16TH NUCLEAR DATA
FOR SCIENCE AND TECHNOLOGY CONFERENCE
JUNE 22ND – 27TH | MADRID (SPAIN) | 2025

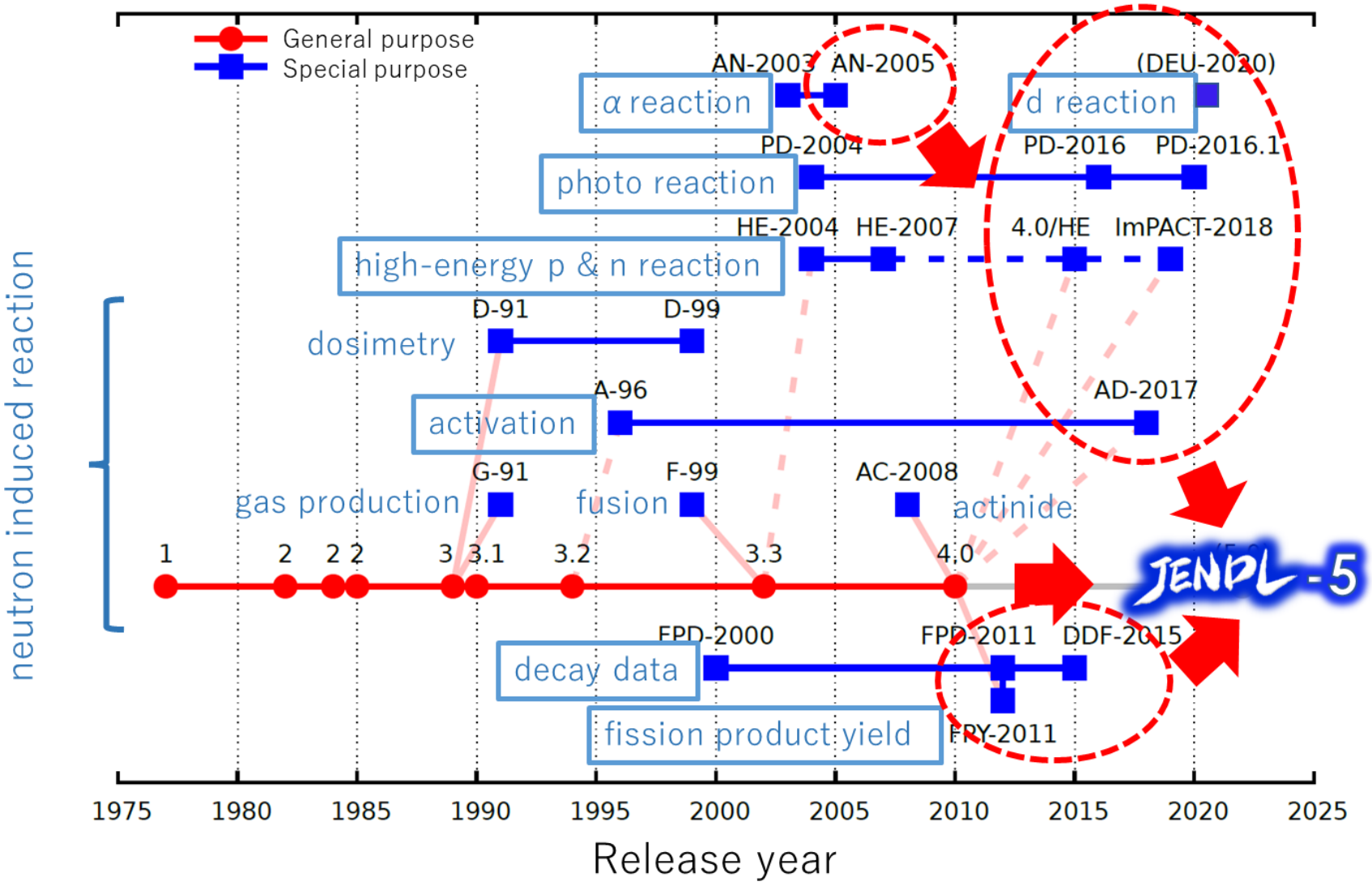
JENDL
Japanese Evaluated Nuclear Data Library

Developing the next version of Japanese Evaluated Nuclear Data Library: JENDL-5.1

Osamu Iwamoto, Nobuyuki Iwamoto, Shinsuke Nakayama

Japan Atomic Energy Agency

History of JENDL Release



JENDL-5.1

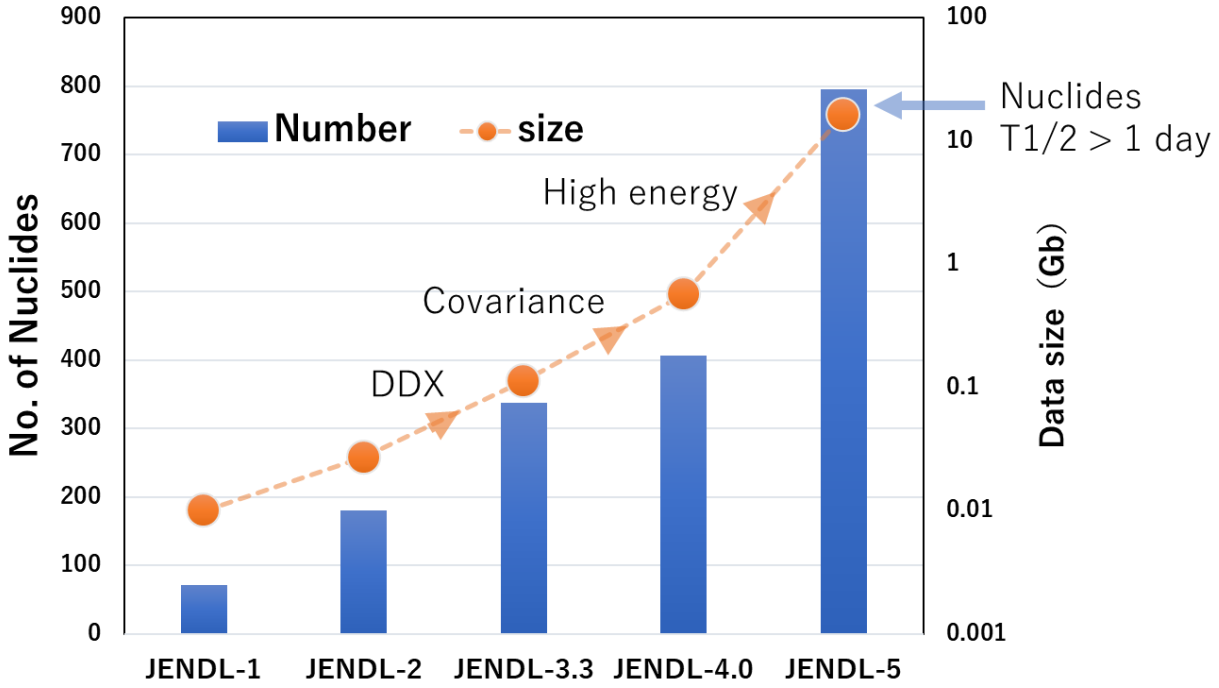
2028
(ND2028 in Japan)

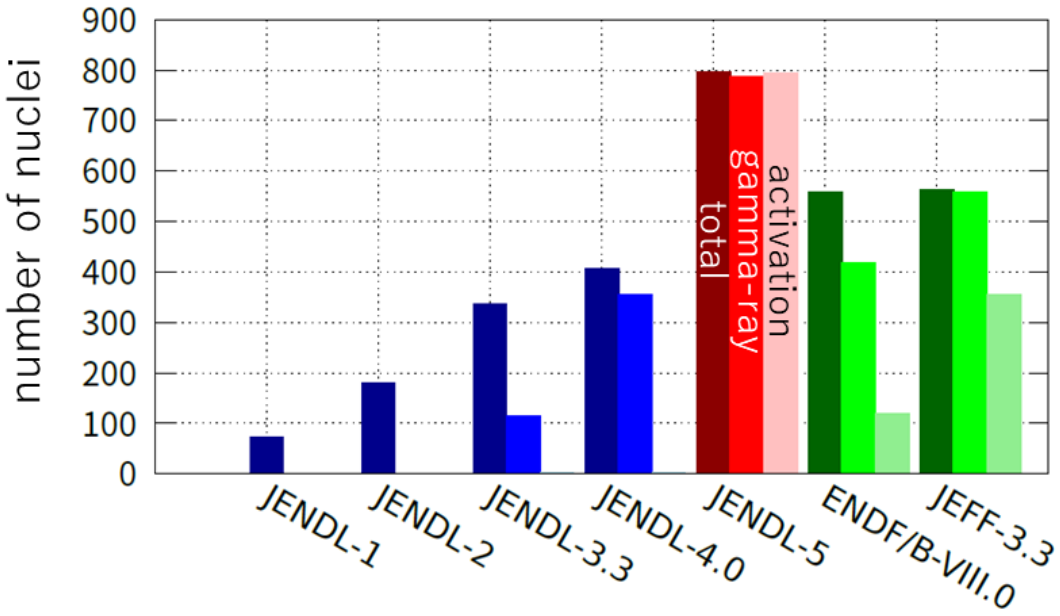
Overview of the latest version JENDL-5

- Integration of special purpose libraries
  - neutron, proton, deuteron, alpha-particle and photon induced reactions
  - activation cross sections
  - high energy reactions (up to 200 MeV) for neutron, proton and photon
- Enhancement of neutron data
  - increase of the number of targets
  - update of a large part of evaluation from light to heavy nuclides
  - improvement of integral benchmark tests
  - own evaluation of thermal neutron scattering law
- Upgrade of nuclear reaction model codes
  - inclusion of recoil energy calculation for nuclear reaction model code CCONE
  - R-matrix analysis code AMUR
  - deuteron induced reaction code DEURACS

