Benchmark test for next FENDL

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Contributor: Chikara Konno[2]

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[2]Japan Atomic Energy Agency (JAEA)

Outline

- We would like to present the following issues as the outstanding actions from the last FENDL meeting in 2018.
  1. INDEN Fe56 benchmark test with QST/TIARA iron shielding experiments for FENDL-3.2
  2. Benchmark test with QST/TIARA concrete shielding experiments for new O16 data
- We would like to introduce some problems of deuteron-induced files in TENDL-2017 that we newly found out.
  3. Problems on neutron production data of deuteron-induced files in TENDL-2017
- Finally, let me talk about…
  4. New Fe56 benchmark test with QST/TIARA iron shielding experiments for next TENDL, TENDL-2019

INDEN Fe56 benchmark test with QST/TIARA iron shielding experiments for FENDL-3.2

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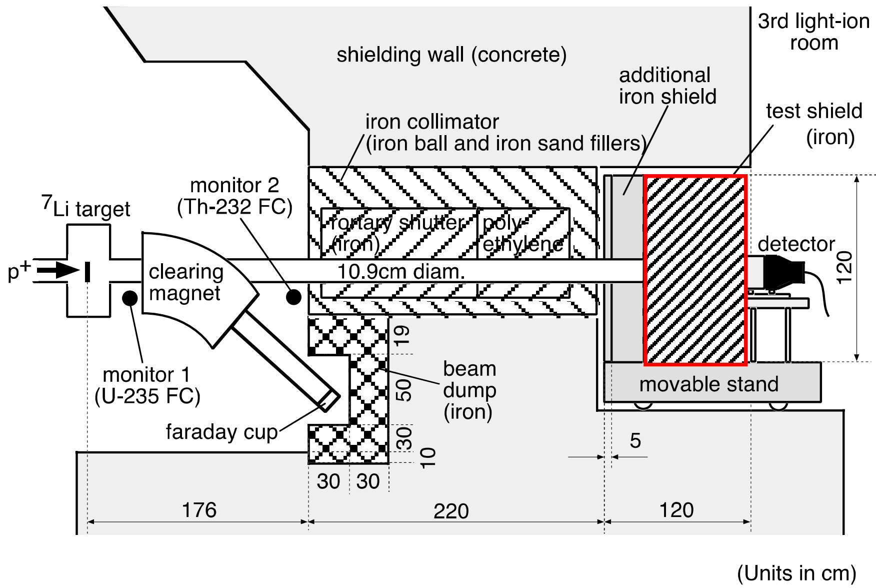
Note: It is forbidden to use figures and data in this slide except for the FENDL project.

Introduction

- At the last Consultants' Meeting on the FENDL Library for fusion neutronics calculations (14-18 Oct. 2018), Dr. Trkov proposed that INDEN Fe56 would be a candidate of FENDL-3.2 Fe56.
- However, it was not clear whether INDEN Fe-56 was better than FENDL-3.1d Fe56.
- Thus, we carried out benchmark tests of INDEN Fe56 based on the action of the last FENDL meeting.
- Here the results with the QST/TIARA iron shielding experiments are presented.
- Those with the JAEA/FNS iron experiments are presented by Dr. Konno.

Experiment & Analysis

Experimental configuration

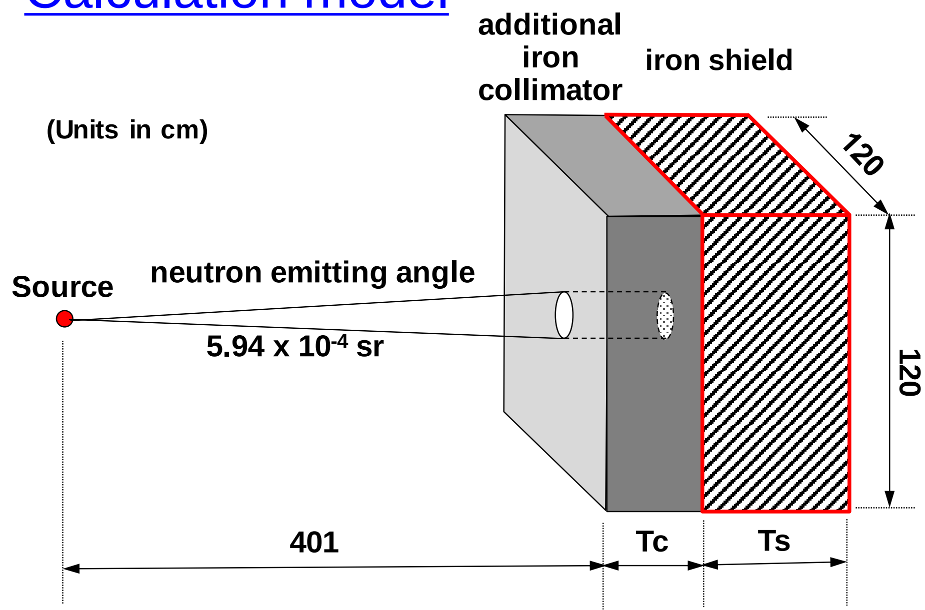


- 43 and 68MeV of protons were bombarded on the Li-7 target.
- The generated neutrons, 40 and 65MeV, were collimated and entered on the iron test shield.
- The neutron spectrum above 5MeV was measured by scintillators.

See the following report for more details about the experiments and analyses:

H. Nakashima et al., JAERI-Data/Code 96-005, 1996

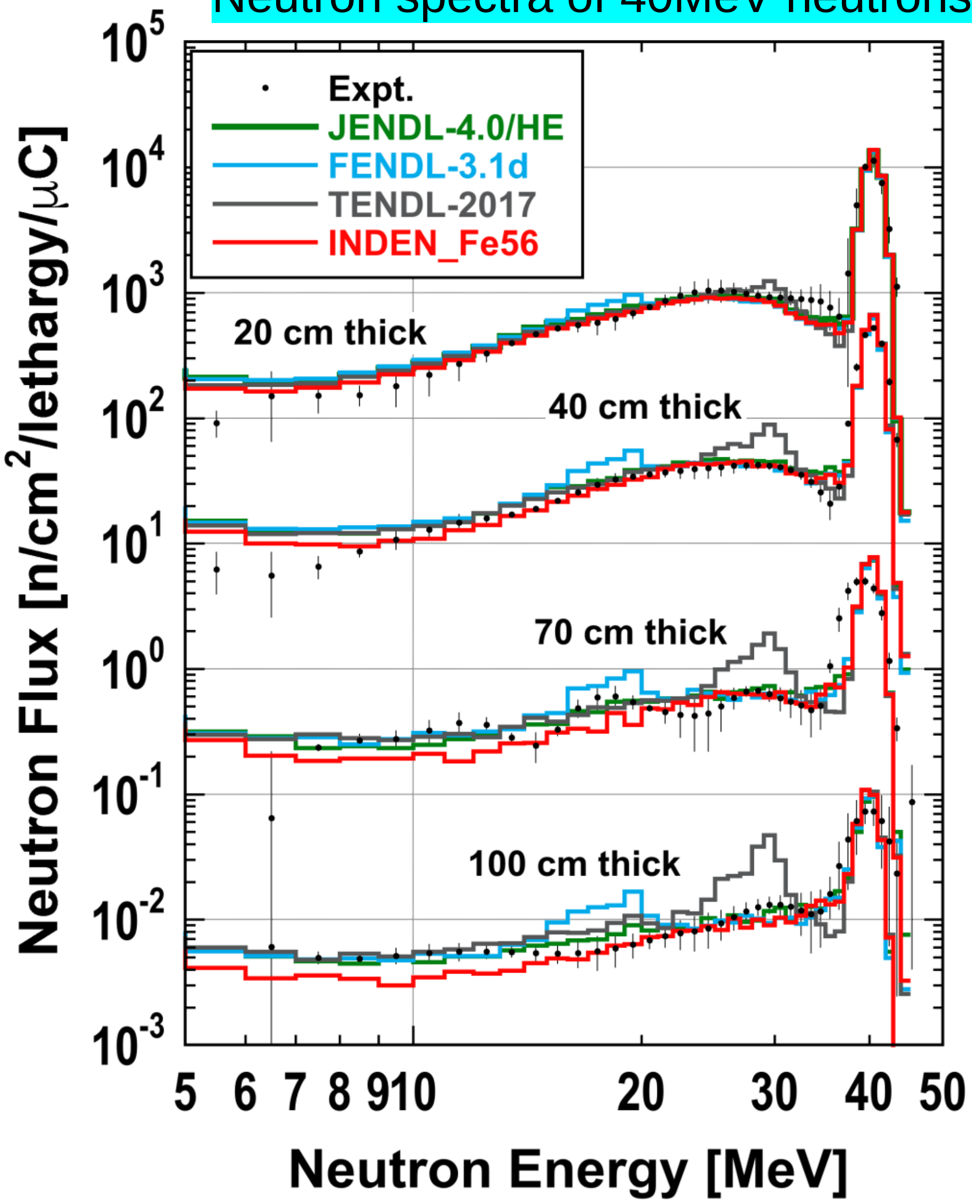
Calculation model



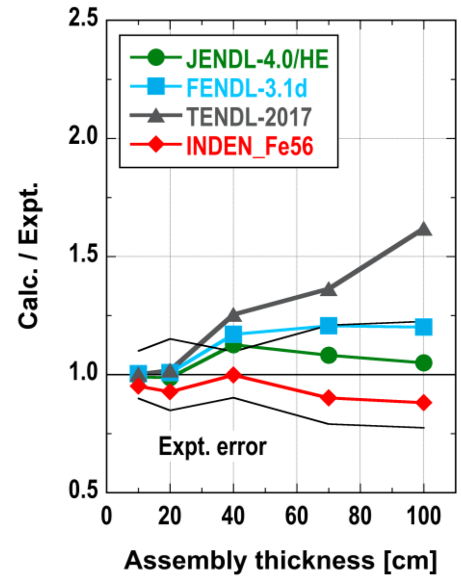
- Code: MCNP6.1.1
- Libraries:
  - FENDL-3.1d (Official ACE file)
  - TENDL-2017 (Official ACE file)
  - JENDL-4.0/HE (Processed with NJOY2016)
  - **INDEN: Fe56 file (^{54,57,58}Fe: FENDL-3.1d)**
- The measured neutron spectrum was used as the neutron source in MCNP.

Result: 40MeV

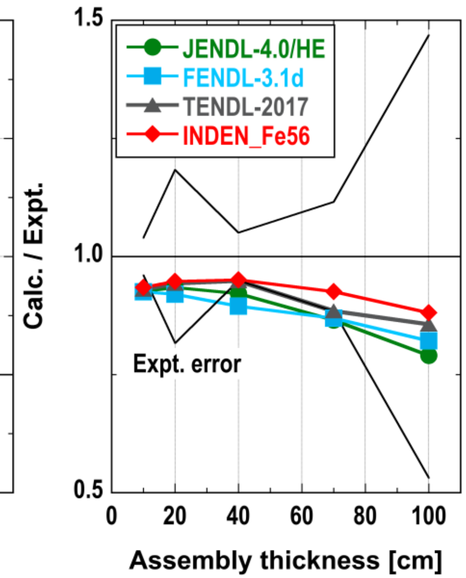
Neutron spectra of 40MeV neutrons



Conti. (10 – 35MeV)



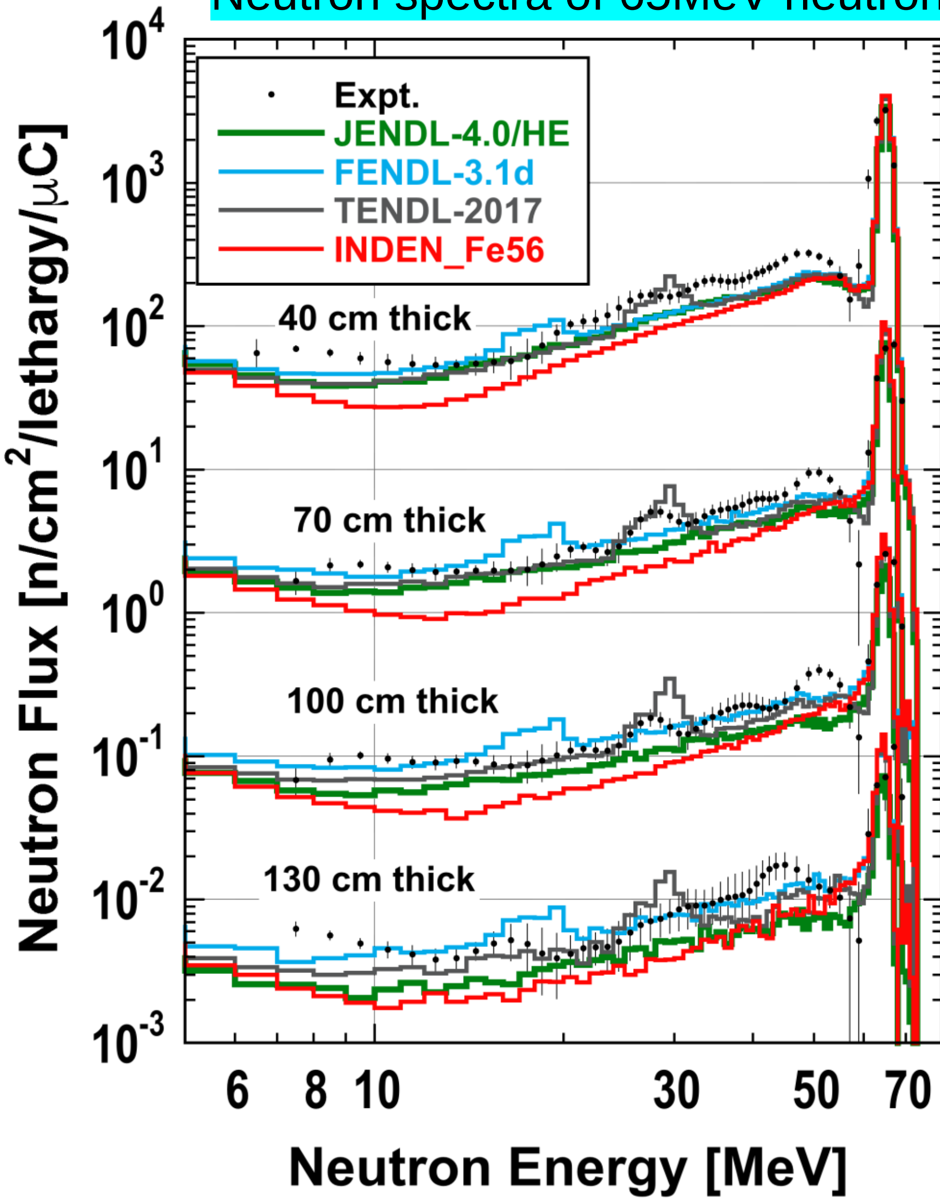
Peak (35 – 45MeV)



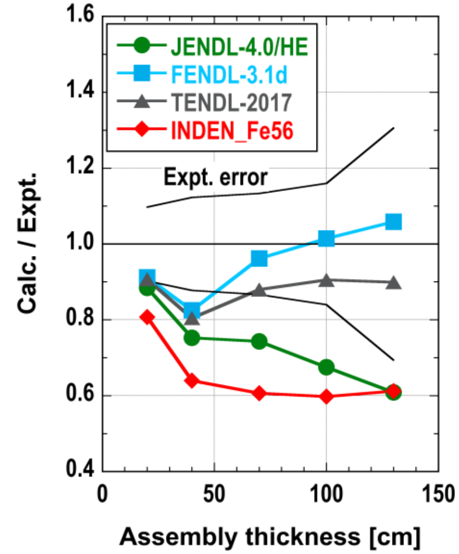
- Continuous region: The calculated neutron fluxes agree well the experimental ones using INDEN-Fe56.
- Peak region: The calculated neutron fluxes agree well the experimental ones using INDEN-Fe56.

Result: 65MeV

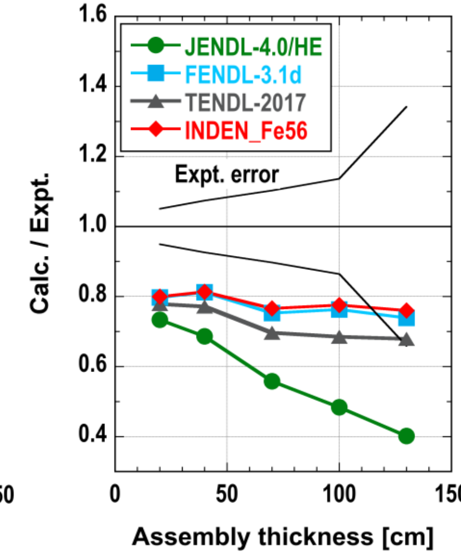
Neutron spectra of 65MeV neutrons



Conti. (10 – 60MeV)



Peak (60 – 70MeV)



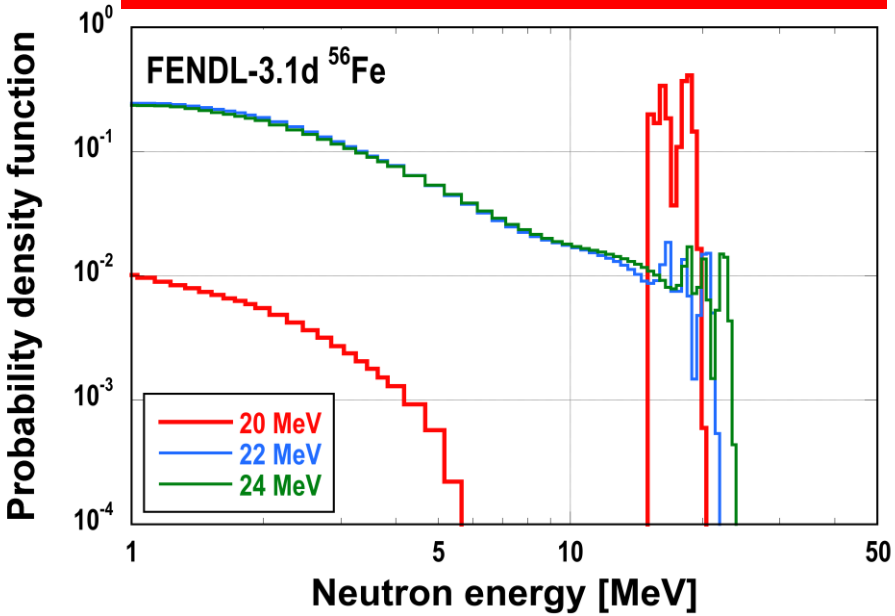
- Continuous region: The calculated neutron fluxes underestimate the experimental ones using INDEN-Fe56 (Bad C/E).
- Peak region: The calculated neutron fluxes underestimate the experimental ones using INDEN-Fe56 (Similar C/E to FENDL-3.1d).

About the FENDL-3.1d (rev.) REVIEW

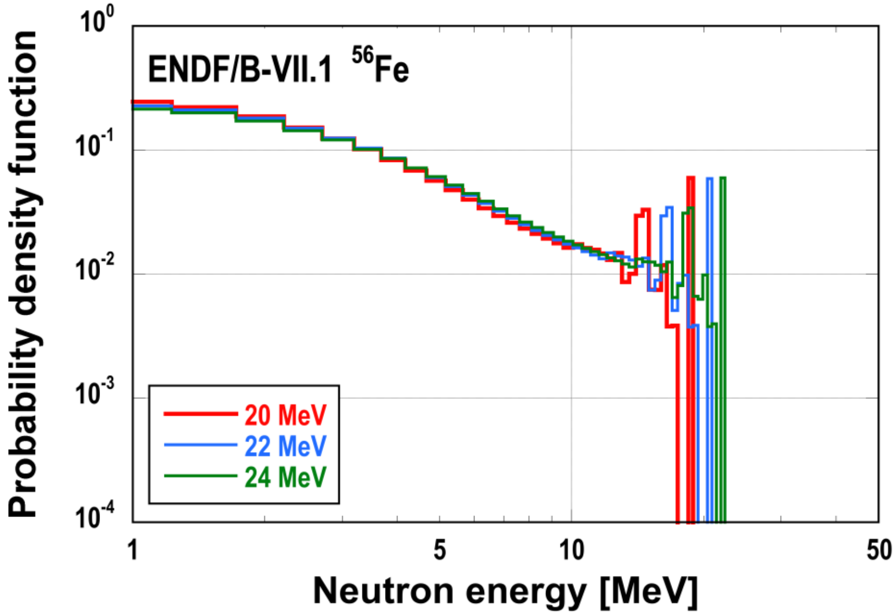
*mt=5: Sum of all reactions not given explicitly in another mt #

- We examined the iron isotopes data in FENDL-3.1d.
- ^{56}Fe data of FENDL-3.1d was taken from TENDL-2011, in range of 20-150MeV.

