

Yield Estimation of Neutrons, Gammas, and Charged Particles in d-Li Target by using JENDL/DEU-2020 for IFMIF and Similar Irradiation Facilities

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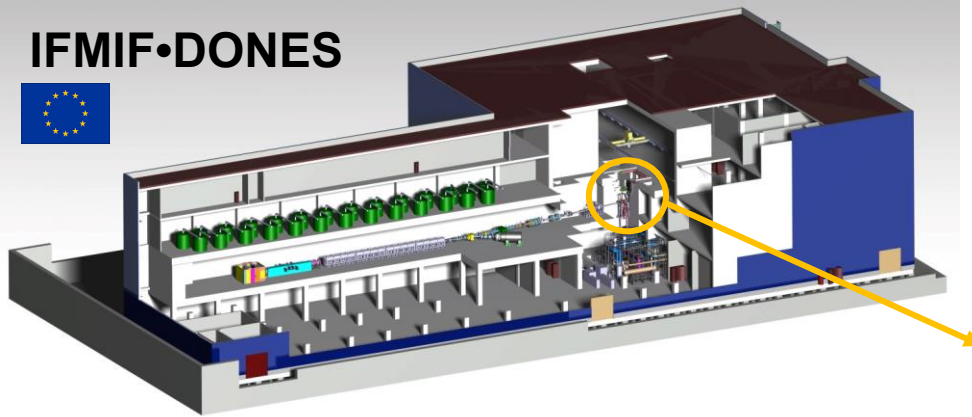
Introduction

- An accelerator-based neutron source using d-Li reactions is one of the most promising neutron sources for fusion material irradiation facilities such as IFMIF, DONES, and A-FNS.
- Yield estimation of neutrons, gammas, and other particles is very important in the design on those irradiation facilities.
- Currently, McDeLicious code is used for those yield estimation, however, it is not open code.
- Recently, a deuteron-induced reaction library of JENDL/DEU-2020 in ACE format was released by JAEA.
- In this study, benchmark tests of JENDL/DEU-2020 and McDeLicious* have been carried out. Moreover, not only neutrons and gammas, but also charged particle yields in Li and the target backplate.

*S.P. Simakov *et al.*, J. Nucl. Mater. **307-311**, 1710 (2002).

Introduction (Cont.)