O. Iwamoto et al., JNST 60, 1 (2023)
K. Tada et al., JNST 61, 2 (2024)
C. Konno et al., JNST 60, 1046 (2023)

Enhancement of neutron data





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

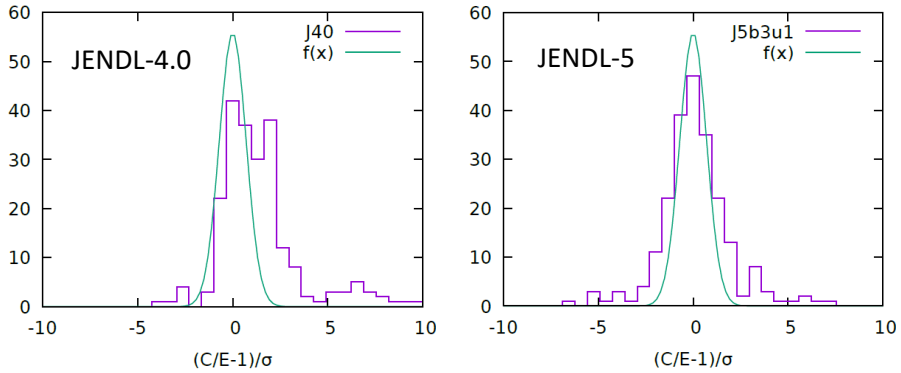
Results of reactor benchmarks

keff of thermal and intermediate spectrum

	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

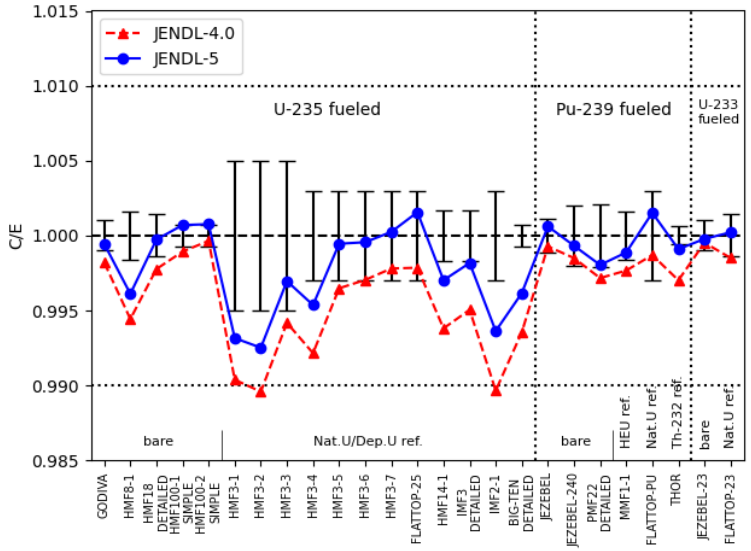
IEU and Pu with JENDL-5 are improved

C/E distribution (Pu + MOX)

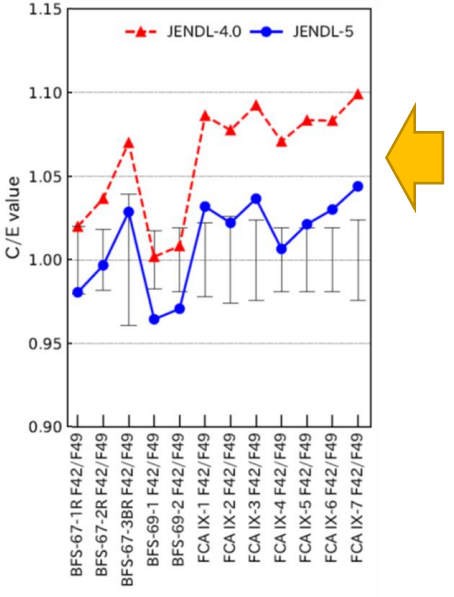


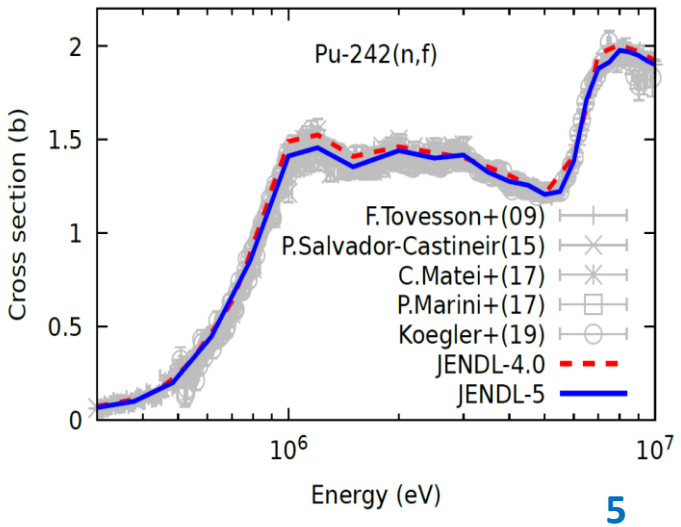
f(x): normal distribution,

keff of fast spectrum with heavy metal core



Fission rate ratio in fast reactor



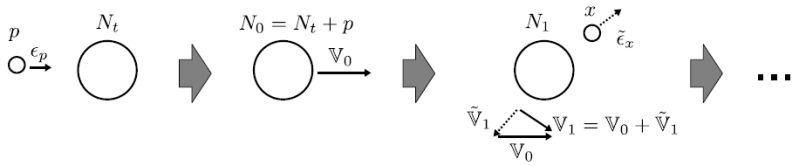


Recoil energy calculation with CCONE

O. Iwamoto, JNST 59, 1232 (2022)

Velocity after particle emissions

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



Velocity distribution by particle emission

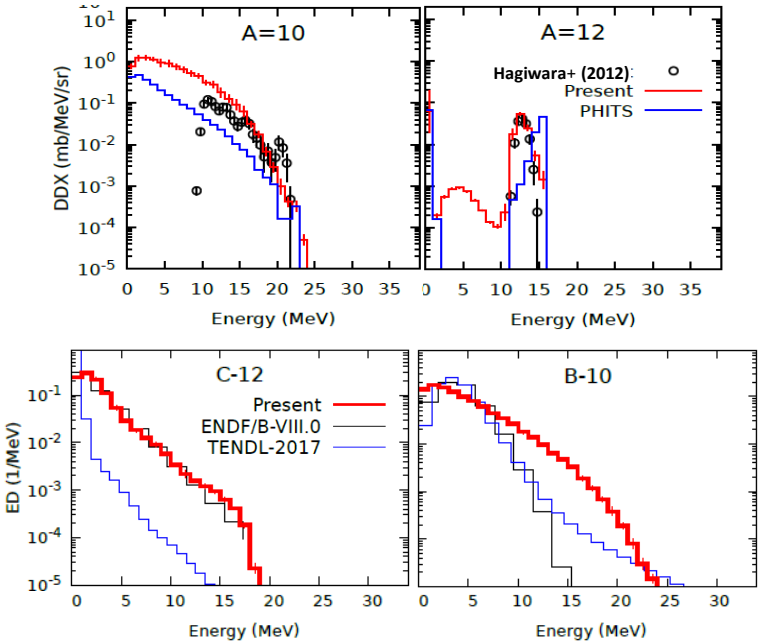
$$f_n(E_n, \mathbb{V}_n) = \sum_x \int\int\int dE_{i_x} d\mathbb{V}_{i_x} d\tilde{\mathbb{V}}_{i_x} \frac{f_{i_x}(E_{i_x}, \mathbb{V}_{i_x})}{f_{i_x}(E_{i_x})} \tilde{\sigma}_x^R(E_{i_x}, \tilde{\mathbb{V}}_{i_x})$$

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

Monte Carlo integral

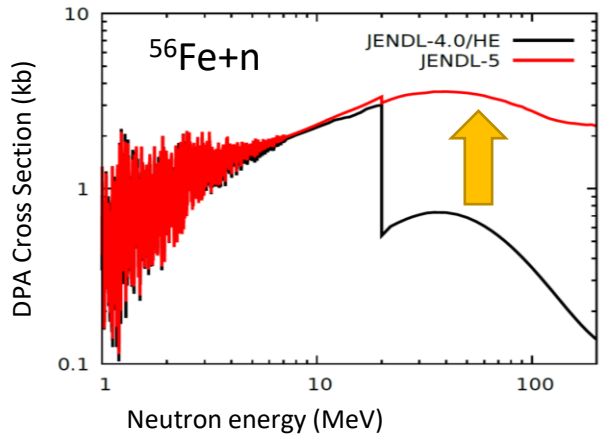
Results

C+p @70MeV



JENDL-5 DPA CS

(no recoil data in JENDL-4.0/HE)



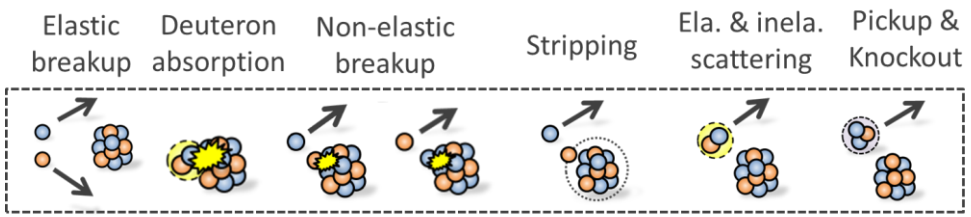
Thanks to C. Konno

Deuteron reaction

JENDL/DEU-2022

S. Nakayama et al., JNST 58, 805 (2021)

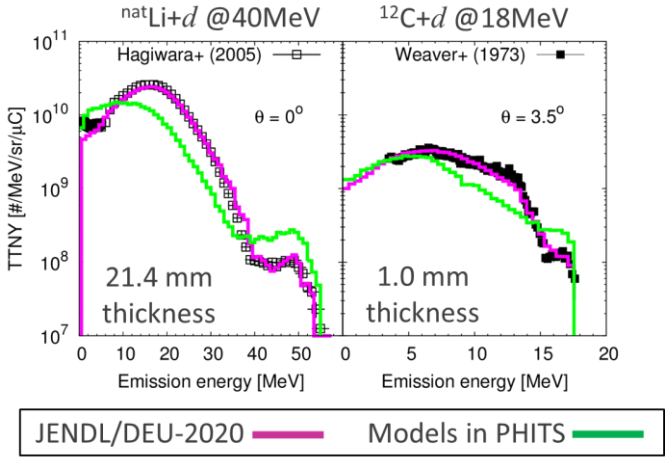
DEURACS



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

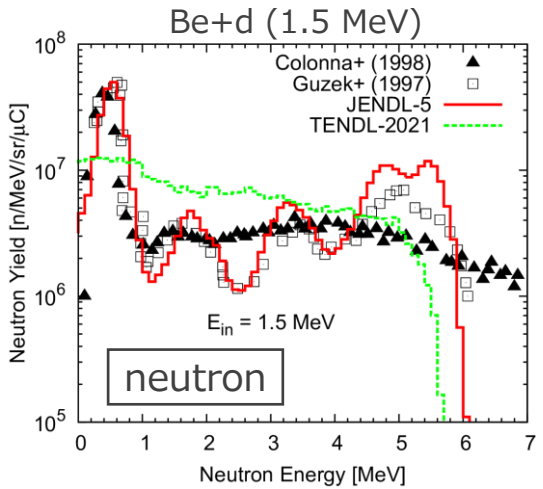
+ CCONE (pre-eq. & compound reac.)

