1-3. Theoretical Study

Theoretical and simulation studies, which have been done on the Large Helical Device (LHD) plasmas through the NIFS collaborative research programs in the Japanese fiscal year 2011, are reported in this section.

Numerical magnetohydrodynamic (MHD) analyses are done in order to investigate the mechanism of plasma temperature collapse phenomena observed during the shift of the magnetic axis in the LHD experiments. By MHD simulations utilizing a multi-scale numerical scheme, the collapse mechanism is identified as the growth, saturation, and relaxation processes of the instability which has the characteristic of an infernal mode.

Full MHD simulations including the chaotic magnetic field region are performed for the first time by using the MIPS code (MHD Infrastructure for Plasma Simulation) for analyzing characteristics of MHD stability of high β LHD plasmas. It is found from linear instability analyses that, as β increases, the dominant eigenmodes expand into the peripheral chaotic magnetic region. Nonlinear simulation results show that the saturation of the MHD instability strongly depends on the magnetic Reynolds number S and higher β plasmas can be maintained for higher S. Effects of the resistivity on the MHD stability β limit in the LHD are analyzed using a hierarchy-integrated code TASK3D which includes the MHD equilibrium module VMEC, the transport module TR, and the linear MHD stability module MSSH. It is found that the achievable β value decreases as the resistivity increases; the achievable β value is 5.7% and 3.2% for $S = 10^8$ and 10^7, respectively, for the peaking factor $\sigma > 1.6$.

Progress is made in developing the TASK3D code for application to predictive and interactive analyses of heat transport in LHD plasmas, in which the modules, TR, DGN/LHD, FIT3D, VMEC, and BOOZER are packaged. For the predictive analyses, the neoclassical heat diffusivity estimated by DGN/LHD and the assumed anomalous diffusivity are used to predict time-dependent temperature profiles with NBI heating power deposition evaluated by FIT3D. On the other hand, the interactive analyses of the heat transport from the experimental measurement can be quickly done by using a newly-developed transport module package TR-snap combined with the real-time magnetic coordinate mapping system TSMAP.

Neoclassical transport analyses using the global drift kinetic simulation code FORTEC-3D are done for a LHD discharge #103619 in which ECH produces a Core Electron-Root Confinement (CERC) plasma characterized by the high electron temperature (Te) and the steep Te gradient of the electron internal transport barrier (eITB). Profiles of the radial electric field and the neoclassical heat diffusivity are evaluated by the FORTEC-3D simulations. It is found that, in the eITB, the strong radial electric field is produced, which keeps the neoclassical heat transport at a low level and is considered to reduce the turbulent transport.

Ion temperature gradient (ITG) turbulence simulations are performed by using the gyrokinetic simulation code GKV-X for a high ion temperature LHD plasma discharge #88343. The turbulent ion heat fluxes and the poloidal wavenumber spectra of the density fluctuations predicted by the GKV-X simulations are in reasonable agreement with those obtained from the experiment. The simulation results show that self-consistent interaction between ITG turbulence and zonal flows determines the resultant turbulent transport level and that, in the neoclassically-optimized magnetic configuration, the turbulent transport is regulated by more efficiently generated zonal flows which enhance the spectral transfer from low to high radial wavenumber regions where the ITG modes are stabilized.

A one-dimensional (1D) steady-state two-fluid model is developed to study the cooling effect of gas-puffed neon on the hydrogen SOL plasma in the LHD. Numerical calculations are carried out by using the 1D model in the low and high plasma density cases, for which the plasma temperature, heat flux, and radiation power are obtained as functions of the neon density. For the purpose of investigating effects of three-dimensional configuration on impurity transport, a new technique is developed, which generates numerical grids covering ergodic, divertor plasma, and vacuum regions in the LHD. (Sugama, H.)