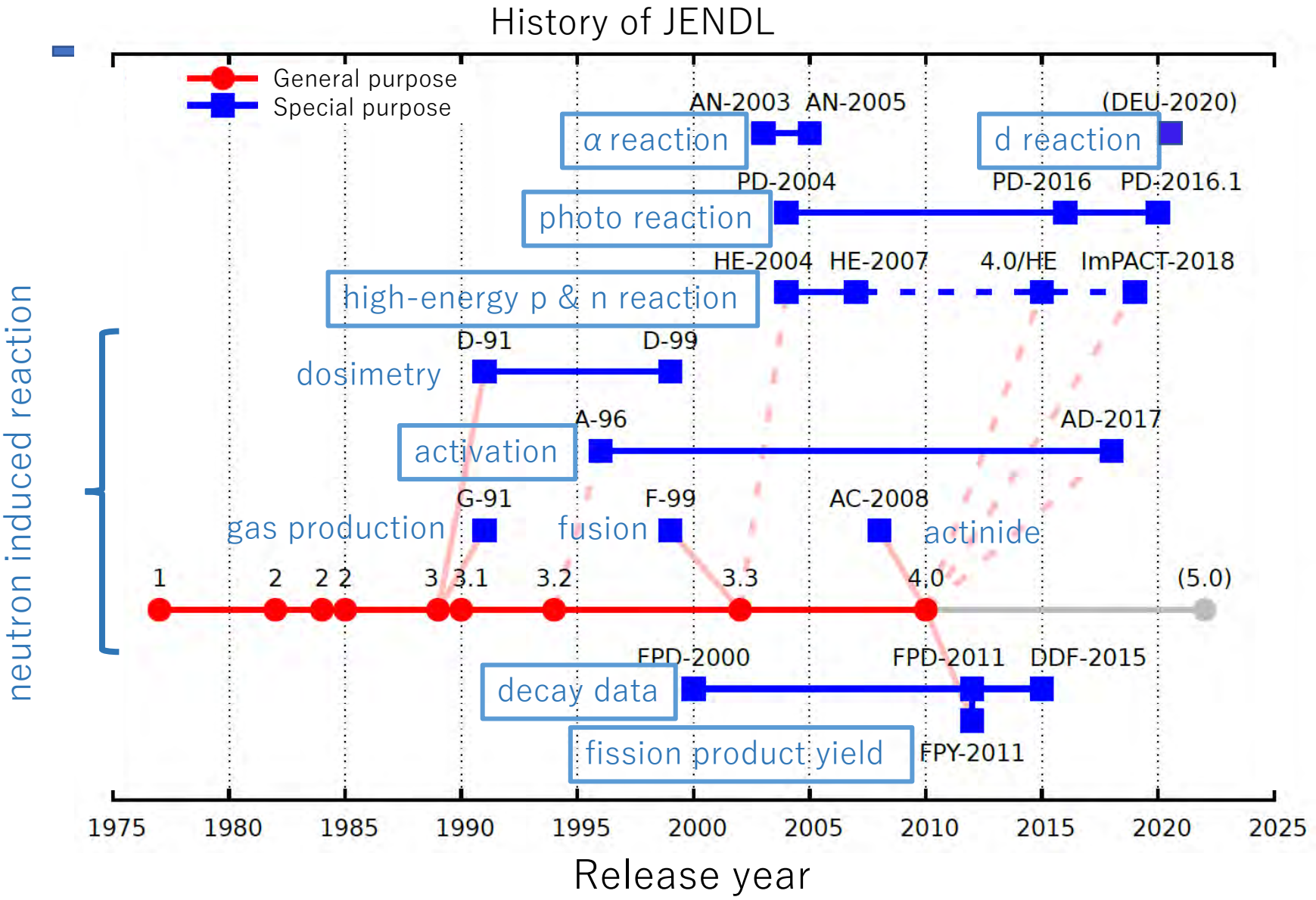
Overview and future of JENDL-5

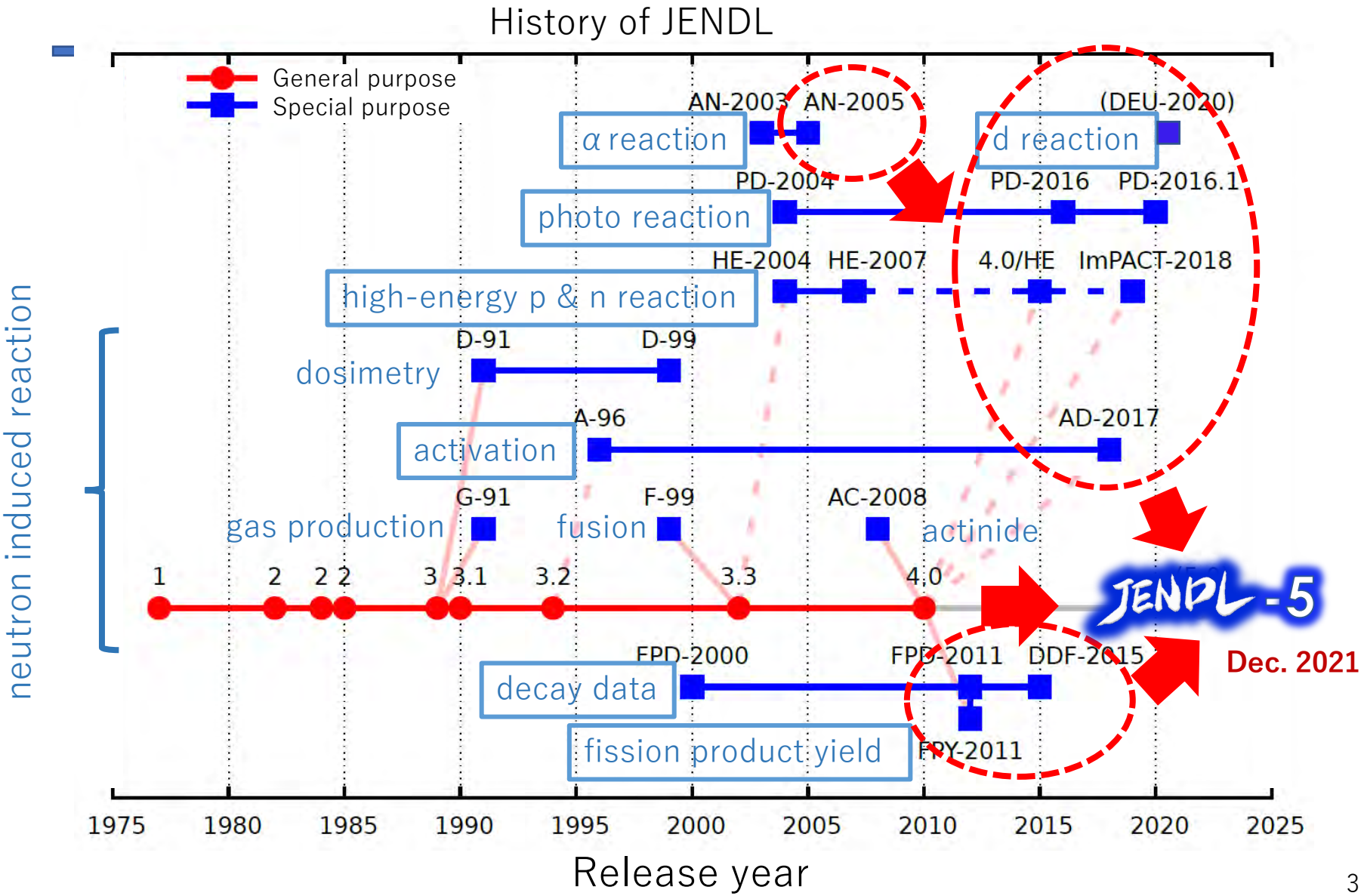
O. Iwamoto

Japan Atomic Energy Agency

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

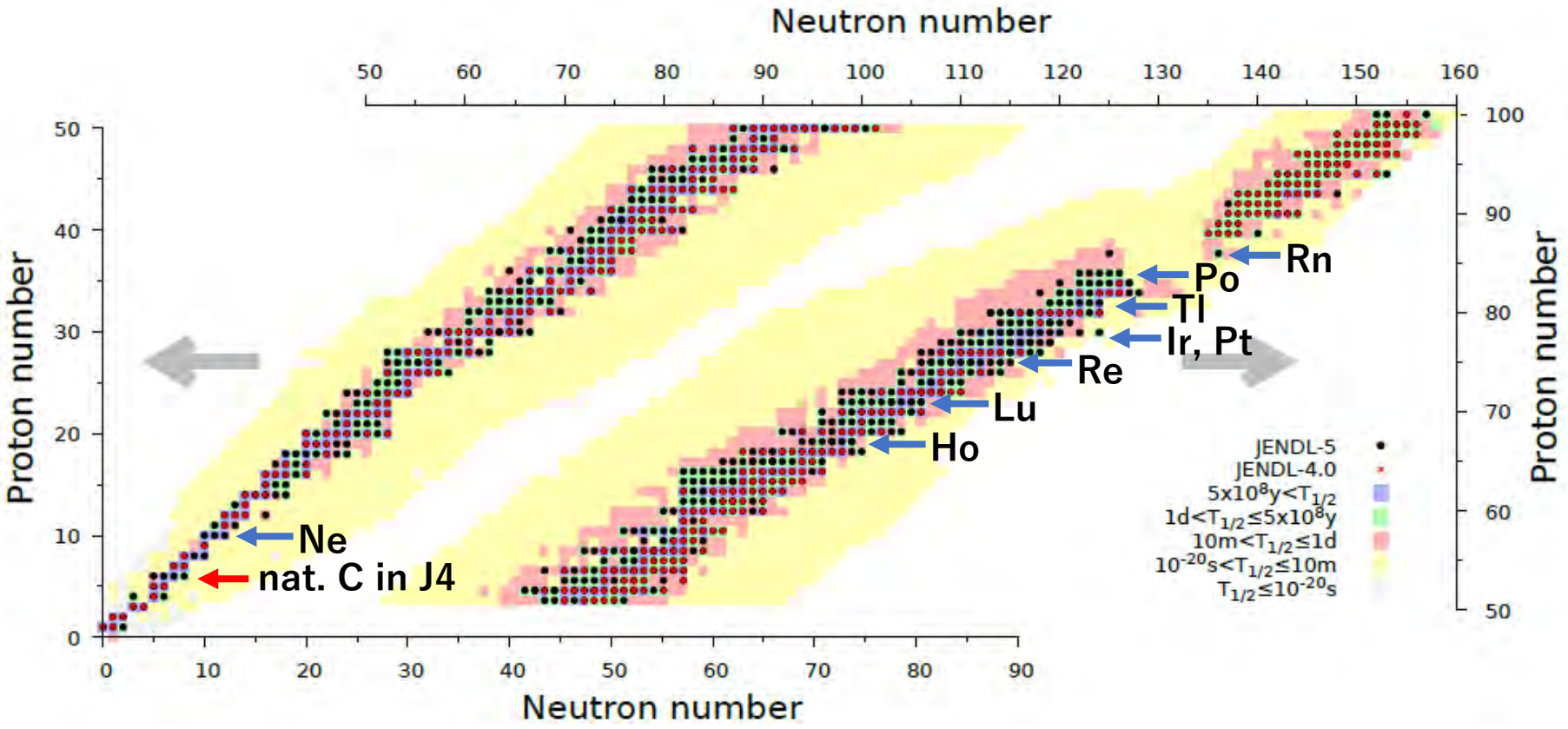
} ENDF/B-VIII.0

Enhanced **quantity**, **quality** and **variety**

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
  - enough 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 (with developing new method)
- Files
  - Full version (up to 200 MeV), pointwise (0k, 300k)
  - U20 (up to 20 MeV), activation file (activation c.s.)