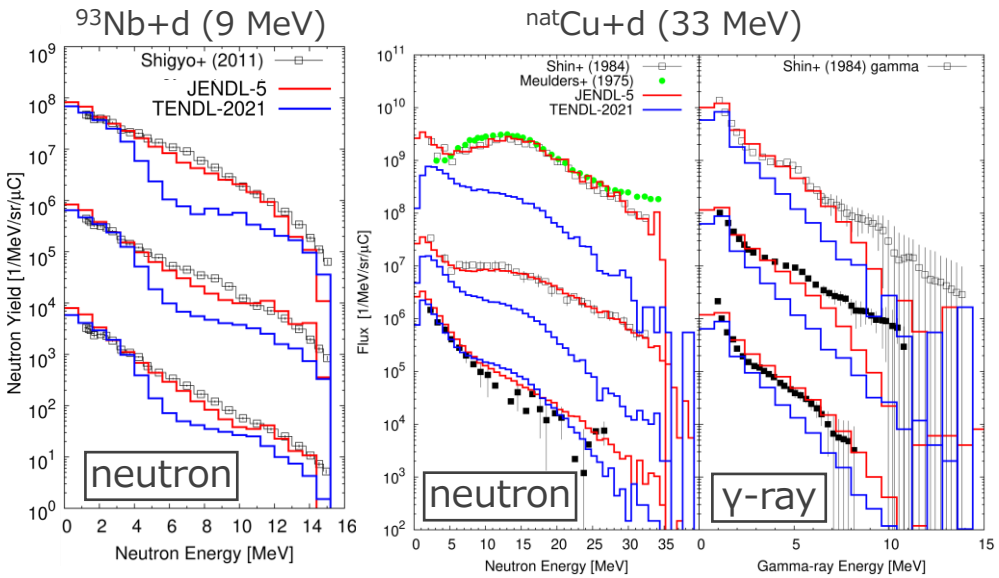
Eval. with DEURACS (Li, Be, C)



JENDL-5

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

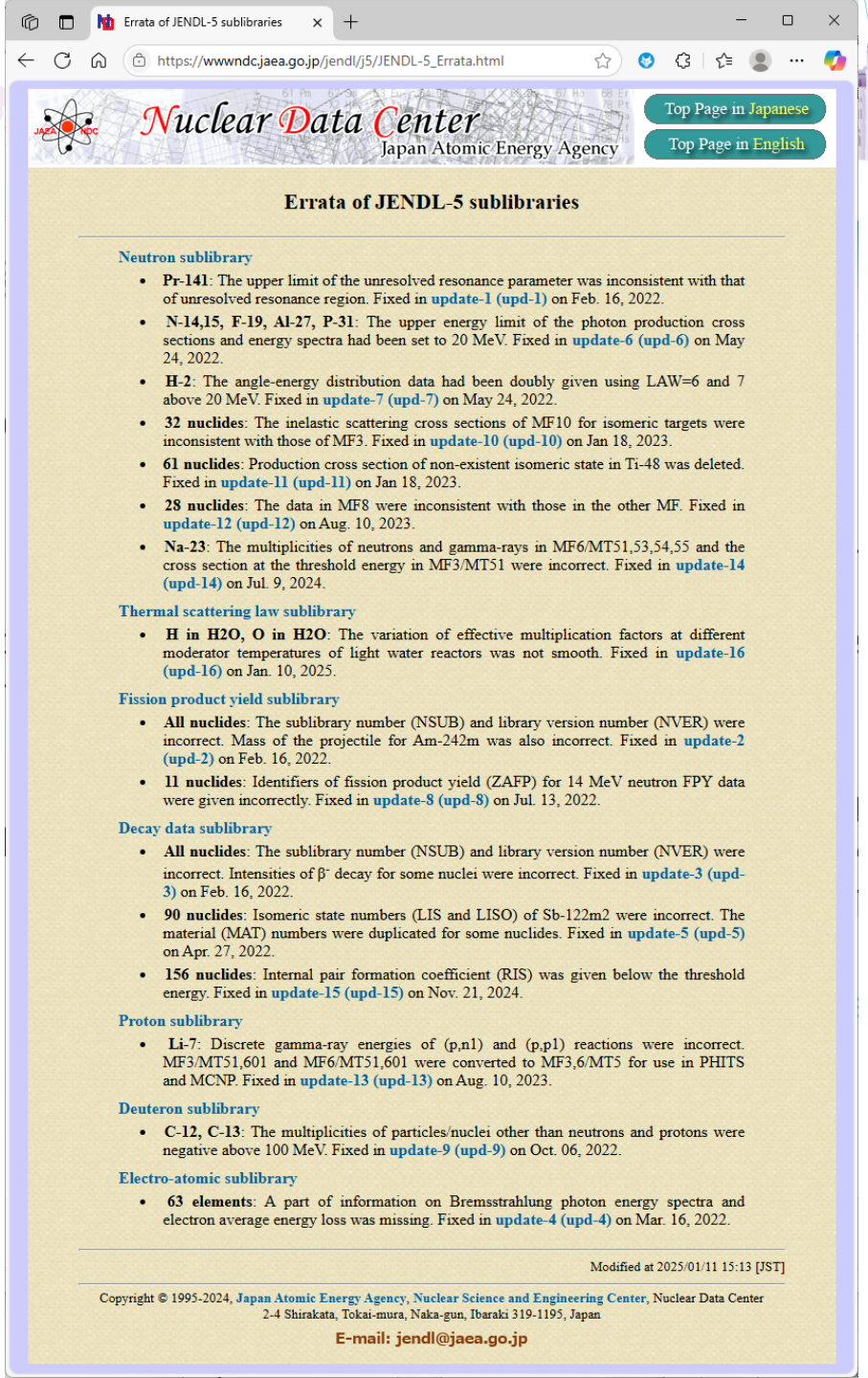




Update of JENDL-5

https://wwwndc.jaea.go.jp/jendl/j5/JENDL-5_Errata.html

- 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
  - upd-14 (2024/7/9) inelastic scattering near threshold for Na-23
- Thermal scattering law
  - upd-16 (2025/1/10) H in H2O, O in H2O: increase MD similation events
- 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)
  - upd-15 (2024/11/21) 156 nuclides: Internal pair formation coefficient below E_{th}
- 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



Errata of JENDL-5 sublibraries

https://wwwndc.jaea.go.jp/jendl/j5/JENDL-5_Errata.html

Nuclear Data Center
Japan Atomic Energy Agency

Top Page in Japanese
Top Page in English

Errata of JENDL-5 sublibraries

Neutron sublibrary

- **Pr-141**: The upper limit of the unresolved resonance parameter was inconsistent with that of unresolved resonance region. Fixed in update-1 (upd-1) on Feb. 16, 2022.
- **N-14,15, F-19, Al-27, P-31**: The upper energy limit of the photon production cross sections and energy spectra had been set to 20 MeV. Fixed in update-6 (upd-6) on May 24, 2022.
- **H-2**: The angle-energy distribution data had been doubly given using LAW=6 and 7 above 20 MeV. Fixed in update-7 (upd-7) on May 24, 2022.
- **32 nuclides**: The inelastic scattering cross sections of MF10 for isomeric targets were inconsistent with those of MF3. Fixed in update-10 (upd-10) on Jan 18, 2023.
- **61 nuclides**: Production cross section of non-existent isomeric state in Ti-48 was deleted. Fixed in update-11 (upd-11) on Jan 18, 2023.
- **28 nuclides**: The data in MF8 were inconsistent with those in the other MF. Fixed in update-12 (upd-12) on Aug. 10, 2023.
- **Na-23**: The multiplicities of neutrons and gamma-rays in MF6/MT51,53,54,55 and the cross section at the threshold energy in MF3/MT51 were incorrect. Fixed in update-14 (upd-14) on Jul. 9, 2024.

Thermal scattering law sublibrary

- **H in H2O, O in H2O**: The variation of effective multiplication factors at different moderator temperatures of light water reactors was not smooth. Fixed in update-16 (upd-16) on Jan. 10, 2025.

Fission product yield sublibrary

- **All nuclides**: The sublibrary number (NSUB) and library version number (NVER) were incorrect. Mass of the projectile for Am-242m was also incorrect. Fixed in update-2 (upd-2) on Feb. 16, 2022.
- **11 nuclides**: Identifiers of fission product yield (ZAFP) for 14 MeV neutron FPY data were given incorrectly. Fixed in update-8 (upd-8) on Jul. 13, 2022.

Decay data sublibrary

- **All nuclides**: The sublibrary number (NSUB) and library version number (NVER) were incorrect. Intensities of β^- decay for some nuclei were incorrect. Fixed in update-3 (upd-3) on Feb. 16, 2022.
- **90 nuclides**: Isomeric state numbers (LIS and LISO) of Sb-122m2 were incorrect. The material (MAT) numbers were duplicated for some nuclides. Fixed in update-5 (upd-5) on Apr. 27, 2022.
- **156 nuclides**: Internal pair formation coefficient (RIS) was given below the threshold energy. Fixed in update-15 (upd-15) on Nov. 21, 2024.

Proton sublibrary

- **Li-7**: Discrete gamma-ray energies of (p,n1) and (p,p1) reactions were incorrect. MF3/MT51,601 and MF6/MT51,601 were converted to MF3,6/MT5 for use in PHITS and MCNP. Fixed in update-13 (upd-13) on Aug. 10, 2023.

Deuteron sublibrary

- **C-12, C-13**: The multiplicities of particles/nuclei other than neutrons and protons were negative above 100 MeV. Fixed in update-9 (upd-9) on Oct. 06, 2022.

Electro-atomic sublibrary

- **63 elements**: A part of information on Bremsstrahlung photon energy spectra and electron average energy loss was missing. Fixed in update-4 (upd-4) on Mar. 16, 2022.

Modified at 2025/01/11 15:13 [JST]

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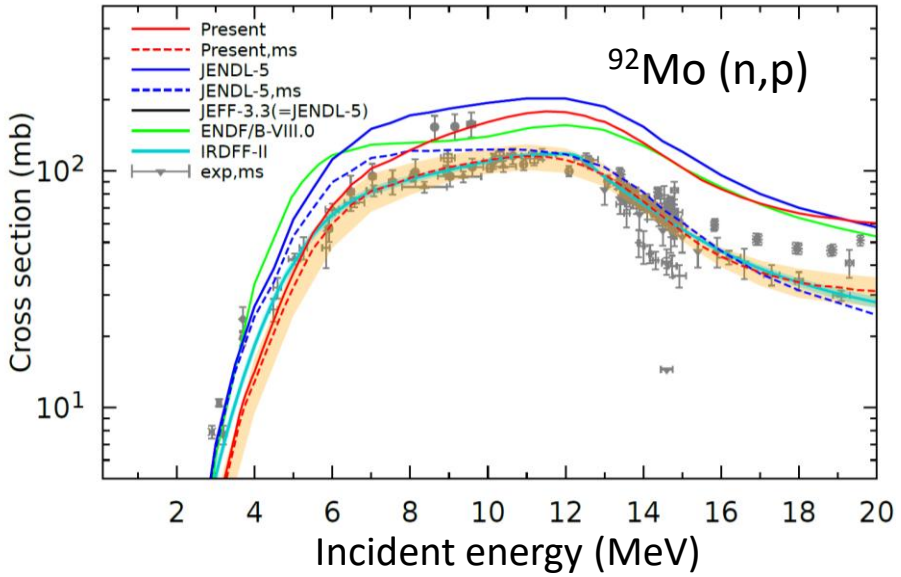
Development of the next version JENDL-5.1

