1. INTRODUCTION

Materials qualification is mandatory for the development of thermonuclear fusion devices. Particular importance presents materials being irradiated with high energy neutrons of D-T plasma of the EU DEMO fusion power plant. For testing neutron-irradiated materials with DEMO-relevant parameters such as neutron damages, helium production, fluxes, fluences, nuclear heating, and temperatures, the International Fusion Materials Irradiation Facility – Demo Oriented NEutron Source (IFMIF-DONES) has been developed in the EU. DONES will be suitable for testing the DEMO structural and functional materials. The DONES Target and Test Cell (TC) functions at the core of the DONES accelerator-based facility [1], producing neutrons in the d-Li stripping reactions for materials irradiation inside the TC modules, and supplying collimated neutrons to the adjacent DONES rooms for conducting a variety of neutron experiments by the DONES users. To guarantee the DONES systems' functional reliability and personnel nuclear safety, conducting rigorous neutronics analyses is requested. The analysis results allow us to design sufficient shielding of the DONES systems, with an arrangement of the irradiated components for the most effective use of generated neutrons and managing the personnel access in the TC-adjacent rooms.

2. METHODOLOGICAL APPROACH

The neutronic specificity of IFMIF-DONES is the precise modeling of the physical phenomena when the deuteron (d) beam at 40 MeV energy and 125 mA current, strikes the liquid Li jet and slows down due to electrostatic energy losses and nuclear reactions with the lithium atoms delivering 5 MW of power. Via the d-Li stripping nuclear reaction Li(d,nx), the total energy integrated neutron flux of $5 \cdot 10^{14}$ n/cm^2/s just behind the target is produced with a broad energy spectrum covering the DT-fusion peak of 14.1 MeV. In addition to neutrons, primary and secondary high-energy photons (gammas) are generated by Li(d,xγ) and (n,xγ) nuclear reactions. All these nuclear reactions have been incorporated into the McDeLicious-17 code, a modified version of the MCNP6 code. The McDeLicious source module explicitly defines the d-Li source of IFMIF-DONES by setting the emission parameters of neutrons and photons. The applied neutronics methodology follows the integrated 3D CAD-based neutronics modeling approaches based on different levels of coupling interfaces with CAD modeling, activation, and thermohydraulic codes as summarized in [2]. The accuracy of the MC calculations was improved by the On-The-Fly Global Variance Reduction (OTF-GVR) developed at KIT. Using McDeLicious with OTF-GVR, the dose rate map for DONES has been calculated as shown in Fig. 1 (left). The corresponding profile of 15 orders of magnitude dose rate attenuation along the Y-line distribution in 4-m thick concrete from the Test Cell (TC) to the Tritium Room is shown in Fig. 1 (right).

3. NEUTRONIC COMPUTATIONAL RESULTS

The results of neutron dose rate (μSv/h) calculations are presented in the 2D map in Fig. 1 (left) and the 1D profile in Fig. 1 (right). They support the decision of personnel access to the TC-adjacent rooms: Tritium Room and Complementary Experiments Room (CER) depicted in the borders of Fig. 1 (left) as rooms outside the DONES TC. The rooms' access for maintenance operations is regulated by the radiation zoning classification established for IFMIF-DONES. The Neutron Beam Shutter (NBS) system with a neutron beam tube and a series of shielding disks is designed to operate in open and closed positions. When NBS is open, collimated by the tube neutrons are streamed from the TC d-Li target to CER. Neutron experiments are planned inside CER for neutron spectra variated from fast to thermal. When the NBS shutter disks rotated in the closed position, the streaming is blocked and the dose rate drops below $1 \cdot 10^3$ μSv/h as shown in the map of Fig. 1 (left), making CER accessible with the class of "limited regulated" radiation zone.

For the DONES systems' reliability, neutronics analyses have been performed for the DONES TC components, and the heating power balance of the 5 MW accelerator-delivered deuterons and released heating power by three particles (deuterons, neutrons, and photons) has been studied, with calculations of heating integrals and distributions. The energy deposition is attenuated by 11 orders of magnitude from TC to the adjacent rooms. The deuteron ions' energy deposition of 110 kW/cc in lithium at the Bragg peak in the d-Li target is attenuated to ~1 μW/cc of neutron and photon deposition in steel inside the Target Interface Room (TIR). The TC integral heating calculations demonstrated that, unlike extremely high heat of 4858.8 kW deposited locally by deuteron ions inside the Li jet target, neutrons and photons transfer much lower energy at significantly longer distances from the Li target. The heat deposition from neutrons and photons to the major components of the TC surrounding the Li-target—including the Target Assembly (TA), High Flux Test Module (HFTM), Removable Biological Shielding Blocks (RBSBs), TC liner, Bucket and its liner, Piping and Cabling Plugs (PCP), and the Lower and

Upper Shielding Plugs—amounts to 141.2 kW. Summing up all the integral heat output released by deuterons in lithium and transported by neutrons and photons to the TC components, the heat output approximates the input power of 5 MW delivered by the accelerated d-beam. As the design of the TC components progresses [1], the heating balance is updated to reflect the changes in the TC design.