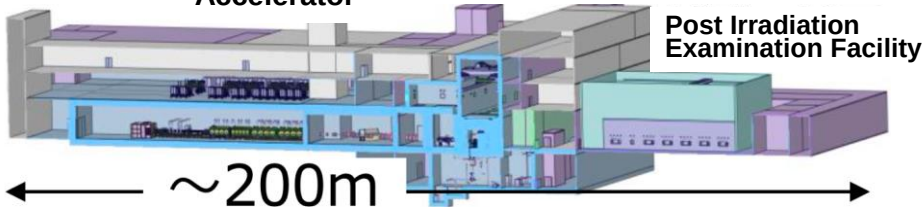
IFMIF•DONES



A-FNS



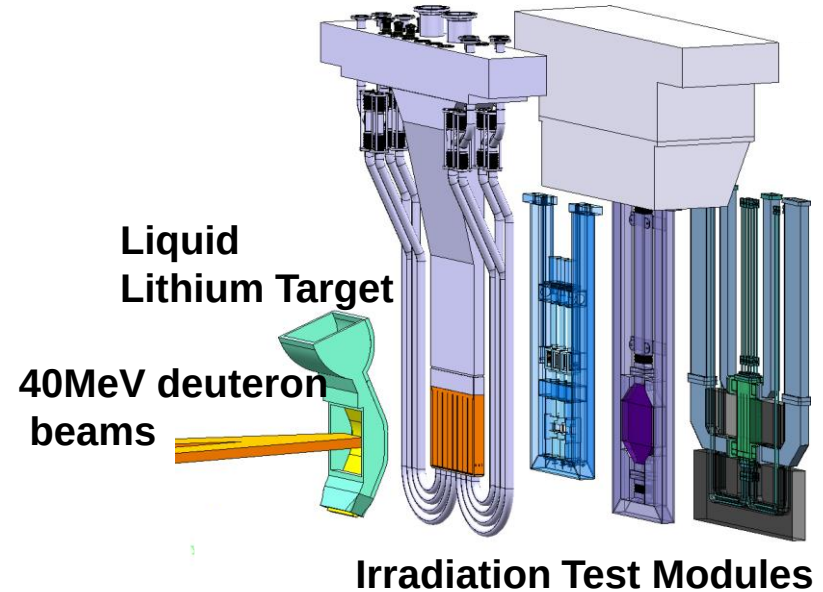
Accelerator



Post Irradiation Examination Facility

~200m

Schematics of Li-target and irradiation modules



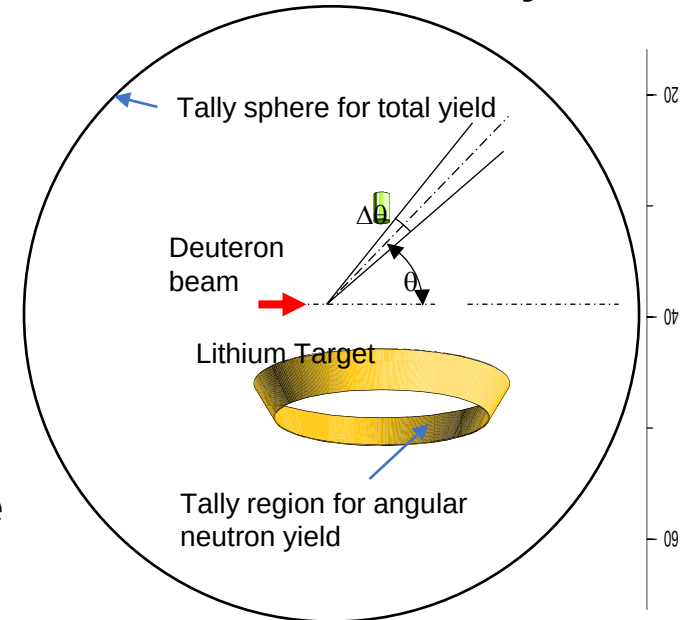
Benchmark Calculation of d-Li Thick-Target Yield

- Neutron, and gamma thick-target yield (TTY) are calculated by PHITS and MCNP with JENDL/DEU-2020 library and embedded nuclear reaction models compared with McDelicious and experimental data.

Code	Library	Nuclear reaction model
PHITS 3.31	JENDL/DEU-2020	
PHITS 3.31		INCL+DWBA
MCNP 6.2	JENDL/DEU-2020	
MCNP 6.2		Bertini

- Size of the lithium target is according to the range of incident deuteron.

Calculation Geometry

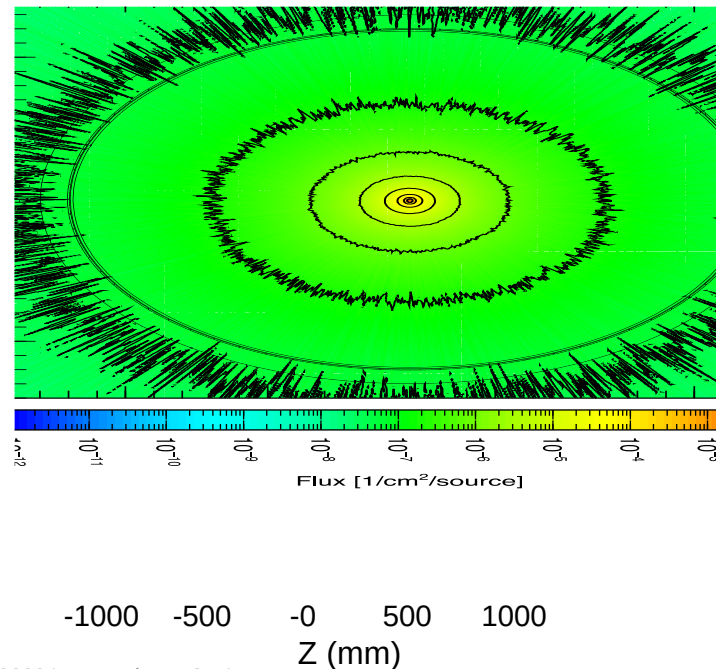
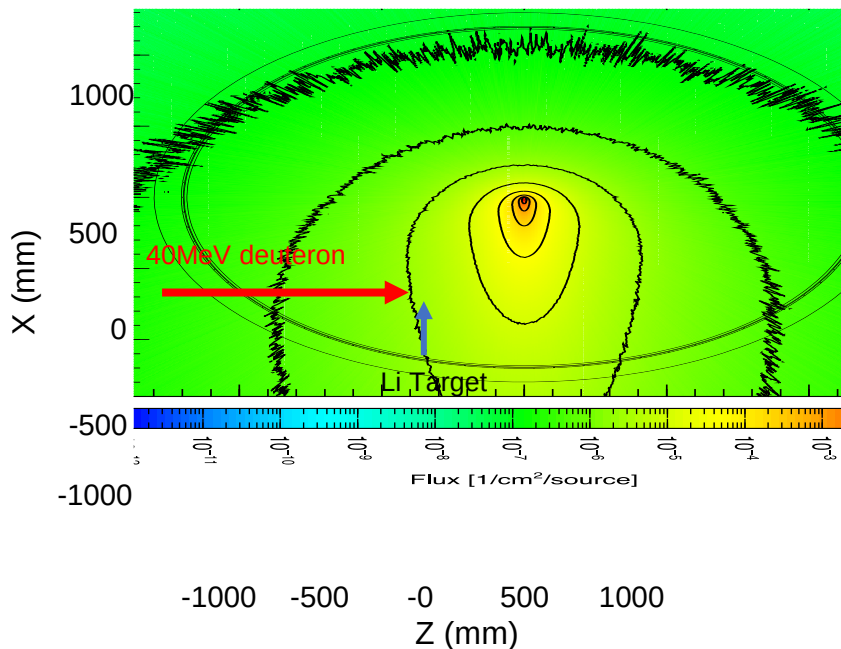


Neutron and gamma emission map

- Neutron emission is strongly forward directional.
- Gamma emission is isotropic.

