Recent progress in JENDL charged particle files

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Introduction

✓ FENDL-3.2b (released in February 2022) includes several sub-libraries to contribute to various fusion relevant applications.

→ The neutron sub-library is the main part. On the other hand, proton and deuteron sub-libraries are also included.

✓ The charged particle sub-libraries consist of relatively old data (TENDL-2011 and JENDL/HE-2007), except for some nuclides.

→ We would need to review these data for the next FENDL.

✓ In addition, alpha-particle data are needed in fusion application field [1].

[1] M. Gilbert, "(a,n) needs for fusion", INDC(NDS)-0836 (2022).

Charged particle data of JENDL-5

✓ In JENDL-5 (released in December 2021), three charged particle sub-libraries are included to contribute to various applications.

1. proton sub-library (239 nuclides, up to 200 MeV)

→ general purpose (various accelerator design, transmutation, etc.)

2. deuteron sub-library (9 nuclides, up to 200 MeV)

→ accelerator-based neutron sources design

3. alpha-particle sub-library (18 nuclides, up to 15 MeV)

→ application mainly in nuclear back-end fields

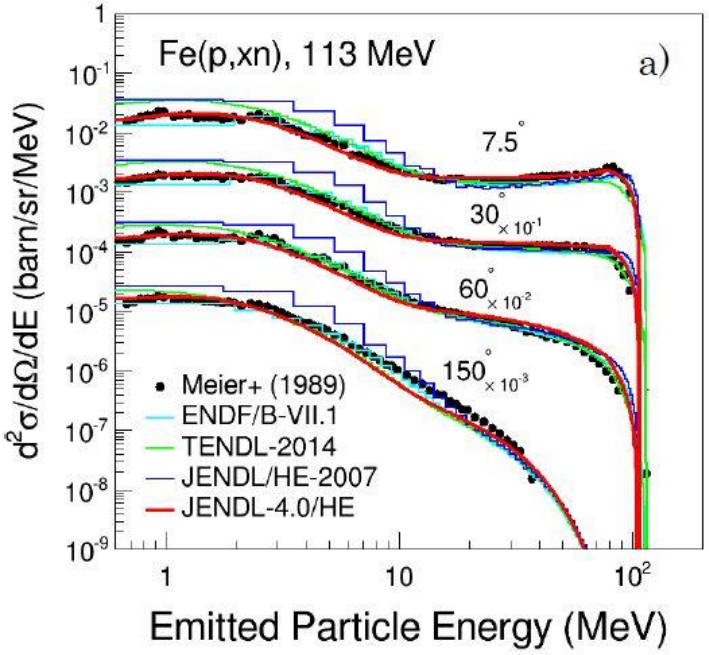
Proton data of JENDL-5

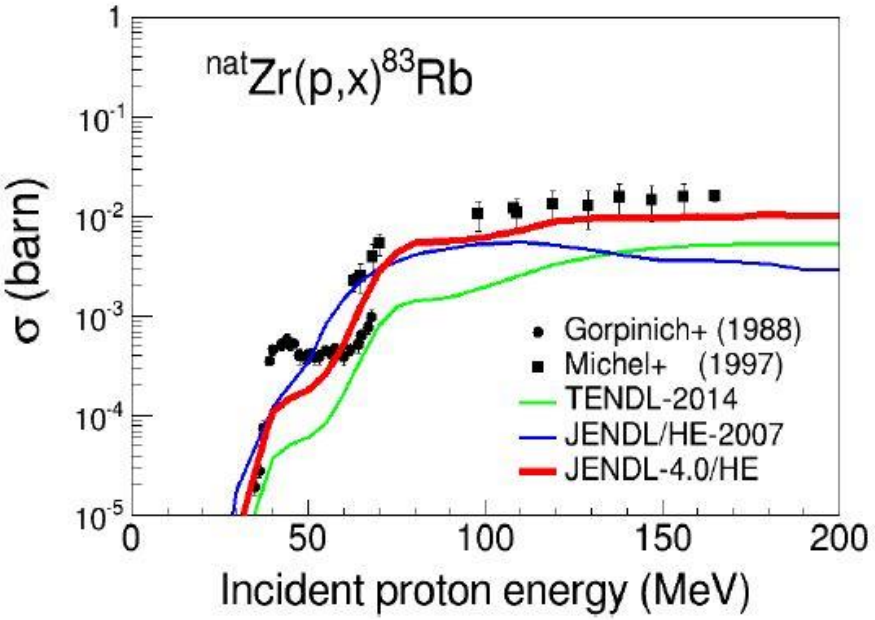
Proton sub-library of JENDL-5

- ✓ Almost all data are carried over from JENDL-4.0/HE [1] and JENDL/ImPACT-2018 [2].

