

Nuclear safety and radwaste aspects of the IFMIF-DONES lithium target assembly

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Objectives and scope of the neutronics analysis:

- The functionality of the whole IFMIF-DONES (International Fusion Materials Irradiation Facility – DEMO Oriented NEutron Source) depends on the safe interaction of the D+ beam with the liquid Li target, avoiding any interactions of D+ with the Target Assembly (TA) structural components, such as the Beam Duct, Li inlet and outlet channels, and Back-plate. That is accomplished by the precise D+ beam dynamics, CAD design modeling, and accurate neutronics analyses. This work presents neutronics aspects of the D+ interaction with TA lithium and structures.

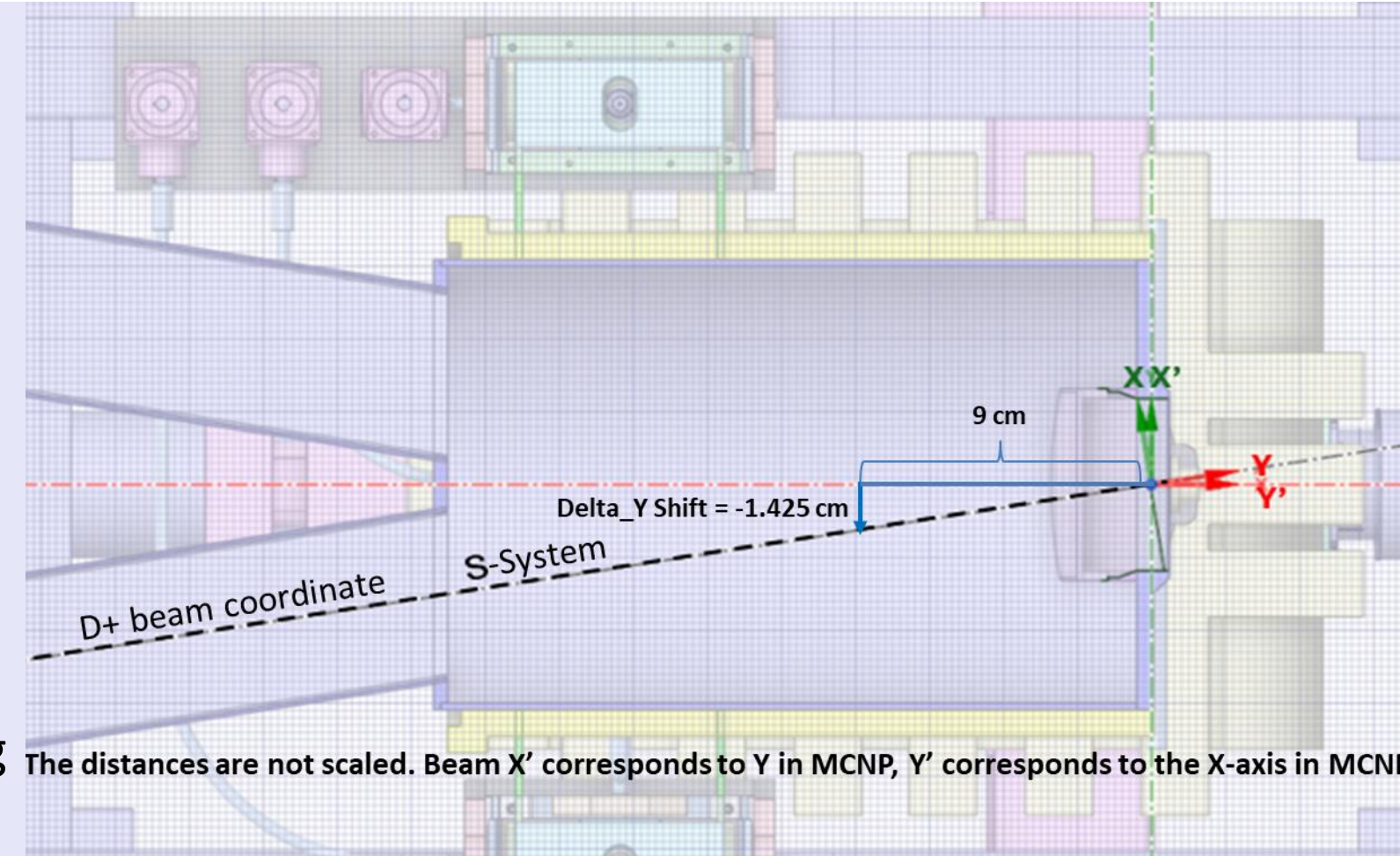
Three steps of the TA components neutronics and thermo-mechanical analyses:

- MCNP geometry modification of the Li channel in Target Assembly;
 - Define the D+ profiles from the CIEMAT results of D+ beam dynamics analyses
- Calculate total heat deposition densities (W/cc) caused by all types of atomic and nuclear interactions: D+ interaction with atomic electron clouds and cascade of nuclear reactions of D+ with nuclei of lithium and structural material of the TA channel (D+, neutron, photon, proton). All nuclear and atomic processes are taken into account, producing heating sources in all the materials of TA (lithium, EUROFER, SS316L steel).
- Neutronics heat sources (W/cc) input for the STAR-CCM+ code thermo-mechanical simulations. Temperature maps at TA calculated as one of the thermal analysis outcomes.

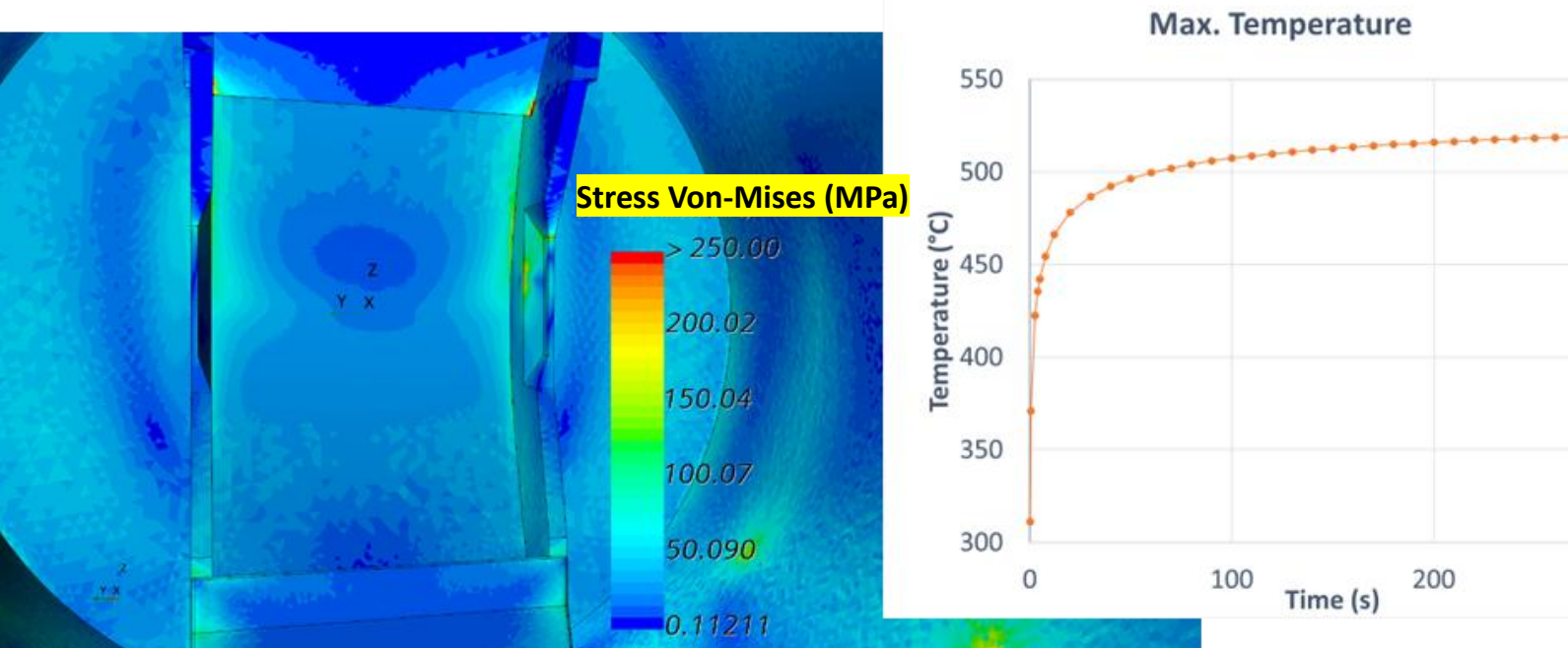
