Current status and urgent needs of nuclear data and experiments for the IFMIF-DONES design analysis

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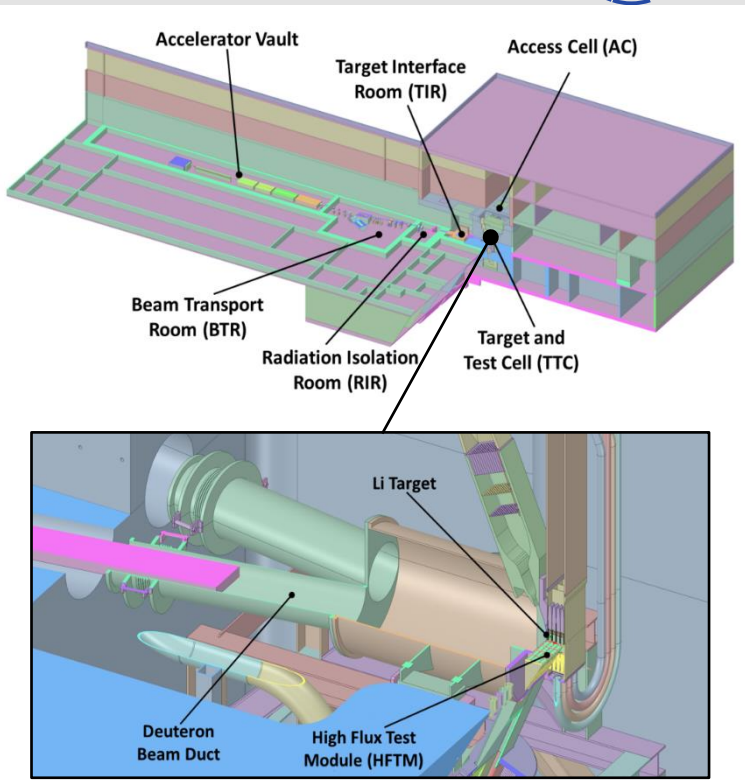
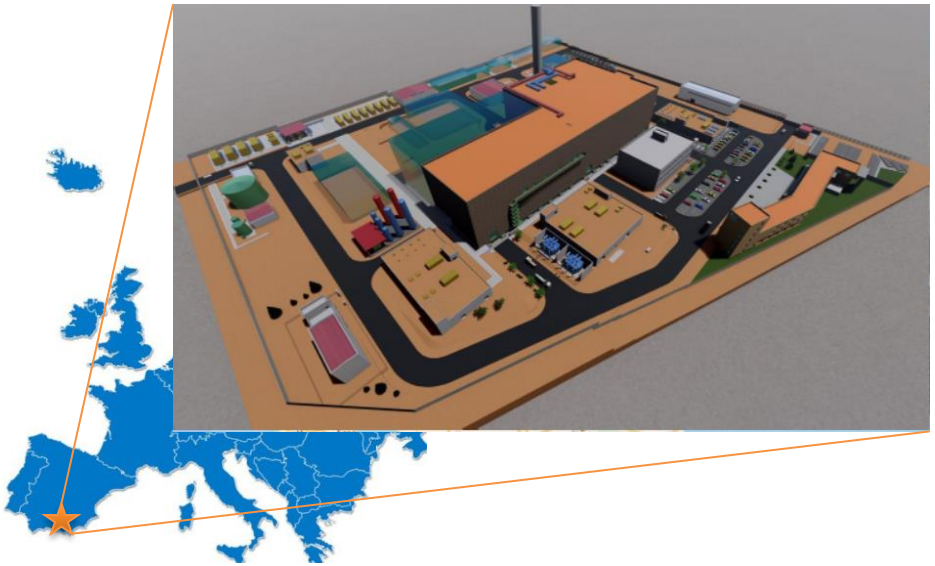
Outline

