Review of nuclear data of major actinides in JENDL-4.0

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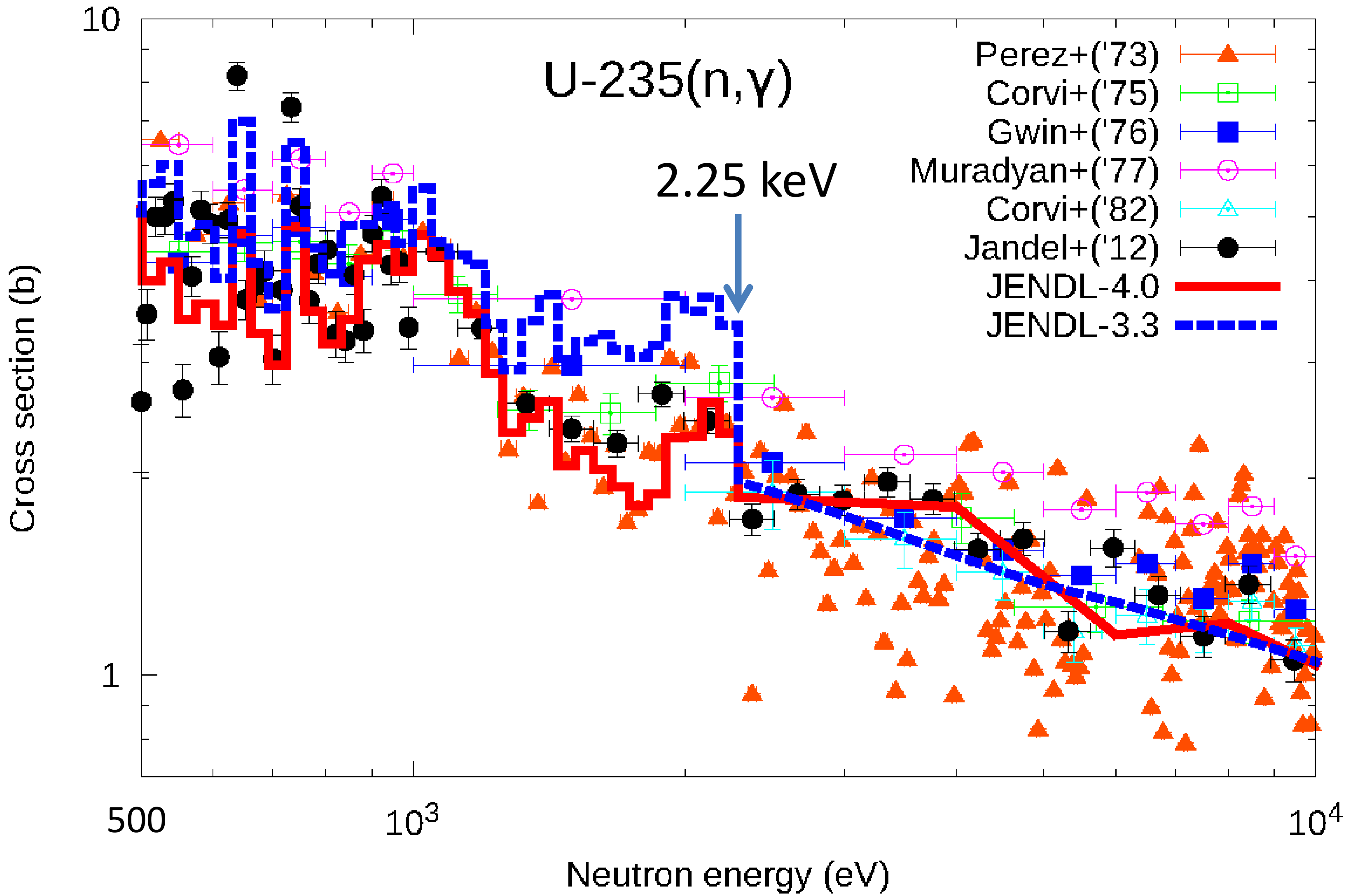
Resonance region

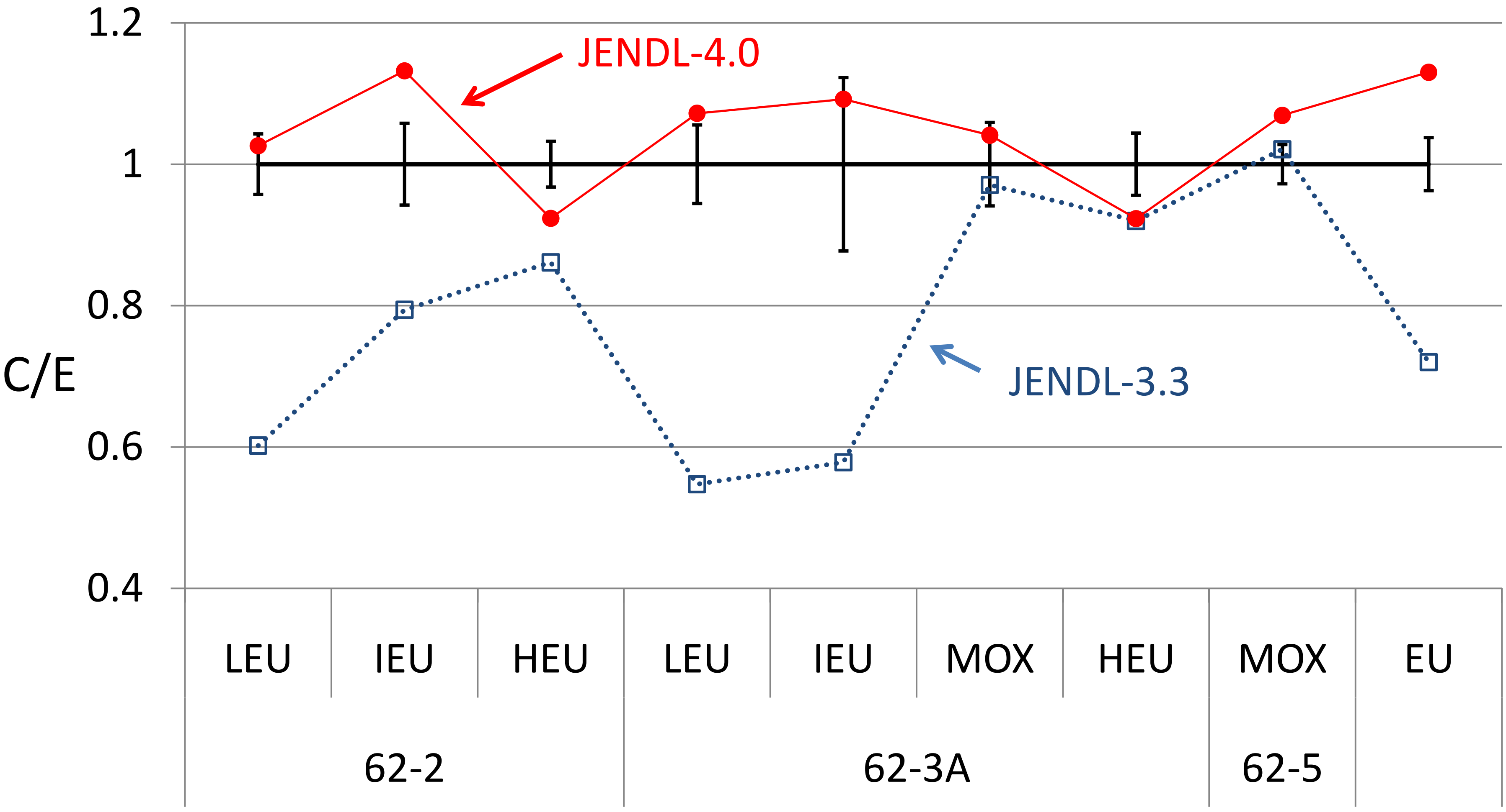
Resolved resonance parameter

- U-235
  - Leal et al. *NSE,131,230(1999)*
    (=JENDL-3.3, ENDF/B-VII.1, JEFF-3.1, CENDL-3.1, ROSFOND-2010)
  - Upper energy limit: 2.25 keV -> 0.5 keV
    - Na-void reactivity(BFS-2, FCA)
- U-238
  - Derrien et al. *NSE,161,131(2009)*
    (=ENDF/B-VII.1,ROSFOND-2010)
- Pu-239
  - Derrien et al. *ND2007,Nice (2007)*

U-235 capture cross section (resonance region)



