## 1. INTRODUCTION

The accurate prediction of the Shutdown Dose Rates (SDDR) [1] is an important issue for the development of the fusion reactor design, ensuring the safety of personnel during maintenance and decommissioning activities. This study presents a detailed analysis of SDDR for next-generation tokamak DEMO [2], using two Monte Carlo particle transport codes, namely OpenMC [3], an open-source code, and MCNP [4], the reference code in DEMO neutronics. The methodology integrates neutron transport simulations, activation calculations, and decay gamma transport to evaluate the spatial distribution of dose rates in both in-vessel and ex-vessel regions. Advanced modelling techniques were employed to account for the complex geometries, material compositions, and operational scenarios of DEMO.

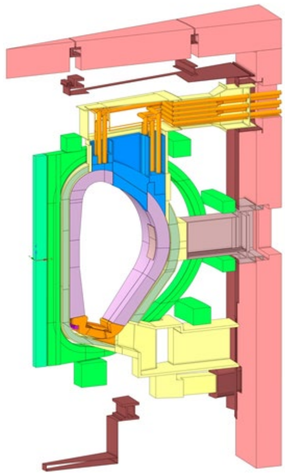

*Fig. 1. MCNP geometry model: 11,25°- degree DEMO Base model 2019.*

## 2. METHODOLOGICAL APPROACH

The study presents a systematic comparison of the SDDR calculated by OpenMC and a coupled transport-activation code based on MCNP, two widely used Monte Carlo codes for neutron transport simulations. Both code systems adopt the Rigorous-2-Step methodology [5]. The objective is to evaluate the consistency and accuracy of SDDR predictions between the two codes, with a focus on the effects of spatial discretization and modelling approaches. The methodological approach involves defining consistent geometry, materials, and decay source terms, followed by a detailed analysis of the spatial and temporal discretization effects on the calculated shutdown dose rates. The results provide insights into the performance of OpenMC and MCNP in handling SDDR calculations, highlighting potential differences and their implications for nuclear safety and shielding design. This work contributes to the ongoing efforts to validate and verify Monte Carlo codes, ensuring their reliability for applications in fusion reactors, nuclear facilities, and radiation protection.

## 3. NEUTRONIC COMPUTATIONAL RESULTS

The study emphasizes the critical role of optimizing material choices and shielding configurations to minimize radiation exposure in nuclear facilities. During the DT irradiation scenario, safe access inside the Vacuum Vessel is not possible because the SDDR remains above the safe limit of 5 mSv/h for all cooling times, even up to several years. In this scenario, dose rates for in-vessel components can exceed 6 kSv/h, while ex-vessel dose rates remain below 0.1 Sv/h. The SDDR for the most heavily loaded element in the tokamak - First Wall (FW) is estimated to reach 80 Sv/h after 12 days of cooling. Reducing the fusion power to 30% from the base irradiation scenario reduces the SDDR in the FW by a factor of 2. Access to in-vessel components may become feasible with a low-power DD source after few days of cooling, as the SDDR drops below 5 μSv/h.

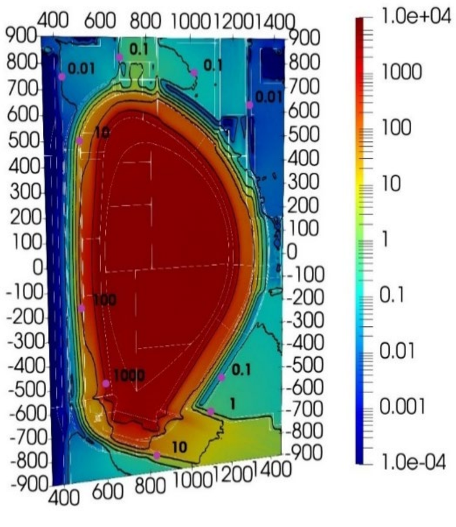


*Fig. 2. SDDR during base irradiation DT scenario with 2000 MW of fusion power inside of the vacuum vessel of the DEMO tokamak after 12 days of cooling, Sv/h.*

The results indicate a less 10% difference in dose rates at cooling times of 12 days when compared to the reference cR2S approach (based on MCNP) [6], highlighting the need for further refinement of the model and resolution of the mesh. Additionally, it is estimated that a smaller mesh voxel size is required to achieve results within approximately 5% of the cR2S reference values for mesh resolutions finer than 5 cm. This highlights the trade-off between computational efficiency and accuracy. Early sensitivity analyses reveal that input parameter uncertainties can lead to dose rate deviations of up to 10-15%. These findings emphasize the importance of optimizing mesh resolution, computational resources, and input data precision to ensure reliable long-term dose rate predictions.

OpenMC has been successfully applied for SDDR calculations, demonstrating its effectiveness as a Monte Carlo radiation transport code. A notable advantage of OpenMC is its internal compatibility with the Rigorous Two-Step methodology, a widely adopted approach for SDDR analysis. The results indicate excellent agreement between OpenMC and MCNP, a well-established benchmark code, in predicting SDDR values. This agreement highlights OpenMC's reliability and computational efficiency, positioning it as a viable alternative for SDDR calculations in nuclear engineering applications.

## 4. CONCLUSIONS

This study provides a framework for SDDR analysis in fusion facilities, usage OpenMC's flexibility and scalability to address the challenges of next-generation tokamaks. The results underscore the necessity of customized shielding designs and maintenance strategies to ensure compliance with stringent safety objectives and to support the sustainable development of fusion energy. The study highlights the critical role of spatial distribution in SDDR predictions, emphasizing the need for high-fidelity modelling to capture the intricate radiation fields in fusion systems. Through detailed case studies and sensitivity analyses, the research identifies key factors influencing SDDR, such as material activation, decay source terms, and geometric complexity. By offering practical solutions for the optimization of DEMO and future fusion power plants, this work contributes significantly to the advancement of fusion reactor design and safety. This research focused on the integration of advanced Monte Carlo tools like OpenMC into the design and licensing processes of fusion reactors, ensuring their safe and efficient operation as part of the global transition to clean and sustainable energy sources.

## ACKNOWLEDGEMENTS

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