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Studies of reducing divertor heat load in the Large Helical Device

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How to reduce divertor heat load, and how to sustain the reduced heat load state stably are crucial issues to realize a nuclear fusion reactor. In the Large Helical Device (LHD) [1], which is a world largest superconducting stellarator / heliotron device, studies of reducing divertor heat load in a non-axisymmetric magnetic confinement system are being conducted. We developed three reduced divertor heat load operations, i.e. a complete detachment in a high density regime, detachment with impurity seeding, and detachment induced by a resonant magnetic perturbation (RMP), in LHD under the condition of using graphite as the material of divertor tiles. In this presentation, the three operations and their physical mechanisms are reviewed and discussed. It should be noted that the material of first wall panels is stainless steel type 316L. That means LHD is a fusion device with high and low-Z mixed plasma facing materials.

In the LHD plasma, a density limit is not disruptive like a tokamak, but appears as a radiation collapse in which plasma temperature decreases and plasma column shrinks inside the last closed flux surface (LCFS). A complete detachment [2] appears near the density limit. Plasma column shrinks, but the shrinking stops before reaching a radiation collapse. As the result, divertor plasma is completely detached. This state can be sustained by proper fueling. On the other hand, this operation can be conducted in limited operational magnetic configurations.

Impurity seeding is a widely used method in fusion experimental devices to reduce divertor heat load. In LHD, nitrogen, neon and krypton have been examined [3-6]. It has been observed that heat load on divertor tiles is reduced by impurity seeding in wide ranges of plasma density and operational magnetic configurations. Radiation loss caused by the seeding reduces electron temperature outside LCFS, and divertor heat load is reduced. To sustain the reduced heat load, a proper control of seeding is necessary. Toroidal asymmetries of the reduction of divertor heat load have been observed. This asymmetry is caused by the local seeding and magnetic field lines trajectories [5].

It was found that the formation of low poloidal mode number (m~1) magnetic island at the edge region with the RMP field has a stabilizing effect on the strongly radiating plasma [3, 7]. The effect is caused by the increase of the radiation volume for light impurities with the flattening of the electron temperature profile in the island at low electron temperature region. In this case, the position of the magnetic island is essential. If the position is well inside LCFS, the radiation enhancement does not appear. That means the detachment induced by RMP can be operated in limited magnetic configurations.

Three operations of reduced divertor heat load have advantages and disadvantages as mentioned above. In all the three operations, a reduction of electron temperature caused by radiation loss outside LCFS is essential. At present, carbon is the main radiator in LHD. However, in a future fusion reactor, plasma facing material will be refractory metals such as tungsten. Therefore, we have to consider combinations of the three operations. It is planned that tungsten divertor tiles are installed in LHD in near future, and we will be able to explore a proper operation of reduced divertor heat load for a future stellarator / heliotron-type fusion reactor based on the current studies.

References

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