UNED activities in IFMIF-DONES: The role of nuclear data

V. Lopez[(1)], F. Ogando[(1)], P. Sauvan[(1)]
(1) Departamento de Ingeniería Energética – UNED

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Outline

- Neutron emission in deuteron nuclear data libraries.
- Comparison against integral experiments and improvement of the responses accuracy.
- Influence of the remaining uncertainties.

TENDL deuteron libraries

- For the IFMIF-DONES activities, deuteron libraries such as TENDL [1] are employed.

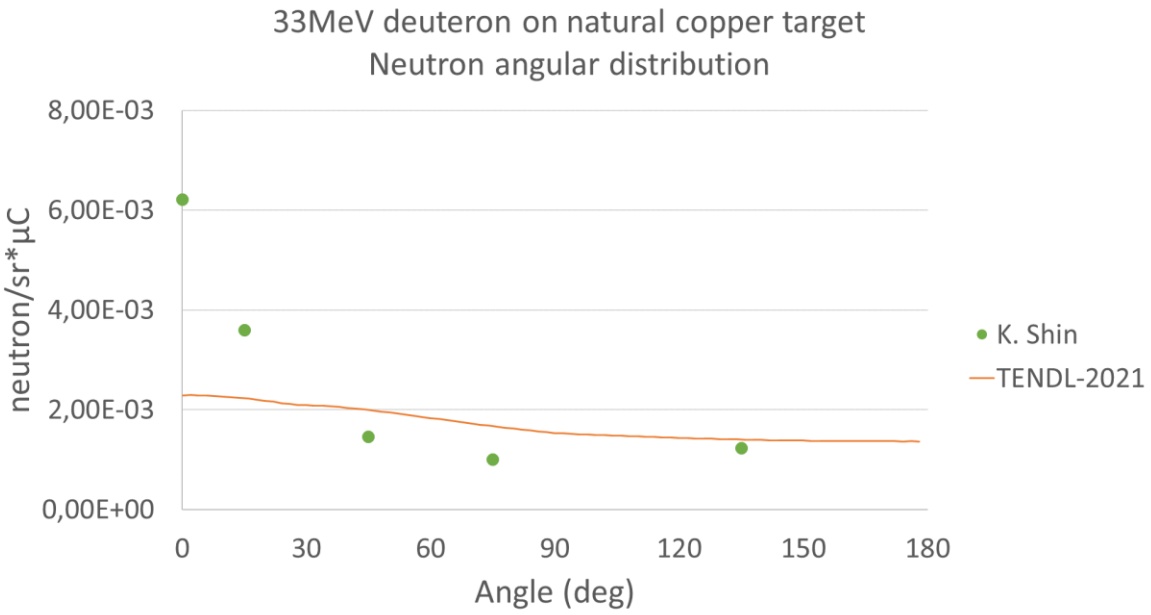
- TENDL is one of the major nuclear data libraries, based on both default and adjusted TALYS calculations and data from other sources, and distributed on ENDF formatted files.

- In ENDF formatted files, the Kalbach-Mann systematics [2] is powerful representation for produced neutron and charged particle energy-angle distributions in high energy reactions.

[1] A.J. Koning, D. Rochman, J. Sublet, N. Dzysiuk, M. Fleming and S. van der Marck, "TENDL: Complete Nuclear Data Library for Innovative Nuclear Science and Technology", Nuclear Data Sheets 155 (2019) 1
[2] C. Kalbach, “Systematics of continuum angular distributions: Extensions to higher energies” Phys. Rev. C 37, 2350 (1988)