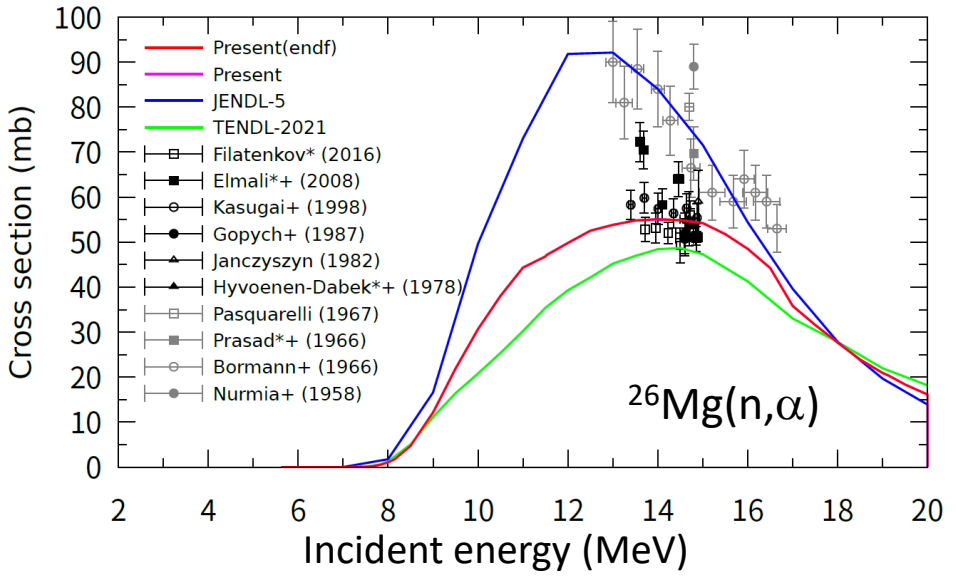
- Covariance data for neutron induced reaction
- Charged particle reaction data (proton, deuteron, alpha-particle)
- Full update of old neutron reaction data with current method
- Resonance parameters
  - new experiments of ANNRI: Am-241, 243, Cm-244, 246, Np-237, I-129, Er-166, 167, Tc-99, Nd-143, 145; other facilities …
- Actinide data extending the energy region to 200 MeV
- Thermal neutron scattering law data
- Incorporation of data from new nuclear data projects
  - Muon nuclear data, Sekiguchi Three-Nucleon Force Project

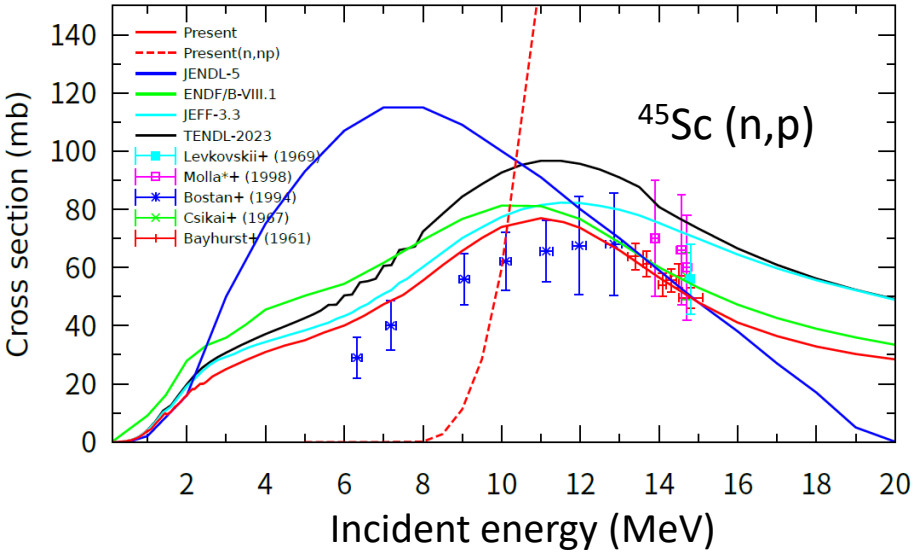
ANNRI related presentations in ND2025

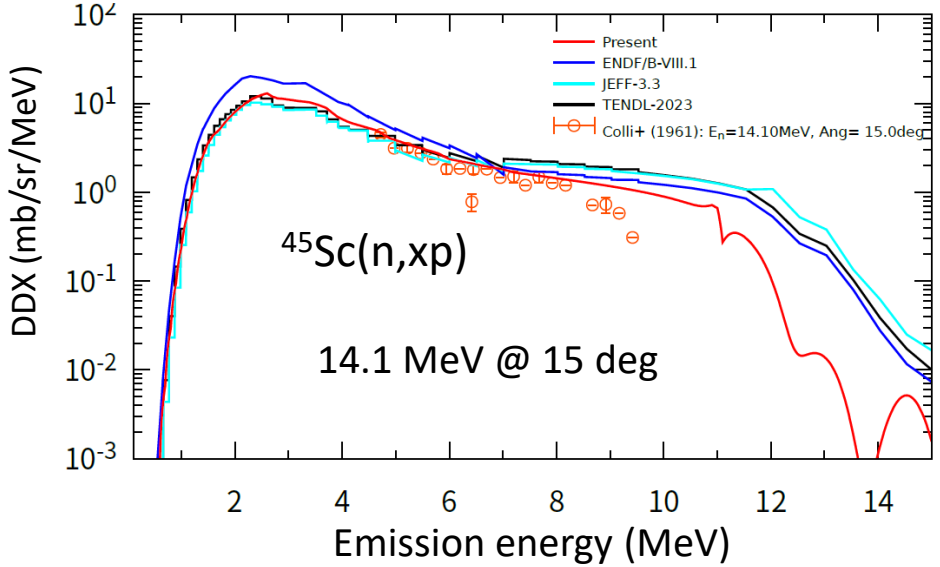
- NR-S1D1A1: Gerard Rovira, total and capture cross-sections of ^{nat}Er at the ANNRI beamline of J-PARC
- Poster: Atsushi Kimura, Improvement of accuracy of neutron-induced fission reaction data for MAs
- Poster: Shunsuke Endo, Correction method for large scattered-neutron background in capture cross-section measurements

Neutron cross sections

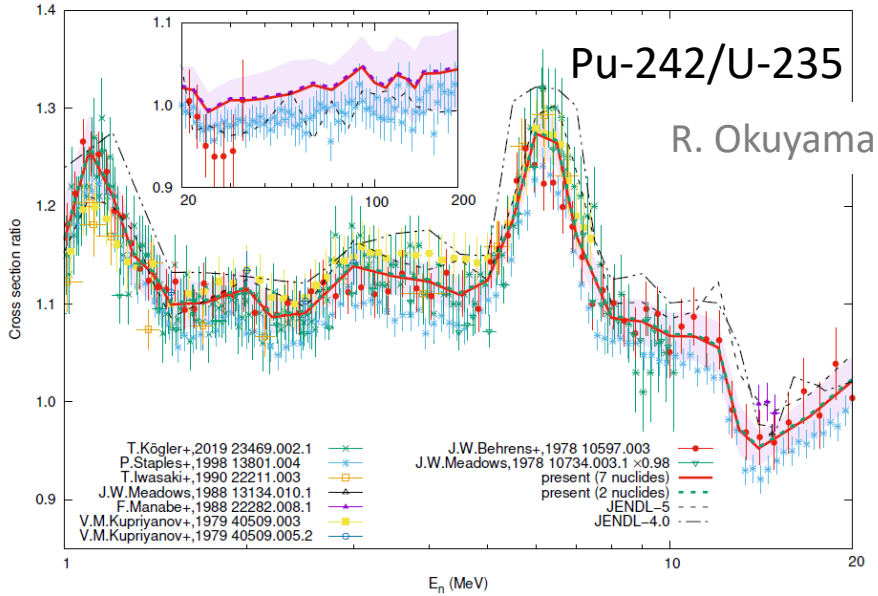






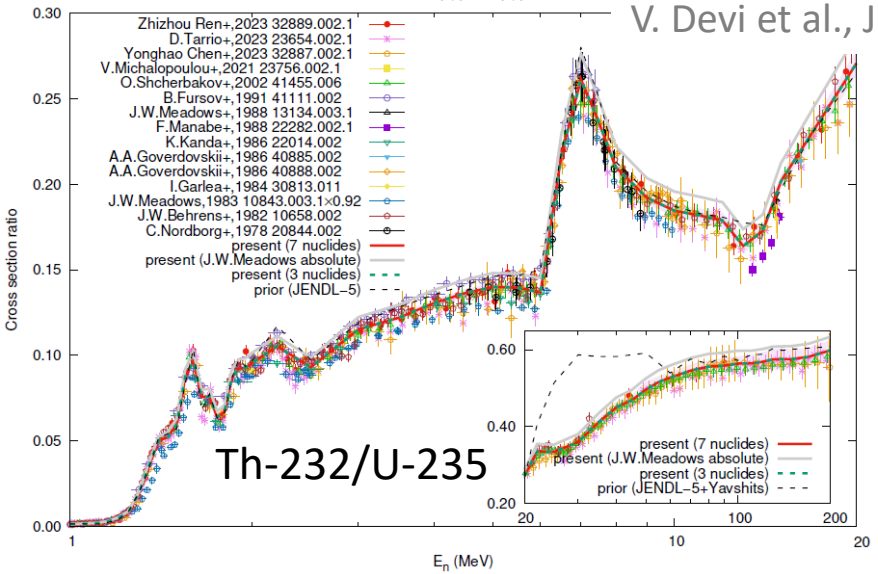


Fission cross section evaluation



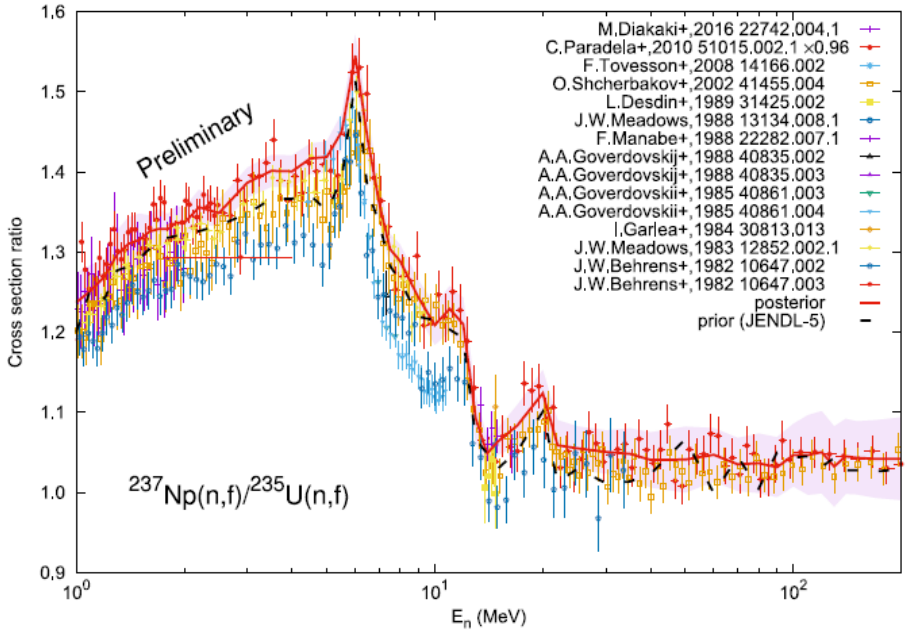
R. Okuyama et al., JNST 61, 57 (2024)

Collaborations with IAEA:
Simultaneous evaluation for actinides using absolute and ratio data with SOK code, which was used for major actinides fission cross sections in JENDL-5.



