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Radiation shielding analyses for the IFMIF-DONES Test Cell

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Motivation of this computational neutronics research work:

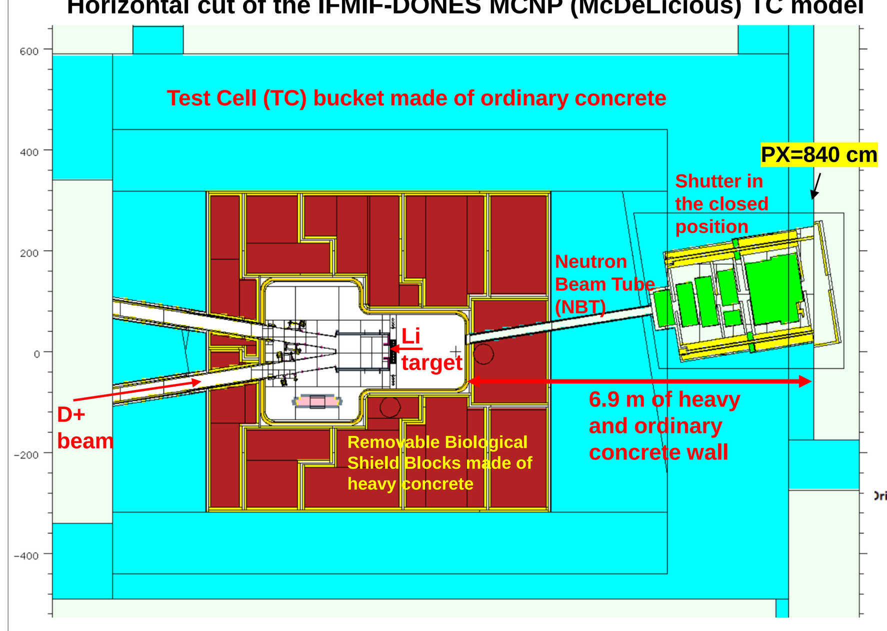
Inside the IFMIF-DONES Test Cell (TC), accelerated to 40 MeV deuterons with a current of 125 mA are impinged at the liquid lithium target, forming a neutron spectrum up to 55 MeV and total neutron flux of 5e14 n/cm2/s by the deuterium-lithium Li(d,xn) nuclear reactions. These neutrons should be used safely and effectively by the IFMIF-DONES users.

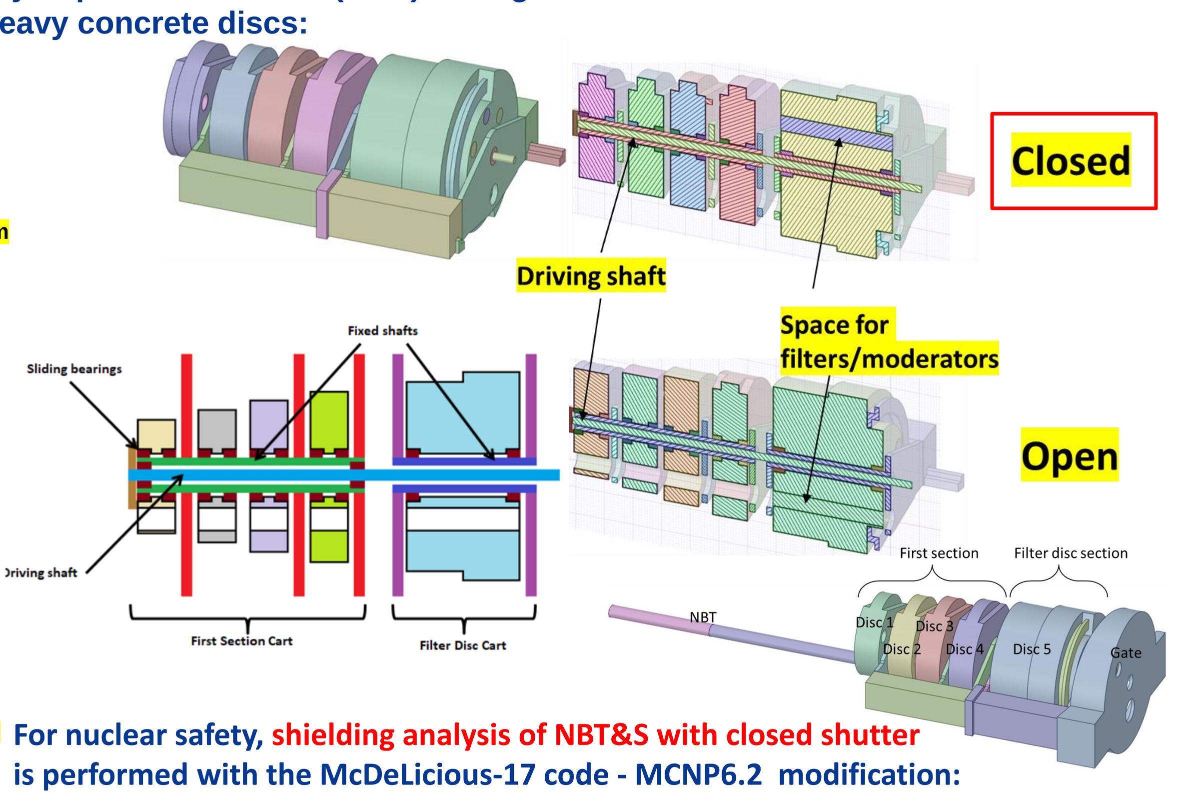
To approximate the radiation environment of the EU DEMO breeding blanket, structural materials will be irradiated inside the High Flux Test Module (HFTM), located immediately behind the Li target. The blanket materials with functions of tritium breeding and neutron multiplication will be irradiated inside the Other Irradiation Modules (OIMs) currently developed for installation in TC.