TENDL deuteron libraries

- However, neutron emission does not always meet the integral experiments

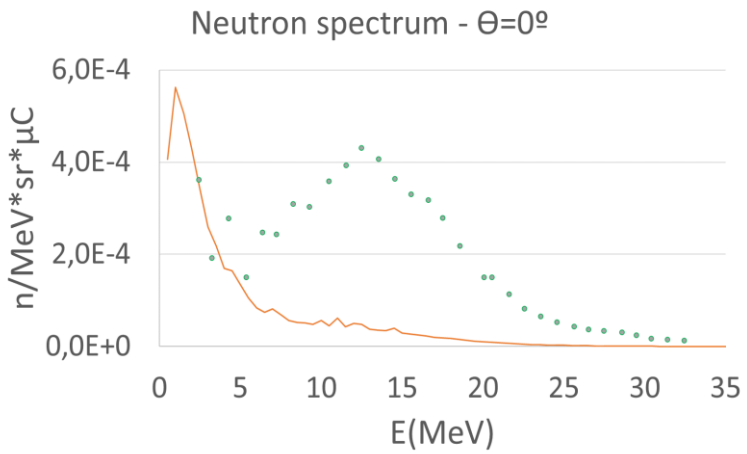


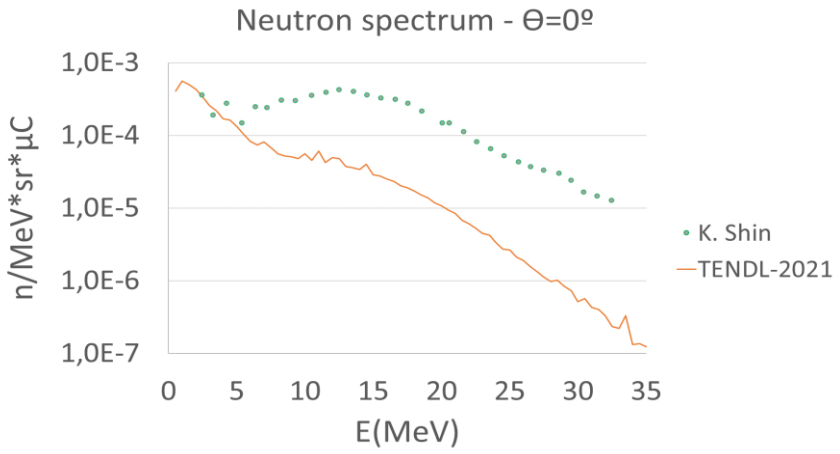
[1] K. Shin, et al "Neutron and photon production from thick targets bombarded by 30-MeV p, 33-MeV d, 65-MeV 3He, and 65-MeV α ions: Experiment and comparison with cascade Monte Carlo calculations", Phys Rev C 29 (1984).

Relevance of the breakup reactions

- The Kalbach-Mann systematics is not able to reproduce the angular distribution of the neutron caused by breakup reactions.

- Breakup reactions cause the emission of a neutron with an angular distribution strongly focused toward forward and with a narrow energy distribution peaked at an emission energy corresponding to the projectile velocity.





Breakup kinematics implementation

- Sauvan [1] et al. proposed a new implementation of the breakup kinematics in ENDF format based on a new global distribution.

