New evaluations of neutron cross sections on ^{238}Pu, ^{237}Pu and ^{236}Pu

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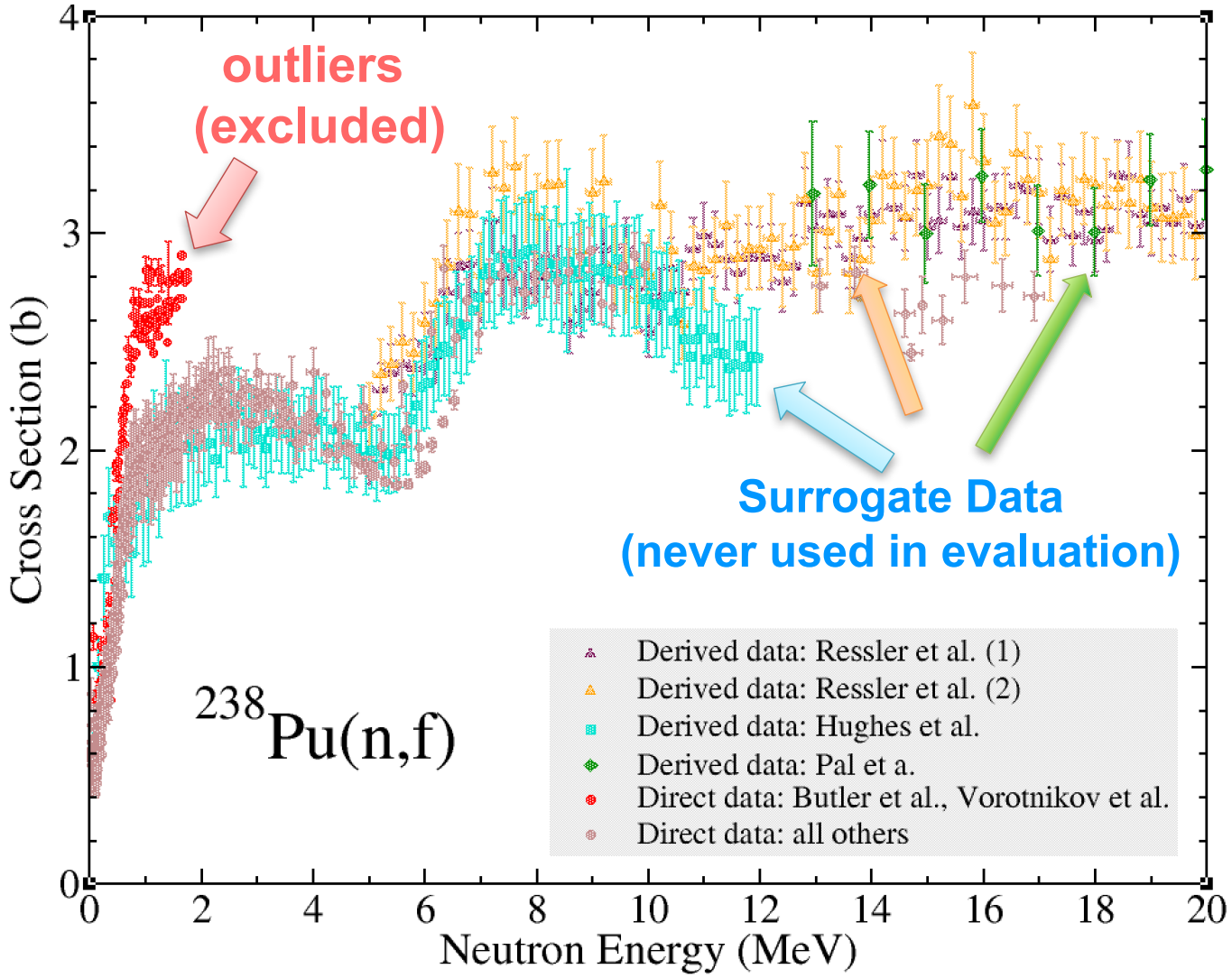
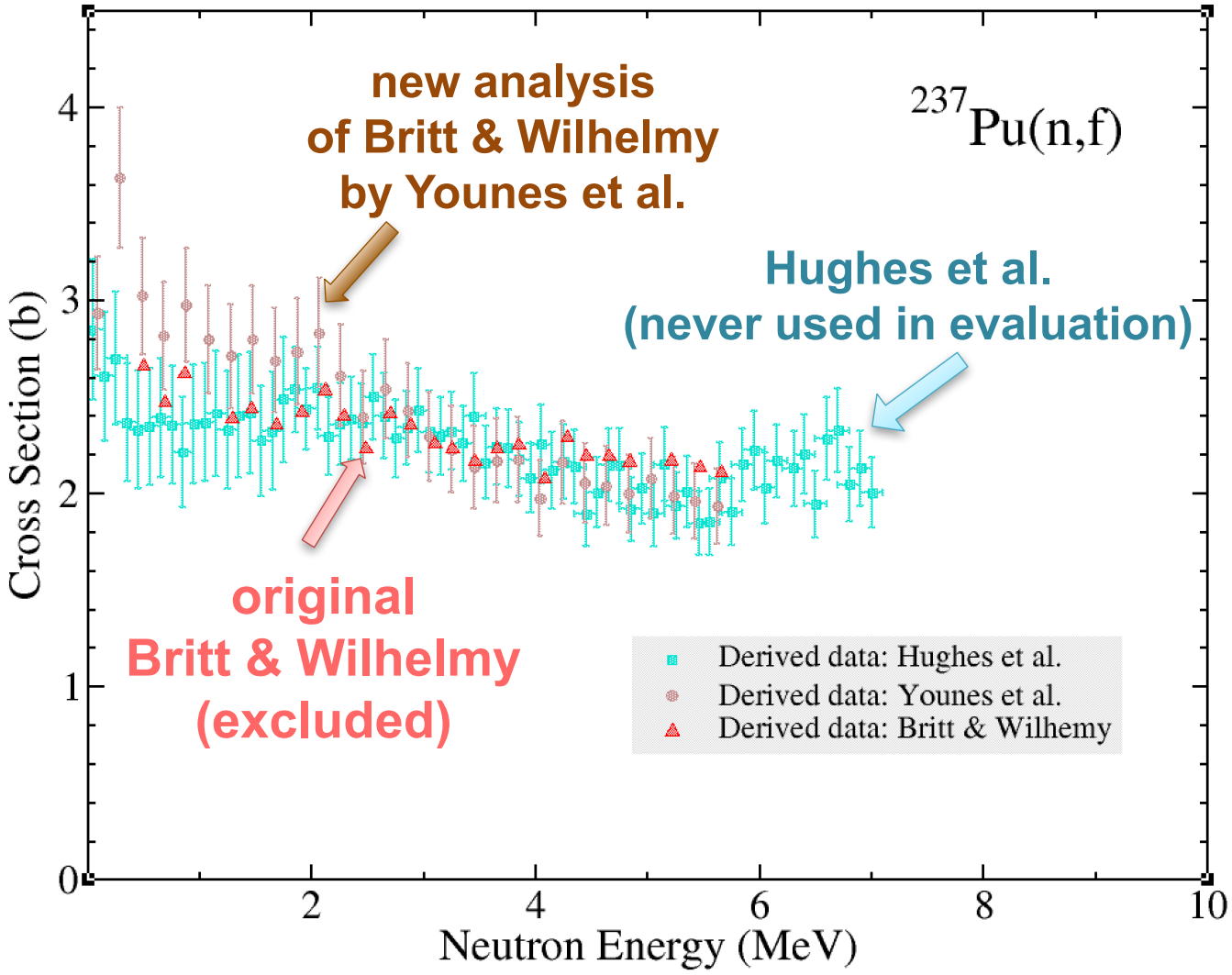
Previous evaluations of ^{238}Pu cross sections did not include data from latest 'surrogate' measurements