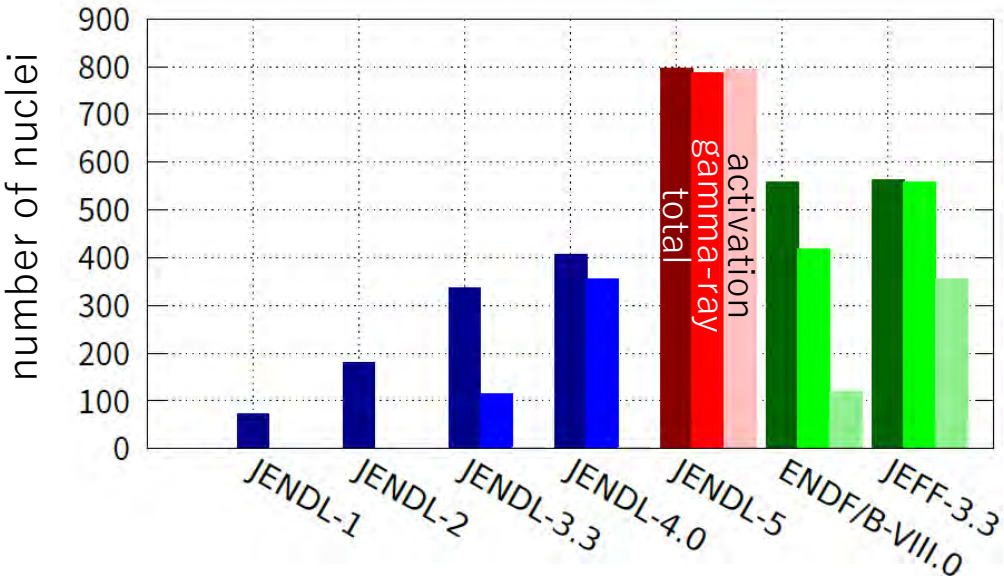
Nuclides in neutron sublibrary



← new isotopes added in JENDL-5

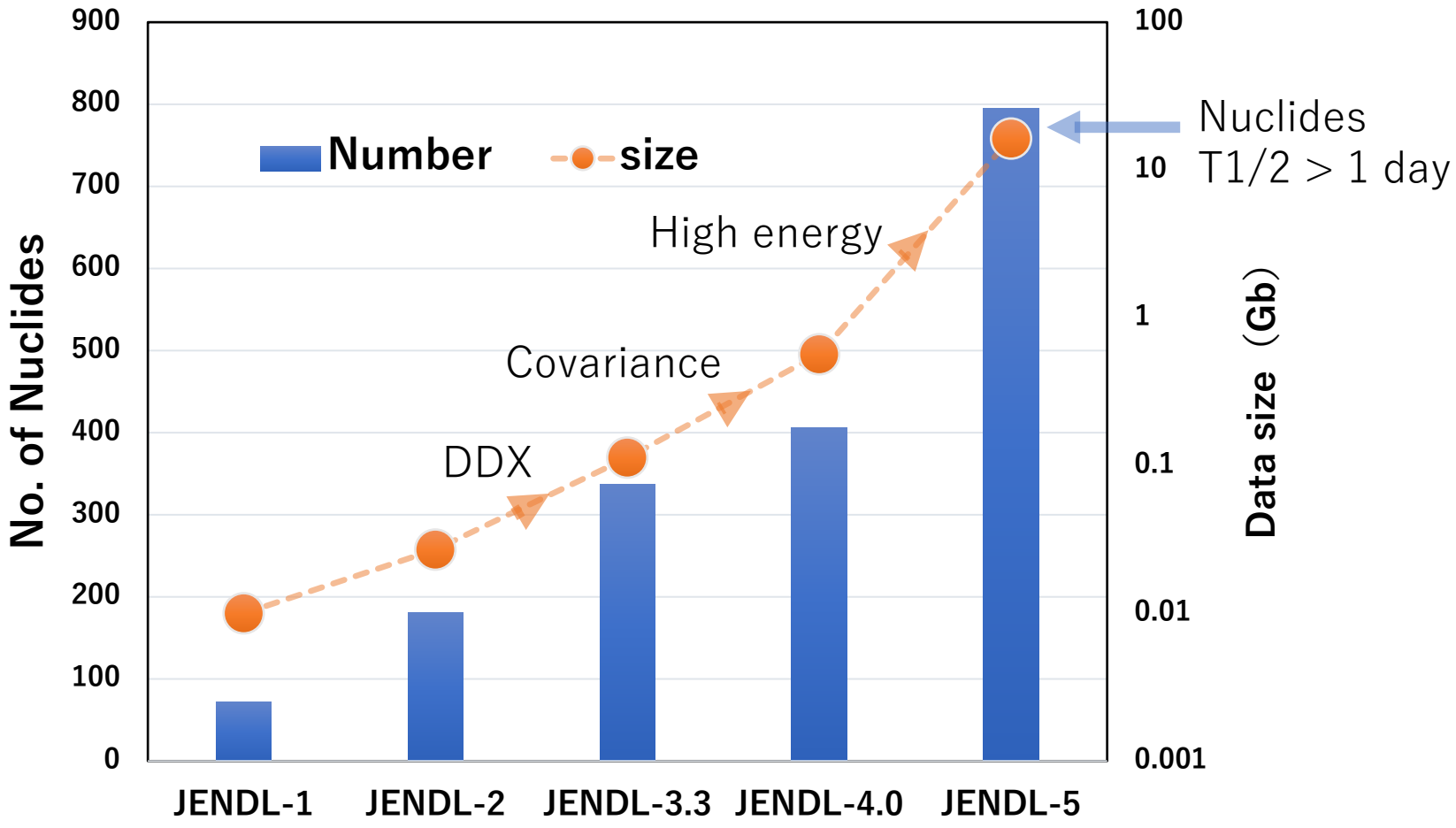
Number of nuclides of neutron reaction data

	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

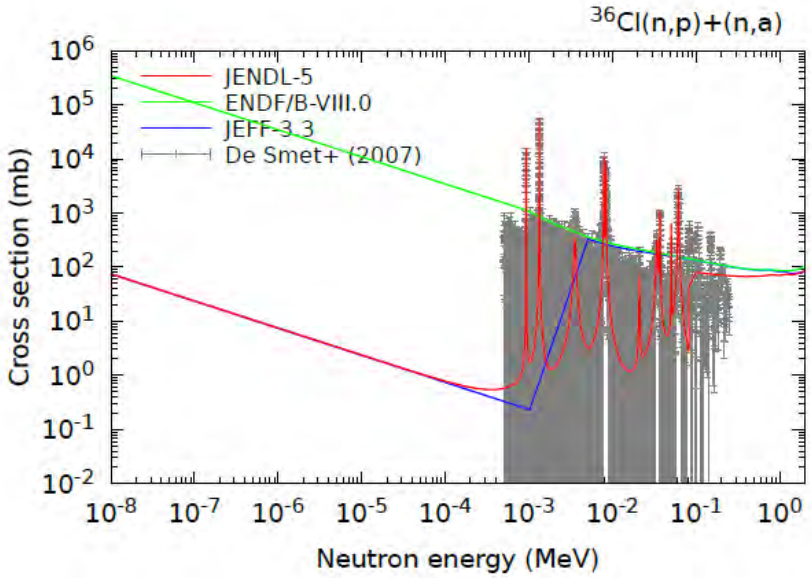
Amount of neutron data in JENDL

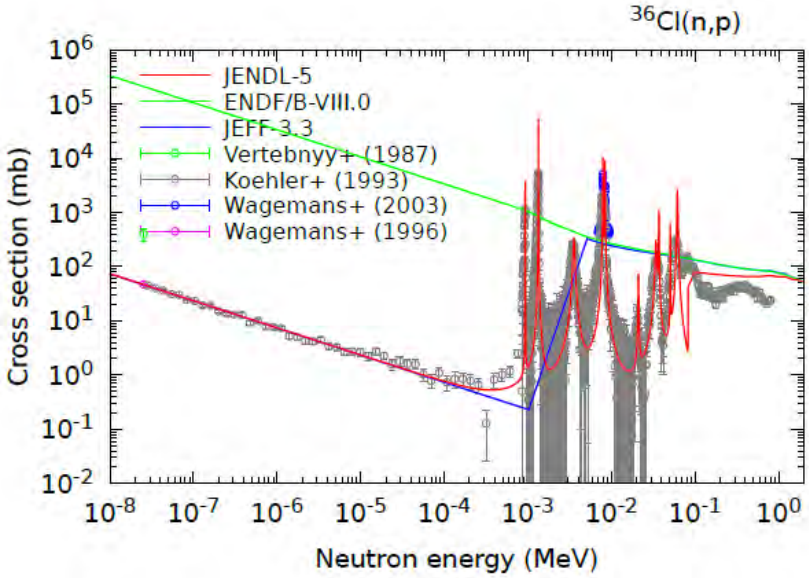


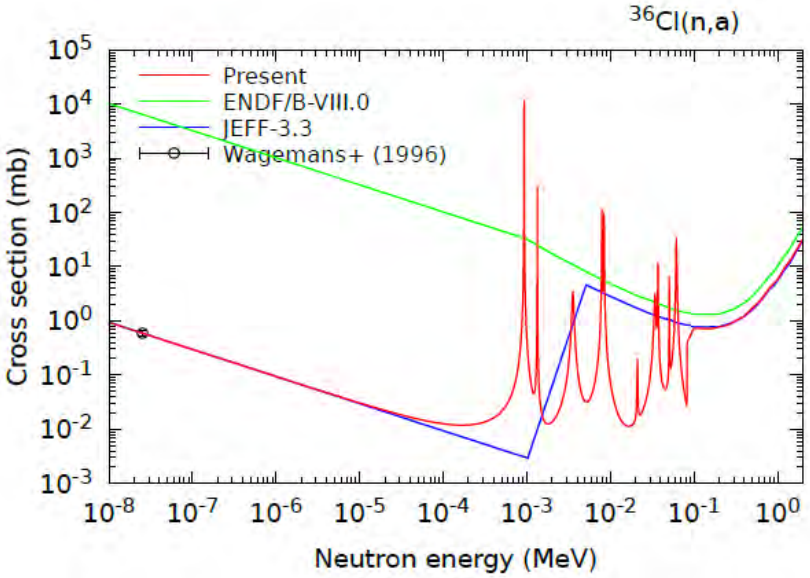
- Inclusion of all nuclides in natural abundance
- Sufficient number of nuclei for neutron activation calculation

New evaluation (example)

Cl-36 (T1/2=301ky)
No data was given in JENDL-4.0.