$$\sigma(d, Xn) = \sigma^{0}\ (d, Xn) + \sigma^{BU}\ (d, n)$$

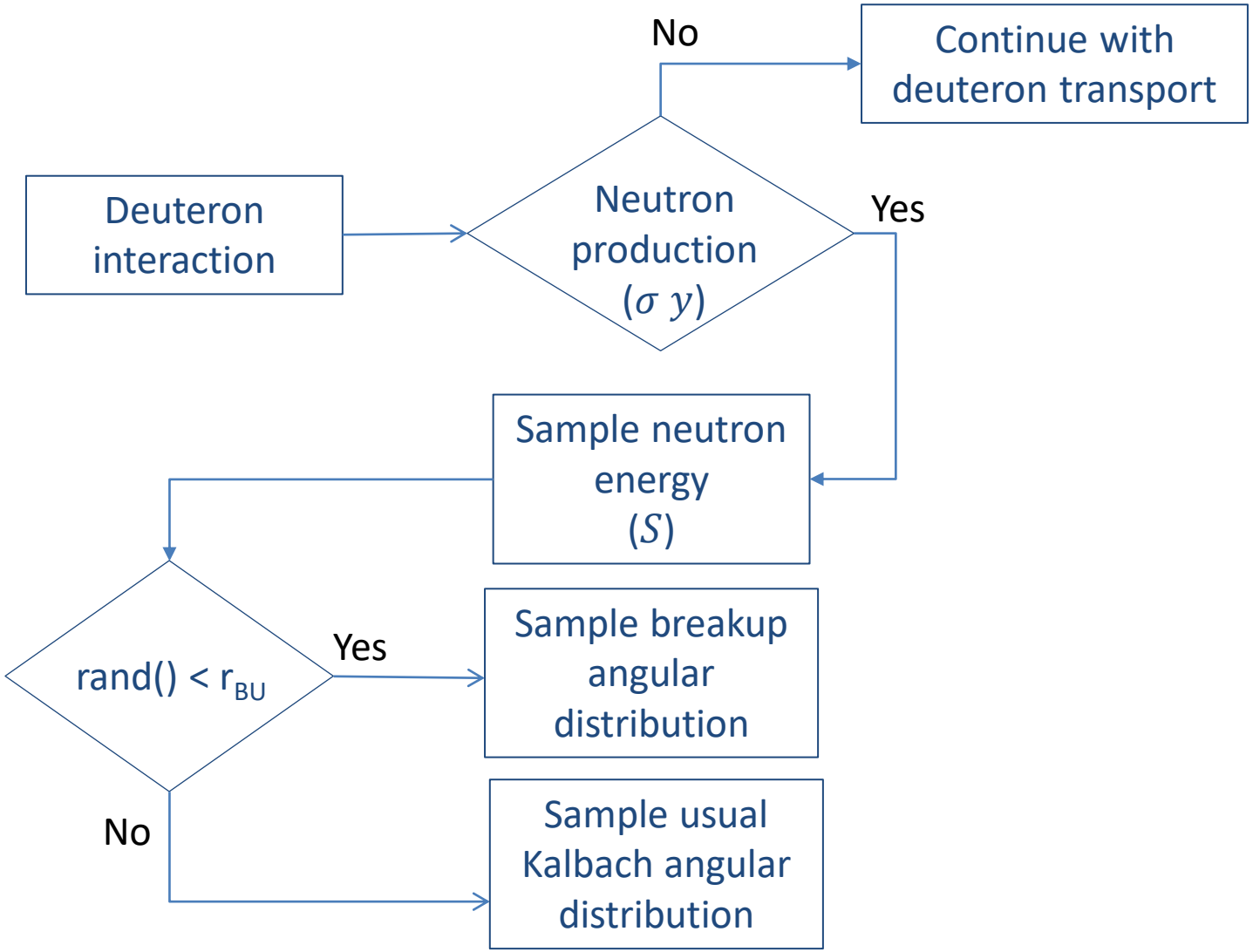
- The total double differential cross section can be defined combining both angular distributions as:

$$\sigma\ = \sigma\ y\ S\ [(1 - r_{BU})D_0(\mu)\ + r_{BU}\ D_{BU}(\mu)\ ]$$

  - y is the total neutron yield.
  - S is the normalized spectra of the neutrons.
  - r_{BU} is the probability of a neutron to be emitted after a breakup reaction
  - D is the angular distribution

[1] P.Sauvan et al. "Implementation of a new energy-angular distribution of particles emitted by deuteron induced nuclear reaction in transport simulations", EPJ Web of Conferences, Vol. 146, 02010 (2017)

Breakup kinematics implementation



Breakup kinematics implementation

- r_{BU} can be tabulated as a parameter a new angular representation in the ENDF format for the deuteron libraries.

