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Particle transport simulation in tokamak plasma by TASK/TX
TASK/TX におけるトカマク粒子輸送シミュレーション

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In a magnetic confinement fusion reactor, fusion output power is strongly influenced by fuel ion density. The density profile of fuel ions is governed by ionization and transport, though the particle transport in tokamak plasmas is not well-known yet. In the previous particle transport analyses, diffusion equations of only ion densities have been solved and electron density is obtained by quasi-neutral condition. We simulate particle transport by the TASK/TX code, a 1D dynamic transport simulation code based on two-fluid equations, and examine parameter dependences to understand physics of particle transport.

1. Introduction

In a magnetic confinement fusion reactor, fusion output power is strongly influenced by fuel ion density. The density profile of fuel ions is governed by ionization and transport, though the particle transport in tokamak plasmas is not well-known yet. In the previous particle transport analyses, diffusion equations of only ion densities have been solved and electron density is obtained by quasi-neutral condition. In this report, we simulate particle transport by the TASK/TX code, a 1D dynamic transport simulation code based on two-fluid equations, and try to resolve various issues in particle transport. TASK/TX is a 1D dynamic transport simulation code based on two-fluid equations. It solves particle transport of electron and ion simultaneously, and solves Gauss's law of radial electric field without using quasi-neutral condition. It enabled us to describe the time evolution of density, rotation and temperature for each species. Our goal is to develop particle transport modeling which reproduces experimental observation by improving physics models and various parameters.

2. Base Equation

The set of flux-surface-averaged 1D two-fluid equations is composed of equation of continuity for density n_s, equation of motion for radial floe velocity u_{sr}, poloidal and toroidal rotations $u_{s\theta}$, and $u_{s\phi}$, and heat transport equation for internal energy $\frac{3}{2}n_sT_s$ and written as

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\begin{aligned}
\frac{\partial n_s}{\partial t} &= -\frac{1}{r}\frac{\partial}{\partial r}(rn_su_{sr}) + S_s \\
\frac{\partial}{\partial t}(m_sn_su_{sr}) &= -\frac{1}{r}\frac{\partial}{\partial r}(rm_sn_su_{sr}^2) + \frac{1}{r}rm_sn_su_{s\theta}^2 - \frac{\partial}{\partial r}(n_sT_s) + e_sn_s(E_r + u_{s\theta}B_\phi - u_{s\phi}B_\theta) \\
\frac{\partial}{\partial t}(m_sn_su_{s\theta}) &= -\frac{1}{r^2}\frac{\partial}{\partial r}(r^2m_sn_su_{sr}u_{s\theta}) + \frac{1}{r^2}\frac{\partial}{\partial r}\left[r^3m_sn_s\mu_s\frac{\partial}{\partial r}\left(\frac{u_{s\theta}}{r}\right)\right] + e_sn_s(E_\theta - u_{sr}B_\phi) \\
&\quad + F_{s\theta}^{\mathrm{NC}} + F_{s\theta}^{\mathrm{C}} + F_{s\theta}^{\mathrm{W}} + F_{s\theta}^{\mathrm{L}} + F_{s\theta}^{\mathrm{N}} + F_{s\theta}^{\mathrm{CX}} \\
\frac{\partial}{\partial t}(m_sn_su_{s\phi}) &= -\frac{1}{r}\frac{\partial}{\partial r}(rm_sn_su_{sr}u_{s\phi}) + \frac{1}{r}\frac{\partial}{\partial r}\left(rm_sn_s\mu_s\frac{\partial u_{s\phi}}{\partial r}\right) + e_sn_s(E_\theta + u_{sr}B_\theta) \\
&\quad + F_{s\phi}^{\mathrm{C}} + F_{s\phi}^{\mathrm{W}} + F_{s\phi}^{\mathrm{L}} + F_{s\phi}^{\mathrm{N}} + F_{s\phi}^{\mathrm{CX}} \\
\frac{\partial}{\partial t}\left(\frac{3}{2}n_sT_s\right) &= -\frac{1}{r}\frac{\partial}{\partial r}\left(\frac{5}{2}ru_{sr}n_sT_s - \frac{3}{2}rn_s\chi_s\frac{\partial T_s}{\partial r}\right) + e_sn_s(E_\theta u_{s\theta} + E_\phi u_{s\phi}) \\
&\quad + P_s^{\mathrm{C}} + P_s^{\mathrm{L}} + P_s^{\mathrm{R}} + P_s^{\mathrm{RF}}
\end{aligned}
$$

The perpendicular viscosity μ_s and thermal conductivity χ_s represent anomalous transport due to the turbulence. The particle source S_s, neoclassical viscous force F_s^{NC}, classical collisional momoentum transfer F_s^{C}, forces due to the interaction with turbulence electric field F_s^{W}, parallel transport loss in the SOL region F_s^{L}, friction force with neutrals F_s^{N}, charge-exchange force F_s^{CX}, collisional energy transfer power P_s^{C}, collisional energy loss power P_s^{L} bremsstrahlung power P_s^{R}, direct RF heating power P_s^{RF} are calculated from local quntities.