Looks something wrong at 20MeV



Looks normal at 20MeV

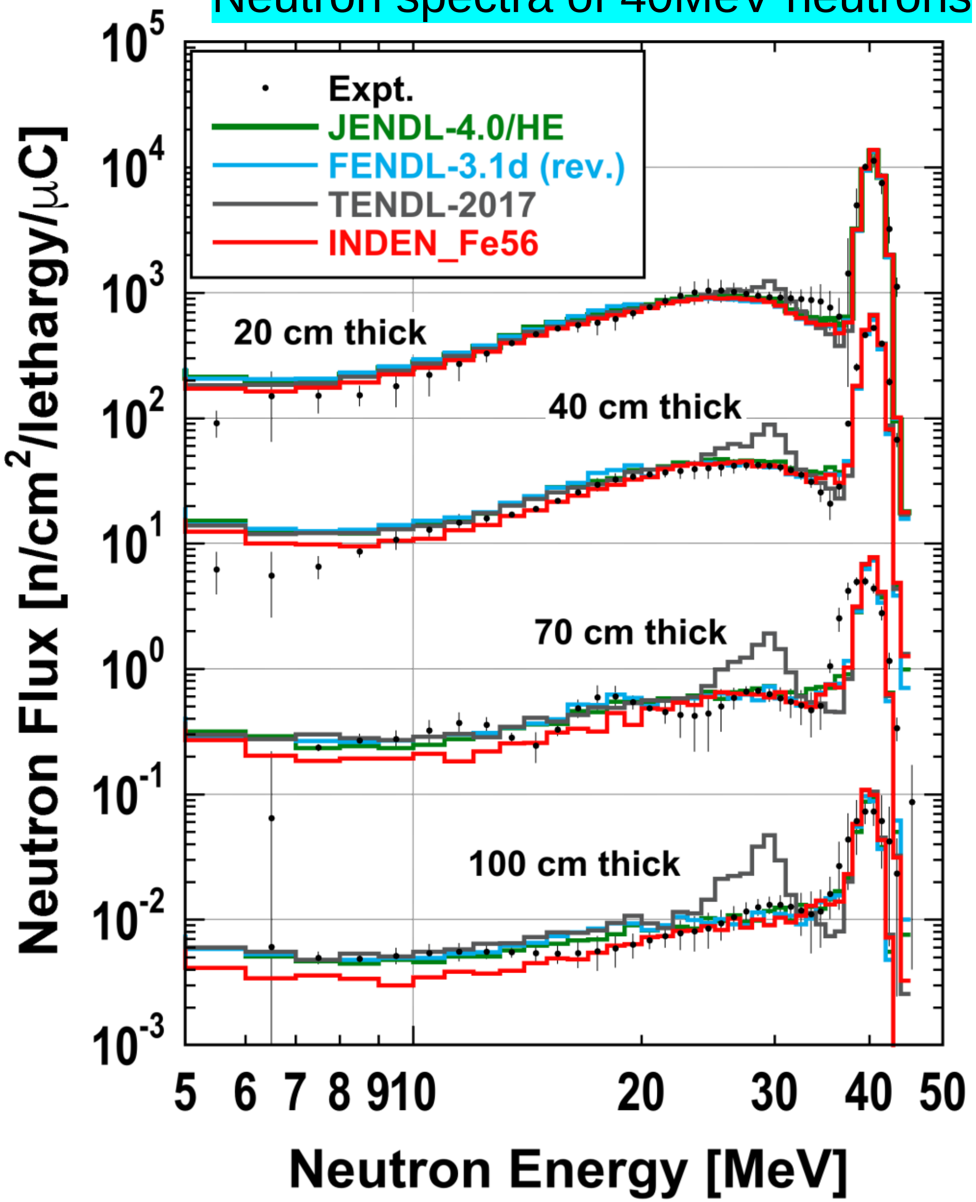


→ **The secondary neutron spectrum data of mt=5* in FENDL-3.1d are incorrect at 20MeV.**

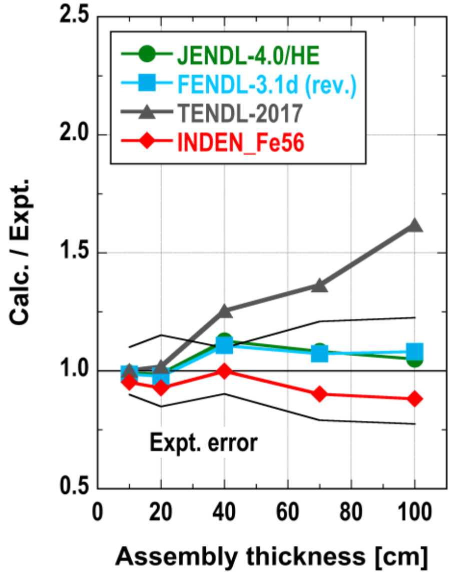
→ **We replaced the incorrect data at 20MeV in FENDL-3.1d with the "normal" secondary neutron spectrum data in ENDF/B-VII.1, as it is called "FENDL-3.1d (rev.)" in the analysis results.**

Result: 40MeV with FENDL-3.1d (rev.)

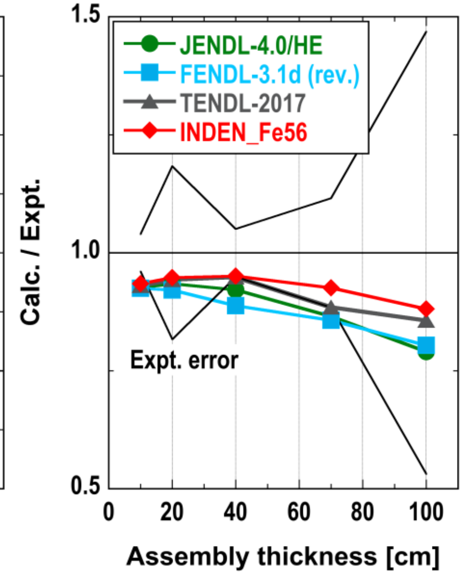
Neutron spectra of 40MeV neutrons



Conti. (10 – 35MeV)



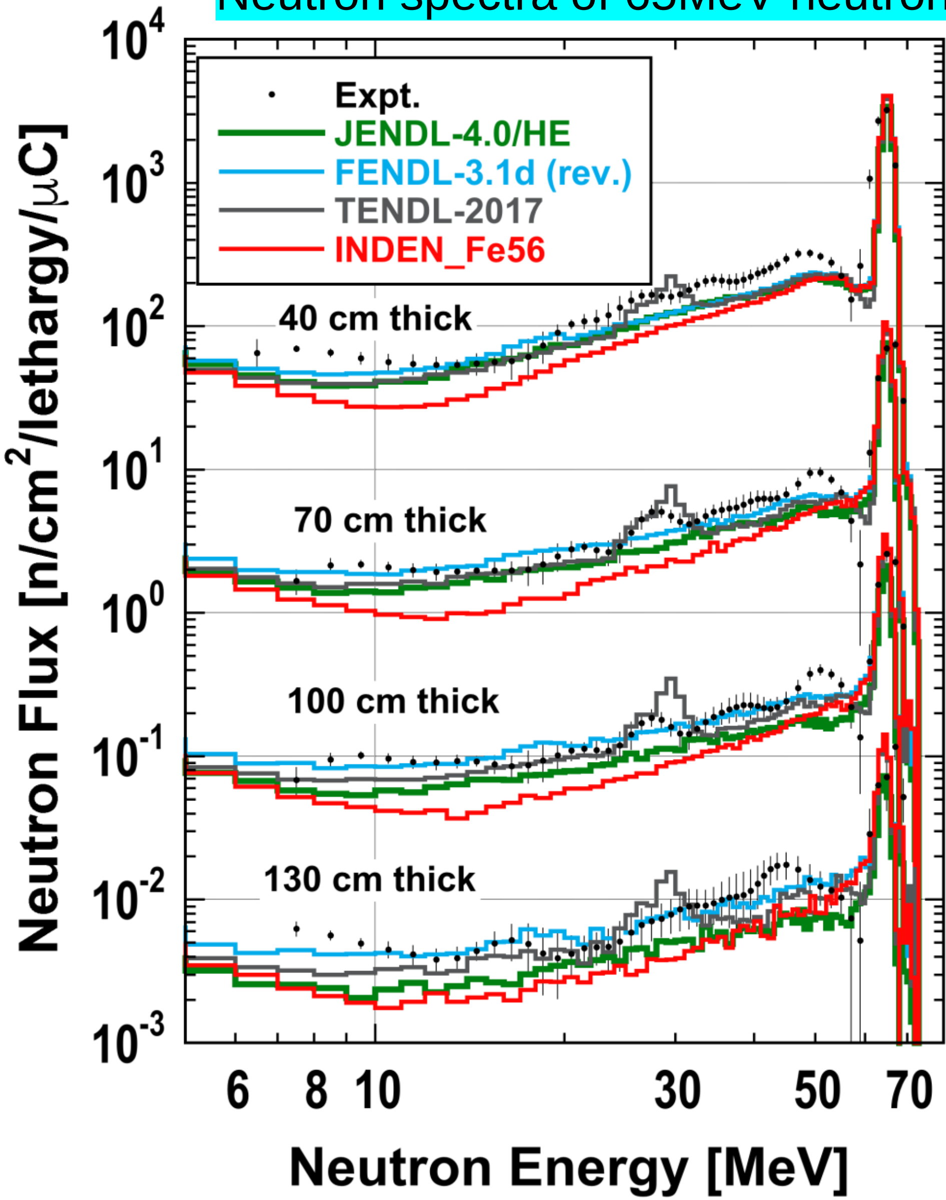
Peak (35 – 45MeV)



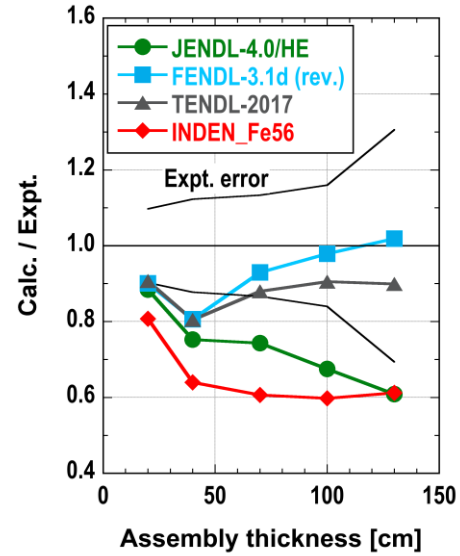
- Continuous region: The calculated neutron fluxes agree well the experimental ones using INDEN-Fe56.
- Peak region: The calculated neutron fluxes agree well the experimental ones using INDEN-Fe56.

Result: 65MeV with FENDL-3.1d (rev.)

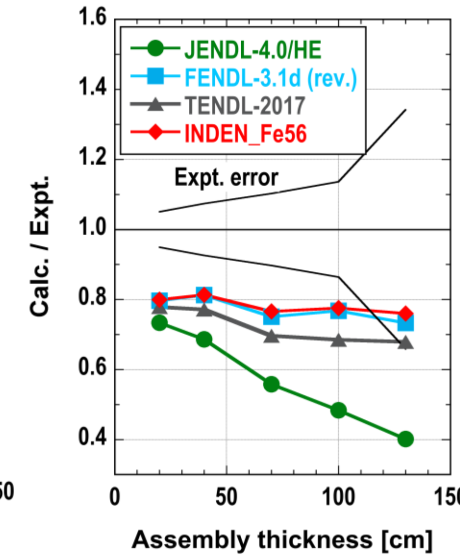
Neutron spectra of 65MeV neutrons



Conti. (10 – 60MeV)



Peak (60 – 70MeV)



- Continuous region: The calculated neutron fluxes underestimate the experimental ones using INDEN-Fe56 (Bad C/E).
- Peak region: The calculated neutron fluxes underestimate the experimental ones using INDEN-Fe56 (Similar C/E to FENDL-3.1d (rev.)).

Concluding remarks

- **In the analyses of QST/TIARA iron shielding experiments, it can not be affirmed that INDEN Fe56 is better than FENDL-3.1d Fe56.**

- **We propose that FENDL-3.2 adopts FENDL-3.1d Fe56, where only the secondary neutron spectrum data at 20MeV in mt=5 are revised.**

Benchmark test with QST/TIARA concrete shielding experiments for new O16 data

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[1]*National Institutes for Quantum and Radiological Science and Technology (QST)*
[2]*Japan Atomic Energy Agency (JAEA)*

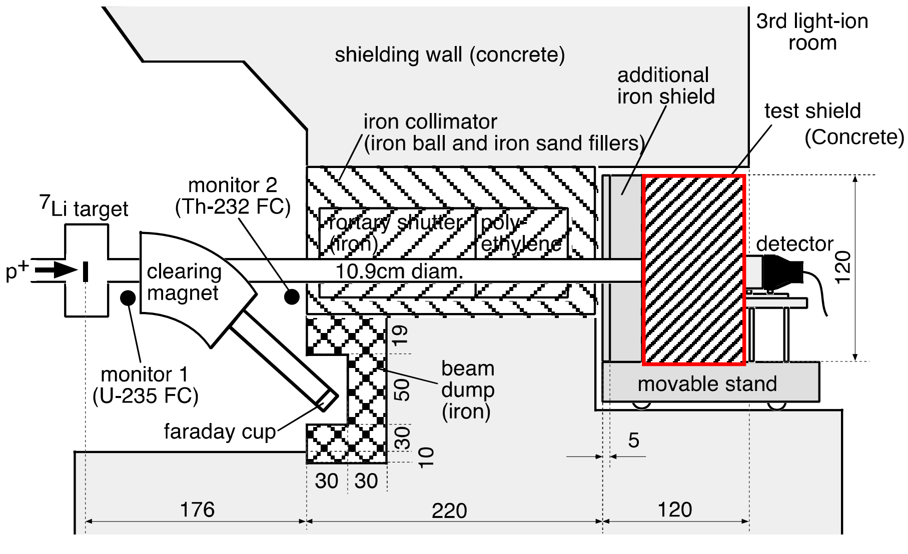
Note: It is forbidden to use figures and data in this slide except for the FENDL project.

Introduction

- As one of the actions at the last Consultants' Meeting on the FENDL Library for fusion neutronics calculations (14-18 Oct. 2018), Dr. Kunieda prepared new O16 data for the next FENDL library.
- The O16 data of FENDL-3.1d was taken from ENDF/B-VII.
- Dr. Kunieda replaced the O16 data of FENDL-3.1d with those of JENDL-4.0/HE over 30MeV, where the upper energy limit was changed from 200 to 150 MeV.
- As a benchmark test of the new O16 data, we analyzed the QST/TIARA concrete shielding experiments.
- Here, our results are presented.

Experiment & Analysis

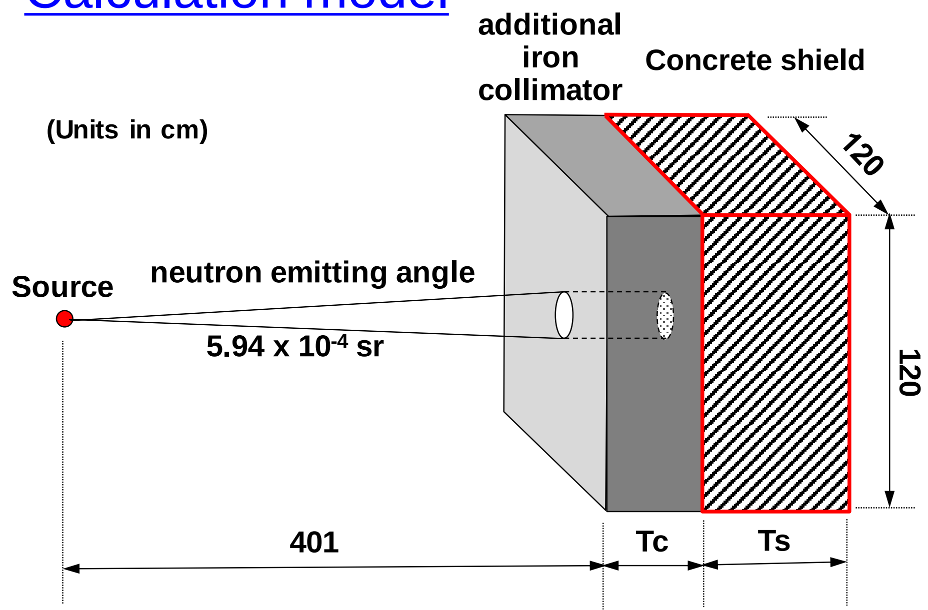
Experimental configuration



- 43 and 68MeV of protons were bombarded on the Li-7 target.
- The generated neutrons, 40 and 65MeV, were collimated and entered on the concrete test shield.
- The neutron spectrum above 5MeV was measured by scintillators.

See the following report for more details about the experiments and analyses:
N. Nakao et al., JAERI-Data/Code 97-020, 1997

Calculation model

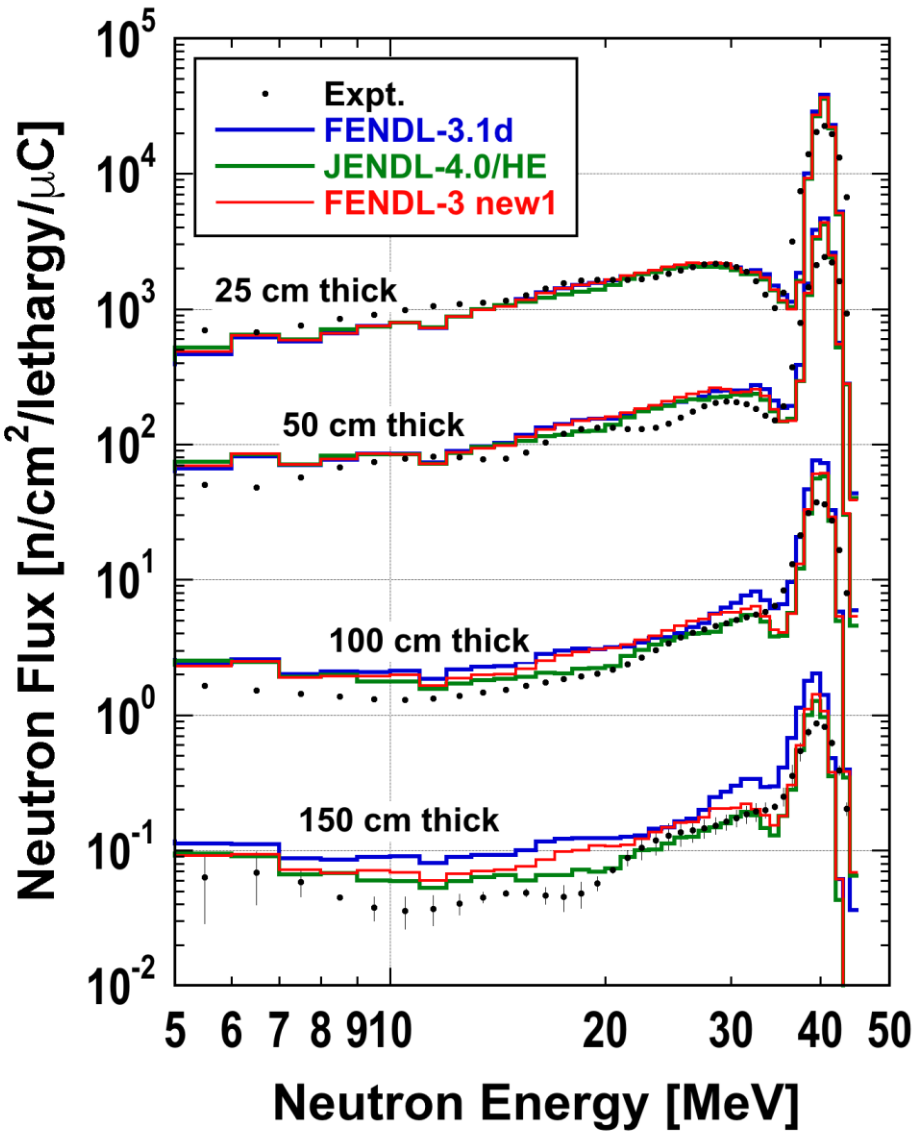


- Code: MCNP6.1.1
- Libraries:
  - FENDL-3.1d (Official ACE file)
  - JENDL-4.0/HE (Processed with NJOY2016)
  - **FENDL-3 new1:**
    - **O16 new 1** (Processed with NJOY2016)
    - others FENDL-3.1d (Official ACE file)
- The measured neutron spectrum was used as the neutron source in MCNP.

