Overview of JENDL-5

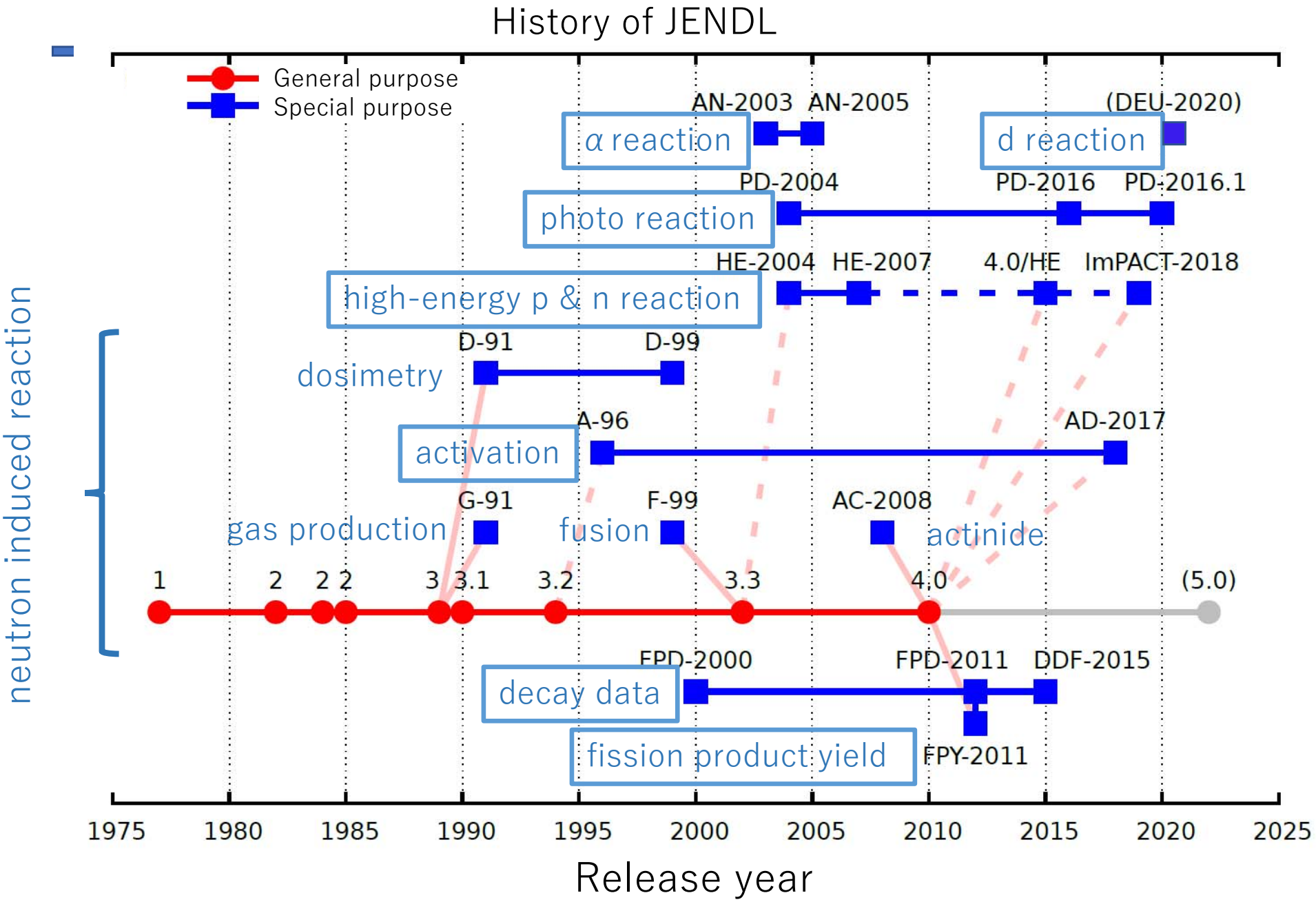
O. Iwamoto

Japan Atomic Energy Agency

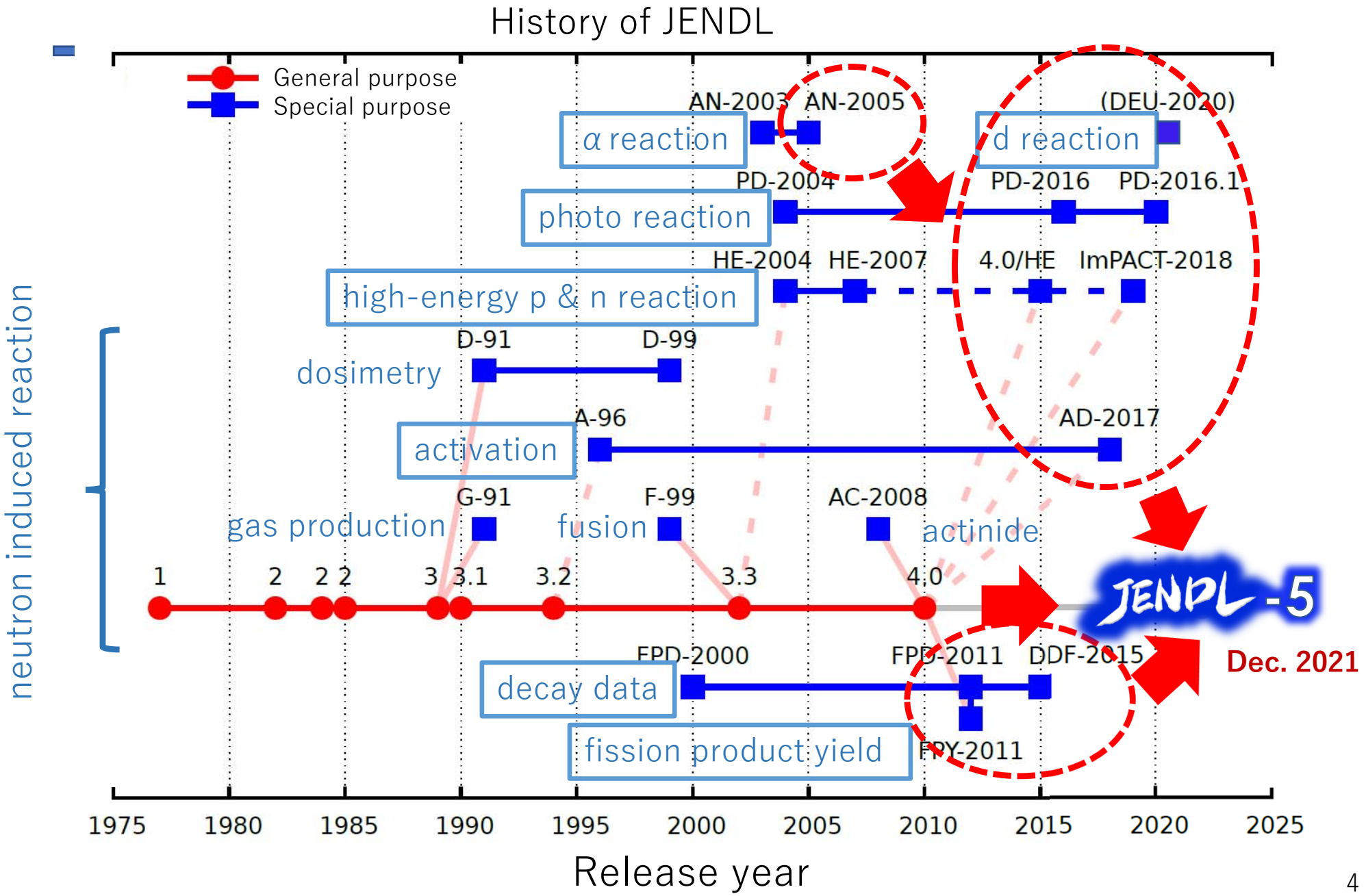
Introduction

- More than 10 years have already passed since the latest version of general-purpose file JENDL-4.0 was released in 2010.
- Many special purpose files have released to meet the needs of various field of nuclear energy and accelerator applications, but the data sometimes deviates from JENDL-4.0.
- Large amount of experimental data have been accumulated since JENDL-4.0 release.
- The JENDL-5 project launched to develop a new general-purpose file that covers over various fields by merging special purpose files with reflecting current knowledge of nuclear data.
- JENDL-5 was released in December 2021.

History of JENDL



History of JENDL



Contents of JENDL-5

JENDL-5 consists of sublibraries:

1. neutron reaction
2. thermal neutron scattering law
3. fission product yield
4. decay data
5. proton reaction
6. deuteron reaction
7. alpha-particle reaction
8. photo-nuclear reaction
9. photo-atomic
10. electro-atomic
11. atomic relaxation

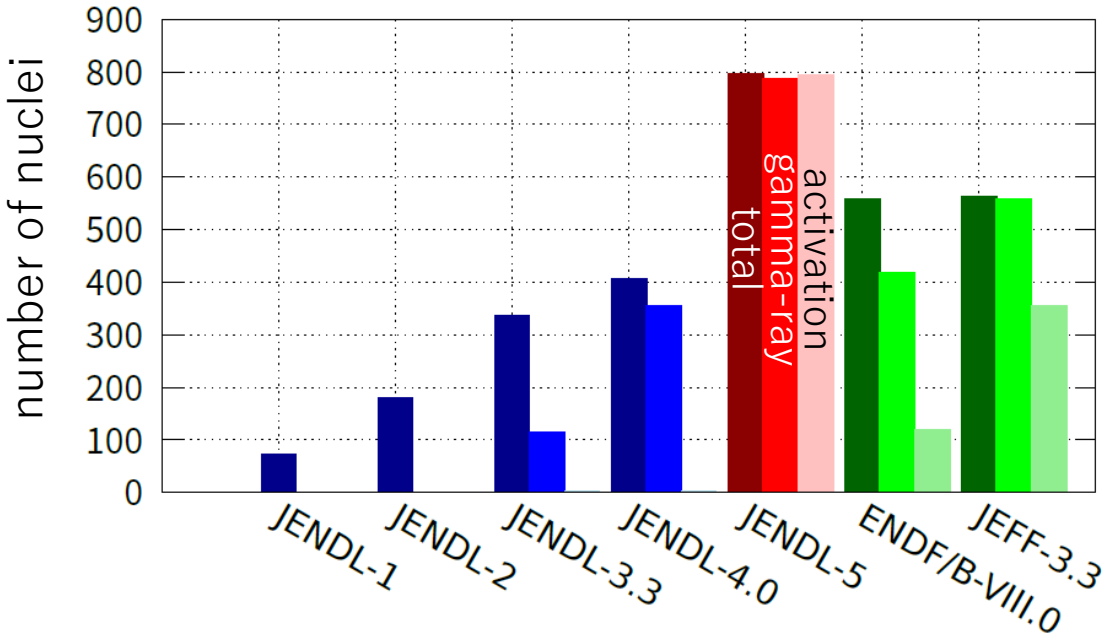
} ENDF/B-VIII.0

Neutron reaction

- Update of important data for reactors and shielding
  - major actinides
  - minor actinides
  - structure material and medium-heavy nuclides
  - light nuclides
  - neutron absorbers
- Increase of the number of nuclei
  - all nuclides in natural abundance
  - sufficient number of nuclei for neutron activation calculation ($T_{1/2}$>1day)
- Integration of activation file
  - merge the data of MF=8, 9, 10 of JENDL/AD-2017
  - new evaluation for isomer production cross section
- Extension to higher energy: 200 MeV
  - new evaluation
  - merge data above 20 MeV in JENDL-4.0/HE and JENDL/Impact-2018
  - recoil spectrum
- Files
  - Full version (up to 200 MeV), pointwise (0k, 300k)
  - U20 (up to 20 MeV), activation file (activation c.s.)