V. Devi et al., JNST 61, 44 (2024)

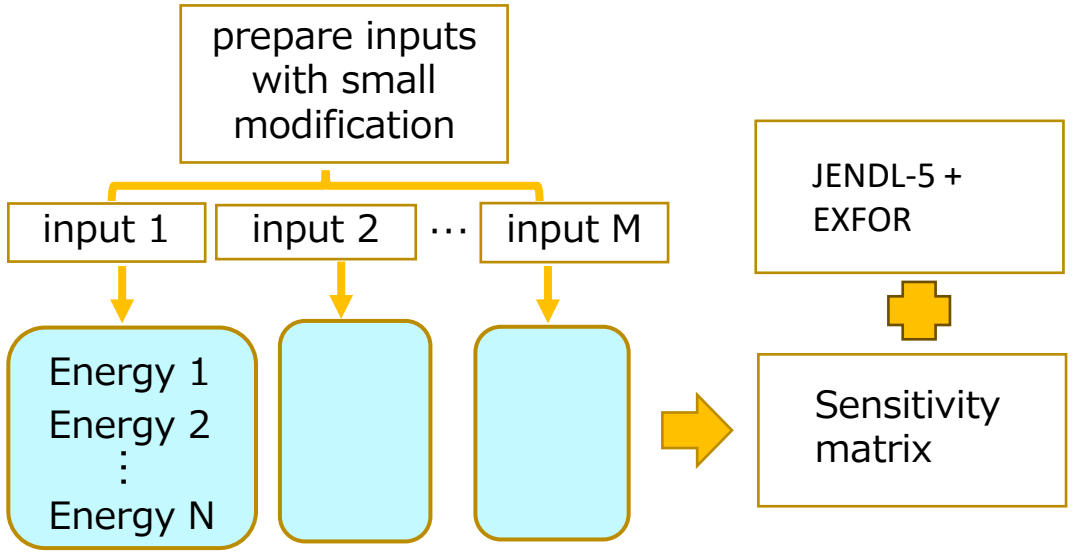
N. Otuka et al., ARI 225, 11903 (2025)



Covariance evaluation

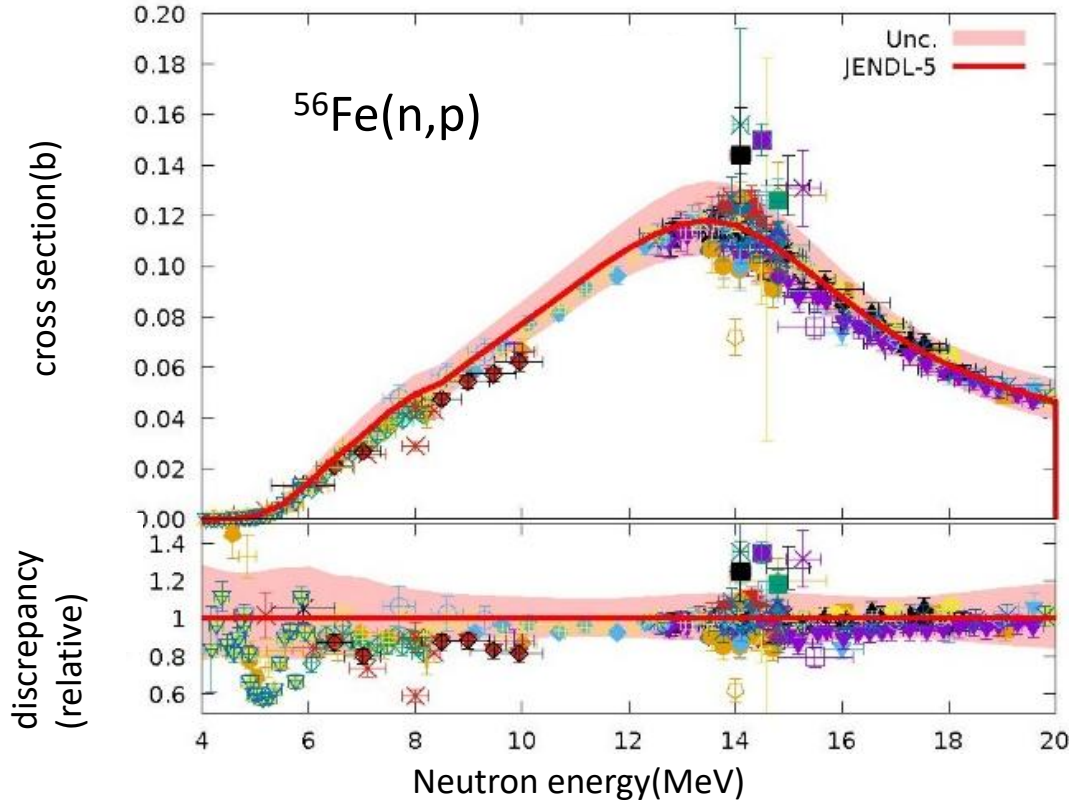
We are going to add the covariance data missing in JENDL5. Those covariance data are generated automatically with JENDL-5 evaluation and EXFOR data.

Updated CCONE code to highly modularized structure with deleting global parameters and introducing generalized input classes



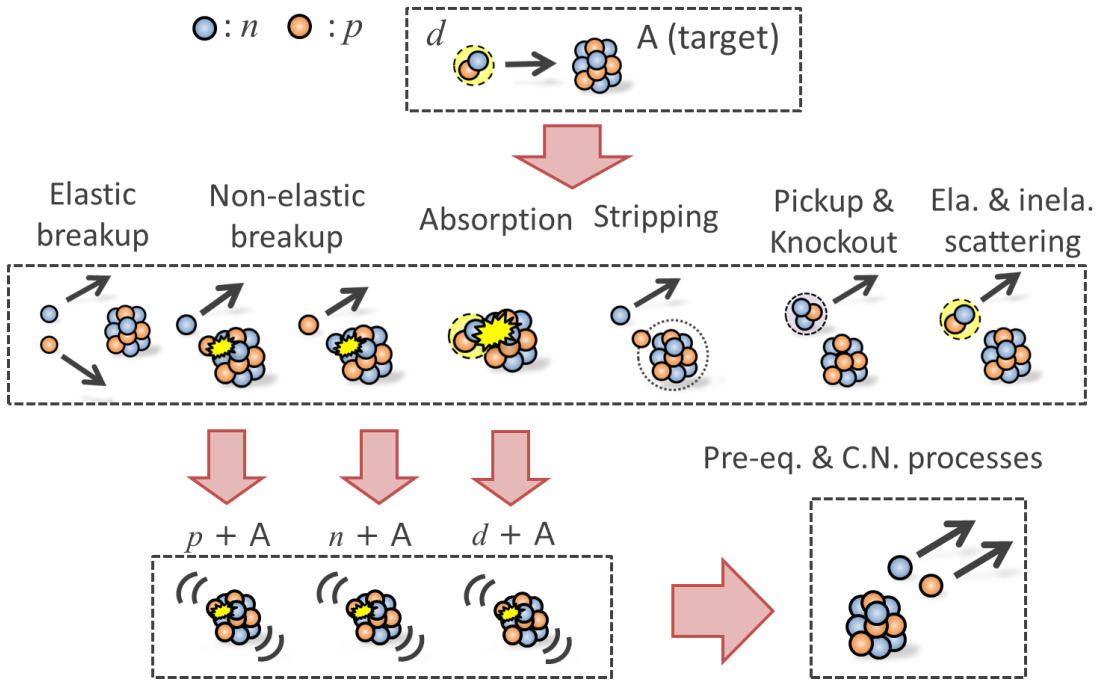
N x M parallel calculation

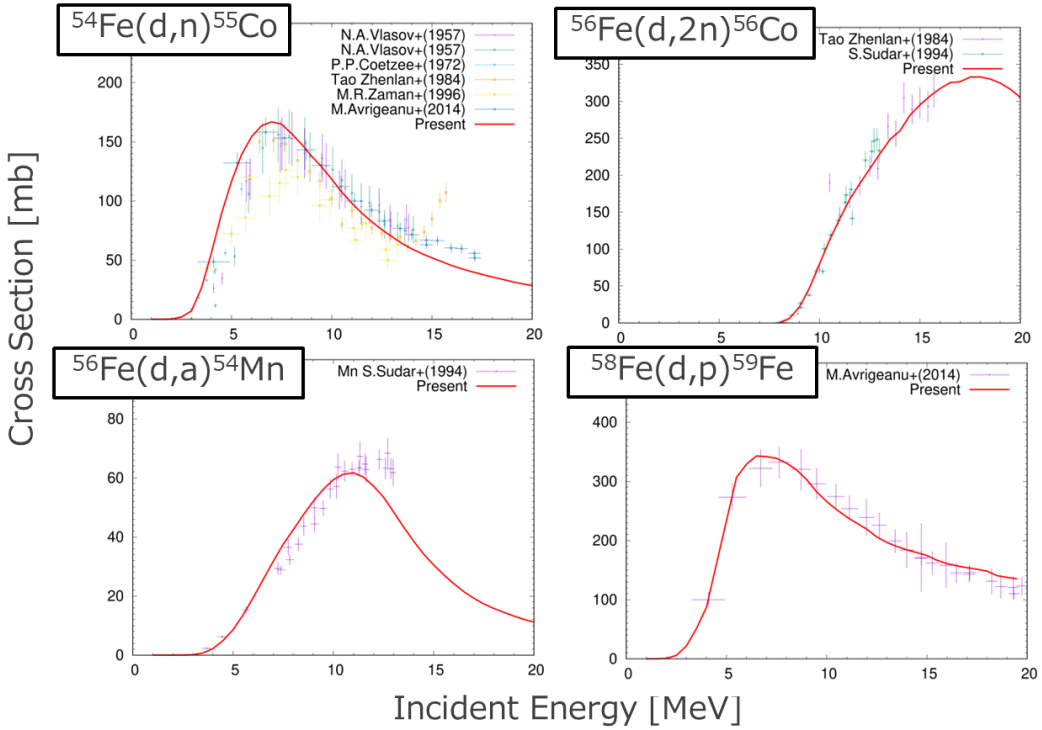
An example of the case for which much experimental data are available. Note: this case is only shown for checking the validity, and actual Fe covariance data are evaluated by human.