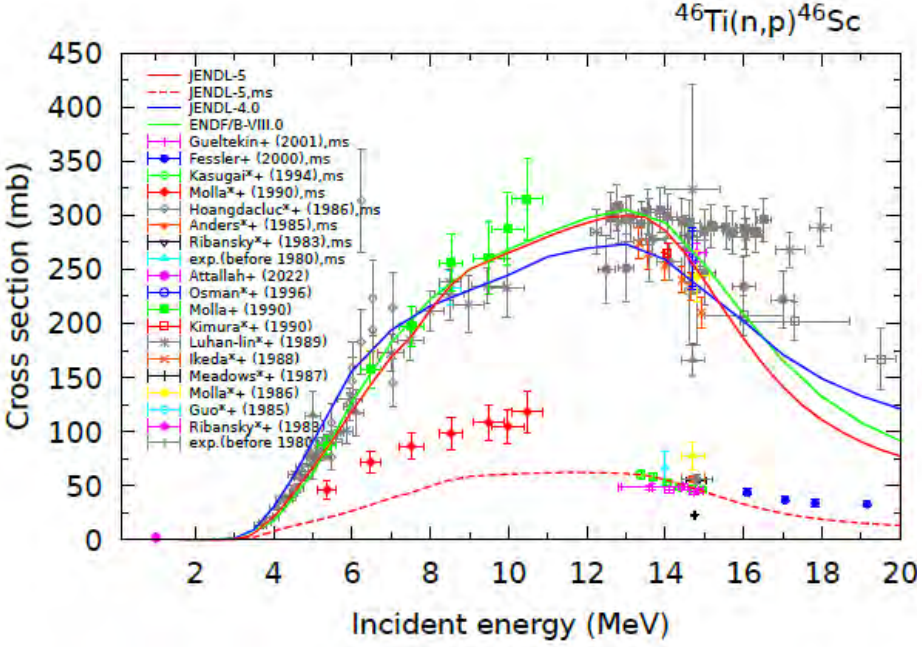






Activation & γ-ray emission

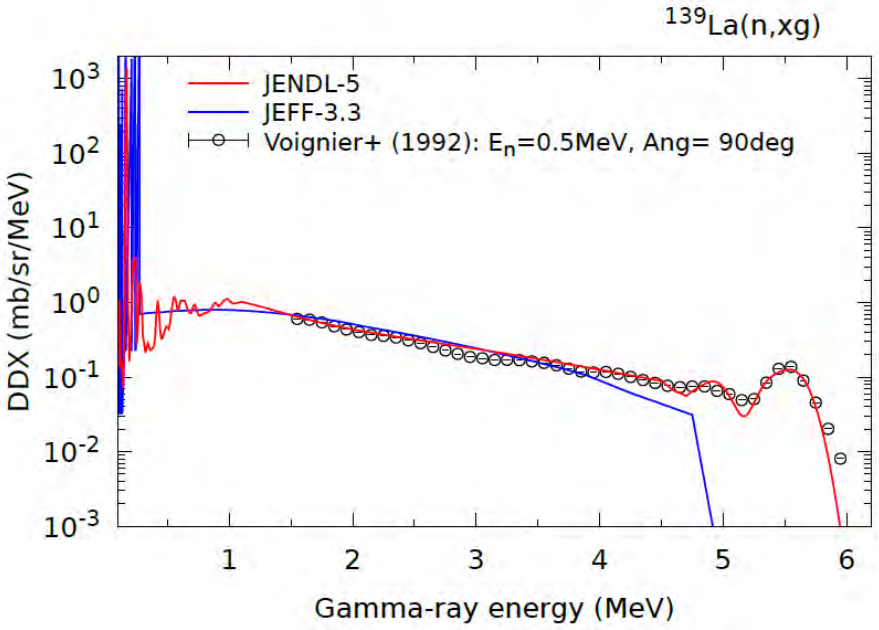
New evaluation with isomer production for activation



Sc-46 T1/2
gs: 84d, ms: 19s

New evaluation with γ-ray emission spectrum

(no γ-ray emission data in JENDL-4.0)



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)

Progress of CCONE development

. . . . .
JENDL-3.3
JENDL/HE

ELIESE, CASTHY, SINCROS, TNG, PEGASUS, ECIS, GNASH, ALICE, …

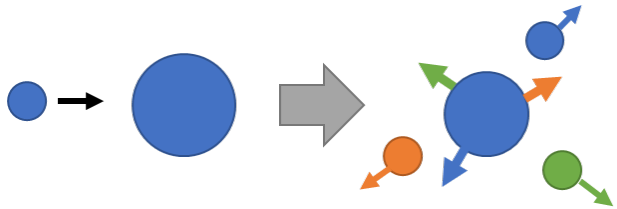
JENDL-4.0
JENDL-4.0/HE
. . . . .

CCONE, (POD)

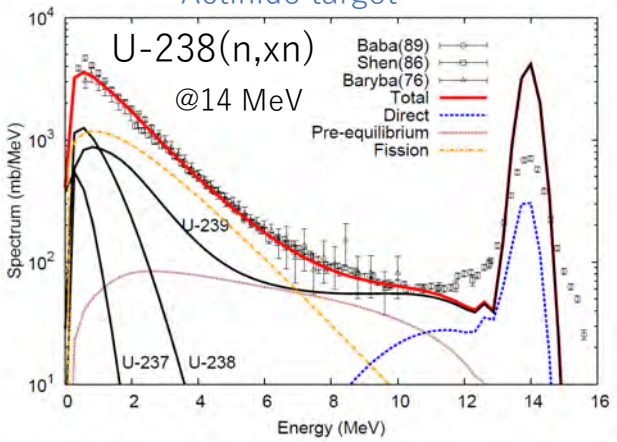
- Actinide evaluation
- HE (pre-eq.): multi & comp. part.
- photon & charged part. induced
- LS spectrum

JENDL-5

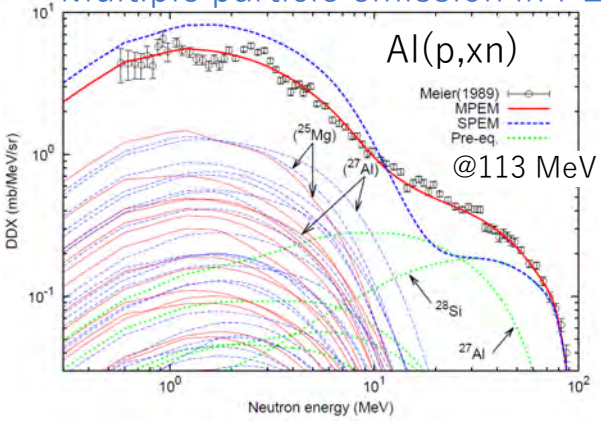
- particle emission from disc. levels
- recoil spectrum