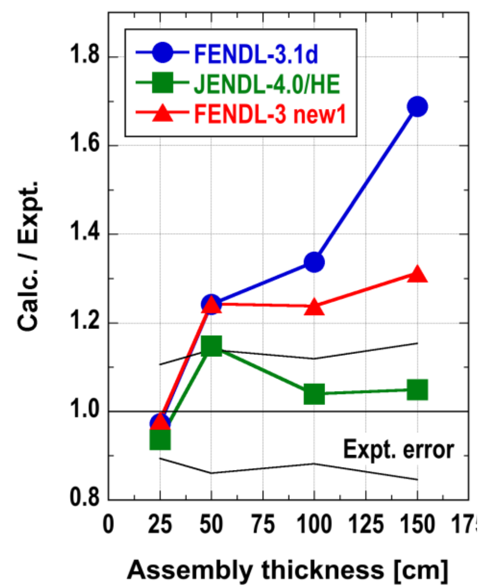
Result: 40MeV (FENDL-3 new1 from Dr. Kunieda)

QST

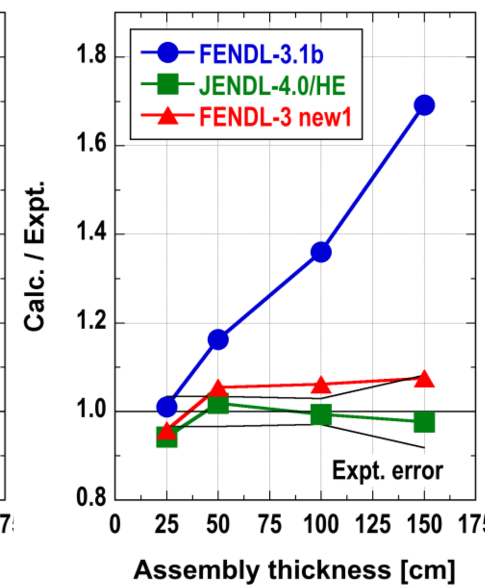
Neutron spectra in 40MeV experiment



Conti. (10 – 35MeV)



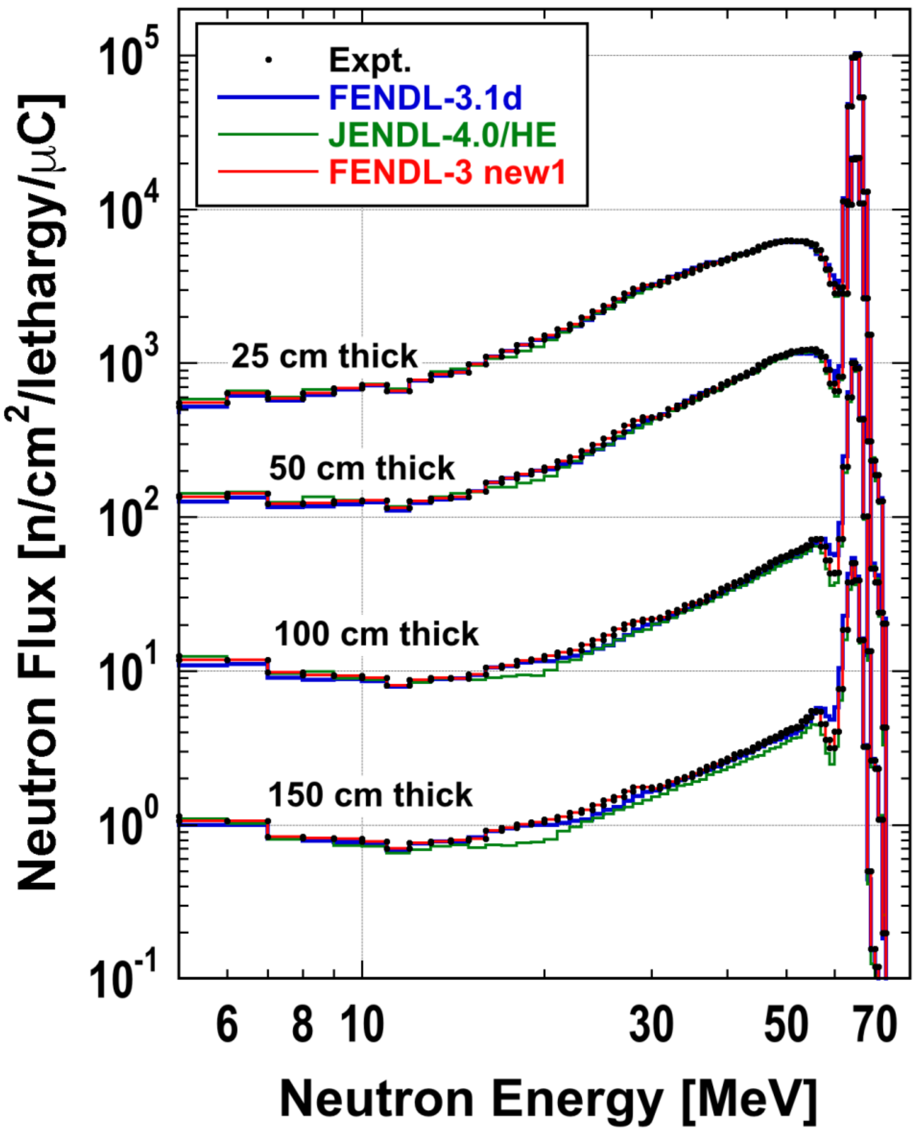
Peak (35 – 45MeV)



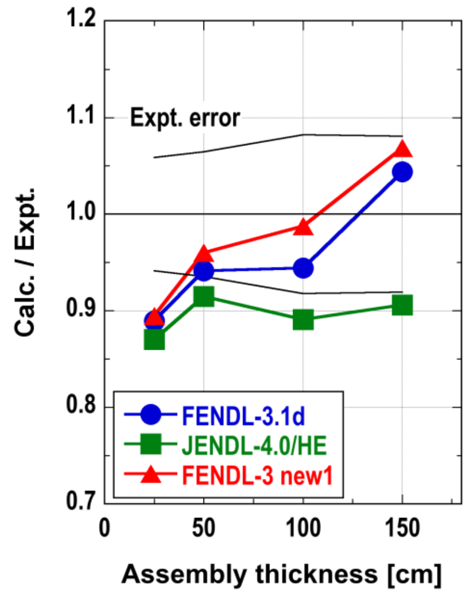
- **Continuous region:** Although the calculated neutron flux still overestimates the experimental one with FENDL-3 new1, it is improved a little bit.
- **Peak region:** The calculated neutron flux agrees well the experimental one with FENDL-3 new1 (improved!).

Result: 65MeV (FENDL-3 new1 from Dr. Kunieda)

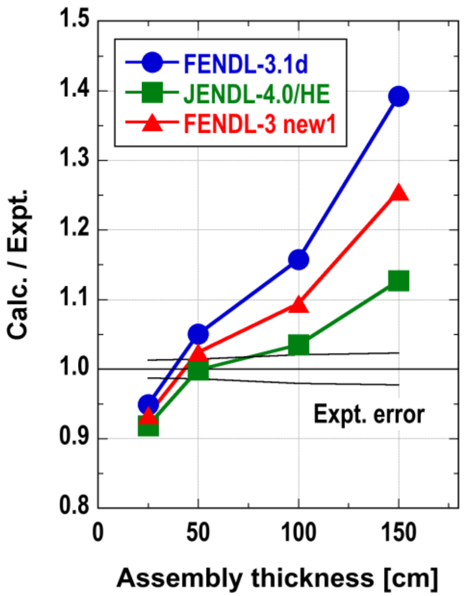
Neutron spectra in 65MeV experiment



Conti. (10 – 60MeV)



Peak (60 – 70MeV)



- **Continuous region:** The calculated neutron flux agrees well the experimental one with FENDL-3 new1.
- **Peak region:** The calculated neutron flux still overestimates the experimental one with FENDL-3 new1 (improved a little bit).

Impact of data above 20MeV

- Dr. Kunieda replaced O16 data of FENDL-3.1d with those of JENDL-4.0/HE over 30MeV (FENDL-3 new1).
- The effects of the above modification are slightly different those by Dr. Konno (Fusion Eng. Des. 98-99 (2015) 2178).
- The difference between the data modified by Kunieda and Konno is the energy region (Kunieda: over 30MeV, Konno: over 20MeV)
- In order to clarify an impact of data between 20 and 30MeV, we modified the Kunieda's O16 data (O16 new2); the data above 20 MeV were replaced with those in JENDL-4.0/HE.
  - Library:

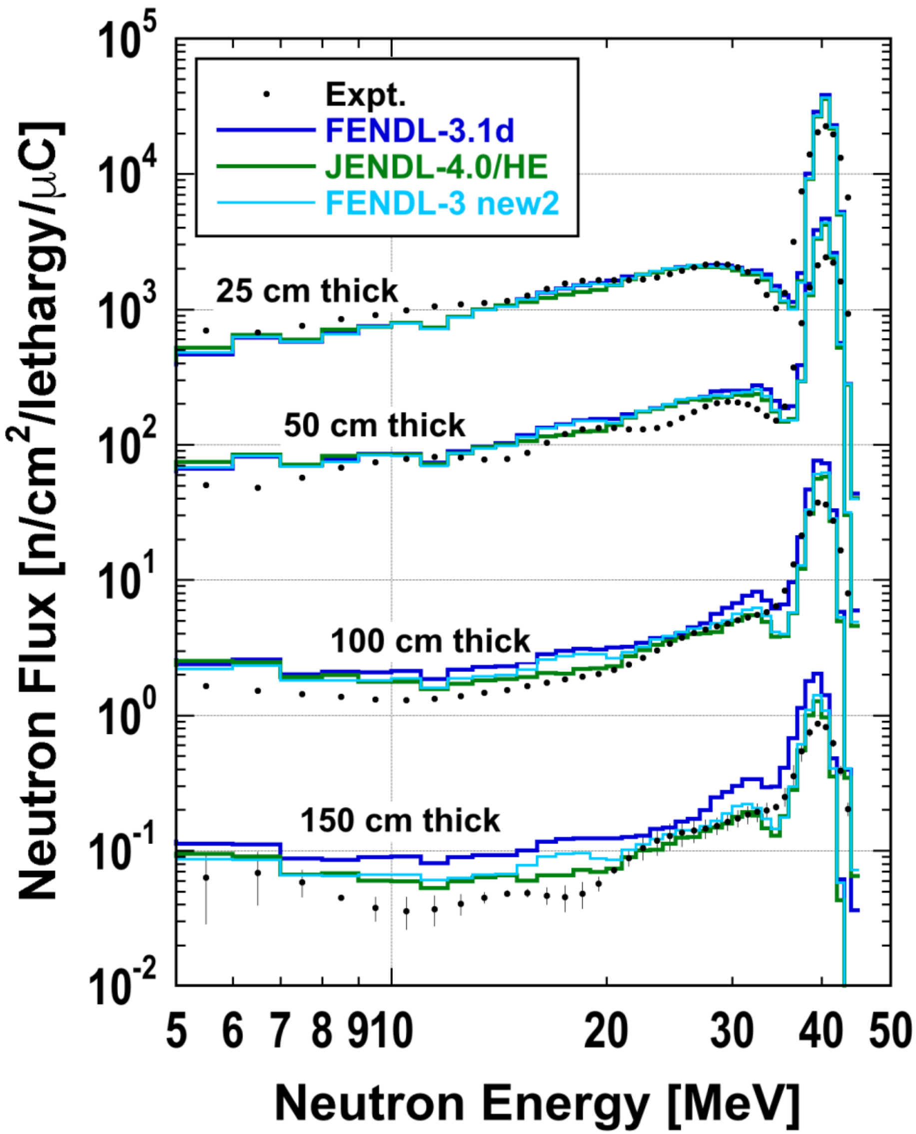
    FENDL-3 new2:

    O16 new 2 (Processed with NJOY2016)

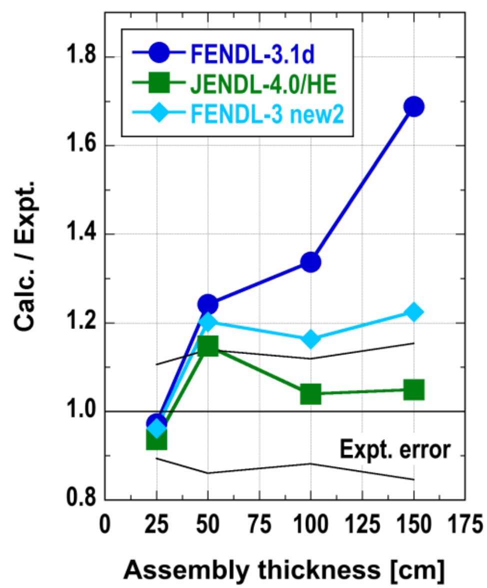
    others FENDL-3.1d (Official ACE file)

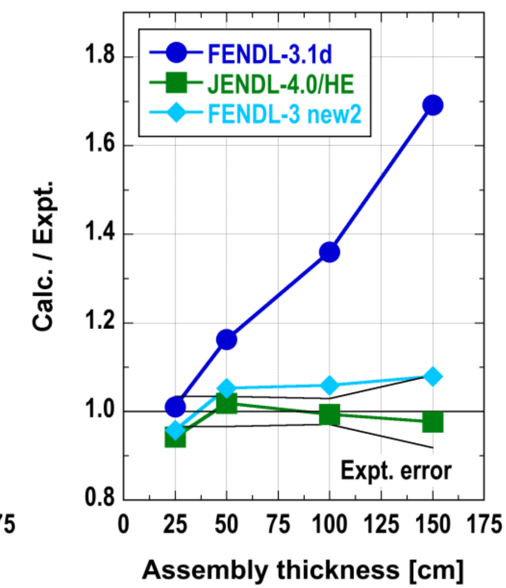
Result: 40MeV (FENDL-3 new2)

Neutron spectra in 40MeV experiment



Conti. (10 – 35MeV) | Peak (35 – 45MeV)

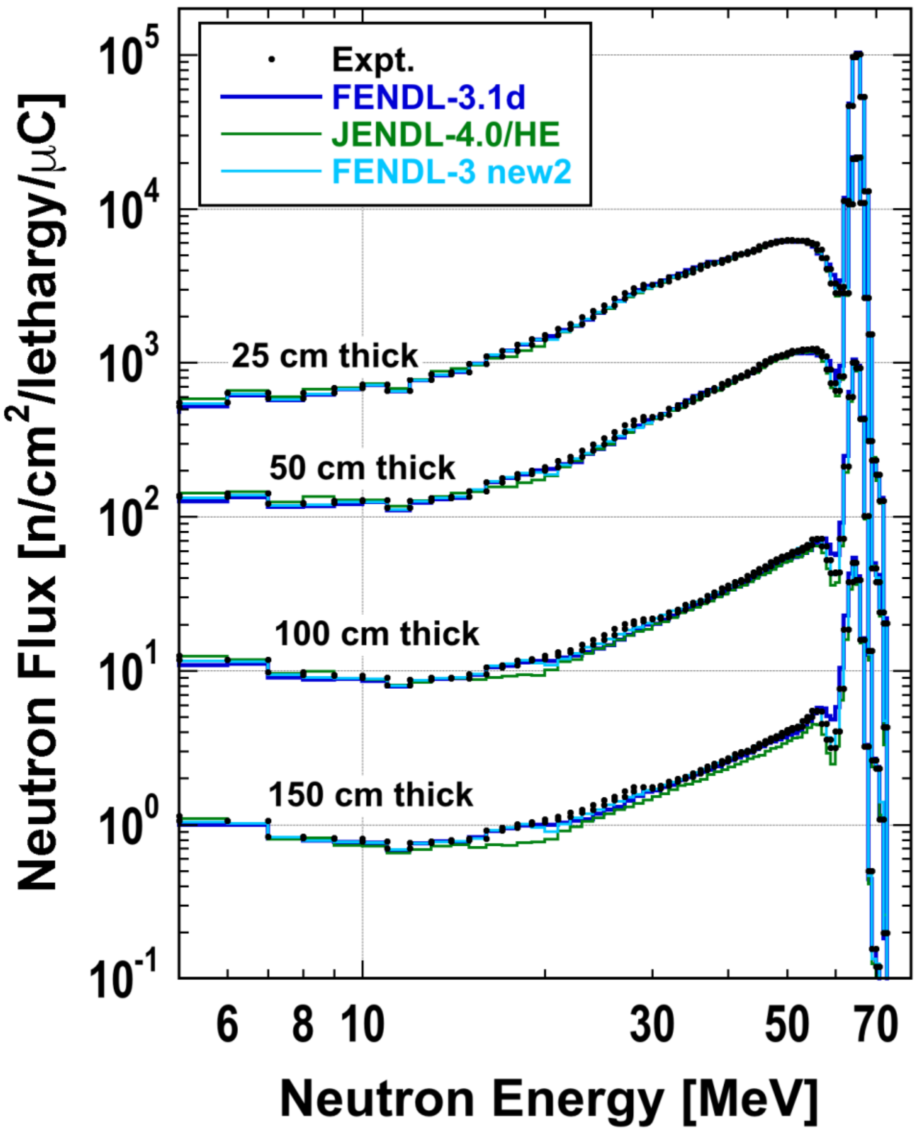




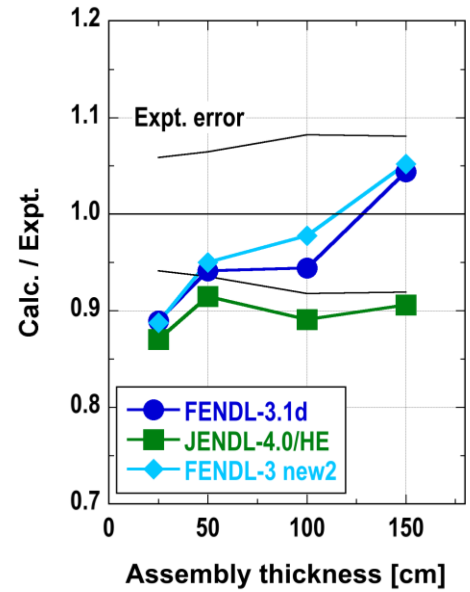
- **Continuous region:** Although the calculated neutron flux still overestimates the experimental one with FENDL-3 new2, it is improved.
- **Peak region:** The calculated neutron flux agrees well the experimental one with FENDL-3 new2 (improved!).