The purpose of this research is to perform radiation shielding analyses for the IFMIF-DONES Test Cell (TC) with the installation of two OIMs: 1) Tritium Release Test Module (TRTM) and 2) **BLUME: Blanket fUnctional Materials modulE** of the Helium Cooled Pebble Bed (HCPB) breeding blanket. Updated design of the Neutron Beam Tube and Shutter (**NBT&S**) system in TC requested to conduct shielding analyses to meet the dose regulations. The NBT&S system supplies with collimated neutrons DONES users inside the Complementary Experiments Room (CER), connected to TC through the 6.9 m thick TC-to-CER wall.

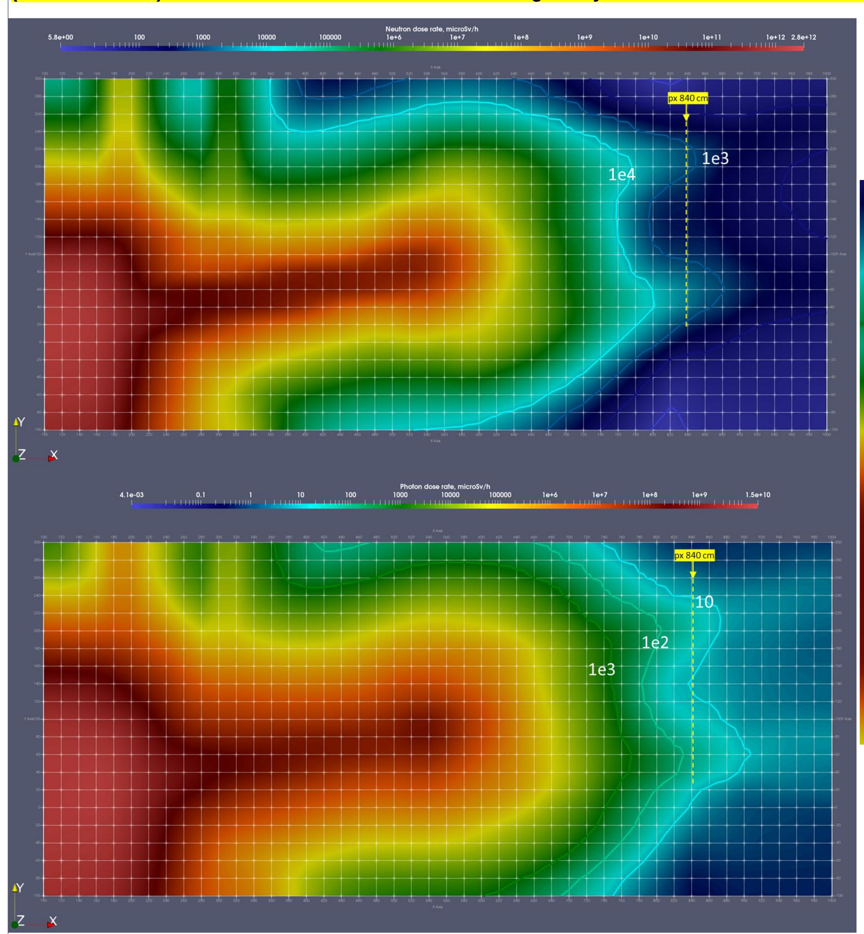
Collimated neutrons supply from TC to the Complementary Experiments Room (CER) through the Neutron Beam Tube and Shutter (NBT&S) system. The shutter is composed of 5 rotating heavy concrete discs:

Horizontal cut of the IFMIF-DONES MCNP (McDeLicious) TC model



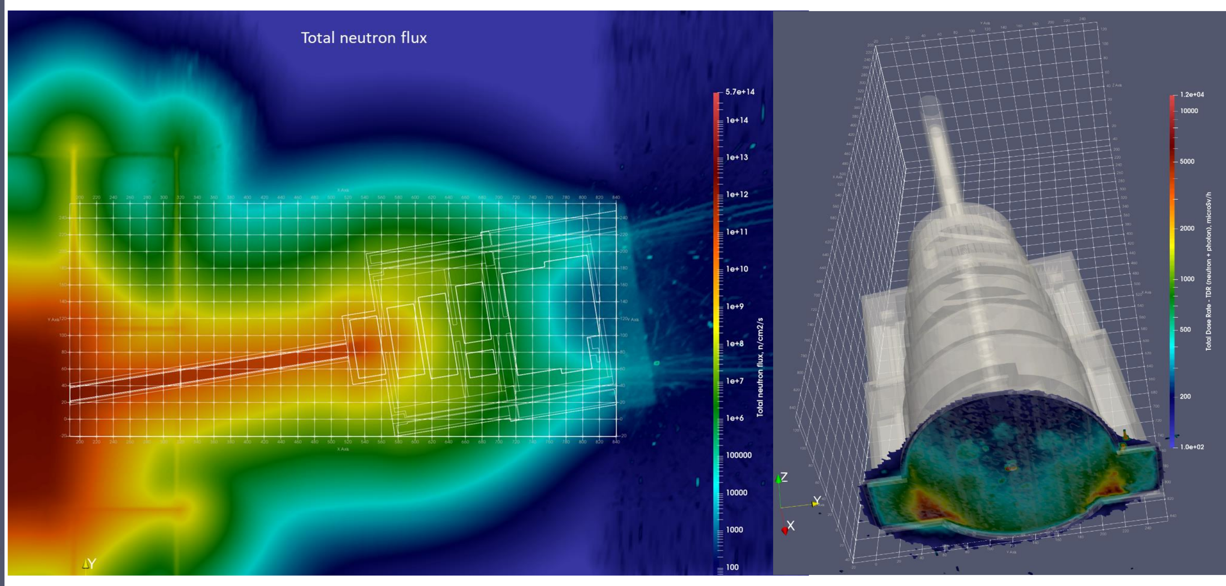


The photon dose rate (dose isoline >10 microSv/h) is 100 times less than the neutron dose rate (>1e3 microSv/h) at the entrance to CER from NBT&S assigned by a vertical surface PX=840 cm



For nuclear safety, shielding analysis of NBT&S with closed shutter is performed with the McDeLicious-17 code - MCNP6.2 modification:

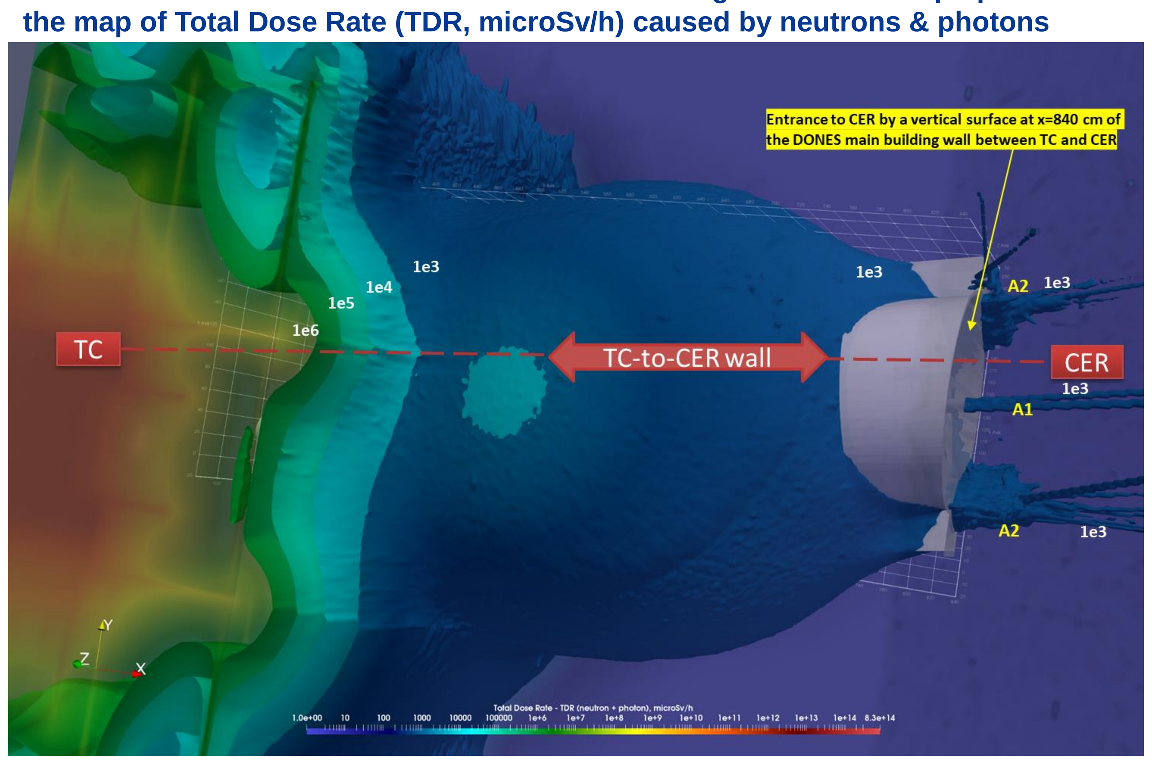
In the NBT&S configuration with closed shutter, two areas A1 & A2 of the excessive neutron streaming were found. These areas A1 & A2 are depicted on pages 34-37 of the MCNP cuts. The first area of streaming A1 is caused by the 1-cm straight gap arranged around the Driving Shaft. The second area A2 is formed by two lateral empty corners between rails and Disk#5 – the last disk of the NB Shutter.



