LA-UR-24-21730

Los Alamos NATIONAL LABORATORY

Fission Product Yield and Gamma-ray Production Evaluation

Status Report 2024

T. Kawano
Theoretical Division

PIs: A. Sonzogni (BNL) and N. Schunck (LLNL)

NNSA National Nuclear Security Administration

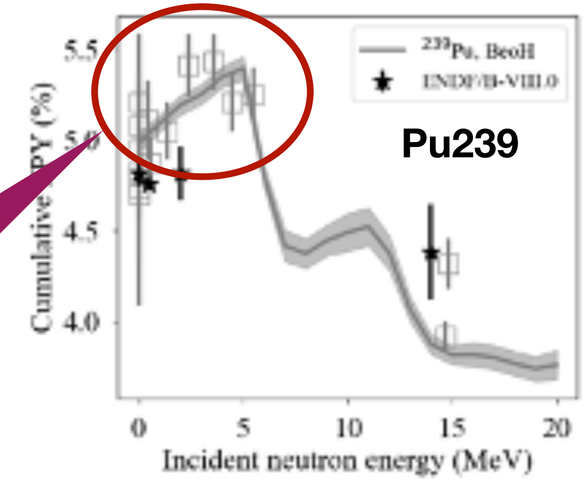
Energy-Dependent FPY Project Funded by NA22

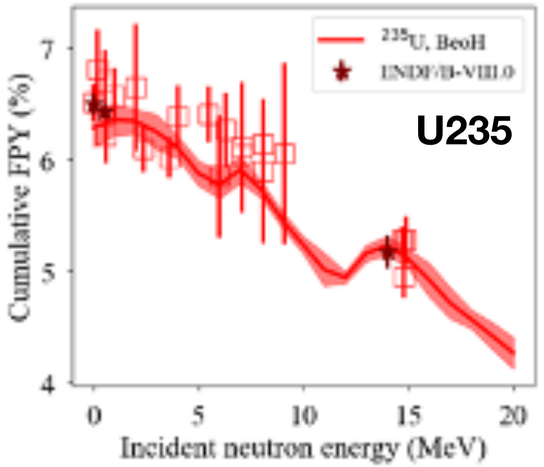
- **Originally five laboratories (LANL, BNL, LBNL, PNNL, and LLNL) joint effort**
  - Experimental parts finished in FY21, and LANL, BNL, and LLNL continued in FY22 and 23
  - 3 years extension approved, LANL/BNL/LLNL project continues until FY26
- **Recent Relevant Meetings**
  - CSEWG (11/13 - 11/17, 2023), BNL
    - A. Lovell, Status of the updated FPY evaluation including isomeric ratios and critical assembly tests
    - R. Vogt, Report on LLNL fission study, initial condition of fission fragments, automatization of potential energy surface calculation
    - A. Mattera, Summary of BNL activities for ENDF/B-VIII.1, correction of unrealistic FPY data and uncertainties
  - Future planning meeting (1/24 - 1/25, 2024), BNL
    - Researchers from LANL, BNL, and LLNL

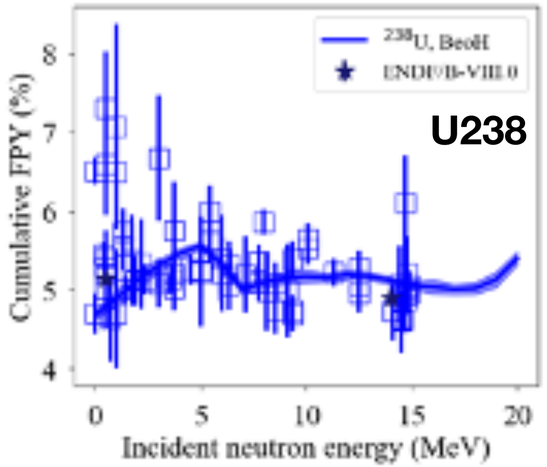
LANL: FPY Evaluation

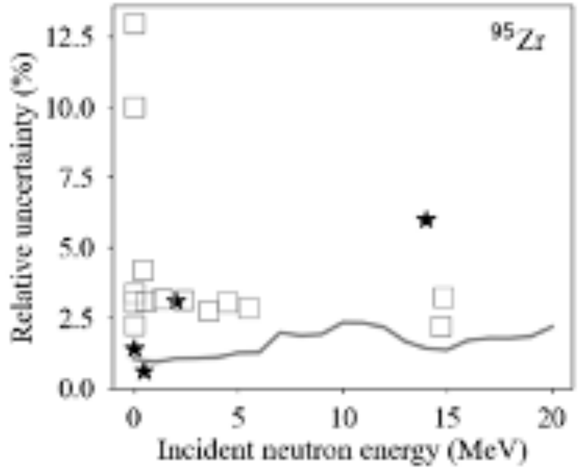
- Major actinide data prepared including covariances
- Extending to minor actinides ongoing
- Example of cumulative FPYs for ^{95}Zr for major actinides