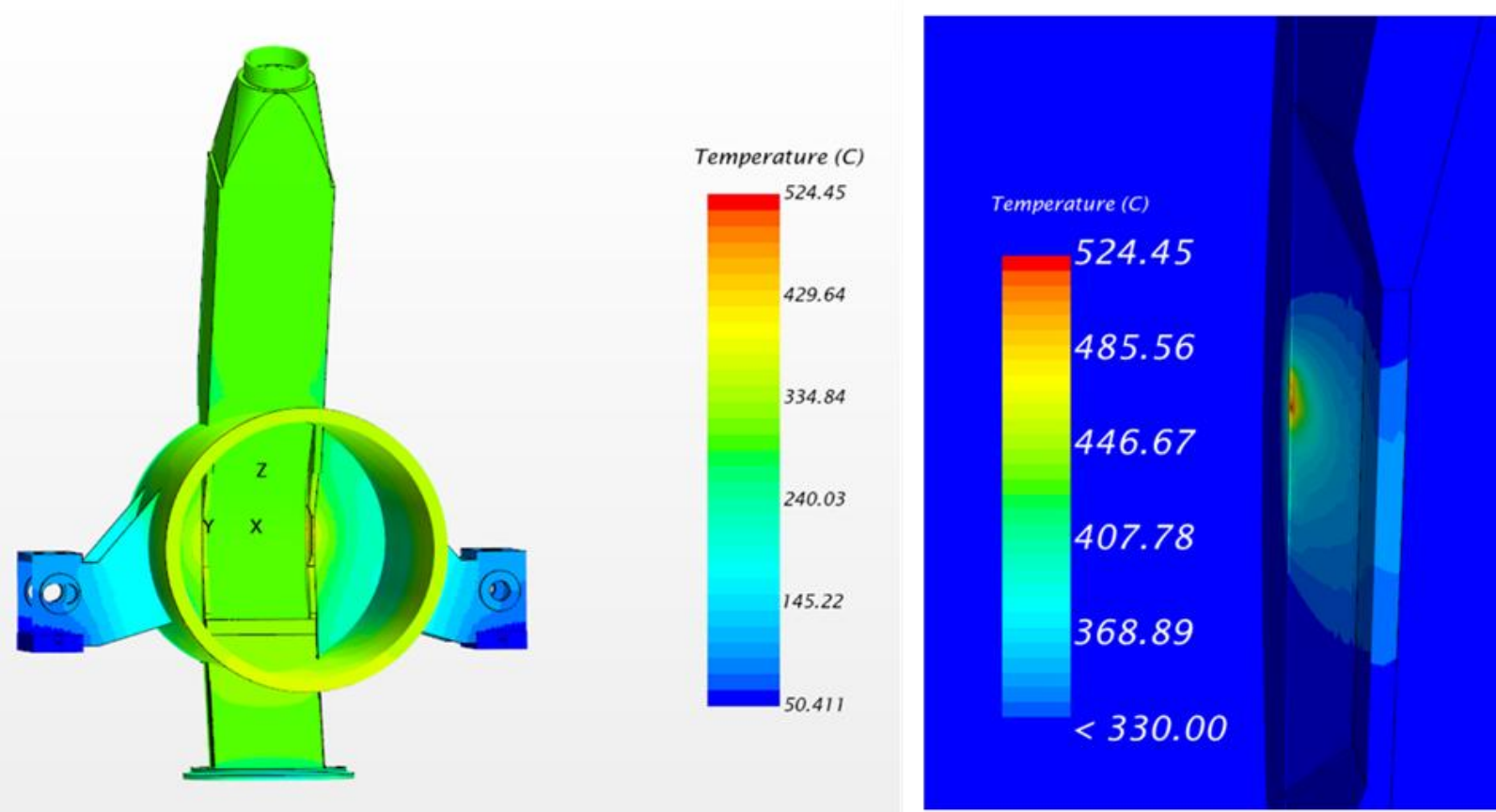
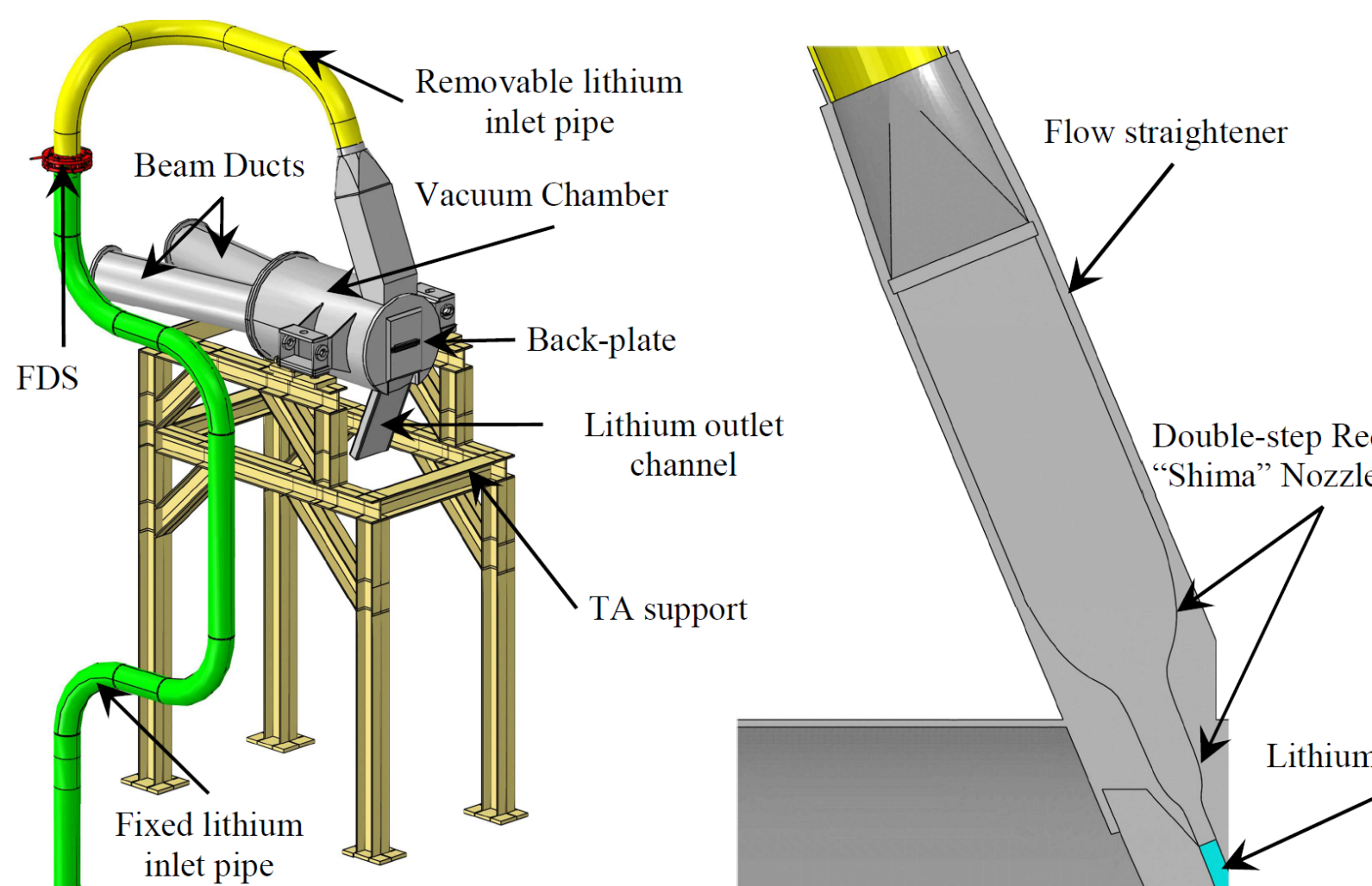
The Deuteron (D+) beam is focused to the center of TA. To investigate the possible interactions of the beam with the channel structure, the beam source is modeled in MCNP at **9 cm upstream of the Li front surface**. The MCNP Y-coordinates were transformed in relation to the beam dynamics coordinates by a horizontal shift:

$\Delta Y = -(9\text{cm} \cdot \tan(9^\circ)) = -1.425\text{cm}$.

The plane perpendicular to the X-axis at X=-11.7 cm is used as the plane D+ source in the MCNP calculations. This D+ beam center has the following MCNP coordinates: X= -11.7cm, Y= -1.425cm, Z=0.



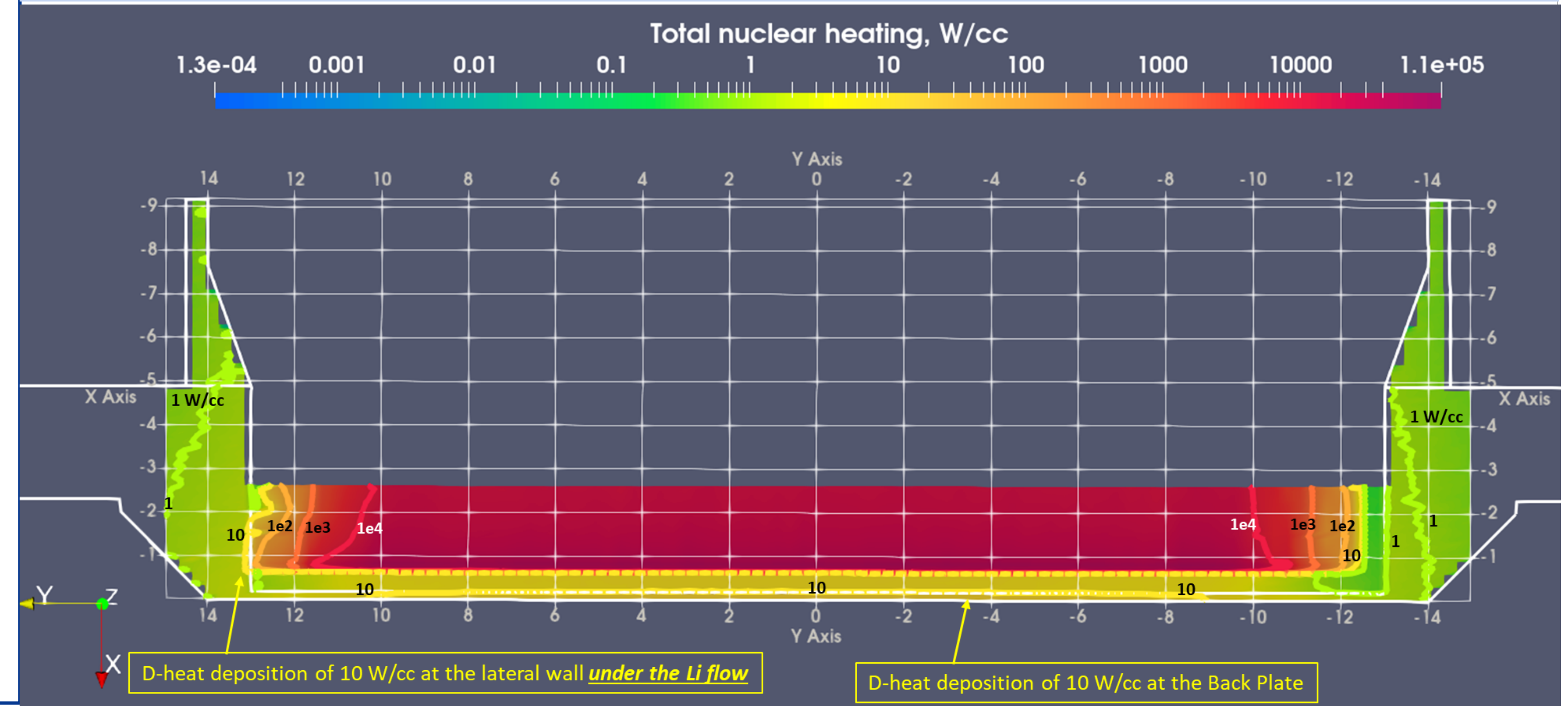
- Safety analyses of D+ beam interaction with the DONES liquid lithium target have been performed, minimizing (avoiding) the interactions of D+ with Target Assembly (TA) structural components, such as the Beam Duct, Li-inlet and outlet channel, and Back-plate.
- Nuclear safety is accomplished by precise D+ beam dynamics, CAD design modeling, and accurate MCNP neutronics analyses. This work presents neutronics aspects of the D+ interaction with TA lithium and structures.



A Monte Carlo CAD-based neutronics methodology developed at KIT with codes such as McDeLicious-17, OTF-GVR, McCad can model the d-Li neutron & photon source at the Li target and perform effective deep-penetration radiation transport calculations.