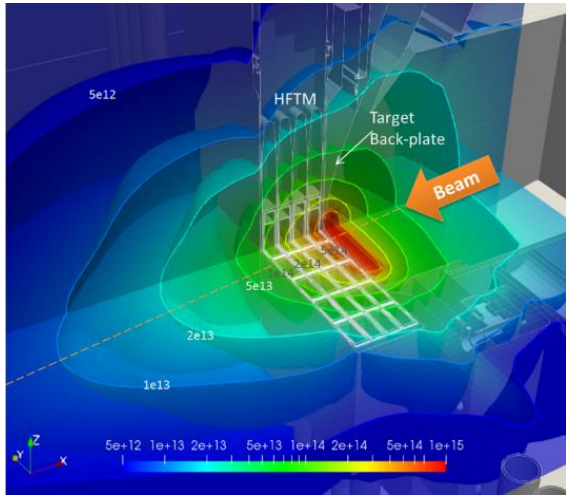
- Introduction of IFMIF-DONES and its source terms
- Current issues with nuclear data and experiments
- Recent Progress
- Summary

Introduction of IFMIF-DONES and its source terms

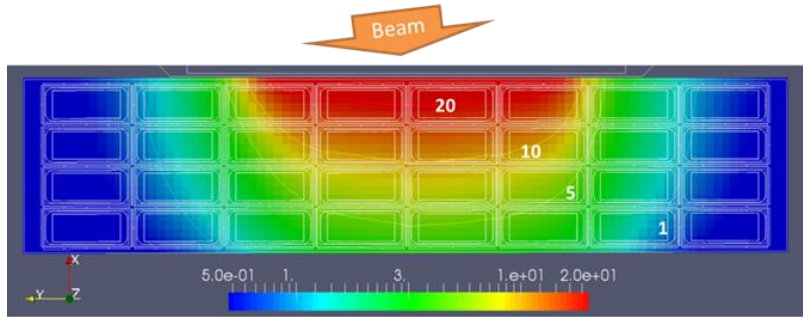
- **IFMIF-DONES: I**nternational **F**usion **M**aterial **I**rradiation **F**acility – **D**emo- **Ne**utron **S**ource
  - **Deuteron-lithium** neutron source. Linear accelerator with **125 mA** and deuteron beam of **40 MeV**.
  - Neutron produced from d-Li stripping reactions, peak flux 10^{15} n/cm^2/s and energy up to **55 MeV**.
  - Lithium target with high-speed Li-flow of 15 m/s. Small specimen hosted in the high flux test modu located immediately behind the target.
  - Producing damage rate up to **20 dpa/fpy**, with irradiation parameters similar to fusion environments.
  - Facility will be built in Granada (Spain).







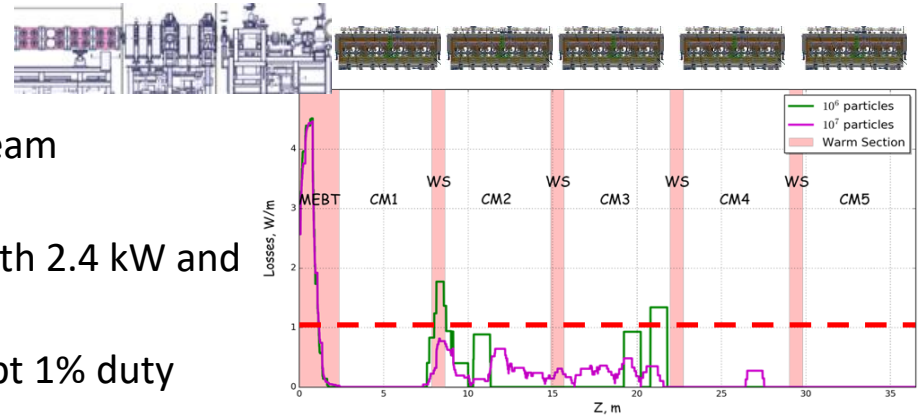
Neutron flux (n/cm^2/s) of the target and HFTM



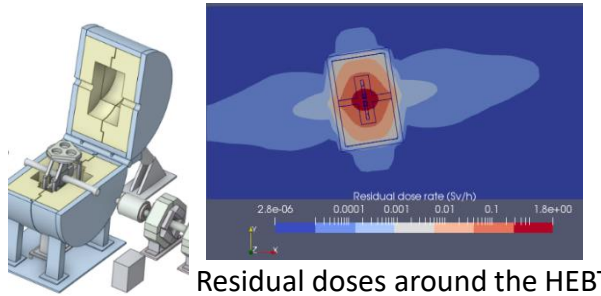
Displacement damage on Iron (dpa/fpy)