- TENDL-2021 deuteron special files have been produced with such format

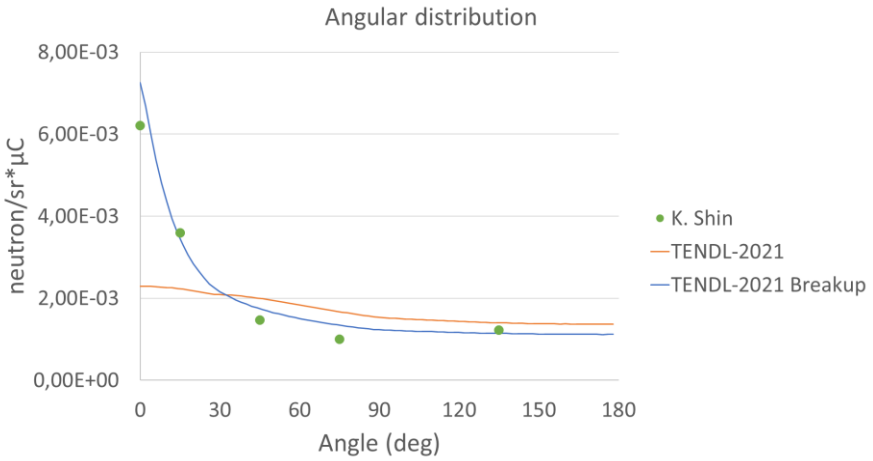
E’	S	r	r_{BU}		
0.000000+0	4.076872-7	9.999770-1	9.996130-1	1.476337+3	4.085957-7
9.999550-1	9.994450-1	3.444785+3	4.112590-7	9.998880-1	9.990990-1
7.381683+3	4.156399-7	9.997780-1	9.986940-1	1.476337+4	4.243479-7
9.995660-1	9.980940-1	3.444785+4	4.504510-7	9.989780-1	9.968390-1
7.381683+4	4.938927-7	9.984040-1	9.956430-1	1.476337+5	5.778256-7
9.994620-1	9.959430-1	2.460561+5	6.546563-7	9.998190-1	9.957200-1

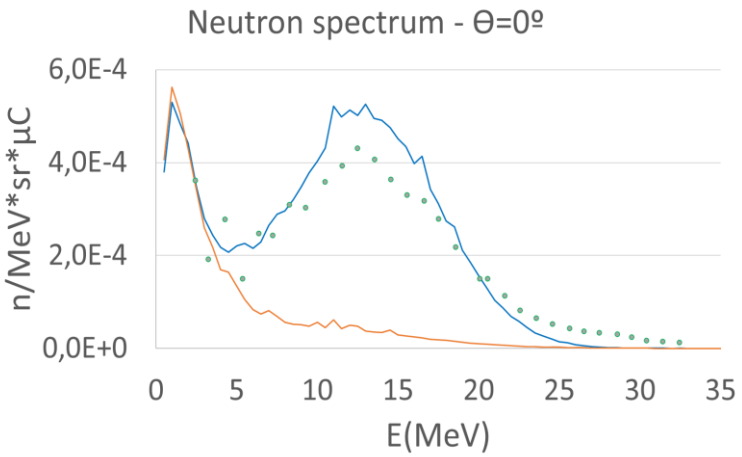
Breakup kinematics implementation

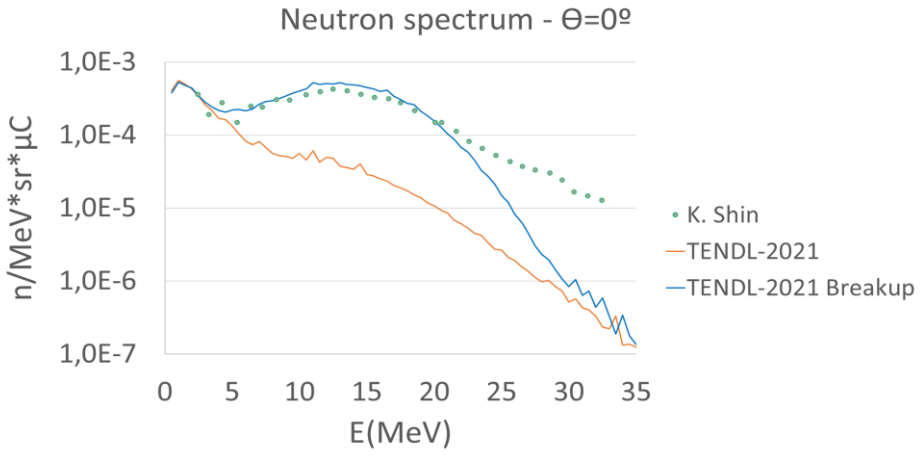
- To take advantage of the breakup angular distribution
  - The NJOY needs to be modified, to allow this new formatted file being converted to ACE.
  - The MCNP6 transport code needs to be modified, to read the new ACE files and reproduce the breakup angular distribution.
  - ENDF format documentation related with new kinematics needs to be updated.

