RADIATION ENVIRONMENT INSIDE THE IFMIF-DONES TARGET INTERFACE ROOM

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ABSTRACT

The joint European project on the development of the International Fusion Materials Irradiation Facility (IFMIF) DEMO-Oriented Neutron Source (DONES), which will be built in Granada, Spain, is now entering the construction phase. Neutrons of a wide energy spectrum peaked at 14 MeV will be produced inside the IFMIF-DONES Test Cell (TC) by the deuterium-lithium nuclear reactions by hitting the liquid lithium target with a 40 MeV deuteron beam from the linear accelerator. The IFMIF-DONES has two beam ducts: the primary duct will be utilized by the deuteron beam, while the second duct will be used for the lithium jet diagnostics. The diagnostics will be installed in the IFMIF-DONES Target Interface Room (TIR) adjacent to the TC. Due to proximity to the intense neutron source, and hence the harsh radiation environment inside the TIR, deliberate radiation transport and shielding analyses are required to perform. This work presents the results of the neutronics analysis, with an estimation of neutron and photon fluxes and biological dose rate maps inside the TIR and nuclear responses of the diagnostic components. The radiation environment inside the TIR is formed predominantly by the streaming of neutrons and photons through the beam ducts passing through the 3 m thick concrete wall. Due to the high radiation doses in TIR, the lithium diagnostic system is made of radiation-resistant materials, and remote handling will be applied for its maintenance. The neutron and photon transport calculations have been conducted with the Monte Carlo McDeLicious code and the IFMIF-DONES reference neutronics models. Neutron and photon fluxes, nuclear heating, neutron damage (displacements per atom), and absorbed dose rate (Gy/s) have been calculated inside the TIR. In conclusion, the impact of increased beam duct aperture has been assessed as a 40% increase in total neutron flux at the entrance to the TIR from TC.

INTRODUCTION

Scientific collaboration in the framework of the EUROfusion Work Package Early Neutron Source (WPENS) is progressing in the development of the International Fusion Materials Irradiation Facility (IFMIF) DEMO-Oriented Neutron Source (DONES). It is an accelerator-based fast-neutron facility to be constructed in the area close to Granada in Spain [1]. Important results of material science and mechanical properties of neutron-irradiated materials will be achieved at IFMIF-DONES to be used in the construction of the next-generation fusion power plant DEMO envisaged following ITER. Due to the radiation sources at the premises of the IFMIF-DONES facility, it is classified as a 'First Category Radioactive Facility' according to the Spanish national nuclear regulations. The nuclear safety assessment of the IFMIF-DONES project is ongoing at every step of its development, now it is at the step of engineering designing [2]. Nuclear assessments are based on the calculation of the radiation loads on the facility components and radiation zoning depending on the effective dose rate environment inside the IFMIF-DONES main building shown in Figure 1. The Test Cell (TC) is the most radiationexposed room in the IFMIF-DONES building because it houses the deuterium-lithium (d-Li) liquid target on which the deuteron beam of 40 MeV energy is impinged, generating high-energy neutrons peaked at 14 MeV with neutron energy tail extended up to 55 MeV. Neutrons cause the irradiation of the investigated materials in form of small specimens located inside the irradiation rigs and capsules of the High Flux Test Module. This work is devoted to radiation environment calculation for the Target Interface Room (TIR), that is room R129 adjacent to the TC upstream of the direction of the deuteron (d) beam direction depicted in Figure 1. The TIR is separated from the TC by the 3-m concrete wall. There are two Through Wall Beam Ducts (TWBDs) passing through the TC-TIR wall. The first, primary TWBD1 is devised carry-on the d-beam to the Li-target, while the second TWBD2 is intended only for the diagnostic purposes of the liquid lithium target. The diagnostic system called In-Vessel Viewing System (IVVS) will measure the stable waves on the liquid Li surface. In addition to the TIR environment, the influences of the neutron streaming along the TWBDs and the arrangement of the shielding box at the end of secondary TWBD2 have been investigated as well.

In this work, neutronics analysis has been performed for the optical head similar to the one used in IVVS previously designed for ITER. The IVVS diagnostics system is installed in TIR and it is irradiated by the TC d-Li source neutrons and secondary photons produced by neutrons interactions. Due to the high radiation doses in TIR, the IVVS diagnostics is made of radiation-resistant materials, and remote handling will be applied for its maintenance.