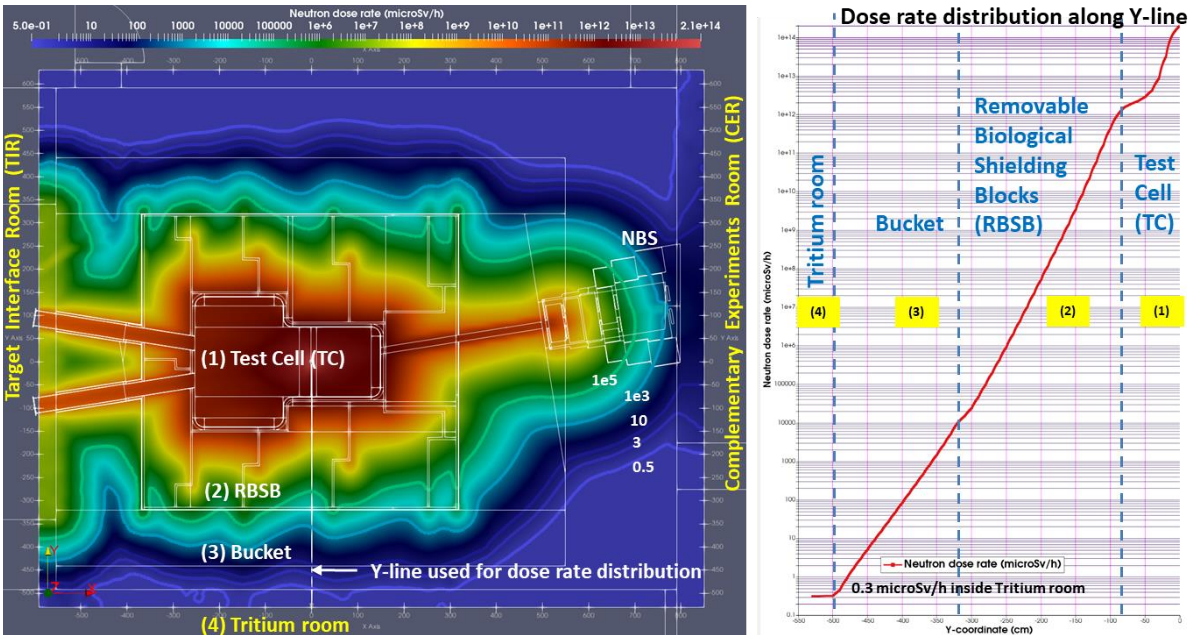

*Fig. 1. (**left**) Map of biological dose rate (μSv/h) caused by neutrons at the horizontal cut of Test Cell (TC); (**right**) profile of neutron dose rate (μSv/h) attenuation along the Y-line distribution from TC to Tritium room pointed on the left map.*

4. CONCLUSIONS

To meet the demand for future fusion reactors, IFMIF-DONES represents the unique neutron source to irradiate fusion-relevant structural and functional materials with high energy and fluence neutrons, comparable with the radiation loads expected at DEMO. The applied Monte Carlo CAD-based integrated neutronics methodology (CAD-to-MCNP models conversion, McDeLicious-17 transport code with OTF-GVR variance reduction) reproduces the d-Li neutron & photon source at the Li target, allowing to perform effective deep-penetration radiation transport calculations in heterogeneous IFMIF-DONES geometry with a strong radiation attenuation across ~6 m concrete shield. The biological dose rate from neutrons can attenuate by 15 orders of magnitude: from $2\cdot10^{14}$ μSv/h in TC to 0.3 μSv/h inside the Tritium room. The open shutter of NBS supplies neutrons to CER, excluding its personnel access. Closing the NBS shutter provides access to the CER, which is classified as a "limited regulated" radiation zone. The integral heating calculations in IFMIF-DONES TC components revealed that d-energy deposition in liquid Li at the d-beam footprint area contributes 97% of total heating in all the TC components.

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