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Core-edge simulations of impurity behaviour for the CFETR advanced scenarios

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The next-step fusion facility China Fusion Engineering Test Reactor (CFETR) has been proposed to bridge the gaps between ITER and DEMO [1]. One of the most important missions for CFETR is tritium self-sufficiency, which requires high fusion fluence and tritium breeding ratio (TBR)>1. CFETR scenarios designed for high fusion fluence need to satisfy simultaneously the requirement of acceptable power load to divertor plate and good plasma performance in the core region. It is anticipated that during plasma operation, penetration of various impurities, such as the intrinsic tungsten (W) from the divertor plate and extrinsic seeded impurities from a radiative divertor, into the core will have to be minimized. Therefore, core-edge simulation of impurity behavior is essential to physics and engineering design of CFETR.

In the present work, the self-consistent core-SOL coupling COREDIV code [2] has been used to simulate the CFETR advanced scenarios with 1 GW fusion power. Simulations are performed with the consideration of different impurities (W, Ne, Ar, Kr). The simulations indicate that if W concentration in the core region is higher than 2×10^{-4}, power to SOL will be smaller than the L-H transition threshold and thus H mode cannot be sustained. In the case of Ne seeding, operation in semi-detachment condition is predicted. However, achievement of this condition leads to significant reduction in fusion power due to plasma dilution by Ne. Seeding of Kr seems to be infeasible because of high contribution to the core radiation and high W sputtering yield. Among all considered seeding impurities, Ar is an optimal choice which can effectively reduce power to divertor while sustaining high plasma performance in the core. In order to have a more comprehensive evaluation of the CFETR operational window for Ar seeding, several key parameters have been analyzed. Impurity pinch in the core seems to have small effects on the global parameters, due to the synergy effect of enhancing power radiation and reducing W erosion. Simulations with different transport coefficients (D_{SOL}=0.15 m^2/s and 0.5 m^2/s) in Scrape-Off Layer (SOL) have been performed. Higher SOL transport of impurity can enhance the screening effect in the SOL region which results in less radiation and dilution in the core. However, higher SOL transport of fuel ions has an opposing effect, which increases impurity concentration in the core. This is due to a lower plasma temperature and thus longer impurity ionization lengths in the SOL region.

The effect of different impurities on tritium burn-up fraction is also evaluated. The simulations indicate that higher He recycling will reduce tritium burn-up fraction (fb) due to plasma dilution by He. Whereas, fb can be strongly increased with higher fuel recycling or lower particle transport, due to the enhancement of “effective” fuel particle confinement time. Ne seeding tends to reduce fb due to plasma dilution. However, if a fixed plasma confinement factor H_{98} is assumed, higher Kr and W source can lead to higher fb due to the reduction of core transport. There is only a small change in fb in the case of Ar.

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[2] R. Zagorski, I. Ivanova-Stanik and R. Stankiewicz, Nuclear Fusion 53 (2013) 073030.