Introduction of IFMIF-DONES and its source terms

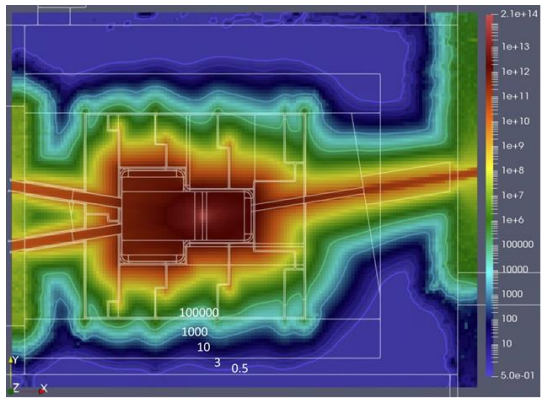
- Source terms of the accelerator systems
  - Beam losses alone the accelerator lines (safety assumption 1 W/m). Beam pipes/ducts make of **Al** and **SS316L**.
  - Radiation from the beam scrapers with **CuCrZr** blades (two scrapers with 2.4 kW and 1.6 kW beam deposition power). Produced neutrons 10^{13} n/s.
  - Radiation from the beam dump under the commissioning phase. Accept 1% duty cycle, i.e. 50 kW beam power, on the **Copper** cone.
- Source terms of the target and test systems
  - d-Li produced neutrons and prompt/decay gamma, and **activation on Li** (produced **^{7}Be, ^{3}H**), and activation corrosion products (ACP).
  - Neutron activation on components structures, Li, cooling water, ACP and atmosphere.



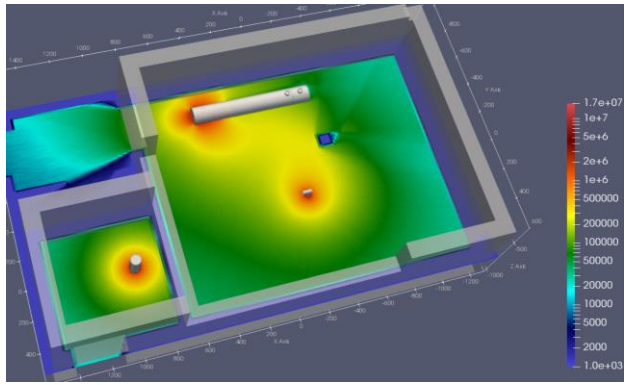
Simulated beam losses in the SFR



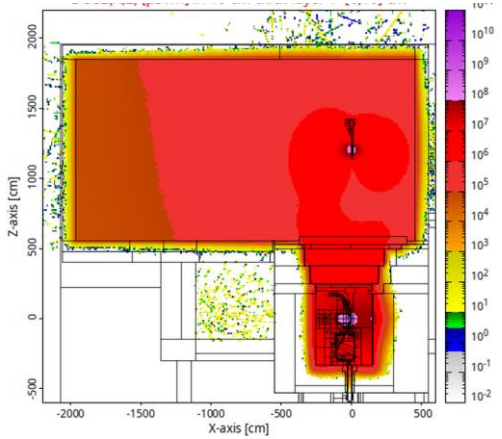
Residual doses around the HEBT scraper after 1-day cooling



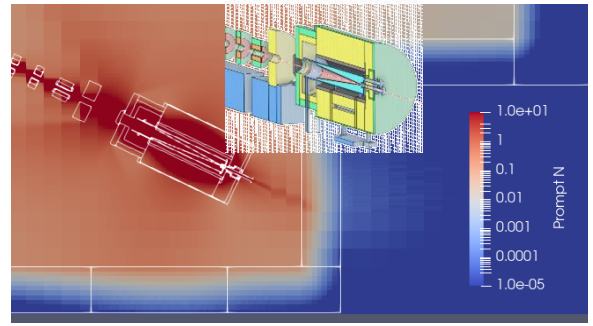
Neutron flux (n/cm^2/s) of the test cell



The dose rate [μSv/h] calculated for the Li loop immediately after shutdown



Shutdown dose rate (SDR) (μSv/h) at 1-day during TC opened and HFTM transporting.