Result: 65MeV (FENDL-3 new2)

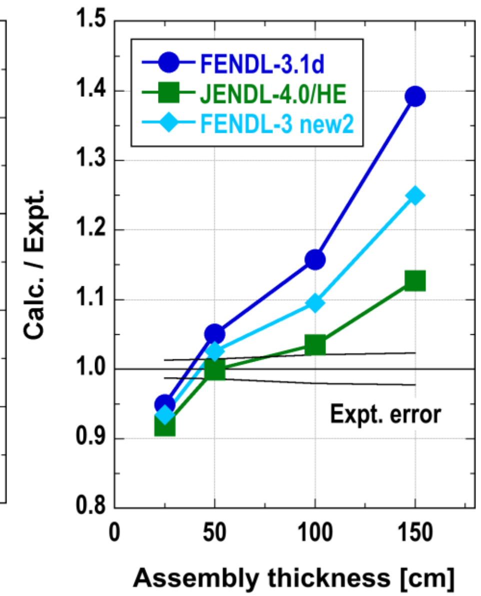
Neutron spectra in 65MeV experiment



Conti. (10 – 60MeV)



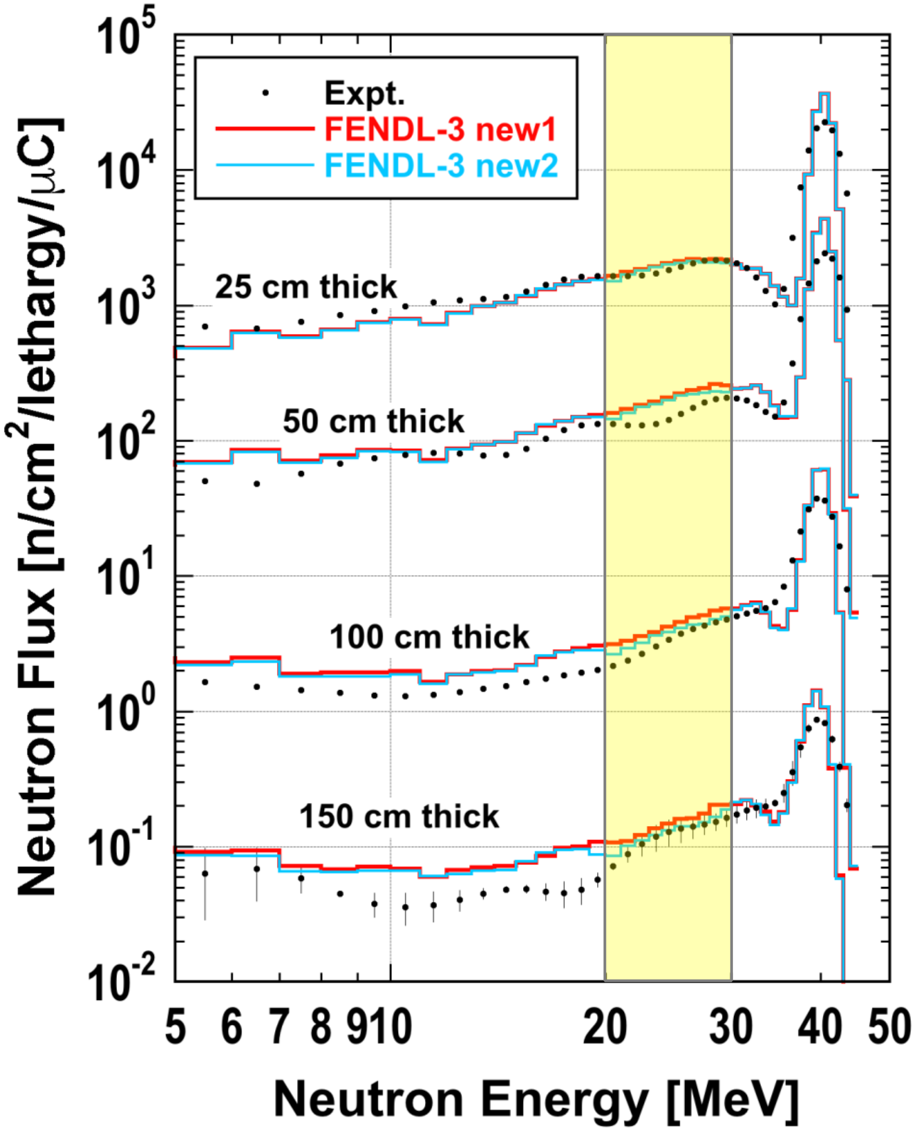
Peak (60 – 70MeV)



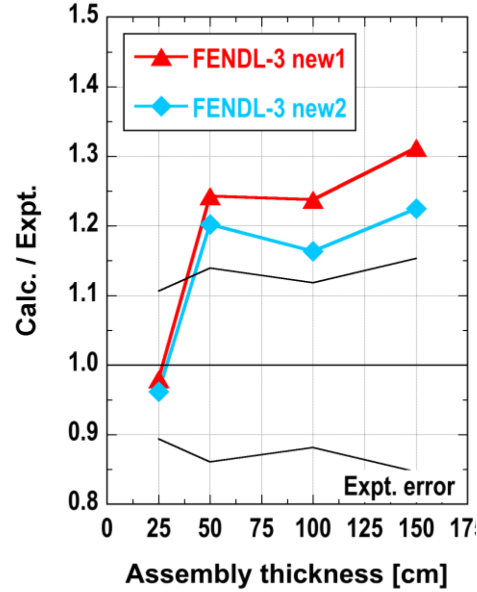
- **<u>Continuous region:</u>** The calculated neutron flux agrees well the experimental one with FENDL-3 new2.
- **<u>Peak region</u>:** The calculated neutron flux still overestimates the experimental one with FENDL-3 new2 (improved a little bit).

Impact of data between 20 and 30MeV

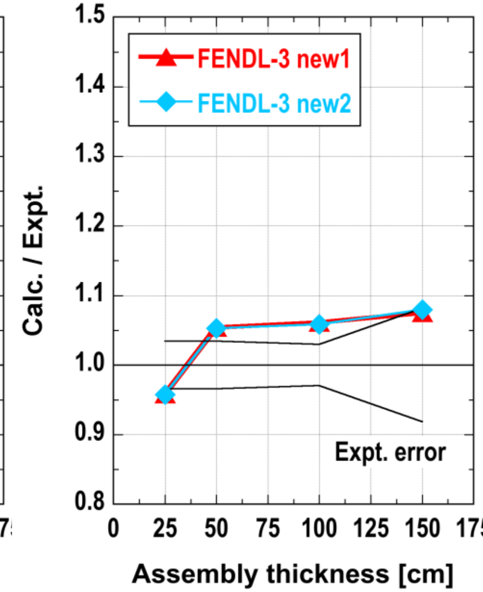
Neutron spectra in 40MeV experiment



Conti. (10 – 35MeV)



Peak (35 – 45MeV)



- **<u>Continuous region:</u>** The calculated neutron flux using FENDL-3 new2 is better than that of FENDL new1.
- **<u>Peak region</u>:** The calculated neutron fluxes using FENDL-3 new1 and 2 are almost the same.

→ The data between 20 and 30MeV in FENDL-3.1d should be replaced with JENDL-4.0/HE.

Concluding remarks

- **The analyses of QST/TIARA concrete shielding experiments affirm that the new O16 data from Dr. kunieda is better than FENDL-3.1d O16 (the same as those of ENDF/B-VII).**
- **We affirm that our new O16 data is also better than FENDL-3.1d O16.**

- **The O16 data over 20MeV in FENDL-3.1d should be replaced with those in JENDL-4.0/HE.**
- **The two new O16 data will be candidates for those in the FENDL-4.**

Problems on neutron production data of deuteron-induced files in TENDL-2017

Saerom Kwon[1]

Contributor: Chikara Konno[2]

[1]National Institutes for Quantum and Radiological Science and Technology (QST)
[2]Japan Atomic Energy Agency (JAEA)

Introduction

- **A-FNS is a fusion neutron source for irradiation tests of fusion materials, and it is similar to IFMIF/DONES in Europe.**
- **A-FNS produces fusion-like neutrons by the Li(d,xn) reaction (E_d=40MeV).**
- **Design activity of A-FNS in Japan is ongoing.**
- **Neutronics analyses of A-FNS have been carried out with Monte Carlo code and FENDL-3.1d (neutron-induced).**
- **In the near future, we will use deuteron-induced nuclear data for the analyses.**
- **Candidates of the deuteron-induced nuclear data are FENDL-3.1d, new JENDL file (release soon) and TENDL-2017.**

Purpose

[1] K.L.Paaren&H.K.Lee, Applied Radiation and Isotopes 146 (2019) 104-114
<Official HP of TENDL-2017>https://tendl.web.psi.ch/tendl_2017/tendl2017.html

- Charged particles-induced files (p, d, t, He3, α up to 200MeV) in TENDL-2017 was released on Dec. 30, 2017.
- ONE nuclide has 3 kinds of ENDF files as the following description:

Evaluated formatted data (i.e. ENDF)
1. The TENDF file (Evaluated Nuclear Data File, explicit channels up to 30 MeV, then MF6/MT5 up to 200 MeV)
2. Special ENDF file (all explicit channels up to 200 MeV)
3. Another special ENDF file (all channels in MF6/MT5 from 0 to 200 MeV)

- There is only official ACE file from "the TENDF file" in TENDL-2017.
- Up to TENDL-2015, the TENDL libraries have only the file corresponding to "Another special ENDF file" of TENDL-2017.
- Recently, K.L.Paaren et al. reported that "The TENDF file" of ^{9}Be in the α-induced files of TENDL-2017 produced strange neutron spectra, while "Another special ENDF file" produced reasonable neutron spectra[1].
- The THREE files must be consistent.

…But they are NOT!

➢ **We investigate whether the deuteron-induced files in TENDL-2017 have the similar problem with the α-induced files or not.**

Method 1

- In order to investigate the three ENDF files of ^{9}Be in TENDL-2017, they are downloaded from the official TENDL-2017 web page.
- Make ACE files of “The TENDF file”, “Special ENDF file” and “Another special ENDF file” of ^{9}Be using NJOY2016.49.mod.
- Extract and compare neutron production cross sections and secondary neutron energy distributions from NJOY outputs of the three ENDF files (no ACE format information for neutron production)

WHY is ^{9}Be first?
→ The TENDF files from H to Li are not calculated with TALYS but taken from ENDF/B-VII.1.

Due to bug of NJOY:
→ MCNP calculations do not finish or produce neutrons when the official ACE file (processed from “The TENDF file”) are used.

Modify NJOY2016.49:
→ **See the next slide**

Strange NJOY output of the TENDF file

QST

- **We found out strange data in the NJOY output of the TENDF file.**
- **No such data in the NJOY outputs of the Special ENDF file and Another special ENDF file.**

reaction descriptors

	reaction	mt	tyr	lsig	land	ldlw	emin	emax	q
	elastic	2			1		1.000000E-11	2.000000E+02	
1	(d,x)	5	-101	1	-1	49	2.999999E+01	2.000000E+02	0.000000E+00
2	(d,n*)d	32	-1	35	-1	10994	2.036442E+00	2.000000E+02	-1.664540E+00
3	inelastic	104	-1	132	-1	15115	2.060250E+00	2.000000E+02	-1.684000E+00
4	(d,pd)	115	-1	226	-1	17866	2.065920E+01	2.000000E+02	-1.688630E+01
5	(d,da)	117	-1	272	-1	18825	2.823290E+00	2.000000E+02	-2.307690E+00
6	(d,n)	4	0	359	-1	20548	1.000000E-11	2.000000E+02	4.362160E+00
7	(d,2n)	16	0	1011			4.		
8	(d,3n)	17	0	1091			2.		
9	(d,n*)a	22	0	1128			2.		
10	(d,2n)a	24	0	1268			7.		
11	(d,n*)p	28	0	1342			2.		
12	(d,n*)t	33	0	1430			1.		
13	(d,n*)he3	34	0	1483			1.		
14	(d,2np)	41	0	1539			4.		
15	(d,gma)	102	0	1620			1.		
16	(d,p)	103	0	2272			1.		
17	(d,t)	105	0	2924			1.		
18	(d,he3)	106	0	3576			1.		
19	(d,a)	107	0	3641			1.		
20	(d,2a)	108	0	4293			6.		
21	(d,2p)	111	0	4370			1.		
22	(d,pa)	112	0	4420			3.		
23	(d,pt)	116	0	4504			1.		
24	(d,xp)	203	0	4563			1.000000E-11	2.000000E+02	0.000000E+00
25	(d,xd)	204	0	5215			2.036442E+00	2.000000E+02	0.000000E+00
26	(d,xt)	205	0	5312			1.000000E-11	2.000000E+02	0.000000E+00
27	(d,xhe3)	206	0	5964			1.393830E+01	2.000000E+02	0.000000E+00
28	(d,xa)	207	0	6029			1.000000E-11	2.000000E+02	0.000000E+00
29	^@^@^@^@^@^@^@^@^@^@		0	0	0		1.043467-320	2.800000E+01	0.000000E+00

mt=11 (d,2nd)

???

Although there is no cross section data of mt=11 (d,2nd), secondary deuteron data of mt=11 exists.

We investigated NJOY2016.49 in detail.

Modify NJOY2016.49

- **We found out that the mt=11 data was not processed adequately in acefc.f90 of NJOY2016.49.**
- **We added "mt.eq.11" to line 5297 in acefc.f90.**

from

```
        if(mt.eq.2.or.mt.eq.32.or.mt.eq.35.or.&
```

to

```
    if(mt.eq.2.or.mt.eq.11.or.mt.eq.32.or.mt.eq.35.or.&
```

- **We compiled the modified acefc.f90, "NJOY2016.49.mod".**
- **We produced a new ACE file of the TENDF file with NJOY2016.49.mod.**

The bug is fixed!

QST

- **The NJOY output of the TENDF file seems normal using the modified NJOY.**

reaction descriptors

reaction	mt	tyr	lsig	land	ldlw	emin	emax	q
elastic	2			1		1.000000E-11	2.000000E+02	
(d,x)	5	-101				.999999E+01	2.000000E+02	0.000000E+00
(d,2nd)	11	-1				.515756E+01	2.000000E+02	-2.056320E+01
(d,n*)d	32	-1				.036442E+00	2.000000E+02	-1.664540E+00
inelastic	104	-1	173	-1	15646	2.060250E+00	2.000000E+02	-1.684000E+00
(d,pd)	115	-1	267	-1	18397	2.065920E+01	2.000000E+02	-1.688630E+01
(d,da)	117	-1	313	-1	19356	2.823290E+00	2.000000E+02	-2.307690E+00
(d,n)	4	0	400			1.000000E-11	2.000000E+02	4.362160E+00
(d,2n)	16	0	1052			4.985412E+00	2.000000E+02	-4.074960E+00
(d,3n)	17	0	1132			2.771231E+01	2.000000E+02	-2.265140E+01
(d,n*)a	22	0	1169			2.275022E-01	2.000000E+02	-1.859550E-01
(d,2n)a	24	0	1309			7.049710E+00	2.000000E+02	-5.762270E+00

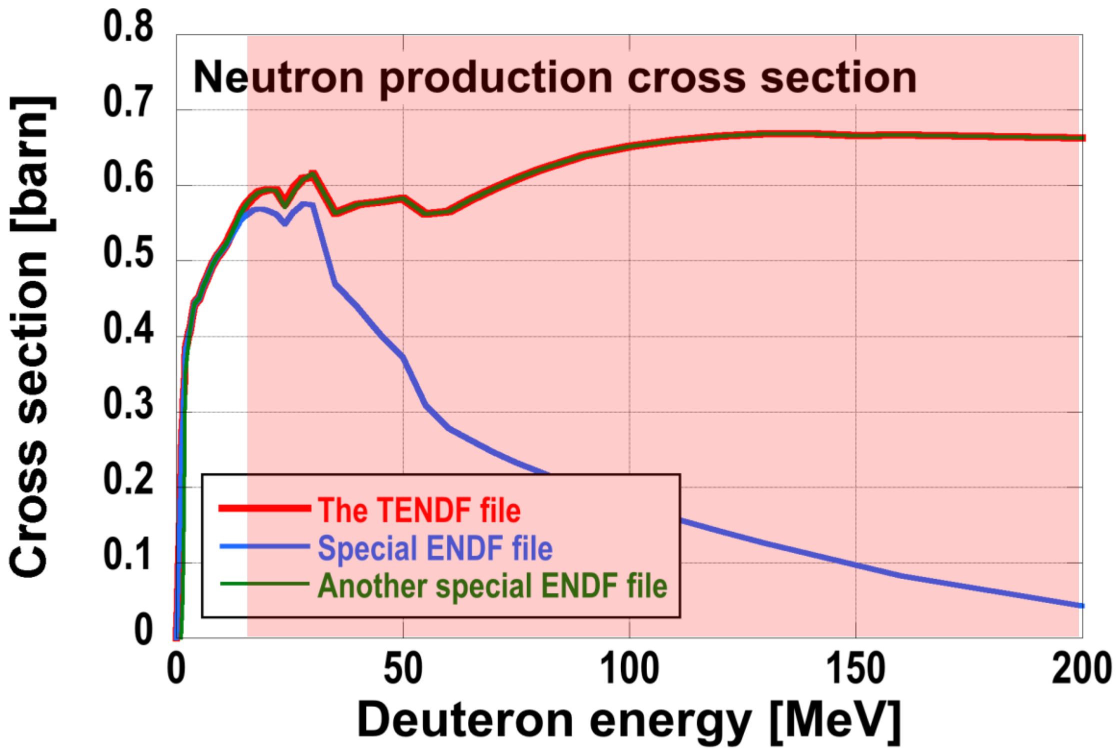
mt=11 exists!

omitted below…

- **MCNP calculations finished and produced neutrons without any troubles using the newly processed ACE file.**

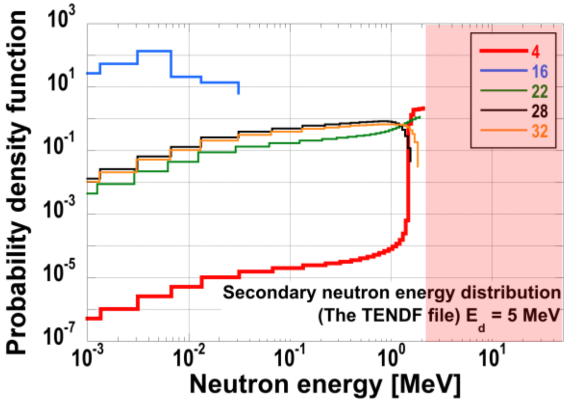
- **The official deuteron-induced ACE files of TENDL-2017 with mt=11 should be replaced with those using the "bug-fixed NJOY", NJOY2016.49.mod.**

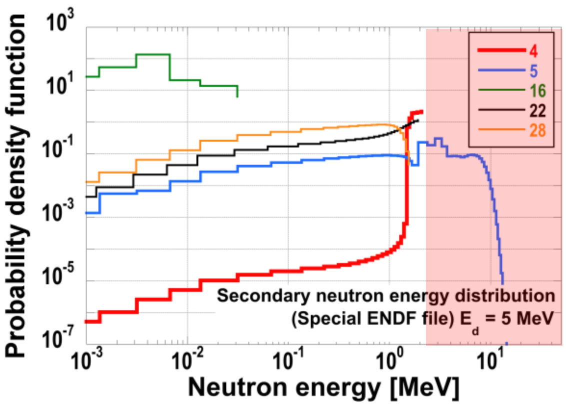
Neutron production xs of ^{9}Be

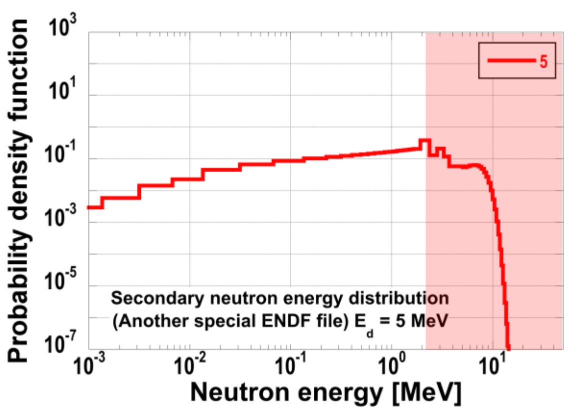


- Neutron production cross section of **Special ENDF file** **differs markedly** from those of The TENDF file and Another special ENDF file.

