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Tungsten monoblock concepts for the U.S. Fusion Nuclear Science Facility (FNSF) first wall and divertor

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Next-step fusion nuclear devices require plasma-facing components that can survive a much higher neutron dose than ITER, and in many design concepts also require higher operating temperatures, higher reliability, and materials with more attractive safety and environmental characteristics. In search of first wall concepts that can withstand surface heat fluxes beyond 2 MW/m^2, we analyzed advanced "monoblock"designs using coolants and materials that offer more attractive long-term performance. These use tungsten armor and heat sinks, similar to previous designs, but replace the coolant with helium and the coolant containment pipe with either low-activation ferritic-martensitic steel or SiC/SiC composite. Two geometries of coolant containment pipe, round pipe and elongated slot (as in microchannels), were examined via 3D thermal and mechanical analysis, which was performed parametrically for optimization. The results of analysis show that helium-cooled steel can remove up to 5 MW/m^2 of steady-state surface heat flux and helium-cooled SiC/SiC can remove nearly 8 MW/m^2 while satisfying all materials and design requirements. This suggests that a He-cooled W/SiC monoblock could withstand divertor-like heat fluxes. More detailed results and conclusions are as follows.

A monoblock with ferritic-martensitic steel round pipes is limited to a steady state surface heat flux of 2.1 MW/m^2, increasing to only 2.4 MW/m^2, with the use of advanced steels. The higher allowable temperature of advanced steel can not be fully exploited because in this case the stress limits performance. The use of a slotted "microchannel"geometry provides substantial additional heat flux handling capability. For "ordinary"ferritic steel, the heat flux limit rose to 3.7 MW/m^2, which roughly meets our original goal to double the performance of the previous He-cooled design with W pins. This value rises to 5.2 MW/m^2 using ODS steel. In this case, stresses did not constrain the performance.

The use of SiC composite pipes to replace steel was considered in the context of large existing R&D programs developing advanced fission fuel cladding. Used inside of a W monoblock configuration, round pipes can satisfy temperature and stress limits up to ~5 MW/m^2 steady state surface heat flux, whereas a microchannel geometry can reach near 8 MW/m^2. This value of heat flux approaches the range expected in a tokamak divertor. Exact specifications of heat flux in the divertor of burning plasma devices are not available, but peak values in the range of 5-15 MW/m^2 are expected.

Our SiC/SiC design variant provides a possible alternative to the He-cooled W-alloy divertor that has been explored in several design studies and R&D programs. The W-alloy divertor has been shown to allow very high performance and heat removal capability, but the availability of an acceptable alloy remains a major uncertainty for its continued development. While SiC composites at present do not achieve the higher heat flux capability of W-alloy, due to limited thermal conductivity, their commercial availability and existing database under neutron irradiation make them a more likely candidate for near-term applications in next-step devices.

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Eligible for student paper award?

Yes

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