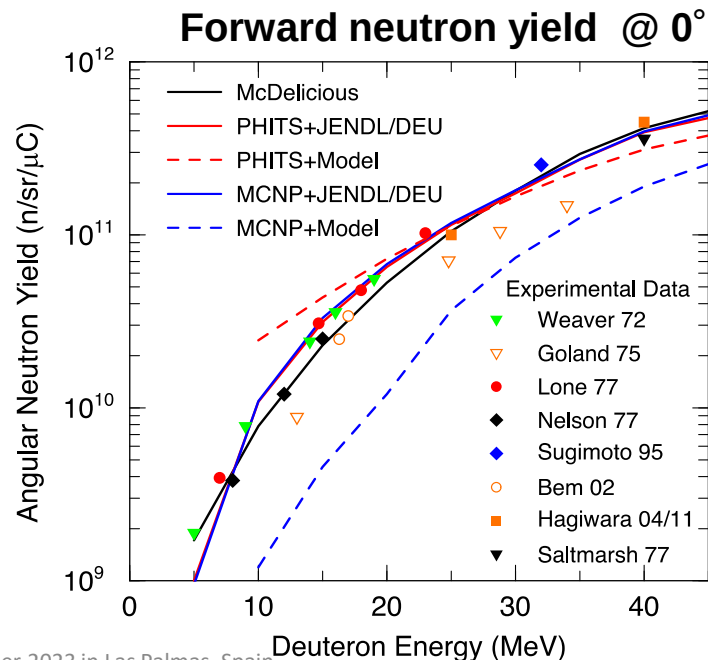
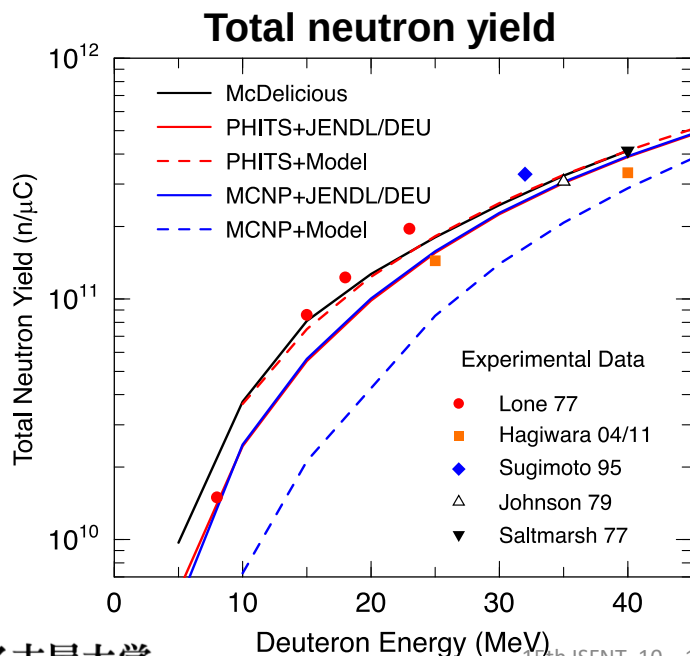
Neutron flux by PHITS+JENDL/DEU

Gamma flux by PHITS+JENDL/DEU



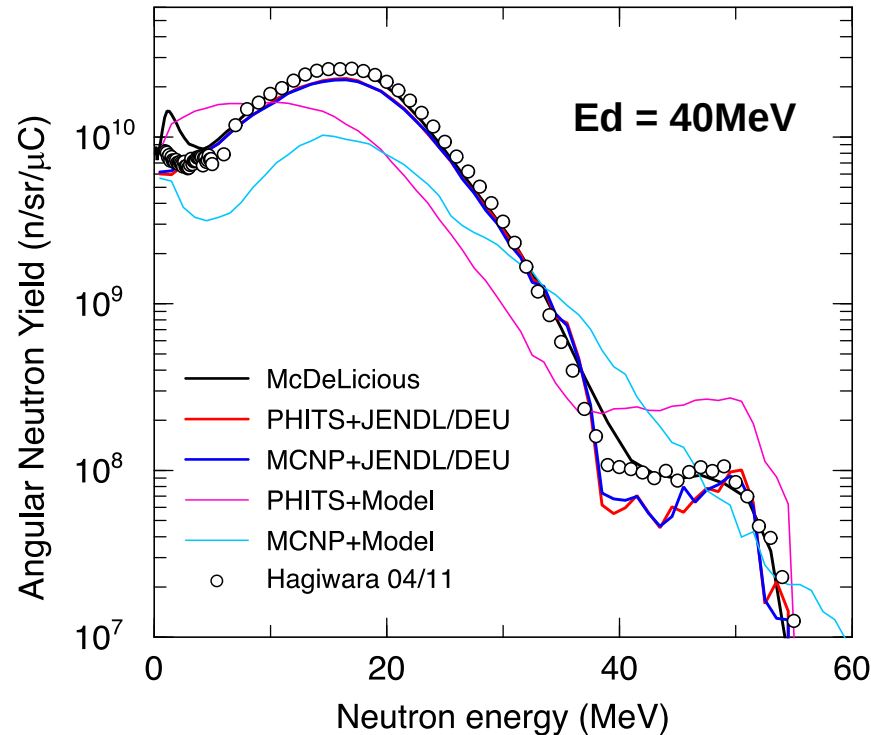
Benchmark: Total and forward neutron TTY