C/E values of sodium void reactivity



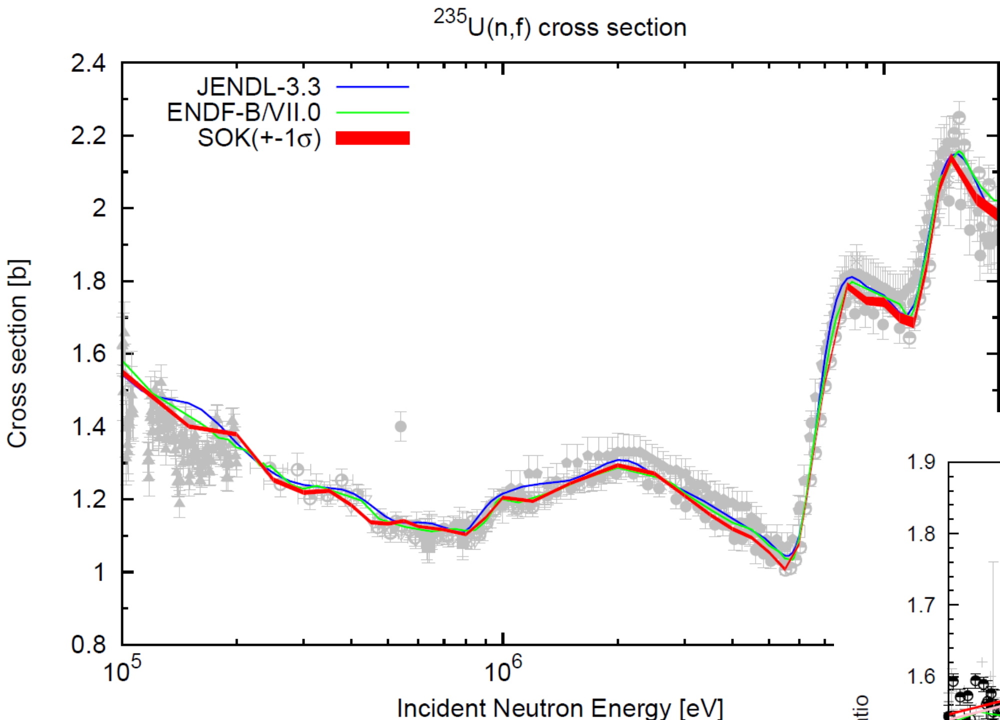
G. Chiba et al. J. Nucl. Sci. Technol. 48, 172 (2011)
M. Fukushima et al. Prog. Nucl. Sci. Technol Vol.2 (2011)

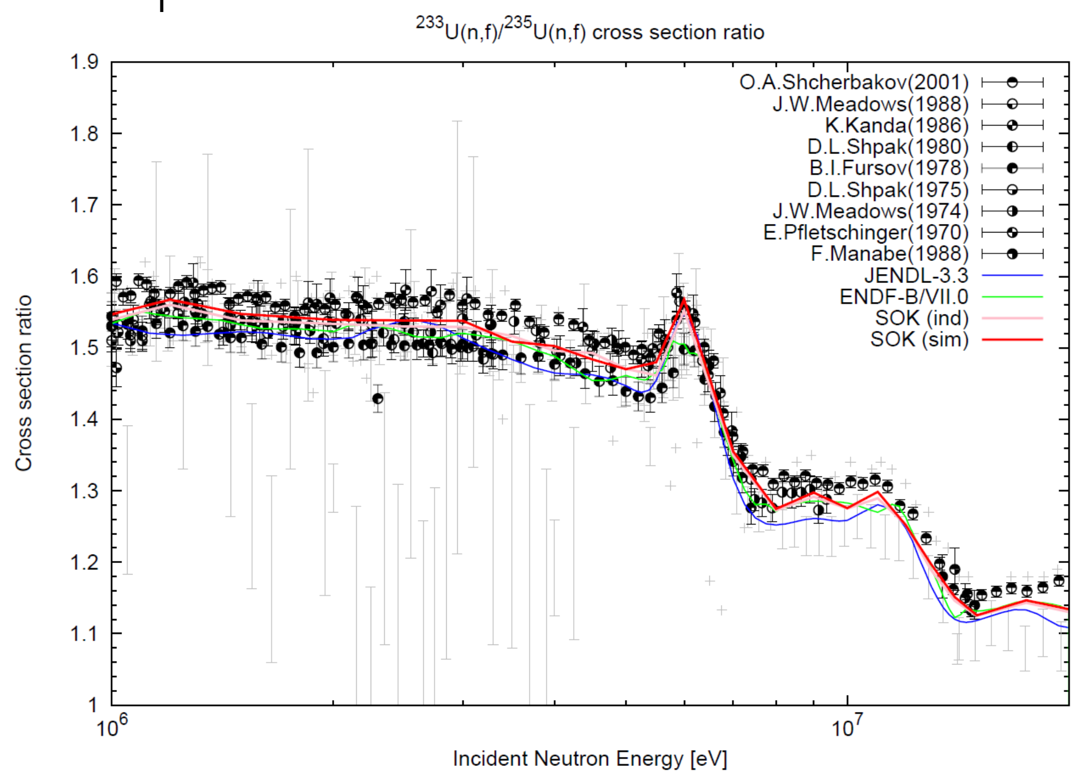
Fission cross section

- Simultaneous evaluation
  - U-233,235,238,Pu-239,240,241
- Least-squares fitting
  - SOK code (Kawano)
  - First order spline
  - linearize ratio data by taking log
- Experimental data

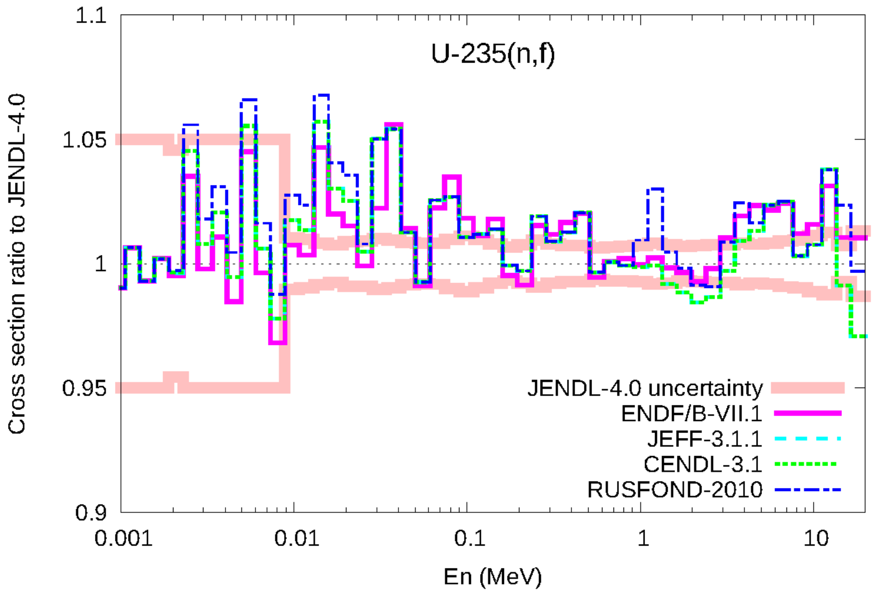
Reaction	sets	Reaction	sets
^{233}U	13	^{233}U/^{235}U	9
^{235}U	17	^{238}U/^{233}U	1
^{238}U	9	^{238}U/^{235}U	18
^{239}Pu	16	^{239}Pu/^{235}U	14
^{240}Pu	4	^{240}Pu/^{235}U	12
^{241}Pu	6	^{240}Pu/^{239}Pu	1
		^{241}Pu/^{235}U	4