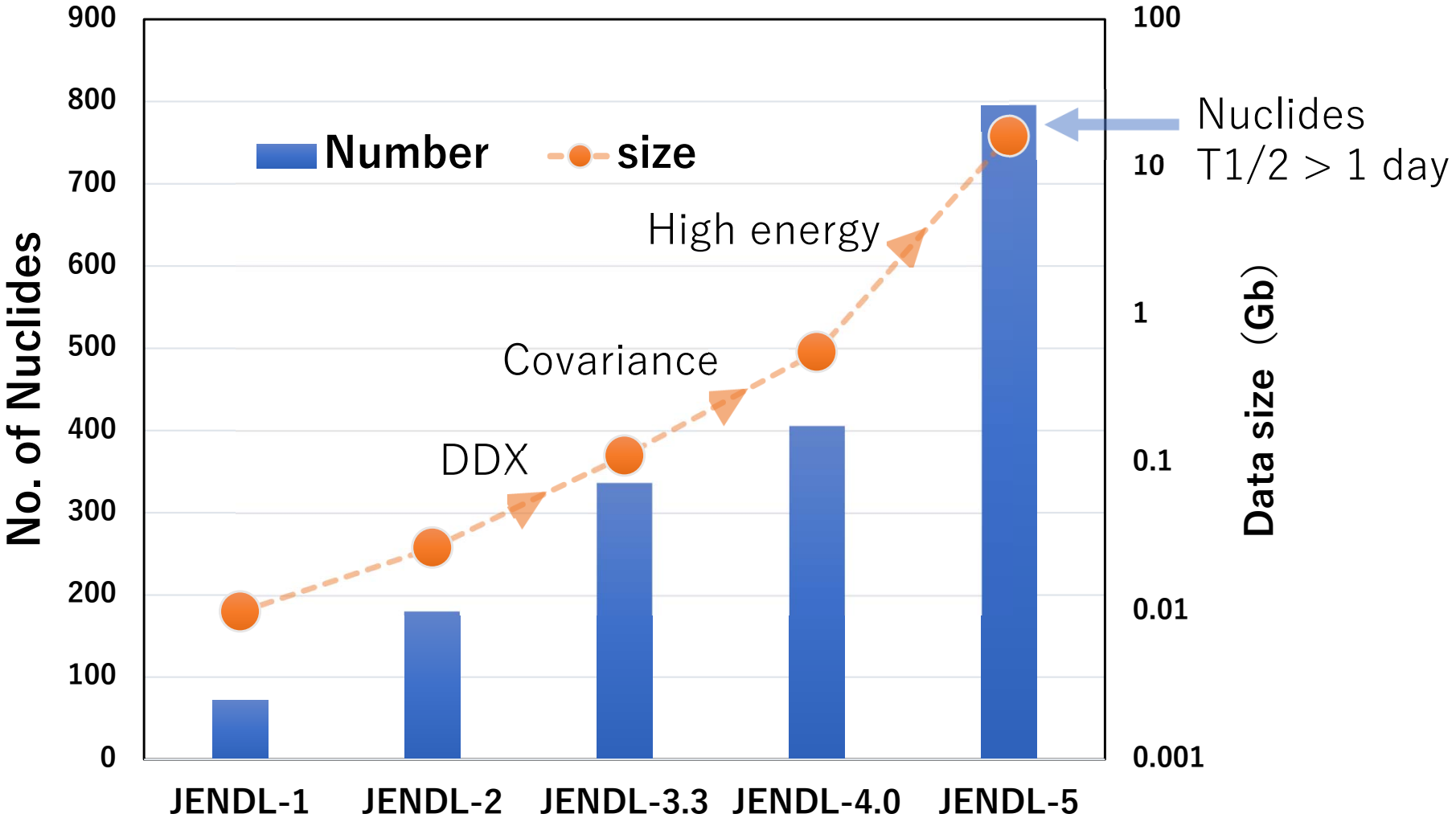
Number of nuclides of neutron reaction data

	JENDL-1	JENDL-2	JENDL-3.3	JENDL-4.0	JENDL-5	ENDF/B-VIII.0	JEFF-3.3
Region	Japan	Japan	Japan	Japan	Japan	USA	EU
Release	1977	1985	2002	2010	2021	2018	2017
No. of nuclides							
Total (elem.)	72 (6)	181 (8)	337 (2)	406 (1)	795 (0)	557 (0)	562 (1)
In natural abn.[1)]	48	130	228	260	287	286[1)]	286[1)]
2nd γ-ray data	0	0	114	354	787[2)] /788	420	559
Activation	0	0	2	3	794[3)]	119	355



1) 287 nuclides in total
   - Ta-180m missing in ENDF
   - C-12 missing in JEFF
2) in case En < 20MeV
   Ar-40: γ–data only En > 20 MeV
3) He-4: elastic scattering only

Amount of neutron data in JENDL



- Inclusion of all nuclides in natural abundance
- Sufficient number of nuclei for neutron activation calculation

Highlight of major actinide

- Resolved resonance parameters
  - adoption of ENDF-B/VIII.0 (CIELO-1) for U-235, 238, and Pu-239(SG-34)
- Fission cross section for fast neutron
  - new simultaneous evaluation for U-233, 235, 238, and Pu-239, 240, 241 with SOK taking account of up-to-date experimental data
  - energy upper limit is extended up to 200 MeV
- Fission neutron spectrum
  - revision of the data below 5 MeV for U-235
- Fission neutron multiplicity
  - revision based on experimental data, WPEC/SG-34(Pu-239)
- Revision based on the results of integral tests
  - fission & capture cross sections, number of prompt fission neutron

Simultaneous evaluation of fission CS

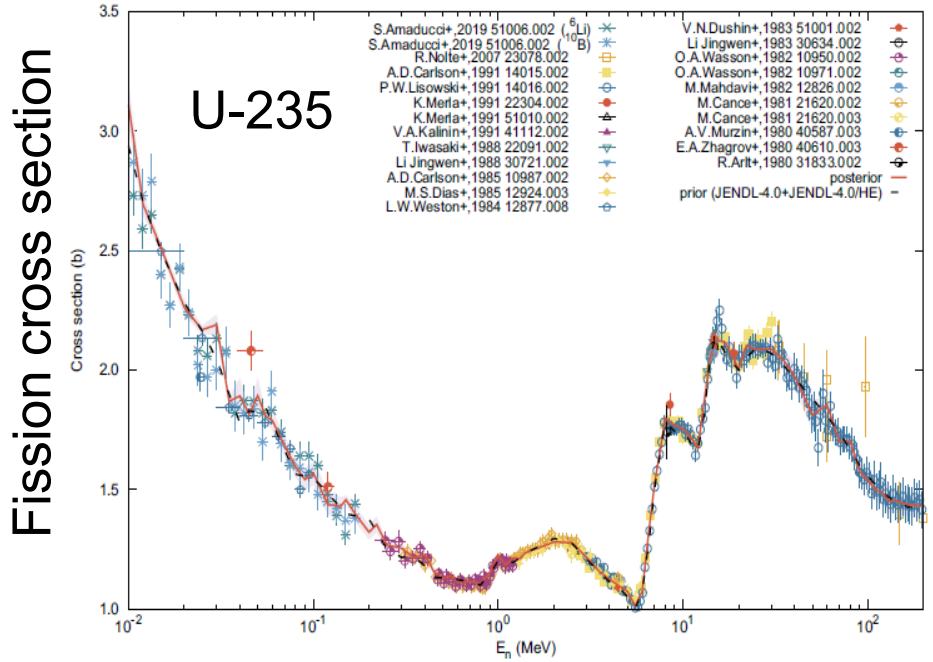
N. Otuka & OI, JNST, 58, 1004 (2022)

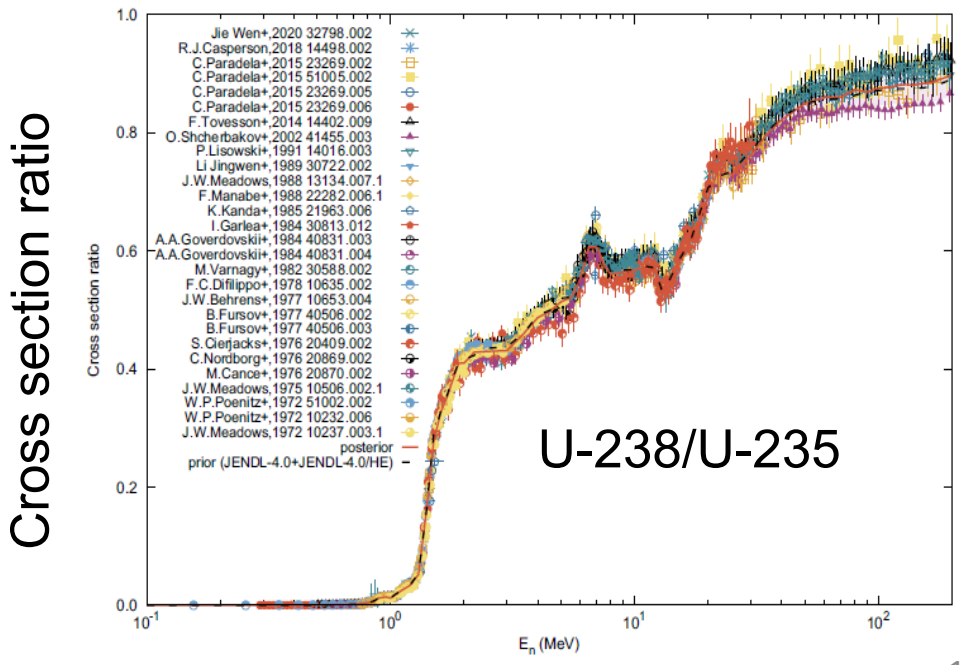
- Least-squares fitting
  - ✓ SOK code
  - ✓ First order spline

Number of experimental data sets

Reaction	J4.0	J5	Reaction	J4.0	J5
^{233}U	13	12	^{233}U/^{235}U	9	12
^{235}U	17	22	^{238}U/^{233}U	1	1
^{238}U	9	14	^{238}U/^{235}U	18	28
^{239}Pu	16	19	^{239}Pu/^{235}U	14	19
^{240}Pu	4	7	^{240}Pu/^{235}U	12	13
^{241}Pu	6	8	^{240}Pu/^{239}Pu	1	2
			^{241}Pu/^{235}U	4	4