- PHITS+JENDL/DEU and MCNP+ JENDL/DEU are almost identical.
- In total neutron yield, McDelicious and PHITS+Model are in good agreement. PHITS•MCNP+JENDL/DEU is a little bit smaller than McDelicious.
- In the forward neutron yield, PHITS•MCNP+JENDL/DEU and McDelicious are in good agreement.



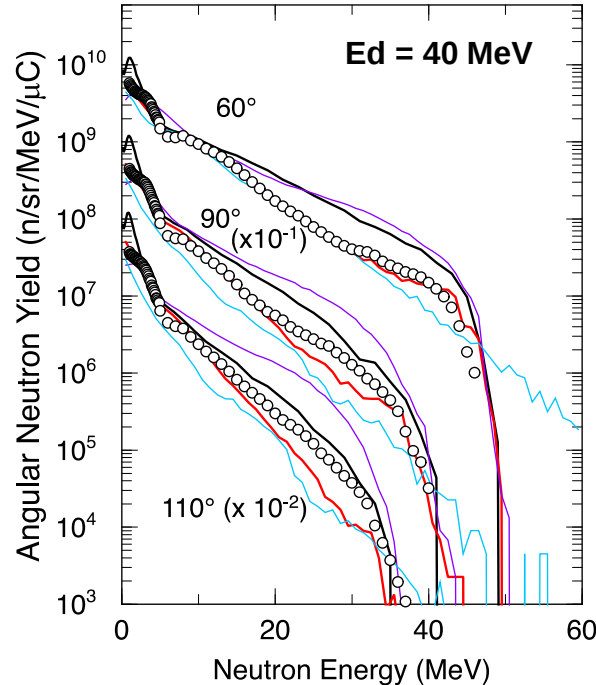
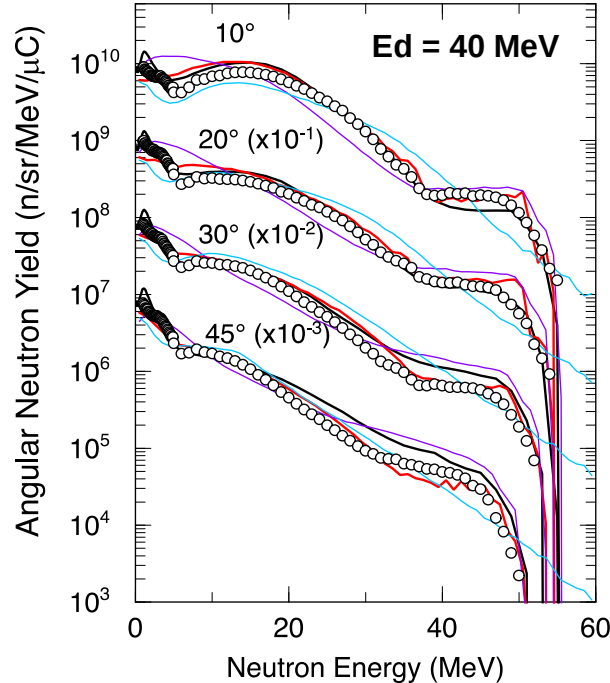
Benchmark: Angular neutron spectra @0°

- McDelicious and PHITS•MCNP+JENDL/DEU in good agreement with experimental data (Hagiwara).
- PHITS•MCNP+ model could not reproduce experimental data.