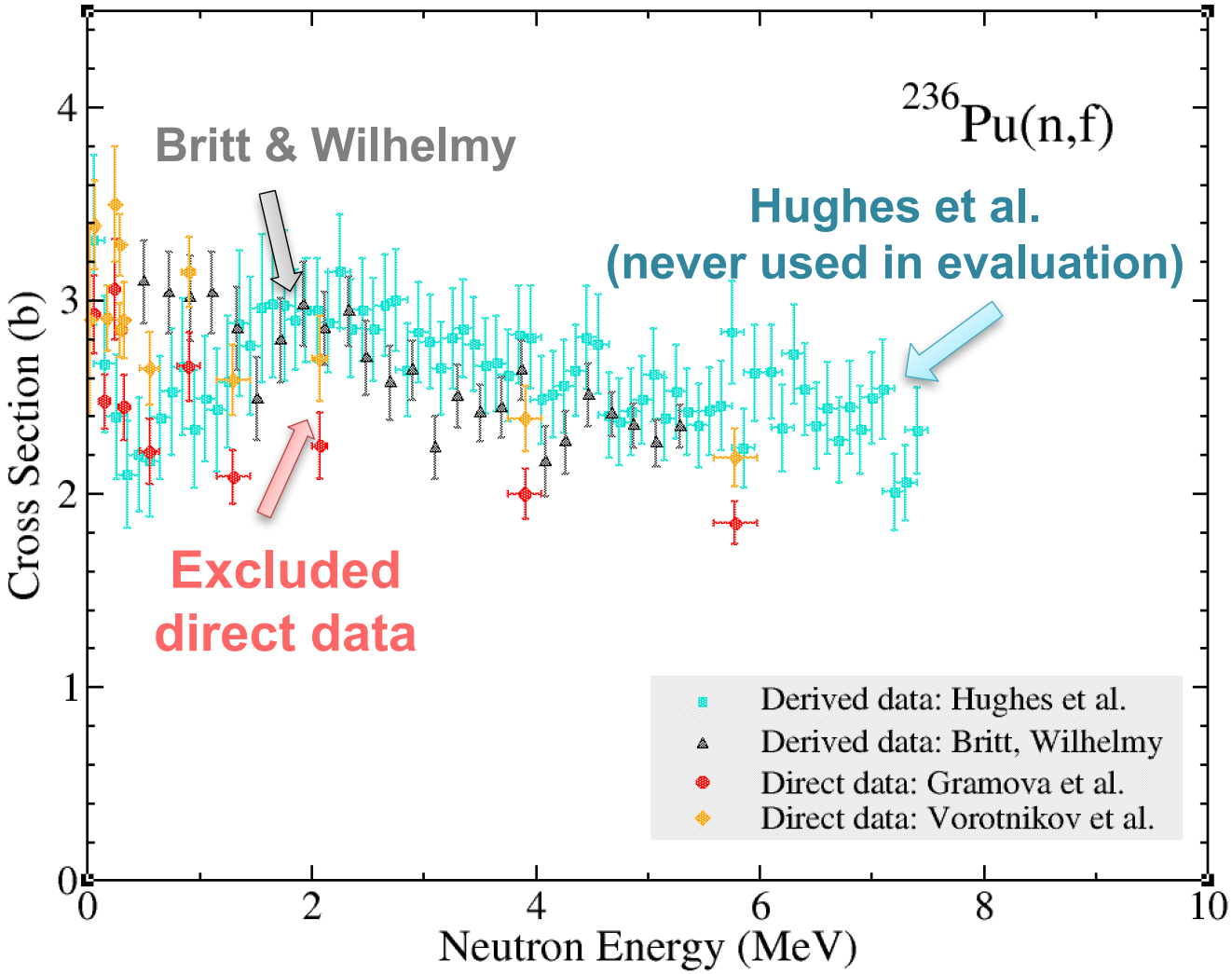
- Direct Data:
  - Multiple data sets available
  - Excluded outliers:
    - 1963 Butler et al.
    - 1966 Vorotnikov et al.
- Surrogate Data (**never used in an evaluation**):
  - Ressler et al. (PRC 83, 054610):
    - **(1)** ^{239}Pu(α,α'f)/^{235}U(α,α'f)
    - **(2)** ^{239}Pu(α,α'f)/^{236}U(α,α'f)
    - 5-20 MeV energy range
  - Hughes et al. (PRC 90, 014304):
    - ^{235}U(p,p'f)/^{239}Pu(p,p'f)
    - ~0-11.9 MeV energy range
  - Pal et al. (PRC 91, 054618):
    - ^{235}U(^{6}Li,d)^{239}Pu/ ^{232}Th(^{6}Li,d)^{236}U
    - 13-22 MeV energy range