Comparison against integral experiment

- The neutron emission show a tighter agreement with the experimental data







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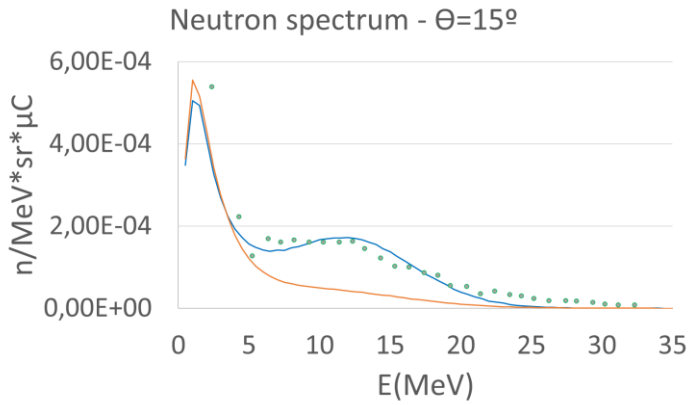
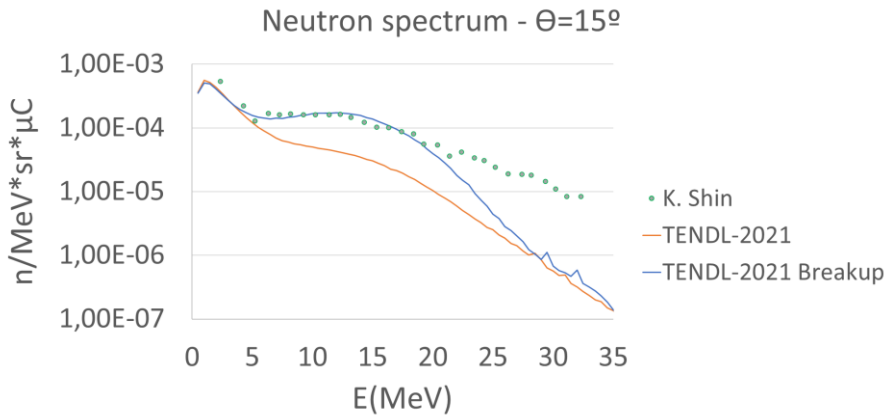
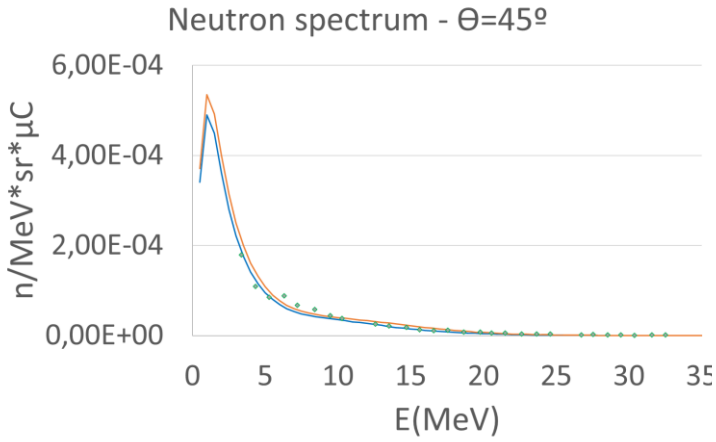
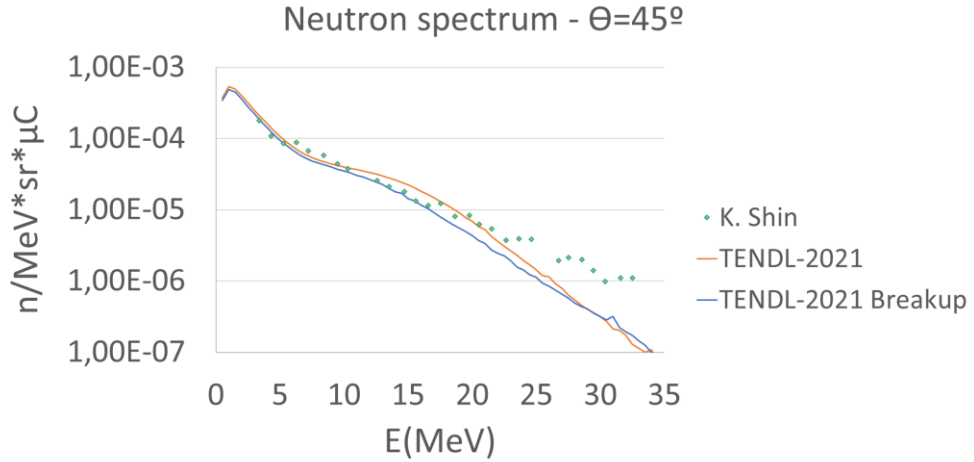