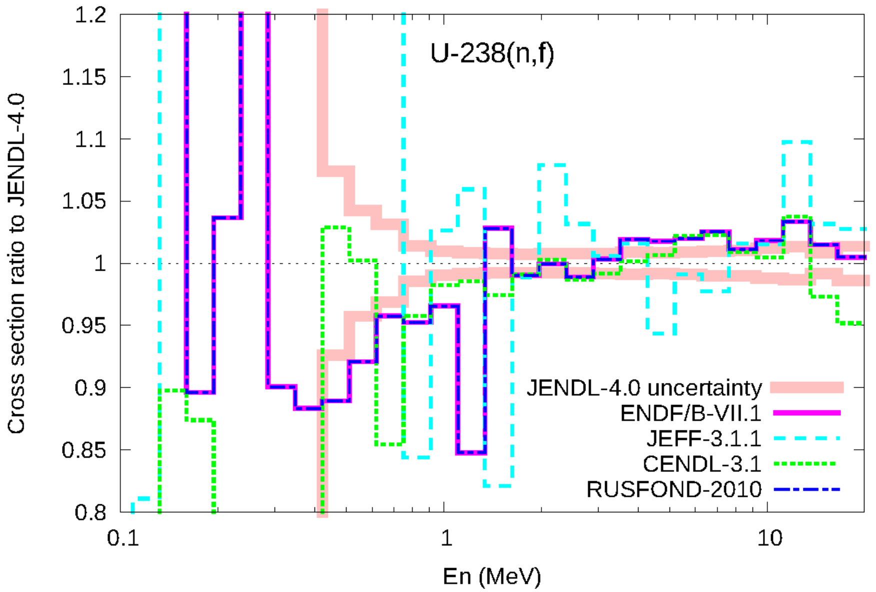
result of SOK

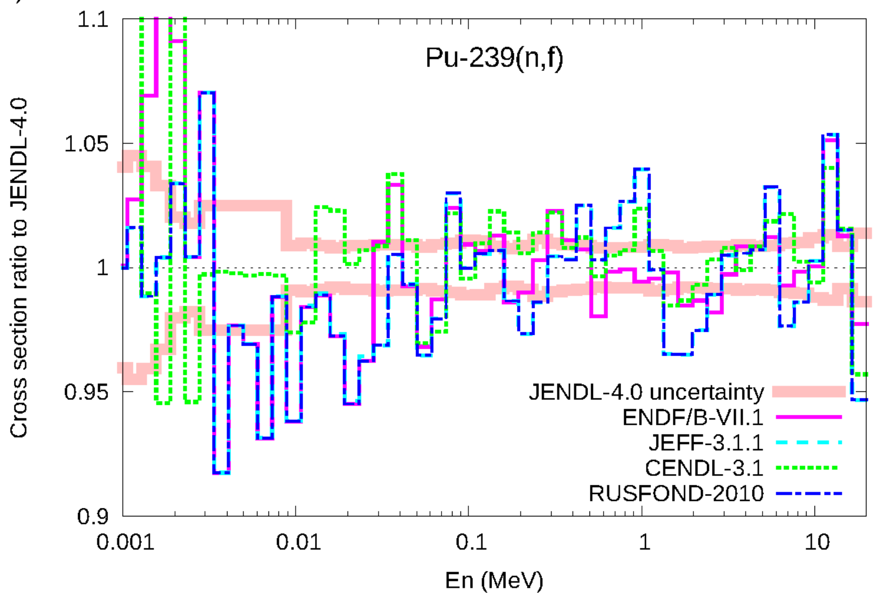




ratio of other evaluated data



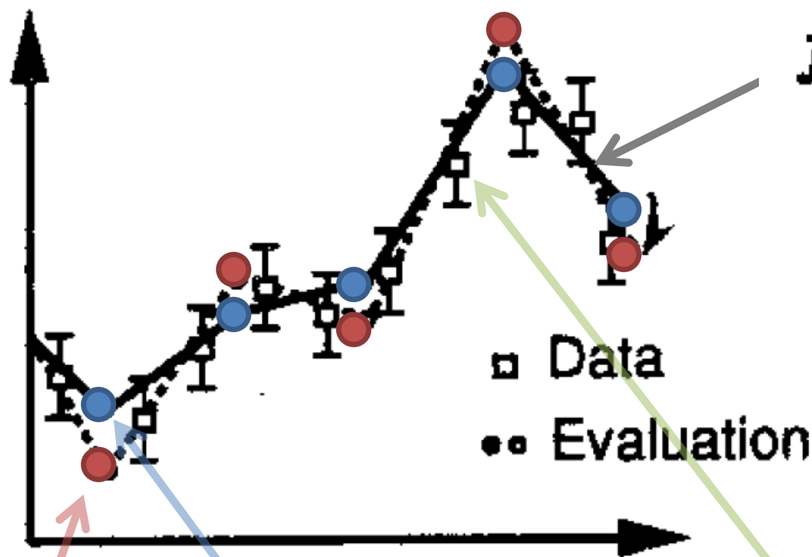




CCONE calculation

- Coupled-channels OMP (Total, shape-elastic, T_l)
  - ground state rotational band (4-8 levels)
  - OMP
    - Soukhovitskii et al. (2005) with modification
    - Kunieda et al. (2007) with modification
- Exciton model
  - Formulation(2 components): Kalbach (1986)
  - Parameter: Koning-Duijvestijn (2004)
- Hauser-Feshbach
  - Moldauer width-fluctuation correction (1980)
  - transmission coefficient (CC)
  - GSF: Enhanced generalized Lorentzian, Kopecky (1993)
  - double-humped fission barrier
  - Fermi-gas + constant-temperature level density
- Covariances
  - CCONE(sensitivity) + KALMAN(least-square method)

CCONE+KALMAN



$$\boldsymbol{f}(\boldsymbol{x}) \cong \boldsymbol{f}(\boldsymbol{x}_0) + \mathrm{C}(\boldsymbol{x} - \boldsymbol{x}_0)$$

reaction modeling (CCONE)

$$x \cong g(t) = g(t_0) + G(t - t_0)$$

$$X = GTG^t$$

sensitivity

model parameter

posterior

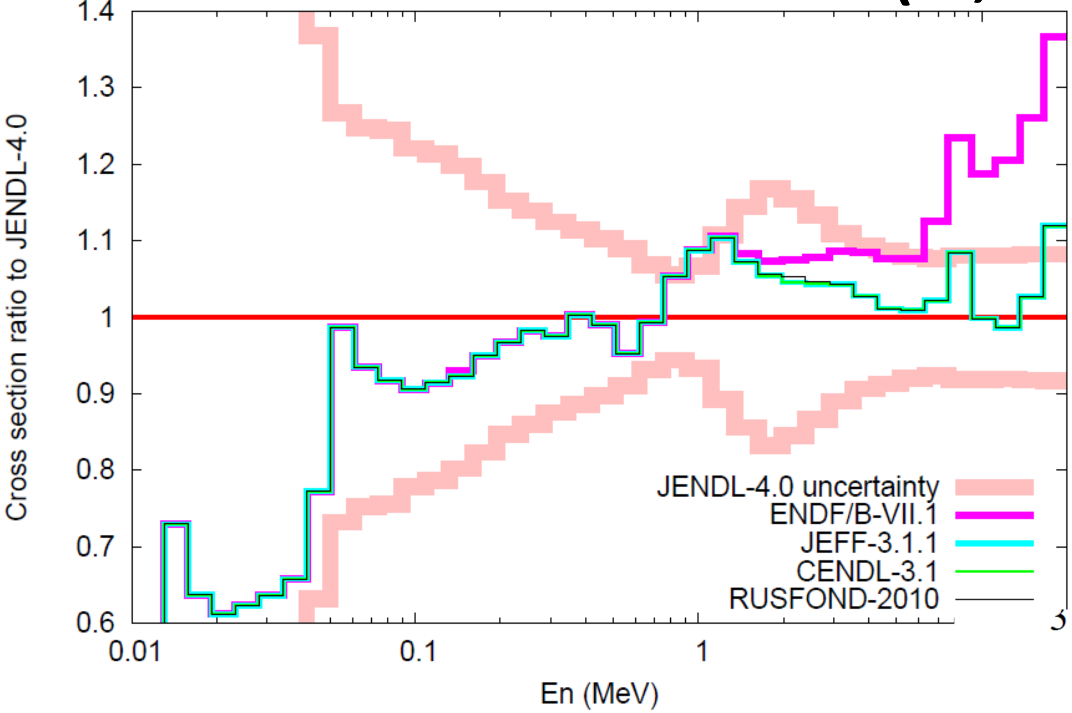
prior

$$\boldsymbol{x}_1 = \boldsymbol{x}_0 + \mathrm{PC}^t\mathrm{V}^{-1}(\boldsymbol{y} - \boldsymbol{f}(\boldsymbol{x}_0))$$