RED: the number increased more than by 50% from JENDL-4.0





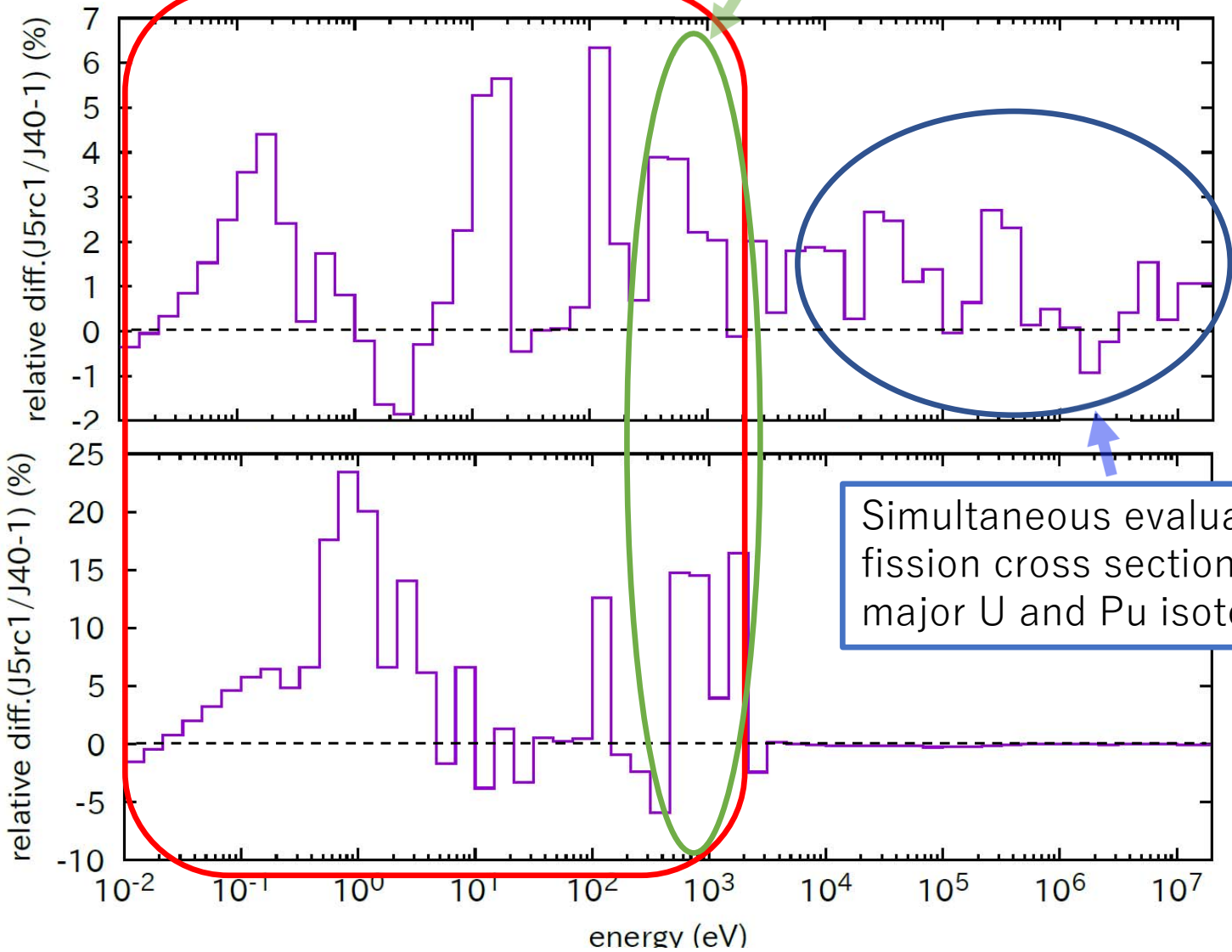
U-235

JENDL-4.0 evaluation between 0.5 – 2.25 keV adopt CS based on old data (JENDL-3.2) to avoid underestimation of Na void reactivity of JENDL-3.3.

RP of ENDF/B-VIII.0 was adopted

Fission

Capture

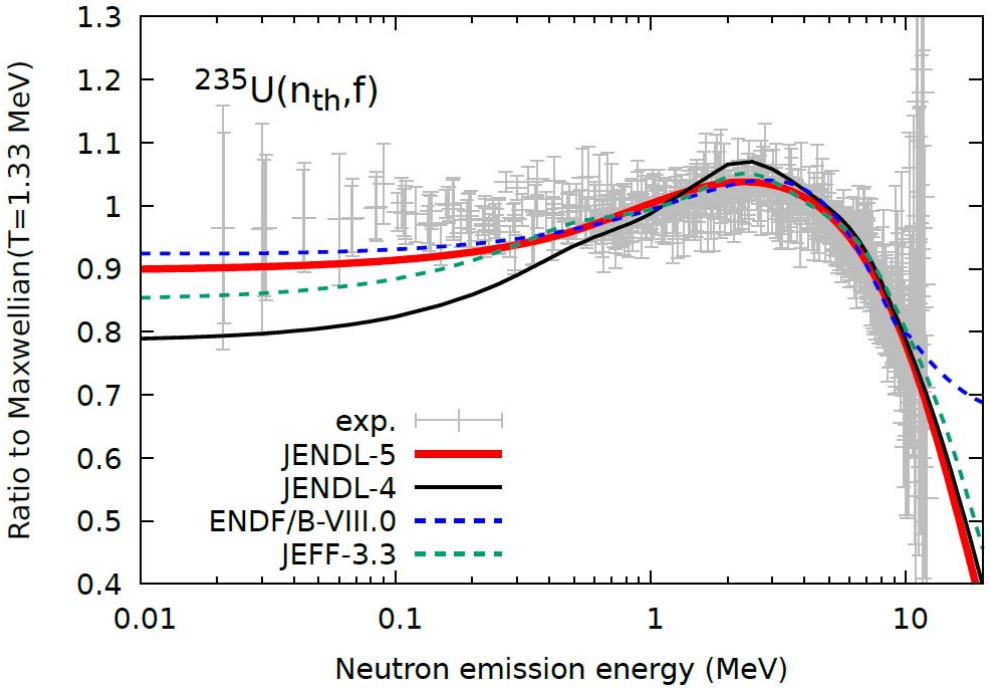


Simultaneous evaluation of fission cross section with major U and Pu isotopes

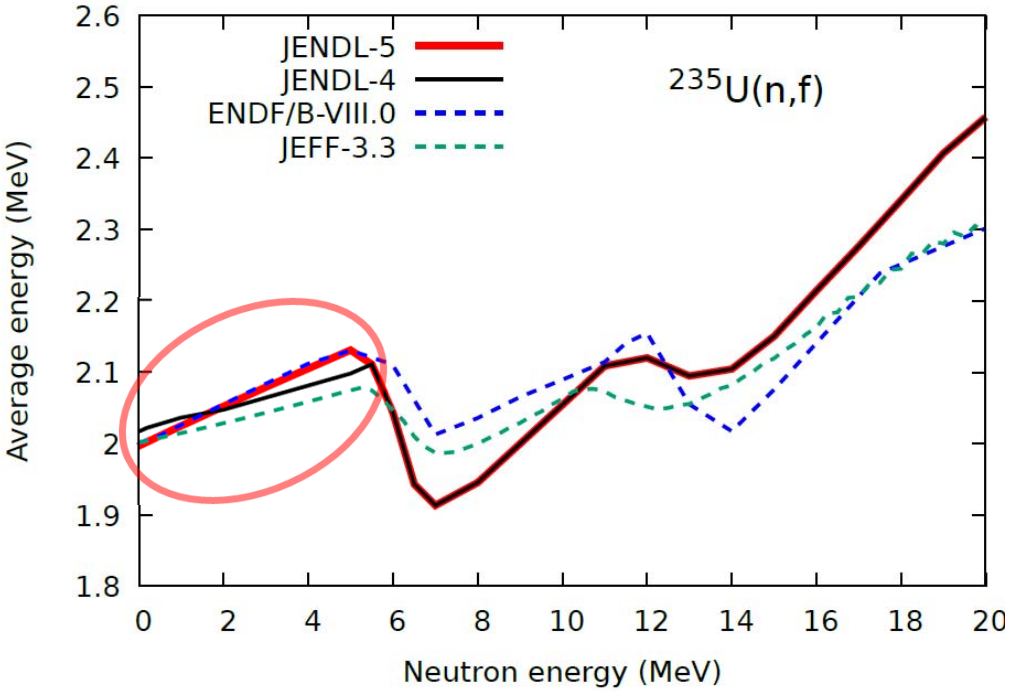
Minor revisions based on benchmark results were made.

Evaluation of U-235 fission spectrum

Fission spectrum for thermal neutron



Average energy of fission neutron



Fitting with modified Los Alamos model

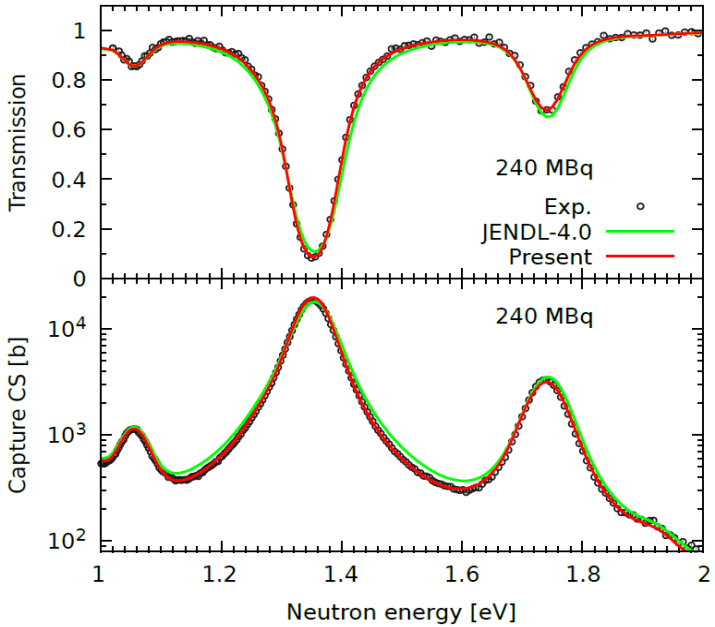
O. Iwamoto, “Systematics of Prompt Fission Neutron Spectra”, JNST 45,910 (2008)

Minor actinide

- Resonance parameter based on new experimental data
  - ANNRI
    - Np-237, Am-241, 243, Cm-244, 246
  - n_TOF
    - Am-241, 243, Pu-242
- Fast neutron
  - ANNRI neutron filter measurement
    - Np-237, Am-241, 243