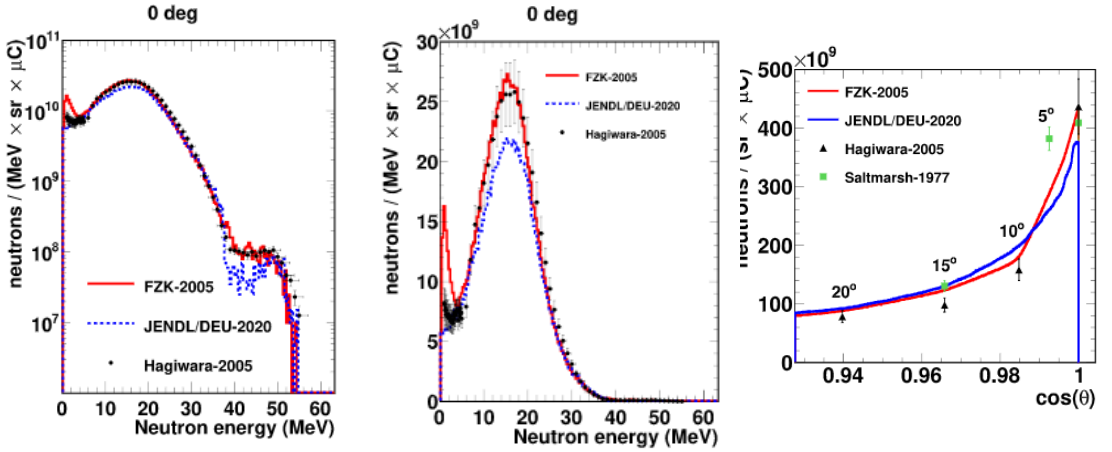
High power beam dump (HPBD) beam-on dose rate (Sv/h)

Current issues with nuclear data and experiments

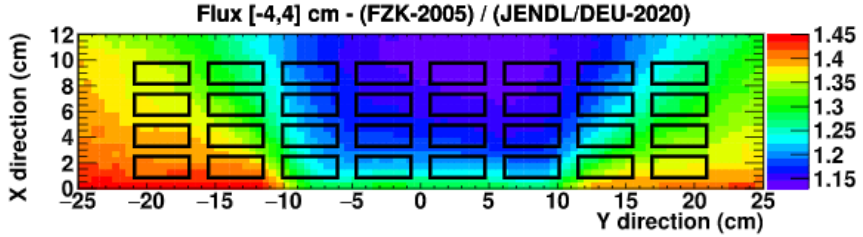
- Deuteron libraries
  - d-Li: (transport/activation) FZK-2005 (ad-hoc libraries of the McDeLicious code)
  - Other isotopes (transport/activation): TENDL (2019/2021).
- Neutron libraries
  - Transport: FENDL-3.1d. Updating to FENDL-3.2 is ongoing.
  - Activation: TENDL (2017+).
- Current issues
  - d-Li: discrepancy in the neutron productions, ^{7}Be and Tritium production
  - Other deuteron libraries: missing deuteron break-up model in TENDL.
  - Lacking specific benchmarking for the high-energy (>20 MeV) data in FENDL.

Current issues with nuclear data and experiments

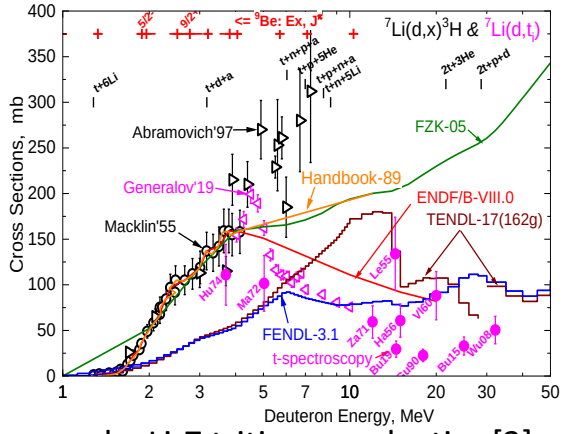
- Current issue with the d-Li nuclear data
  - Current two evaluations: **FZK-2005 And JENDL-DEU 2020**.
  - Comparisons by E. Mendoza [1]show some discrepancies in the **forward angles**, and neutron yield for lower energy (**~1 MeV**).
  - Results for the neutron flux and other nuclear responses results in the High Flux Test Module result in a **large discrepancy** (>20%).
- Current issues with the d-Li activation data
  - **Tritium production**: d + ^{7}Li tritium production, FZK-2005 (McDeLicious data) and TENDL-17 data deviate by **a factor of 3** at 40 MeV.
  - **^{7}Be production**: ^{6}Li (d,n) ^{7}Be production is missing in FZK-2005.
  - Request submitted by Dr Simakov on NEA Nuclear Data High Priority Request List. More up-to-date evaluations and experiments are needed.