Previous evaluations of ^{237}Pu cross sections did not include data from latest 'surrogate' measurements



- No Direct Data
- Surrogate Data (excluded):
  - Britt & Wilhelmy (NSE 72, 222)
    - deduced from (^{3}He,xf)
    - original analysis
- Surrogate Data (never used in an evaluation):
  - Younes et al. (UCRL-TR-201913):
    - re-analysis of Britt & Wilhelmy data
    - correction to account for spin mismatch between (n,f) and surrogate reaction
    - ~0-6 MeV energy range
  - Hughes et al. (PRC 90, 014304):
    - ^{235}U(p,df)/^{239}Pu(p,df)
    - ~0-7.1 MeV energy range

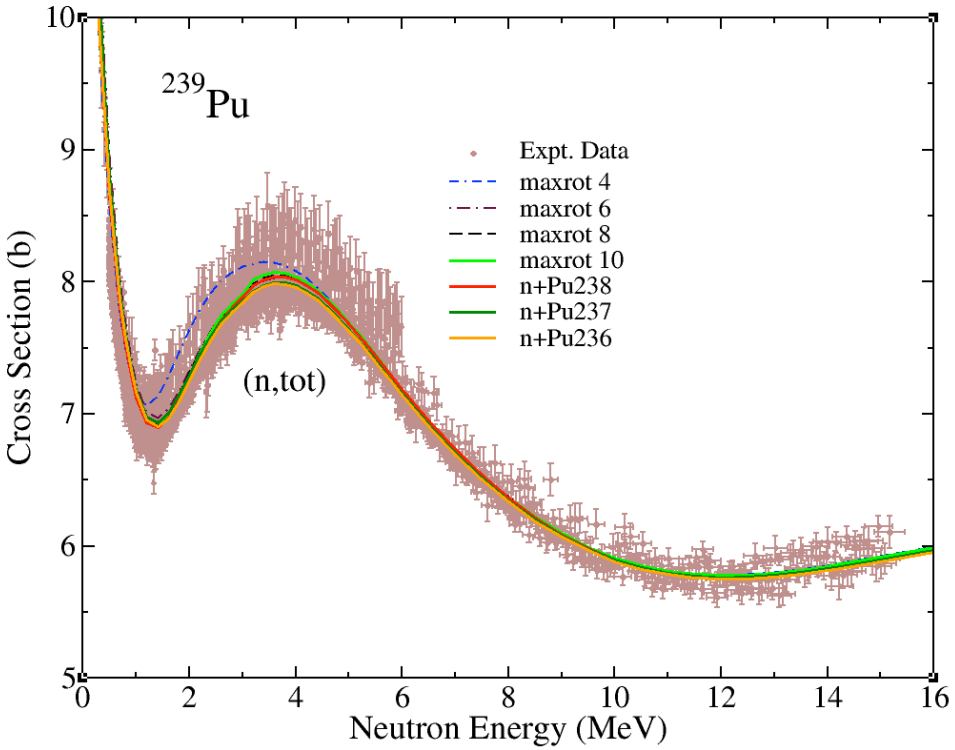
Previous evaluations of ^{236}Pu cross sections did not include data from latest 'surrogate' measurements