→ Almost all data for stable nuclide are taken from JENDL-4.0/HE.

→ FENDL-3.2b adopt JENDL/HE-2007 (and TENDL-2011).





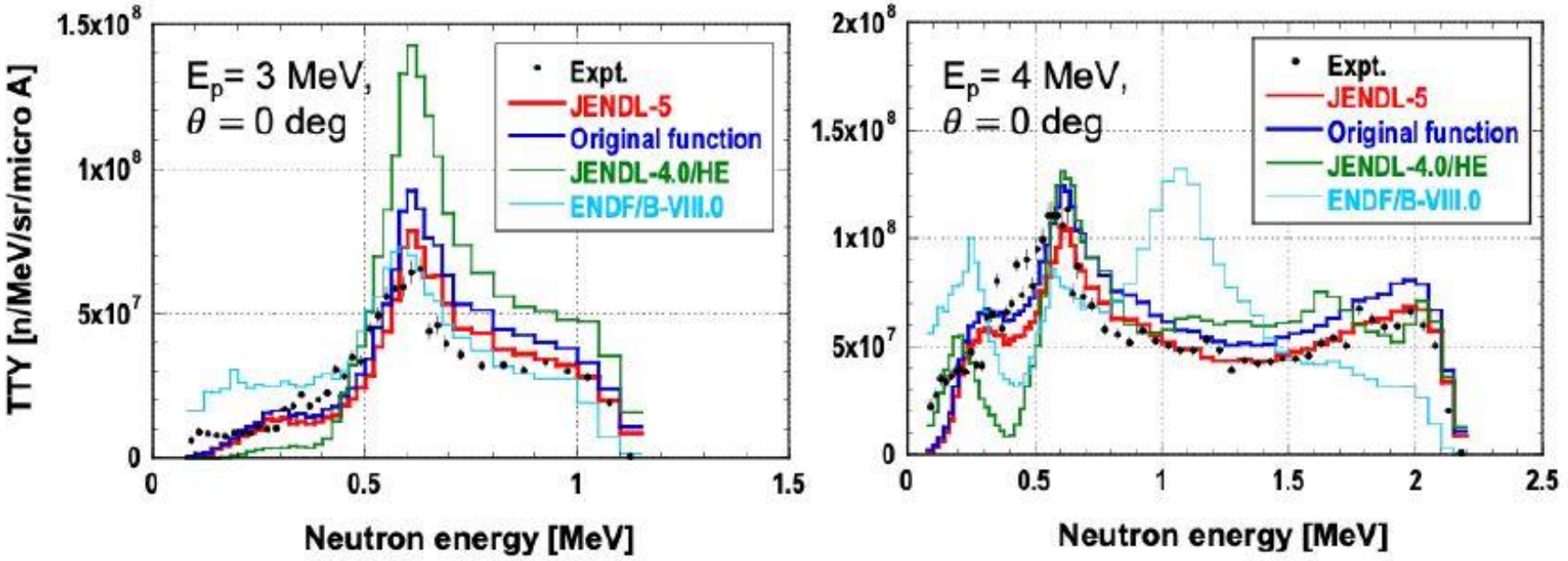
[1] S. Kunieda et al., JAEA-Conf 2016-004, 41-46 (2016).
[2] S. Kunieda et al., J. Nucl. Sci. Technol. 56, 1073-1091 (2019).

Improvement of JENDL-5 from JENDL-4.0/HE

✓ Data of the ^{9}Be(p,xn) reactions (< 12 MeV) were improved [1].