      G. Rovira et al. JNST, published online (2022)
      Y. Kodama et al. JNST, 58, 1159(2022)
  - Feedback from integral test
    - fission cross section: reaction rate ratio
    - capture cross section: PIE
- Number of fission neutron
  - JAEA Tandem surrogate measurement
    - Cm-244, 246

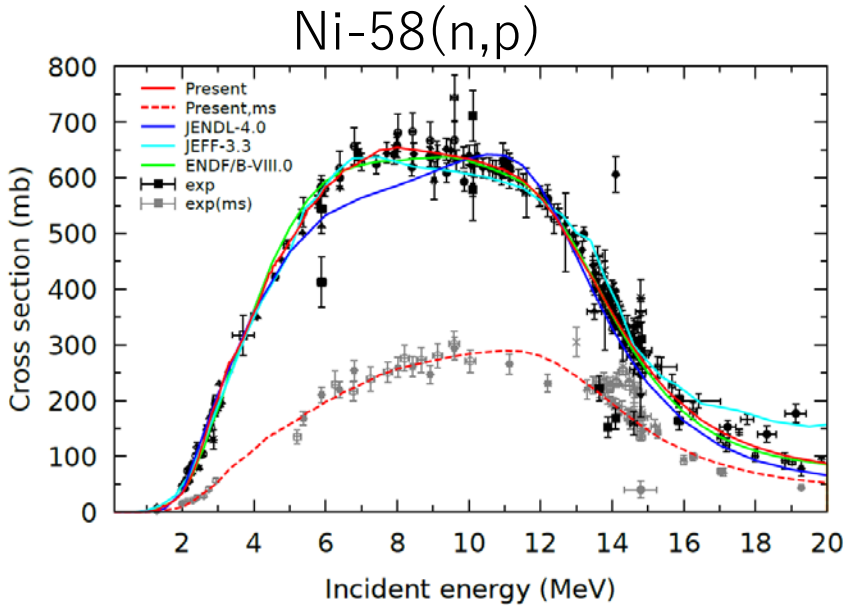
Am-243 ANNRI



A. Kimura et al., JNST 56, 479 (2019)

Structure material and medium to heavy nuclei

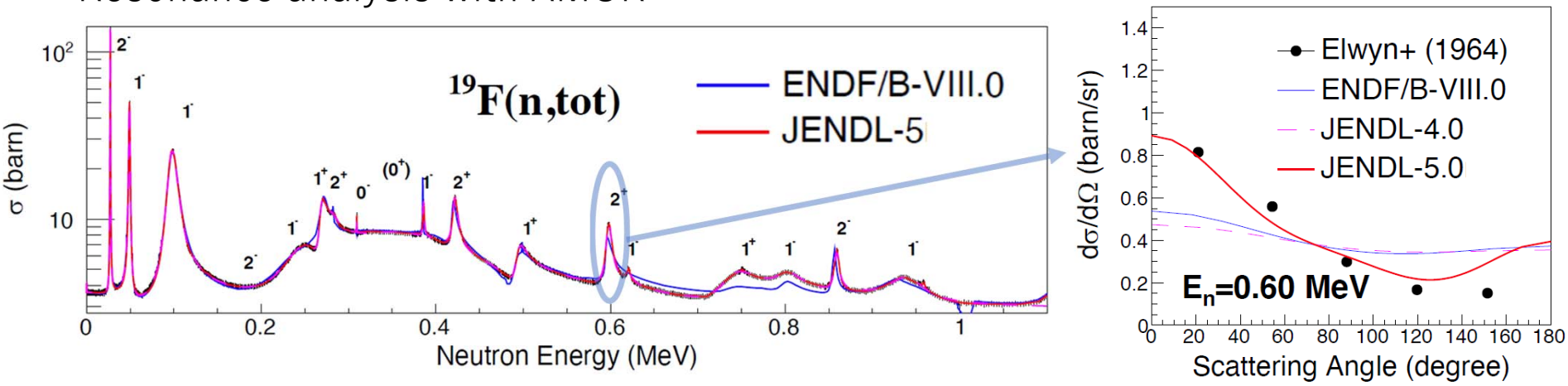
- Revision of the data of many nuclides in JENDL-4.0:
  - Ti, Cr, Mn, Fe, Co, Ni, Zn, Zr, Nb, Sn, Pb etc.
  - Cross sections, resonance parameters, elastic angular distributions, …
- New evaluation for isotopes of the elements missing in JENDL-4.0
  - Ho, Lu, Re, Ir, Pt, Tl, Po, Rn
- Addition of activation cross sections:
  - New evaluation + JENDL/AD-2017
  - Isomer production (MF=9, 10)
  - Produced nuclides information (MF=8)
- Addition of many unstable isotopes



Light nuclei

- H-1 from ENDF/B-VIII.0
- AMUR resonance analysis
  - C-12, C-13, N-15, O-16, F-19, Na-23
- New data
  - H-3 (ENDF/B-VIII.0)
  - New evaluation including stable and unstable nuclei:
    - Be-7, 10, C-11, 12, 13, 14, O-17,18, Ne-20-22, Na-22,24, Mg-28, Al-26, Si-31,32
  - Elemental data (Carbon) are separated to isotopic data (C-12, 13)

Resonance analysis with AMUR



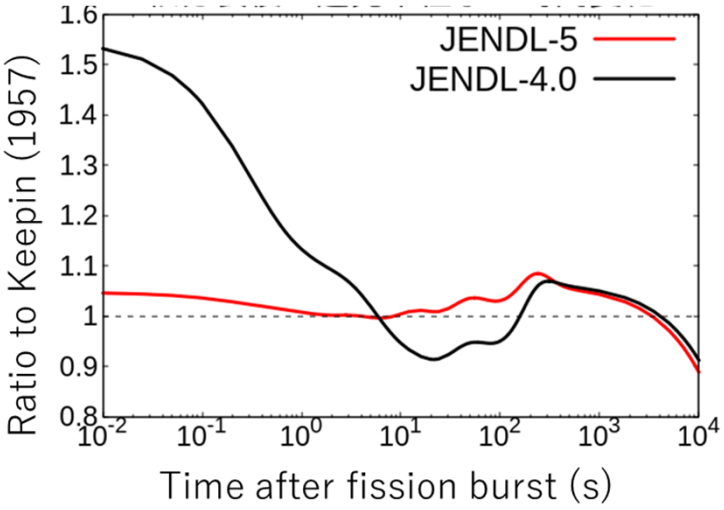
Fission product yield and decay data

- Fission product yield

  K. Tsubakihara et al., JNST 58, 151, 2021

  - New evaluation for all data in JENDL-4.0
  - Experimental data + model of charge dist. (odd-even, shell, isomer) + GLS
  - Covariance evaluation
- Decay data (4071 nuclides)
  - Up-to-date ENSDF + new measurement + IAEA/CRP
  - TAGS data
  - Theoretical calculation for beta decay with delayed neutron emission