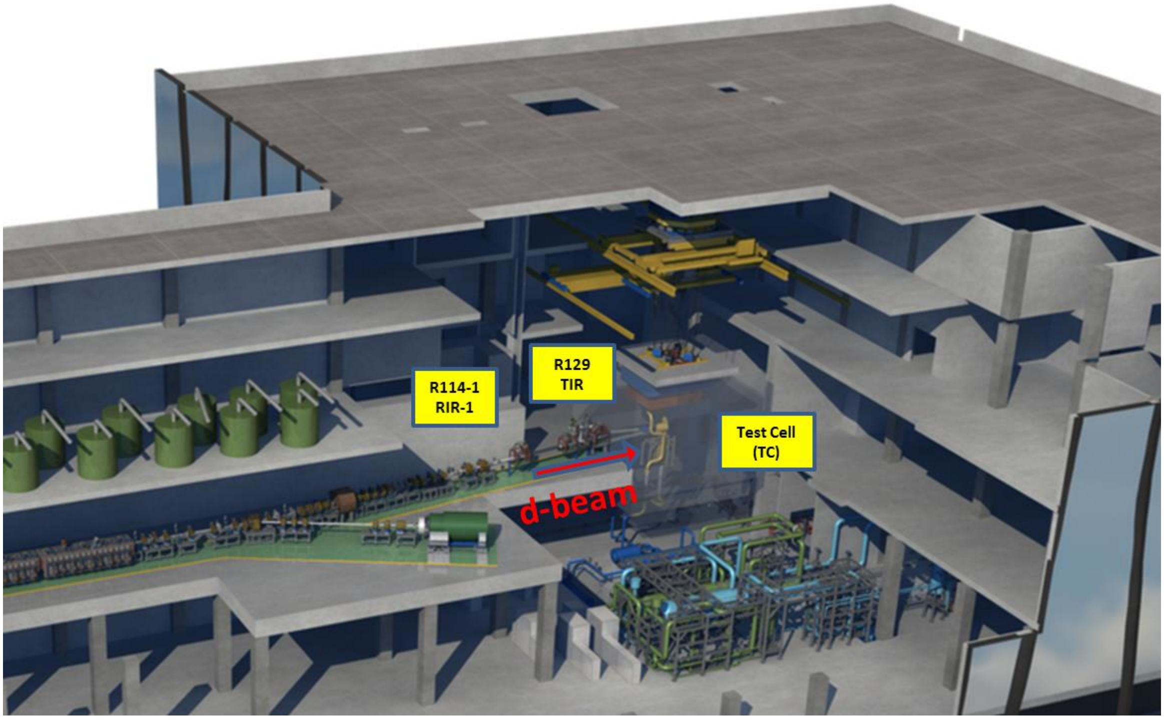

Figure 1: **CAD model** of the IFMIF-DONES main building, pointing to three rooms analyzed in this work: Test Cell (TC), Room 129 of Target Interface Room (TIR), and Room 114-1 of Radiation Isolation Room -1 (RIR-1).

METHODOLOGY

The Monte Carlo (MC) stochastic method implemented in the MCNP6 code [3] is the most preferred one for radiation transport calculations in the complex geometry of the IFMIF-DONES, with many streaming pathways. Due to the independence of the MC particle histories, the tracks can be processed in parallel. Parallel computations on high-performance cluster supercomputers substantially increase calculations speed-up and efficiency, as it was investigated in papers [4, 5]. The MC radiation transport calculations have been performed on the HPC EUROfusion Marconi-Fusion supercomputer [6]. The recent advances in integrated computer modelling in fusion technology [7] allowed us to use the benefits of CAD-based neutronics computations. The CAD model parts of the IFMIF-DONES have been automatically converted into the MCNP models using the SuperMC geometry conversion code [8]. To simulate the neutron source with d-^{6,7}Li nuclear reactions, the standard MCNP6 has been extended to the McDeLicious code [9]. The converted CAD-to-MCNP model of TC and TIR is shown in Fig. 2.

