§21. Integrated Modeling of Peripheral and Core Plasmas Including Impurities

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The heat and particle control taking account of impurities not only produced from divertor plates and first walls but also seeded to reduce heat load on the divertor plates is the most important and challenging issue in ITER and DEMO. The purpose of this collaborative work is to understand key physics of peripheral and core plasmas including impurities for the development of control method. For this purpose, we are progressing modeling of impurities, core and peripheral plasmas, plasma-wall interactions, and then integrated modeling of their interactions. We here pick up some of collaborative works.

(1) Development of core impurity transport code and its coupling with integrated transport code for core plasma

Core impurity transport code IMPACT, which was formerly used for experimental analysis in JAEA, has been developed to simulate the time evolution of impurity transport [1]. Then, IMPACT is coupled with integrated transport code for core plasma TOPICS, which was developed partially in previous NIFS collaboration related with this one. This coupling enables us to study self-consistently impurity transport and its effect on the core plasma such as radiation and dilution.

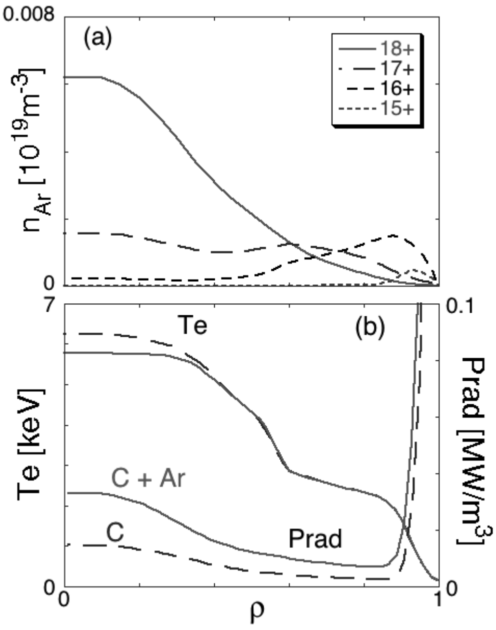

Fig. 1. Profiles of (a) argon density with charge states 15+-18+ (b) electron temperature and radiation without/with argon (intrinsic carbon exists in both cases) for a JT-60SA scenario.

(2) Accumulation of impurity seeded to reduce the divertor heat load and its effect on the plasma performance

The above developed code has been used to evaluate a JT-60SA high-beta steady-state scenario [1]. Integrated divertor code SONIC showed that the low divertor heat load (< 10 MW/m^2) with low SOL density (< 1.5 × 10^{19} m^{-3}), which is required for the scenario, was achieved by Ar gas puffing of 0.86 Pa m^3/s to the divertor region. The Ar inflow to the core is evaluated from the SONIC result and is assumed to be injected as MC neutrals in IMPACT, the neoclassical transport is calculated by NCLASS, and anomalous diffusivities are set to the neoclassical level to consider the maximum accumulation. Figure 1 shows integrated simulation results of IMPACT and TOPICS. Ar with charge states from 15+ to 18+ are accumulated in the core and the radiation increases slightly (+ 1.5 MW). The Ar accumulation is so mild that the plasma performance can be recovered by additional heating within the machine capability. Due to the strong dependence of accumulation on the pedestal density gradient, the high separatrix density is important for low accumulation as well as low divertor heat load.

(3) Kinetic modeling of neoclassical transport of high-Z impurity

In order to study the impurity neoclassical transport in core and peripheral plasmas, gyro-motion orbit-following Monte Carlo code has been developed taking account of distribution function distortion due to the temperature gradient of background plasma [2]. The code reproduces theoretical velocities of inward pinch and temperature screening effect due to up-down asymmetry in Pfirsh-Schluter regime, and shows the limiter position can change the impurity invasion to core region.

(4) Impurity seeding and divertor heat exhaust in DEMO

The influence of impurity radiation fraction and fusion power on the divertor heat exhaust has been studied by SONIC simulations [3]. The simulations show that, at the fusion power of 3 GW in a machine with major radius of 5 m, the divertor heat load is around 10 MW/m^2 due to the radiation zone near the divertor plates even with the high radiation fraction of 92 %. On the other hand, at 2 GW fusion power, the radiation zone is apart from the plates and the heat load is reduced to 6 MW/m^2.

1) N. Hayashi, et al., "Progress in integrated modeling of JT-60SA plasma operation scenarios with model validation and verification", 56st Annual Meeting of APS division of Plasma Physics, Oct. 2014, New Orleans ; Plasma Conference 2014, Nov. 2014, Niigata
2) Y. Homma, et al., "Kinetic modeling of classical and neo-classical transport for high-Z impurities in fusion SOL/divertor plasmas using binary collision method", 25th IAEA FEC, Oct. 2014, St. Petersburg
3) K. Hoshino, et al., "Studies of impurity seeding and divertor power handling in fusion reactor", 25th IAEA FEC, Oct. 2014, St. Petersburg