PROGRESS ON NEUTRONICS DESIGN AND ANALYSIS ON FUSION REACTORS IN SWIP

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1. INTRODUCION

Neutronics design and analysis are indispensable for the functional and safety design of fusion reactors, and they are of great significance to the design, operation, and decommissioning of fusion reactors. Based on the requirements of fusion neutronics, Southwestern Institute of Physics (SWIP) has carried out a large amount of work in the field of fusion neutronics research and has accumulated certain experience and achievements. This paper introduces the main progress of SWIP in the aspects of fusion neutronics design analysis and code development.

2. PROGRESS IN NEUTRONICS DESIGN AND ANALYSIS

Based on the latest design of the CN HCCB TBS and the common component design of the #18 window in primary design (PD) phase, the establishment of a 3D neutronics analysis model has been completed. The neutronics models of the TBM (Test Blanket Module) frame, HCCB TBS, Pipe Forest (PF), biological shielding, and Auxiliary Equipment Unit (AEU) have been integrated into the latest ITER-C model. Secondly, using the MCNP code based on the FENDL 3.1d, the radiation field analysis calculation under a 500 MW fusion power for the CN HCCB TBS has been completed. The nuclear performance analysis of the HCCB TBS has also been carried out, including the tritium production rate (TPR), nuclear heat, radiation damage, and gas production rate. Then, the neutronics activation calculation of the CN HCCB TBS was completed using the FISPACT code. Based on the MCNP code and the neutron-decay photon nuclear library, the shut-down dose rate (SDDR) of the HCCB TBS was performed using the Direct 1-step (D1S) method. These analyses have provided inputs for thermal-hydraulic analysis, safety analysis, tritium system design, helium cooling system design, and radioactive waste management. These will support the PDR.

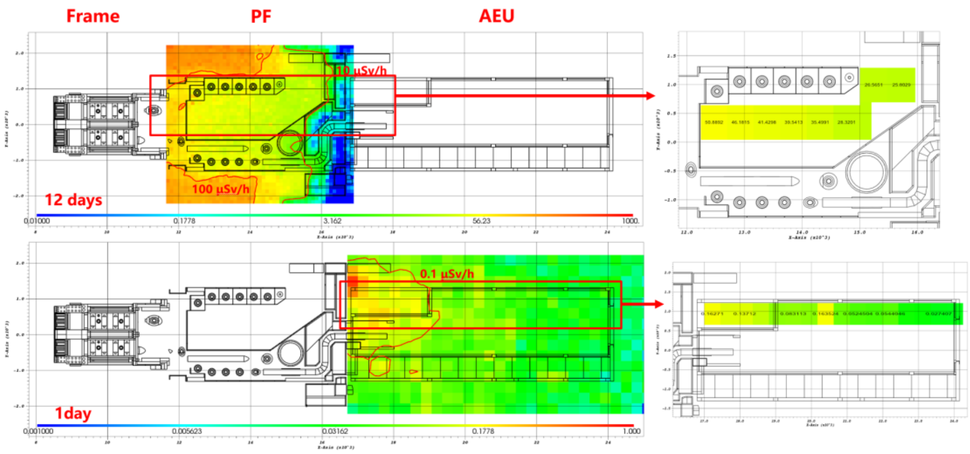

Figure 1. SDDR analysis for CN HCCB TBS

Also, the neutronics and shielding design of CFETR HCCB blanket was performed. Based on the latest profile and layout configuration of CFETR TBB, the preliminary neutronics design, optimization and analysis of HCCB TBB have been completed. After several rounds of neutronics design and optimization, the tritium breeding ratio (TBR) of HCCB TBB is 1.177, and the value drops to 1.101 considering the influence of auxiliary systems, which can meet the design objectives of CFETR. The total nuclear heating of HCCB TBB is 1402 MW at 1500 MW fusion power. Among all the blanket modules, blanket module #3 is subjected to the strongest neutron irradiation. Meanwhile, the overall shielding analysis for TF coils of CFETR has also been performed, and the preliminary shielding design and optimization for the weak shielding areas such as HCCB

TBB, divertor and neutral beam injector (NBI) port have been carried out. After shielding optimization, the fast neutron fluence and nuclear heating of all TF coils are below the design limit. [1]

3. PROGRESS IN NEUTRONICS CODE DEVELOPMENT

Firstly, regarding the neutronics analysis of fusion reactors, a full-process code development and testing application has been carried out. 1) Aiming at the need for rapid assessment of the neutronics performance of tritium breeding blankets in the PD phase of fusion reactors, a parametric neutronics automatic modelling code has been developed. It can generate a neutronics model containing the blanket, plasma, and vacuum vessel based on 2D sketch contour data [2]. 2) Based on the 3D Monte Carlo neutron-photon coupled transport code, a D1S-based SDDR analysis code for fusion reactors has been developed and verified. It can obtain the spatial distribution of SDDR at different times after shutdown through parallel computing on HPC. This code has been applied to the SDDR analysis of the ITER HCCB TBS and compared and verified with the results from KIT. 3) Meanwhile, a hybrid Monte Carlo - deterministic coupled neutron - photon transport code has been developed, providing a theoretical and tool basis for solving the deep - penetration shielding calculation problems in fusion reactors. This code has been preliminarily applied to the full-reactor radiation field calculation of CFETR and is expected to be further comprehensively verified and improved in functionality.

Besides, regarding to the engineering and technological challenges for tritium self-sufficiency in fusion reactors, this paper comprehensively considers functions of blanket such as tritium breeding, heat removal, shielding, structural integrity, engineering feasibility, and compatibility. Based on neutron perturbation theory and various intelligent optimization algorithms, the global TBR characteristics and multi-objective efficient optimization methods of the fusion reactor blanket under the multi-physics coupling fields (nuclear-thermal-density) are studied [3]. A multi-physics coupling and neutronics intelligent optimization code, MCINO, has been developed. Demonstrative applications and tests have been completed for various reactor types, including ITER, CFETR, and fusion-fission hybrid reactors, based on multiple blanket concepts such as HCCB, WCCB, and WCLL [4].

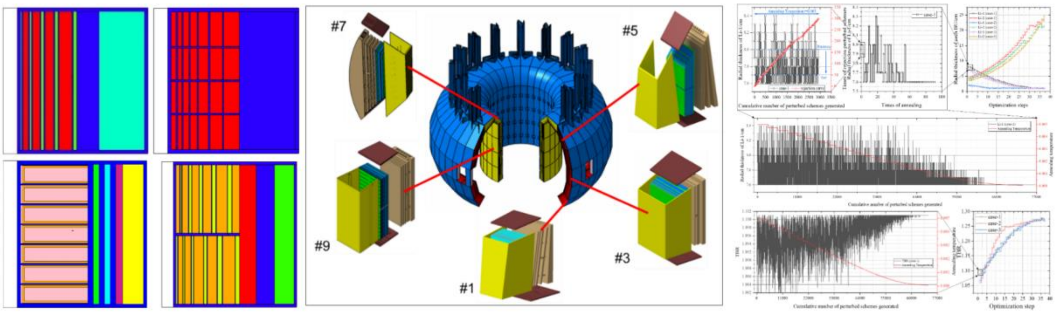

Figure 2. Application and verification of MCINO

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