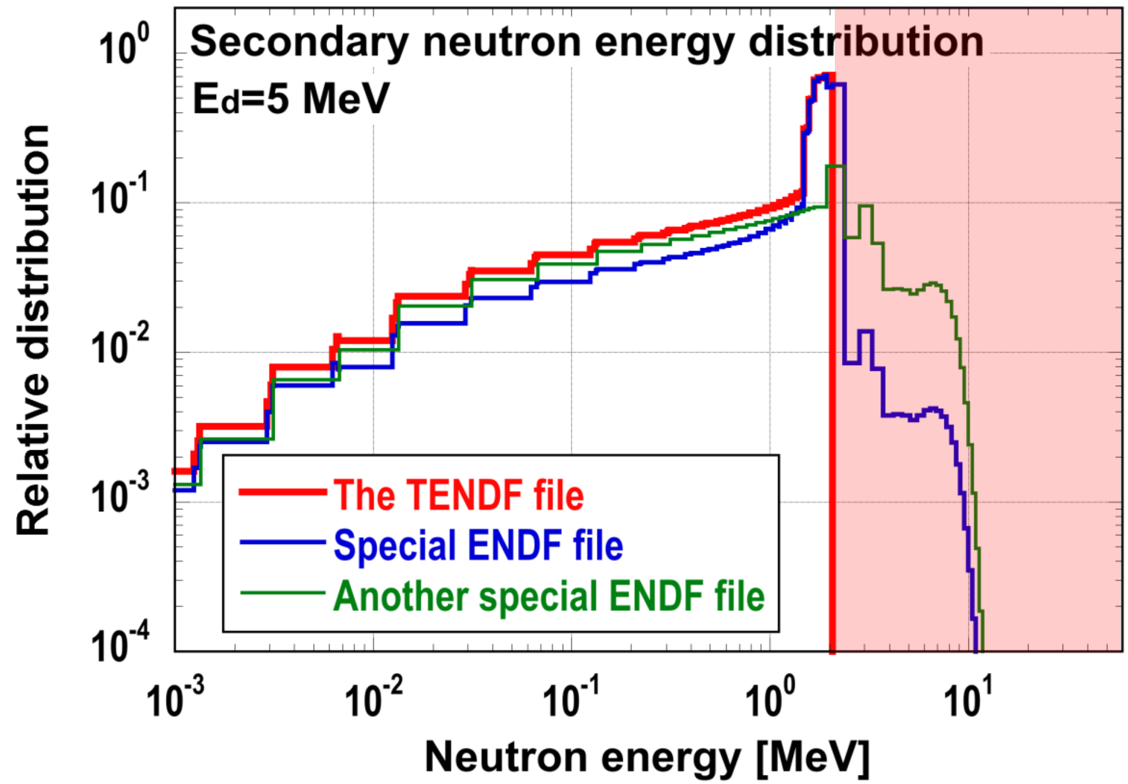
Secondary neutron energy distribution of ^{9}Be (E_d=5MeV)





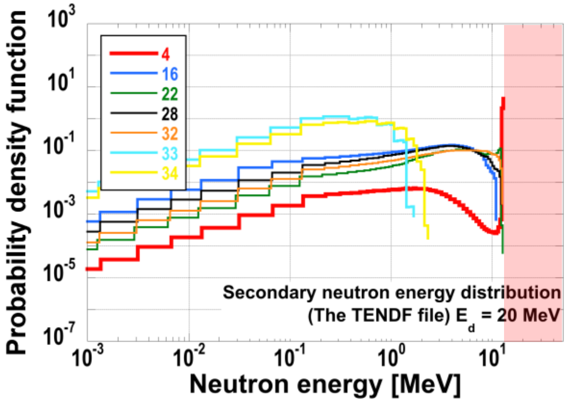


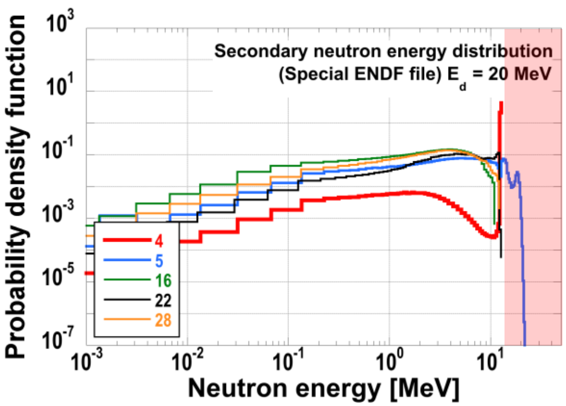
A summation with following item of each reactions:
Secondary neutron spectrum * Neutron yield * xs

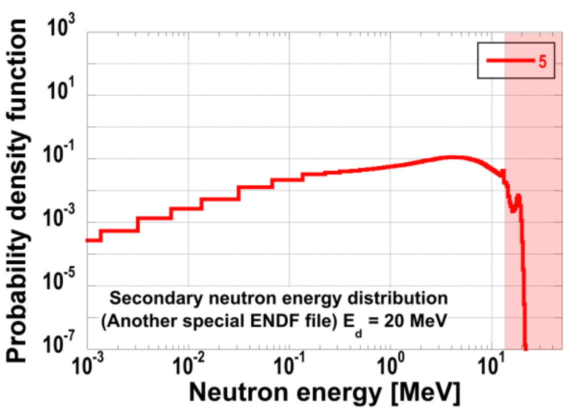


- **No neutrons above 2MeV** in the TENDF file.
- Others have mt=5 data above 2MeV.

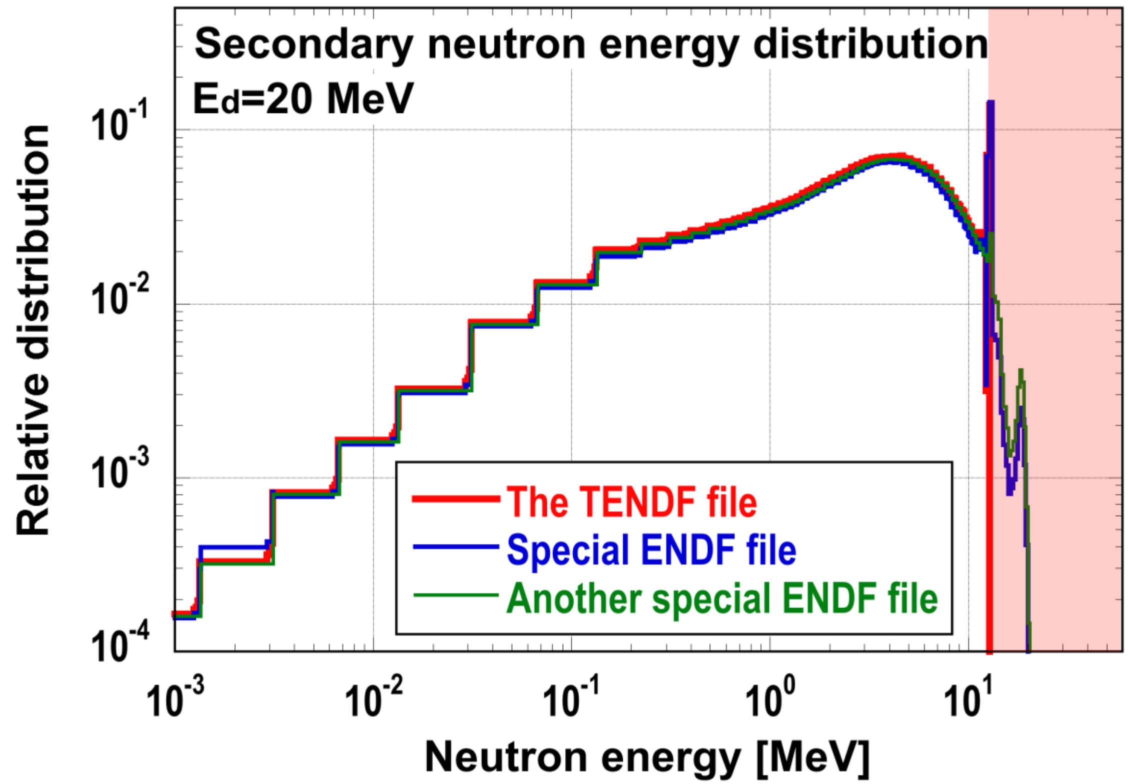
Secondary neutron energy distribution of ^{9}Be (E_d=20MeV)







A summation with following item of each reactions:
Secondary neutron spectrum * Neutron yield * xs



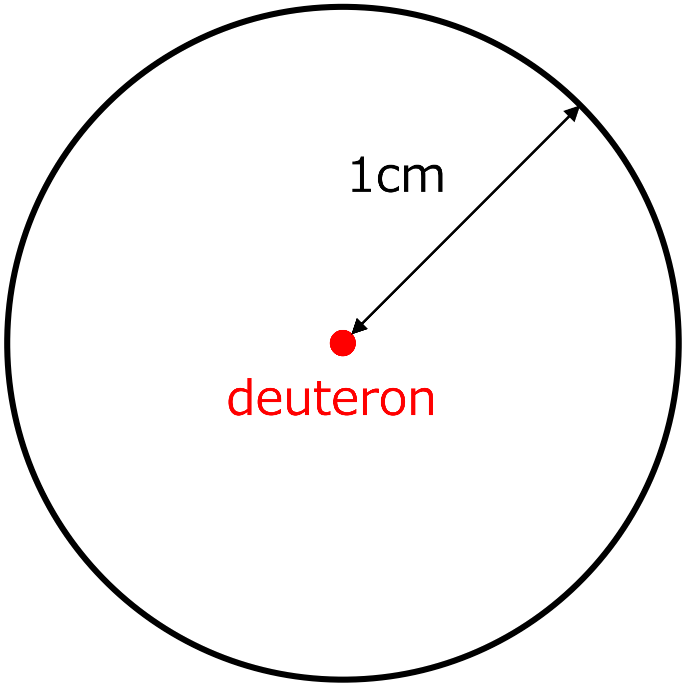
- **No neutrons above 12MeV** in the TENDF file.
- Others have mt=5 data above 12MeV.

Method 2

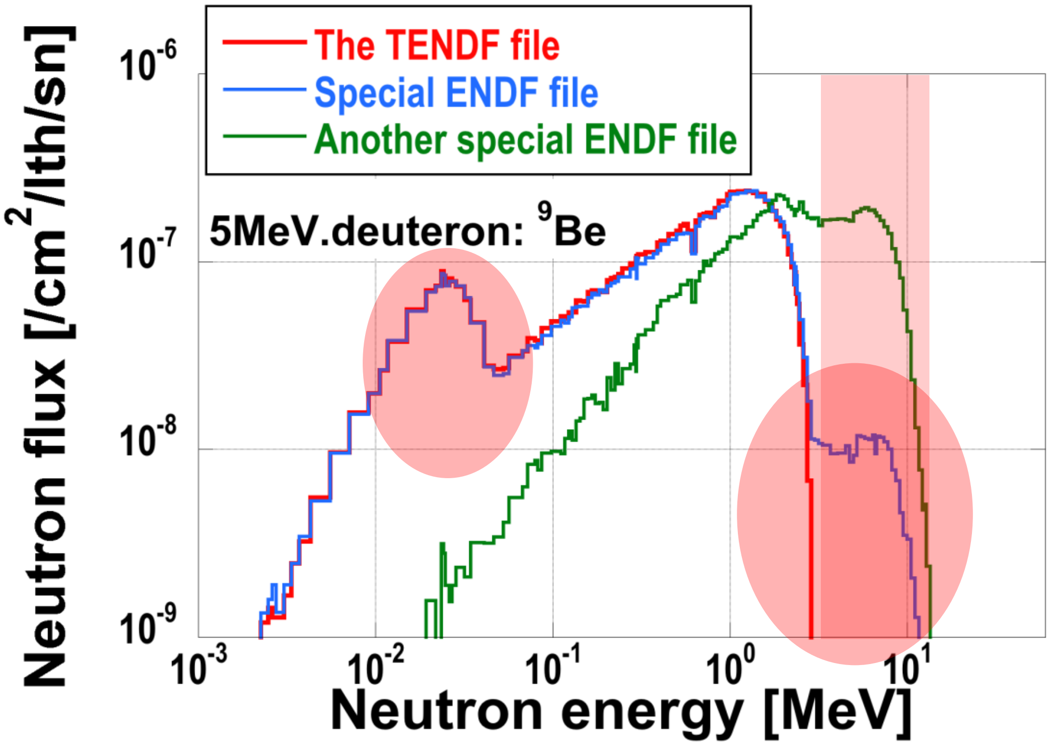
- We found out that neutron production cross section and secondary neutron energy distribution data of the TENDF file, Special ENDF file and Another special ENDF file have large differences each other.
- We calculated neutron spectra with a virtual model and MCNP6 to examine effects of the differences.

<Calculation condition>

- Beryllium sphere of radius 1cm
- Isotropic 5MeV, 20MeV, 40MeV, 50MeV deuterons in the center
- ACE files (The TENDF file, Special ENDF file and Another special ENDF file) processed by ourselves using NJOY2016.49.mod
- Calculate leakage neutron flux from Be sphere

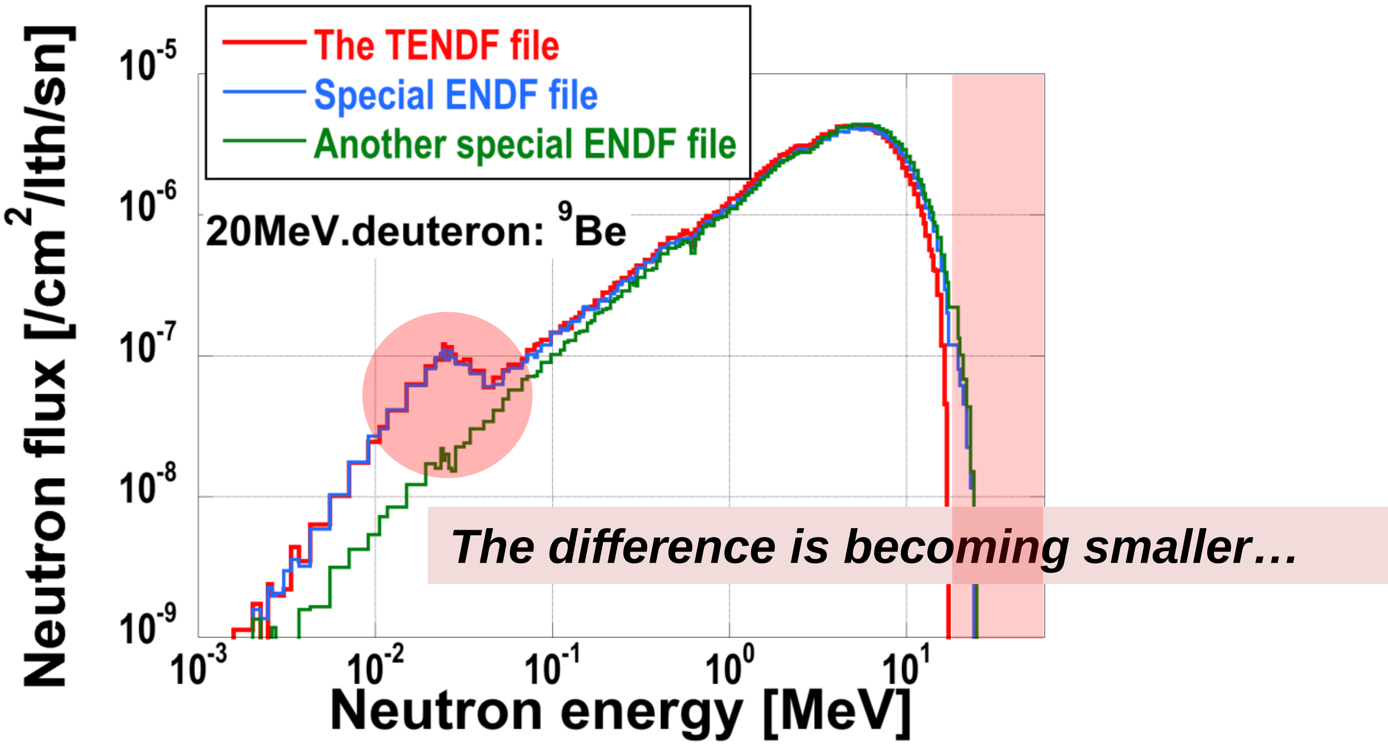


Leakage neutron flux from Be sphere (E_d=5MeV)



- Upper energy limit of calculated neutron spectra using the TENDF file and Special ENDF file is small.
- Calculated neutron spectra using the TENDF file and Special ENDF file have an unnatural peak near 30keV.
- Calculated neutron spectrum using Special ENDF file has unphysical neutron flux over 3MeV.

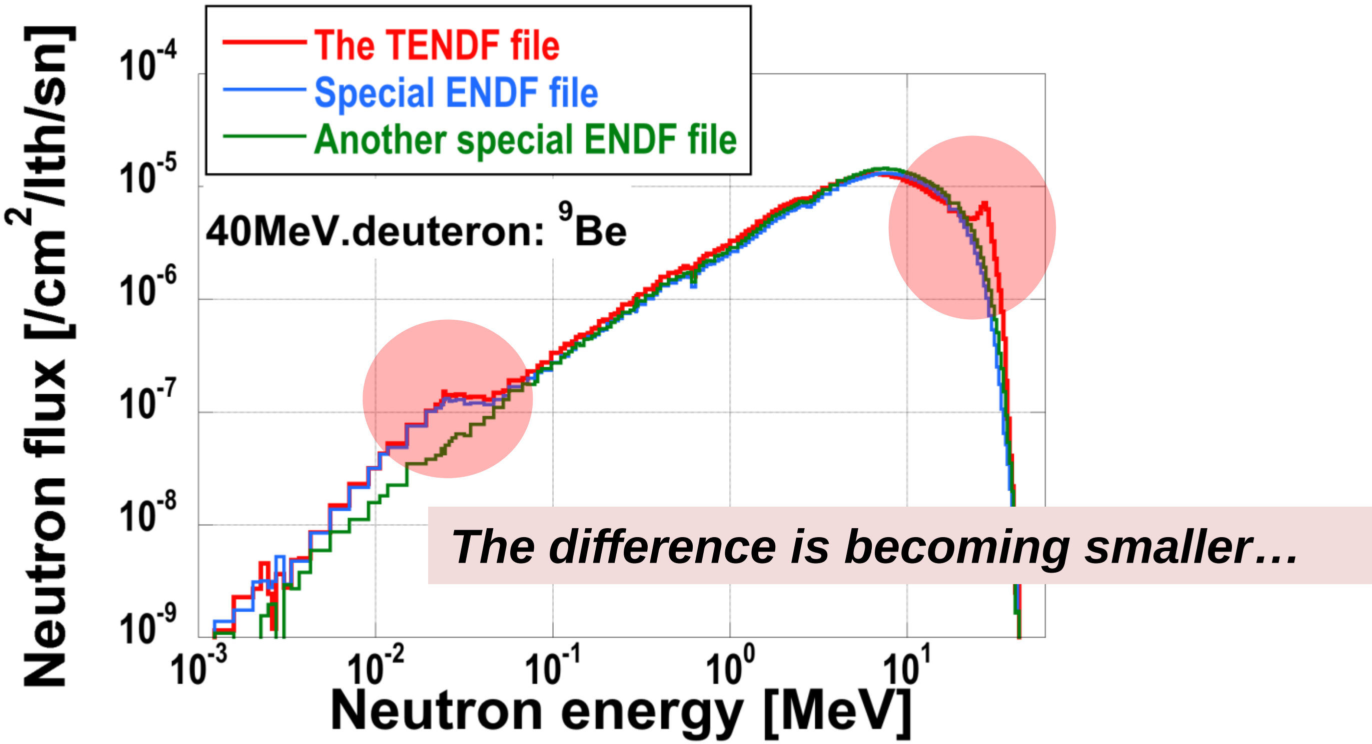
Leakage neutron flux from Be sphere (E_d=20MeV)



- Upper energy limit of calculated neutron spectrum using the TENDF file is small.

- Calculated neutron spectra using the TENDF file and Special ENDF file still have the unnatural peak near 30keV.

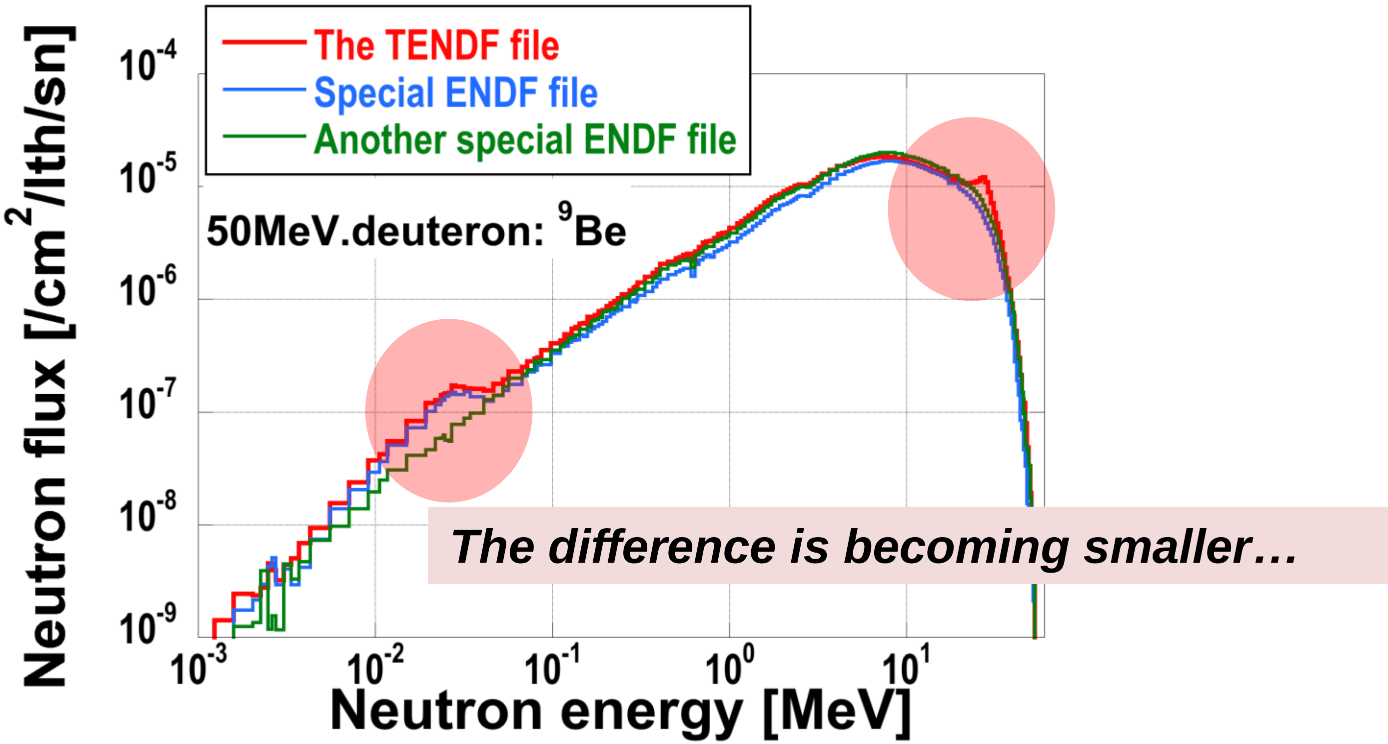
Leakage neutron flux from Be sphere (E_d=40MeV)



- Calculated neutron spectra using the TENDF file and Special ENDF file still have the unnatural peak near 30keV.

