§10. Impurity Shielding Criterion for Steady-State Hydrogen Plasmas in LHD

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In order to estimate impurity behavior in future helical devices, it is very important to understand physical mechanism and to make clear operational regime without impurity accumulation. Furthermore, understanding of impurity transport in edge plasma region is dispensable for obtaining the full picture of impurity behavior in helical plasma. We study the impurity-shielding effect in edge plasma region for steady-state hydrogen plasmas and make clear the critical condition for screening intrinsic impurities. Here, we report impurity-shielding criterion for long pulse hydrogen discharges in LHD.

Figure 1 shows a typical long pulse hydrogen discharge with impurity accumulation. The total heating power is about 6 MW with tangential and perpendicular NBIs. The average plasma density is controlled so as to keep the constant density of 4.5 x 10^{19} m^{-3} during the discharge. The plasma temperature and density profiles have peaked and flat shapes, respectively, and they are kept almost the same during the discharge. The radiation power density in the plasma center increases with time though there is no big change of the radiation in the peripheral region. The intrinsic impurity line intensity (Fe XXIII) brightening in the core plasma also increases remarkably with time. On the other hand, the C III line intensity in the edge region is kept almost constant. In the operation regime, there is an impurity accumulation window for plasma density (impurity collisionality) as found before.

Here, impurity accumulation is strongly connected with impurity shielding effect in edge plasma region and the critical condition is investigated experimentally. First of all, the role of radial electric field (E_r) is studied in low collisionality region. The neoclassical impurity flux strongly depends on E_r and the shielding effect due to positive E_r is essential in the edge region. Figure 2 shows the dependence of E_r and dS_{rad}/dt on impurity collisionality in the edge plasma region (ρ ~ 0.8). The ramp up speed of radiation (dS_{rad}/dt) indicates the strength of impurity accumulation. The background plasma moves from electron root ($E_r > 0$) to ion root ($E_r < 0$) with increasing the collisionality. Impurity accumulation appears at the negative E_r of about - 4 kV/m for both magnetic configurations (R = 3.6, 3.9 m). However, the critical collisionality for impurity accumulation moves to high collisionality side in the outward shifted configuration (R = 3.9 m). This is due to the difference in the magnitude of effective helical ripple. Therefore, the critical condition in low collisionality region is determined by a specified critical collisionality. On the other side, there is another impurity shielding effect, which is a unique feature of helical system. The edge magnetic islands in helical devices have a screening effect on intrinsic impurities and it depends on local power balance in the separatrix region. Figure 3 shows an n-T diagram on impurity behavior in long pulse hydrogen discharges. The electron density and temperature are measured at ρ ~ 1. The impurity accumulation is judged by the increase of radiation in the core plasma. The critical condition in high collisionality region can be explained by the force balance condition between friction and thermal forces as indicated in the form of T_e ~ 126 $n_e^{0.4}$, which does not depend on the magnetic configuration. As mentioned before, the critical condition in low collisionality side is determined by the specified impurity collisionality ($n_eT_e^2$ = constant) and depends on the magnetic configuration.

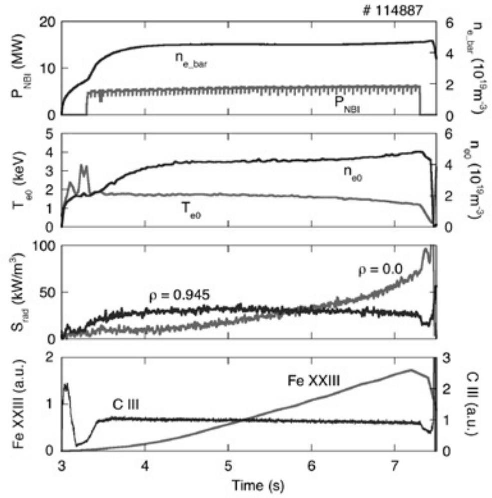

Fig. 1. A typical discharge with impurity accumulation

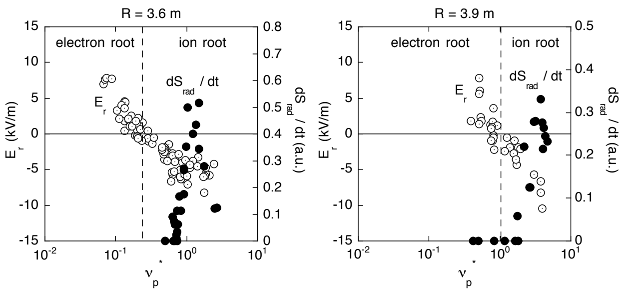

Fig. 2. Dependence of E_r and dS_{rad}/dt on impurity collisionality in the edge plasma region (ρ ~ 0.8)

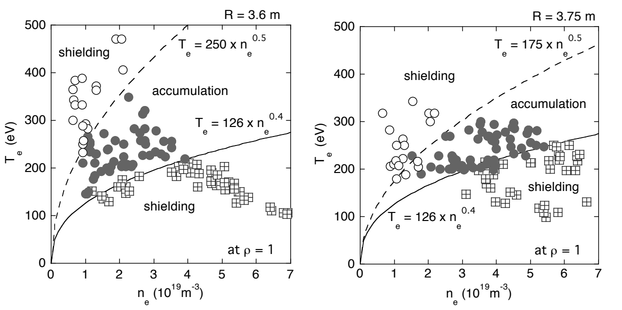

Fig. 3. n-T diagram on impurity behavior