Benchmark: Angular neutron spectra

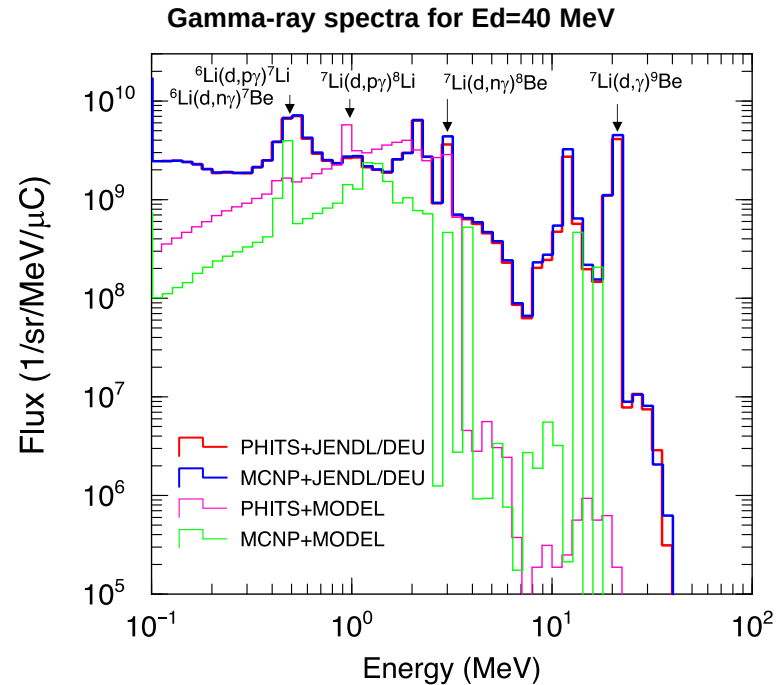
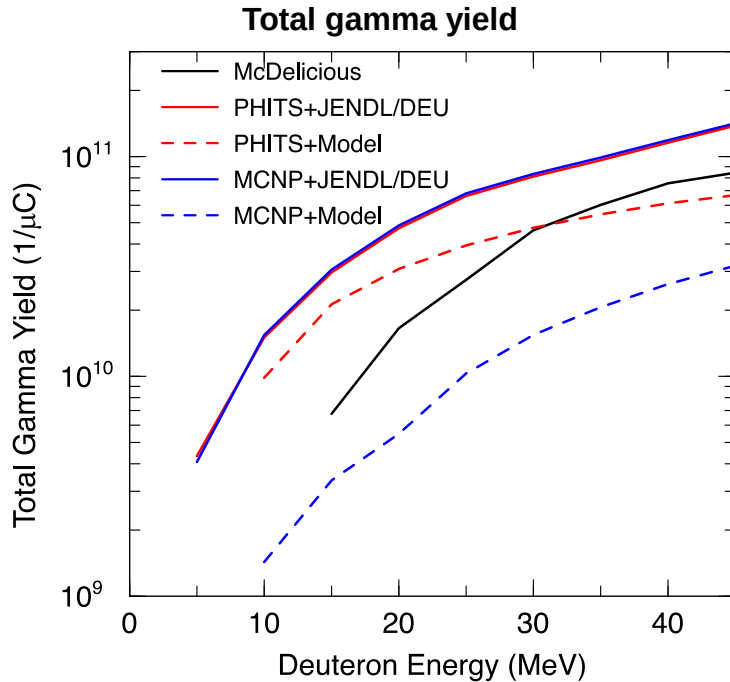
- For 10-45°, McDelicious and PHITS•MCNP+JENDL/DEU in good agreement with experimental data (Hagiwara). PHITS•MCNP+JENDL/DEU reproduces experimental data better than McDelicious for 60-90°.
- PHITS•MCNP+ model could not reproduce experimental data well.



*MCNP+JENDL/DEU is not shown because it is identical with PHITS+JENDL/DEU.

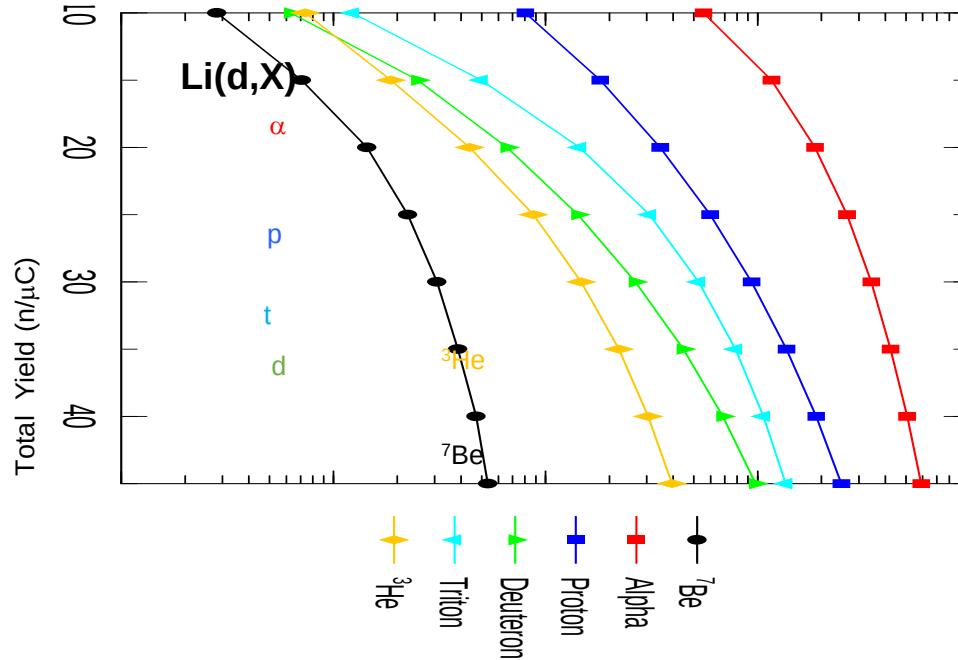
Benchmark: Gamma yields and spectra

- In the total gamma yield, PHITS•MCNP+JENDL/DEU is approximately 2 times larger than McDelicious. MCNP+Model is 2—3 times smaller than McDelicious.
- Spectra by PHITS•MCNP+ model are much different from that by PHITS•MCNP+JENDL/DEU.