→ The empirical model by Wakabayashi et al. [2] was adopted for angle- and energy-distribution, and XS were revised.

Neutron spectrum from thick ^{9}Be target bombarded protons



[1] S. Kunieda et al., J. Neutron Research, 24, 329-335 (2023).
[2] Y. Wakabayashi et al., J. Nucl. Sci. Technol. 55, 859-867 (2018).

Revision of JENDL-5

✓ ^{7}Li data (< 10 MeV) were revised in August 2023.

1. Discrete gamma-ray energies from (p,n_1) and (p,p_1) reactions.

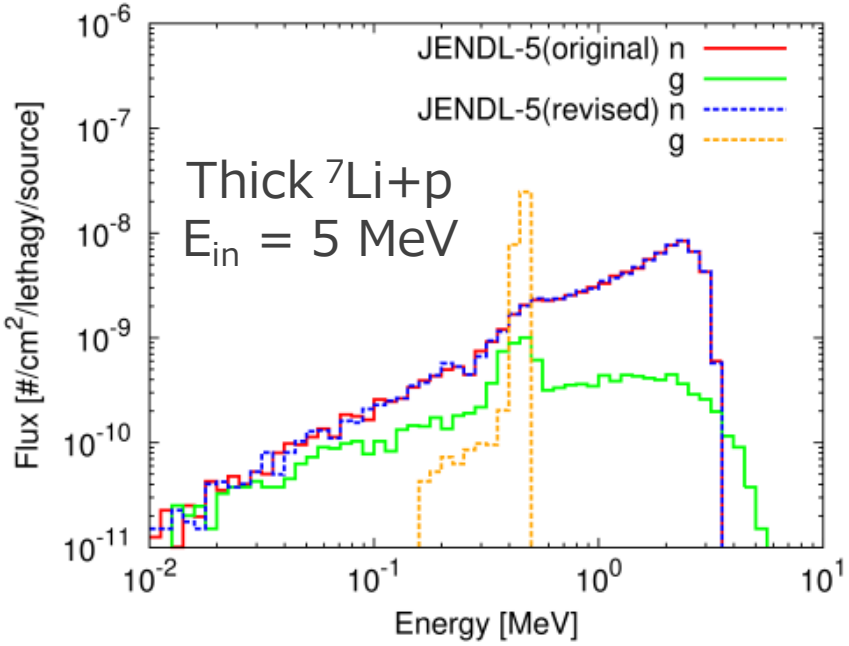
→ 429.1 and 477.6 GeV were corrected to 429.1 and 477.6 keV.

2. Gamma-ray production data of (p,n_1) and (p,p_1) were merged from MF6/MT51,601 to MF6/MT5.

→ MCNP and PHITS cannot handle gamma-ray data in multiple MTs.

✓ ^{7}Li+p data of JENDL-4.0/HE (adopted in FENDL-3.2b) also have this problem.

→ We should correct ^{7}Li+p data in the next FENDL.



Deuteron data of JENDL-5

Deuteron sub-library of JENDL-5

used in IFMIF etc.

1. Beam target material in neutron source (^{6,7}Li, ^{9}Be, ^{12,13}C)

✓ The JENDL/DEU-2020 [1] data (adopted in FENDL-3.2b) were slightly modified and adopted.

→ ^{6}Li(d,xt) cross sections at low incident energies, etc.

✓ Neutron production data below 50 MeV are not changed.