Deuteron induced reaction on Fe isotopes

Evaluated with the DEURACS code system

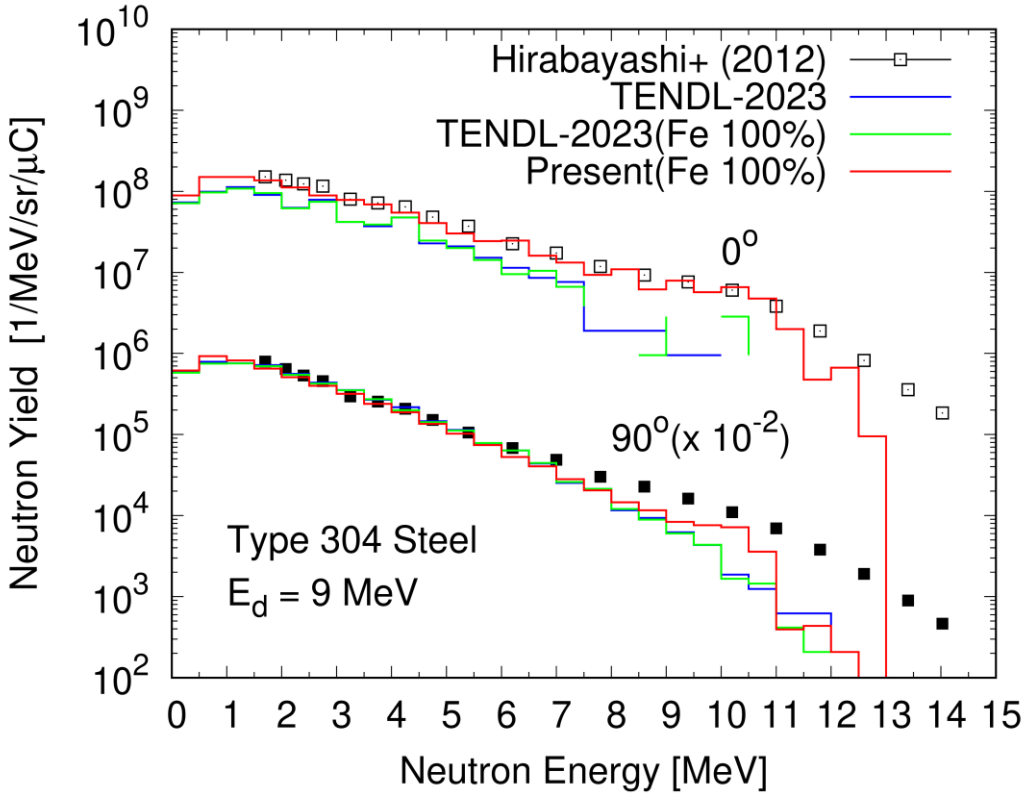




Neutron spectrum for deuteron reaction

TTY Neutron Spectra

Experiment: 304 stainless steel target
（Fe:74%, Cr：18%, Ni：8%）



The deuteron data evaluated with DEURACS reproduce both experimental data of isotope production and neutron emission spectrum.

Thermal scattering law for graphite

Inelastic Scattering

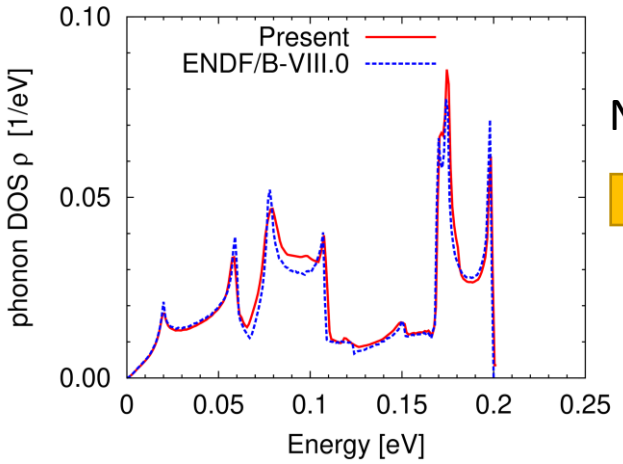
first-principles lattice dynamics simulations for ideal crystalline graphite

Elastic Scattering

Estimation of Bragg peak strengths

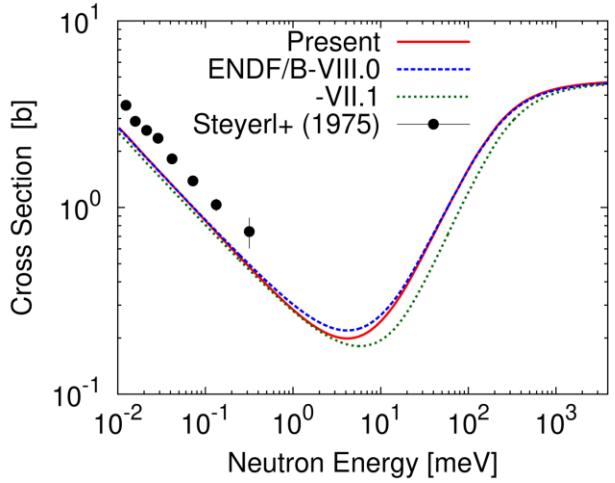
Phonon DOS

(Quantum ESPRESSO + Phonopy)

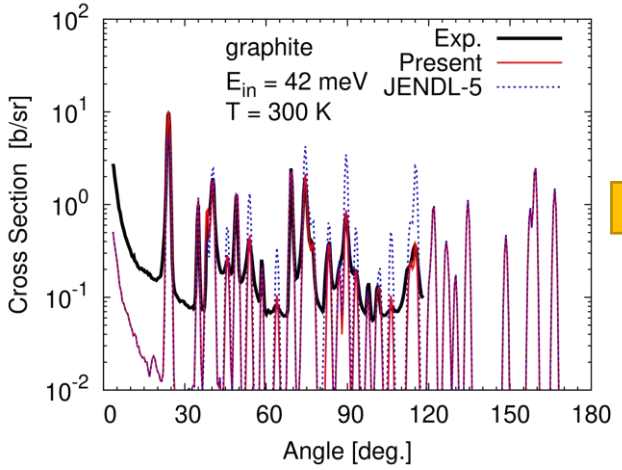


NJOY

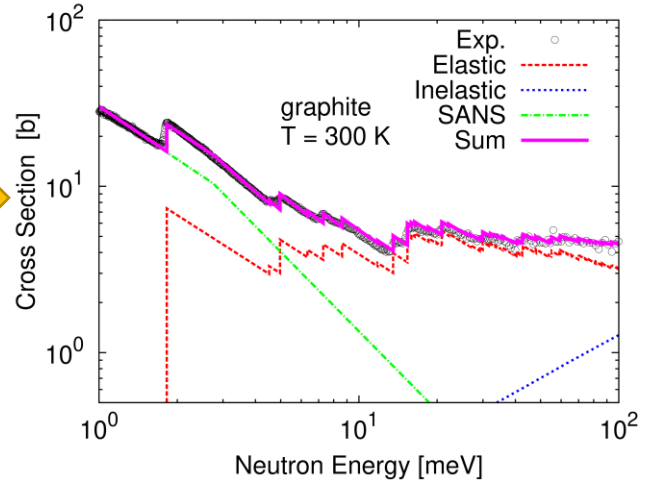
Inelastic scattering cross section



Elastic scattering cross section



Total cross section

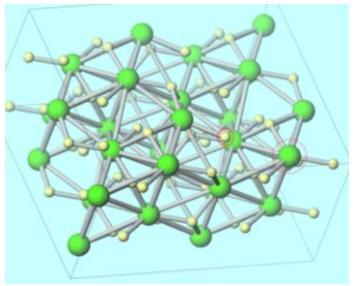


Thermal scattering law for CaH_2

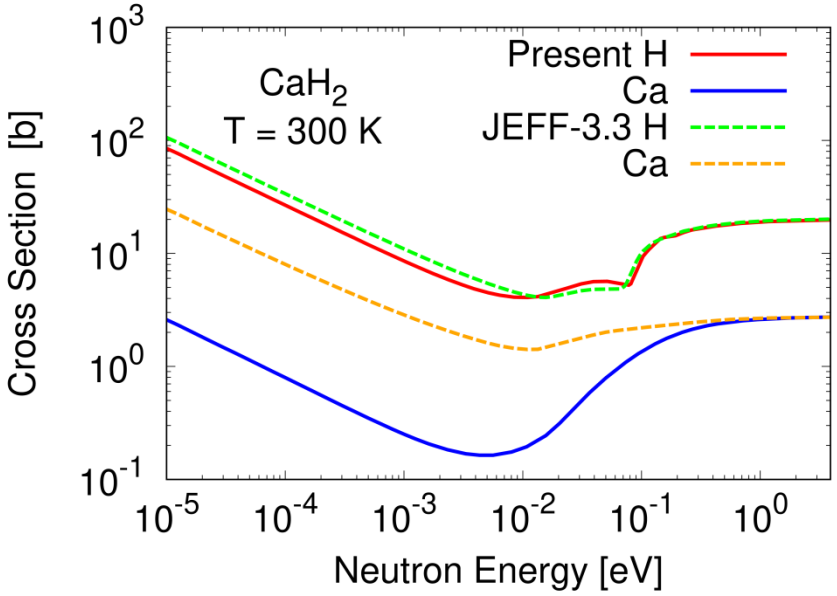
Evaluation methods

- DFT calculation (Quantum ESPRESSO)
- Phonon DOS (Phonopy)
- TSL (NLOY2016/LEAPR)

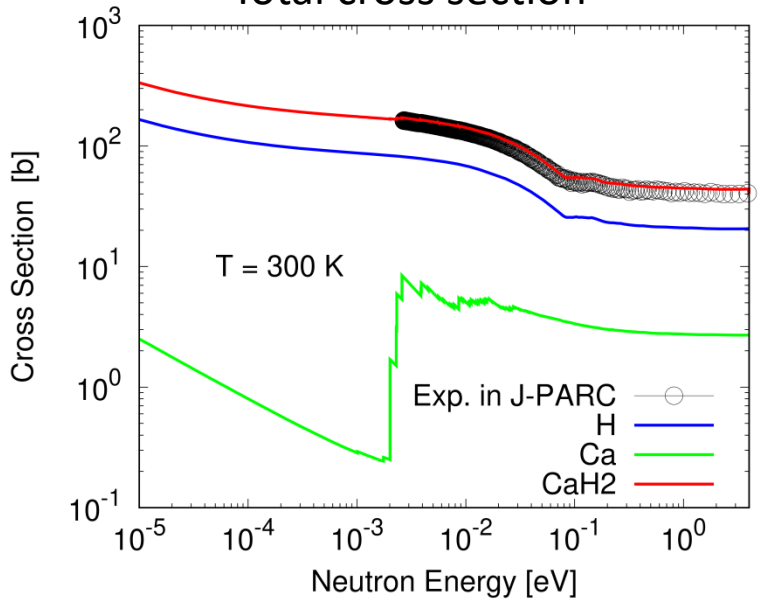
CaH2 super cell



Inelastic scattering cross section



Total cross section



TS-S7D2M2:Shinsuke Nakayama, Evaluation and measurement of thermal neutron scattering laws at reactor operating temperatures

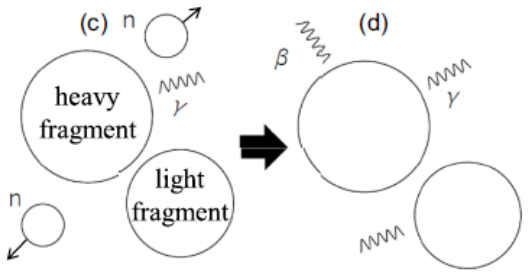
Optimization with fission related quantities