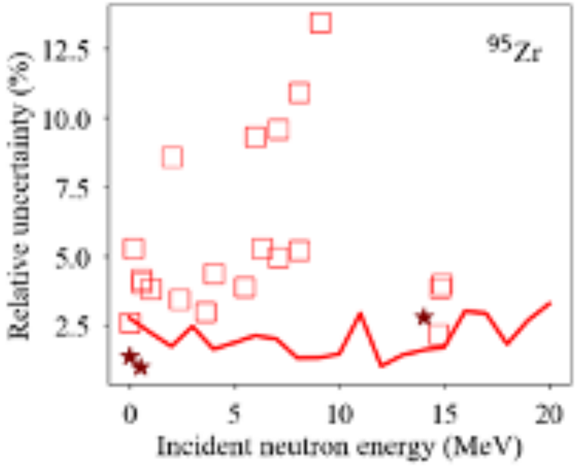
New data influence energy dependence

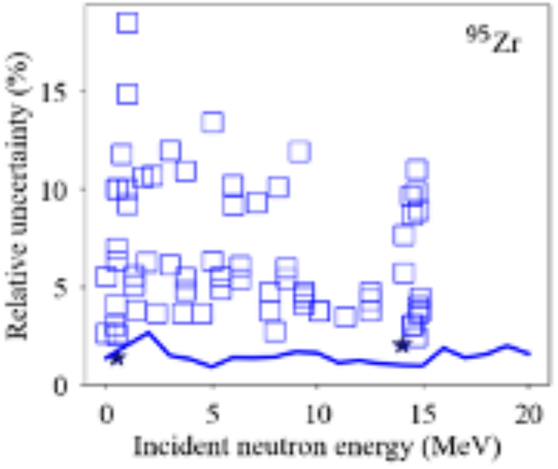








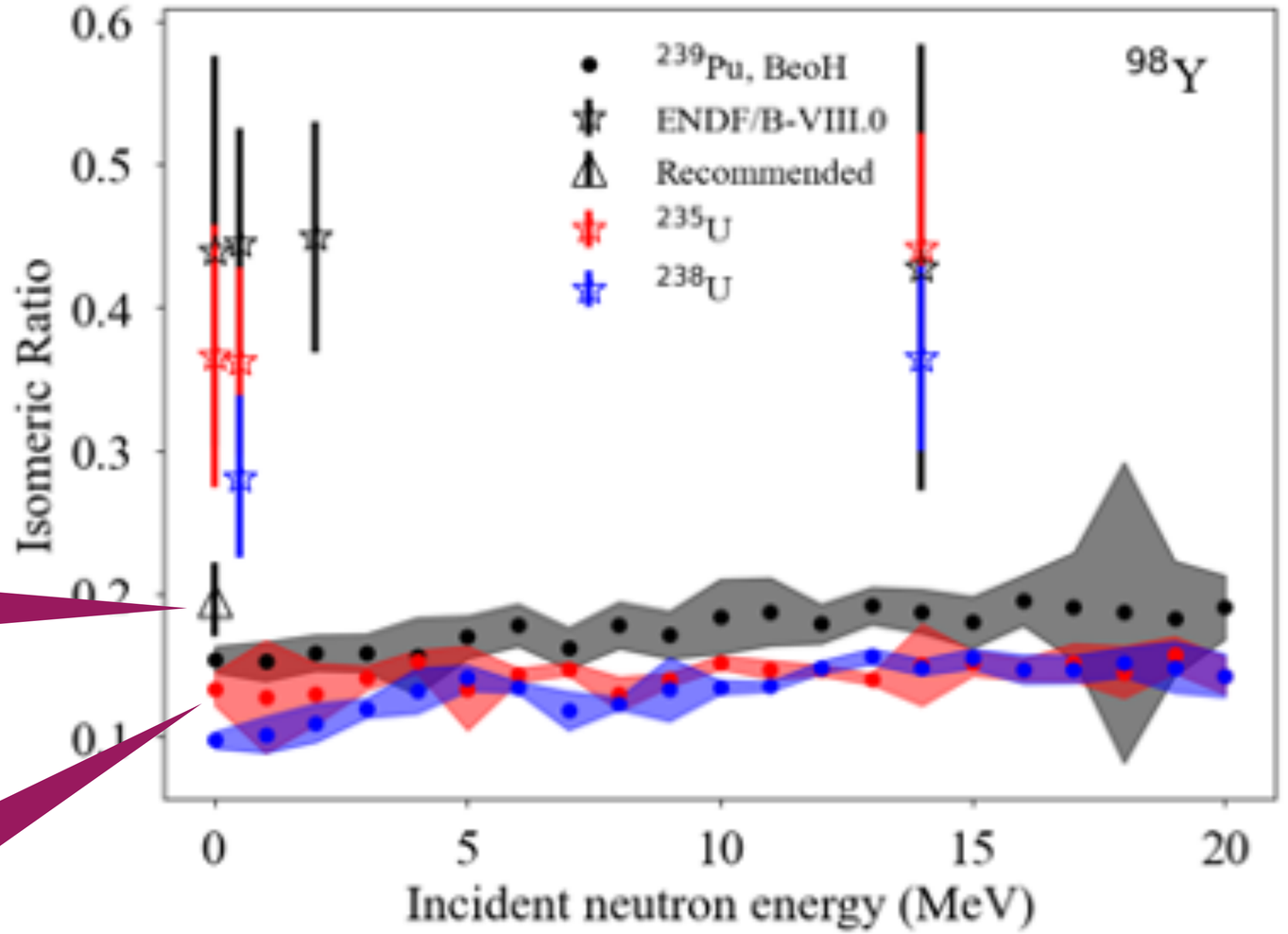




Los Alamos NATIONAL LABORATORY

LANL: Investigation of Isomeric Ratios is Underway