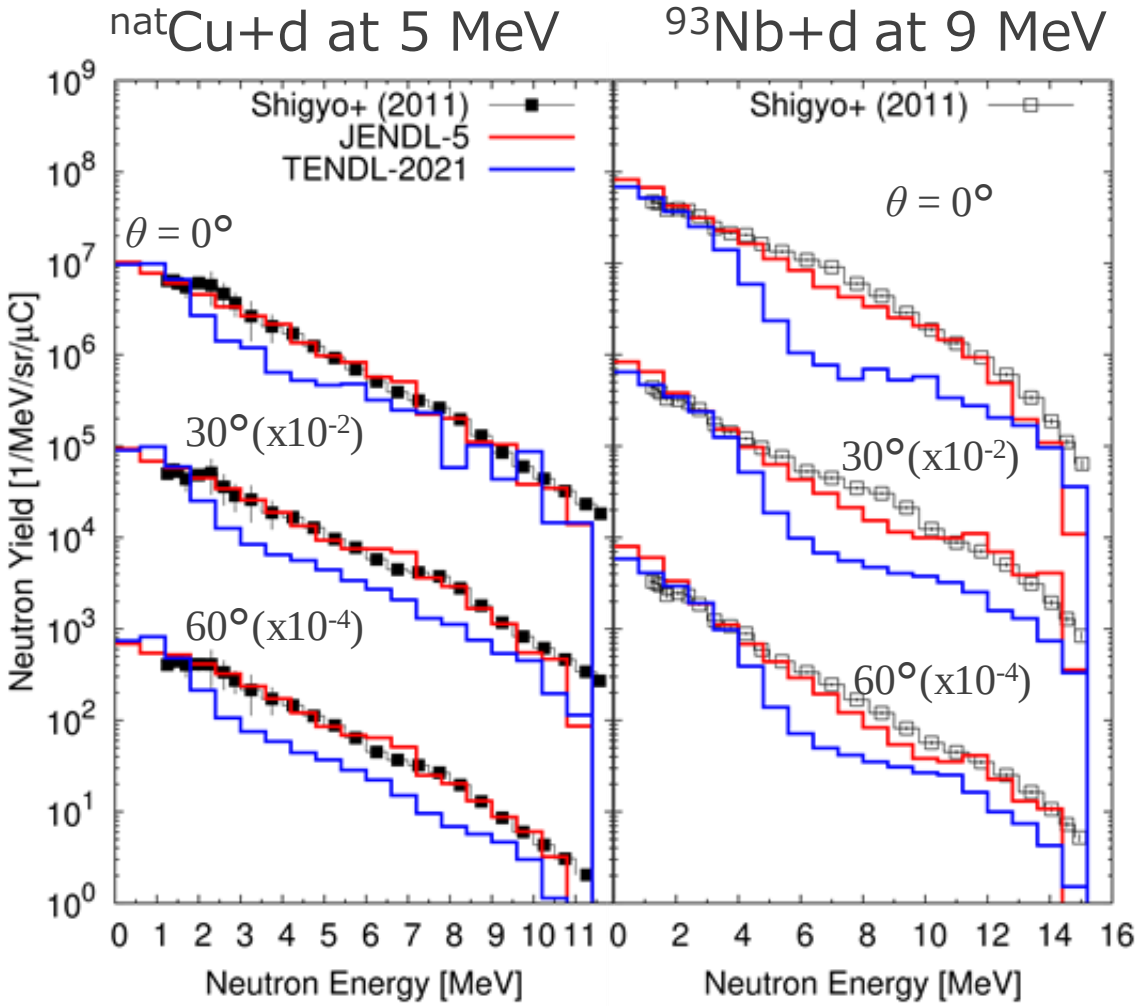
2. Structural materials (^{27}Al, ^{63,65}Cu, ^{93}Nb)

✓ Important in the shielding design of accelerator facilities.

✓ Newly evaluated up to 200 MeV with the DEURACS code [2].

[1] S. Nakayama et al. J. Nucl. Sci. Technol. 58 805 (2021).
[2] S. Nakayama et al. Phys. Rev. C **94**, 014618 (2016).

Neutron yields from structural materials (low E_{in})