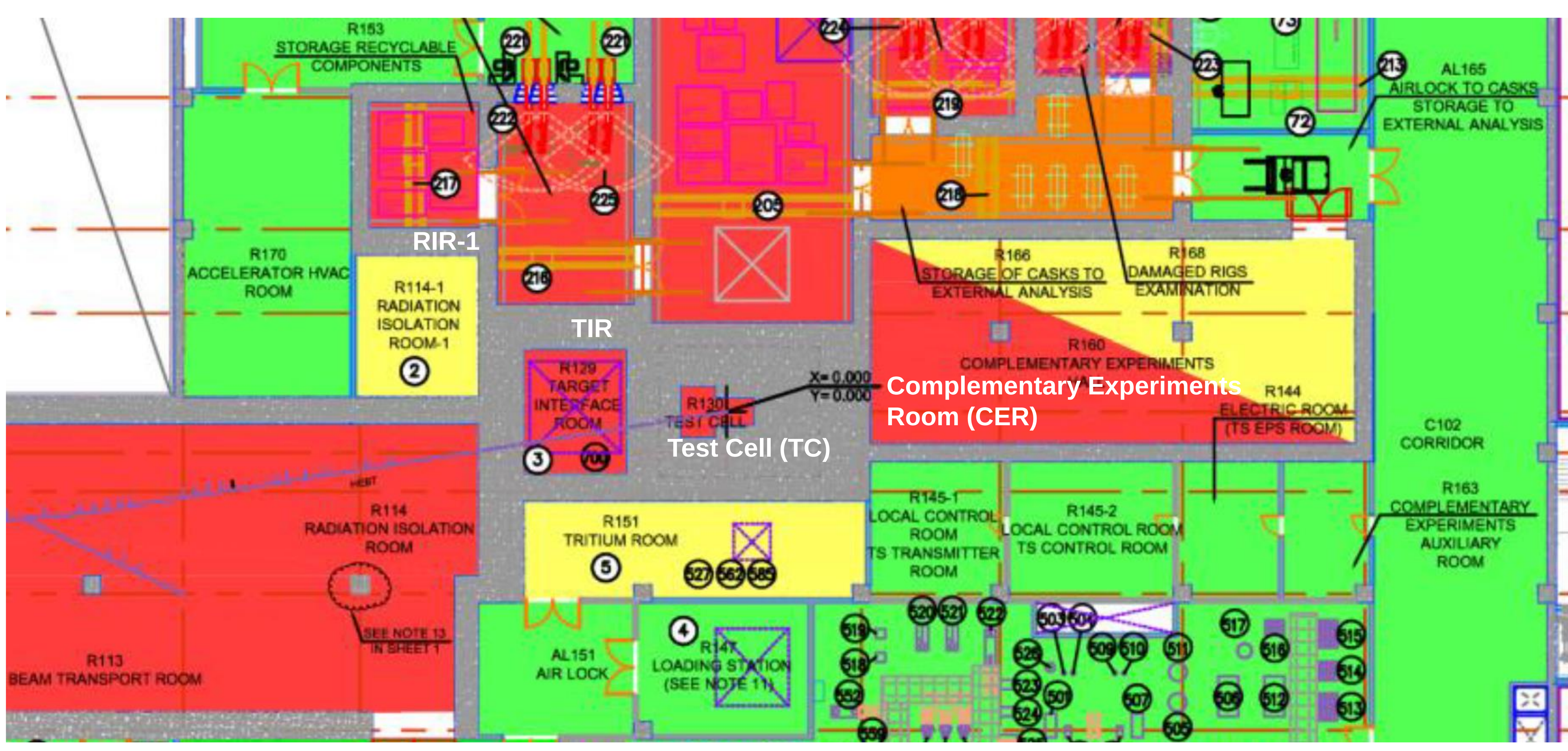
IRRADIATION AREA CLASSIFICATION

Area		Colour	Total dose rate Effective dose rate external & internal exposure
Unrestricted area within the facility			
Unrestricted area		White	< 0.5 μSv/h
Controlled and Supervised areas			
Supervised area		Blue	< 3 μSv/h
Controlled area	Free Permanenced	Green	< 10 μSv/h