- **Calculated IRs**
  - 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 needs nuclear structure information**



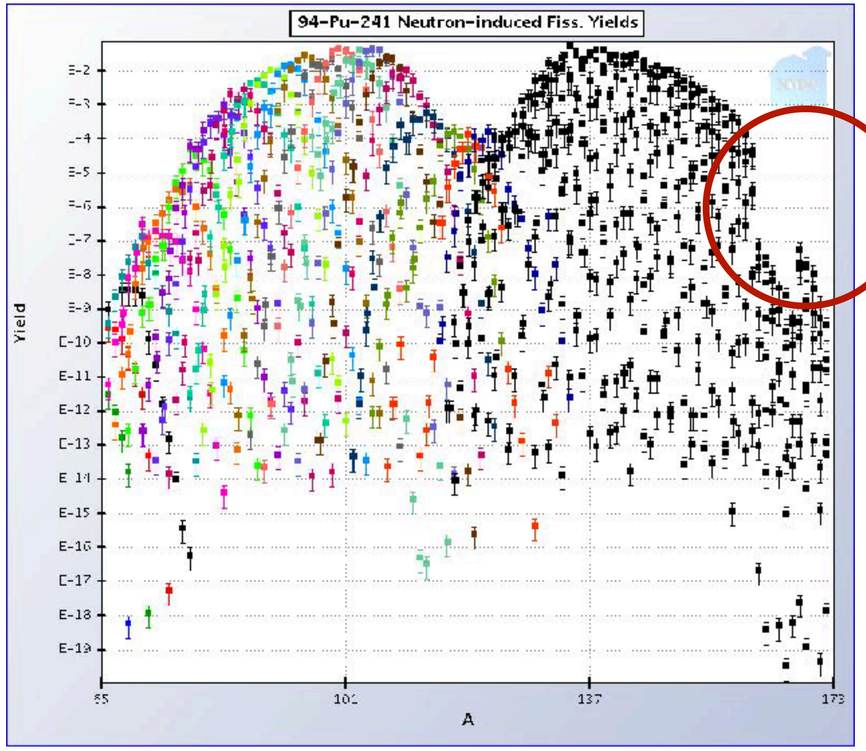
BNL Recommended:
C.J. Sears, et al. NDS 173, 118 (2021)