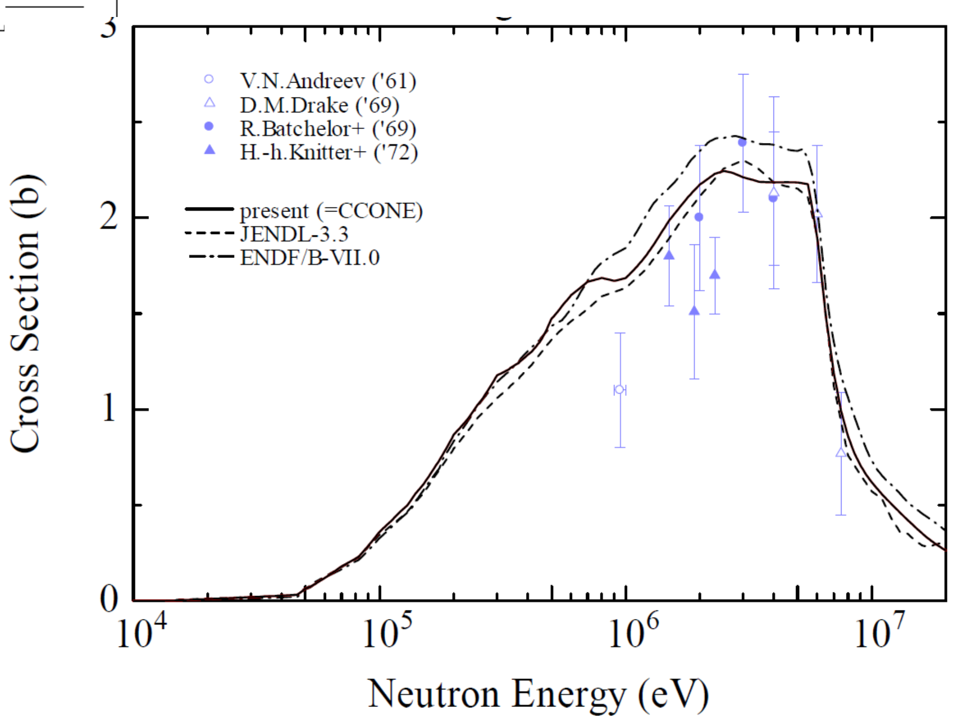
covariance

$$\mathrm{P} = \left(\mathrm{X}^{-1} + \mathrm{C}^t\mathrm{V}^{-1}\mathrm{C}\right)^{-1}$$

U-235(n,n’)

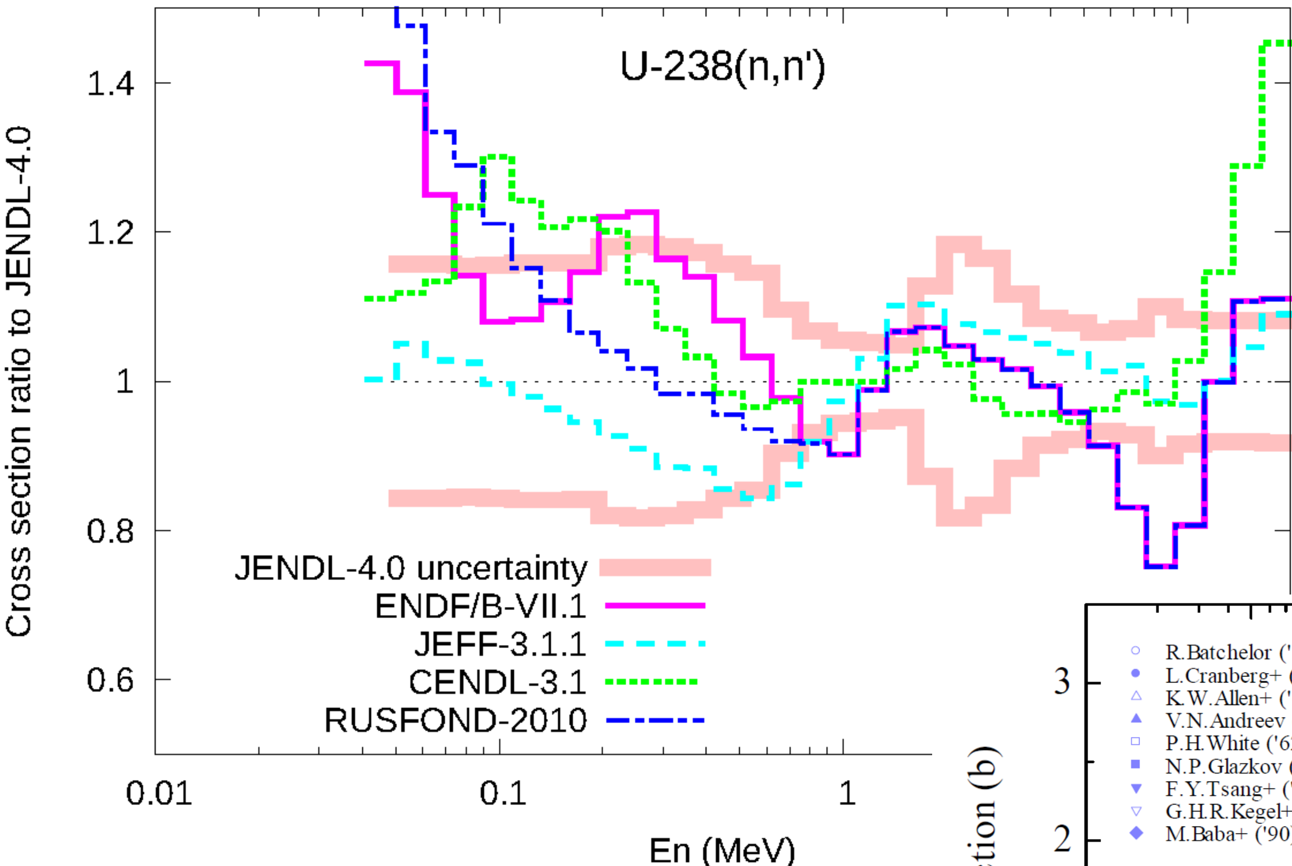


Cross section ratio to JENDL-4.0
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.01
0.1
1
En (MeV)
JENDL-4.0 uncertainty
ENDF/B-VII.1
JEFF-3.1.1
CENDL-3.1
RUSFOND-2010

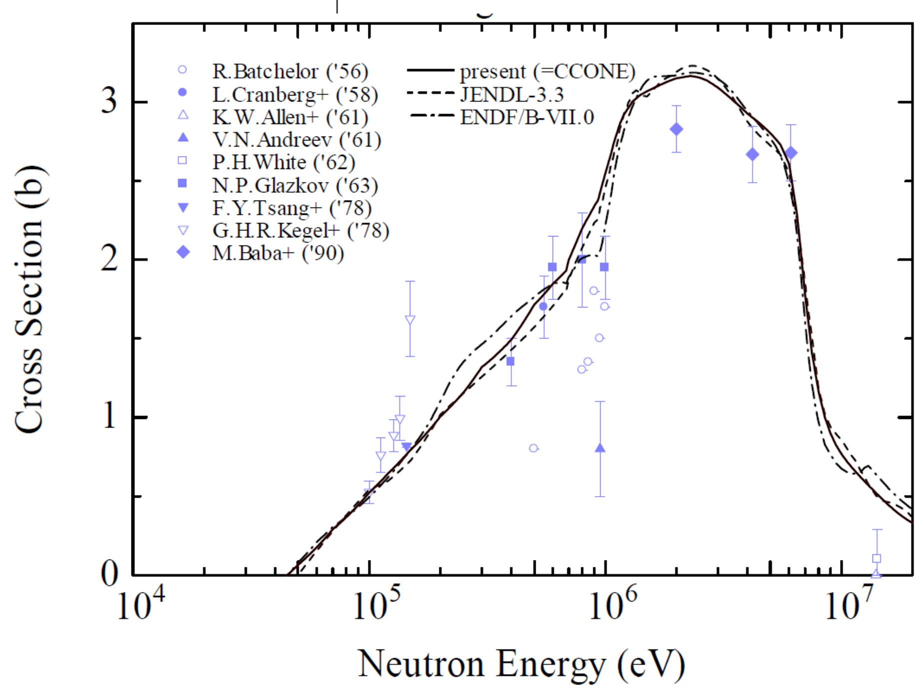


V.N.Andreev ('61)
D.M.Drake ('69)
R.Batchelor+ ('69)
H.-h.Knitter+ ('72)
present (=CCONE)
JENDL-3.3
ENDF/B-VII.0
Cross Section (b)
0
1
2
10^4
10^5
10^6
10^7
Neutron Energy (eV)

U-238(n,n’)