- Excluded Direct Data:
  - Vorotinikov et al. (1987)
  - Gramova et al. (1990)
    - same data but ~0.5b shift
- Surrogate Data:
  - Britt & Wilhelmy (NSE 72, 222)
    - deduced from (^{3}He,xf)
- Surrogate Data (never used in an evalution):
  - Hughes et al. (PRC 90, 014304):
    - ^{235}U(p,tf)/^{239}Pu(p,tf)
    - ~0-7.4 MeV energy range

Evaluation method

- Calculations for neutron energies above the resonance region and up to 20 MeV, using **TALYS-1.8**
  - Coupled channel calculations
    - **Optical model:** Soukhovitskii et al. (2004) with deformation parameters β_2=0.212 and β_4 = 0.066 taken from neighboring ^{239}Pu
    - **Rotational states:** all known, or a minimum of 10
  - Preequilibrium reactions calculations
    - Two-component exciton model of Koning and Duijvestijn



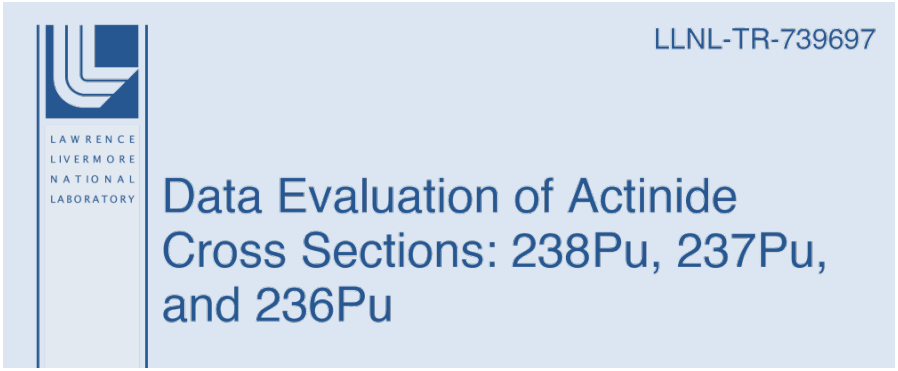
Convergence of the ^{239}Pu(n,tot) cross section with maximum number of rotational states. Overlaid are also the (n,tot) cross sections for ^{238}Pu, ^{237}Pu and ^{236}Pu.

Evaluation method

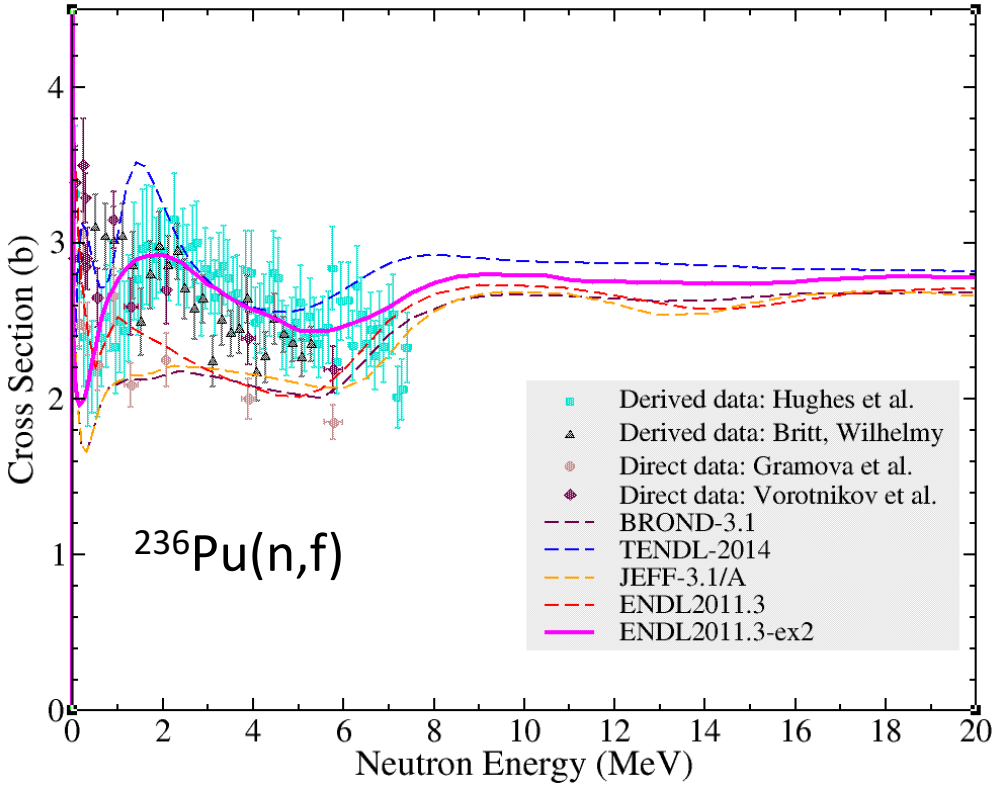
- Calculations for neutron energies above the resonance region and up to 20 MeV, using **TALYS-1.8**
  - Hauser-Feshbach statistical calculations
    - **Decay channels:** fission, γ, n, p, d, t, h and α
    - **Level densities:** constant-temperature model of Gilbert & Cameron with shell correction energy and collective enhancement
      - Adjusted parameters: $a(S_n)$, pairing gap, P_{shift}, δ_W, T, E_0, and E_M
    - **Fission:** double-humped barriers, Hill-Wheeler effective transmission coefficient
      - No class II states, continuum states assumed above barriers
      - Adjusted parameters: $B_1, \hbar\omega_1, B_2, \hbar\omega_2$
  - Gamma-ray strength functions from ENDF/B-VII.1 (= JENDL-AC-2008)
    - **E1 transitions:** generalized Lorentzian form of Kopecky and Uhl
    - **All other transitions**: Brink-Axel standard Lorentzian form