Delayed neutron

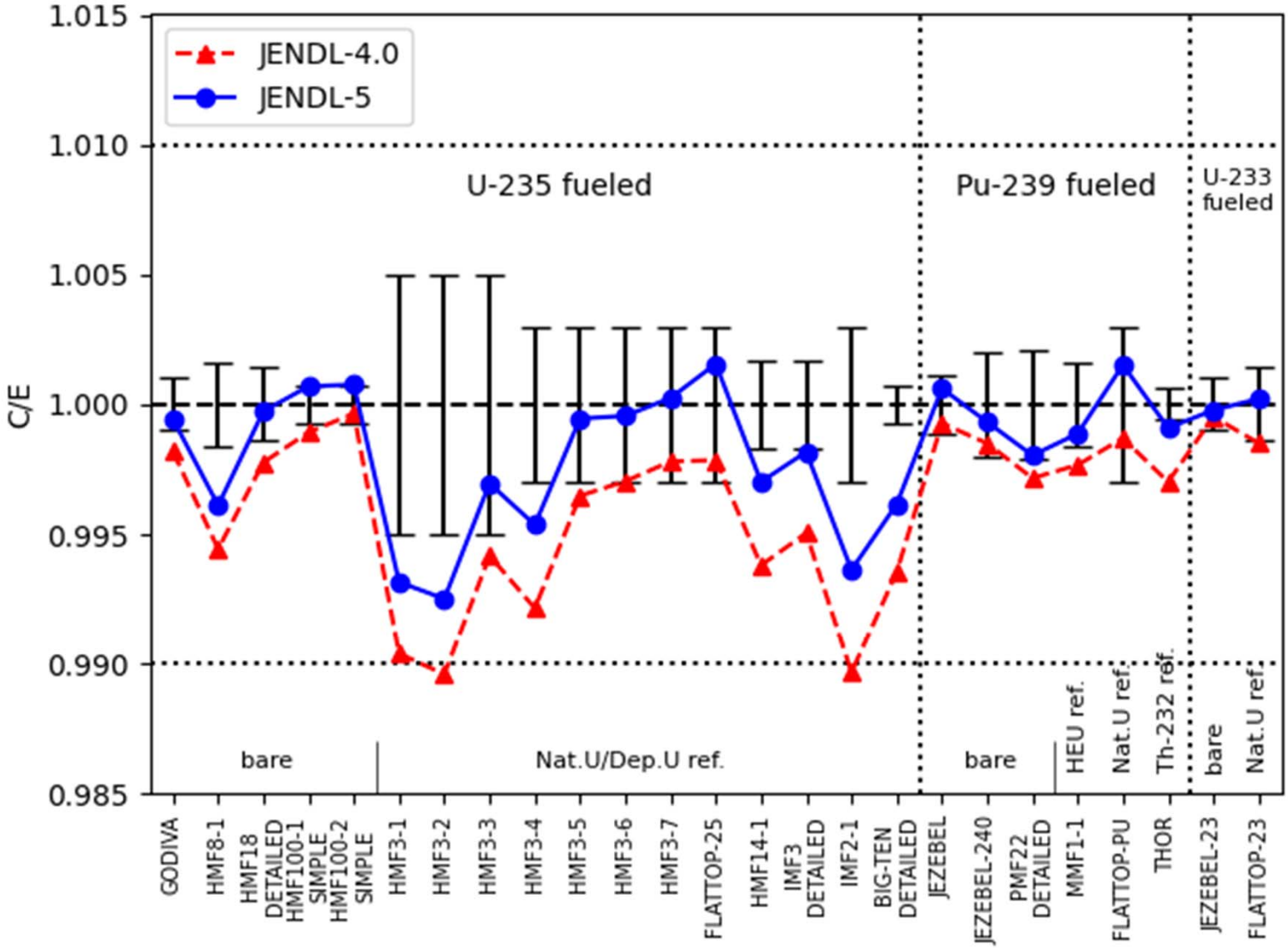


Neutron thermal scattering law

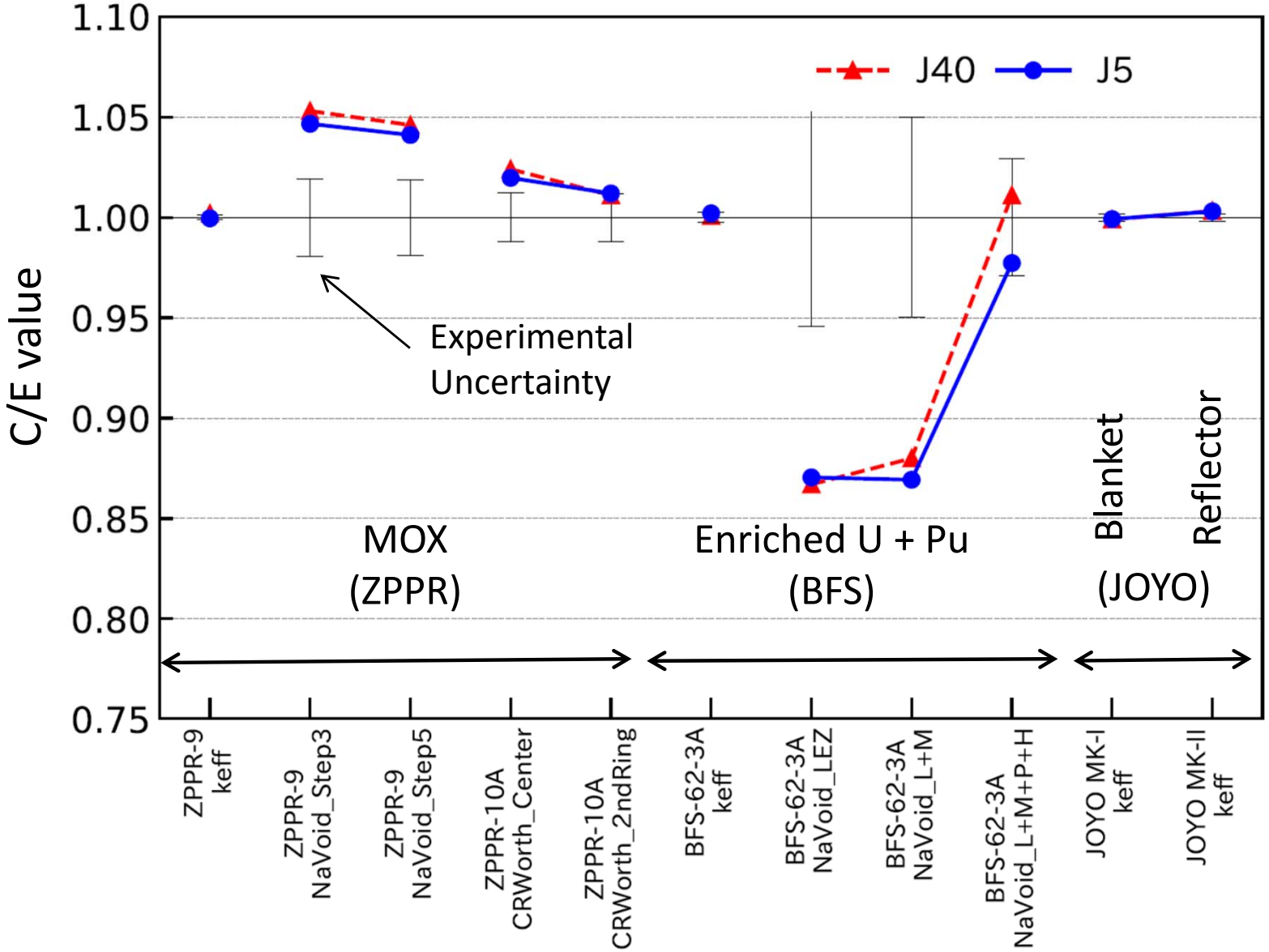
- New evaluation based on MD
  - H_2O, D_2O, methane, mesitylene, benzene, toluene, ethanol, m-xylene, triphenylmethane

    Y. Abe et al., NIMA 735, 568, 2014
    A. Ichihara et al., JAEA-Conf 2022-001, p.175
- Adoption of ENDF/B-VIII.0
  - YH_2, ZrH, Ice-Ih, Be-metal, BeO, graphite(crystalline, 10% porosity, 30% porosity), polyethylene, lucite, SiC, SiO_2(alpha, beta), UO_2, Al, Fe, UN
- Adoption of JEFF-3.3
  - H(para, ortho), D(para, ortho)

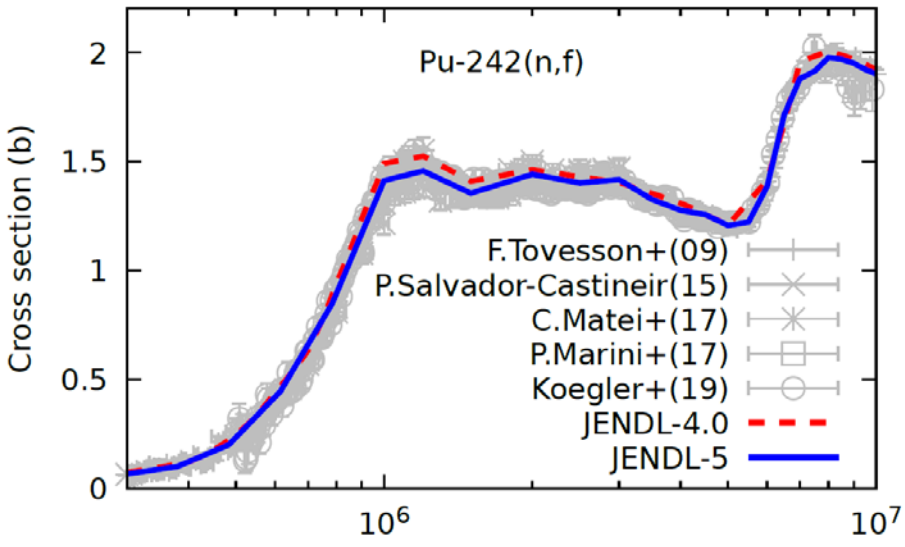
Criticality for Heavy Metal-Loaded Systems

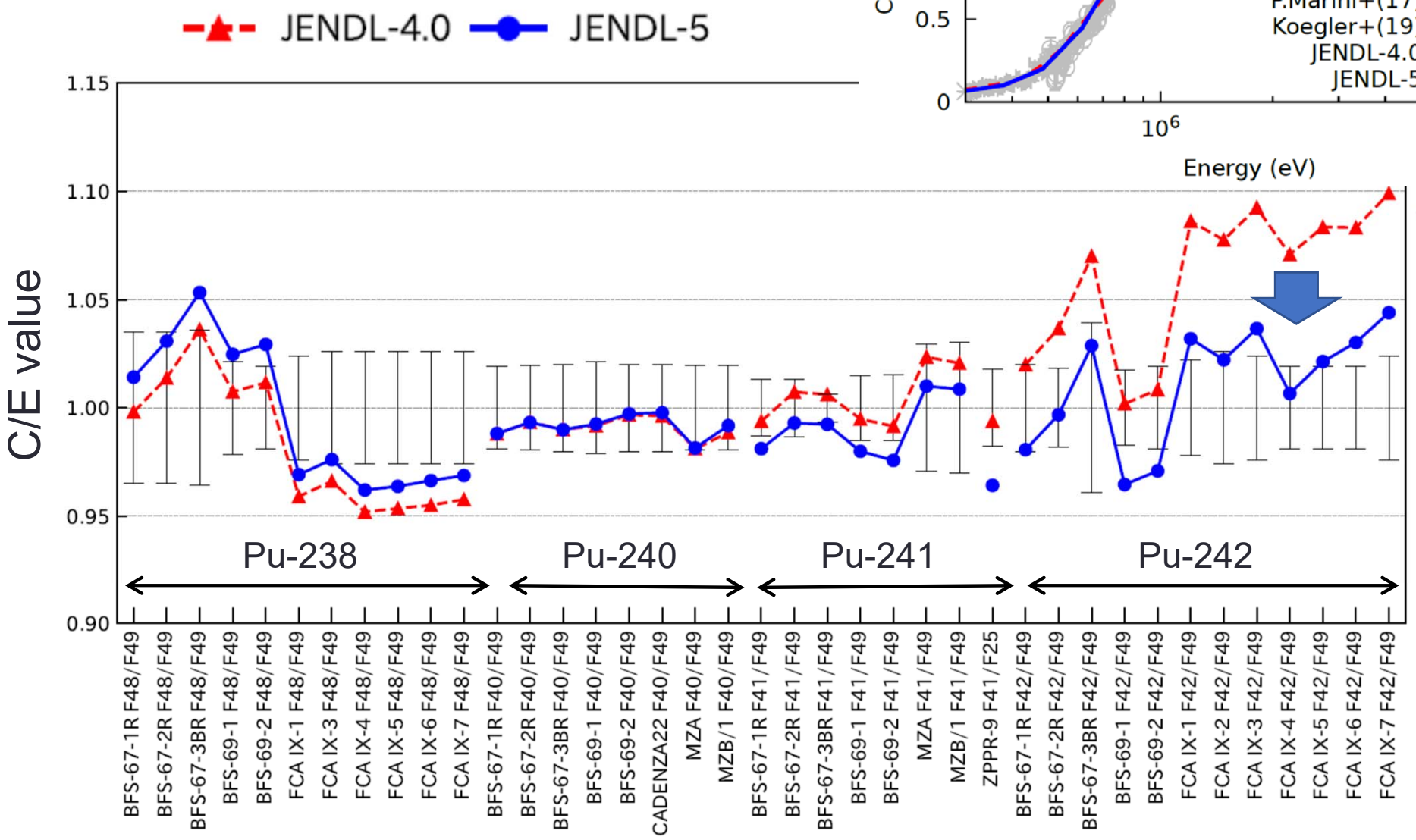


Middle- and large-fast reactors



Fission rate ratio in FR





Criticalities for thermal and intermediate spectrum systems

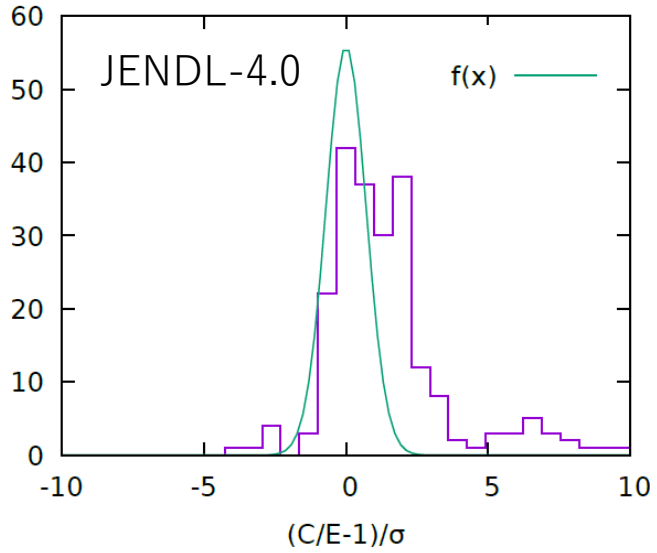
chi-squares of C/E (MVP calculation)