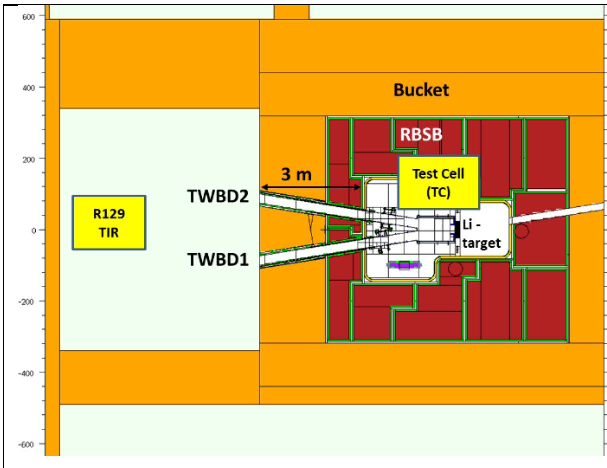

Figure 2a: **MCNP model** horizontal cut at the center of the Li target and two TWBD beam ducts

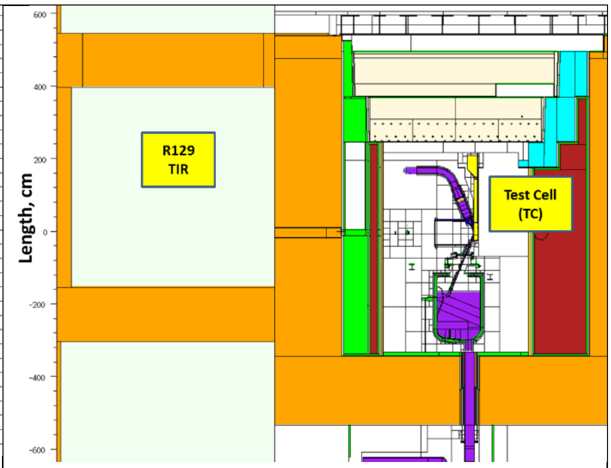

Figure 2b: **MCNP model** vertical cut throught the center of the Li target. Length in [cm] on the axis

RESULTS

The radiation environment in rooms around the Test Cell (TC), where the d-Li neutron source is located, has been assessed with the superimposed mesh-tally depicted in Figure 3. It is a rectangular mesh-tally distinguished by large size of 20x12x5.9 m^3 and a resolution of 10x10x10 cm^3, completely covering the extension of three rooms under investigation (TC, TIR, and RIR-1) and mapping the radiation pathways from other rooms in Figure 3. This mesh is fine enough to find the main radiation streaming directions and attenuation in the concrete walls of the IFMIF-DONES main building.

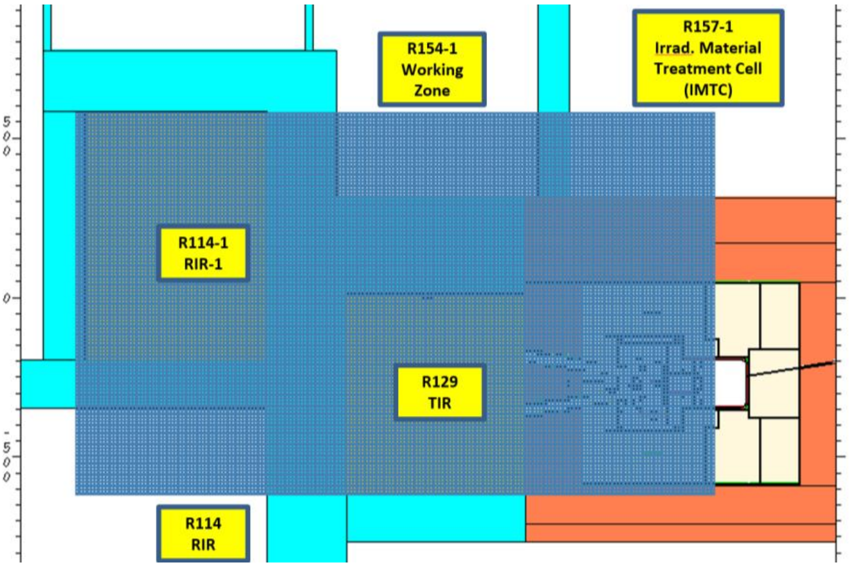

Figure 3: Horizontal cut of the MCNP model with mesh tally used in radiation environment calculations