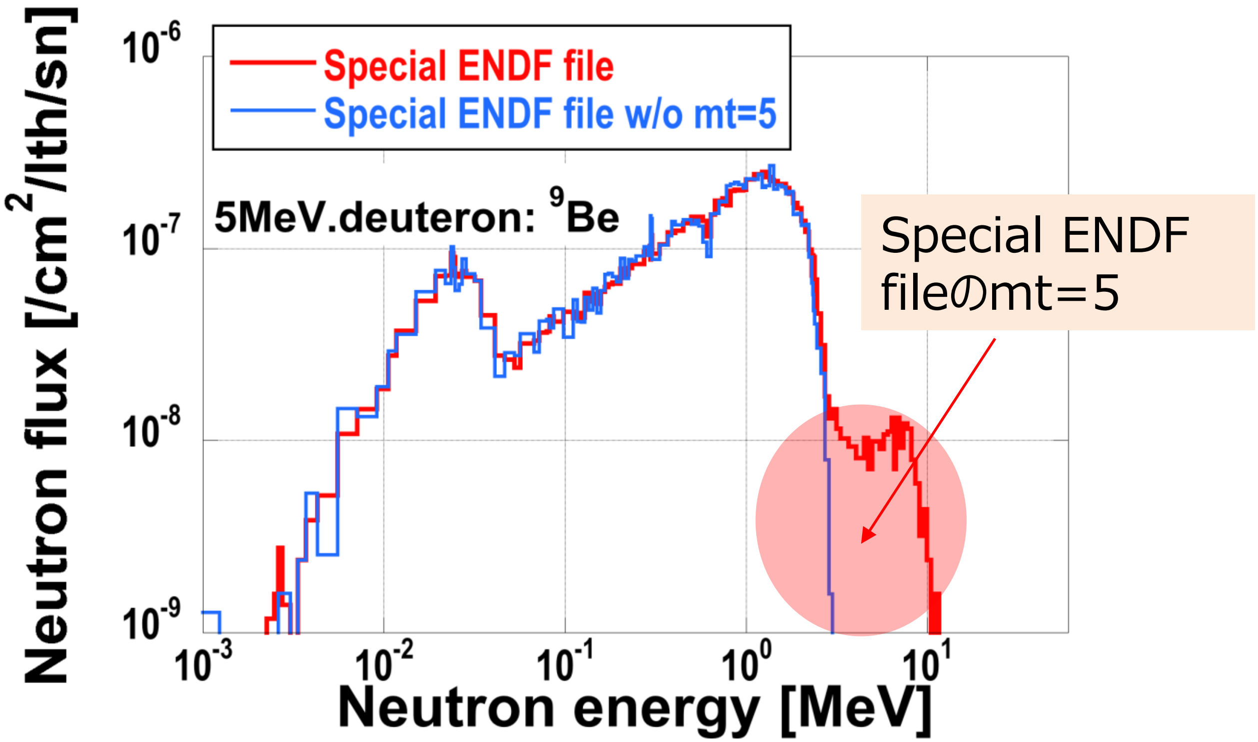
- Calculated neutron spectrum using the TENDF file has a small peak near 30MeV (Never seen up to 30MeV of deuteron energy).

Leakage neutron flux from Be sphere (E_d=50MeV)



- Calculated neutron spectra using the TENDF file and Special ENDF file still have the unnatural peak near 30keV.
- Calculated neutron spectrum using Special ENDF file is smaller than those using other files. → Due to small neutron production cross section!
- Calculated neutron spectrum using the TENDF file has the small peak near 30MeV.

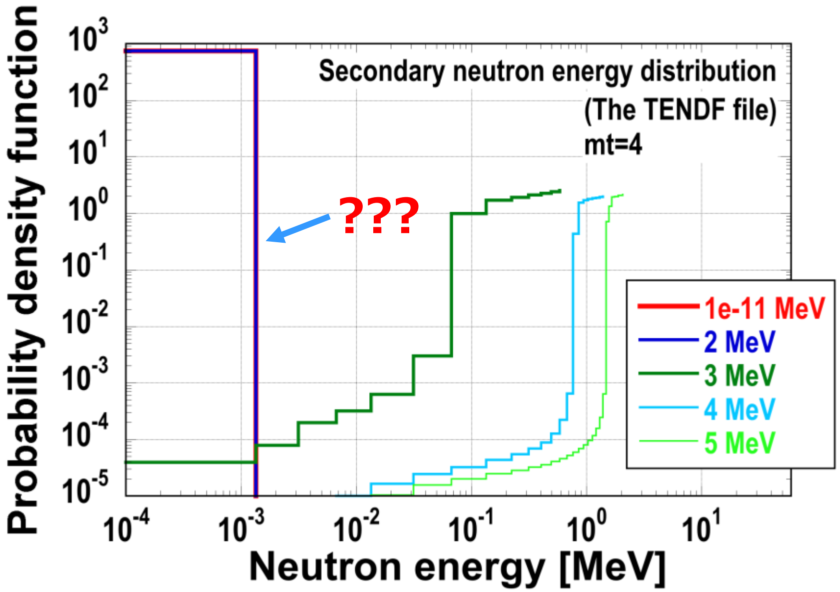
Reason of difference in neutron spectra (1)

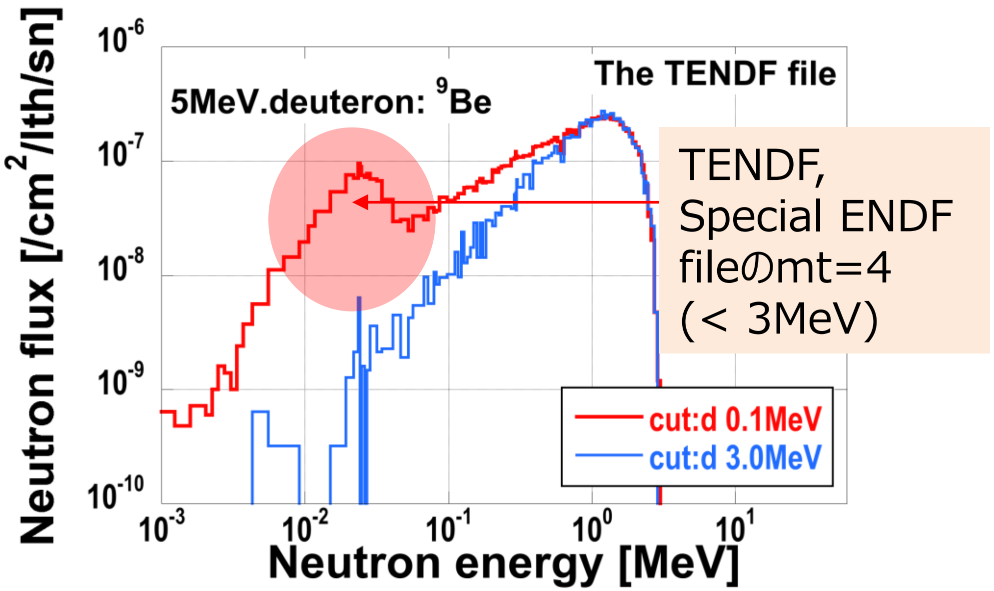


- We prepared modified ACE file of Special ENDF file where mt=5 data was deleted.
- Calculated neutron spectrum using the modified ACE file has no neutron flux over 3MeV.

→ **The mt=5 data in Special ENDF file caused the unphysical neutron flux over 3MeV.**

Reason of difference in neutron spectra (2)

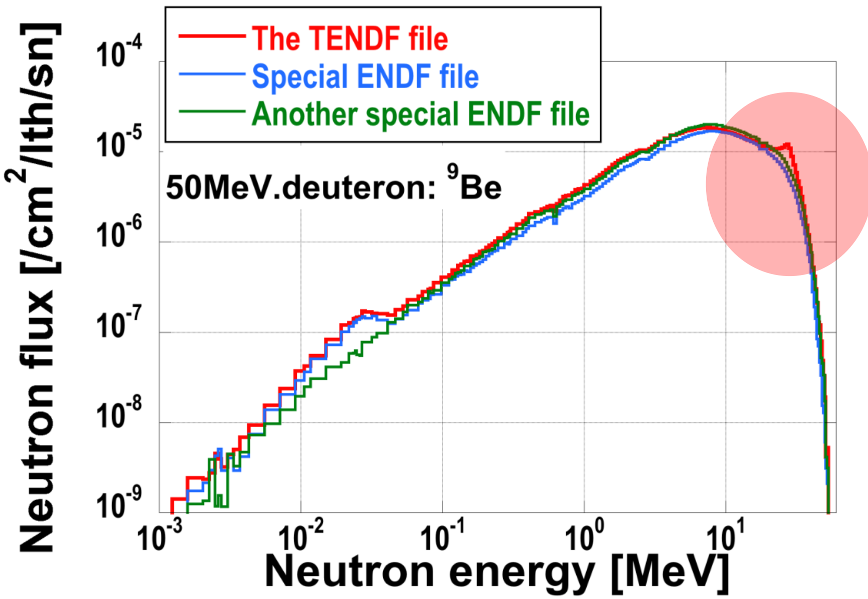




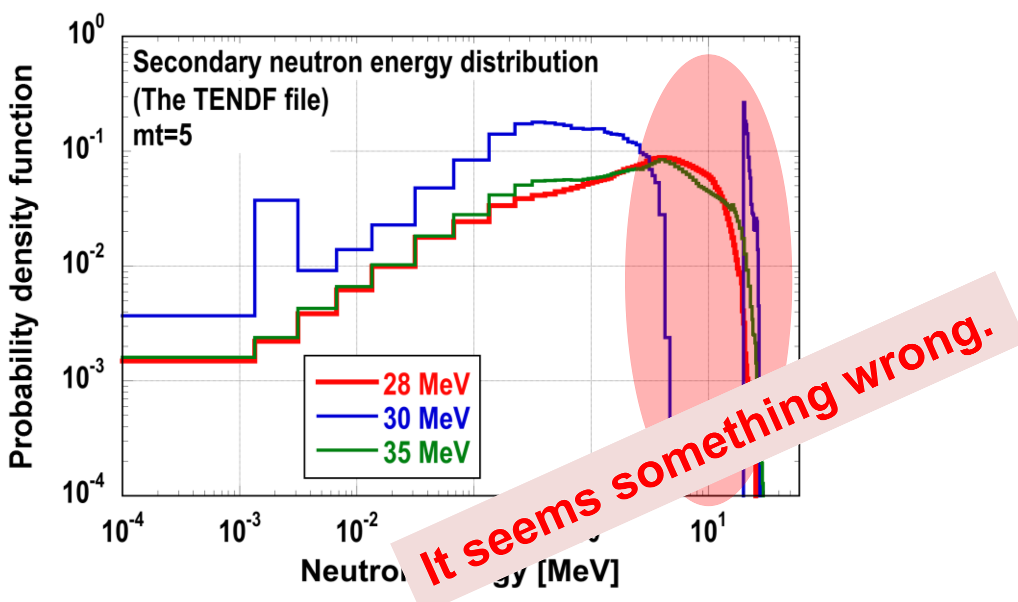
- We found out unphysically small secondary neutron energy of mt=4 data (<3MeV) in the TENDF file and Special ENDF file.
- The peak disappeared using deuteron cut off option in MCNP input (cut:d j 0.1 → cut:d j 3.0).

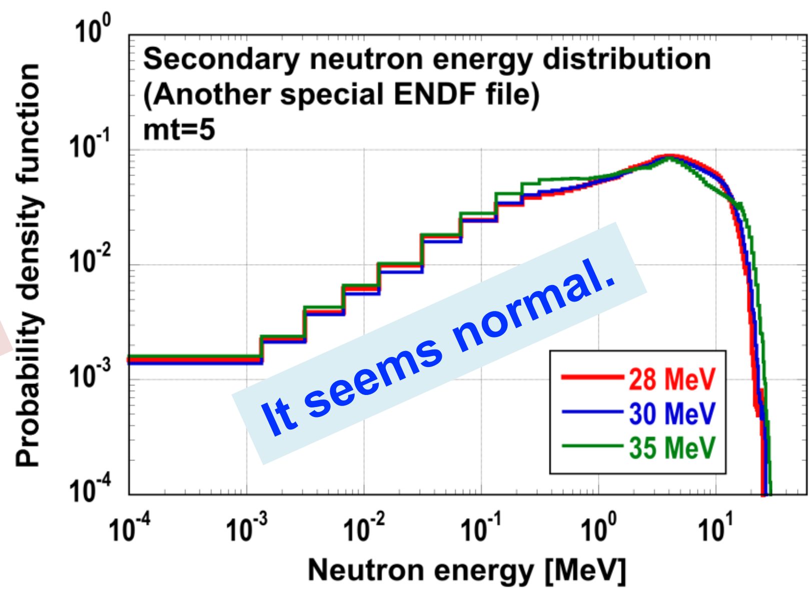
→ We figured out that the reason of unnatural peak near 30keV is small secondary neutron energy of mt=4 (<3MeV) in the TENDF file and Special ENDF file.

Reason of difference in neutron spectra (3)

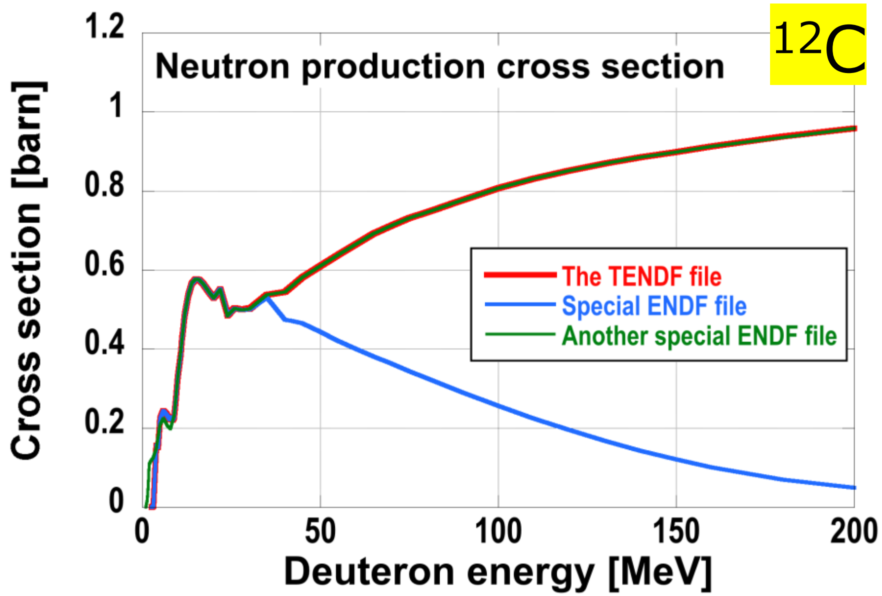


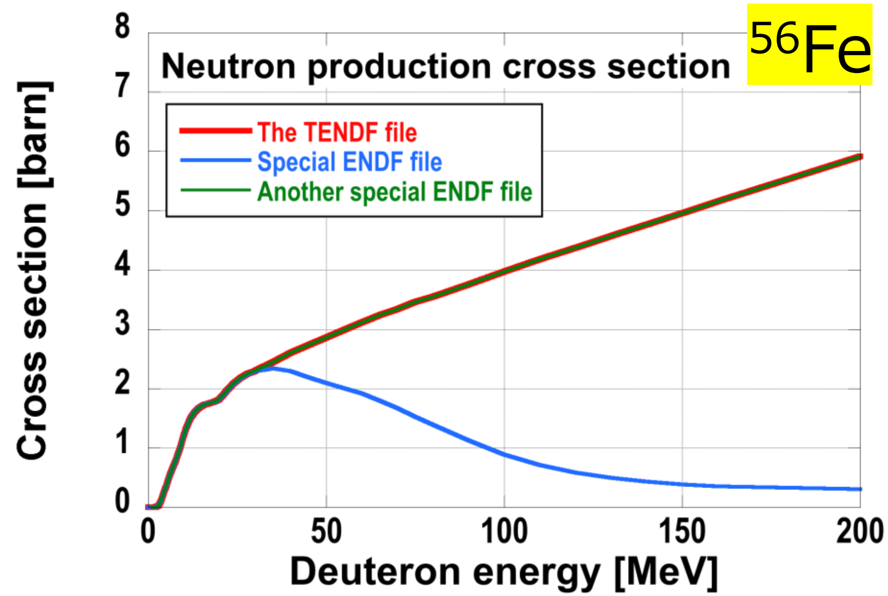
- We inferred that the small peak near 30MeV in the calculated neutron spectrum using the TENDF file from wrong secondary neutron energy distribution data at 30MeV of mt=5.
- **These results suggest that Another special ENDF file is the best in the three ENDF files.**

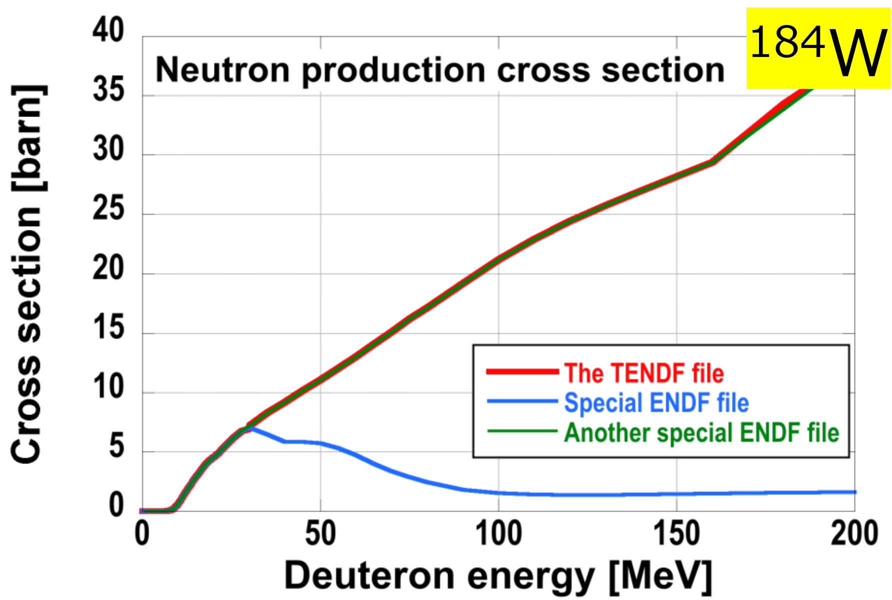




Status of other nuclides





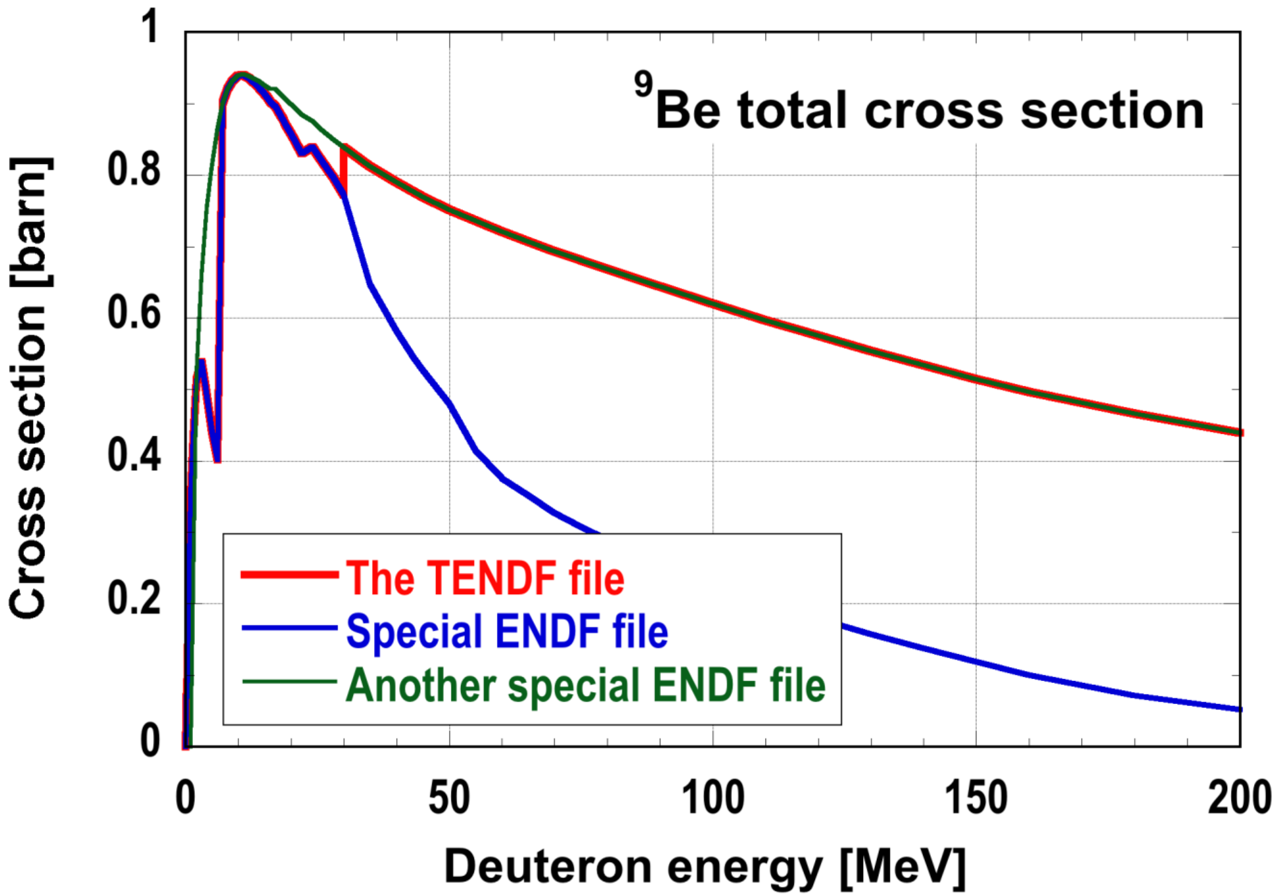


- These problems are not only in ^{9}Be data.
- Probably the same problems occur in data of other nuclei.