	Limited Regulated	Yellow	< 1 mSv/h
	Specially Regulated	Orange	< 100 mSv/h
	Forbiden	Red	≥ 100 mSv/h

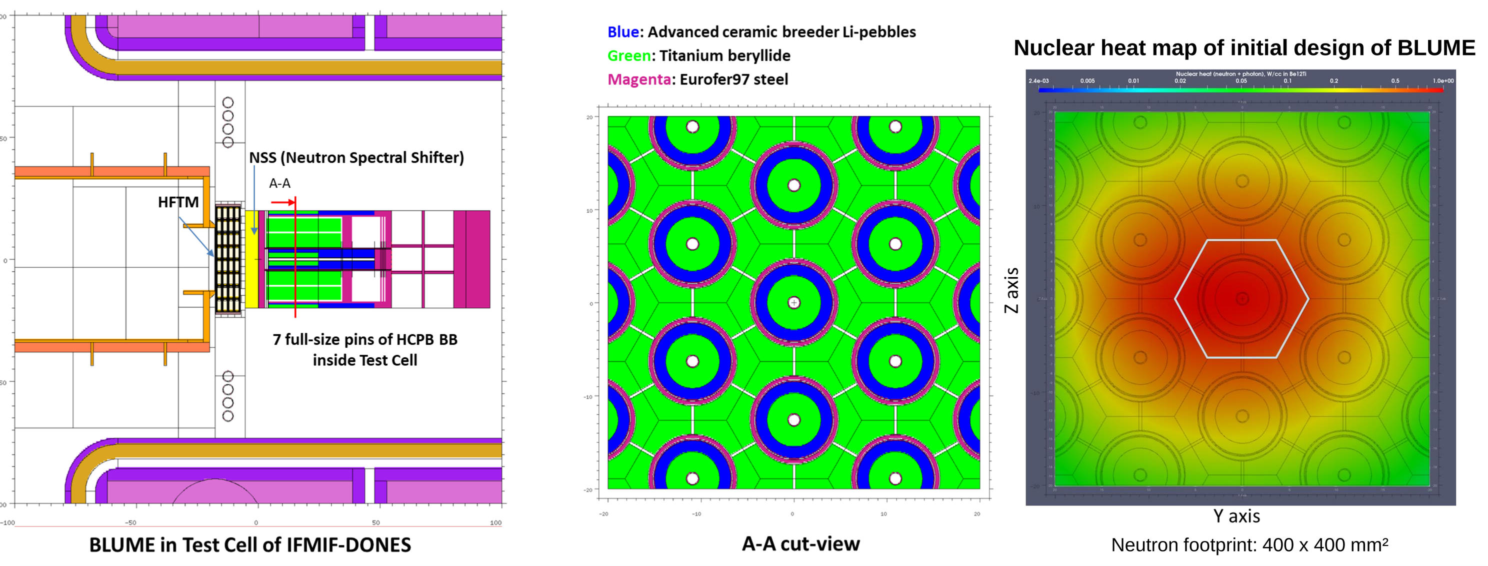
Two Areas A1 & A2 of the need for neutron shielding reinforcement pinpointed on the map of Total Dose Rate (TDR, microSv/h) caused by neutrons & photons