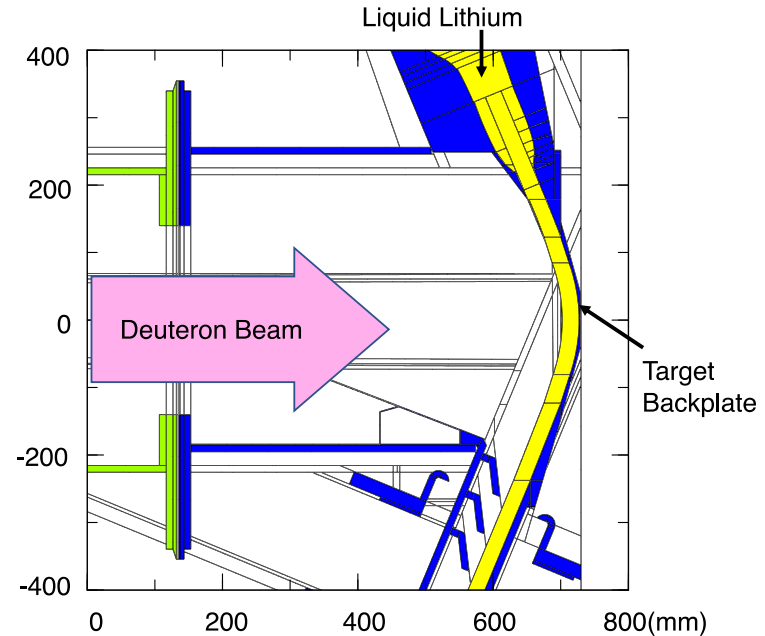
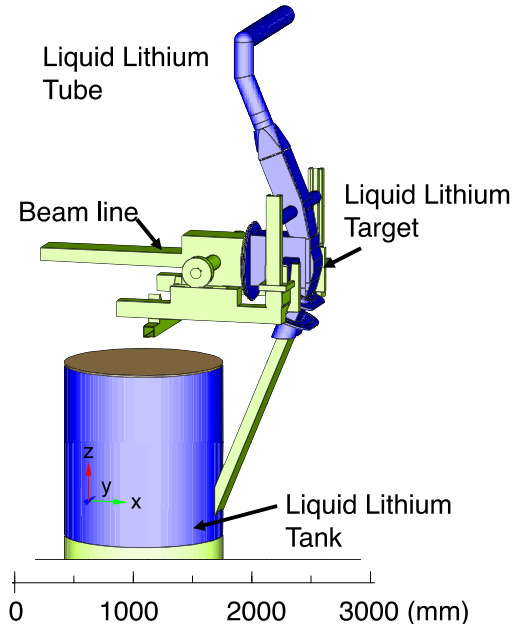
Charged particle yield in Thick Target

- Primary charged particle yields in Thick Target were calculated with PHITS+JENDL/DEU.
- Yield of alphas is almost the same as that of neutrons.
- Yield of ^7Be is 2-order smaller than that of neutrons.