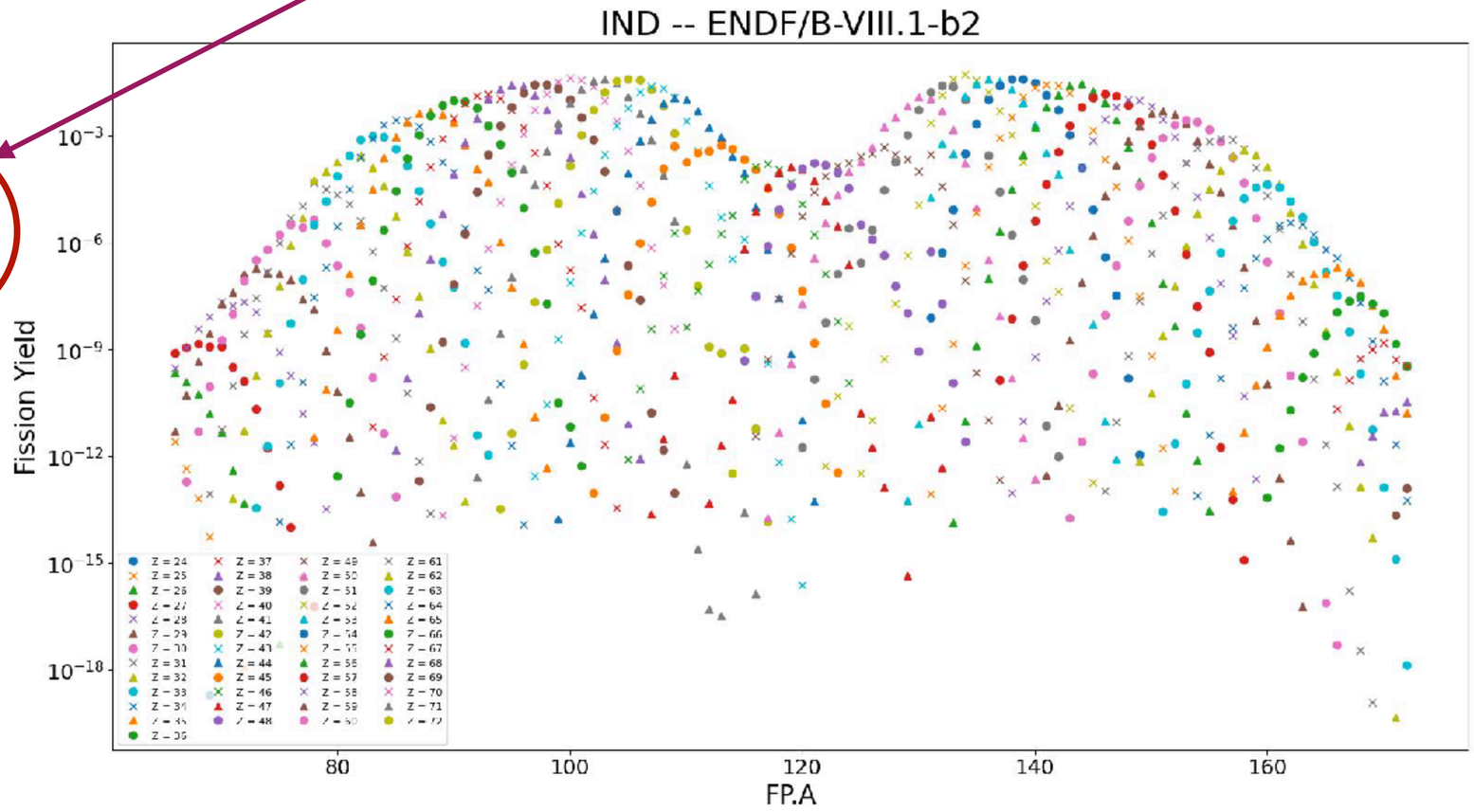
LANL evaluation

Los Alamos NATIONAL LABORATORY

BNL: Correction of ^{241}Pu Thermal FPY

- An issue was logged in 2019 on the NNDC git concerning the FYs of ^{241}Pu having a hole in the heavy-mass peak
- Origin of this issue investigated
- Correction made by BNL by rescaling / renormalizing data