Concluding remarks

- **We figured out that neutron production data significantly differed among three ENDF files of ^{9}Be in TENDL-2017.**
  1) Neutron production cross section above 30 MeV in Special ENDF file differs markedly from those in the other ENDF files.
     → Special ENDF file produces smaller neutron fluxes for deuteron > 30 MeV.
  2) Wrong secondary neutron energy distribution data in the TENDF file and/or special ENDF file :
     → Broad peak near 30 keV in the calculated neutron spectrum
     → Small peak near 30 MeV in the calculated neutron spectrum
- **Another special ENDF file seems to be physically correct in the three ENDF files. Hereafter, we will validate it with experimental data (EXFOR?).**
- **Probably the same problems occur in other nuclei of TENDL-2017.**
- **The official deuteron-induced ACE files in TENDL-2017 should be revised based on our study.**

Supplementary material: Total xs of ^{9}Be



Special ENDF file:

- Total cross section over 30MeV is smaller than those of others.
- Due to including only reactions for activation calculations?

The TENDF file: a little bit strange?

Supplementary material: simple question

- Up to **TENDL-2015**, the TENDL libraries have only the file corresponding to "**Another special ENDF file**" of TENDL-2017.
- There is only **official ACE file** from "**the TENDF file**" in TENDL-2017.

- However, we found out **some problems** in data of "**the TENDF file" and its ACE file**.
- Our study suggests that "**Another special ENDF file**" is the **best** in the three ENDF files.

(Q) WHY is "the TENDF file" a default in TENDL-2017?

Prompt report

New Fe56 benchmark test with QST/TIARA iron shielding experiments for next TENDL, TENDL-2019

Saerom Kwon[1]

Contributor: Chikara Konno[2]

[1]*National Institutes for Quantum and Radiological Science and Technology (QST)*
[2]*Japan Atomic Energy Agency (JAEA)*

Note: It is forbidden to use figures and data in this slide except for the FENDL project.

Introduction

- We pointed out **strange data in TENDL-2017** at the last FENDL meeting (14-18 Oct. 2018).
- **2595 nuclei** in TENDL-2017 had **incorrect secondary neutron spectrum data at 30MeV** (among 2807 data).

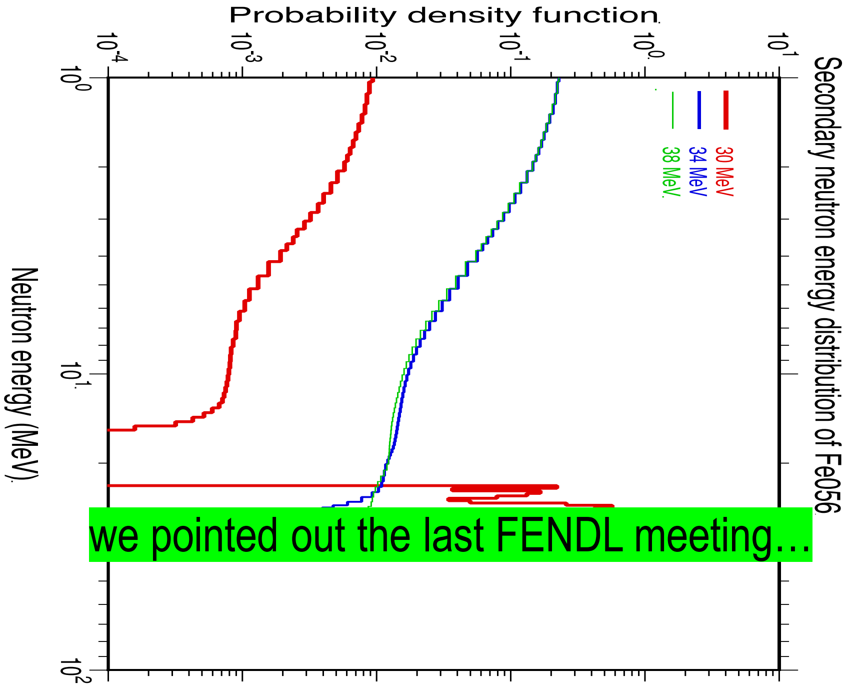
- Dr. Koning prepared **new Fe56 data for TENDL-2019** where a **format error at 30MeV was corrected**.

- Thus, we carried out a **benchmark test of the new Fe56 data** with the **QST/TIARA iron shielding experiments**.

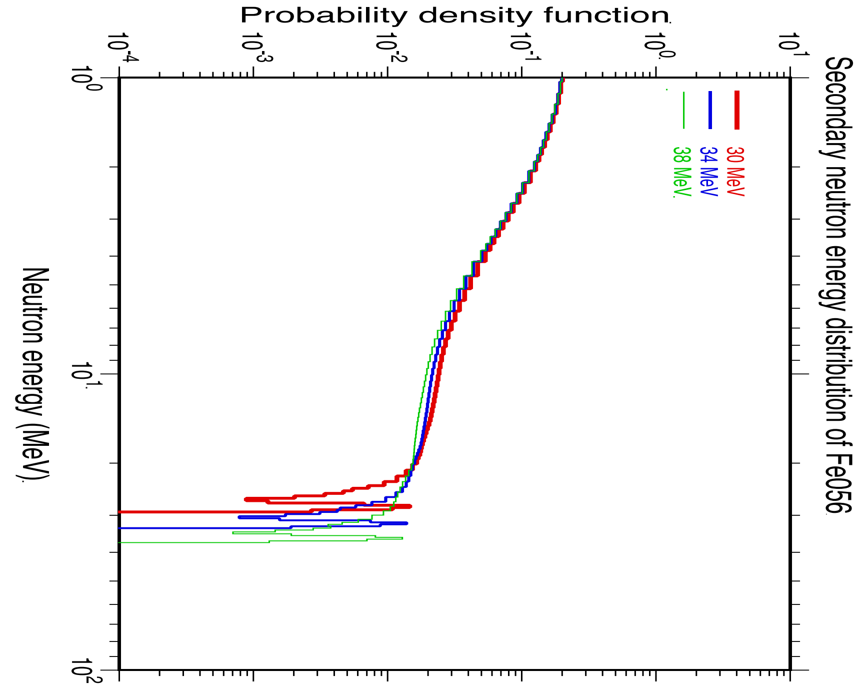
- Here the results are presented.

The format error was fixed in Fe56

TENDL-2017



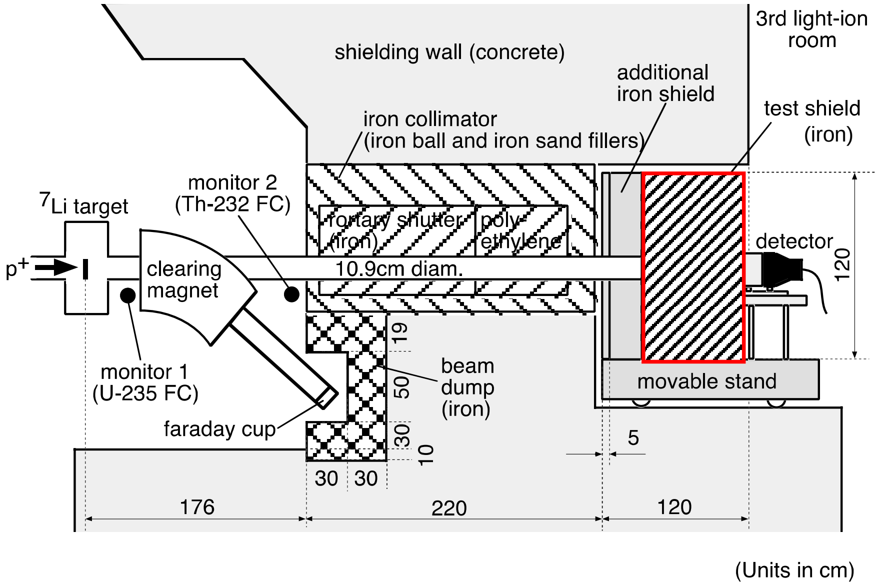
new Fe56 from Dr. Koning



- **The incorrect secondary neutron energy spectrum data in Fe56 of TENDL-2017 are corrected well in the new Fe56 data.**

Experiment & Analysis

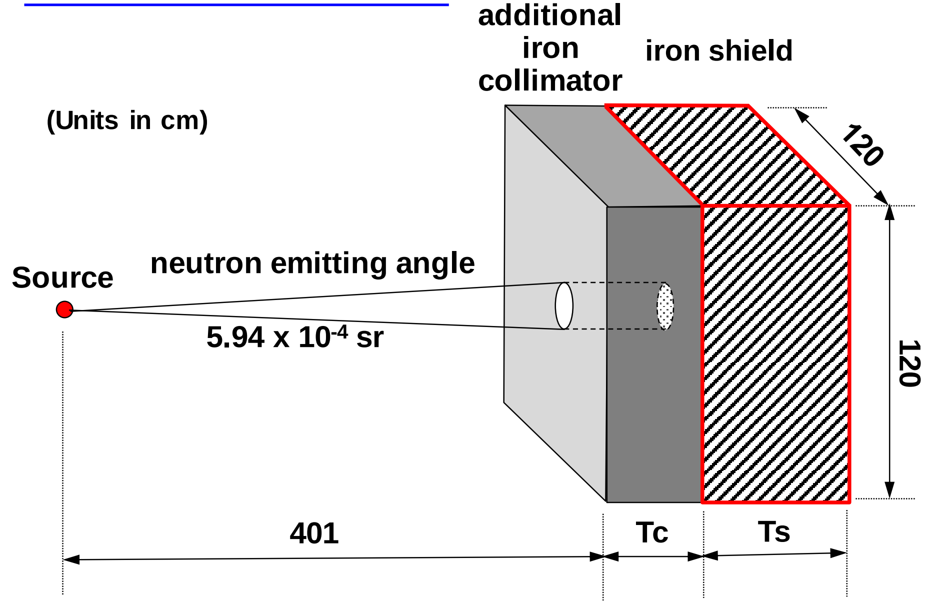
Experimental configuration



- 43 and 68MeV of protons were bombarded on the Li-7 target.
- The generated neutrons, 40 and 65MeV, were collimated and entered on the iron test shield.
- The neutron spectrum above 5MeV was measured by scintillators.

See the following report for more details about the experiments and analyses:
H. Nakashima et al., JAERI-Data/Code 96-005, 1996

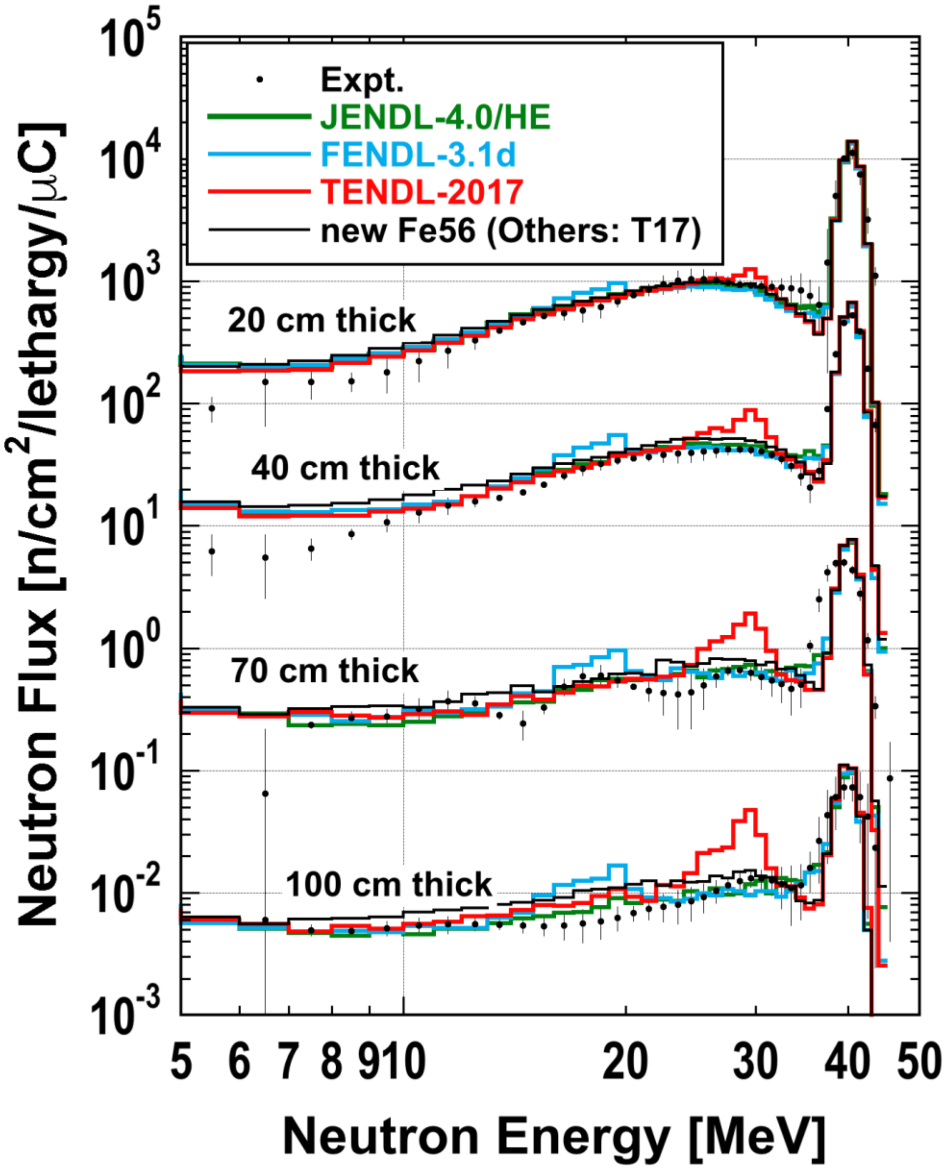
Calculation model



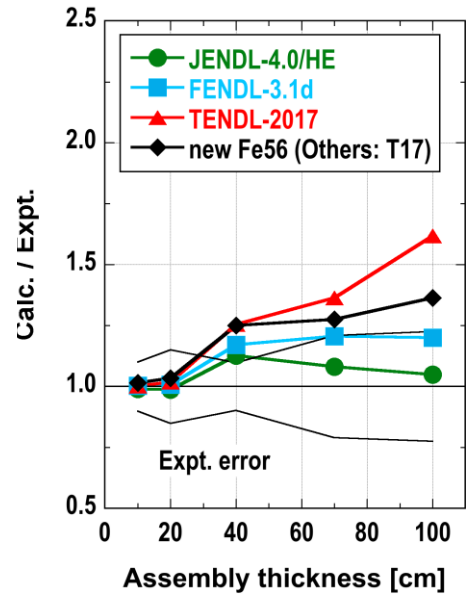
- Code: MCNP6.1.1
- Libraries:
  - FENDL-3.1d (Official ACE file)
  - TENDL-2017 (Official ACE file)
  - JENDL-4.0/HE (Processed with NJOY2016)
  - **New Fe56 file from Dr. Koning**
  - **(^{54,57,58}Fe: , FENDL-3.1d)**
- The measured neutron spectrum was used as the neutron source in MCNP.

Result: 40 MeV

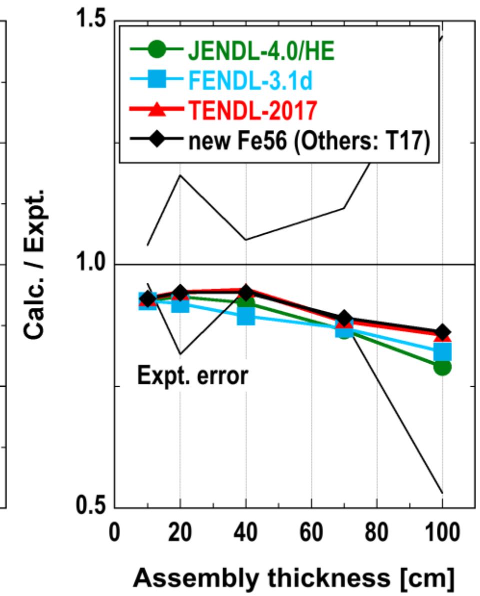
Neutron spectra of 40MeV neutrons



Conti. (10 – 35MeV)



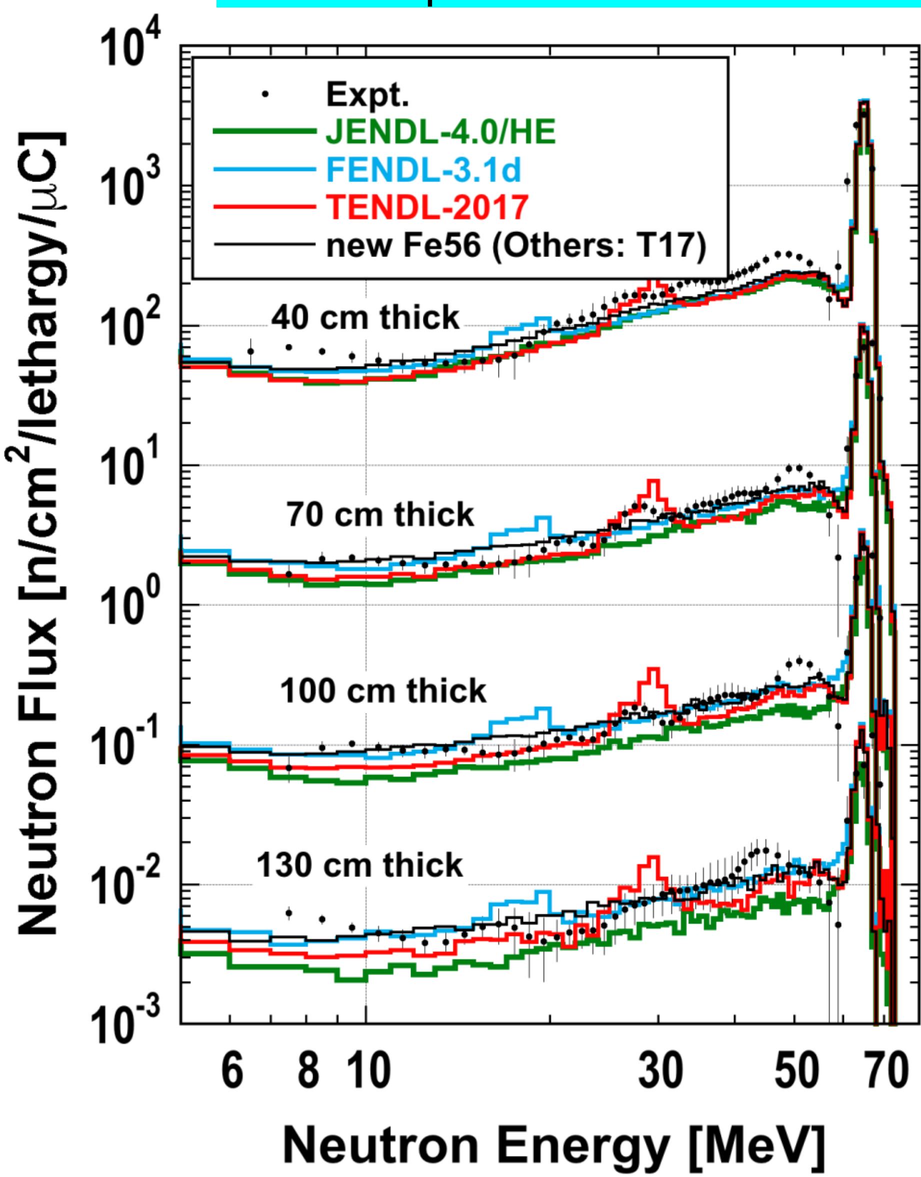
Peak (35 – 45MeV)



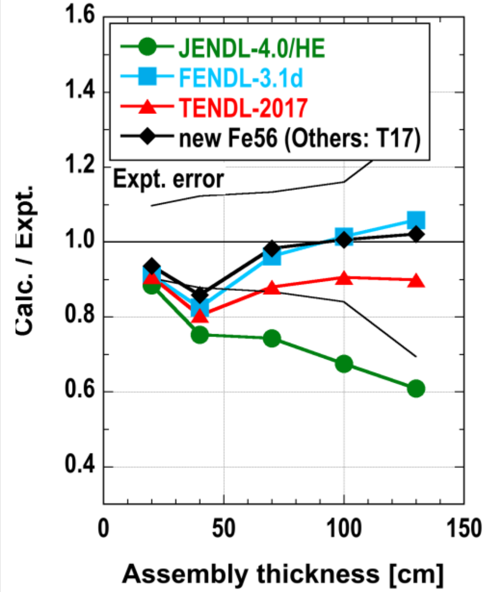
- Continuous region: No peak around 30 MeV. The calculated neutron fluxes still overestimate the experimental ones using new Fe56 (but improved!).
- Peak region: The calculated neutron fluxes agree well the experimental ones using new Fe56 (almost the same to those using TENDL-2017).