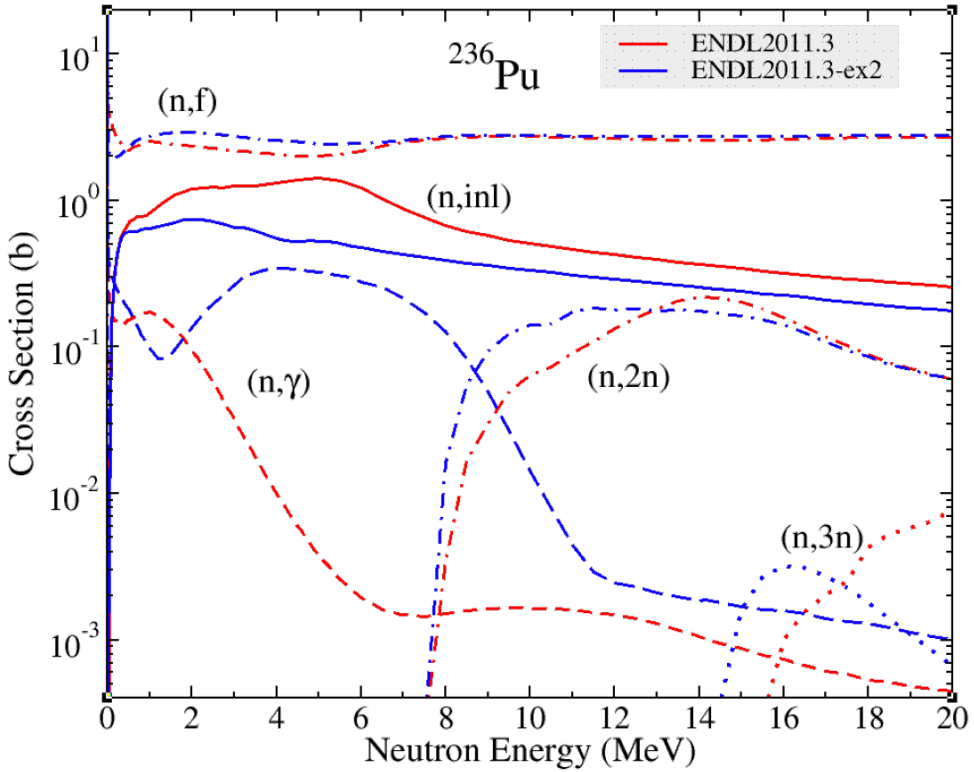
Data Processing and Release Procedures

- Translated from TALYS output to ENDL format using GEFT
  - will be translated into ENDF6 format, using TEFAL
- Resonance data and fission product data adopted unchanged from the previous evaluations in the ENDL2011.3 library
  - sourced from JENDL and subsequently ENDF/B-VII
- Released within LLNL in experimental ENDL2011.3-ex2 library (=ENDL2011.3 except for ^{238}Pu, ^{237}Pu, and ^{236}Pu)
- Details in **LLNL-TR-739697**
  - Report available upon request
  - TALYS-1.8 input/output files available upon request