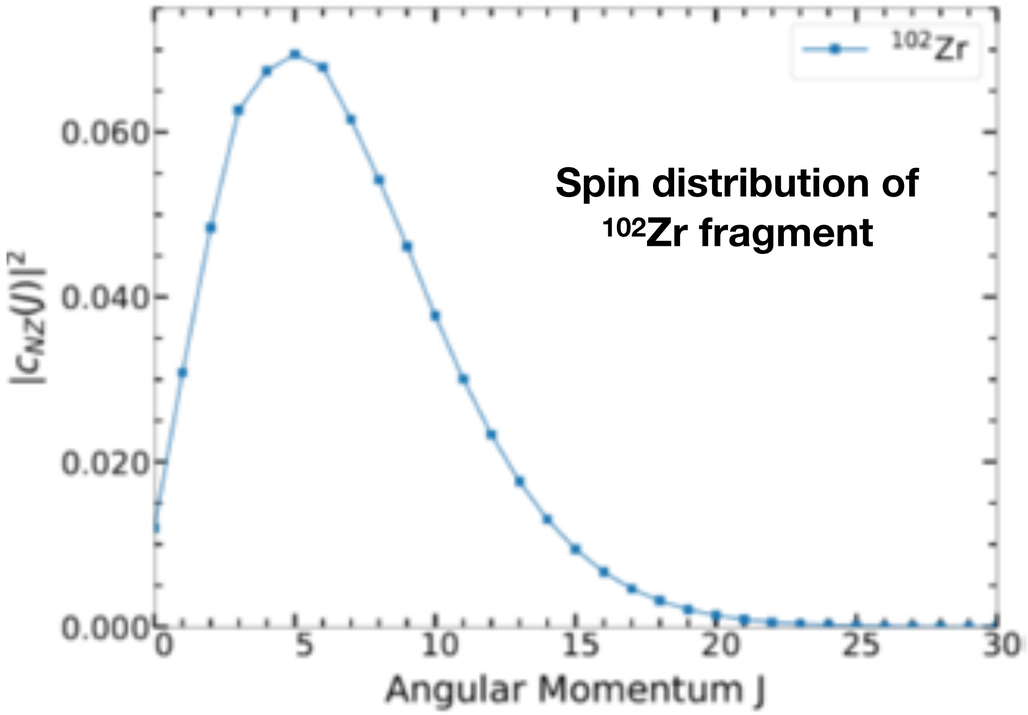


Los Alamos NATIONAL LABORATORY

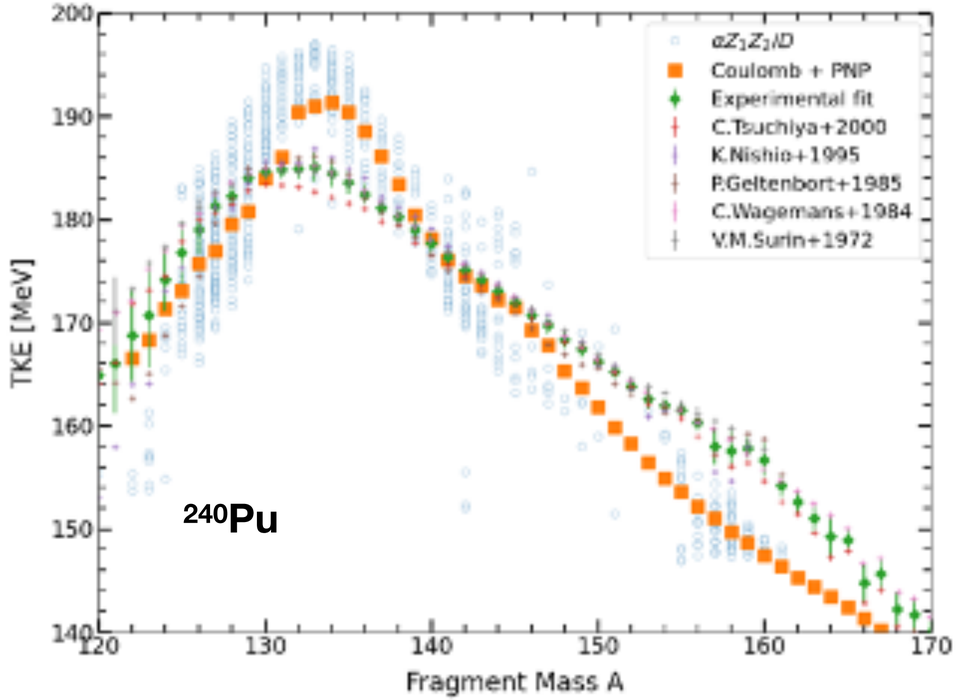
LLNL: Leveraging Projection Techniques

LLNL uses particle number projection to build a predictive model for TKE and to improve the prediction of spin distributions in fission fragments

- Combine particle number and angular momentum projection to extract spin distribution of fission fragments
  - Joint AMP+PNP implemented and validated
  - Next: Fold in probabilities of population



- Predict TKE by weighing $\alpha Z_1 Z_2/D$ with probabilities p(Z,N) in each scission configuration
  - Proof of concept gives decent agreement in ^{240}Pu
  - Next: Fold in probabilities of population



