Inelastic Scattering Cross Section for Pu-239

T. Kawano

T-2, LANL

Nov. 3–5, 2014

Introduction

- ^{239}Pu Evaluation in the fast energy range
- Model calculations center
  - P. Young (LANL), GNASH
  - O. Iwamoto (JAEA), CCONE
  - P. Romain (CEA/DAM), TALYS
  - R. Capote (IAEA), EMPIRE (mainly focus on ^{238}U)
- Discussions at CEA/DAM
  - Optical potential gives considerable differences in calculated inelastic scattering cross sections
  - new theoretical development, such as Engelbrecht-Weidenmüller transformation

Direct Channel in Hauser-Feshbach

- Approximated Method
  - calculate transmissions from Coupled-Channels S-matrix

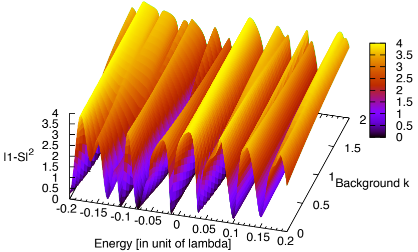
$$T_a = 1 - \sum_c |\langle S_{ac} \rangle \langle S^*_{ac} \rangle|^2$$

  - eliminate flux going to the direct reaction channels
  - at least $\sum_a T_a$ gives correct compound formation cross section
  - HF performed in the direct-eliminated cross-section space
- Engelbrecht-Weidenmüller transformation
  - diagonalize S-matrix to eliminate the direct channels
  - HF performed in the channel space
  - transform back to the cross section space

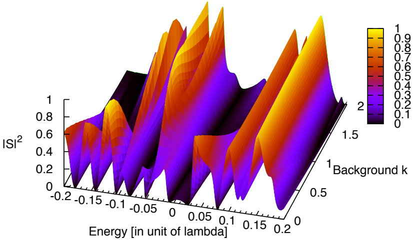
GOE Generated Elastic/Inelastic Cross Sections

Fixed resonances, background component K_{ab} changed from 0 to 2
$N = 100, \Lambda = 2$

Elastic



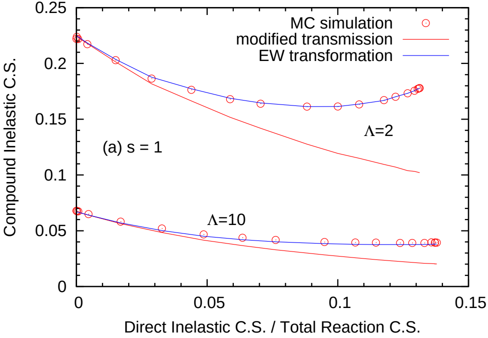
Inelastic



Inelastic scattering cross sections affected by the direct reaction strongly due to the interference between the resonances and the background term.

Inelastic Scattering Enhancement

Compound inelastic scattering cross section as a function of $\sigma_{\mathrm{DI}}/\sigma_{\mathrm{R}}$



- The approximation method using the modified transmission coefficients does not work when the direct channels are strong,
- since the compound inelastic scattering cross sections will be largely underestimated.
- This happens when
  - direct cross section is strong
  - the number of open channels small

Moldauer and Engelbrecht-Weidenmüller

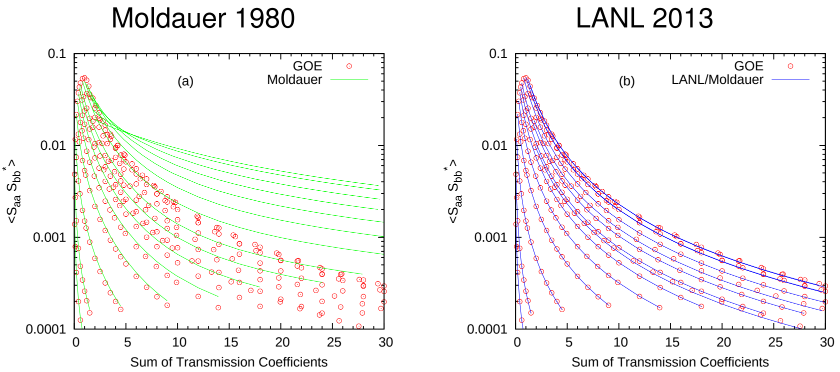
- In the actual cross section calculation, there are a lot of uncoupled channels (fission and capture)
- GOE triple-integral calculation for all channels are impractical
- Apply Engelbrecht-Weidenmüller transformation to Moldauer's WFC

$$P_{ab} = \delta_{ab} - \sum_c \langle S_{ac} \rangle \left\langle S^*_{bc} \right\rangle , \qquad (UPU^\dagger)_{\alpha\beta} = \delta_{\alpha\beta} p_\alpha \tag{1}$$

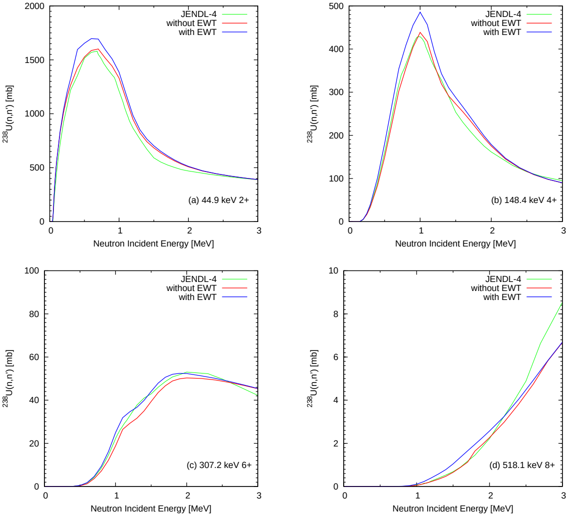
$$\begin{aligned} \langle \sigma^{\mathrm{fl}}_{ab} \rangle &= \sum_{\alpha\beta} U^*_{\alpha a} U^*_{\beta b} \left\{ U_{\alpha a} U_{\beta b} + U_{\alpha a} U_{\beta b} (1 - \delta_{\alpha\beta}) \right\} \left\langle |\tilde{S}_{\alpha\beta}|^2 \right\rangle \\ &\quad + U^*_{\alpha a} U^*_{\beta b} U_{\alpha a} U_{\beta b} \left\langle |\tilde{S}_{\alpha\alpha} \tilde{S}^*_{\beta\beta}| \right\rangle \end{aligned} \tag{2}$$