Result: 65 MeV

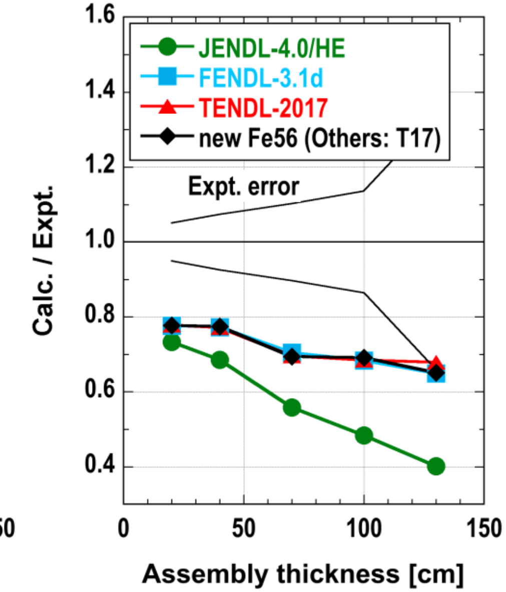
Neutron spectra of 65MeV neutrons



Conti. (10 – 60MeV)

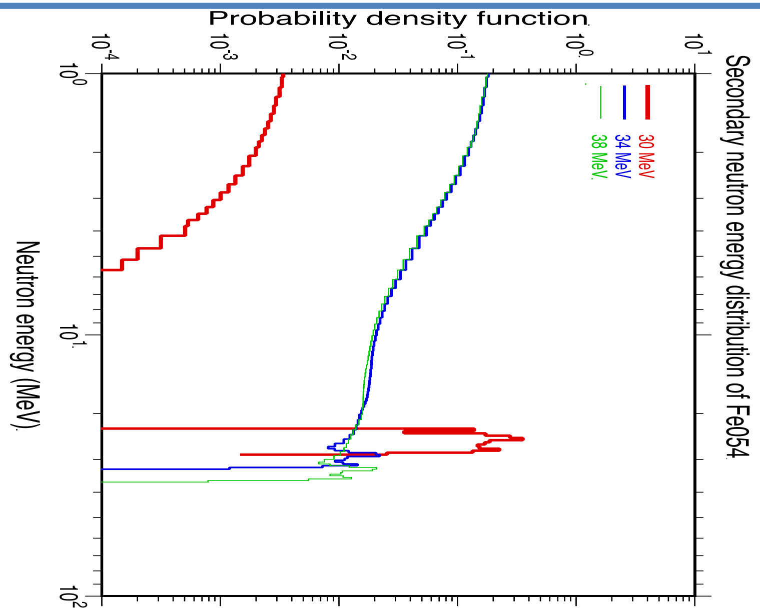


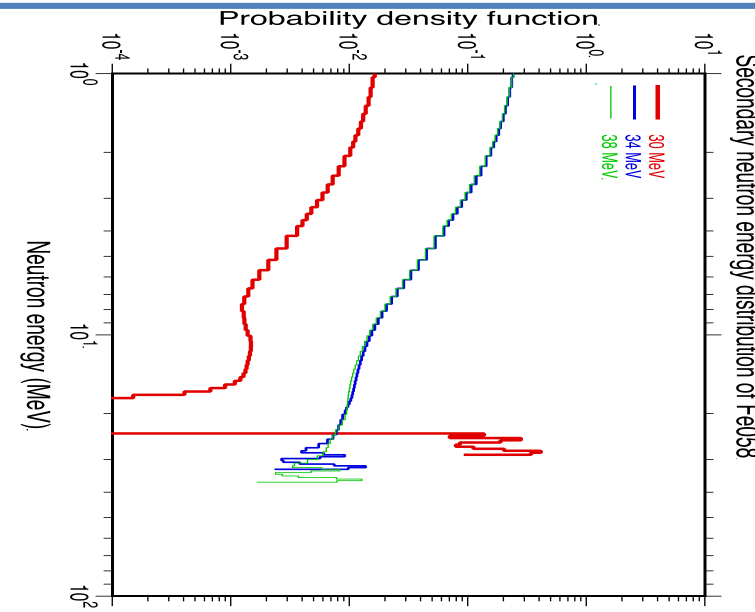
Peak (60 – 70MeV)

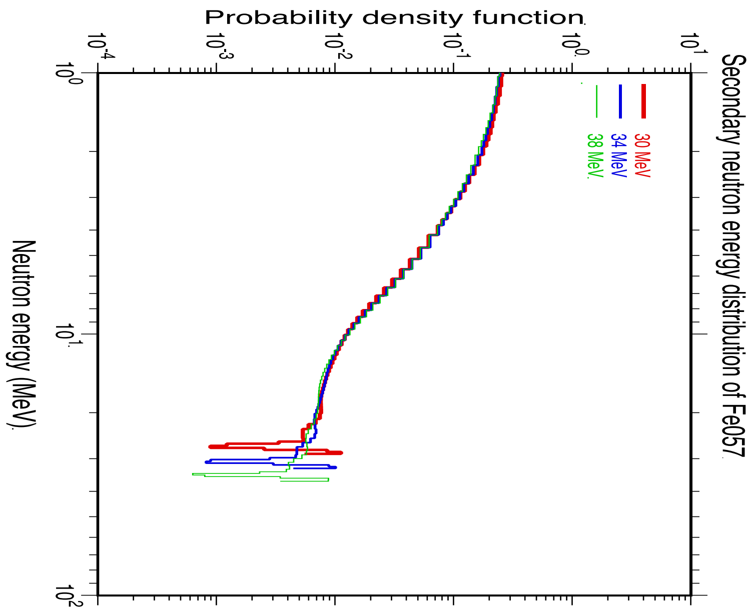


- Continuous region: No peak around 30 MeV. The calculated neutron fluxes agree well the experimental ones using new Fe56 (similar C/E to FENDL-3.1d).
- Peak region: The calculated neutron fluxes underestimate the experimental ones using new Fe56 (similar C/E to FENDL-3.1d, TENDL-2017).

Other iron isotopes in TENDL-2017





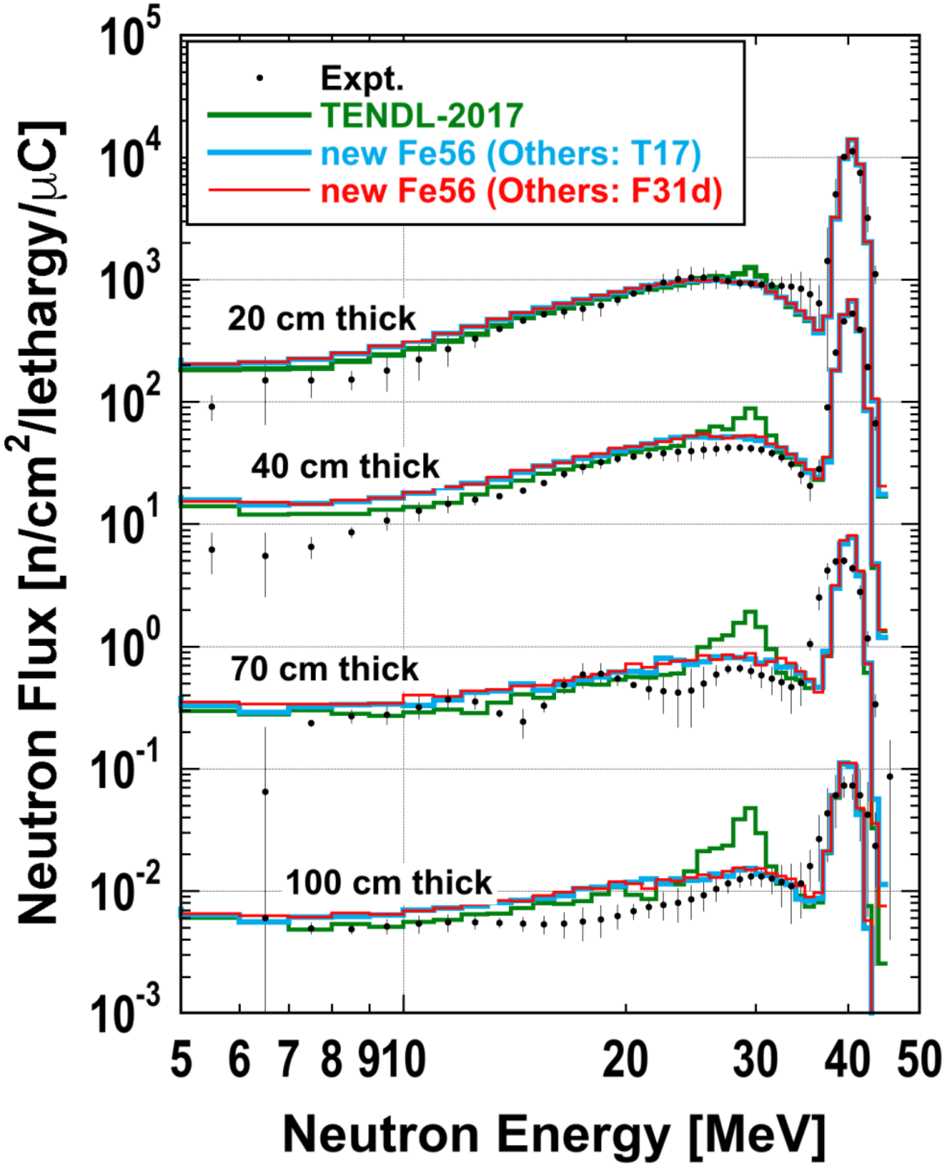


- **The incorrect secondary neutron energy spectrum data in Fe54 and Fe58 of TENDL-2017 have to be corrected.**
- **Only Fe57 have correct secondary neutron energy spectrum data.**

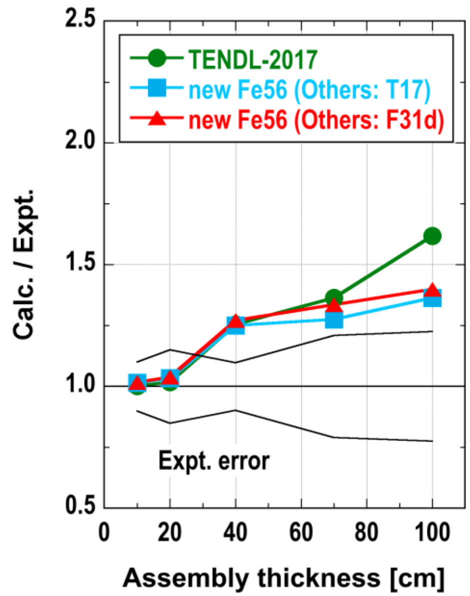
Result: 40 MeV (Effect of other iron nuclei)

QST

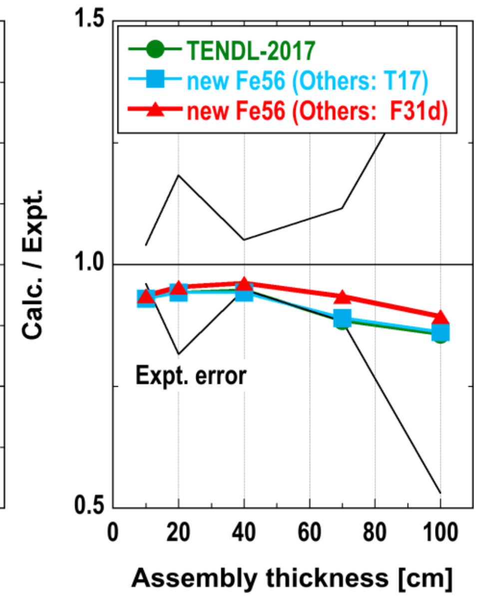
Neutron spectra of 40MeV neutrons



Conti. (10 – 35MeV)



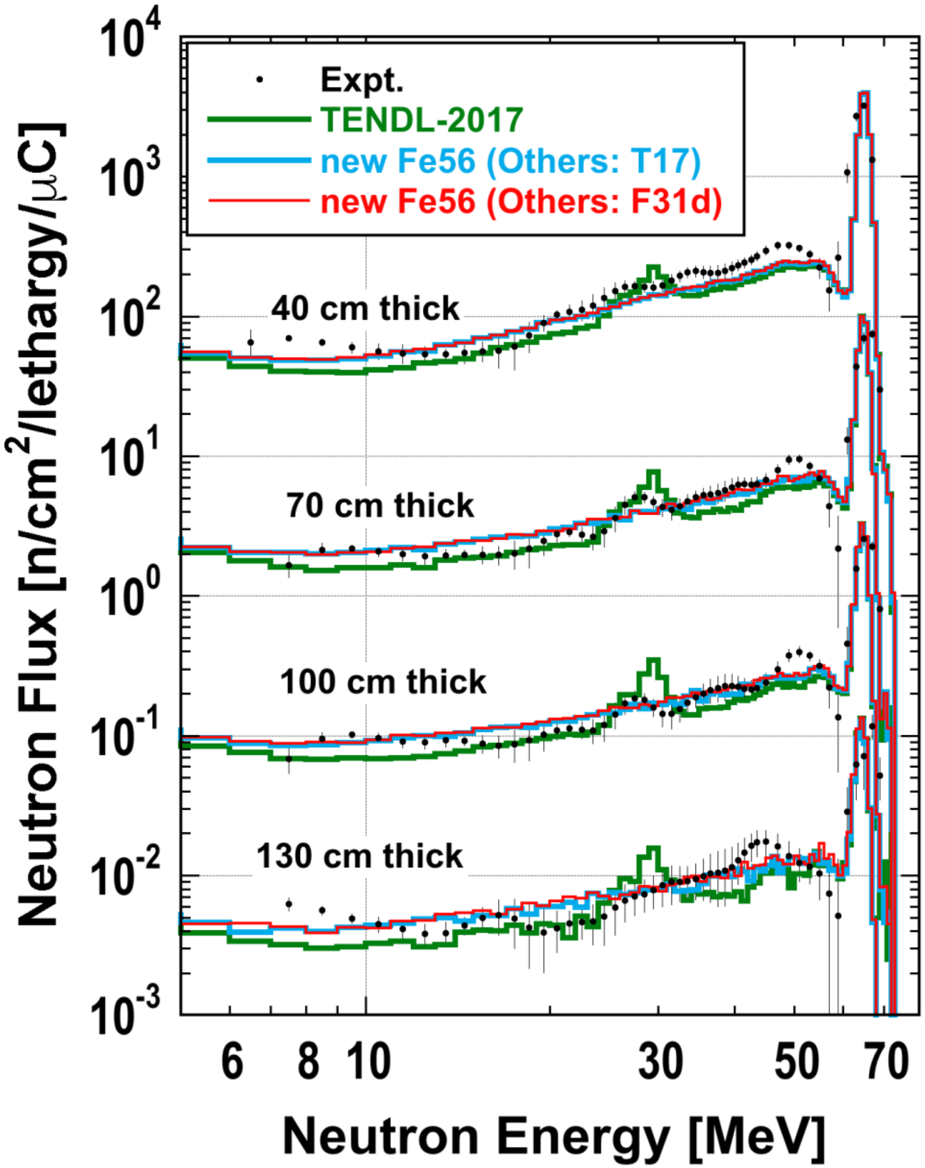
Peak (35 – 45MeV)



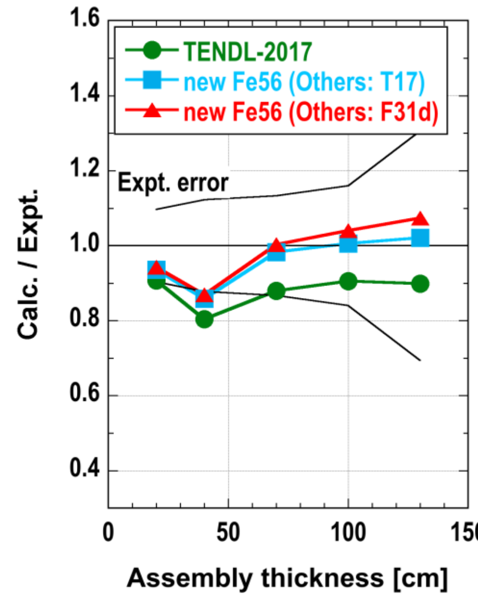
- Continuous region: The calculated neutron fluxes using TENDL-2017 for the other iron nuclei have similar tendency of C/E to those using FENDL-3.1d.
- Peak region: There is a small effect using FENDL-3.1d for the other iron nuclei than that using TENDL-2017.

Result: 65 MeV (Effect of other iron nuclei)

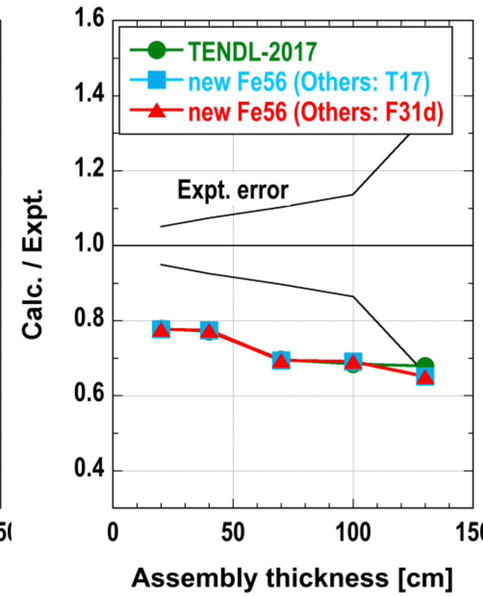
Neutron spectra of 65MeV neutrons



Conti. (10 – 60MeV)



Peak (60 – 70MeV)



- Continuous region: The calculated neutron fluxes using TENDL-2017 for the other iron nuclei have similar tendency of C/E to those using FENDL-3.1d.
- Peak region: There is almost no effect using FENDL-3.1d for the other iron nuclei than that using TENDL-2017.

Concluding remarks

- **The analyses of QST/TIARA iron shielding experiments affirmed that the new Fe56 data are better than those in TENDL-2017, although the new Fe56 data are not “perfect”.**
- **We checked the effect of other iron nuclei data.**
- **Further study should be performed including to improve other iron nuclei data.**
- **The new Fe56 data will be a candidate for that in the next FENDL.**

Thank you for your attention!