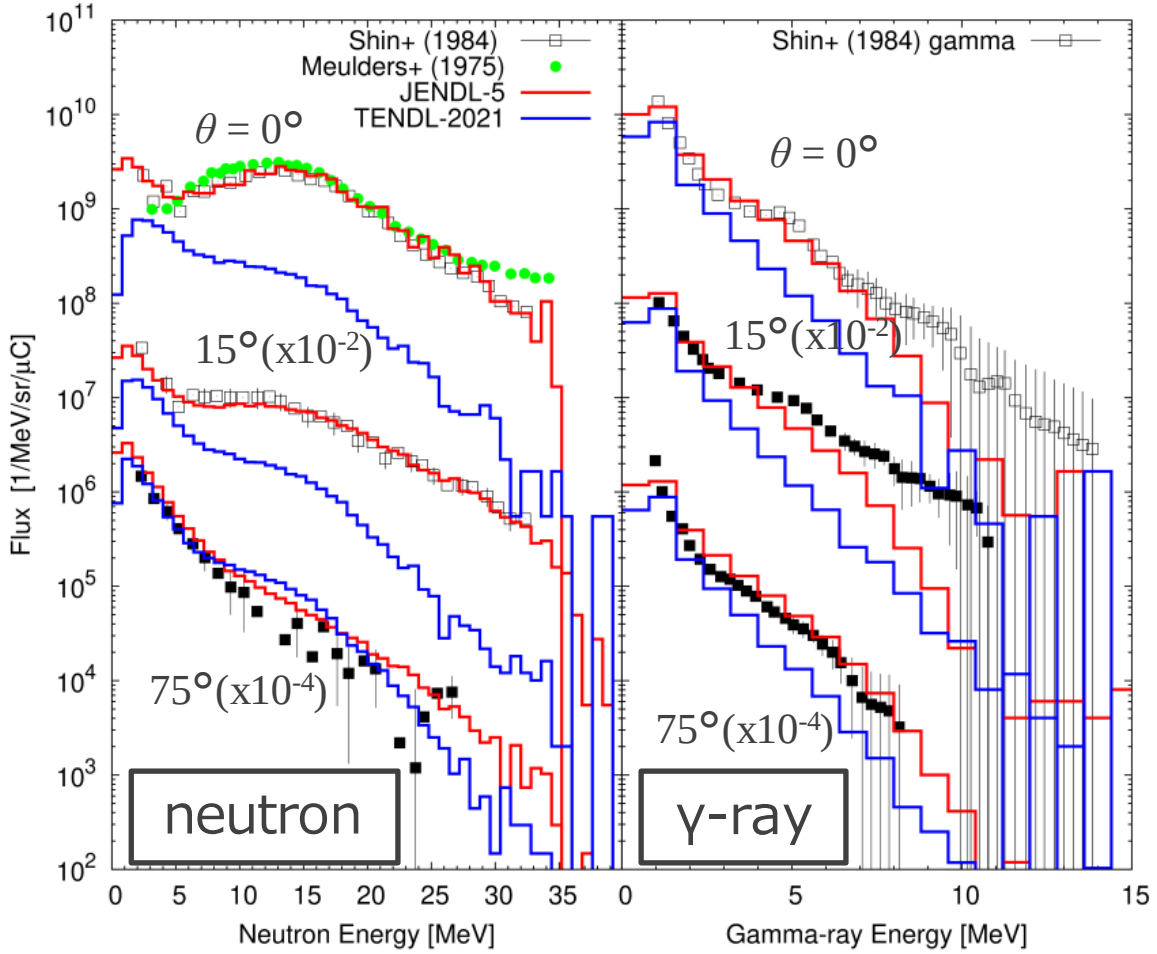


- ✓ JENDL-5 allows for more accurate simulations at the deuteron energies below 10 MeV.

→ Due to consideration of (d,n_i) transfer reaction to low-lying states.

Neutron and gamma-ray yields (high E_{in})

^{nat}Cu+d at 33 MeV



✓ JENDL-5 well reproduces the experimental data at high energy.

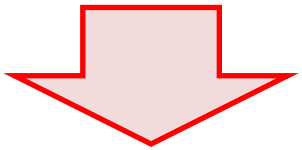
→ Due to the better consideration of deuteron breakup.

Alpha-particle data of JENDL-5

α-particle data in back-end fields

- ✓ Trans-uranium (TRU) and light elements (C, N, O, F, etc.) often coexist in storage and transportation of irradiated fuel.
- ✓ Decay α-rays from TRU can produce neutrons by the reactions with the surrounding light nuclei.

→ (α,xn) reaction data on light nuclides are important in the radiation shielding and criticality safety of back-end facilities.



(α,xn) reaction data on 17 light nuclides (from Li to Si) up to 15 MeV were evaluated and released as JENDL/AN-2005.