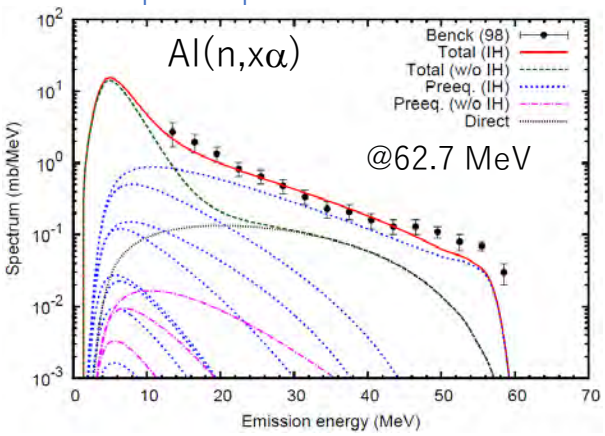
Actinide target



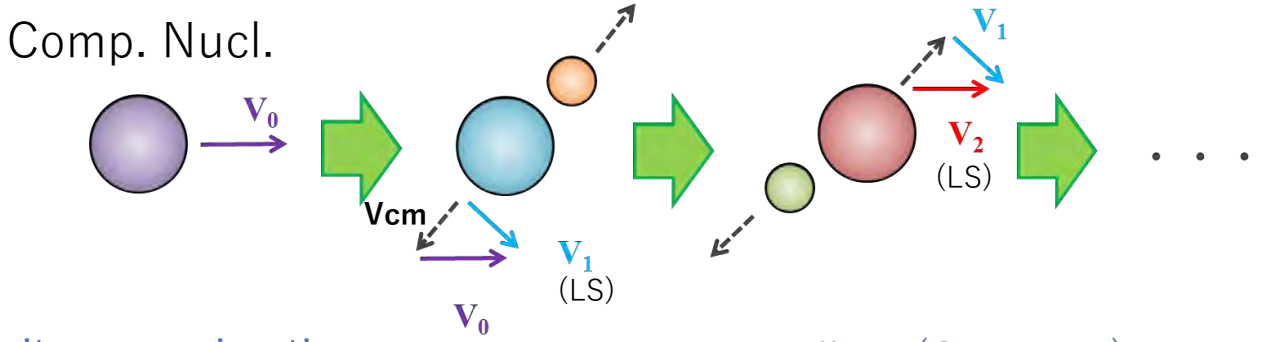
Multiple particle emission in PE



Composite particle emission in PE



Recoil of residual (for DDX of LPE)



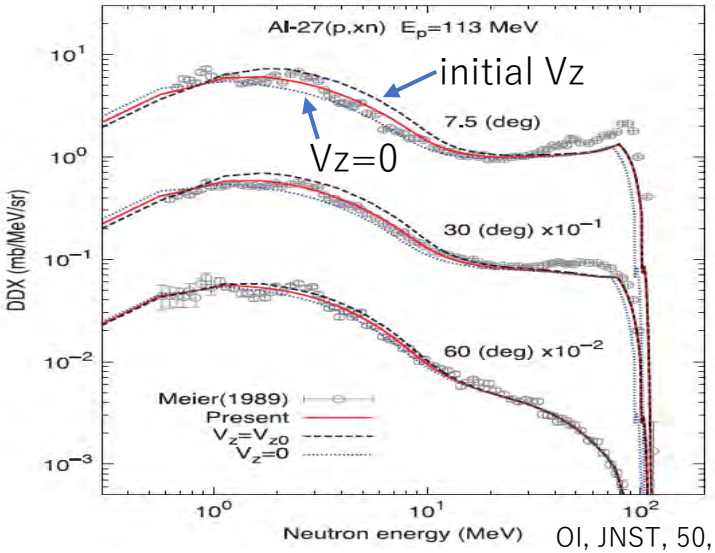
Average velocity approximation (for J4/HE)

$$V_z^i = \frac{V_z^{i-1} Q_+^{i-1} + \sum_x \int d\epsilon_x V_z^{j,x}(\epsilon_x) Q^j W_x^j}{Q^i}$$

$$V_z^{j,x}(\epsilon_x) = V_z^j - \mu(\epsilon_x) V(\epsilon_x)$$

averaged recoil velocity by part. x emission

1 parameter



OI, JNST, 50, 409 (2013)

Maxwellian (Gaussian) approximation

(for particle emission from disc. level)

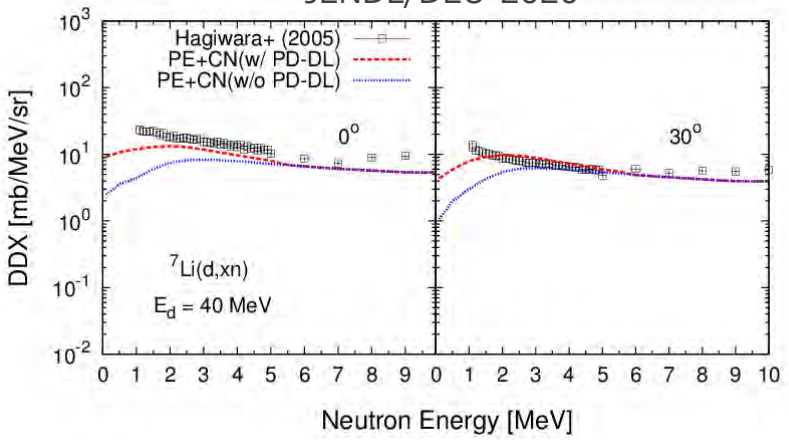
$$f_i(\vec{V}) = N(V_{zi}, \sigma_i; \vec{V})$$

$$f_{i+1}(\vec{V}) = \int d\vec{v_x} f_i(\vec{v_x} - \vec{V}) N(v_{x0}, \sigma_x; \vec{v_x})$$

$$= N(V_{zi+i}, \sigma_{i+1}; \vec{V})$$

2 parameters (analytic form)

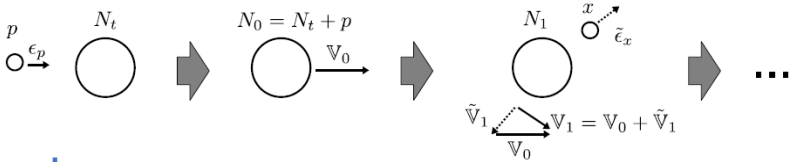
JENDL/DEU-2020



Recoil of residual (for residual ES)