3. Simulation Results

We use JT-60-like plasma parameters：the major radius $R_0 = 3.2\,\mathrm{m}$, the minor radius $a = 0.8\,\mathrm{m}$, the toroidal magnetic field $B_\phi = 2.68\,\mathrm{T}$, the plasma current $I_p = 1.0\,\mathrm{MA}$, the gas puff rate $\Gamma_0 = 1.0 \times 10^{20}\,\mathrm{m}^{-2}\mathrm{s}^{-1}$, and the recycling rate $\gamma_0 = 0.8$. We turn the gas puff on and off alternately with a time period of 200 ms, and obtain the results in a quasi-steady state at $t = 1.4\,\mathrm{s}$.

In figs. 1 and 2, we show the dependence of particle diffusion coefficients at edge, and those on the magnetic axis.

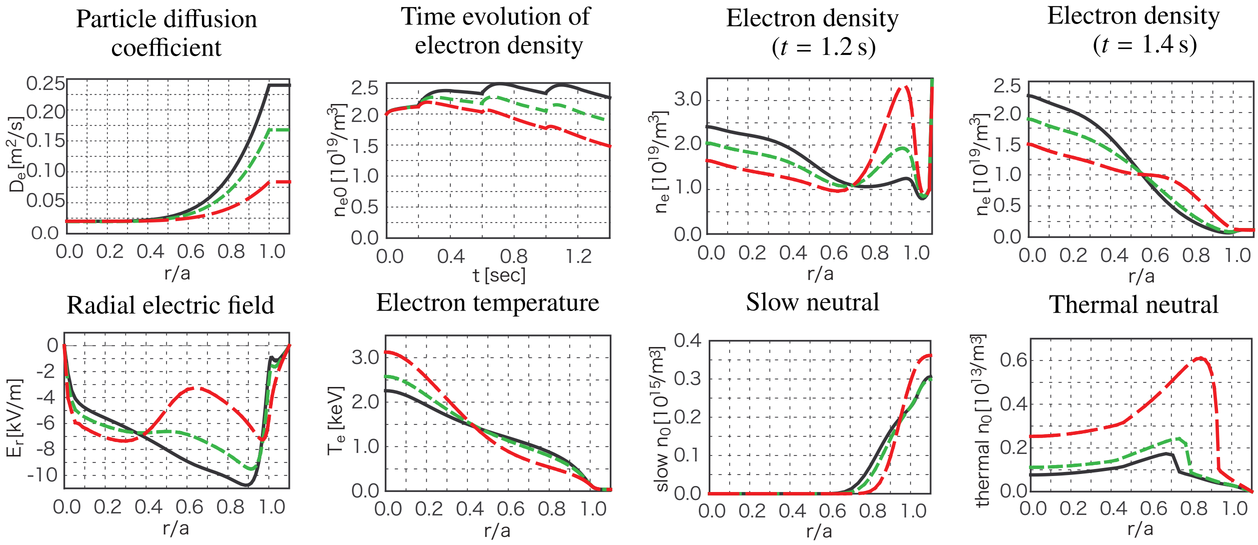

Fig. 1. Radial profile and time evolution for various values of D at edge

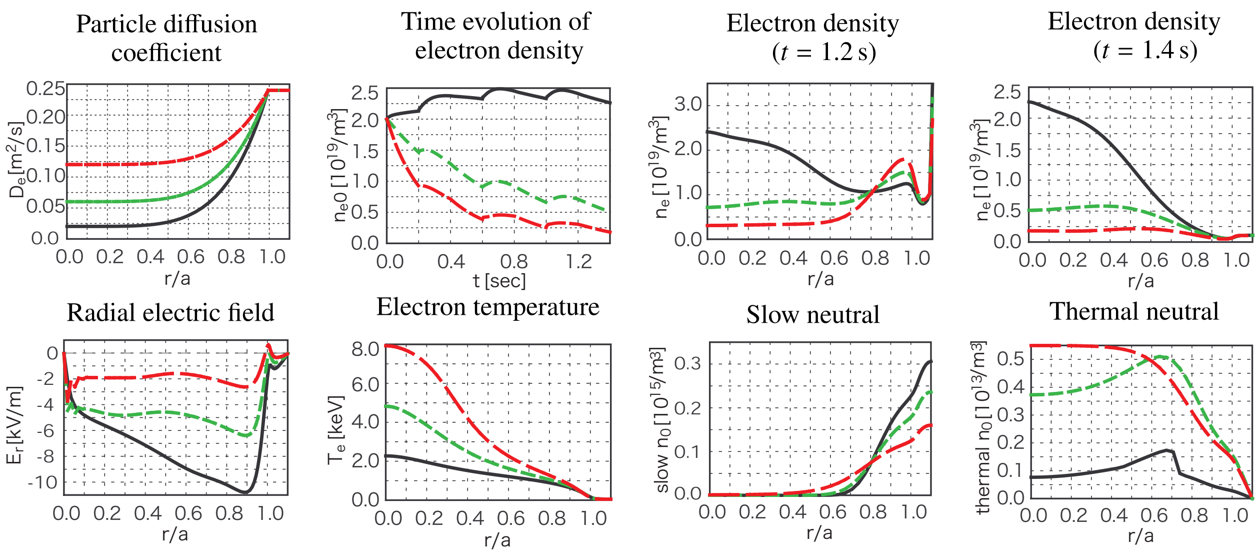

Fig. 2. Radial profile and time evolution for various values of D on the magnetic axis

4. Summary

We have examined parameter dependences in transport simulation by TASK/TX in order to improve the understanding of particle transport. It is our future task to compare these results with experimental data and to introduce turbulence diffusion coefficient based on theoretical model.