[1] T. Murata et al. JAEA-Research 2006-052 (2006).

Alpha sub-library of JENDL-5

- ✓ Cross-sections of neutron emission channels were maintained from JENDL/AN-2005.

→ The data of JENDL/AN-2005 are in good agreement with experimental data including resonance structure (next page).

- ✓ Other data up to 15 MeV were calculated with the CCONE code[1] and were added to JENDL/AN-2005.

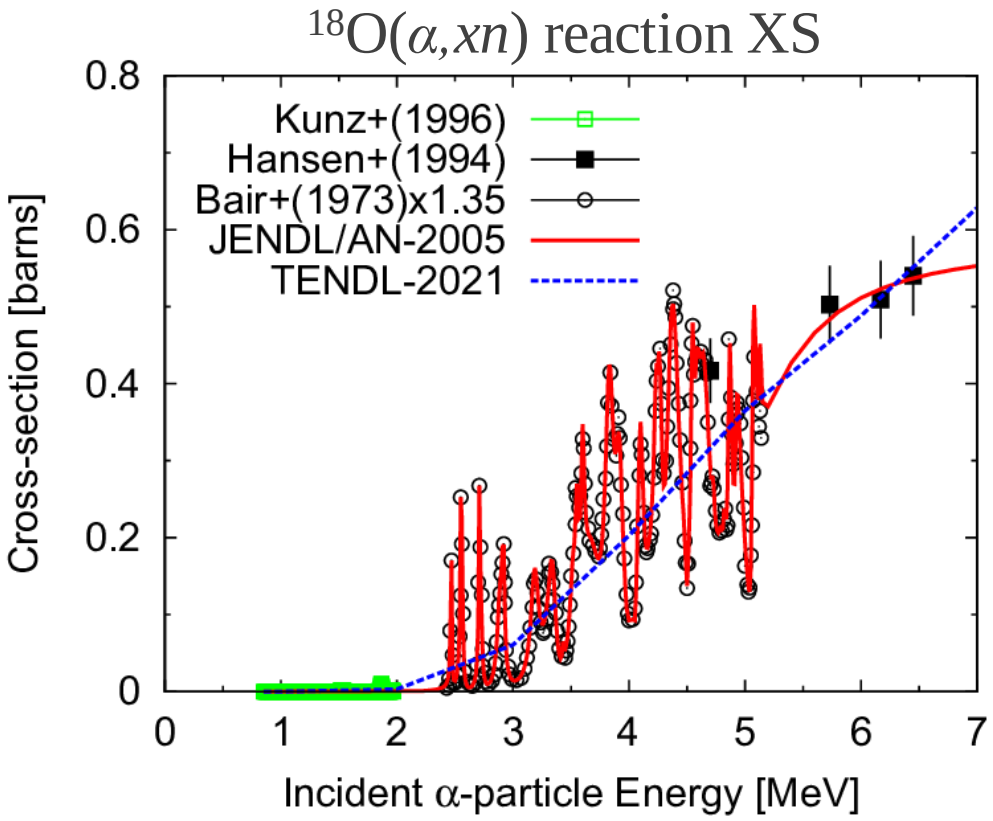
→ JENDL/AN-2005 has some problems in angle- and energy-distribution of outgoing neutron [2].

→ No data for gamma-ray production from various reaction channels are included in JENDL/AN-2005.

[1] O. Iwamoto et al., Nucl. Data Sheets 131, 259 (2016).
[2] D.P. Griesheimer et al., Nucl. Eng. Technol. 49, 1199 (2017).

Neutron production cross-section

✓ There are few evaluated (α,xn) reaction data on light nuclides.



