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Numeral Analysis of the Tungsten Wall Erosion in a Tokamak Fusion Reactor

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In tokamak fusion reactors, the next generation of decarbonized power sources for fusion power generation, high energy fusion plasma is confined by a magnetic field. High energy plasma leaking from the confinement region due to collisions reaches the tungsten wall inside the fusion reactor. On the wall, erosion by plasma occurs and affects the fusion plasma performance and the operating availability of the fusion reactor. In addition, tungsten impurities generated by sputtering can deposit on the walls, affecting the cooling performance of the reactor.

Analysis of erosion and deposition of the tungsten is essential to understand and control the erosion and deposition distribution and its impact on the fusion plasma performance and the operation availability. In a previous study[1], erosion and deposit processes on the divertor wall, which is the most heavily loaded by the plasma, are numerically analyzed for the fusion demonstration reactor concept in Japan. The simulation showed that most of the tungsten sputtered from the divertor returned and deposited on the divertor. The other tungsten impurities are transported to the wall other than the divertor wall (hereinafter referred to as the first wall). The first wall is composed of the blanket, which is the module for fuel generation, and the surface tungsten is thin to increase fuel breeding efficiency. In the steady-state fusion reactor, even a small amount of erosion and deposition on the first wall may affect fuel breeding efficiency and cooling performance.

Therefore, wall erosion and impurity deposition are crucial issues for the design of the divertor wall and blanket. In this study, erosion and deposition, especially, on the first wall, in the fusion demonstration reactor is numerically analyzed.

To simulate erosion and deposition, the impurity particle transport code IMPGYRO[2] is used as the previous studies. In this code, temperature, density, velocity, and magnetic field configuration data of the background plasma are given as inputs and impurity transport is tracked with the Larmor motion in real geometry and real magnetic field configuration. Coulomb collisions between the background plasma and impurities are simulated using a binary collision model with kinetic thermal and friction forces that are important for impurity transport. In addition, anomalous diffusion, ionization, and recombination processes are taken into account.

The model is extended to evaluate the erosion and deposition of the first wall, and the steady-state impurity density distribution and the amount of erosion and deposition and impurity deposition on the tungsten wall are analyzed. In this study, the tungsten impurities sputtered from the outer divertor.

The IMPGYRO simulation showed that the tungsten particles sputtered from the divertor were widely transported, and deposited on the first wall and the furthest inner divertor wall. Near the mid-plane, the tungsten impurity came from the outer divertor, which has high energy and significantly sputters the first wall. Because the energy of the sputtered tungsten is low and the electron temperature is high, the tungsten sputtered from the first wall ionizes immediately and deposits on the place similar to the prompt re-deposition. As a result, net deposition was observed near the mid-plane. A peak of net deposition speed is about 4.2×10^{-11} m/s near the outer mid-plane. At the plasma top, erosion and deposition are rarely observed due to the magnetic drift toward the X-point and less radial transport in wider SOL width.

Under the present simulation condition, the thickness of the deposition layer near the mid-plane after one year of operation may become several millimeters, which may hinder the fusion reactor operation.

Other results of the different plasma conditions will be discussed in the presentation. In the future, an analysis of the impact of the tungsten impurity on the background plasma and the development of the tungsten impurity control will be performed.

References

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[2] S. Yamoto, *et al.*, Computer Physics Communications, **248**, 106979 (2020).