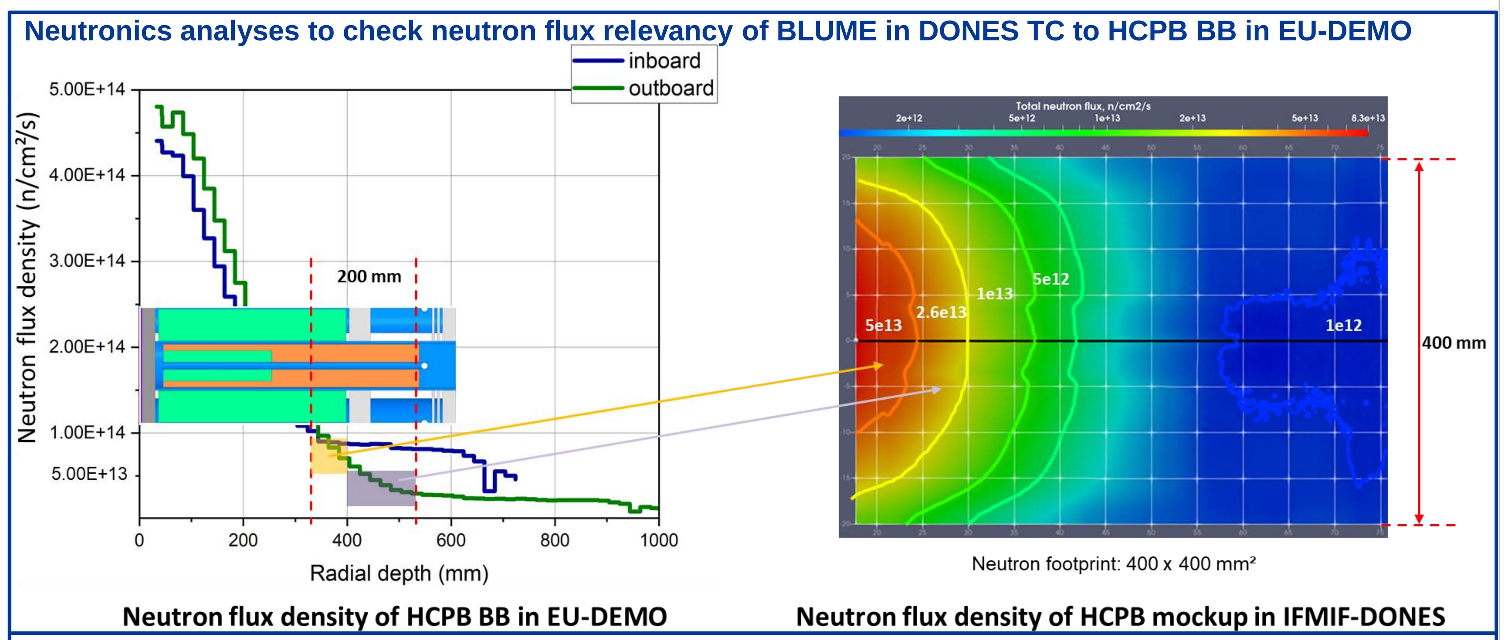
Radiation Zoning according to SC04.D012 - Safety Analysis Report-2021 [EFDA_D_2PHGE4]



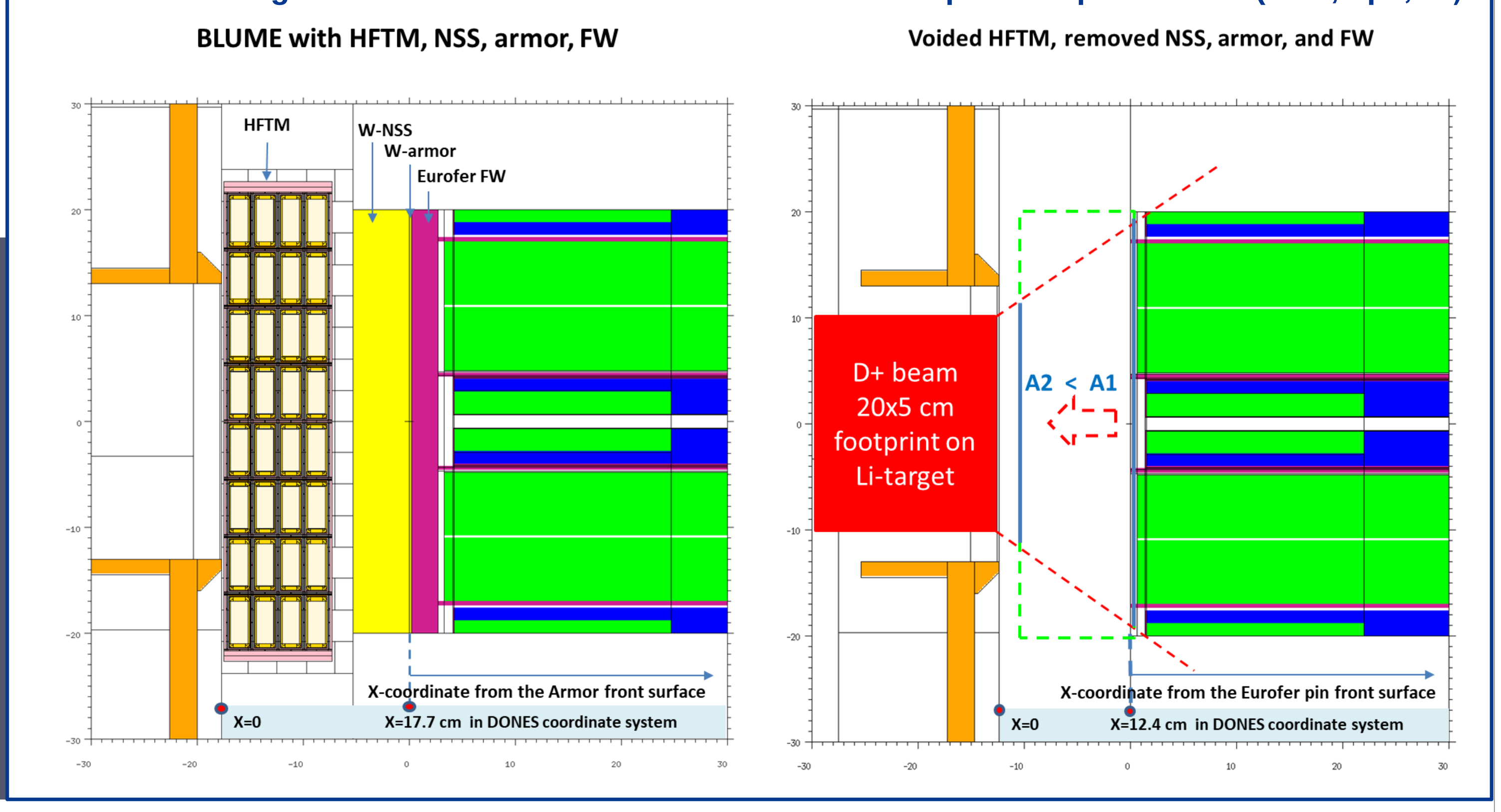
Neutronics parameterization for the design of the BLUME: Blanket fUnctional Materials modulE to be irradiated inside the IFMIF-DONES Test Cell