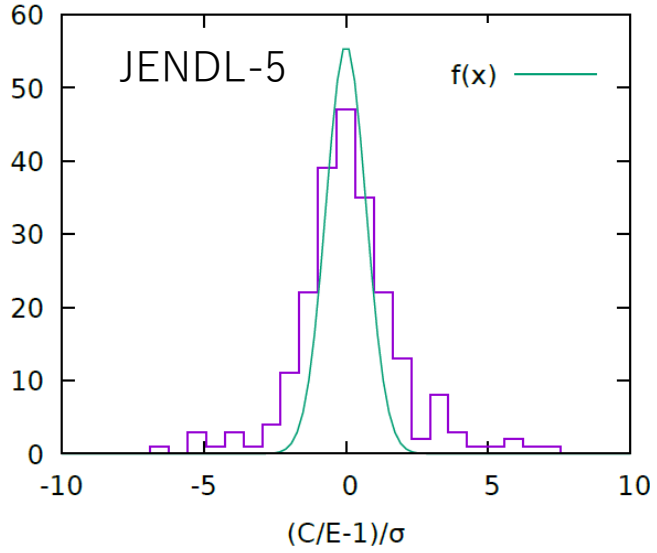
	J40	B7.1	B8.0	J5
All	5.35	4.90	3.87	3.90
HEU	4.72	4.88	4.20	4.20
IEU	3.89	1.81	0.85	1.05
LEU	4.31	3.19	3.00	3.60
MOX	0.58	0.45	0.90	0.97
Pu	11.10	11.13	6.24	5.36
U233	4.02	3.69	4.13	4.10

JENDL-5 gives smaller values than JENDL-4.0 in most cases.

- Results of IEU and Pu with JENDL-5 are much smaller than JENDL-4.0.
  (Similar to ENDF/B-VIII.0)

C/E distribution (Pu + MOX)





f(x): normal distribution,

High energy reaction up to 200 MeV

- Neutron data: 579 nuclides (73%)
  - Merge JENDL-4.0/HE and JENDL/ImPACT-2018 above 20 MeV
  - New evaluation with CCONE
- Proton data: 239 nuclides
  - JENDL-4.0/HE and JENDL/ImPACT-2018
  - Revision of cross section with Gaussian process regression: ^{9}Be, ^{27}Al, ^{93}Nb, ^{197}Au

    H. Iwamoto et al., JNST 59, 334 (2022)
- Recoil spectrum
  - Develop a new method to calculate recoil spectrum accurately for multiple particle emission with Monte Carlo

    O. Iwamoto, JNST 59, 1232 (2022)

High energy (p & n reactions)

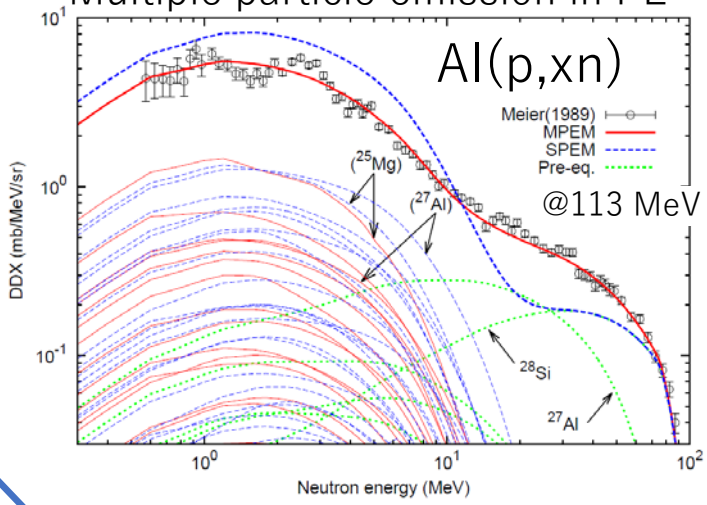
JENDL/HE-2004 (66 nucl.)
JENDL/HE-2007 (106 nucl.) } ECIS+GNASH

JENDL-4.0/HE (130(n), 133(p) nucl.)
JENDL/ImPACT-2018 (163 nucl.) } CCONE

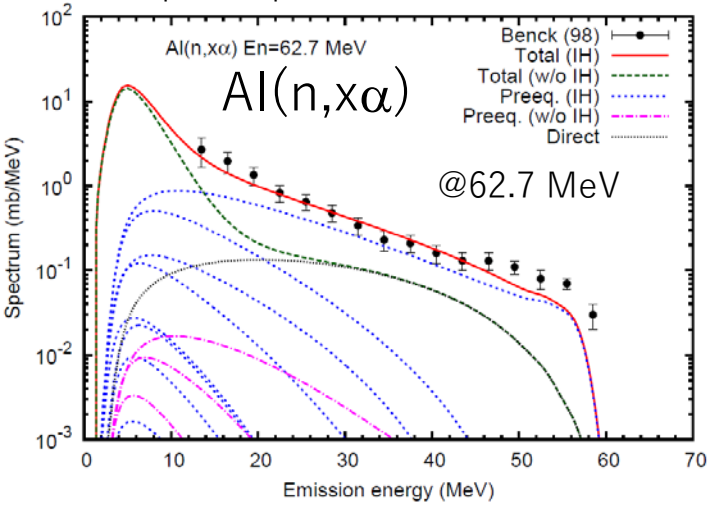
JENDL-5 (up to 200 MeV)

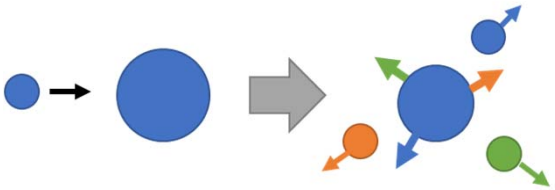
- n: 579 nucl. (73%), p: 239 nucl.
- CS eval. with GPR (9Be, 27Al, 93Nb, 197Au)
  H. Iwamoto et al., JNST (2022)
- Recoil spectrum (CCONE)
  O. Iwamoto, JNST (2022)

Multiple particle emission in PE

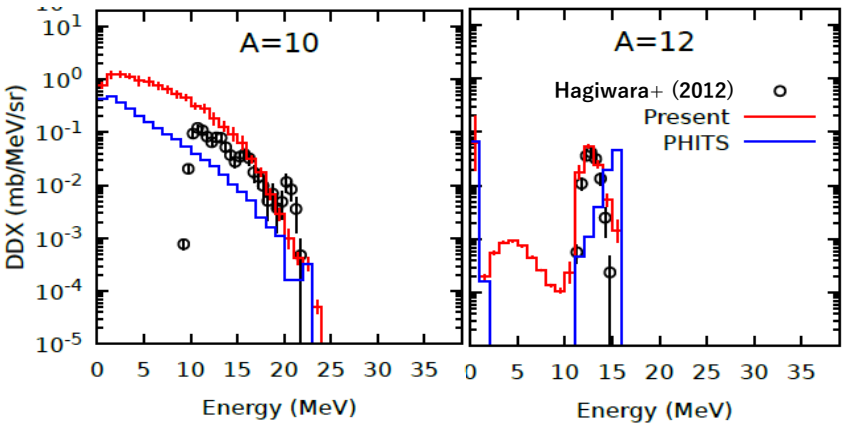


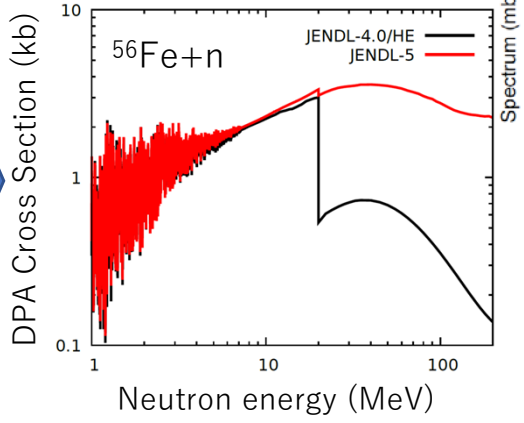
Composite particle emission in PE





Recoil spectrum calc. with CCONE



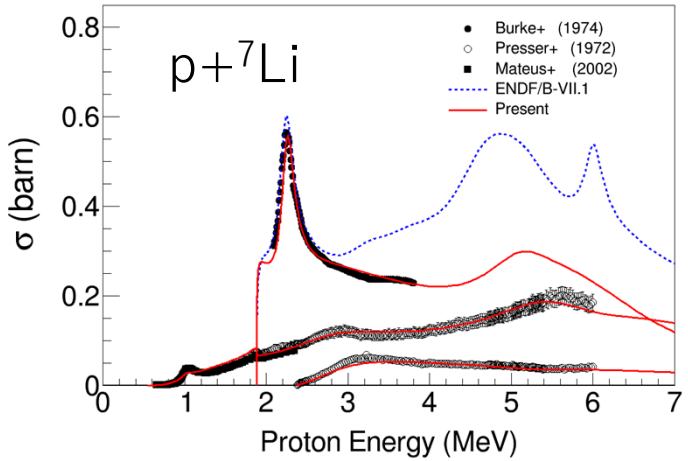


Thanks to C. Konno

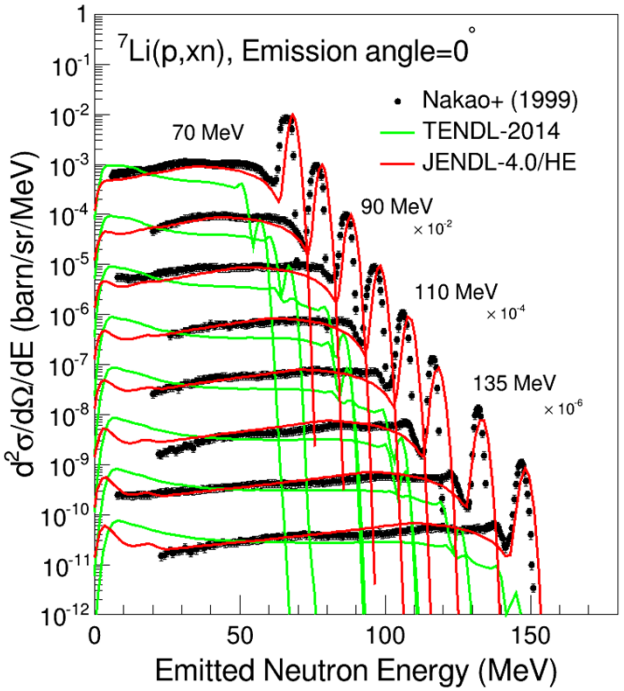
Proton reaction (low energy)