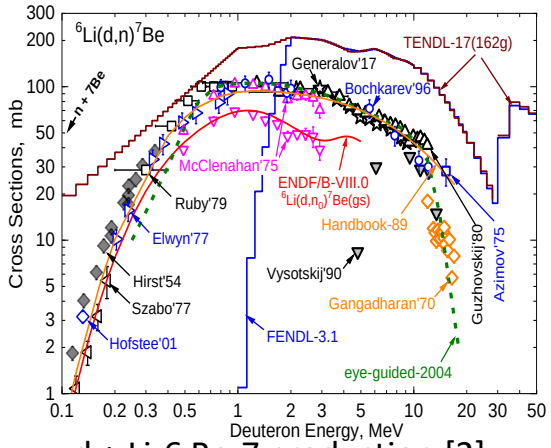
d-Li (40 MeV) Neutron yields as a function of the energy and angels (E. Mendoza, et.al)



IFMIF-DONES neutron flux comparison between FZK-2005 and JENDL DEU-2020 (E. Mendoza, et.al)



d + Li-7 tritium production[2]



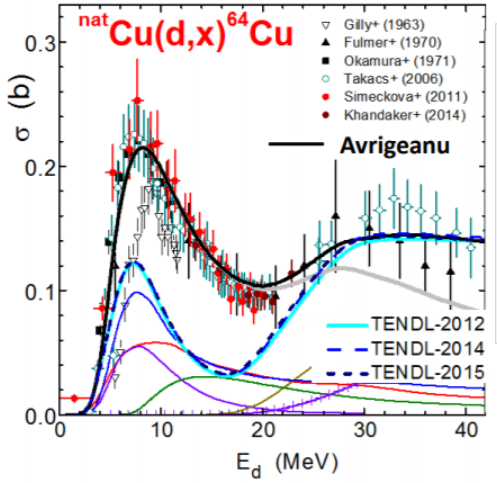
d + Li-6 Be-7 production [2]

[1]Mendoza, E., Cano-Ott, D., Ibarra, A., Mota, F., Podadera, I., Qiu, Y., & Simakov, S. P. (2022). Nuclear data libraries for IFMIF-DONES neutronic calculations. Nuclear Fusion, 62(10), 106026. https://doi.org/10.1088/1741-4326/ac814f

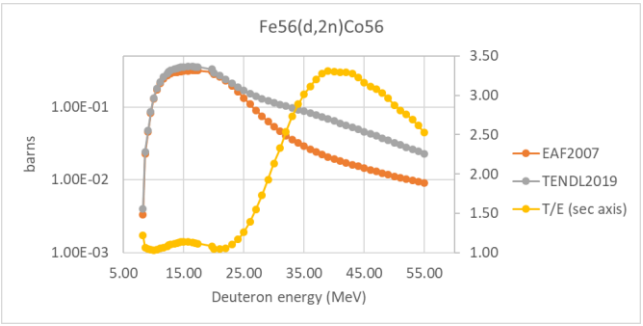
[2]Simakov, Stanislav P., Ulrich Fischer, and Alexander Yu Konobeyev. Status and Benchmarking of the Deuteron Induced Tritium and Beryllium-7 Production Cross Sections in Lithium. Karlsruher Institut für Technologie (KIT), 2020.