F. Minato & OI, PRC 110, 054311 (2024)

Optimize parameters of fission fragments
（113 parameters）

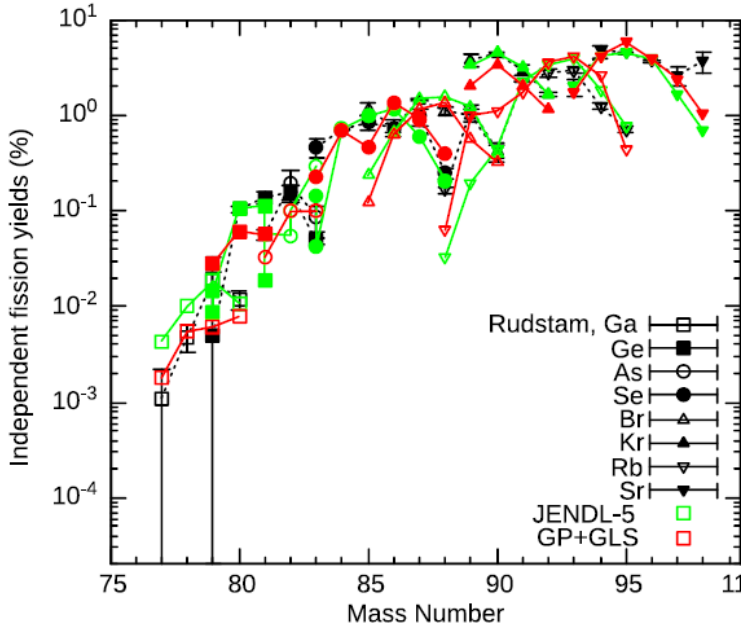
$$(x_0, \Delta x_0) = \begin{cases} (0,\ 1.00) & \text{for} & \delta Z_p \\ (0,\ 0.25) & \text{for} & \delta \sigma_p \\ (1,\ 0.50) & \text{for} & R_T \\ (1,\ 1.00) & \text{for} & f_Z, f_N \\ (1,\ 0.50) & \text{for} & f_a \\ (1,\ 4.00) & \text{for} & f_s \end{cases}$$

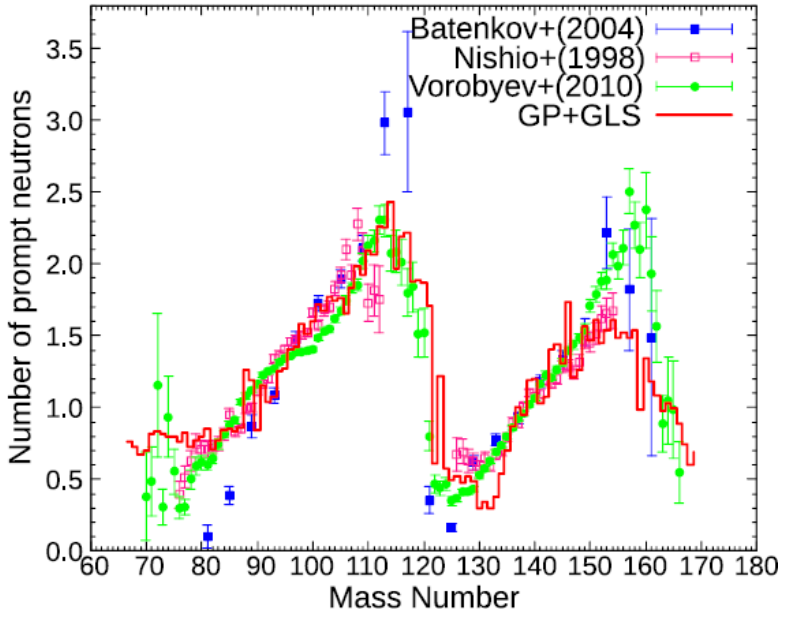
charge dist.
temp. ratio
even odd dist.
level density
spin dist.



fission and particle evaporation

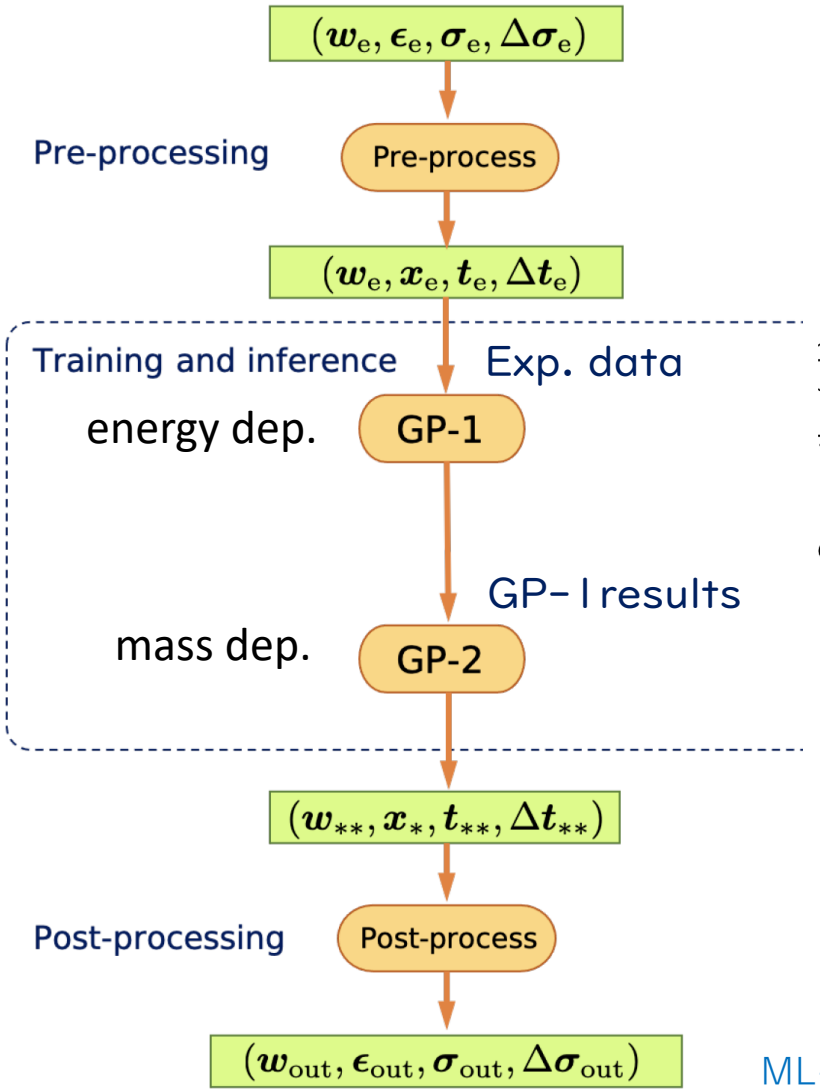
β-decay, γ-deexcitation, etc.

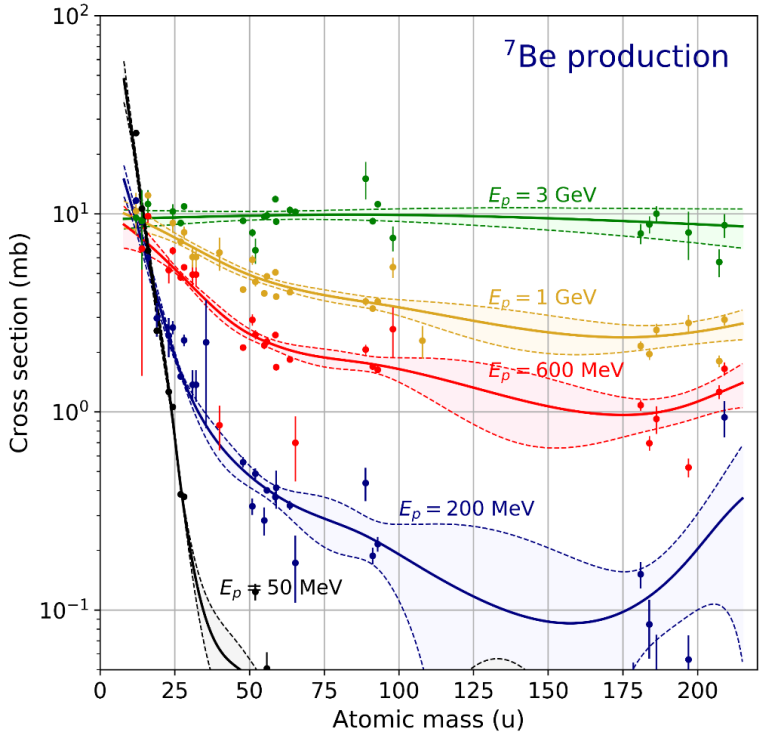




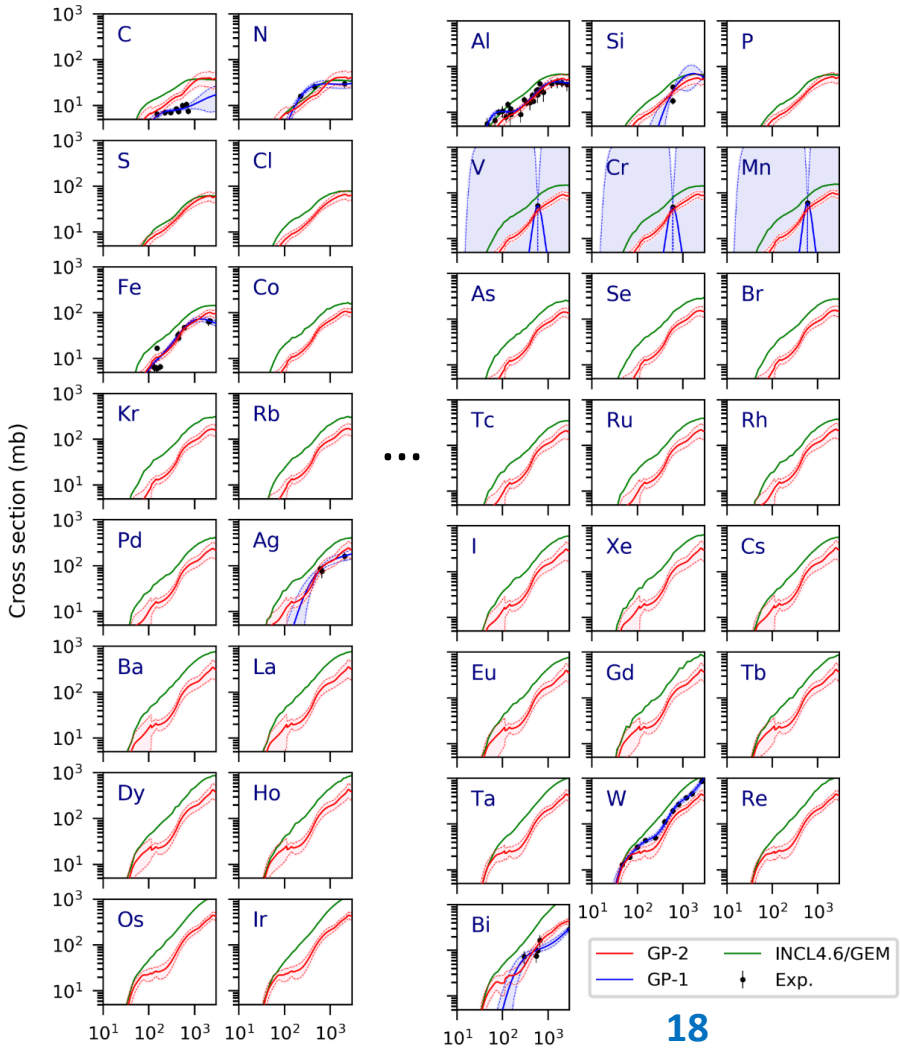
Nuclide production cross sections with Machine Learning