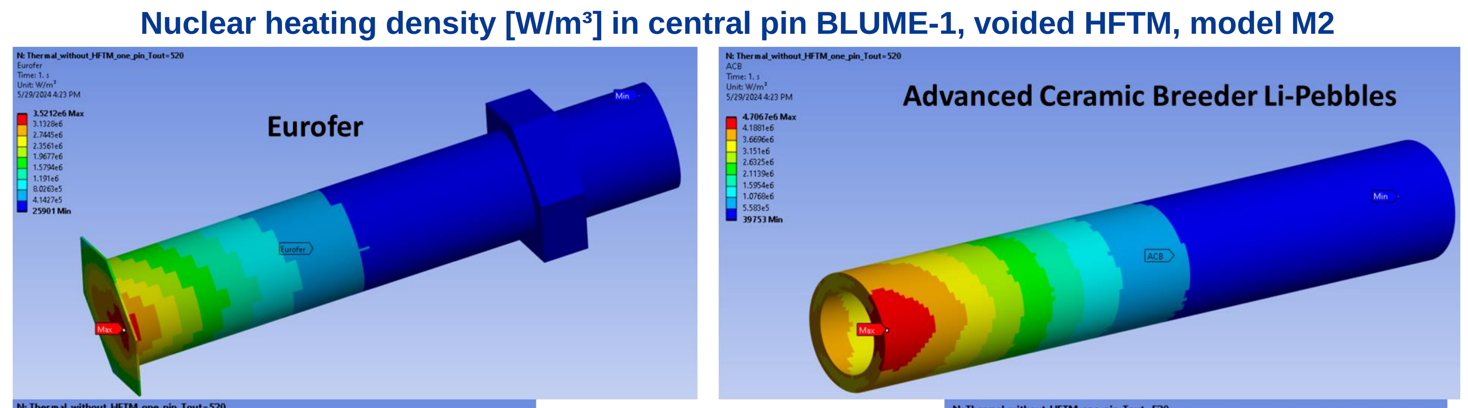
Neutronics analyses to check neutron flux relevancy of BLUME in DONES TC to HCPB BB in EU-DEMO

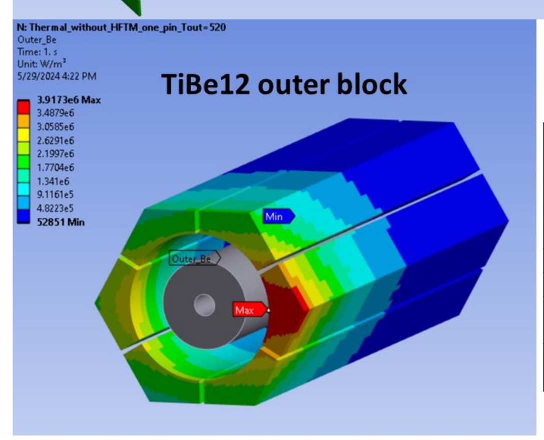


HFTM-voiding to maximize neutron load at BLUME and dependent parameters (heat, dpa, …)