Current issues with nuclear data and experiments

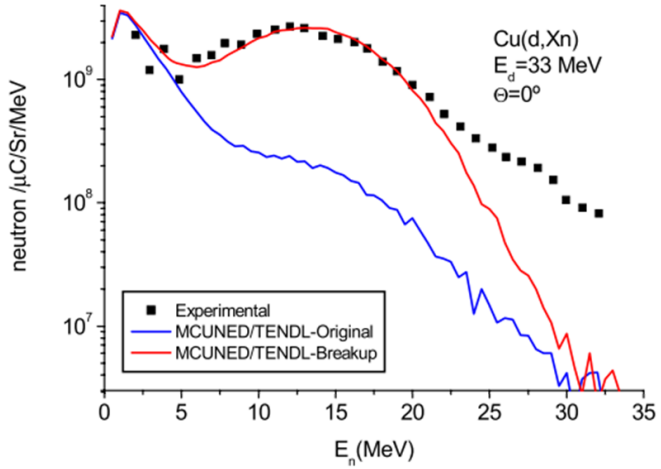
- Current Issues with the deuteron libraries of other isotopes
  - The deuteron activation cross section for the important materials Cu, Nb, Al, SS has deviations of a factor 2~3 for TENDL-2015 and EAF-2007.
  - A new deuteron breakup model has been implemented into the new version of the TALYS code, based on the enhanced model by M. Avrigeanu et al *. However, the latest version of the TENDL 2021 deuteron data library still hasn't implemented this important update.
  - P. Sauvan has implemented an important update on the implementation of the Kalbach neutron angular distribution from the deuteron break-up reaction. However, only special versions of TENDL libraries have the necessary parameters needed for MCUNED code.
  - Experimental benchmarks are missing for the deuteron data elevations and code developments, e.g. shutdown dose.



d-Cu cross section comparisons (U. Fischer | ND-2019)



d-Fe activation cross section (F. Ogando)

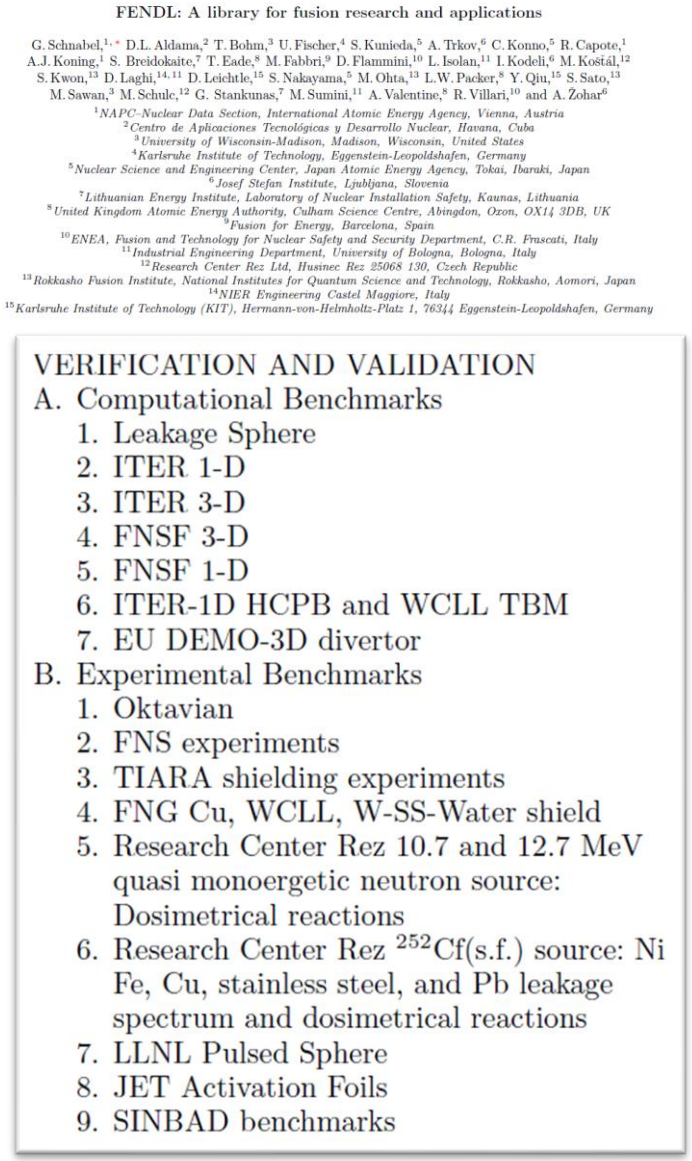


Neutron spectra produced by 33MeV deuteron on thick (3mm) Copper target (P. Sauvan et.al.)