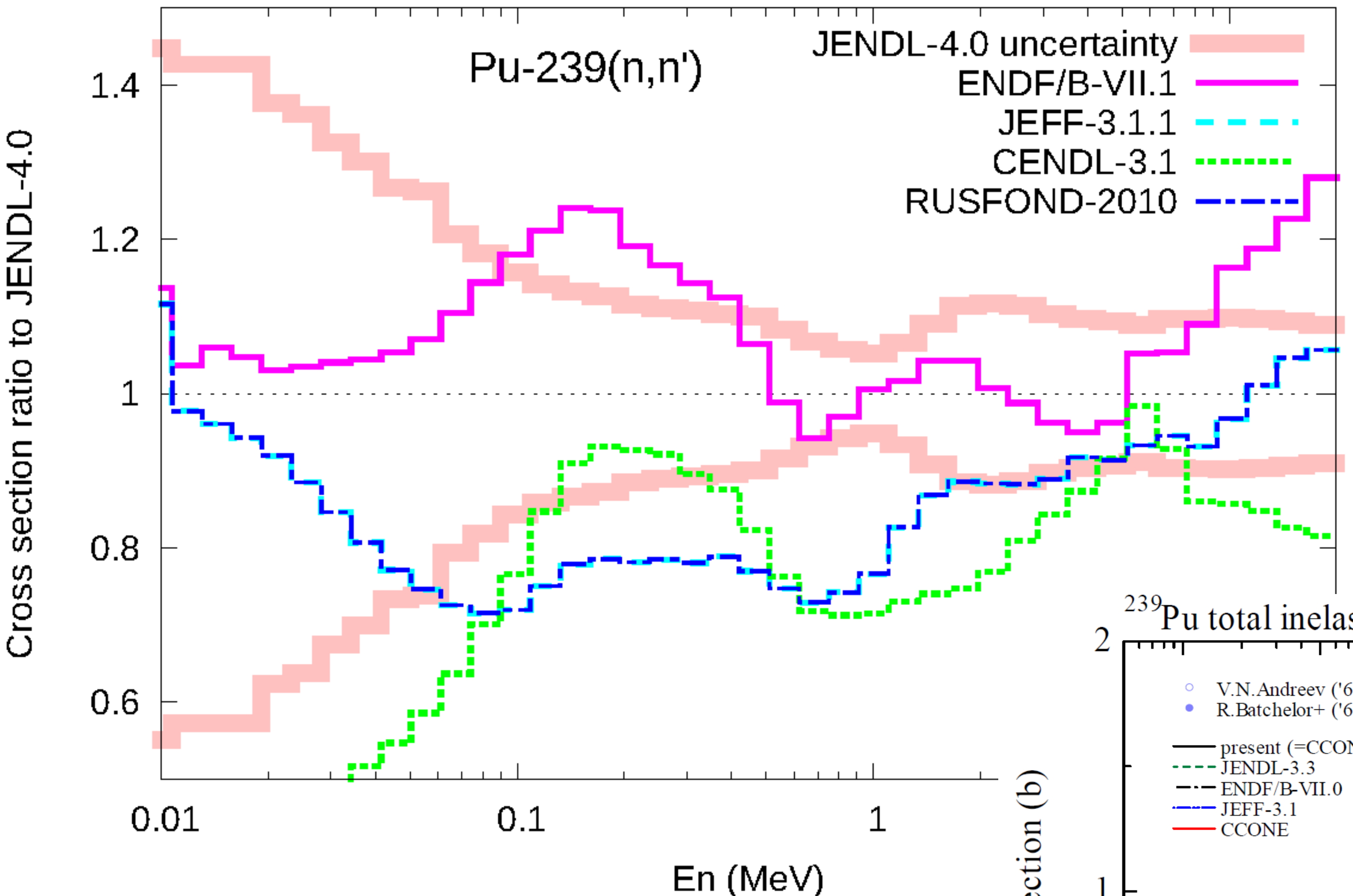


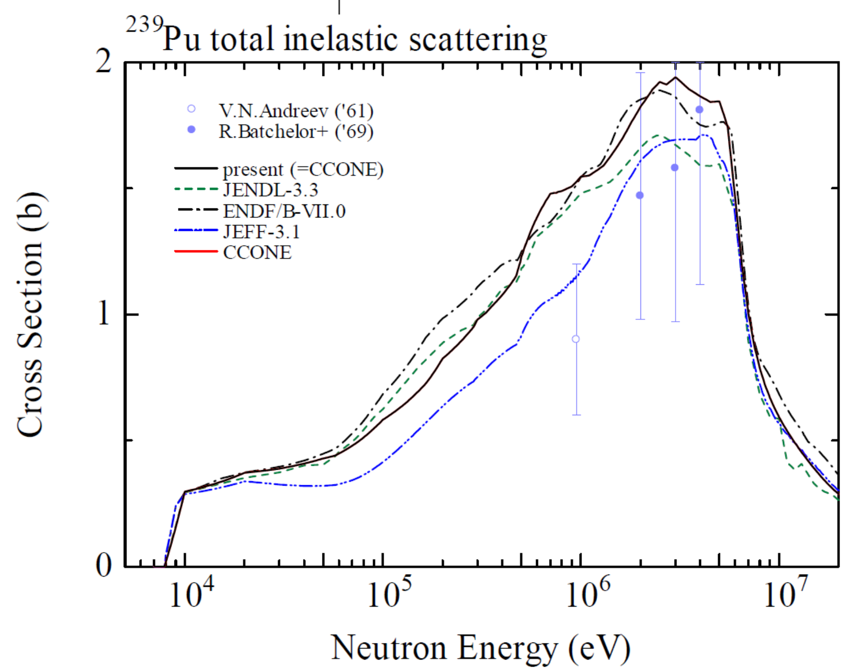
U-238(n,n')
Cross section ratio to JENDL-4.0
1.4
1.2
1
0.8
0.6
0.01
0.1
1
En (MeV)
JENDL-4.0 uncertainty
ENDF/B-VII.1
JEFF-3.1.1
CENDL-3.1
RUSFOND-2010



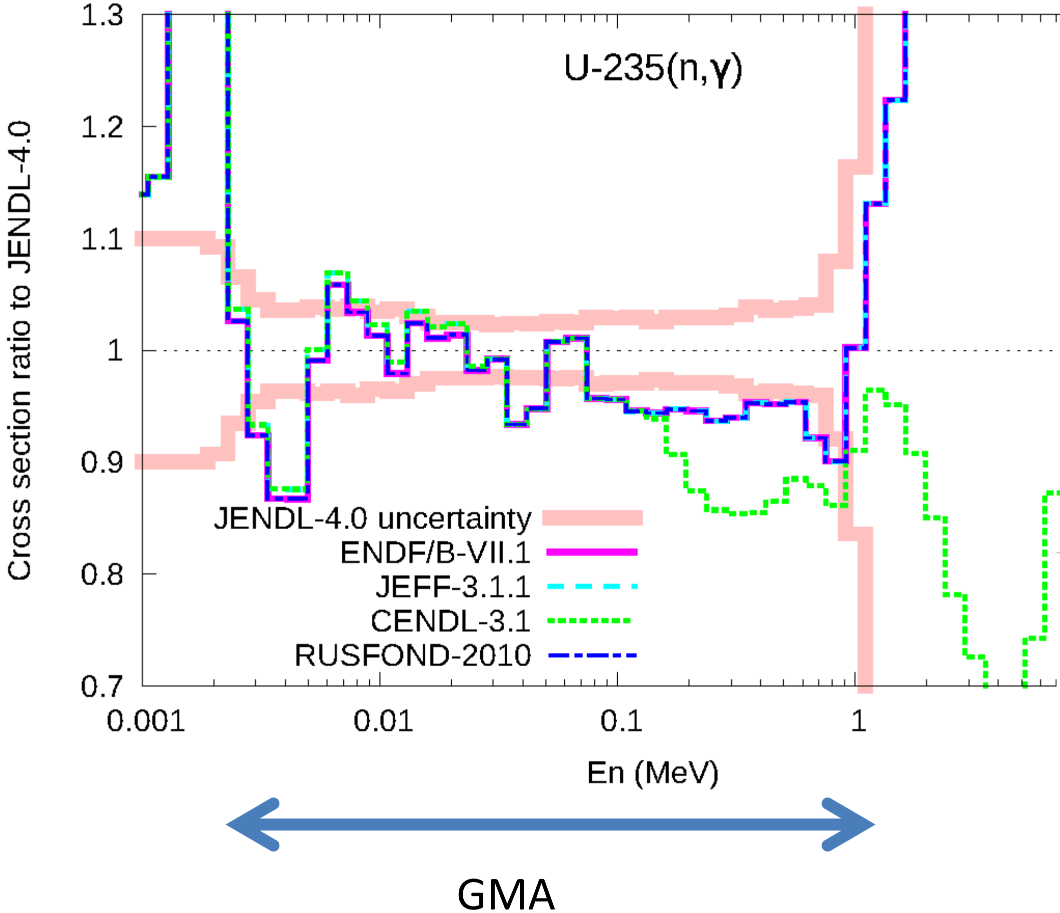
R.Batchelor ('56)
L.Cranberg+ ('58)
K.W.Allen+ ('61)
V.N.Andreev ('61)
P.H.White ('62)
N.P.Glazkov ('63)
F.Y.Tsang+ ('78)
G.H.R.Kegel+ ('78)
M.Baba+ ('90)
present (=CCONE)
JENDL-3.3
ENDF/B-VII.0
Cross Section (b)
Neutron Energy (eV)

