Topic: TH-C

Advanced Transport Modeling of Toroidal Plasmas with Transport Barriers

A. Fukuyama, S. Murakami, M. Honda, Y. Izumi
Graduate School of Engineering, Kyoto University, Kyoto, Japan
E-mail: fukuyama@nucleng.kyoto-u.ac.jp

M. Yagi, Research Institute of Applied Mechanics, Kyushu University, Kasuga, Japan

N. Nakajima, National Institute for Fusion Science, Toki, Japan

Y. Nakamura, Graduate School of Energy Science, Kyoto University, Uji, Japan

T. Ozeki, Japan Atomic Energy Research Institute, Naka, Japan

Transport modeling of toroidal plasmas is the most important issue to predict time evolution of burning plasmas and to develop control schemes in reactor plasmas. In order to describe the plasma rotation and rapid transition self-consistently, we have developed a dynamical transport model and applied it to the analysis of transport barrier formation. First we propose a new transport model and examine its behavior by the use of conventional diffusive transport model. Then the dynamical transport model is studied for both edge and internal transport barriers. The possibility of kinetic transport analysis in velocity space is also examined. Finally the modular structure of integrated modeling code for tokamaks and helical systems is discussed.

Diffusive Transport Analysis: In conventional transport modeling, diffusive transport equations based on the flux-gradient relations, which assumes force balance and heat flow balance in a stationary state, describe the time evolution of macroscopic quantities. Various turbulent transport models have been proposed to characterize the flux-gradient relations. We have derived a set of model equations which describe both the electrostatic toroidal ion temperature gradient mode and the electromagnetic ballooning mode and evaluated the turbulent transport coefficients from the nonlinear marginal stability condition of the most unstable mode [1]. Fig. 1 illustrates a typical behavior of the ion thermal diffusivity χ_i as a function of normalized pressure gradient α for various values of magnetic shear s. The transport coefficients strongly depend on α and decrease with the decrease of s. The rapid increase of χ_i for $\alpha \gtrsim 0.1$ is attributed to the excitation of ballooning modes. We have derived an approximate formula of χ for small α and

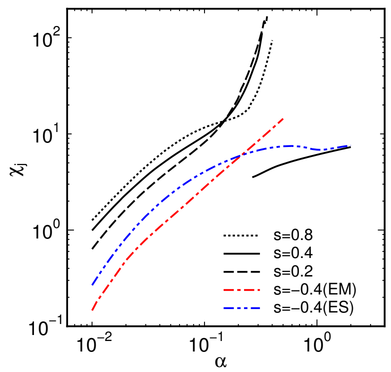

Fig. 1. Pressure gradient dependence of the transport coefficients for various values of s.

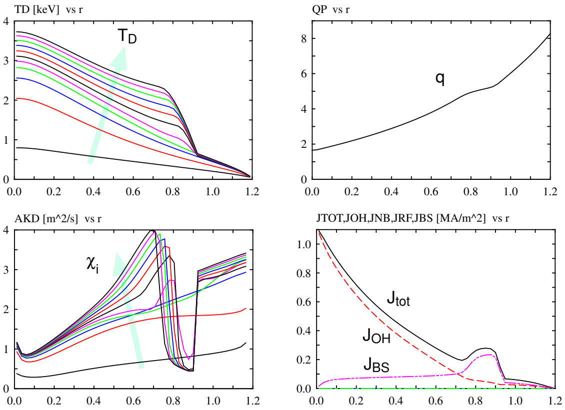

Fig. 2. Radial profiles of ion temperature, safety factor, ion thermal diffusivity, and current density in the high-β_p operation mode.

carried out a diffusive transport simulation with this formula by the use of TASK/TR code [2]. In the case of high β_p operation, the internal transport barrier can be reproduced as shown in Fig. 2. Extension of the model for large α and comparison with experimental results on JT-60 and ITPA profile database is under way.

Dynamical Transport Analysis: Recently it has been widely recognized that plasma rotation and radial electric field, E_r, strongly affect the radial transport, especially the formation of transport barriers. In order to evaluate the rotation as well as E_r self-consistently and describe the dynamics of transport barriers, we have formulated a set of dynamical transport equations [3], which consists of flux-surface-averaged fluid equations and Maxwell's equations. The neoclassical effect is included as a poloidal viscosity in tokamaks and both poloidal and toroidal viscosities in helical systems. Enhanced loss along the field line dominates in the SOL region ($\rho > 1.0$). This model was implemented as a transport module TASK/TX. The analysis without turbulent transport has revealed that large E_r is generated near the separatrix owing to the difference of transport mechanism in the regions of nested and open magnetic surfaces (Fig. 3). If the suppression of turbulent transport due to the poloidal $E \times B$ rotation shear is included in the model, edge transport barrier formation is reproduced. Detailed analysis and comparison with empirical scaling are in progress. In a non-axisymmetric devices, the neoclassical toroidal viscosity leads to the bifurcation between the electron root and the ion root. Transport simulation in a LHD plasma will be also presented.

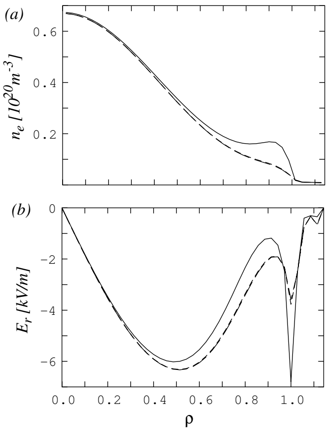

Fig. 3. Radial profiles of the density and E_r with (dashed lines) and without (solid lines) turbulent transport.

Kinetic Transport Analysis: The velocity distributions in a fusion plasma will not be necessarily close to the Maxwellian, especially in the initial phase. The TASK code includes a three-dimensional bounce-averaged Fokker-Planck module TASK/FP which has been used for the analysis of electron cyclotron heating and current drive. This module can be enhanced to describe the time evolution of non-Maxwellian velocity distribution in a transport time scale. We are formulating the neoclassical radial diffusion and parallel force driven by the spatial gradient. Turbulent diffusion in velocity space and radius will be also implemented. The kinetic transport analysis may be a long-range task, but the framework of the integrated modeling code should be prepared for such advanced analyses.

Integrated Modeling of Toroidal Plasmas: We are proposing a framework of integrated modeling of toroidal plasmas. The central part of the framework is a set of data interface for various numerical codes and experimental profile databases. As a sample implementation and for verification of the interface, the TASK code is being renovated. It comprises the modules for equilibrium, transport, velocity distribution, ray tracing, full wave and data conversion. Most of modules are applicable for non-axisymmetric configuration. Comparison of integrated analyses and experimental results will be presented for transport barrier formation.

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[2] A. Fukuyama, M. Uchida and M. Honda, 9th IAEA TM on H-mode Physics and Transport Barriers (San Diego, 2003) C1.

[3] A. Fukuyama, Y. Fuji, K. Itoh and S.-I. Itoh, Plasma Phys. Control. Fusion **36** (1994) A159.