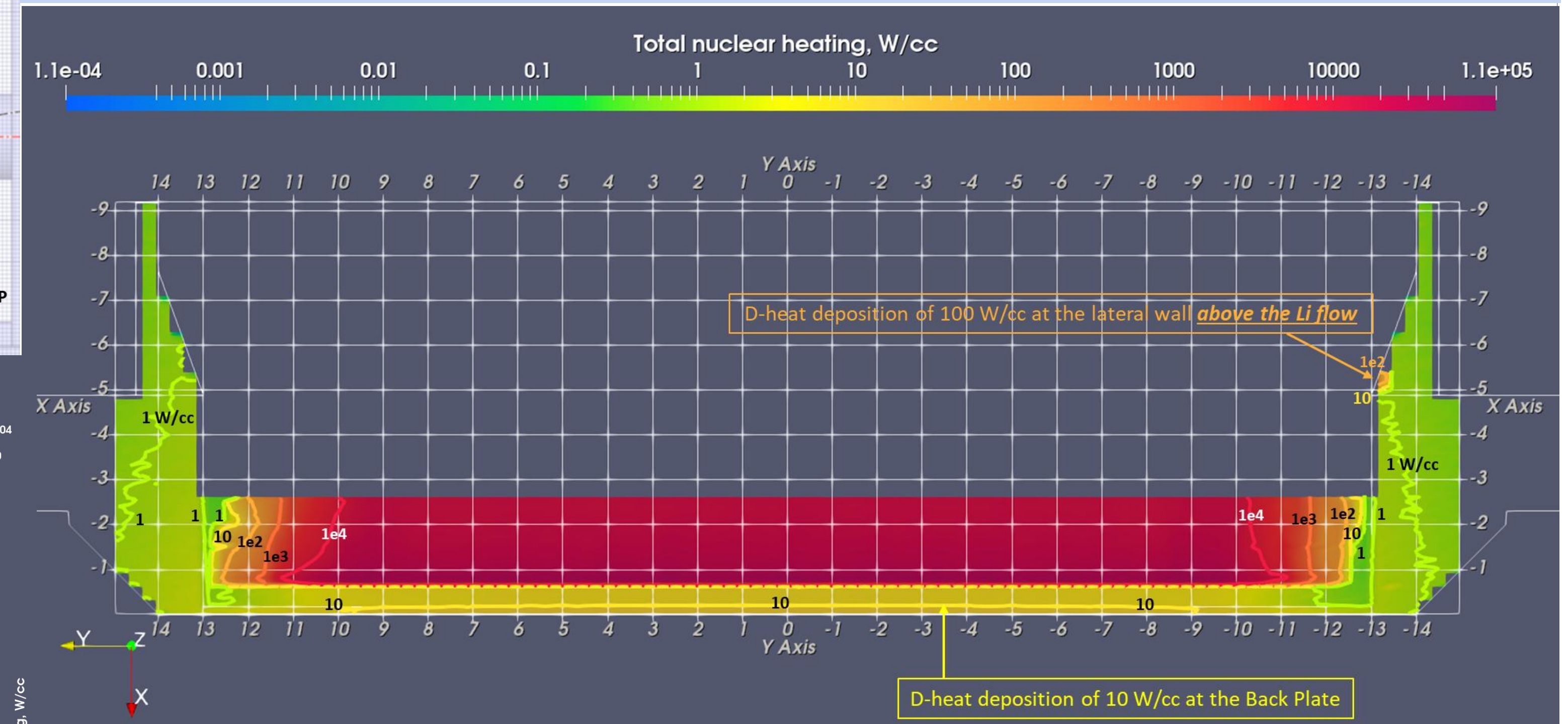
- The neutronics computations have been performed on Marconi-Fusion, Leonardo, and Pitagora HPC Cineca, Italy. Neutron and photon fluxes, neutron damage, T-production, and nuclear heating have been analyzed for the structural and functional materials in <https://indico.ifmif-dones.es/event/29/contributions/785/>
- The beam of deuteron (d) ions is accelerated to 40 MeV with a current of 125 mA to impinge on the target of liquid lithium (Li) jet, producing by nuclear stripping reaction Li(d,xn) neutron flux of $5e14$ n/cm²/s peaking at the energy of 14-15 MeV.