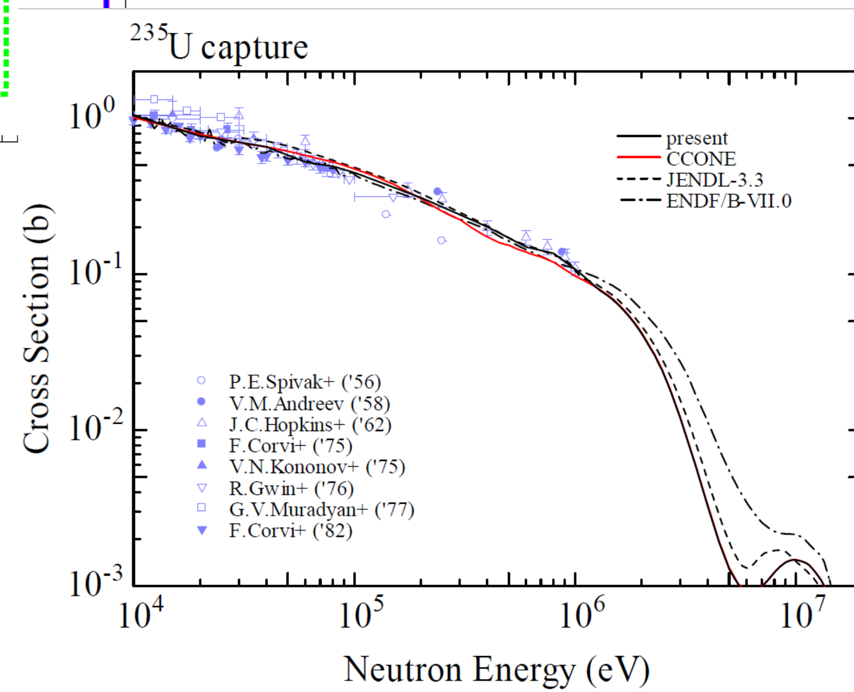
U-239(n,n')


Pu-239(n,n')
JENDL-4.0 uncertainty
ENDF/B-VII.1
JEFF-3.1.1
CENDL-3.1
RUSFOND-2010
Cross section ratio to JENDL-4.0
1.4
1.2
1
0.8
0.6
0.01
0.1
1
En (MeV)

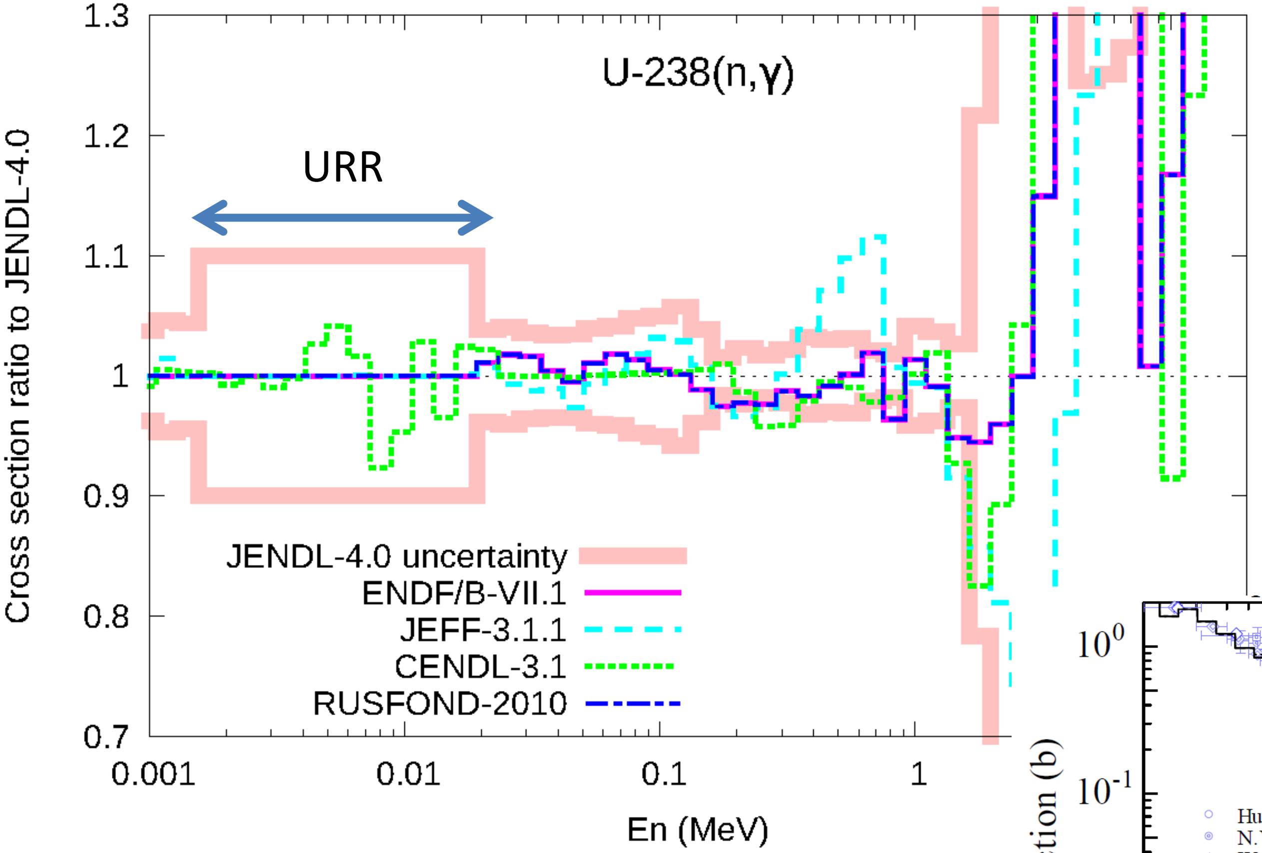

^{239}Pu total inelastic scattering
V.N.Andreev ('61)
R.Batchelor+ ('69)
present (=CCONE)
JENDL-3.3
ENDF/B-VII.0
JEFF-3.1
CCONE
Cross Section (b)
2
1
0
10^4
10^5
10^6
10^7
Neutron Energy (eV)

U-235(n,γ)

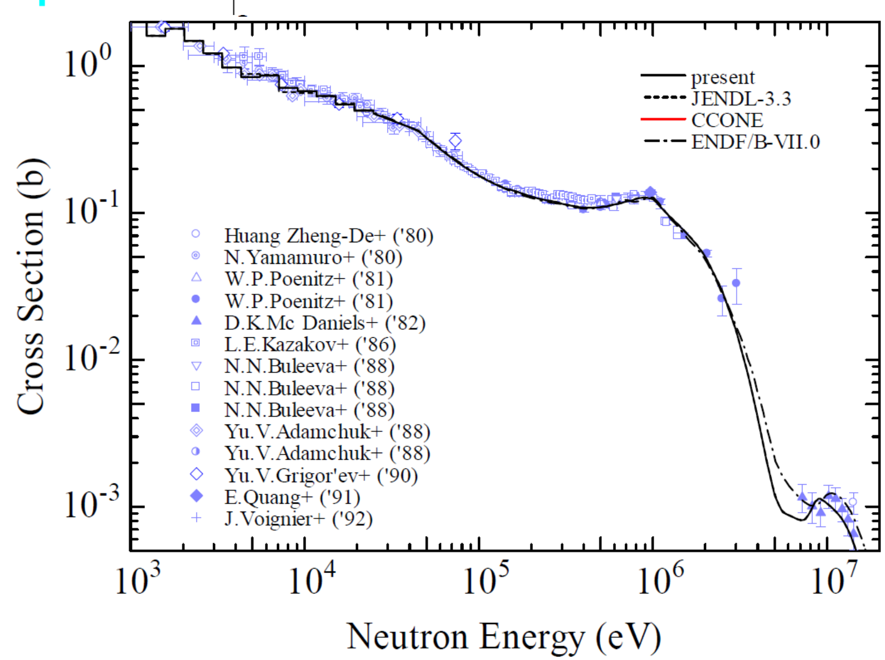

U-235(n,γ)
Cross section ratio to JENDL-4.0
1.3
1.2
1.1
1
0.9
0.8
0.7
0.001
0.01
0.1
1
En (MeV)
JENDL-4.0 uncertainty
ENDF/B-VII.1
JEFF-3.1.1
CENDL-3.1
RUSFOND-2010
GMA


