Transport analysis of high-Z impurity with MHD effects in tokamak system

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In fusion reactors, the divertor and the other plasma facing components get some interactions with hot plasmas, by ion backscattering, chemical and physical sputtering processes, and then produce impurities. Especially heat loads on divertor plates are predicted to be very large, and high-Z materials such as tungsten will be used in such parts because of its high heat conductivity and low erosion rate. However, resulting high-Z impurity tends to accumulate in plasma core due to strong inwardly directed drift velocities caused by neo-classical convection and cause large radiation loss. Besides they displace reacting ions by the large number of electrons produced by them and cause fuel dilution. In order to check the access to ignition regime it is important to clarify the plasma radial profile and the local energy balance including impurity effects in burning plasmas with internal transport barrier (ITB). Moreover, it is necessary to avoid impurity accumulation in the plasma core.
For the prediction of tokamak reactor plasmas, transport analysis has been carried out by using the 1.5D (1D transport / 2D equilibrium) toroidal transport analysis linkage code TOTAL [1] coupled with NCLASS. NCLASS code is utilized for the calculation of the neoclassical impurity fluxes for arbitrary aspect ratios and collisionalities. In this code, multi-species of impurity ions can be treated including neoclassical transport and radial electric field effects. For the impurity charge-state dynamics, the rate equation and diffusion equation are solved by using IMPDYN code with ADPAK atomic physics package.

$$\frac{\partial n_k}{\partial t} = -\frac{1}{V'}\frac{\partial}{\partial \rho}\left(V'\Gamma_k\right) + \left[\gamma_{k-1}n_{k-1} + \alpha_{k+1}n_{k+1} - \left(\gamma_k + \alpha_k\right)n_k\right]n_e + S_k \tag{1}$$

$$\Gamma_k = \Gamma_k^{NCs} + \Gamma_k^{NCa} - D_k(\rho)\frac{\partial n_k}{\partial \rho} + V_k(\rho)n_k \tag{2}$$

$$\Gamma_k^{NCs} = -D_k^{NC}\nabla n_k + D_k^{NC}n_k\left[\sum_{l\neq k}\left(g_{nl\to k}\nabla n_l/n_l\right) + g_{Ti}\nabla T_i/T_i + g_{Te}\nabla T_e/T_e\right] \tag{3}$$

First, we clarify the permissible impurity level for tokamak plasma. Secondly, we make a study of impurity behavior for ITB plasma. Our results indicate that density control, such as pellet injection, can prevent high-Z impurity from accumulating inside the ITB. Thirdly, the MHD effects on impurity such as internal disruptions are investigated. Internal disruption is known to affect the transport of main plasma and impurity, periodically flattening radial profiles of densities and temperatures in the core plasma. We clarify the important consequences for impurity confinement.

[1] K. Yamazaki, T. Amano, Nucl. Fusion **32** (1992) 633.