JENDL-4.0/HE

R-matrix analysis

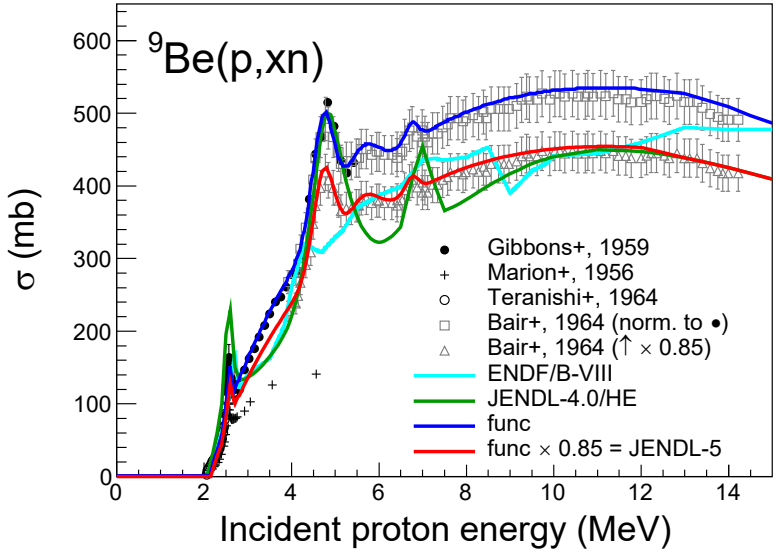


DWBA + CCONE

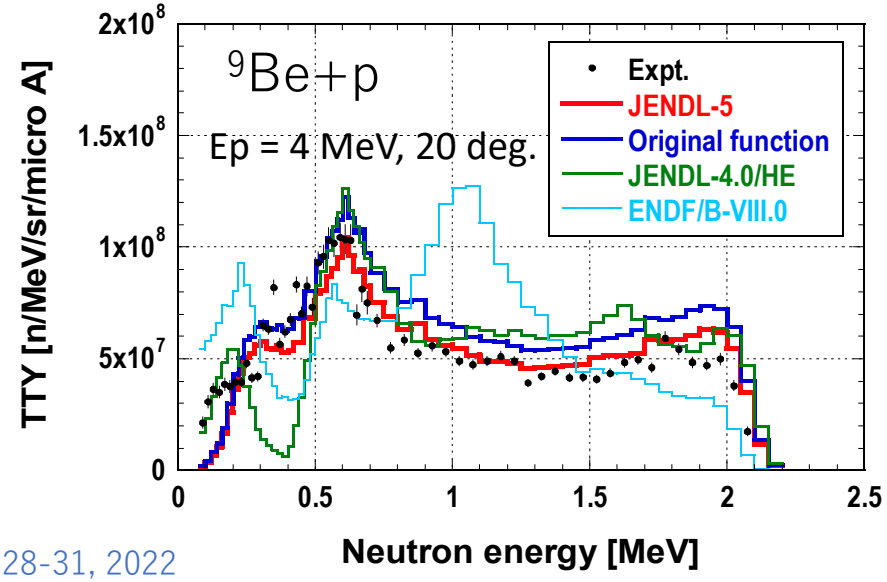


JENDL-5

Wakabayashi's function (JNST, 55, 859, 2018)
- neutron emission (cross section, angular dist., energy spect.)



Monte Carlo simulation (MCNP/PHITS)



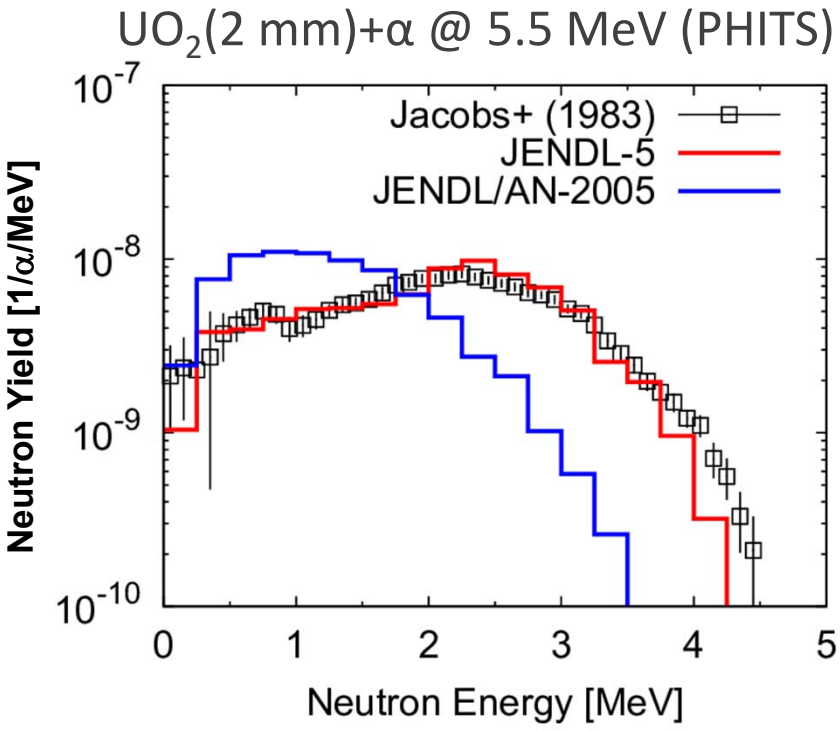
Deuteron and α-particle reaction

Deuteron reaction

- JENDL/DEU-2020 (Li, Be, C) with revision
- New evaluation for Al, Cu, Nb with DURACS

Alpha-particle reaction

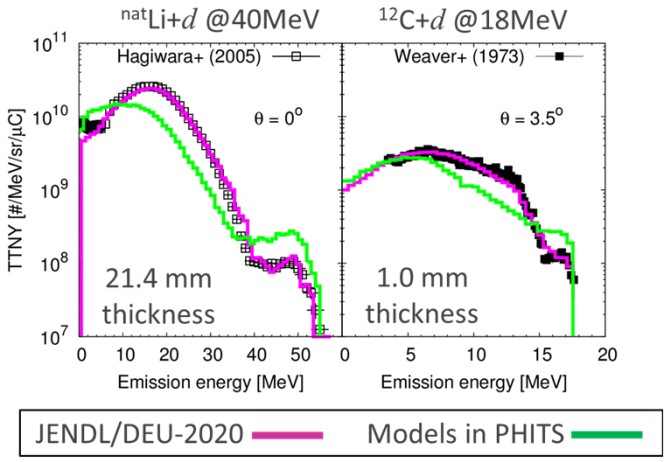
- JENDL/AN-2005: (α,xn) c.s.
  + CCONE
  (Li, Be, B, C, N, O, F, Na, Al, Si)
- Revision of the neutron emission energy-angular distribution
- Addition of other data needed in Monte Carlo simulation



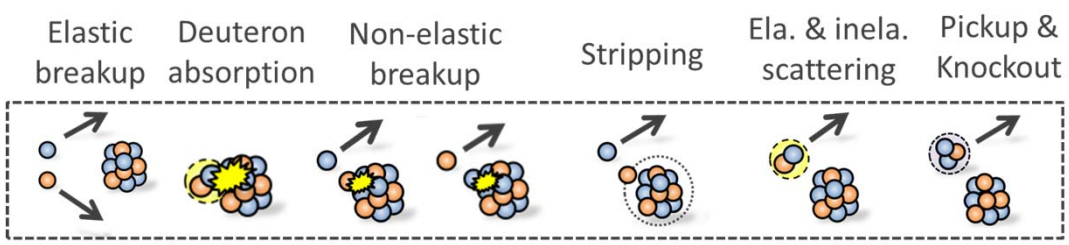
Deuteron reaction

JENDL/DEU-2022

Eval. with DEURACS (Li, Be, C)



DEURACS

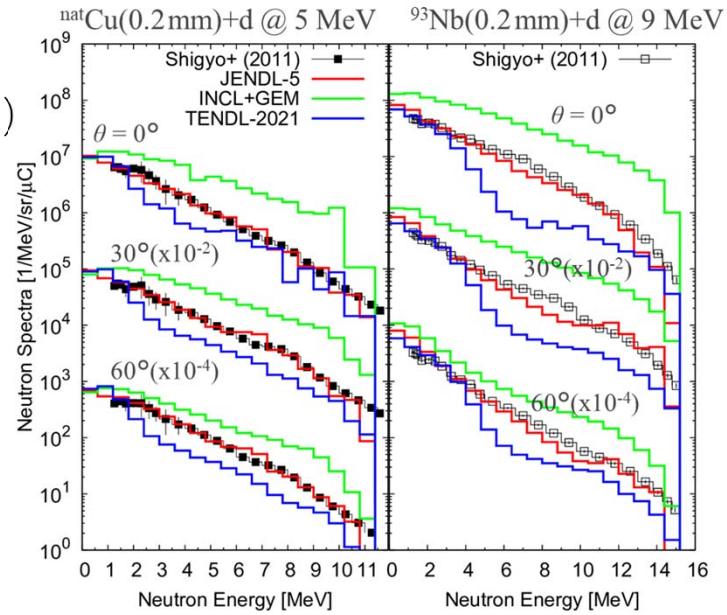


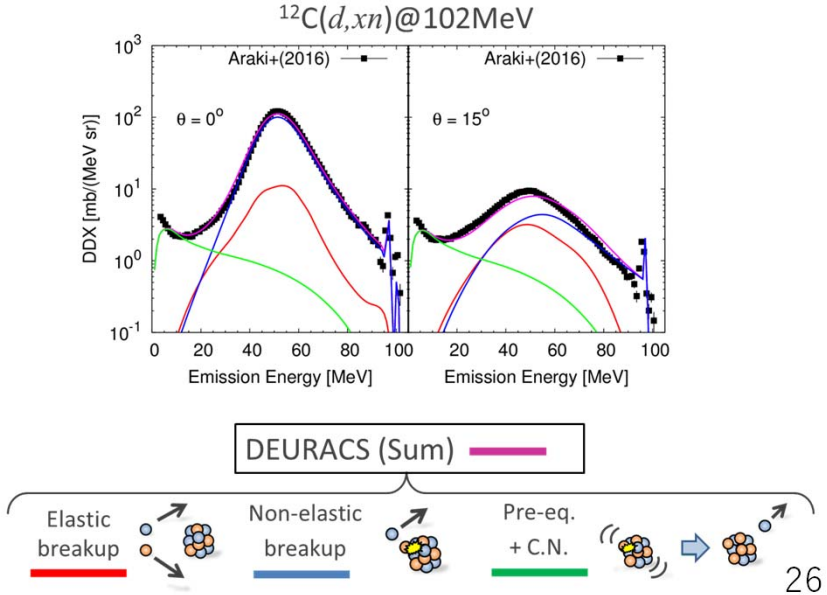
CDCC[1]	Glauber[2]	DWBA	Kalbach[3]
Elastic breakup	Non-elastic breakup	Stripping, Inelastic scat.	Pick-up, Knockout Inelastic scat.

+ CCONE (pre-eq. & compound reac.)