Results for ^{236}Pu

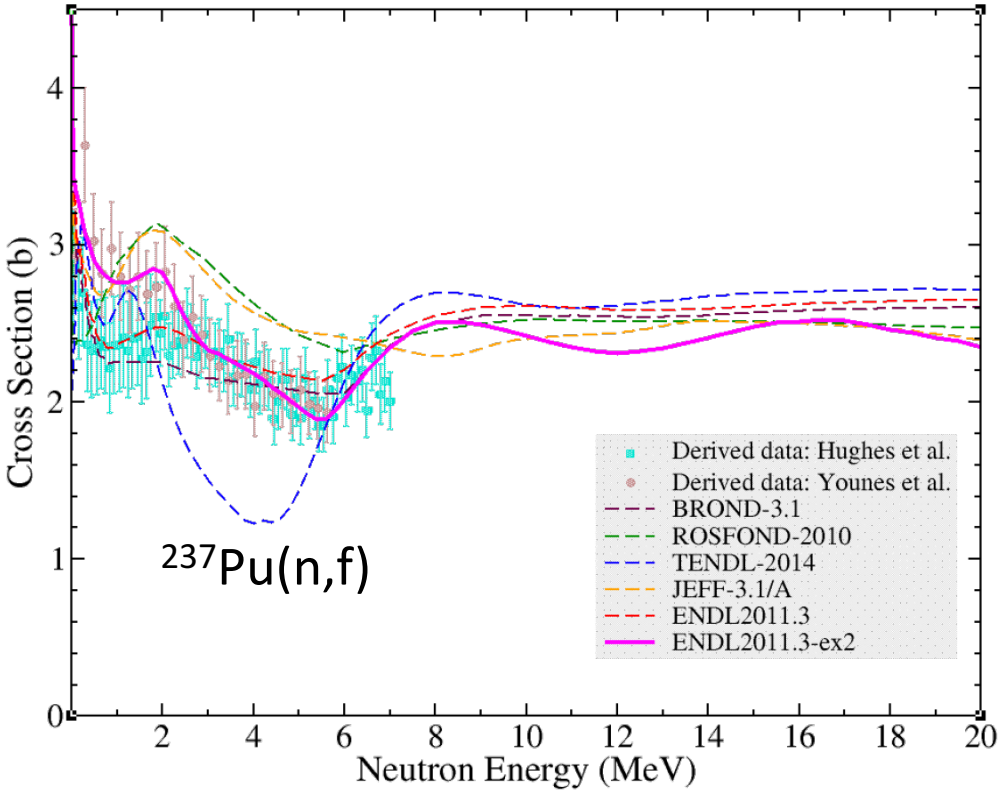


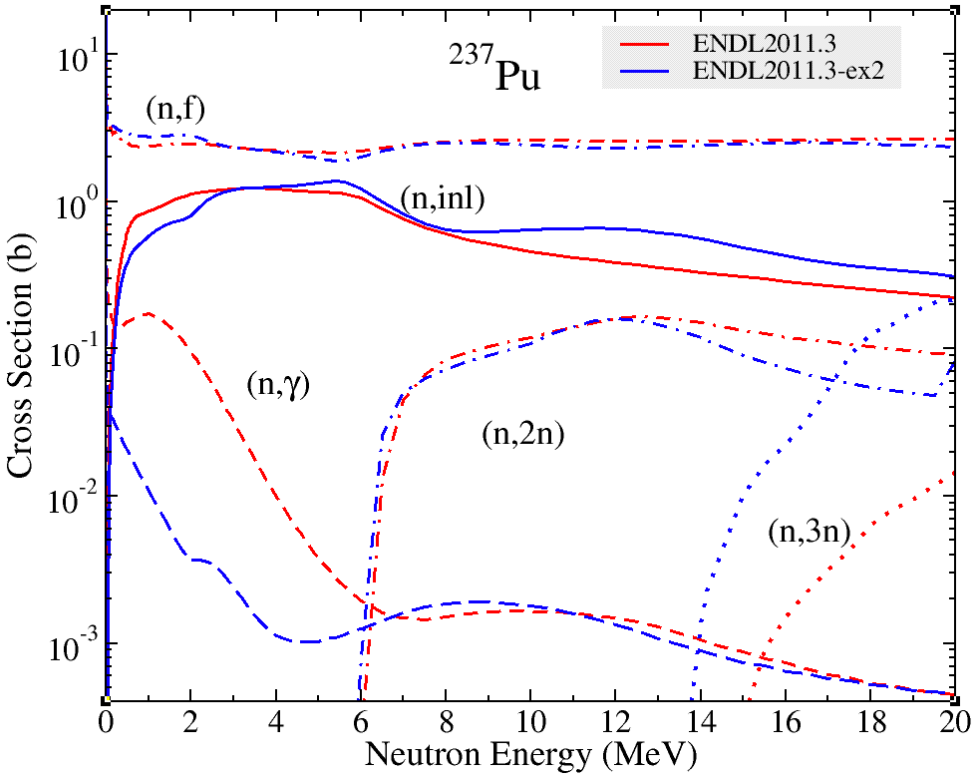


- (n,f) differs from previous evals below 8 MeV
  - follows trend of surrogate data
  - okay also below 1 MeV, because ^{237}Pu compound is an odd-even nucleus

- Changes in (n,n') and (n,γ) correlated with those in (n,f)
- (n,3n) could be further improved

