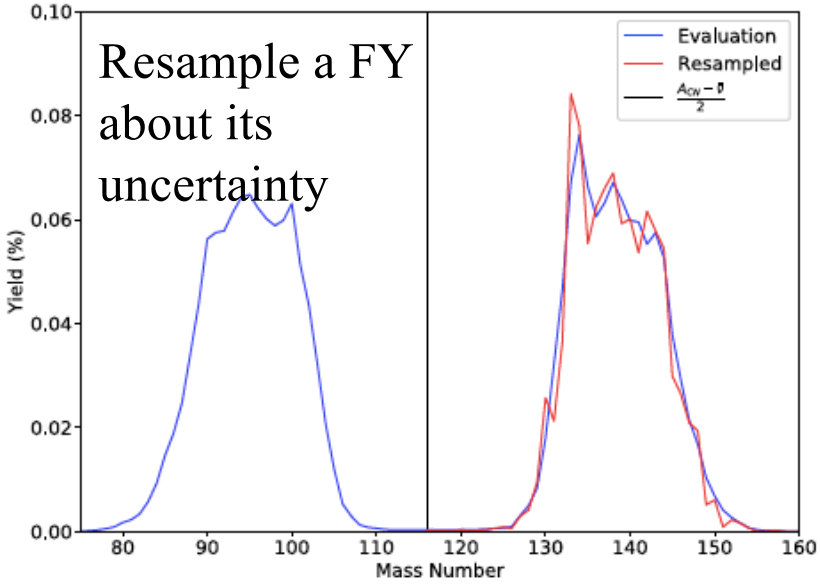


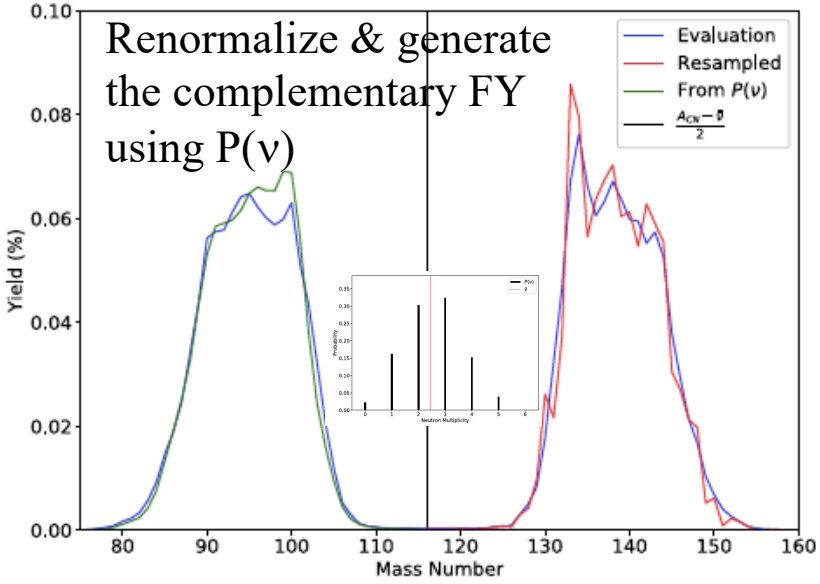
E. Matthews

The plan is to run ^{238}U, ^{235}U and ^{239}Pu

*E.F. Matthews *et al.*, NIM, A 891 (2018) 111

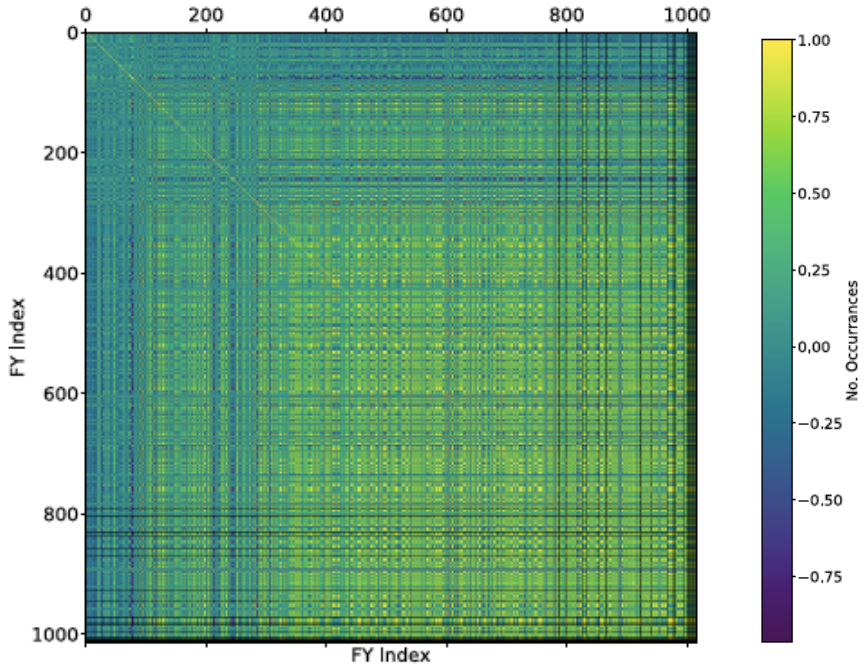
They have also developed a model-independent method of determining fission yield covariances





$$Y_{frac}(Z_{CN} - Z, A_{CN} - A - \nu) = P(\nu)\, Y(Z, A)$$

$$Y(Z_{CN} - Z, A_i) = \sum_{\nu} Y_{frac}(Z_{CN} - Z, A_i)$$



This method complements model-dependent FY covariance determination

FPY Project at LLNL

- Use microscopic fission theory to compute initial fragment (distributions and excitation energy) as a function of neutron incident energy
- Started this FY
- Team
  - N. Schunck, R. Vogt, M. Verriere
  - Collaboration with LBNL on FREYA
- Objectives
  - Initial fission fragment distributions of major actinides for thermal neutrons (Q1-Q2)
  - Fission fragment excitation energy from time-dependent density functional theory (Q2-Q3) calculations
  - With LBNL: Integrate FIER capability into FREYA (Q2-Q4)
  - Incorporate particle number dispersion in fission fragment calculations (Q4)