The impact of increasing TWBD aperture from the original size of 25x10 cm^2 to 27x12 cm^2 on neutron streaming from TC to TIR has been assessed as a 40% increase in total neutron flux at the entrance to the TIR from TC. As illustrated in Figures 4-6, the Shield Box of the IVVS Diagnostics arranged at the end of TWBD2 reduces the biological dose rate at least by one order of magnitude in the next room RIR-1. Figure 7 displays neutron and photon heating contributors to nuclear heat density (W/cc) distributions in the materials of TWBD2 with its IVVS Diagnostic system and steel plates of the IVVS shield box. The nuclear heating results integrated by the volumes of the shield plates are listed in Table 1. It is found that the maximum nuclear heating is reached at the back plate Nr.4 of the IVVS shield box – see Fig. 7 and Table 1, where the total (neutron+photon) nuclear heat is 6.58E-1 W. The maximum absorbed dose in IVVS prism is 0.6 MGy/FPY (photon), and the total (n+p) dose is 1.13 MGy/FPY. Taking into account the limiting values of 4.88 MGy (photon) and 10 MGy (total) from experimental works [10, 11], the IVVS lifespan could be ~10 years without significant damage to the IVVS piezo-motor.

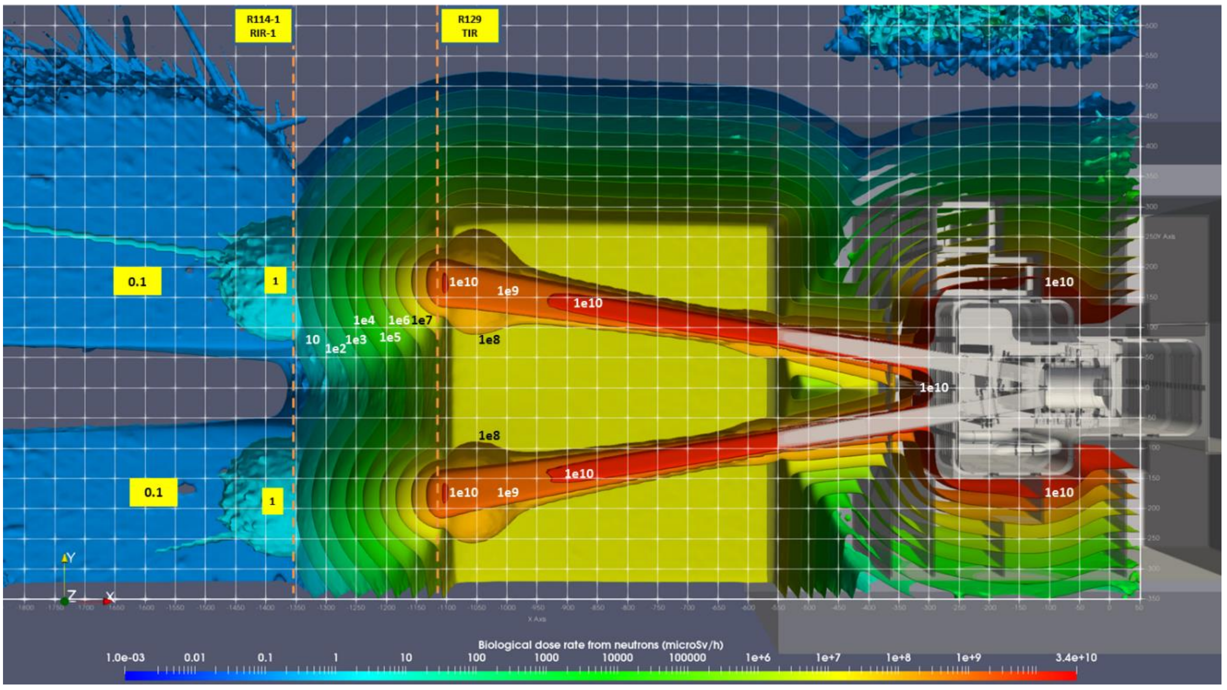

Figure 4: Top view of **empty TIR:** map of biological dose rate (microSv/h) contributed by neutrons