Heating (W/cc) by all particles for the Reference case 9cmBP



Comparison of Ref. vs. worst-case total heating deposition in Li flow and Eurofer channel at the central slice (pz=0)

Heating (W/cc) by all particles for the Worst-case 9cmBP



Activation analysis and radwaste management of the TA Back-Plate:

TA Back-Plate (BP)

- To support the IFMIF-DONES licensing and the Target Assembly (TA) radwaste assessments and management, activation analyses were performed for the Back-Plate (BP), the most radioactive component in DONES.
- The study evaluated two candidate materials, **SS316Ti** and **Eurofer-97**, using the **MCNP6.2** and **FISPACT-II** codes. Specific (Bq/kg) and total (Bq) activities were determined for all identified radioisotopes to ensure compliance with Low- and Intermediate-Level Radioactive Waste (LILW) acceptance criteria for disposal by ENRESA at the El Cabril facility in Spain.
- The TA Back Plate materials were irradiated by neutrons during **1 FPY (365 days)** at DONES with 1 accelerator with 125 mA deuteron current
- The activation analysis across the entire BP identified the footprint zone as the most activated part.

Total activity (Bq) in SS316Ti & EUROFER of DONES BP vs. ENRESA waste acceptance criteria Levels 1&2

Level 1		Limit Cylindrical Packaging (Bq)			Limit Parallelepiped Packaging (Bq)		Total Activity SS316Ti (Bq)	Total Activity EUROFER (Bq)
Radionuclides	Conditioned Waste	Non-compactable waste	Compactable waste	All Types				
H-3	2,12E+10	1,06E+10	9,81E+09	1,87E+10		9,62E+10	9,46E+10	
C-14	1,06E+10	1,06E+10	4,91E+09	4,91E+09		2,652E+08	7,900E+07	
Mn-54	1,06E+10	1,06E+10	4,91E+09	9,37E+09		3,00E+13	3,42E+13	
Fe-55	1,06E+10	1,06E+10	4,91E+09	9,37E+09		4,96E+13	6,46E+13	
Co-58						8,587E+13	1,162E+11	
Co-60	1,06E+10	1,06E+10	4,91E+09	9,37E+09		5,87E+11	1,51E+10	
Zn-65	2,87E+10	2,87E+10	1,33E+10	2,53E+10		5,165E+07	5,161E+05	
Ni-59	1,06E+10	1,06E+10	4,91E+09	9,37E+09		2,277E+08	1,884E+05	
Ni-63	1,06E+10	1,06E+10	4,91E+09	9,37E+09		1,91E+10	1,06E+08	
Nb-94	2,67E+08	2,14E+08	1,12E+08	1,66E+08		9,00E+06	1,11E+06	
Tc-99	2,23E+09	1,78E+09	9,37E+08	1,39E+09		6,17E+08	1,24E+06	

Level 2		Limit for packages to be generated in cylindrical and/or parallelepiped packaging (Bq)		Limit for existing or unscheduled generation packages (Bq)		Total Activity SS316Ti (Bq)	Total Activity EUROFER (Bq)
Radionuclides	All natures	Non-compactable waste	Compactable waste				
H-3	2,23E+12	1,78E+12	9,37E+11			9,621E+10	9,46E+10
C-14	4,45E+11	3,57E+11	1,87E+08			2,652E+08	7,900E+07
Ni-59	1,40E+11	1,12E+11	5,90E+10			2,277E+08	1,884E+05
Co-60	1,11E+14	8,92E+13	4,68E+13			5,869E+11	1,513E+10
Ni-63	2,67E+13	2,14E+13	1,12E+13			1,912E+10	1,056E+08
Nb-94	2,67E+08	2,14E+08	1,12E+08			9,002E+06	1,111E+06
Tc-99	2,23E+09	1,78E+09	9,37E+08			6,17E+08	1,24E+06

Conclusions: Neutron activation studies have been conducted on EUROFER and SS316Ti materials with the objective of evaluating activation levels for their management and disposal as low- and intermediate-level radioactive waste (LILW) by the National Radioactive Waste Management Company in Spain (ENRESA). The results demonstrate that both SS316(Ti) and EUROFER can be managed as LILW at the El Cabril disposal facility, since all radionuclides generated by activation comply with the ENRESA-established level 2 waste acceptance criteria.