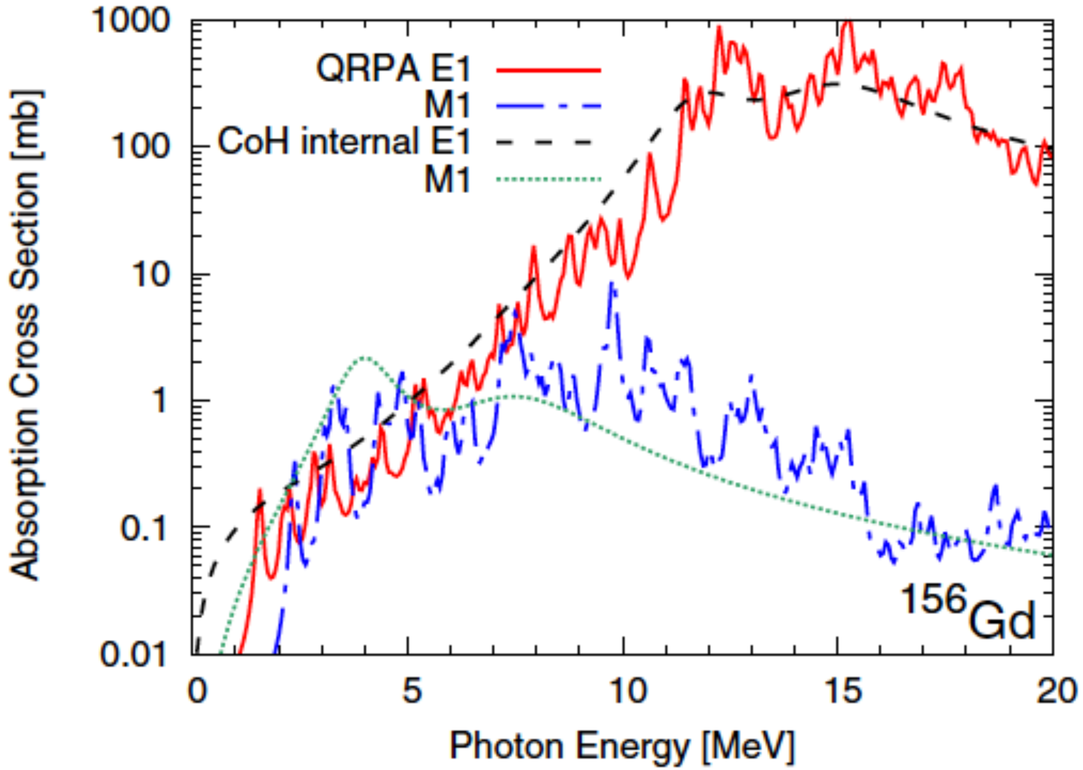
Los Alamos NATIONAL LABORATORY

Evaluation of Gamma Production: Introduction

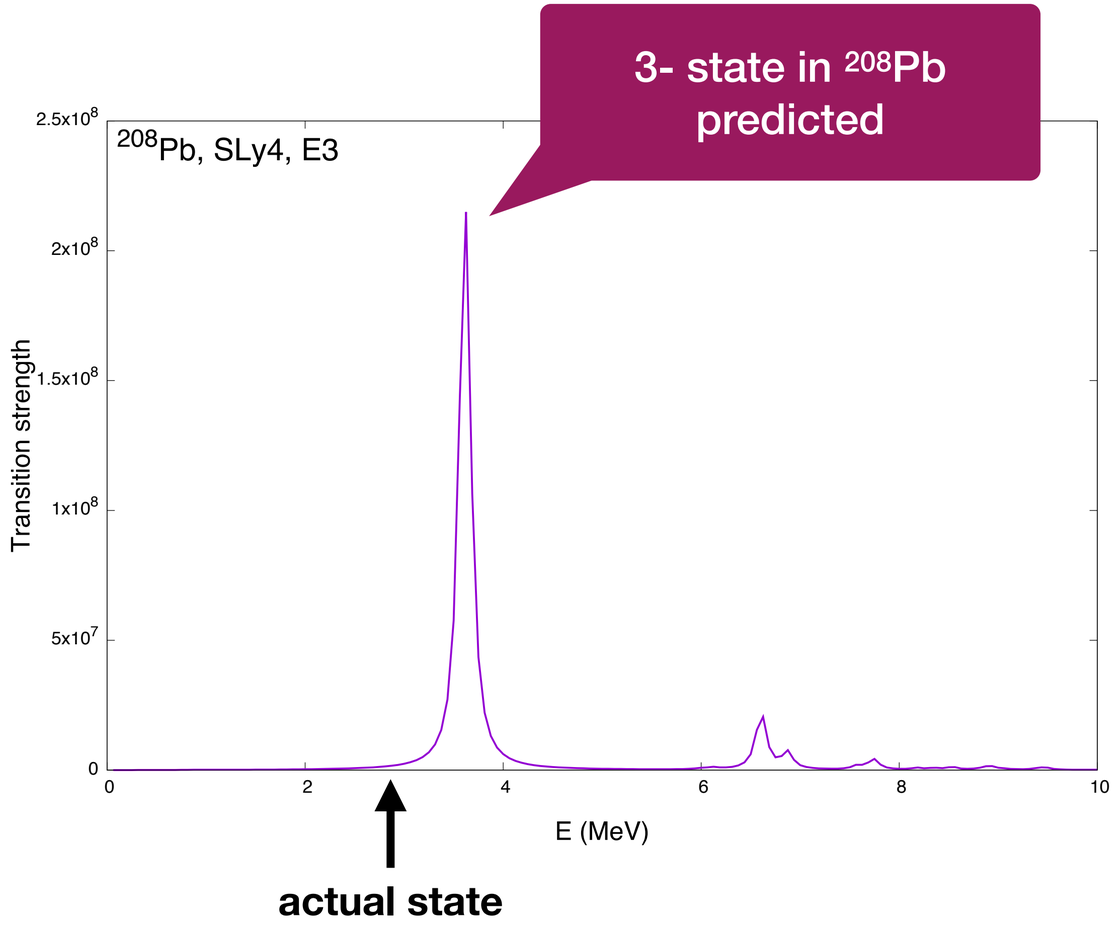
- **Gamma rays emitted by nuclear reactions (esp. neutron-induced reactions)**
  - inherent signatures of materials and nuclear reaction mechanisms
    - discrete gamma-lines produced by various nuclear reactions are used to identify materials in a non-destructive way
    - large number of gamma-ray multiplicities implies fissile materials
  - play an important role both in fundamental nuclear science and in a broad range of applications
- **Accurately modeling the gamma-ray emission process heavily depends on theoretical insights into the nuclear reaction and structure physics**
  - neutron radiative capture and inelastic scattering cross sections require a special expertise in nuclear data evaluation
- **This project aims at**
  - improving both the modeling of nuclear structure and nuclear reactions in order to produce the first state-of-the-art comprehensive evaluation of gamma-ray production
  - delivering a complete and realistic data library for applications

LANL: Finite Amplitude Method / Random Phase Approximation

- **Microscopic approach to nuclear excitation**
  - Electro-magnetic interaction for photo-absorption and neutron capture cross section
  - Effective NN interaction for nucleon inelastic scattering
  - Gamow-Teller for beta-decay



Sasaki, et al. PRC107, 054312 (2023)