H. Iwamoto et al., PRC109, 054610 (2024)





GP-1: points
GP-2: lines



ML-S5D3A2: H. Iwamoto, Evaluating nuclear data with Bayesian machine learning

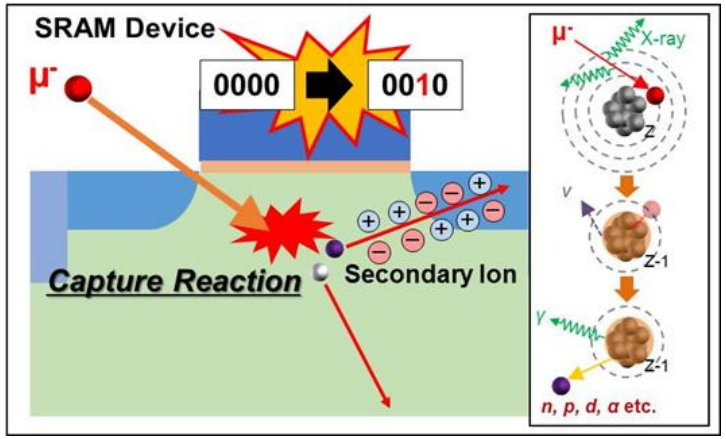
Development of Muon Nuclear Data (μND)

4 sub-libraries

(1) muon X-ray Energy and Intensity (XEI)
(2) muon Nuclear Capture Rate (NCR)
(3) Energy Spectra of emitted Particles (ESP)
(4) Residual Production Branching ratio (RPB)

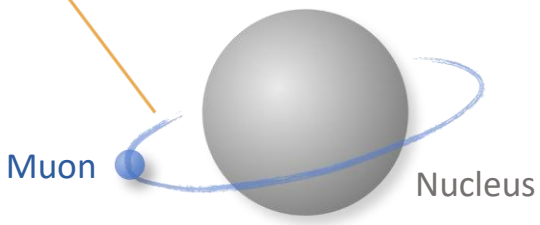
M. Niikura et al., JAEA Conf. 2024-02, 29-34 (2024).

Soft errors caused by cosmic-ray muons



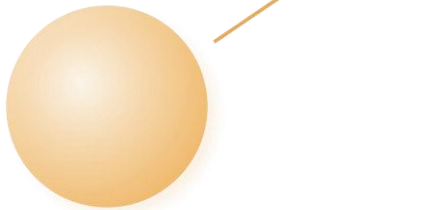
Nuclear transmutation for nuclear waste

(1) Muonic X-ray



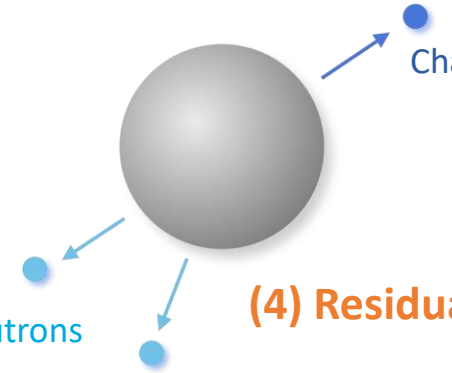
Muonic Atom

(2) Capture rate



Muon Capture and Compound formation

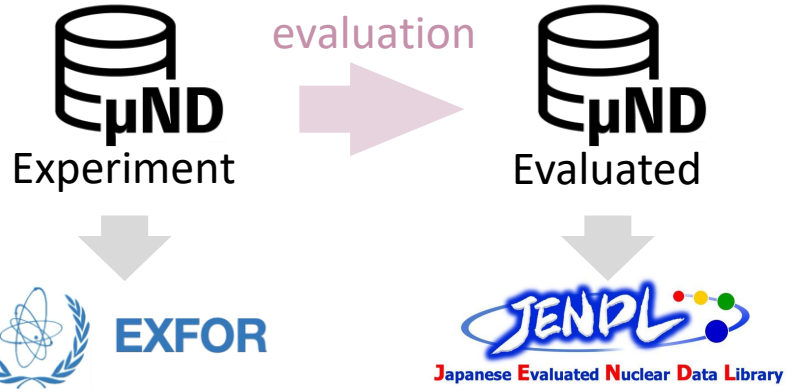
(3) Particle evaporation



(4) Residual Nucleus

Development of Muon Nuclear Data (μND)

2 data sets



Related talks:
- Y. Watanabe, AP-S4D1M2 (Overview of the project)
- M. Niikura, NS-S5D1A2 (Experiment for nuclear capture rate)
- R. Mizuno, NS-S5D1A2 (Experiment for residual production)
- S. Kawase, AP-S5D2A1 (Experiment for energy spectra of particles)
- F. Minato, NS-S4D2A1 (Theory of nuclear muon capture)
- H. Iwamoto, ML-S5D3A2 (Machine learning for data evaluation)

2 teams

JENDL committee
μND Working Group (from 2025)

Data compilation and evaluation
Database construction

M. Niikura, M. Aikawa, H. Iwamoto, O. Iwamoto, K. Uzawa, N. Otsuka, S. Kawase, F. Minato, Y. Watanabe

μND Development team
(from 2023)

Experiments, Theories
Machine learning, Simulations

M. Niikura, S. Abe, S. Biswas, A. Hillier, H. Iwamoto, N. Kawamura, S. Kawase, T. Matsuzaki, F. Minato, R. Mizuno, D. Tomono, Y. Watanabe, Y. Yamaguchi

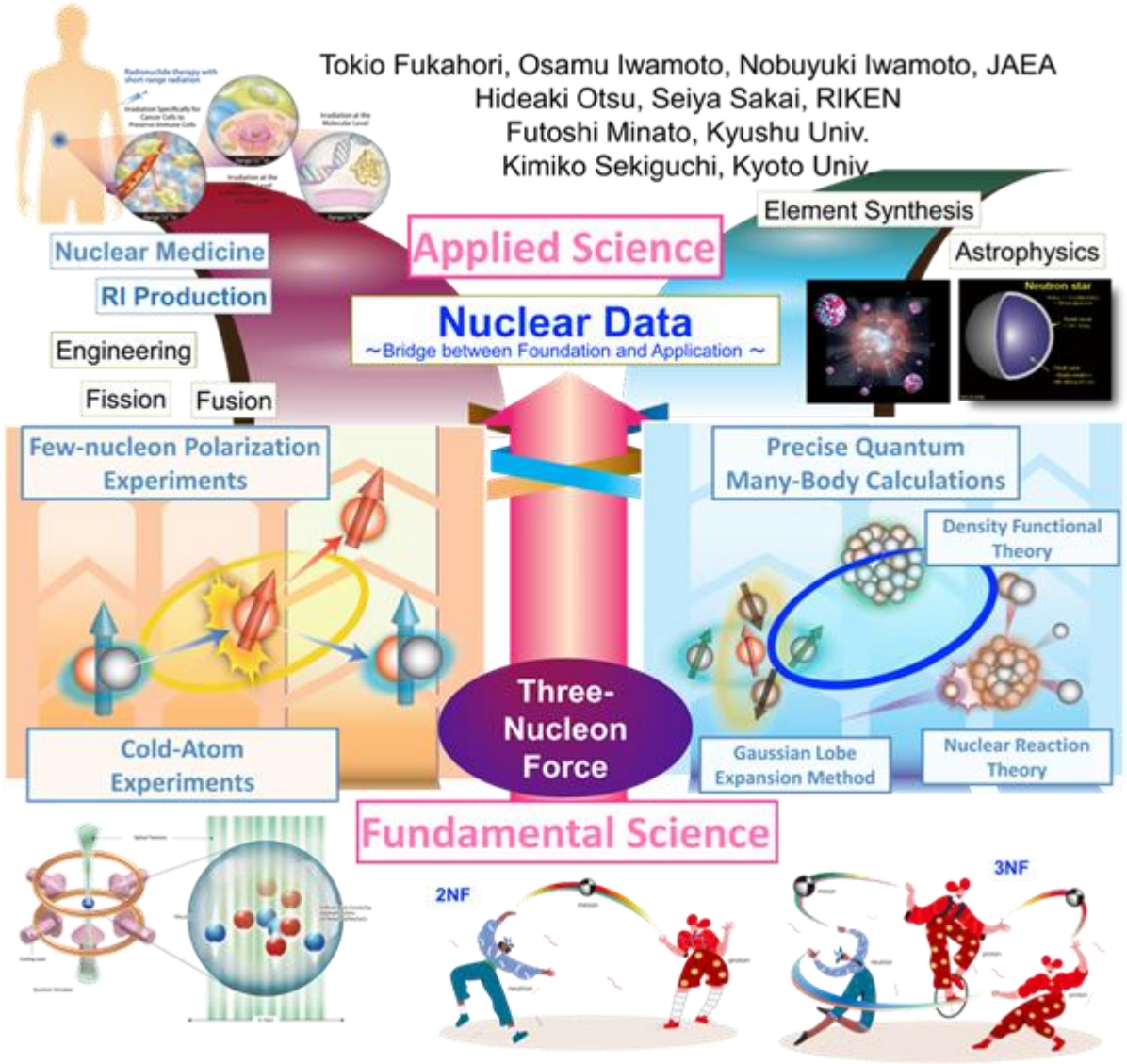
TOMOE ERATO JST Japan Science and Technology Agency

Sekiguchi Three-Nucleon Force Project (TOMOE Project)

Tokio Fukahori, Osamu Iwamoto, Nobuyuki Iwamoto, JAEA
Hideaki Otsu, Seiya Sakai, RIKEN
Futoshi Minato, Kyushu Univ.
Kimiko Sekiguchi, Kyoto Univ.

"Our project aims to establish the simulation tool of nuclear properties with high predictive power based on the high-precision nuclear forces, including the three-nucleon forces, and then extend it to applied science."

https://www.jst.go.jp/erato/sekiguchi/en/



poster: T. Fukahori et al., Introduction of the Sekiguchi Three-Nucleon Force Project (TOMOE Project)

This work is supported by JST ERATO Grant No. JPMJER2304, Japan

Summary

- The latest version JENDL-5 was released in 2021
  - Integration of special purpose files; n, p, d, α and γ-ray induced reactions
  - enhancement of neutron data; # of nuclides, updates, activation, energy region, …
- Developing the next version JENDL-5.1
  - expecting to be released in 2028
  - enhancing covariance data
  - enhancing charged particle induced reaction
  - updating neutron induced data with new experiments and model codes
  - progressing new nuclear data projects