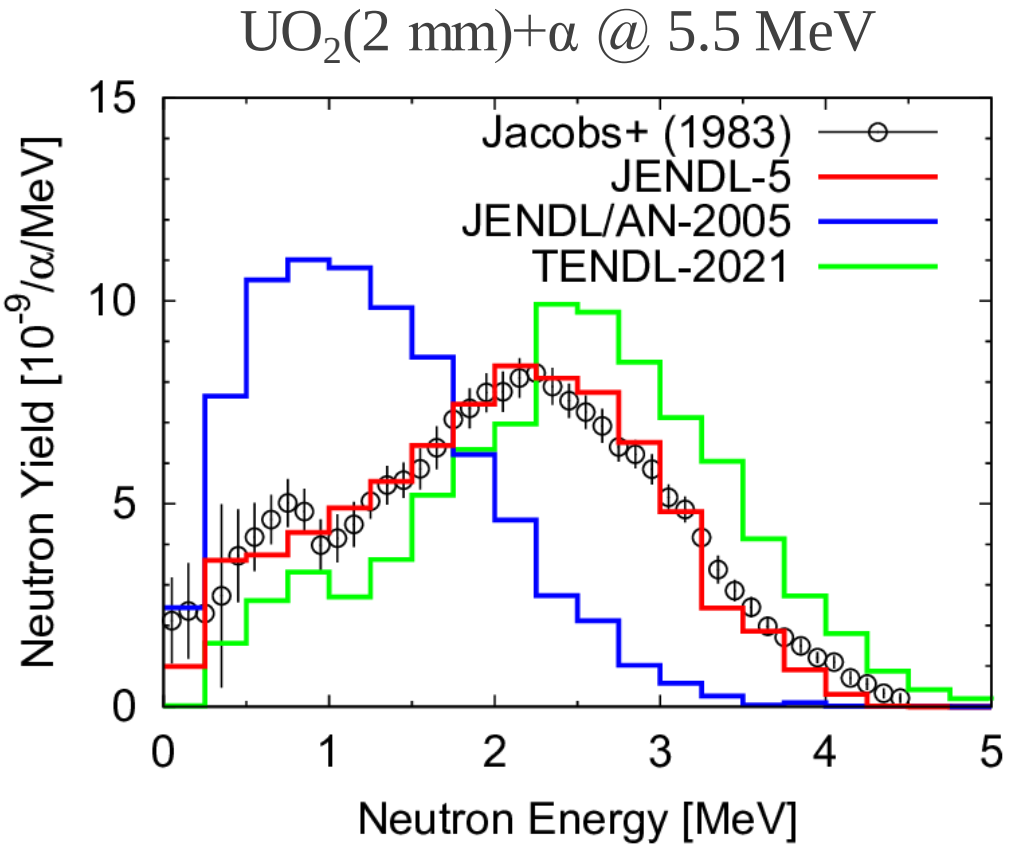
x 1.35 was pointed out by Bair et al. themselves [1].

Taken into account in the evaluation of JENDL/AN-2005.

JENDL/AN-2005 is in good agreement with the experimental data including resonance structures.

[1] J.K. Bair and J. Gomez del Campo, Nucl. Sci. Eng. 71, 18 (1979).

Neutron spectrum from thick target



*Contribution from $^{18}O(\alpha, n)$ reaction is dominant.

✓ Simulation based on JENDL-5 reproduces the experimental data better than those based on the other libraries.

→ Deu to the revision of outgoing neutron spectrum.

Summary and suggestion

✓ In JENDL-5, the sub-libraries for three charged particles (proton, deuteron, and alpha-particle) are included.

✓ Suggestions (at this time) for the next FENDL.

1. Proton data

— Data taken from JENDL/HE-2007 and TENDL-2011 should be replaced with JENDL-5 and the latest version of TENDL.

— ^{7}Li data should be replaced with the revised data of JENDL-5.

2. Deuteron data

— Data taken from TENDL-2011 should be replaced with the latest version of TENDL (most nuclides are applicable).

— ^{27}Al, ^{63,65}Cu, ^{93}Nb data should be replaced with those of JENDL-5.

Summary and suggestion (cont.)

✓ Suggestions (at this time) for the next FENDL.

3. Alpha-particle data

— These will be included according to the needs from the fusion application field.

— The candidate is to supplement JENDL-5 (18 nuclides) with TENDL.

✓ Improvements are still needed for activation cross sections for deuteron and alpha-particles sub-libraries of JENDL-5.

→ They are evaluated mainly for neutron and gamma-ray transport calculations.

✓ Requests for nuclear data from the fusion application fields are welcome.