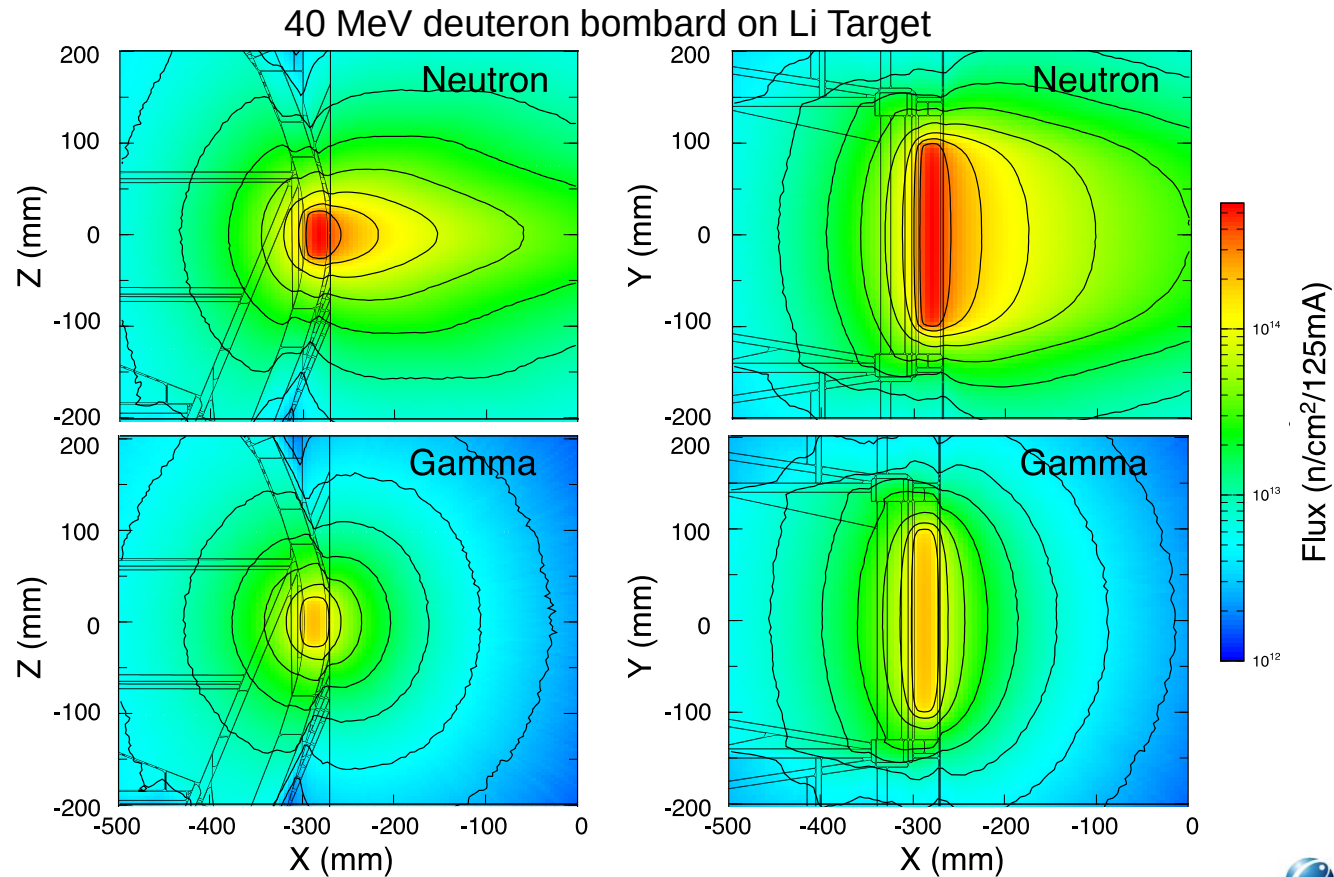
Yield Estimation in the A-FNS Li-Target

- Structure of the A-FNS Li-Target is almost the same as that of IFMIF and DONES. However, the d-beam line is single (40 MeV, 125mA) with the footprint of 200X50 mm².
- Neutron, gamma, and charger particles yield in Li- target and charged particles yield and DPA in Backplate have been calculated with PHITS+JENDL/DEU-2020.



Neutron and Gamma Flux Map around A-FNS Target

- Neutron emission is strongly forward directional.
- Gamma emission is weakly forward directional due to the target structure.



Total Neutron and Gamma Yield of A-FNS Target

- Total neutron and gamma yields of the A-FNS Li Target (40MeV, 125mA) have been evaluated by PHITS+JNEDL/DEU.
- Total neutron yield is approximately 10% smaller than that of McDelicious.
- Total gamma yield is approximately 2 times larger than that of McDelicious.

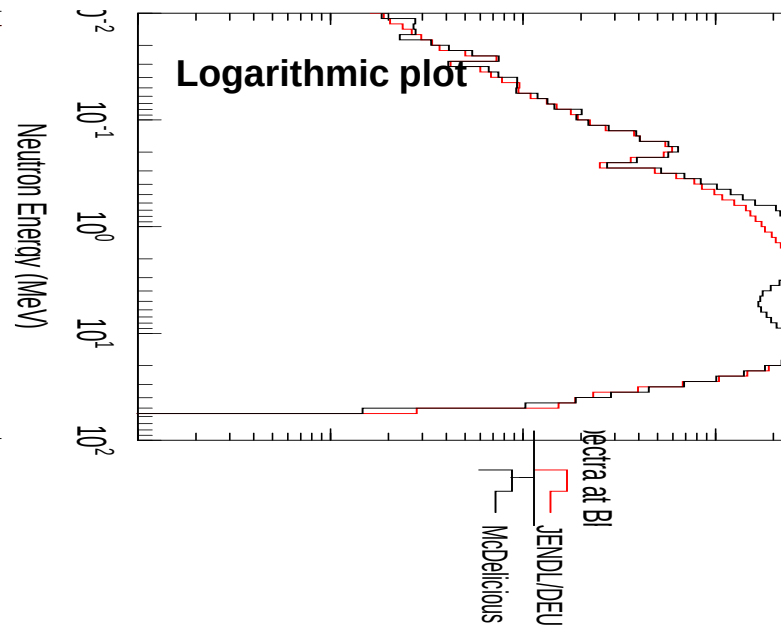
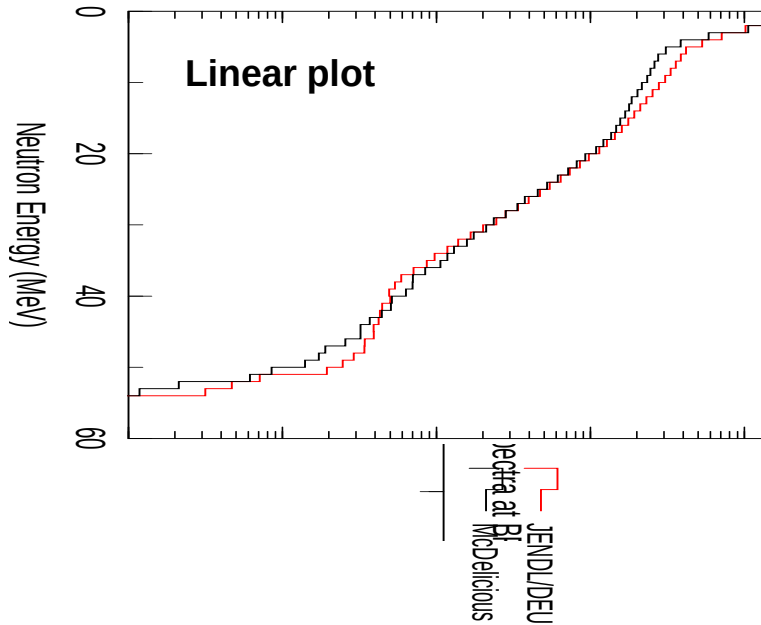
Items	PHITS+JENDL/DEU		McDelicious for IFMIF *
	Primary	Total	Total (for 125mA)
Neutron yield at 125 mA	4.87×10^{16}	6.11×10^{16}	6.83×10^{16}
neutron/deuteron	0.0624	0.0783	0.0876
Gamma yield at 125 mA	1.45×10^{16}	1.79×10^{16}	9.5×10^{15}
Gamma/deuteron	0.0186	0.0230	0.012
Gamma/neutron	0.297	0.293	0.14