Velocity after particle emissions

$$\mathbb{V}_n = \mathbb{V}_0 + \sum_{i=1}^{n} \tilde{\mathbb{V}}_i$$



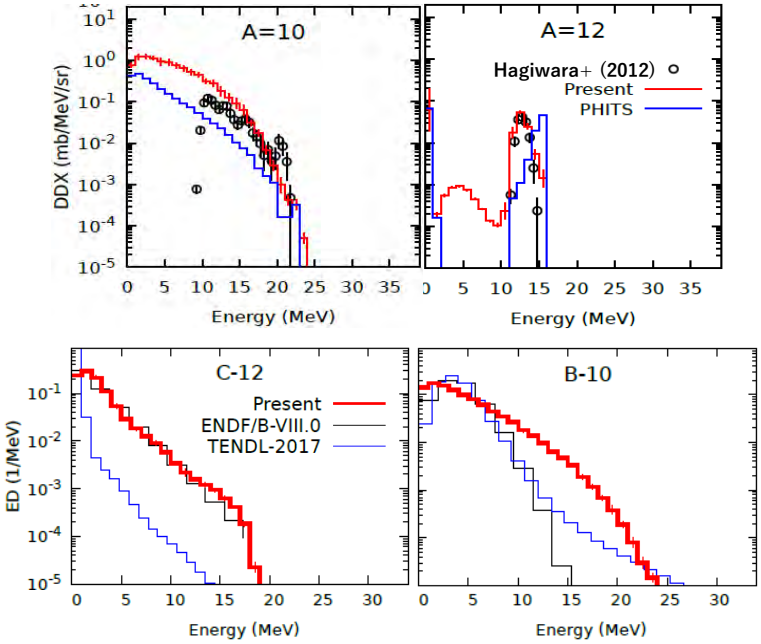
Velocity distribution by particle emission

$$f_n(E_n, \mathbb{V}_n) = \sum_x \int\int\int dE_{i_x} d\mathbb{V}_{i_x} d\tilde{\mathbb{V}}_{i_x} \frac{f_{i_x}(E_{i_x}, \mathbb{V}_{i_x})}{f_{i_x}(E_{i_x})} \tilde{\sigma}_x^R(E_{i_x}, \tilde{\mathbb{V}}_{i_x})$$

$$\times \delta(E_{i_x} - S_{i_x}(x) - \tilde{\epsilon}_x - E_n)\delta(\mathbb{V}_{i_x} + \tilde{\mathbb{V}}_{i_x} - \mathbb{V}_n),$$ apply Monte Carlo integral

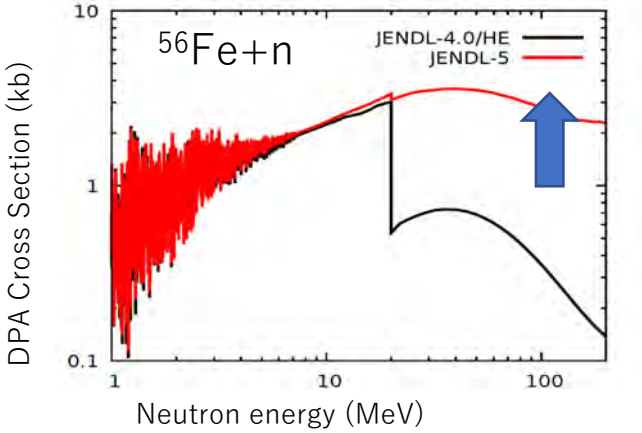
Results

C+p @70MeV



JENDL-5 DPA CS

(no recoil data in JENDL-4.0/HE)

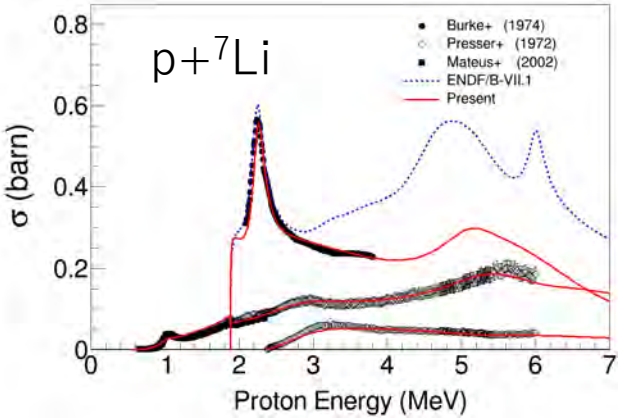


Thanks to C. Konno

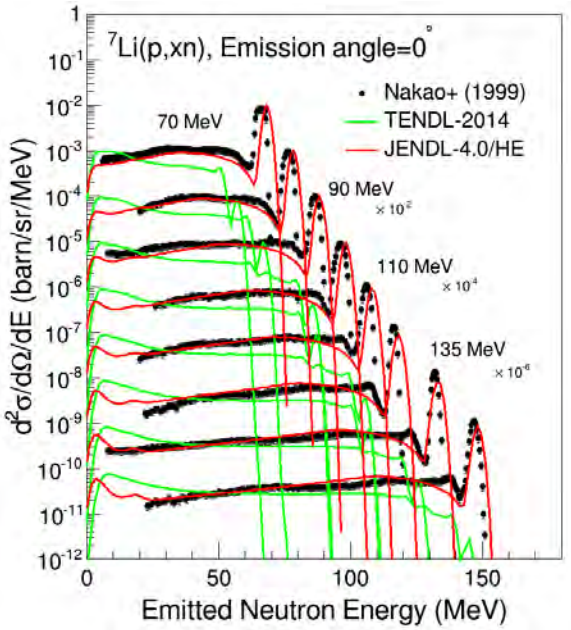
Proton reaction (low energy)