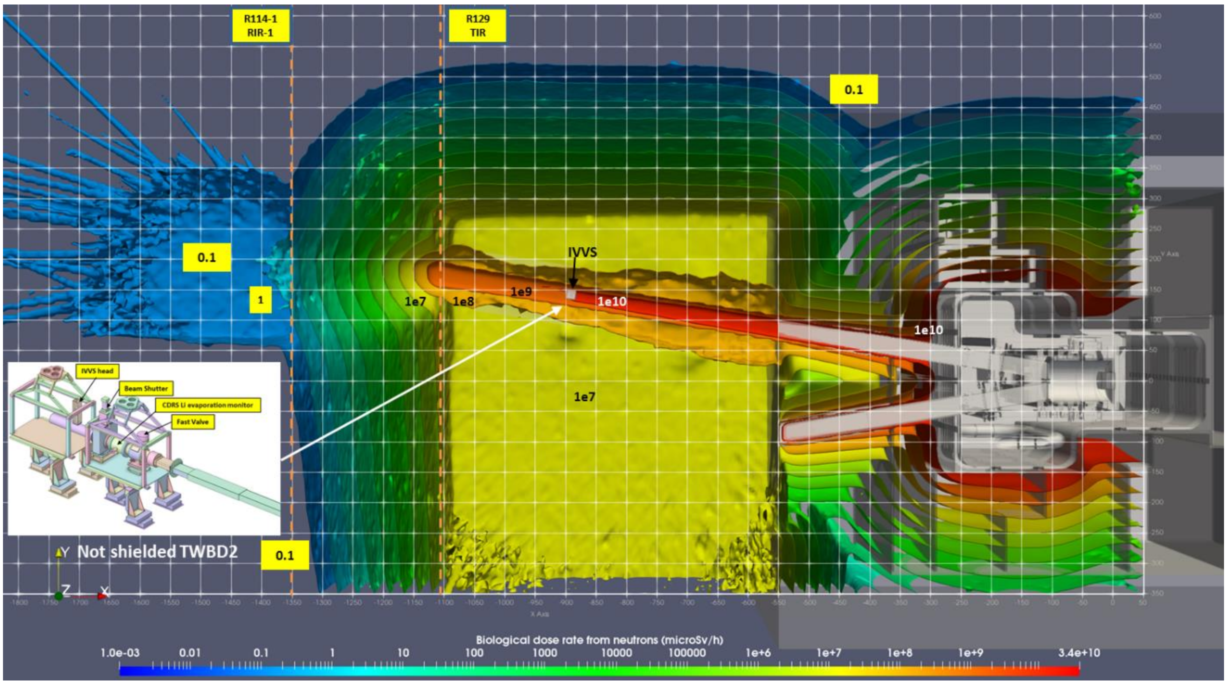

Figure 5: **Not shielded** secondary Through Wall Beam Duct (TWBD2) inside TIR: map of biological dose rate (microSv/h) contributed by neutrons