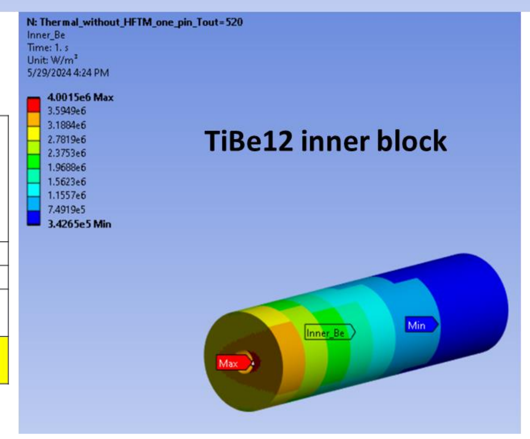
Nuclear heating density [W/m³] in central pin BLUME-1, voided HFTM, model M2



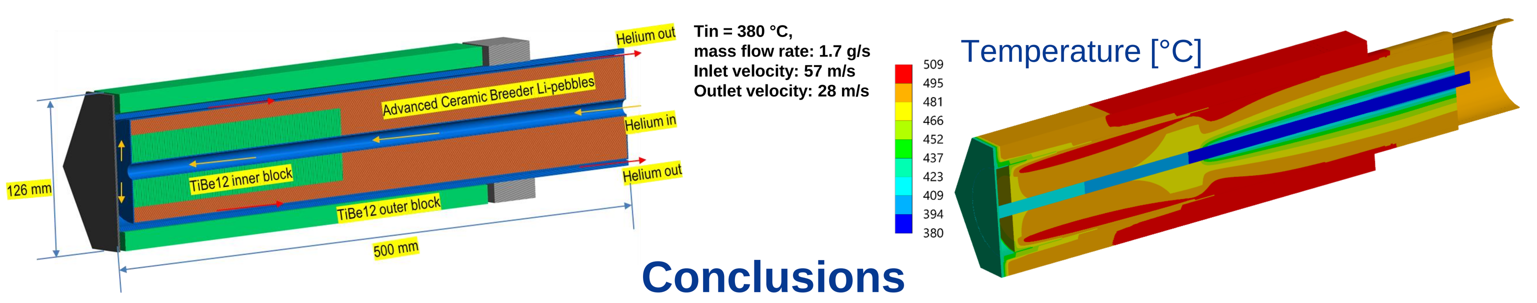


HFTM-voiding impact factor

Material	Max heat density [W/m3] for V1 (with HFTM)	Max heat density [W/m3] for V2 (voided HFTM, model M2)	Factor V2/V1
Eurofer	5.94E+05	3.52E+06	5.93E+00
ACB	1.83E+06	4.71E+06	2.57E+00
TiBe12 - outer	5.83E+05	3.92E+06	6.72E+00
TiBe12 - inner	5.15E+05	4.00E+06	7.77E+00



ANSYS thermal analysis of BLUME-1 behind HFTM, setting heat sources in one-pin V1 (MCNP model with HFTM)



Conclusions

- ✓ Shielding analyses of the neutron and photon effective dose rate maps reveals the dominancy by 100 times of neutron dose at the entrance to CER from TC with NBT&S system when the shutter is closed. Therefore, neutrons contributes the most dose coming from the TC radiation.
- ✓ The neutron streaming analyses found two local "hot spot" areas A1 & A2 on the dose map where dose rate is above the limit 1 mSv/h of the yellow radiation zone specified for CER. Based on the performed analyses, additional neutron shielding will be introduced later. In the future analyses, the CER experimental installations-consumers of the NBT&S delivered neutrons, which require hands-on, hands-off, or remote maintenance will be considered according to the updated criteria for hands-on/hands-off/RH classifications in accordance with the safety requirements TID 3-5-0-32-01.
- ✓ Neutron fluxes and nuclear heating densities (W/cc) have been analyzed for BLUME's structural and functional materials. Nuclear heating 3D mesh-tally distributions have been calculated in the following three materials: ACB, titanium beryllide, and Eurofer97. Tritium production has been assessed as 0.34 mg for one-day irradiation inside the one-pin BLUME-1 design behind HFTM.
- ✓ The parametrization analysis presented in this work shows the possibility of increasing the total neutron flux at the front of BLUME-1 to 1.6e14 n/cm^2/s at the MFTM location if HFTM is removed from TC. Neutronics simulations of such HFTM-voiding effect indicated an increase of maximum values of nuclear heating densities at the front of BLUME-1 up to 8 times in TiBe12 and up to 3 times in ACB.
- ✓ The 3D heating density distributions have been used as input data for thermohydraulic analyses with the ANSYS code. The results indicated that nuclear heating leads to the ACB temperature between 408°C - 509 °C, suitable for effective tritium extraction.

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