JENDL-4.0/HE

R-matrix analysis

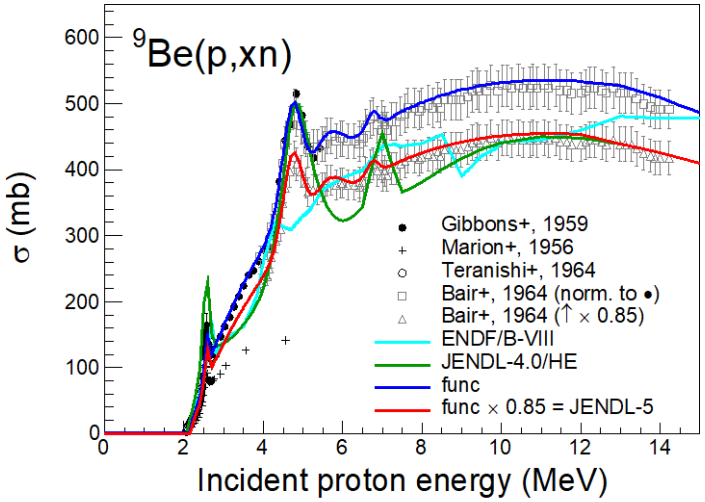


DWBA + CCONE

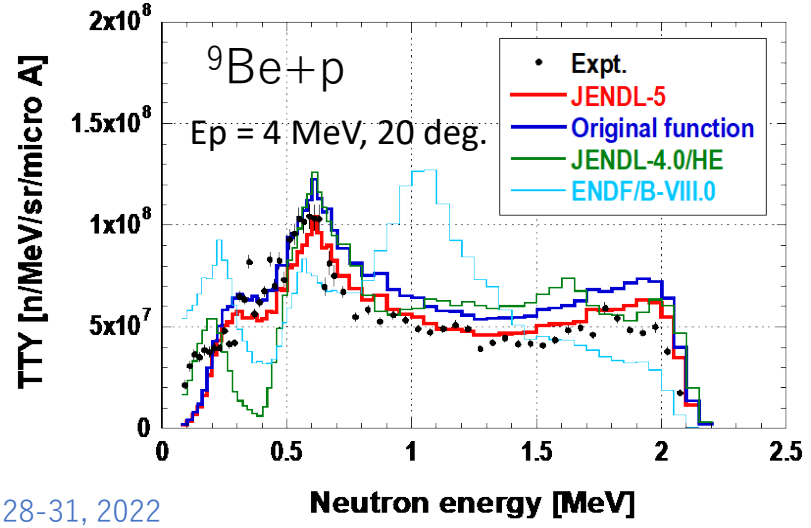


JENDL-5

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



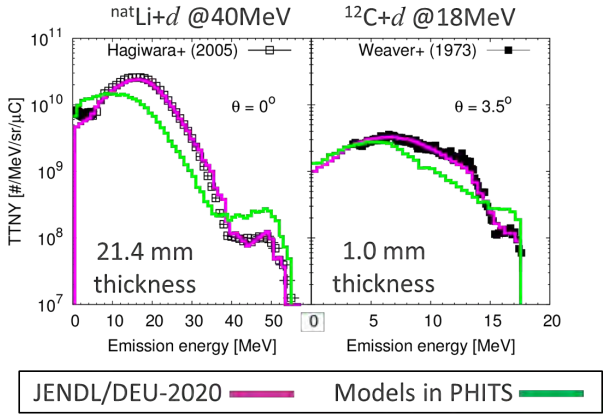
Monte Carlo simulation (MCNP/PHITS)



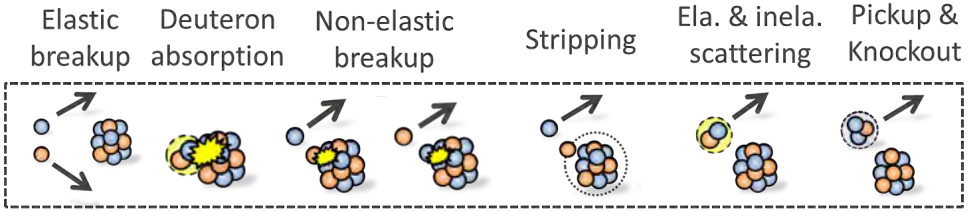
Deuteron reaction

JENDL/DEU-2022

Eval. with DEURACS (Li, Be, C)



DEURACS

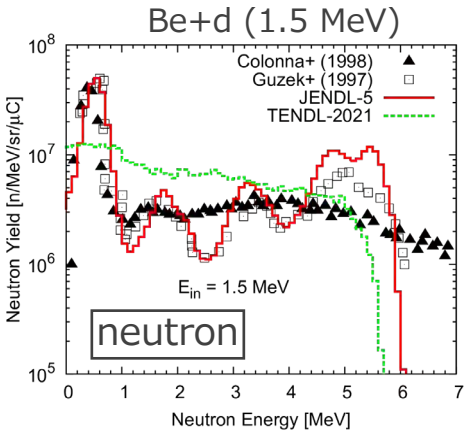


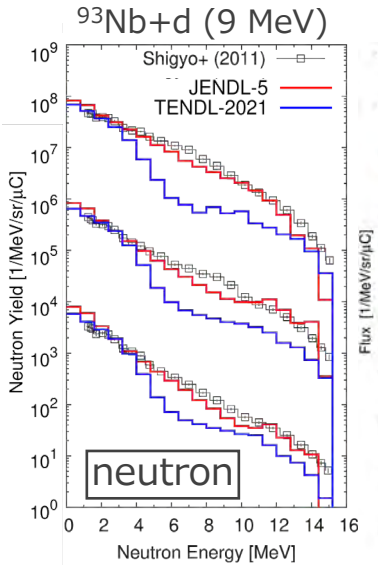
CDCC	Glauber	DWBA	Kalbach
Elastic breakup	Non-elastic breakup	Stripping, Inelastic scat.	Pick-up, Knockout Inelastic scat.

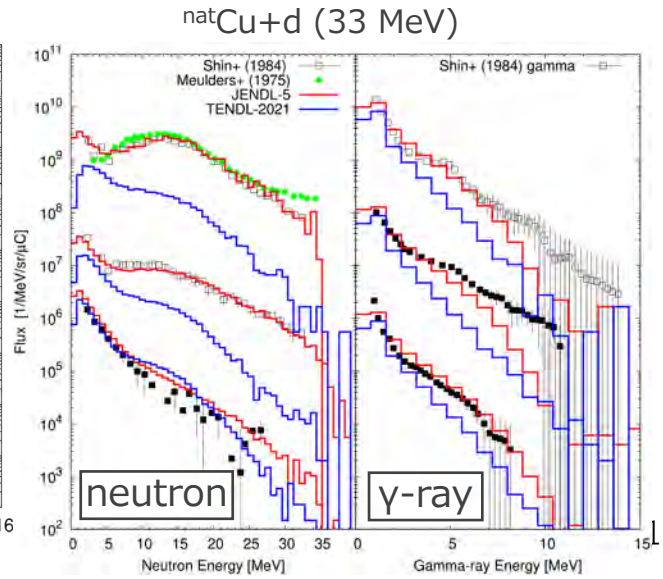
+ CCONE (pre-eq. & compound reac.)

JENDL-5

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





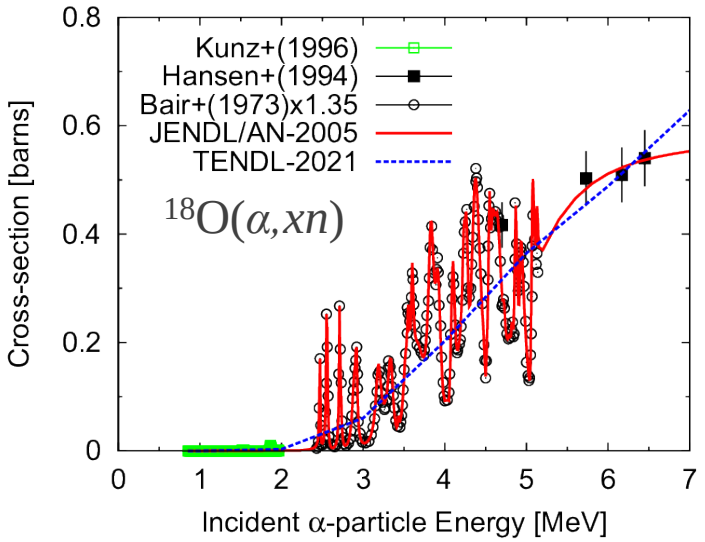


Alpha-particle reaction

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 of CS with the experimental data including resonance structures

➢ insufficient data for particle transport
➢ unreasonable spectrum



JENDL-5

- JENDL/AN-2005(CS) + CCONE
- Revision of the neutron emission energy-angular distribution
- Addition of other data needed in Monte Carlo simulation