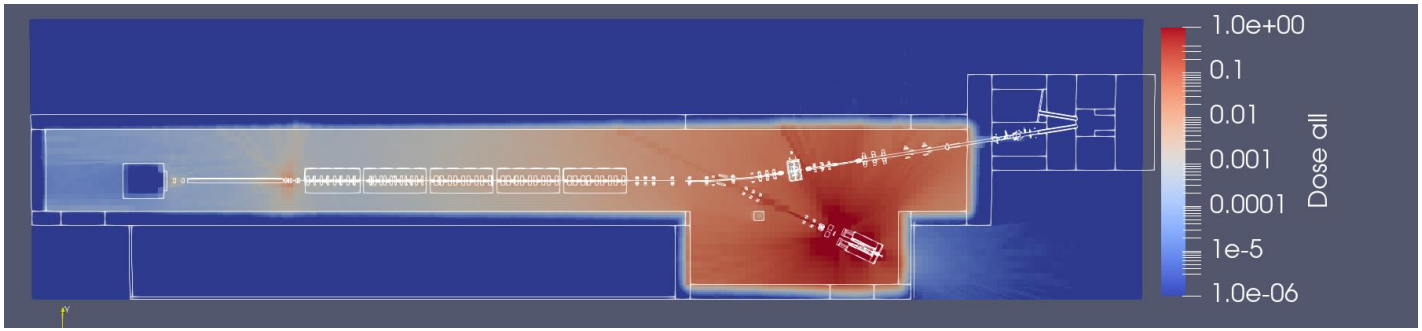






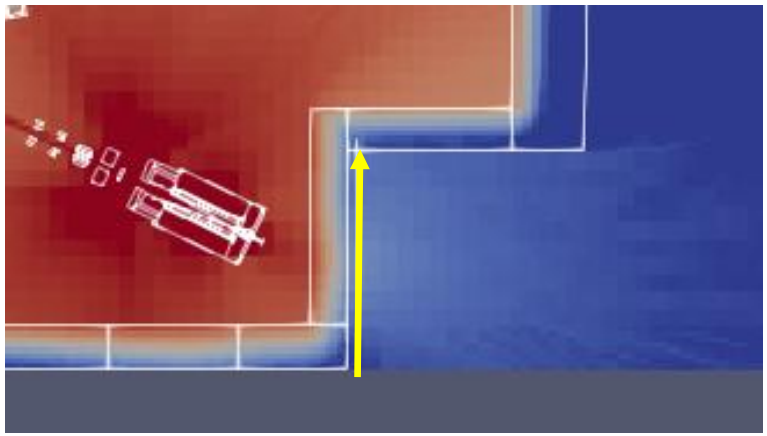
Influence of the high energy tails

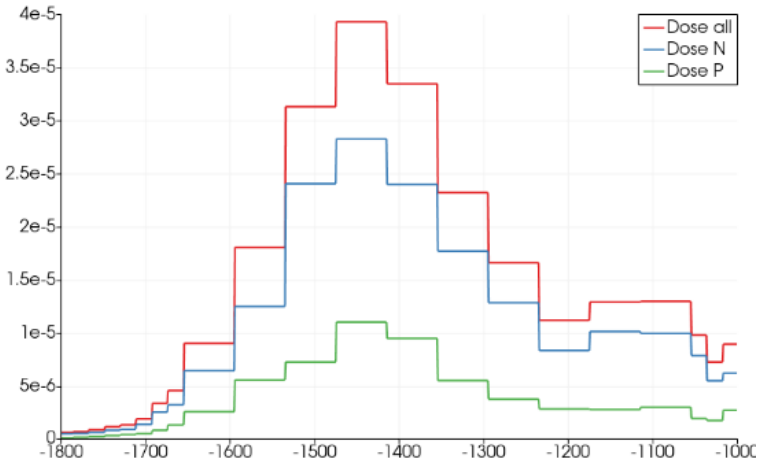
- The results of the simulations follow the trend of the experimental data.
- However, the results present an underestimation of the spectrum for higher energies at forward directions.
- This underestimation can be relevant for DONES applications