$$\left\langle |\tilde{S}_{\alpha\alpha} \tilde{S}^*_{\beta\beta}| \right\rangle = \left(\frac{2}{\nu_\alpha} - 1 \right)^{1/2} \left(\frac{2}{\nu_\beta} - 1 \right)^{1/2} \sigma_{\alpha\beta} . \tag{3}$$

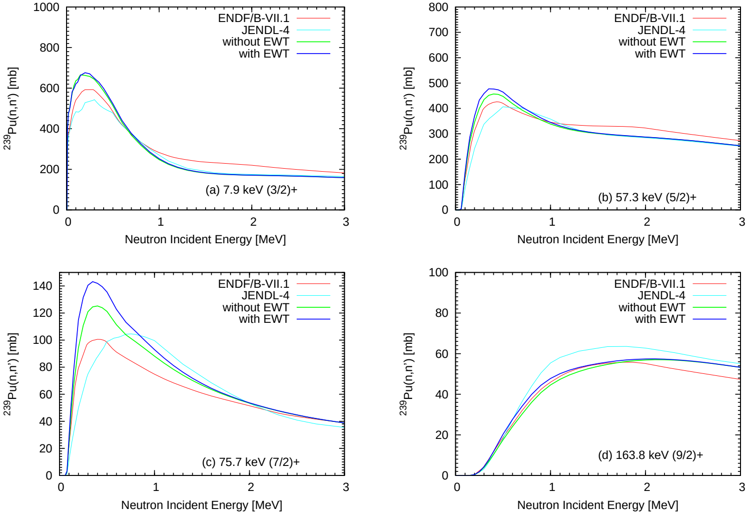
Moldauer's $\langle S_{aa} S_{bb} \rangle$ Term



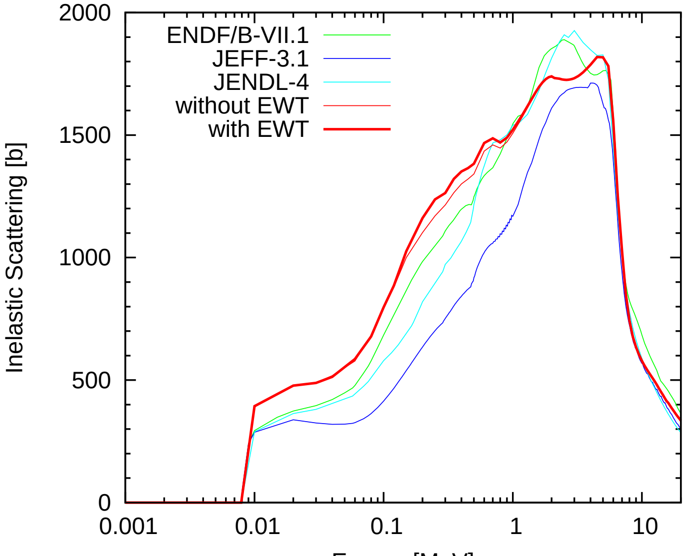
U-238 Inelastic Scattering Cross Section



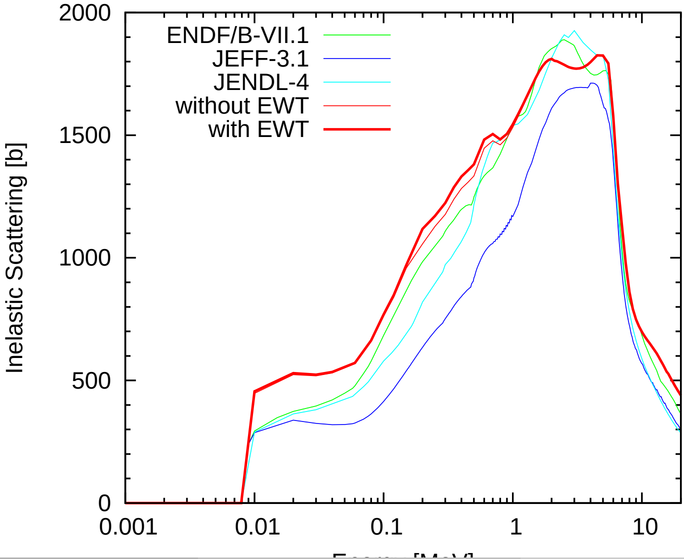
Pu-239 Inelastic Scattering Cross Section



Pu-239 Total Inelastic Scattering Cross Section



Phil. Young Optilcal Potential



Remarks

- Unresolved resonance region
  - use LSSF=1 option, similar to CEA/DAM and JAEA
  - smooth connection with the resonance region from ORNL and CEA/DEN
- Model calculation to be finished
  - optical potential — Soukhovitskii et al. with some modification
  - Engelbrecht-Weidenmüller transformation included
- New sections to be provided
  - MF=6 for all reaction channels will be provided, to resolve the lumped fission γ-ray problem
  - possible re-evaluation of $\overline{\nu}_p$ around 1 MeV region
  - Engelbrecht-Weidenmüller transformation included