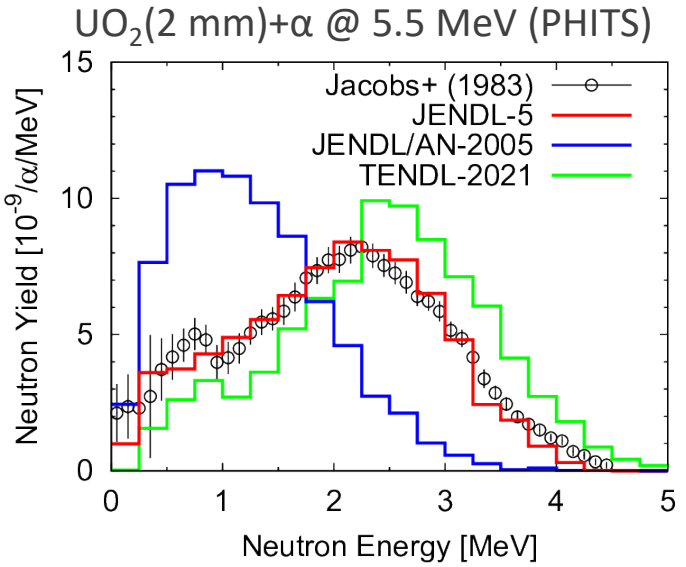


Photo-nuclear reaction

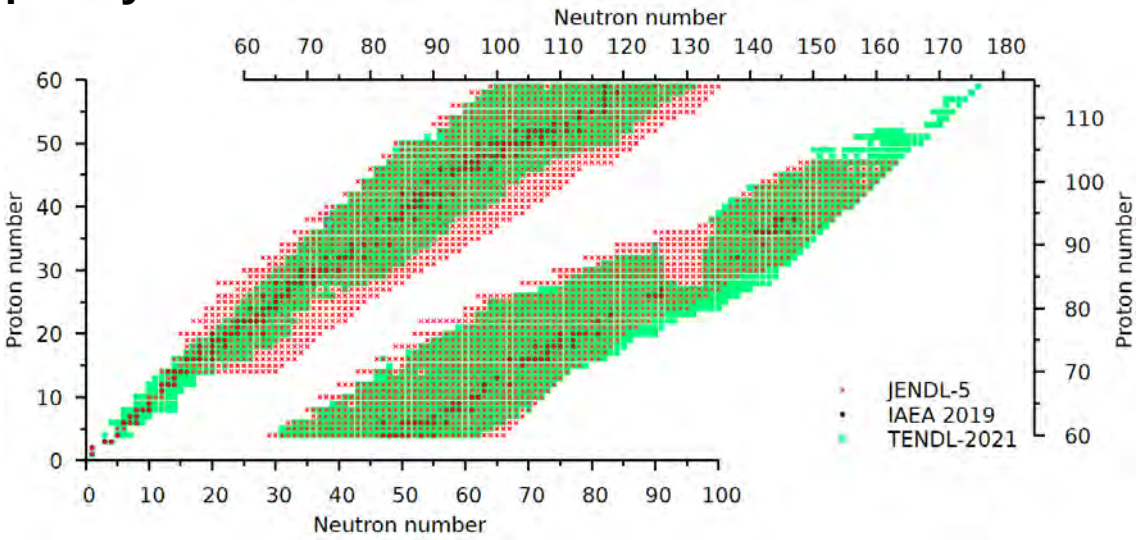
Comprehensive and **high-quality** data

JENDL/PD

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

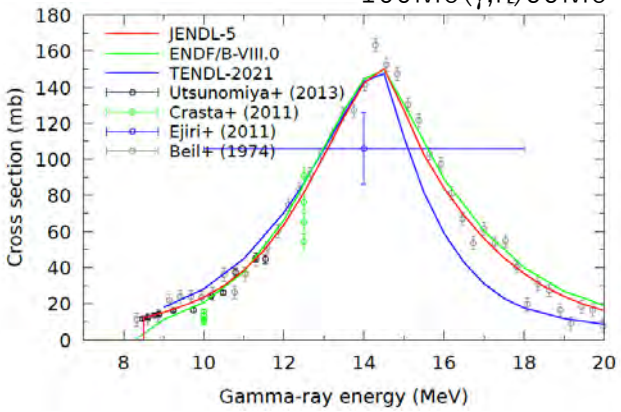
JENDL-5 (2021)

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



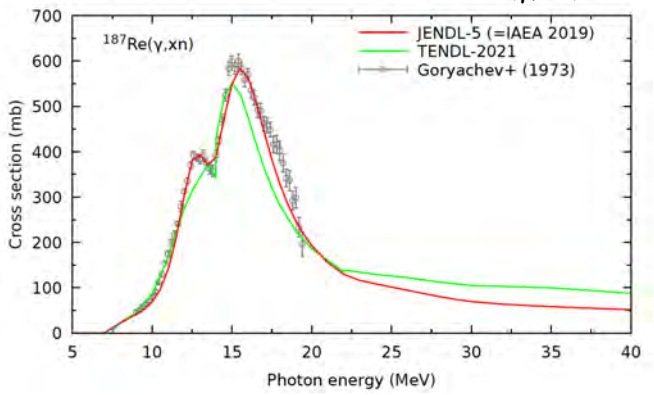
Medical isotope production

100Mo(γ,n)99Mo



99Mo: parent isotope of 99Tc

187Re (γ,xn)



186Re: β & γ emitter

JENDL-5 update

Release updated data for errors found in JENDL-5

- Neutron
  - upd-1 (2022/2/16) Pr-141: upper limits energy (ULE) of RP
  - upd-6 (2022/5/24) N-14,15, F-19, Al-27, P-31: ULE of photon
  - upd-7 (2022/5/24) H-2: duplication of DDXs in LAW=6 & 7
  - upd-10 (2023/1/18) 32 nuclides: isomer data
  - upd-11 (2023/1/18) 62 nuclides: isomer assignments of Ti-48
  - upd-12 (2023/10/10) 28 nuclides: inconsistent MF8 with other MF
- FPY & DD
  - upd-2 & 3 (2022/2/16) all nuclides: NSUB(sublib. #), NEVER (lib. #)
  - upd-5 (2022/4/27) Sb-122m2: LIS, ISO(isomer #)
  - upd-8 (2022/7/13) 11 nuclides: ZAFP(ID of FP)
- Proton & Deuteron
  - upd-13 (2023/8/10) Li-7: (p,n1), (p, p1)
  - upd-9 (2022/10/6) C-12, 13: multiplicity other than neutron emission
- Electro-atomic
  - upd-4 (2022/3/16) 63 elements: Bremss. photon ene. spec. & electron ave. ene. loss

Future plan

- Provision of covariance data enough for nuclear reactor and neutron shielding calculations
  - Neutron reaction cross sections
  - Thermal scattering law
  - Reasonable values for reactor calculations
- Increase of charged particle induced reaction data
- Subject to be focused
  - Cross correlations among different quantities and nuclides
  - Utilization of machine learning
  - Refinement of nuclear reaction modeling
- Next release would be in FY 2027 or 2028

Sigma Committee Workshop

Workshops are being planned for the future JENDL development

- Muon nuclear data
  - 2023/12/14 (13:00-17:10) RIBF + Zoom
- Nuclear reactor and regulation
  - 2023/12/21 (13:25-15:30) Zoom
- Fission product yield evaluation
  - under planning
- Medical isotope production & radiation therapy dose evaluation
  - under planning

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
- Future
  - Intense of covariance and charged-particle data, …
  - Workshops are planed in Sigma Committee