Neutron X-sections: FENDL-3.1d

* S.P. Simakov et al. Fusion Eng. Design 84 (2009) 1770–1773.

Neutron Spectrum at Backplate

- Neutron spectrum at Backplate was calculated by PHITS+JENDL/DEU compared with that by McDelicious, where the total neutron yield was normalized to that of PHITS+JENDL/DEU case.
- Small discrepancy is observed in 0.3–20 MeV between PHITS+JENDL/DEU and McDelicious.



Charged particle yields and heating in Li of A-FNS Target

- Heating rate is approximately 80% larger than that by McDelicious.
- Mass of ^7Be after 1FPY is less than 1/3 of that by McDelicious which is to be discussed.

Items in Li jet	PHITS+JENDL/DEU		McDelicious for IFMIF*
	Primary	Total	Total (at 125mA)
Neutron flux (n/cm ² /s)	3.56×10^{14}	4.47×10^{14}	6.55×10^{14}
Gamma flux (n/cm ² /s)	1.38×10^{14}	1.58×10^{14}	1.55×10^{14}
Nuclear heating (W/g)		11.0	6.75
Alpha production rate (n/s)	6.31×10^{16}	6.45×10^{16}	
Proton production rate (n/s)	2.35×10^{16}	2.36×10^{16}	
Triton production rate (n/s)	1.32×10^{16}	1.43×10^{16}	
^7Be production rate (n/s)	5.82×10^{14}	5.85×10^{14}	
Tritium Mass w/o decay (g/FPY)	2.08	2.25	3.2
^7Be Mass w/o decay (g/FPY)	0.213	0.214	0.75

* S.P. Simakov et al. Journal of Nuclear Materials 329–333 (2004) 213–217.

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Charged particle yields and heating of Backplate

- Neutron and gamma fluxes are approximately 45% smaller than that by McDelicious. HFTM(High Flux Test Module) may reflect neutrons and gammas backward the backplate in the McDelicious calculation*.
- Charged particle yields reasonably agree with those by McDelicious*.

Items	PHITS+JENDL/DEU	McDelicious for IFMIF * with HFTM at 125mA
Neutron flux (n/cm ² /s)	3.59×10^{14}	6.85×10^{14}
Gamma flux (n/cm ² /s)	9.67×10^{13}	1.55×10^{14}
Nuclear heating (W/g)	1.63	1.55
Alpha production rate (ppm/FPY)	315.3	312.5
Proton production rate (ppm/FPY)	1801	1602
Triton production rate (ppm/FPY)	5.23	4.7
DPA/FPY	23.0	29.5

* S.P. Simakov et al. Fusion Eng. Design 84 (2009) 1770–1773.

Summary

- Lithium Thick Target Yield (TTY) has been calculated by the PHITS code with the deuteron nuclear data library of JENDL/DEU-2020, which reproduces well the experimental data and also the McDelicious results.
- For the A-FNS Li target and the backplate, Yields of neutrons, gammas, and charged particles, and heating rate, etc. have been evaluated by PHITS +JENDL/DEU-2020, which reasonably agrees to the literature derived from McDelicious except ^7Be .
- As the conclusion, JENDL/DEU-2020 is applicable to the neutronic design of IFMIF and similar neutron irradiation facility.
- JENDL/DEU-2020 can be obtained from the Japanese Nuclear Data Center. Also, FENDL-3.2d adopts JENDL/DEU-2020 for Li, Be, and C in the deuteron files.