Influence of the high energy tails

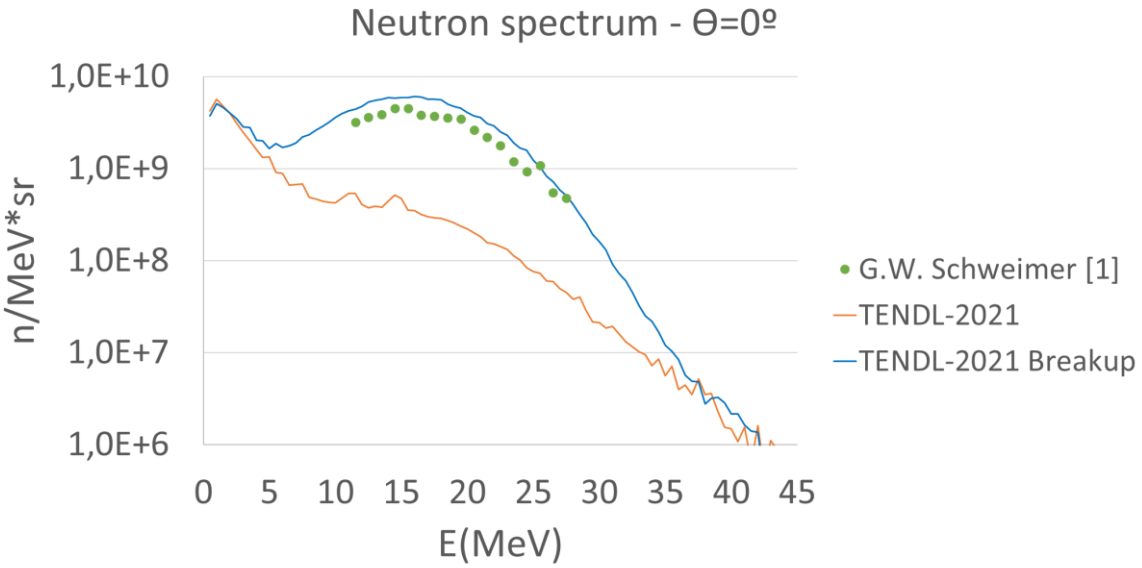
- The results of the simulations follow the trend of the experimental data surrounding the breakup peak.
- However, the results present an underestimation of the spectrum for higher outgoing energies at forward directions.
- This underestimation can be relevant for DONES applications





Influence of the high energy tails

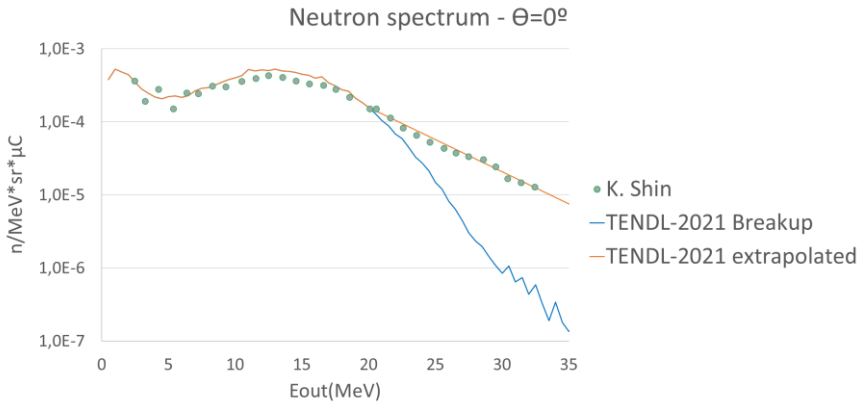
- The experimental data for incident deuterons at 40MeV from Schweimer present a limited energy range.