JENDL-5

JENDL/DEU-2022(rev.)
+ new eval.
(Al, Cu, Nb)

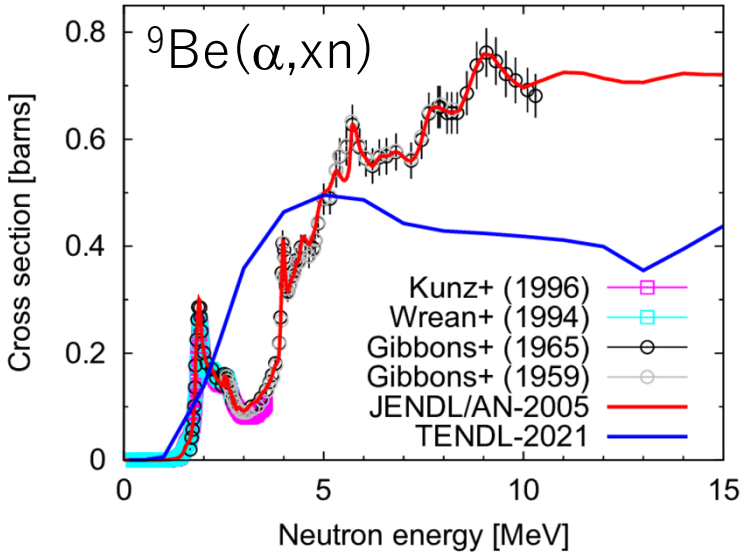




Alpha-particle reaction

JENDL/AN-2005

- Li-6,-7, Be-9, B-10,-11, C-12,-13, N-14,-15, O-17,-18, F-19, Na-23, Al-27, Si-28,-29,-30
- Good agreement with the experimental data including resonance structures



JENDL-5

- JENDL/AN-2005: (α,xn) c.s. + CCONE
- Revision of the neutron emission energy-angular distribution
- Addition of other data needed in Monte Carlo simulation

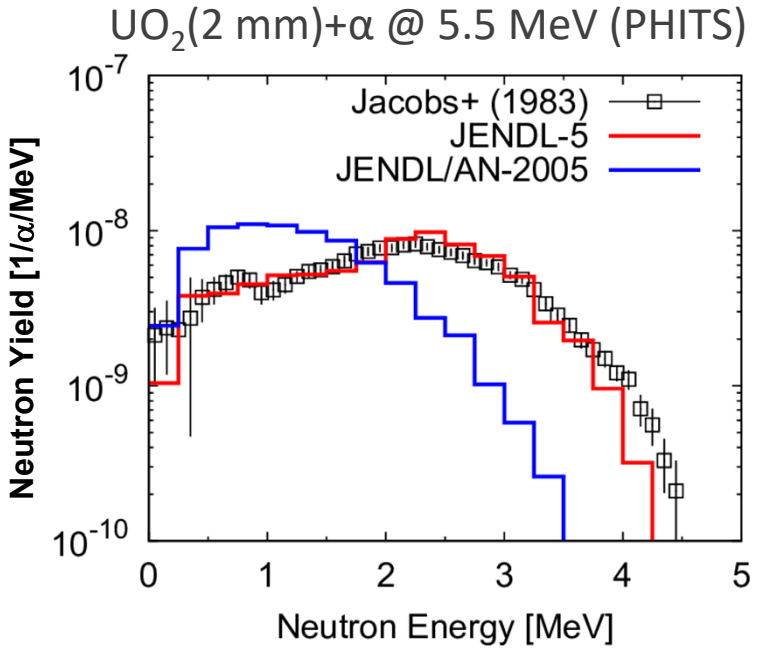
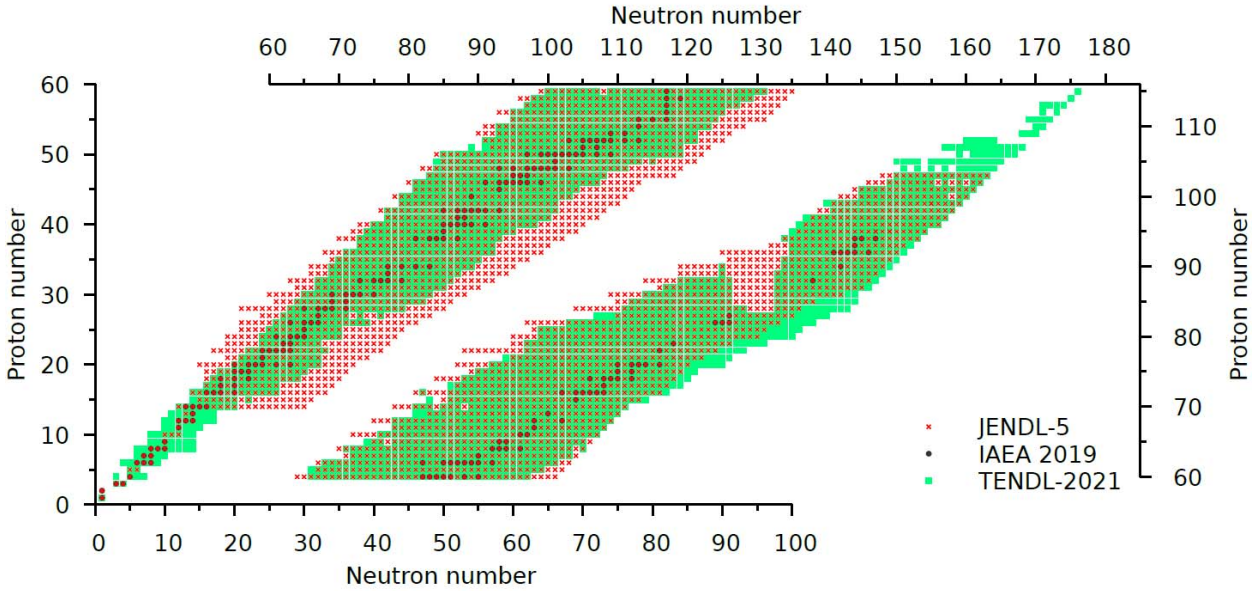


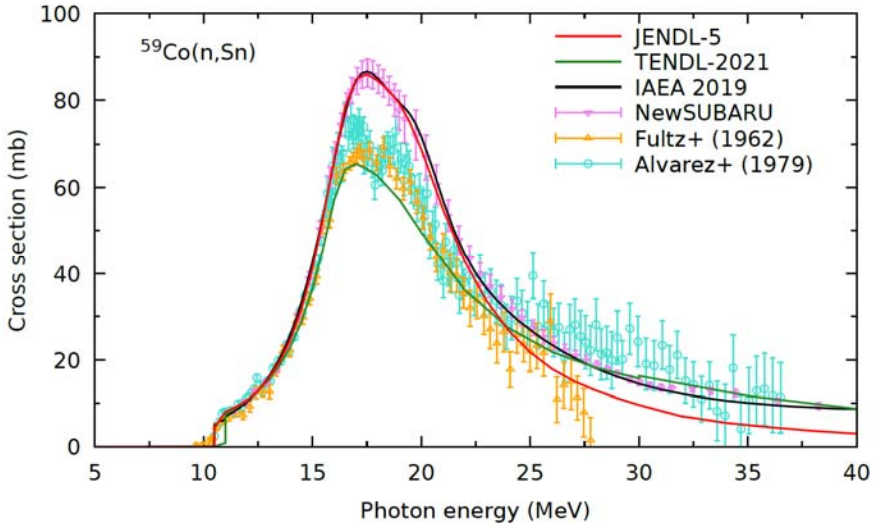
Photo-nuclear reaction

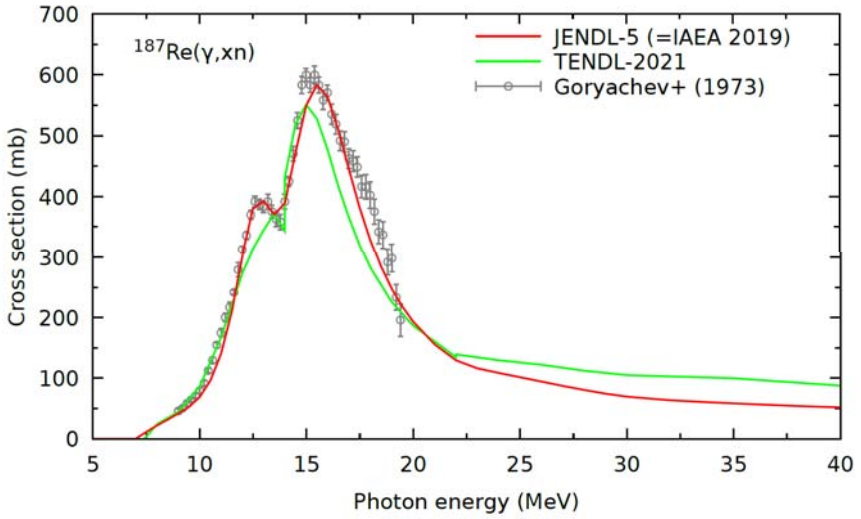
Comprehensive and high-quality data

JENDL/PD
- PD-2004 (2004) 68 nuclides
- PD-2016 (2017) 2,671 nuclides
- PD-2016.1 (2020) 2,684 nuclides

JENDL-5 (2021)
- PD-2016.1 with revision
- New evaluation with CCONE
  (Y, Rh, Tb, Ho, Tm, Ta, Au, Bi)







Note: 187Re(γ,n)186Re (medical isotope of β & γ emitter)

Summary

- JENDL-5 has been developed with features:
  - Increase of the number of nuclei for neutron reaction data with complete isotopes in natural abundance
  - Revision of large amount of nuclear data taking into account up-to-date knowledge from light to heavy nuclei
  - Adoption of the first original evaluation of neutron thermal scattering law
  - Integration of special purpose files of activation and high energy reaction for neutron reaction
  - Addition of recoil spectra with newly developed method
  - Sublibraries of various particle induced reactions: neutron, proton, deuteron, alpha-particle, photon
- Improvement of benchmark results
  - Criticalities of Pu and IEU systems
  - Fission rate ratios of MAs are improved.

JENDL-5 paper will be published in JNST (in press).

Main contributors to JENDL-5

- JAEA:
  - N. Iwamoto, A. Ichihara, S. Kunieda, F. Minato, S. Nakayama, K. Shibata (retired), H. Iwamoto
  - Y. Nagaya, K. Tada, C. Konno, N. Matsuda, A. Oizumi, T. Kashima (Rikoh Kagaku co.), K. Yokoyama, H. Taninaka, T. Jin (NESI), S. Okita, K. Okumura, T. Matsumura, M. Sakamoto
- Tokyo Tech.:
  - K. Tsubakihara (Asahikawa NCT), S. Okumura (IAEA), C. Ishizuka, T. Yoshida, S. Chiba
- Kyoto Univ.: Y. Abe
- Hokkaido Univ.: G. Chiba
- QST: S. Sato, M. Ohta, S. Kwon
- IAEA: N. Otsuka, J. C. Sublet
- JENDL committee
  - Activation Cross Section Evaluation WG
  - Reactor Integral Test WG
  - Shielding Integral Test WG
  - WG on Evaluation of Nuclide Generation and Decay Heat