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Core plasma start-up simulation by the integration code TASK
統合コード TASK による炉心プラズマ立ち上げシミュレーション

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In order to quantitatively describe the transition process of fusion plasmas from intensive external heating by neutral beam injection and ion cyclotron wave to self-heating by alpha particles generated by fusion reaction, it is necessary to evaluate the generation of energetic ions and the fusion reaction rate correctly. The velocity distribution function module TASK/FP of the integrated tokamak modeling code TASK was employed to simulate the time evolution in the start-up phase of ITER plasmas, and the results are compared with those of conventional transport simulation with TASK/TR.

1. Introduction

Optimization of start-up scenario of burning plasmas in tokamaks is one of the key issues in preparing research plans and designing fusion reactors. In order to accurately predict the behavior in the start-up phase of burning plasmas and to develop reliable schemes controlling them, development of integrated modeling codes for burning plasmas is needed. Fusion reactions and external plasma heating and control modify the momentum distribution functions of electrons and ions and affect transport phenomena and various instabilities as well as the heating and current-drive efficiencies. In order to self-consistently describe these phenomena, we have developed a kinetic integrated modeling code, TASK3G [1], based on the time evolution of momentum distribution functions. It is an extension of the integrated tokamak modeling code TASK [2]. Previous analyses of momentum distribution functions usually assume background species with Maxwellian distribution and the temperatures of the bulk components are fixed during the analyses. These assumptions are not satisfied in the burning start-up phase where energetic ions and electrons can be easily generated and the bulk temperature changes rapidly. In TASK3G, the Fokker-Planck component TASK/FP describes the behavior of the tail and bulk components including radial transport, and self-consistently simulates the start-up phase of burning plasmas.

2. Fokker-Planck analysis

The relativistic bounce-averaged Fokker-Planck component TASK/FP [3] has been extended to describe the time evolution of the multi-species momentum distribution function $f_s(p, \theta, \rho)$ where s, p, θ and ρ are particle species, magnitude of momentum, pitch angle and normalized minor radius, respectively. In this modeling, axisymmetry, time scale longer than the particle bounce time, and small bounce orbit width are assumed. The Fokker-Planck equation includes nonlinear Coulomb collision, quasi-linear wave-particle interaction, parallel electric field acceleration, radial diffusion, and particle source. Collisional power transfer between species is calculated self-consistently by using the nonlinear collision operator which conserves momentum and energy with reasonable numerical accuracy. The radial transport is induced by the neoclassical diffusion due to collision and the quasi-linear diffusion due to turbulent electric field. In the present analysis, however, we employ a simple empirical diffusion model $D_{rr}(\rho) = 0.1(1 + 9\rho^2)\,[\mathrm{m^2/s}]$ for simplicity and an inward pinch term to keep the initial density profile. The Fokker-Planck code is parallelized in three directions, radial position, total momentum, and particle species to increase the computational performance.

3. Analysis of multi-scheme heating in ITER plasmas

Typical simulation results for standard inductive operation of ITER plasma are shown. Fig. 1 illustrates the time evolution of the contours of $f_s(p_\parallel, p_\perp)$ for four particle species at $\rho = 0.17$. Deuterons are heated by NBI and tritons are heated by second-harmonic cyclotron damping of ICRF waves. Since 1

MeV tritons are produced by DD fusion reaction and accelerated by the second-harmonic cyclotron resonance, triton heating is slightly enhanced by this synergy effects. Fig. 2 indicates the radial dependence of the distribution functions. The radial transport diffuses energetic particles and reduces the fusion power. Fig. 3 shows the time evolution of average kinetic energy density and bulk temperature of electrons, D and T, as well as the collisional power transfer. The average kinetic energy exceeds the bulk temperature owing to the generation of energetic ions. Their radial profiles are shown in Fig. 4.

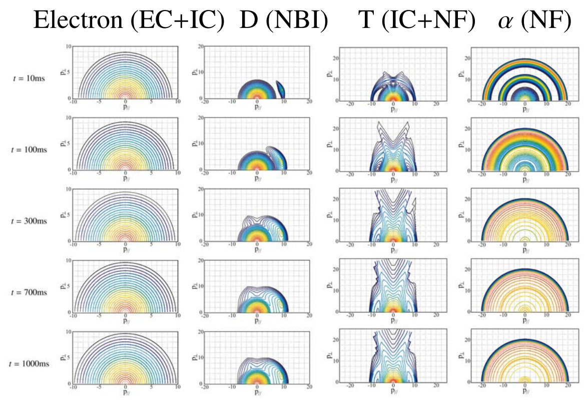

Fig.1 Time evolution of momentum distribution functions of four particle species

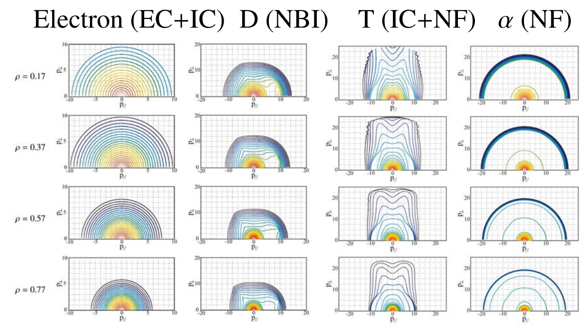

Fig.2 Radial dependence of momentum distribution functions of four particle species

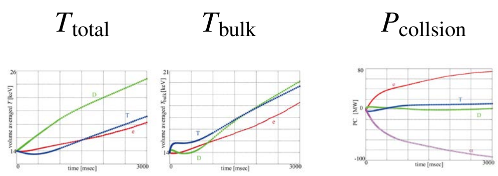

Fig.3 Time evolution of average energy density, average temperature, and total collsional power transfer

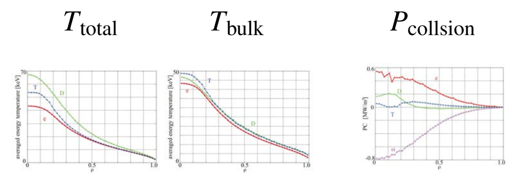

Fig.4 Radial profile of average energy density, average temperature, and total collsional power transfer

4. Optimization of start up operation of burning plasmas

Since the enhancement of fusion reaction rate is much higher for lower bulk temperature, the time evolution of burning plasmas in a start-up phase is strongly affected by the presence of energetic ions. We have carried out kinetic integrated simulations in the burning start-up phase of standard inductive operation in ITER plasmas. The results are compared with the results of conventional diffusive transport simulations. The dependence of the transition to a burning state on heating parameters, such as absorbed power, deposition location, and start timing of NBI and ICRF heating has been studied, and the optimum condition for reducing total heating power is discussed.

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