^{235}U capture
Cross Section (b)
Neutron Energy (eV)
10^0
10^{-1}
10^{-2}
10^{-3}
10^4
10^5
10^6
10^7
present
CCONE
JENDL-3.3
ENDF/B-VII.0
P.E.Spivak+ ('56)
V.M.Andreev ('58)
J.C.Hopkins+ ('62)
F.Corvi+ ('75)
V.N.Kononov+ ('75)
R.Gwin+ ('76)
G.V.Muradyan+ ('77)
F.Corvi+ ('82)

U-238(n,γ)

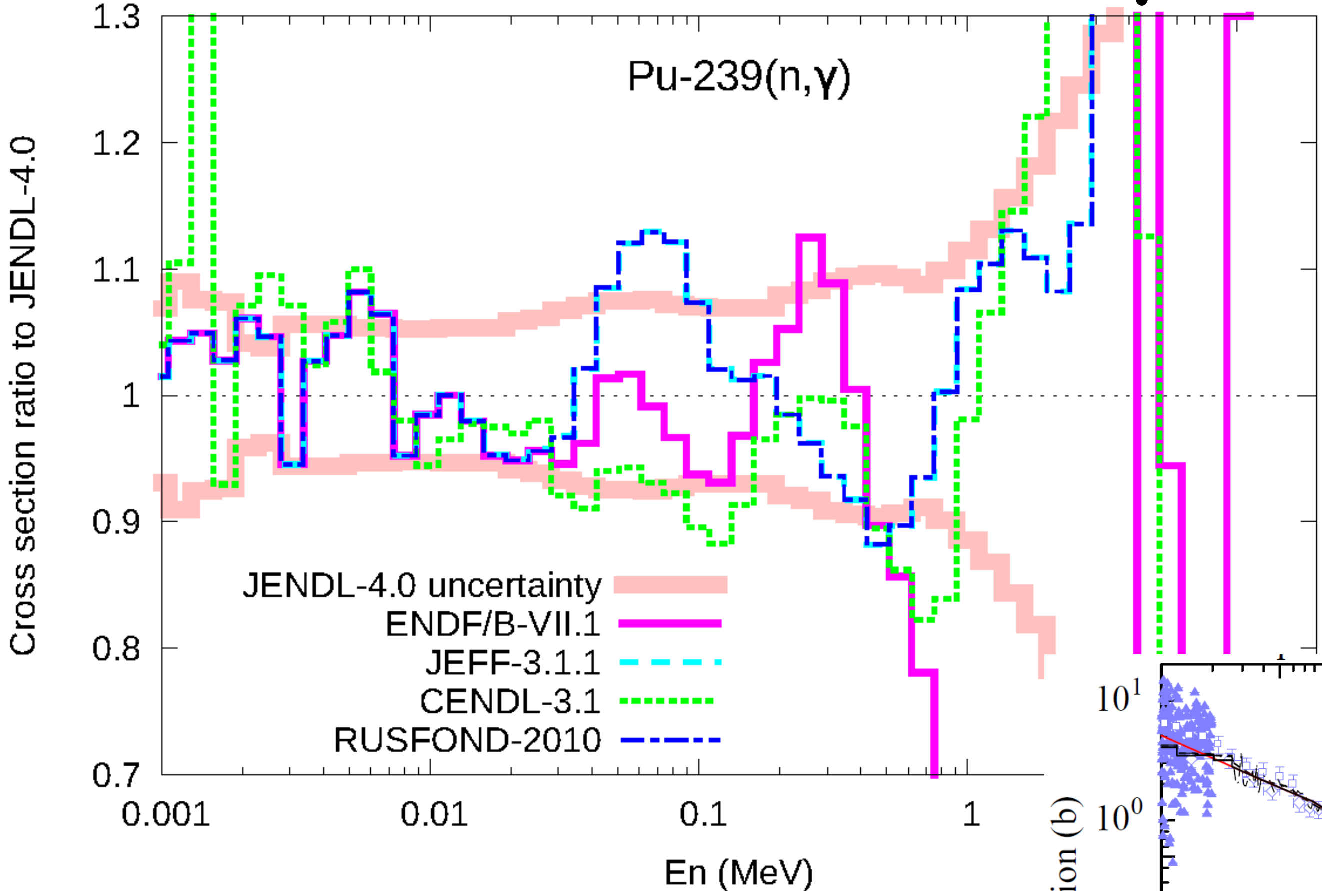


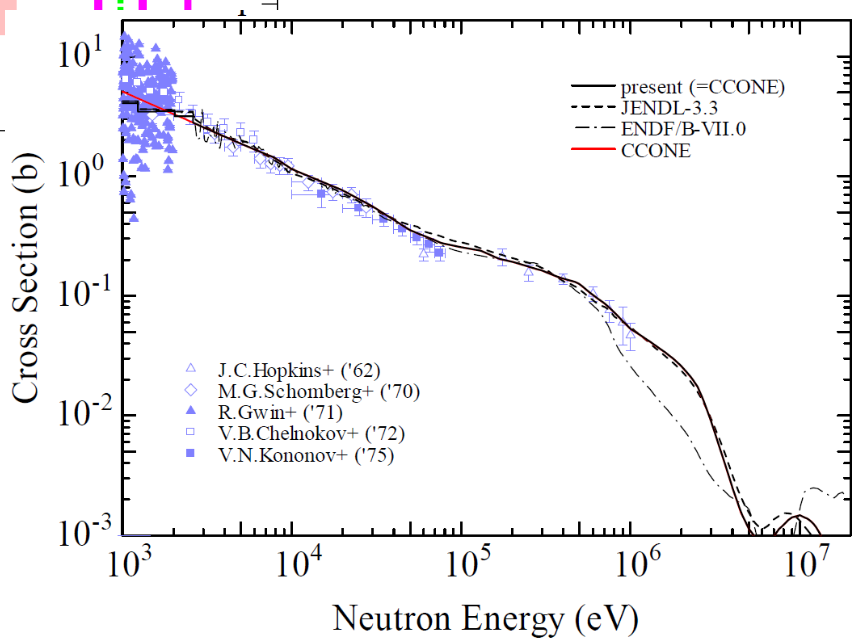
U-238(n,γ)
URR
Cross section ratio to JENDL-4.0
En (MeV)
JENDL-4.0 uncertainty
ENDF/B-VII.1
JEFF-3.1.1
CENDL-3.1
RUSFOND-2010
1.3
1.2
1.1
1
0.9
0.8
0.7
0.001
0.01
0.1
1



Cross Section (b)
Neutron Energy (eV)
present
JENDL-3.3
CCONE
ENDF/B-VII.0
Huang Zheng-De+ ('80)
N.Yamamuro+ ('80)
W.P.Poenitz+ ('81)
W.P.Poenitz+ ('81)
D.K.Mc Daniels+ ('82)
L.E.Kazakov+ ('86)
N.N.Buleeva+ ('88)
N.N.Buleeva+ ('88)
N.N.Buleeva+ ('88)
Yu.V.Adamchuk+ ('88)
Yu.V.Adamchuk+ ('88)
Yu.V.Grigor'ev+ ('90)
E.Quang+ ('91)
J.Voignier+ ('92)

Pu-239(n,γ)


Pu-239(n,γ)
Cross section ratio to JENDL-4.0
1.3
1.2
1.1
1
0.9
0.8
0.7
0.001
0.01
0.1
1
En (MeV)
JENDL-4.0 uncertainty
ENDF/B-VII.1
JEFF-3.1.1
CENDL-3.1
RUSFOND-2010