Results for ^{237}Pu

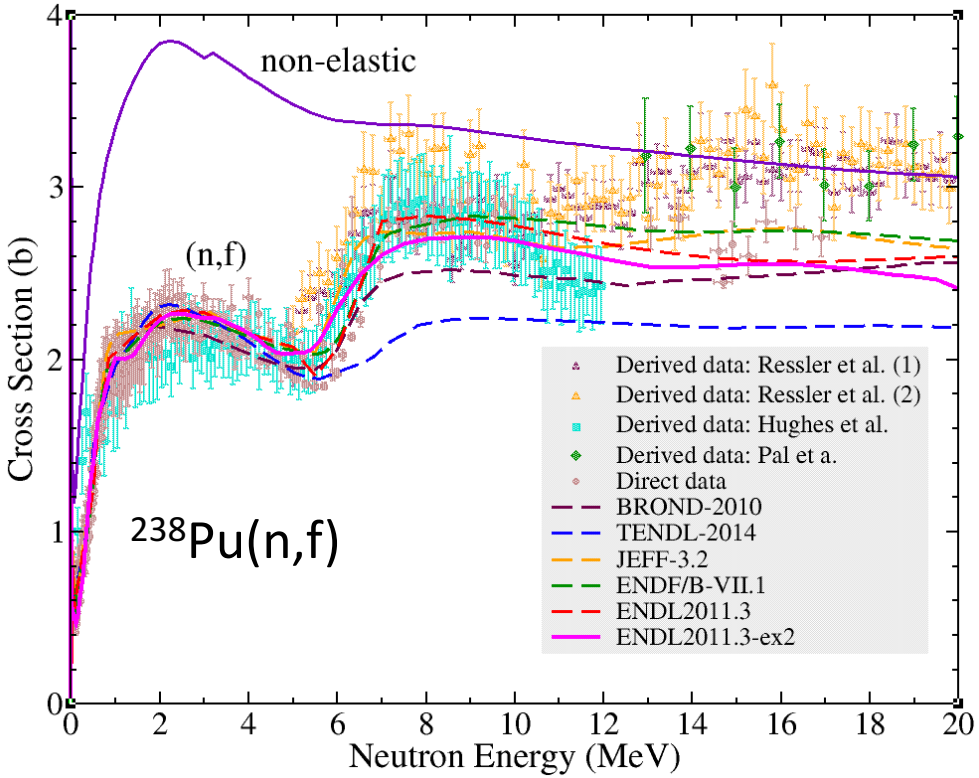


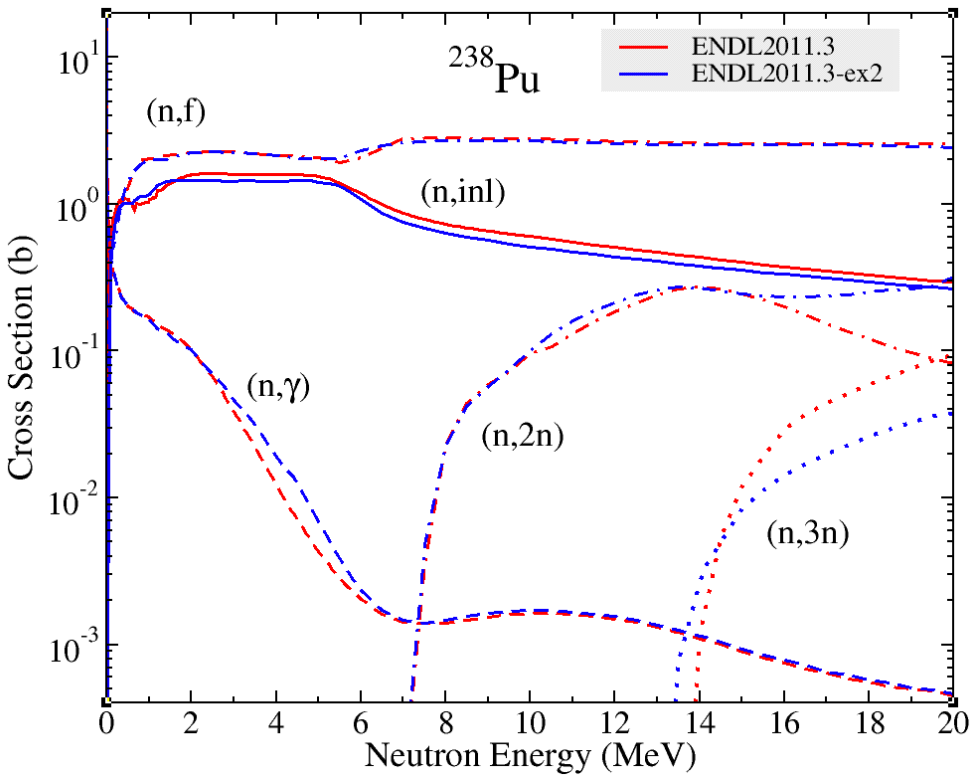


- (n,f) main difference below 3 MeV
  - follows Younes' analysis of Britt & Wilhelmy
  - second and third chance constrained by ^{236}Pu evaluation

- Changes in (n,n') and (n,γ) correlated with those in (n,f)
- (n,2n), (n,3n) could be further improved above ~ 13 MeV

