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Progress of divertor design concept for Japanese DEMO

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Power exhaust scenario for the feasible DEMO plasmas and the divertor design have been studied with a high priority in the steady-state Japanese (JA) DEMO with the fusion power of 1.5 GW-level and the major radius of 8 m-class. The power exhaust concept requires large power handling in the SOL and divertor, i.e. Psep~250 MW, and Psep/Rp~30 MWm-1 corresponds to 1.8 times larger than ITER. Long leg divertor (Ldiv = 1.6 m; 1.6 times longer than ITER) was proposed as a reference design. SONIC simulation demonstrated that the peak heat load on the target (qtarget) was reduced to less than 10 MWm-2 under the partially detachment with large radiation fraction of (Pradsol+Praddiv)/Psep ~0.8. A design concept of the monoblock target and cooling water pipes for the JA DEMO was proposed in 2016 [1]: two different water-cooling units, i.e. 200°C, 4MPa pressurized water in CuCrZr pipe and 290°C, 15MPa pressurized water in Reduced Activation Ferritic–Martensitic steel (F82H) pipe, are used. The heat exhaust unit with the CuCrZr pipe can be applied near the strike-point (0.8 m) for the high heat load region, while the replacement is expected every 1-2 years due to the maximal irradiation dose on the CuCrZr pipe of 2 displacement-per-atom (DPA).

Recently, cassette structure for the DEMO divertor was designed to incorporate the heat exhaust units and coolant pipes. One cassette covers the toroidal area of 7.5°, and 3 cassettes are replaced from a lower maintenance port (total 16 ports). The cassette design is consistent with reduction in the fast neutron flux to protect the vacuum vessel and replacement of the inner and outer heat exhaust units of the CuCrZr pipe. The cassette structure consists of F82H, and the total thickness of 25 cm can reduce the fast neutron flux efficiently by arranging two lines of puddles for the pressurized water with the path length ratio of 7:3 for F82H and water, respectively. The water flow (1m/s) in the puddles removes the total nuclear heat of 0.7 MW in one cassette (totally 32 MW for 48 cassettes).

Heat transport analyses of the W-monoblock and CuCrZr-pipe was performed in the three-dimensional (3-D) modeling by using the ABAQUS finite element method (FEM) code, considering the monoblock geometry (shaped target surface is used to protect the leading edge) and the heat flux components (radiation power, neutral flux and nuclear heat as well as plasma heat load along the field line) given by SONIC and MCNP-R simulations. Maximum temperature on the W-surface appears near the downstream edge in the plasma-wetted area. The critical operation temperature of 1200℃, i.e. W-recrystallization, corresponds to the total peak heat load of 13.5 MWm-2, which is 1.8 times higher than the result simulated by SONIC (7.5 MWm-2). The maximum temperature of the CuCrZr pipe is 351°C, and mechanical toughness of the cooling pipe is also near critical against thermal fatigue. Elasto-plastic analysis of the displacement and thermal stress on the W-monoblock and CuCrZr pipe under the higher heat load have been performed, and the results are presented.

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