* Avrigeanu, M., Rochman, D., Koning, A. J., Fischer, U., Leichtle, D., Costache, C., & Avrigeanu, V. (2022). **Advanced breakup-nucleon enhancement of deuteron-induced reaction cross sections**. *European Physical Journal A*, *58*(1), 1–13. https://doi.org/10.1140/epja/s10050-021-00659-6

Current issues with nuclear data and experiments

- Current issues with neutron cross sections
  - Current FENDL-3.1d is the references libraries for neutron transport.
  - The new FENDL3.2 has been released, with a large set of computational and experimental benchmarks being conducted.
  - Systematic checking on the important elements for the DONES application is still ongoing, e.g. gas production, heating
  - Experimental benchmarks for the **high-energy neutrons** (DONES: 25% neutrons >14 MeV) are not still lacking. The only one performed is the TIARA shielding experiment for Iron and concrete.
  - The TENDL activation cross section on the high neutron energy needs dedicated benchmarks for DONES application, which is important for safety-relevant evaluation, e.g. Shutdown dose.



FENDL: A library for fusion research and applications

G. Schnabel,[1,*] D.L. Aldama,[2] T. Bohm,[3] U. Fischer,[4] S. Kunieda,[5] A. Trkov,[6] C. Konno,[5] R. Capote,[1] A.J. Koning,[1] S. Breidokaite,[7] T. Eade,[8] M. Fabbri,[9] D. Flammini,[10] L. Isolan,[11] I. Kodeli,[6] M. Košťál,[12] S. Kwon,[13] D. Laghi,[14,11] D. Leichtle,[15] S. Nakayama,[5] M. Ohta,[13] L.W. Packer,[8] Y. Qiu,[15] S. Sato,[13] M. Sawan,[3] M. Schulc,[12] G. Stankunas,[7] M. Sumini,[11] A. Valentine,[8] R. Villari,[10] and A. Zohar[6]

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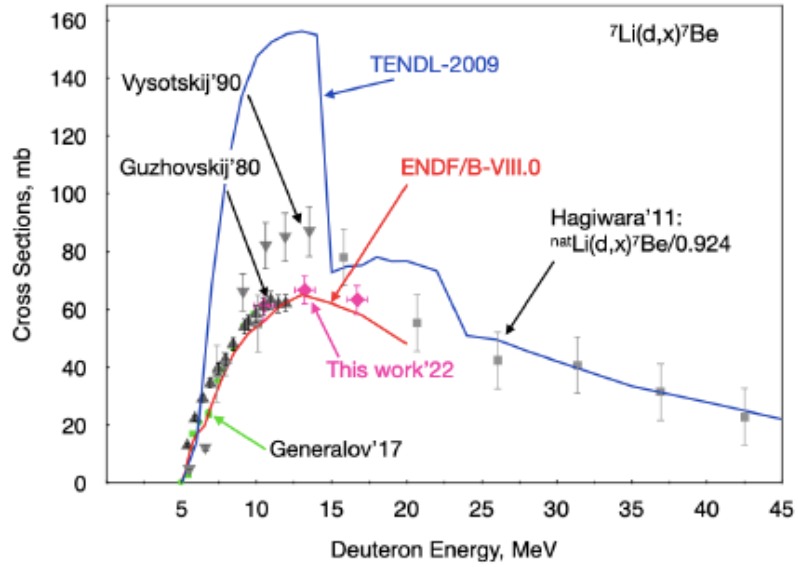
VERIFICATION AND VALIDATION

A. Computational Benchmarks
   1. Leakage Sphere
   2. ITER 1-D
   3. ITER 3-D
   4. FNSF 3-D
   5. FNSF 1-D
   6. ITER-1D HCPB and WCLL TBM
   7. EU DEMO-3D divertor

B. Experimental Benchmarks
   1. Oktavian
   2. FNS experiments
   3. TIARA shielding experiments
   4. FNG Cu, WCLL, W-SS-Water shield
   5. Research Center Rez 10.7 and 12.7 MeV quasi monoergetic neutron source: Dosimetrical reactions
   6. Research Center Rez ^{252}Cf(s.f.) source: Ni Fe, Cu, stainless steel, and Pb leakage spectrum and dosimetrical reactions
   7. LLNL Pulsed Sphere
   8. JET Activation Foils
   9. SINBAD benchmarks