Results for ^{238}Pu

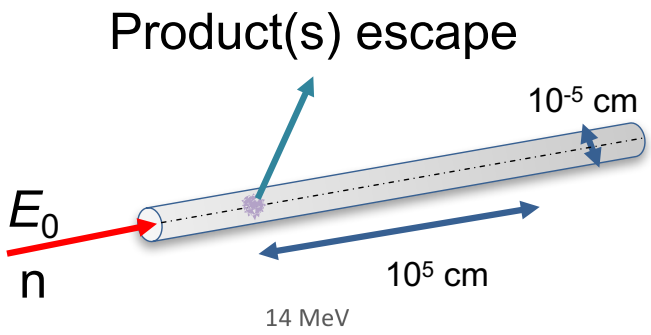


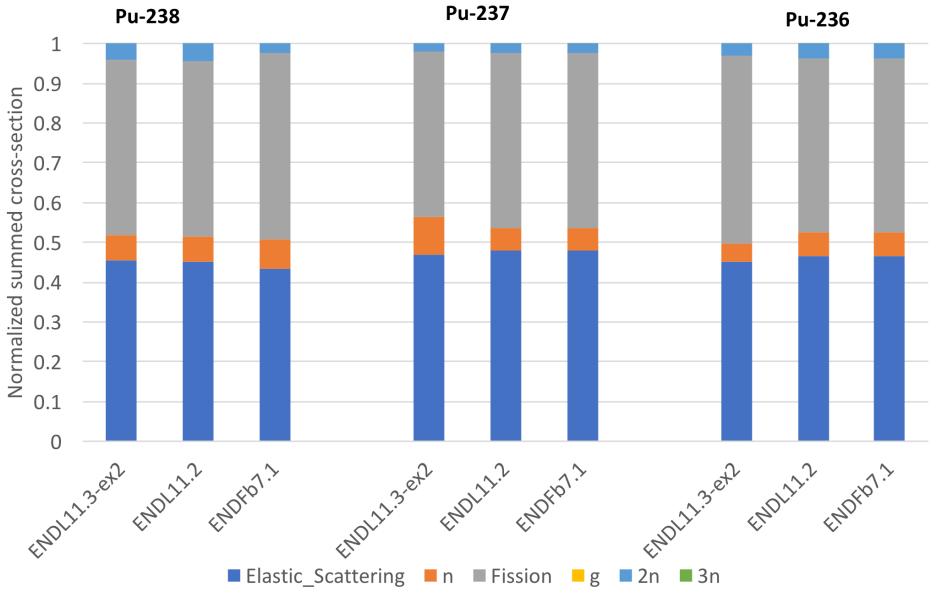


- (n,f) close to ENDF/B-VII.1 evaluation
  - Ressler and Pan data very hard to reproduce
  - Not enough non-elastic, constrained by ^{237}Pu, ^{236}Pu evaluations

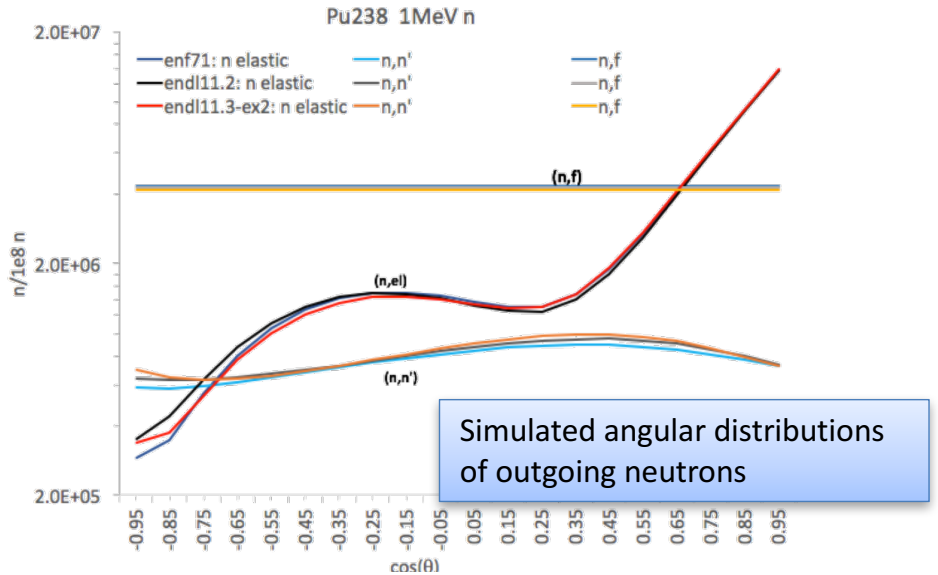
- Small changes in all reaction channels
- (n,2n), (n,3n) could be further improved above ~ 14 MeV

Verification test: 'Broomstick' problem, LLNL's Monte Carlo particle transport code Mercury

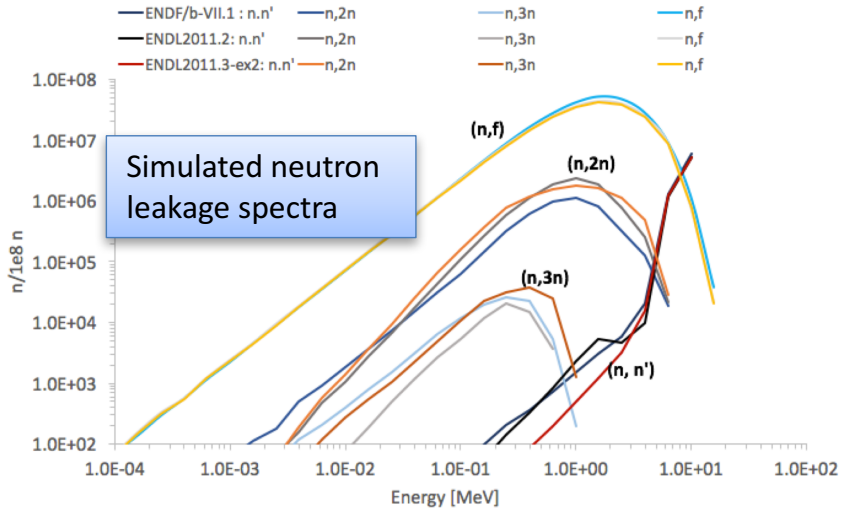




Normalized summed cross-section contributions



Simulated angular distributions of outgoing neutrons



Simulated neutron leakage spectra

Conclusions

- New evaluations of neutron cross sections on ^{238}Pu, ^{237}Pu, ^{236}Pu
  - Include latest data sets from surrogate measurements that had never been evaluated before
  - Calculations for neutron energies above the resonance region and up to 20 MeV, using TALYS-1.8
  - Resonance data and fission product data adopted unchanged from the previous evaluations in the ENDL2011.3 library
  - Released within LLNL in experimental ENDL2011.3-ex2 library (=ENDL2011.3 except for ^{238}Pu, ^{237}Pu, and ^{236}Pu)
  - Verification test: 'Broomstick' problem, using LLNL's Monte Carlo particle transport code Mercury
  - Possible candidate for ENDF/B-VIII.1