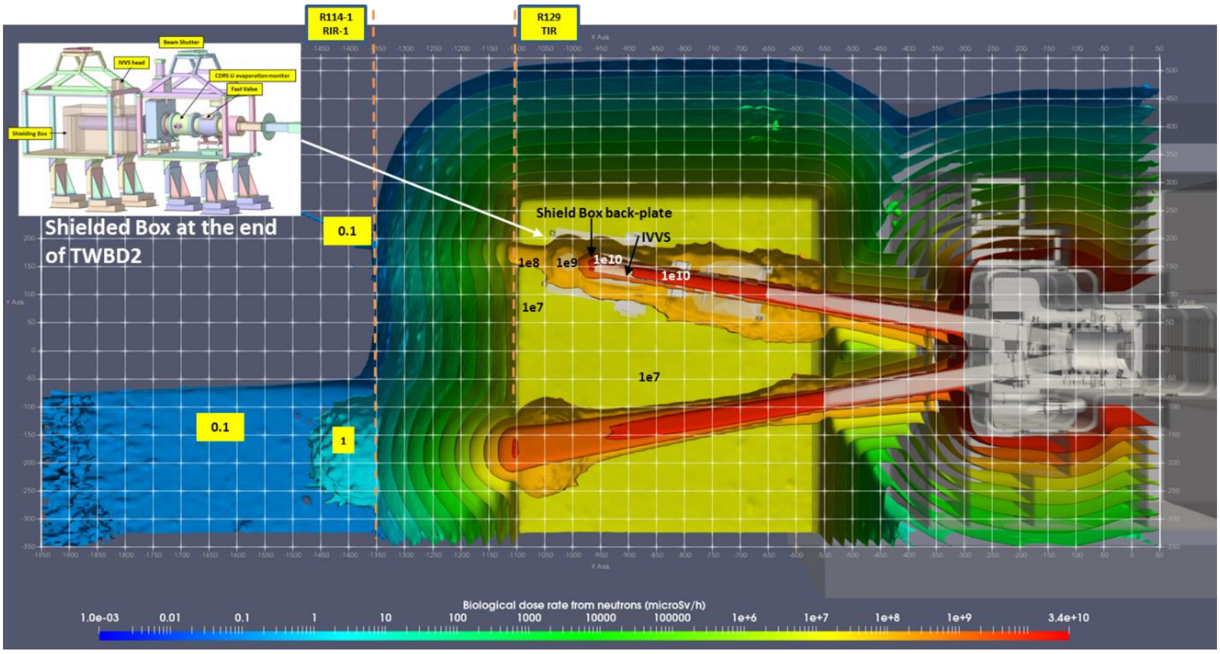

Figure 6: Comparison of two TWBDs inside TIR: **Shielded** TWBD2 vs. empty TWBD1. View from the top on the map of biological dose rate (microSv/h) contributed by neutrons

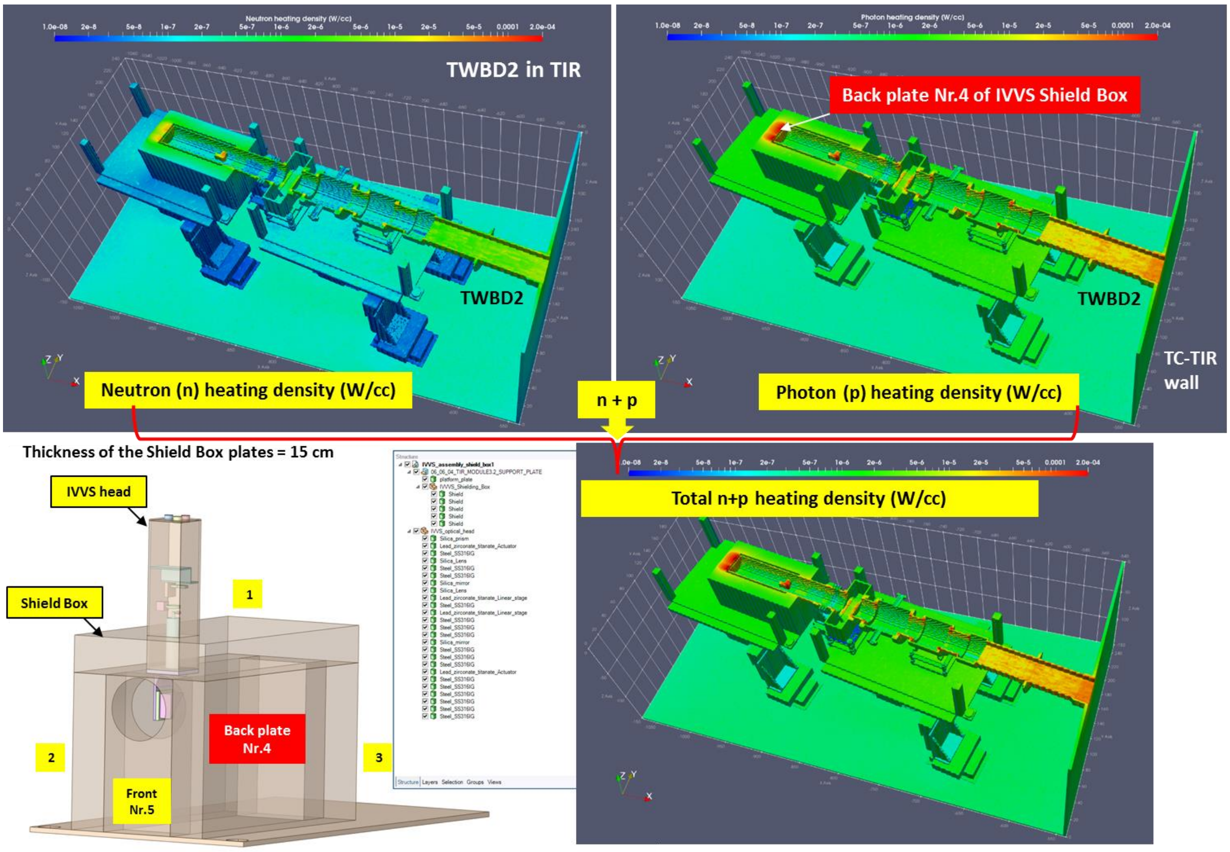

Figure 7: Neutron and photon heating contributors to nuclear heat density (W/cc) and configuration of the shield plates at the IVVS Diagnostics Shield Box, with nuclear heating results in Table 1