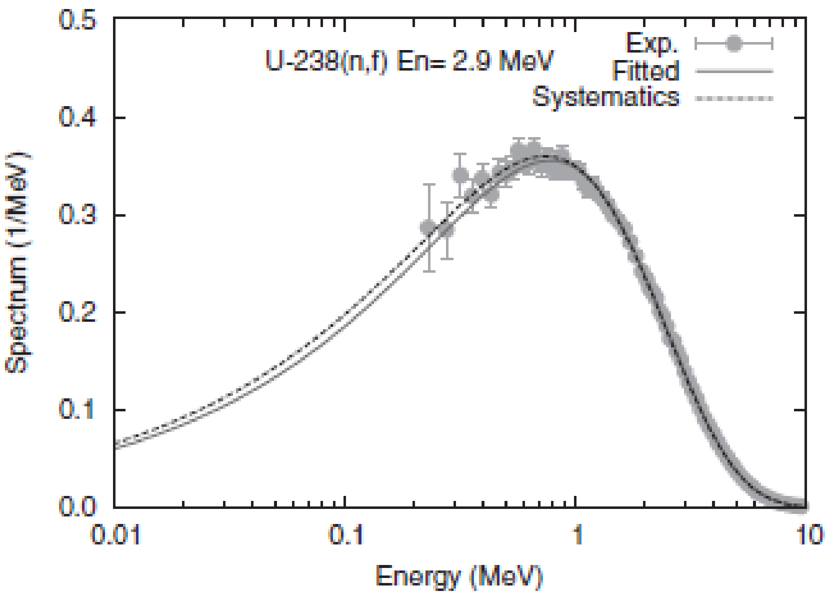

Cross Section (b)
Neutron Energy (eV)
present (=CCONE)
JENDL-3.3
ENDF/B-VII.0
CCONE
J.C.Hopkins+ ('62)
M.G.Schomberg+ ('70)
R.Gwin+ ('71)
V.B.Chelnokov+ ('72)
V.N.Kononov+ ('75)

Prompt fission neutron spectrum

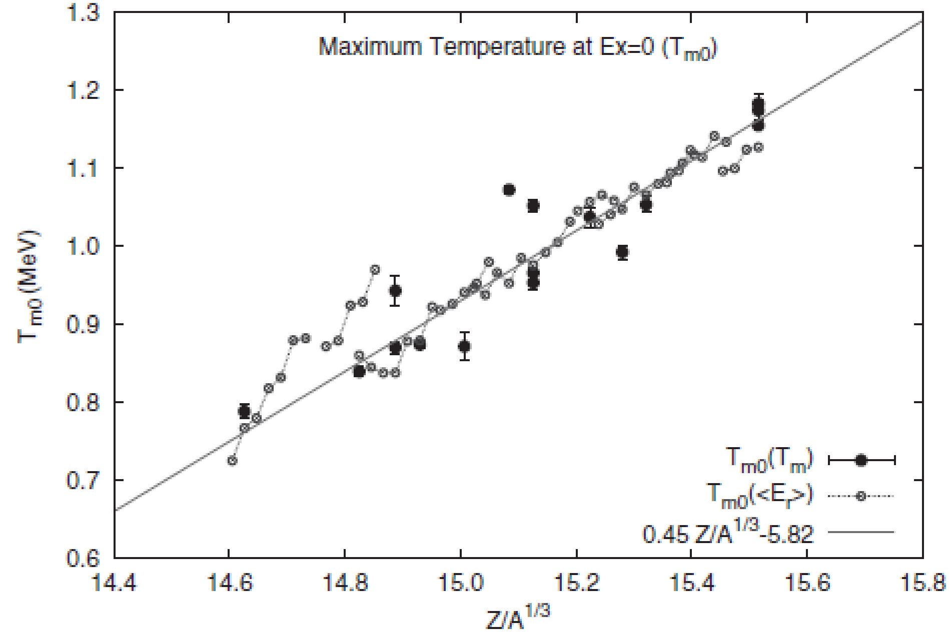
- En < 5 MeV
  - Madland-Nix model combined with multimodal random-neck rupture of the fission process
    - Ohsawa, JAERI-Conf 2001-006, 157 (2001)
  - U-235, Pu-239 (= JENDL-3.3)
  - U-238 (=JENDL-3.2)
- En > 5 MeV
  - Systematics with modified Madland-Nix model
    - Iwamoto, J. Nucl. Sci. Technol. 45, 910 (2008)
  - incorporated with preequilibrium-statistical model (CCONE code)

Fission spectrum above second chance fission

Fission spectrum systematics



$$T_{m0}(T_m) = \sqrt{T_m^2 - \frac{E_x}{a}},$$



Max nuclear temperature, Tm, was determined by fitting to experimental data.

Nuclear temperature dependence on $Z/A^{1/3}$

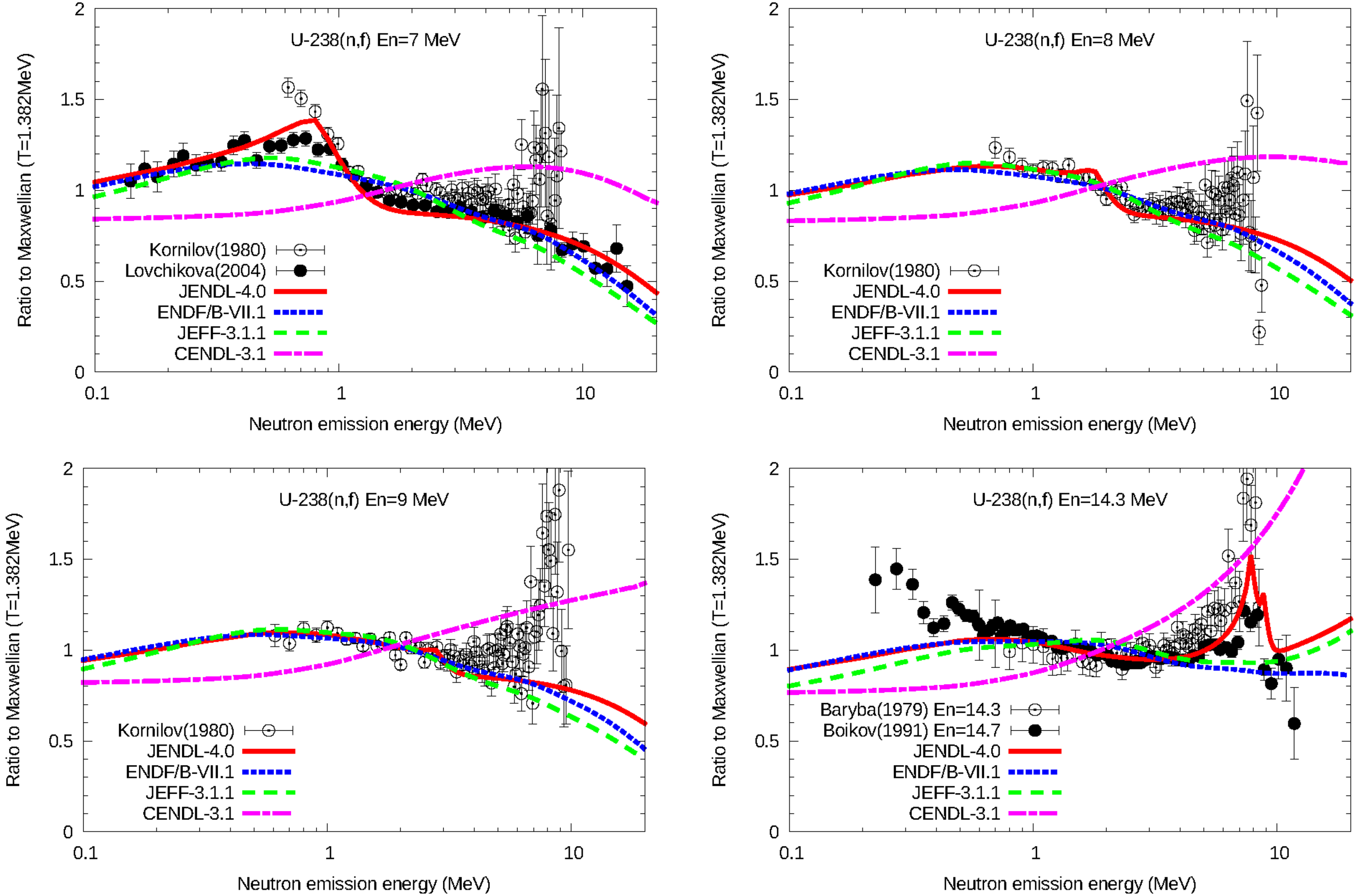
Pre-equlibrium + statistical model calc.

- average fissioning nucl. excitation energy
- pre-scission neutron spectrum

$$T_m = \sqrt{T_{m0} + \frac{E_x}{a}}$$

fission spectum

U-238 PFNS above second chance fission



Summary

- Methods and results of evaluation of JENDL-4.0 were reviewed.
- The upper limit of RRR of U-235 for JENDL-4.0 was lowered and the capture cross section was reduced to the level of JENDL-3.2 to improve the Na-void reactivity.
- Inelastic scattering and capture cross section data of JENDL-4.0 were compared with experimental data and other libraries.
- Most of data of JENDL-4.0 agree with other evaluations within uncertainties excepting Pu-239.
- Fission neutron spectrum above the second chance fission was shown. The pre-scission neutrons might be important to reproduce the experimental data.