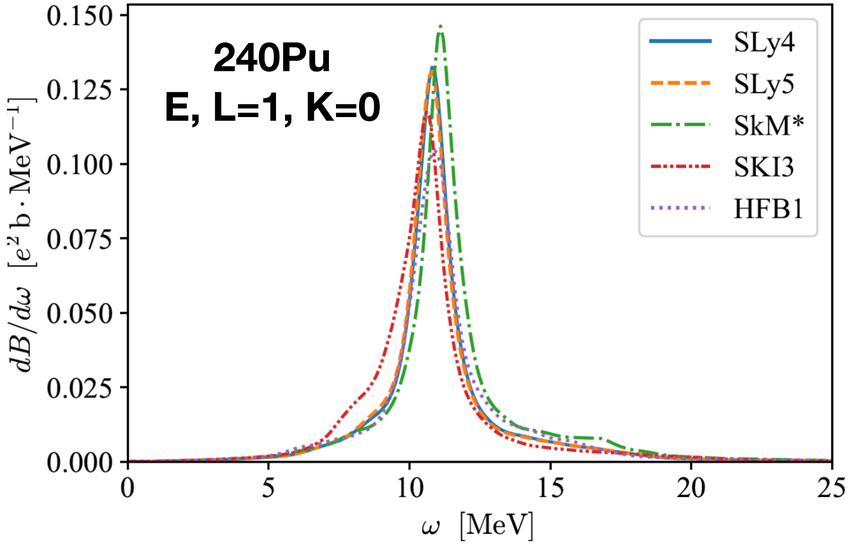


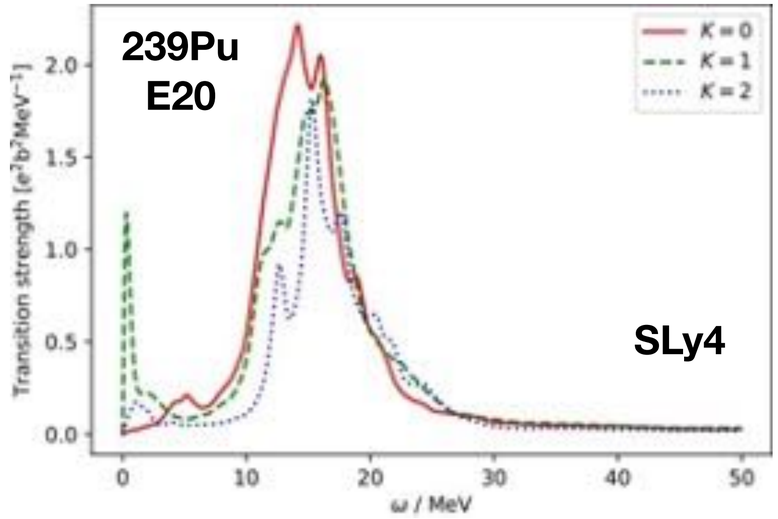
Los Alamos NATIONAL LABORATORY

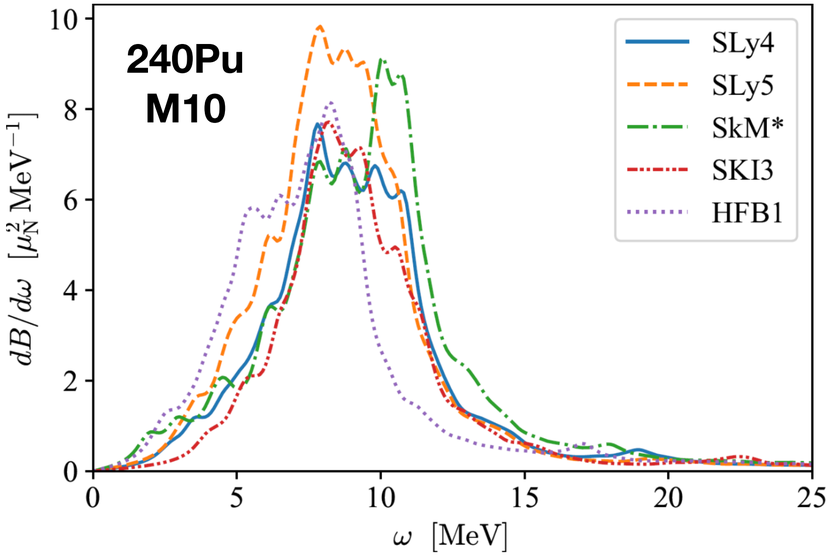
LLNL: Microscopic FAM Calculations

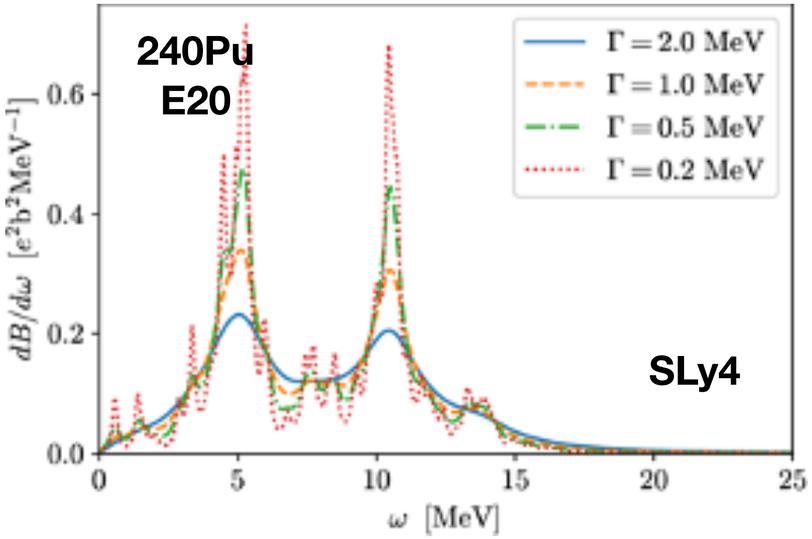
LLNL developed a new code to compute excitation strength functions with the finite-amplitude method in a fully microscopic theory