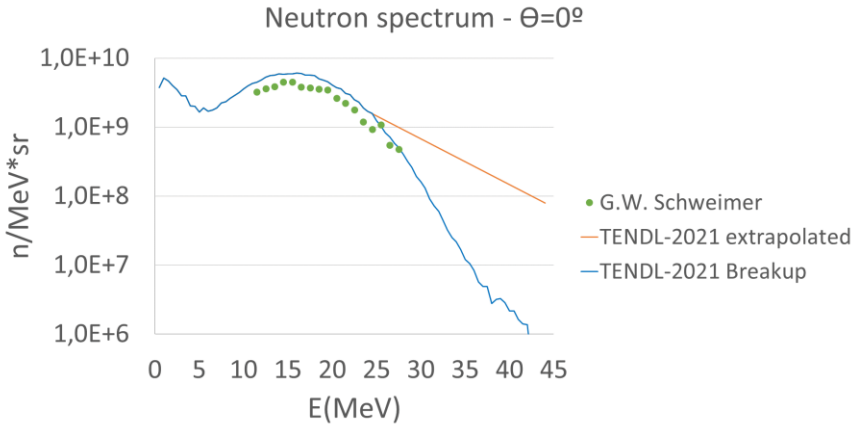


[1] G.W. Schweimer, “Fast neutron production with 54 MeV deuterons”, Nuclear Physics A 100 (1967).

Influence of the high energy tails

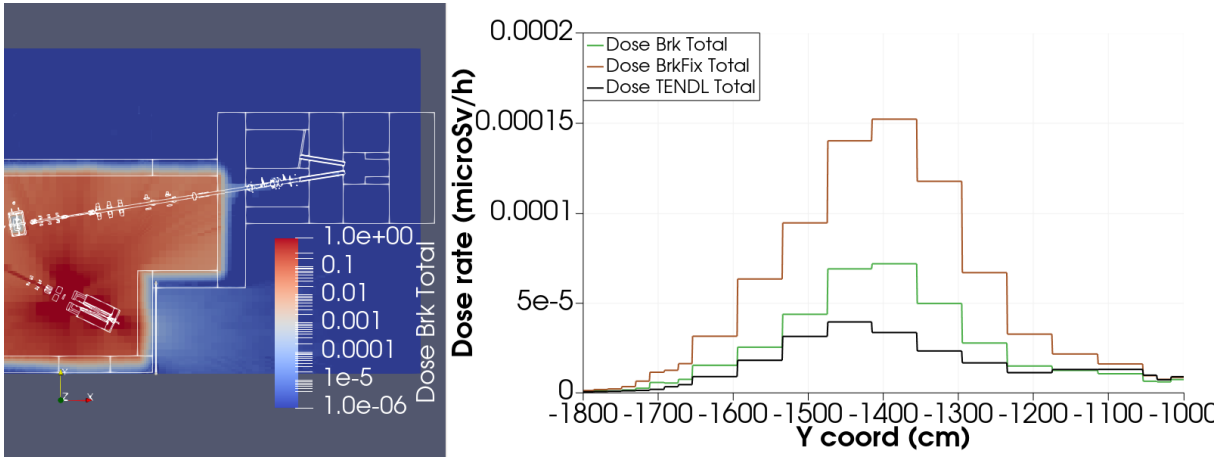
- To mimic the experimental data from K. Shin at 33MeV, at angles lower than 15º, the neutron spectrum for energies from 25 MeV has been extrapolated





Influence of the high energy tails

- Even though it is a small part of the flux, this tail has proven to have a major impact on the dose rates.



Conclusions

- Outside doses may be as high as three times the computed values using TENDL libraries.
- It also has a direct impact on the residual doses, since neutron escapes determine the residual dose field from neutron induced activation.
- This disparity of results, and the scarcity of experimental data to test with, indicates a large uncertainty in the calculations.
- Further experiments are required in order to reduce the uncertainty

Thank you for your attention