Recent Progress

- Progress on the d-Li data
  - With the synergies of building an IFMIF-like facility in JAPAN (the A-FNS facility), a bilateral agreement between EUROfusion and QST is currently undergoing on the V&V of JENDL-5 deuteron libraries, in particular with the d-Li data.
  - The urgent need for experimental data on d-Li activation (^{7}Be, ^{3}H) is current in the High Priority Request List (HPRL) NEA Nuclear Data bank. Some activities are ongoing in NPI-Rez [1].



Cross section of $_{7}$Li(d,x)$_{7}$Be reaction compared with other experimental data and libraries (Koliadko, et.al)

[1]D. Koliadko, et.al.High Priority Request List cross-section measurements: 7Li(d,x)7Be/3H and 39K(n,p)39Ar, proceedings at 15th International Conference on Nuclear Data for Science and Technology, 2022.

Recent Progress

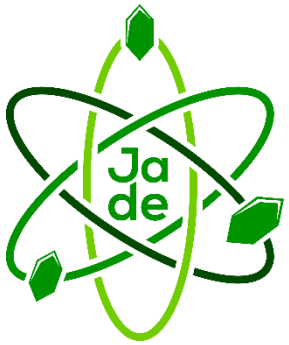
- Progress on the deuteron data transport and activation data
  - Collaboration with the EUROfusion nuclear data program in pushing the update of TENDL version 2023 deuteron data with the deuteron break-up enhancement model.
  - Special version of TENDL will be produced with the Kalbach angular distributions parameters for MCUNED code.
  - Comparison with the available data files of JENDL-5 deuteron data (available: C, Be, Li, Al, Cu, Nb) will provide additional confirmation on the data quality of TENDL deuteron data.
- Progress on the neutron data
  - FENDL-3.2 library computational benchmarks will be performed thoroughly for all the isotopes, using automatic tools such as JADE[1].
  - Dedicated tasks have been planned in 2023 on performing computation benchmarks with the DONES engineering model.

SPHERE LEAKAGE TEST RESULTS RECAP: ERRORS

ZAID		TALLY								
Zaid	Zaid Name	Neutron Flux at the external surface in Vitamin-J 175 energy groups	Neutron heating with F4+FM multiplier	Neutron heating F6	He ppm production	T production	DPA production	Gamma flux at the external surface [FINE@FISPACT MANUAL 24 Group Structure]	Gamma heating with F4+FM multiplier	Gamma heating F6
1001	H-1	9.66%	0.99%	0.99%	0.00%	0.00%	1.61%	2.78%	2.61%	2.61%
1002	H-2	2.48%	12.00%	0.95%	0.00%	1.64%	0.47%	2.46%	2.44%	51.00%
1003	H-3	0.84%	0.96%	0.96%	0.00%	0.00%	0.47%	0.00%	0.00%	0.00%
2003	He-3	3.34%	1.40%	1.40%	1.29%	9.73%	24.00%	6.09%	1.18%	1.18%
2004	He-4	0.78%	1.09%	1.09%	0.00%	0.00%	0.69%	0.00%	0.00%	0.00%

LEGEND	
	> 50%
	20% ≤ 50 %
	10% ≤ 20 %
	< 10%

According to MCNP manual



[1]Laghi, D., Fabbri, M., La Rovere, S., Isolan, L., Pampin, R., Portone, A., & Sumini, M. (2023). Status of JADE, an open-source software for nuclear data libraries V&V. *Fusion Engineering and Design*, *187*, 113380. https://doi.org/https://doi.org/10.1016/j.fusengdes.2022.113380

Summary

- IFMIF-DONES facility is a neutron source facility for fusion material irradiation and qualifications. Its design and safety licensing rely strongly on high-quality nuclear data.
- Currently there are issues in the nuclear data including the d-Li neutron production, d-Li activation (^{7}Be, ^{3}H), and other deuteron transport/activation libraries.
- Progress is made on these fronts, including EUROfusion, EU, and international collaboration. However, more efforts are still needed in particular on the experiments.