- FAM Formalism extended to odd-mass nuclei and finite temperature
- New code can give response to EL and ML operators (L=0,1,2,3) in even-even, odd or odd-odd nuclei at T=0 or T>0
- Paper in preparation to perform a systematic study of uncertainties
  - Dependency of energy functional
  - Trend as function of N
- Calculation of the chart of isotopes to follow





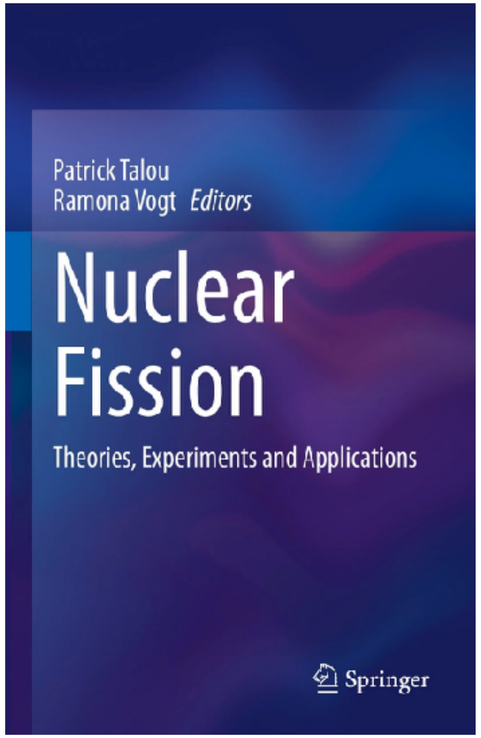




Los Alamos NATIONAL LABORATORY

Publications

- Energy dependent calculations of fission product, prompt, and delayed neutron yields for neutron induced fission on ^{235}U, ^{238}U, and ^{239}Pu, S. Okumura, T. Kawano, A. E. Lovell, T. Yoshida, J. Nucl. Sci. Technol. **59**, 96 (2022)
- Two body weak currents in heavy nuclei, E.M. Ney, J. Engel, N. Schunck, Phys. Rev. C **105**, 034349 (2022).
- Noniterative finite amplitude methods for E1 and M1 giant resonances, H. Sasaki, T. Kawano, I. Stetcu, Phys. Rev. C **105**, 044311 (2022)
- β-delayed one and two neutron emission probabilities southeast of ^{132}Sn and the odd-even systematics in r-process nuclide abundances, V. H. Phong, et al., Phys. Rev. Lett. **129**, 172701 (2022)
- β-delayed fission in the coupled quasiparticle random-phase approximation plus Hauser-Feshbach approach, M. R. Mumpower, * T. Kawano, and T. M. Sprouse, Phys. Rev. C **106**, 065805 (2022)
- Consideration of memory of spin and parity in the fissioning compound nucleus by applying the Hauser-Feshbach fission fragment decay model to photonuclear reactions, T. Kawano, A. Lovell, S. Okumura, H. Sasaki, I. Stetcu, P. Talou, Phys. Rev. C **107**, 044608 (2023)
- QRPA calculations for M1 transitions with the noniterative finite amplitude method and application to neutron radiative capture cross sections, H. Sasaki, T. Kawano, I. Stetcu, Phys. Rev. C **107,** 054312 (2023)
- Theory of nuclear fission, N. Schunck,D. Regnier, Prog. Part. Nucl. Phys. **125**, 103963 (2022)
- Axially-deformed solution of the Skyrme-Hartree-Fock-Bogoliubov equations using the transformed harmonic oscillator basis (IV) HFBTHO (v4.0): A new version of the program, P. Marevic, N. Schunck, E. M. Ney, R. Navarro Perez, M. Verriere, J. O'Neal, Comput. Phys. Commun. **276**, 108367 (2022)
- Microscopic calculation of fission product yields for odd-mass nuclei, N. Schunck, M. Verriere, G. Potel Aguilar, R. C. Malone, J. A. Silano, A. P. D. Ramirez, A. P. Tonchev, Phys. Rev. C **107**, 044312 (2023)
- Examination of decay heat measurements and their relevance for understanding the origin of the reactor antineutrino anomaly, A. Sonzogni, R.J. Lorek, A. Mattera, E. A. McCutchan, Phys. Rev. C **108**, 024617 (2023)
- Nuclear Fission - Theories, Experiments and Applications, Eds. P. Talou, R. Vogt, Springer (2023)



Los Alamos NATIONAL LABORATORY