Table 1: Nuclear heating [W] in steel plates of IVVS Diagnostics Shield Box at the end of TWBD2

Shield Plate Nr.in Fig. 7	Volume [cc]	Plates of the Shield Box, thickness = 15 cm shown in Figure 7 left-bottom	Photon heat [W]	Neutron heat [W]	Total (neutron+photon) nuclear heat [W]
1	1.03E+05	Upper plate of shield box (steel SS316L)	1.94E-01	3.12E-02	2.25E-01
2	1.09E+05	Left plate of shield box (steel SS316L)	2.16E-01	3.38E-02	2.50E-01
3	1.09E+05	Right plate of shield box (steel SS316L)	2.09E-01	3.30E-02	2.42E-01
4	2.95E+04	Back plate of shield box (steel SS316L)	5.56E-01	1.02E-01	6.58E-01
5	2.20E+04	Front plate of shield box (steel SS316L)	5.51E-02	9.13E-03	6.42E-02
Total:	3.73E+05	Integral heating for Shield Box	1.23E+00	2.09E-01	**1.44E+00**

CONCLUSION

The proposed Shield Box around the IVVS Diagnostics at the end of the secondary Through Wall Beam Duct (TWBD2) inside the room TIR allows reducing the biological dose rate at least by one order of magnitude inside the next room RIR-1. The Shield Box is made of steel SS316L plates with a thickness of 15 cm, the box's whole weight is 2.96 tons. The total (neutron + photon) nuclear heating in steel plates integrated over the Shield Box volume is 1.44 W. Performed neutronics analysis provided supporting results for the proposed design of the IVVS Diagnostic system. Neutronics results indicated the possibility to implement the IVVS Shield Box design in TWBD2 inside the TIR of IFMIF-DONES.

REFERENCES

[1] W. Krolas, A. Ibarra, F. Arbeiter, et al., “The IFMIF-DONES fusion oriented neutron source: evolution of the design”, Nuclear Fusion, **61** (2021), 125002.

[2] M.E. García, F. Martín-Fuertes, et al.,“Integration of Safety in IFMIF-DONES Design”, Safety (2019**)**, 5(4), 74; https://doi.org/10.3390/safety5040074.

[3] D.B. Pelowitz, editor, “MCNP6 User’s Manual – Version 1.0,” LA-CP-13-00634, May 2013.

[4] A. Serikov, U. Fischer, D. Grosse, “High Performance Parallel Monte Carlo Transport Computations for ITER Fusion Neutronics Applications”, Progress in NUCLEAR SCIENCE And TECHNOLOGY, Vol. 2, pp. 294-300 (2011), https://doi.org/10.15669/pnst.2.294.

[5] A. Serikov, U. Fischer, et al., “High performance computations of Monte Carlo radiation transport for ITER fusion neutronics,” Proceedings of the Workshop “Computational Methods in Science and Engineering” (SimLabs@KIT 2010), Nov. 29-30, 2010, Karlsruhe, Germany, KIT Scientific Publ., 2011, ISBN 978-3-86644-693-9.

[6] MARCONI-FUSION high-performance computing facility: https://www.hpc.cineca.it/

[7] S. Smolentsev, G.A. Spagnuolo, A. Serikov, et al., On the role of integrated computer modelling in fusion technology, Fusion Engineering and Design, **157** (2020) 111671.

[8] Y. Wu, J. Song, H. Zheng, et al., “CAD-Based Monte Carlo Program for Integrated Simulation of Nuclear System SuperMC”, Annals of Nuclear Energy, **82** (2015) 161-168.

[9] S.P. Simakov, U. Fischer, K. Kondo, P. Pereslavtsev, Status of the McDeLicious approach for the D-Li neutron source term modeling in IFMIF neutronics calculations, Fusion Science and Technology, **62** (2012) 233–239.

[10] C. Neri, et al., “ITER in vessel viewing system design and assessment activities,” Fusion Engineering and Design, **86** (2011) 1954–1957.

[11] P. Rossi et al., “IVVS actuating system compatibility test to ITER gamma radiation conditions,” Fusion Engineering and Design, **88** (2013) 2084 – 2087.