Integrated Transport Simulation of time-development LHD plasma using GNET-TD and TASK3D

H. Yamaguchi, S. Murakami, A. Sakai, A. Wakasa, H. Takahashi[1], H. Takahashi[1], K. Nagaoka[1], H. Nakano[1], M. Yokoyama[1], I. Yamada[1], A. Fukuyama and LHD experiment group[1]

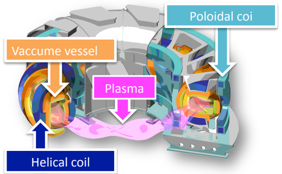
Department of Nuclear Engineering, Kyoto University, [1]National Institute for Fusion Science

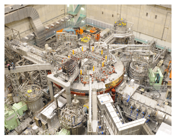
Abstract

- An integrated transport code for helical plasmas, TASK3D, has been developed.
- In order to validate the prediction accuracy for time-development plasmas, we apply TASK3D to the time-development LHD plasma by using GNET-TD code.
- The simulation result of time evolution of temperature well agreed with experimental result.
- Further, employing the extended gyro-Bohm with gradT model for turbulent transport for ion, temperature profile was well reproduced.

Introduction

- Helical fusion reactor
  - Confinement magnetic field is generated mainly by the external coils.
  - Steady-state plasma is obtained without plasma current.
  - Three-dimensional magnetic configuration.

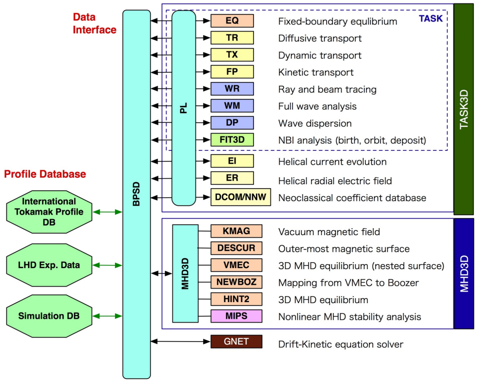




- Large Helical Device (LHD)
  - Major radius is 3.9m, minor radius is 0.6m, Magnetic strength at the center is 3-4 T.
  - Electron Cyclotron, Ion Cyclotron Resonance Frequency, and Neutral Beam Injection Heating have been installed.

- Integrated transport code, TASK3D
  - TASK3D[1] is an integrated transport code for helical plasmas based on TASK[2].
  - We combine the various models for different physical processes to describe the whole time evolution of the plasma.
    - Systematical understanding of the confinement physics
    - Prediction of the achievable parameters in future reactor.

Modular structure of TASK3D



TR
1D (radial) diffusive transport module.
DGN/LHD
Neoclassical transport database module.
ER
Radial electric field calculation module.
FIT3D
NBI heating power calculation code.
VMEC
3D MHD equilibrium calculation code.

- Heat deposition: GNET-TD code
  - We solve drift kinetic equation in 5-D phase space using GNET-TD code.

$$\frac{\partial f}{\partial t}+(\mathbf{v}_{/\!/}+\mathbf{v}_D)\cdot\nabla f+\dot{\mathbf{v}}\cdot\nabla_{\mathbf{v}} f=C^{coll}(f)+L^{particle}(f)+S_{beam}$$

f : Beam ion distribution function
$v_{/\!/}$: Velocity parallel to the field line
v_D : Drift velocity
C^{coll} : Coulomb collision term
$L^{particle}$: Particle loss term (orbit & charge exchange)
S_{beam} : Beam ion source term (evaluated by a part of FIT3D module)

  - GNET-TD is a Monte Carlo code for time-development plasma based on GNET code[3].
  - Guiding-center orbit of test particles are followed in Boozer coordinates.
  - Time development of the density and temperature is considered.
    - Successive load of n_e, T_e →Time change of collision operator
    - Successive addition of test particles→Time-dependent source term

We can evaluate non-stationary beam distribution and deposition in time-development plasmas.

- Heat transport equation: TR module
  - We solve 1-D diffusive heat transport equation.

$$\frac{\partial}{\partial t}\left(\frac{3}{2}n_sT_s\right)=-\frac{1}{V'}\frac{\partial}{\partial\rho}\left(V'\langle|\nabla\rho|\rangle n_sT_s\left(V_{K_s}+\frac{3}{2}V_s\right)-V'\langle|\nabla\rho|^2\rangle\left(\frac{3}{2}D_sT_s\frac{\partial n_s}{\partial\rho}+n_s\chi_s\frac{\partial T_s}{\partial\rho}\right)\right)+P_s$$

D_s : the particle diffusion coefficient　χ_s: the thermal diffusion coefficient
V_s: the particle pinch velocity　V_{Ks}: the heat pinch velocity

$$D_s=D_s^{NC}+D_s^{TB},\quad \chi_s=\chi_s^{NC}+\chi_s^{TB},\quad V_s=V_s^{NC}+V_s^{TB},\quad V_{K_s}=V_{K_s}^{NC}+V_{K_s}^{TB}$$

NC, neoclassical transport coefficient: neoclassical transport database, DGN/LHD.
TB, turbulent transport coefficient: the turbulent transport models.

  - In this study, we consider the turbulent term is only χ^{TB}. ($D_s^{TB}=V_s^{TB}=V_{Ks}^{TB}=0$).
  - We employ two turbulent models and compare the results.

simple gyro-Bohm

$$\chi_e=C_e^{(0)}\frac{1}{16}\frac{T_e}{eB}\frac{\rho_i}{a}\qquad \chi_i=C_i^{(0)}\frac{1}{16}\frac{T_i}{eB}\frac{\rho_i}{a}$$

not Including the Effect of Temperature Gradient

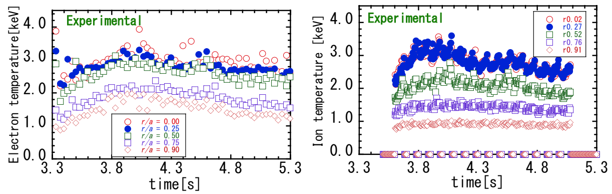
extended gyro-Bohm with gradT

$$\chi_i=C_i^{(1.5)}\frac{1}{16}\frac{T_i}{eB}\frac{\rho_i}{a}\left(\frac{\nabla T_i}{T_i}a\right)$$

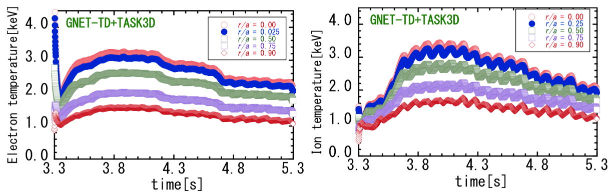
Including the Effect of Temperature Gradient

Simulation Results

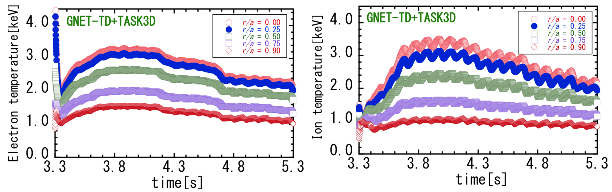
- Heat transport simulation



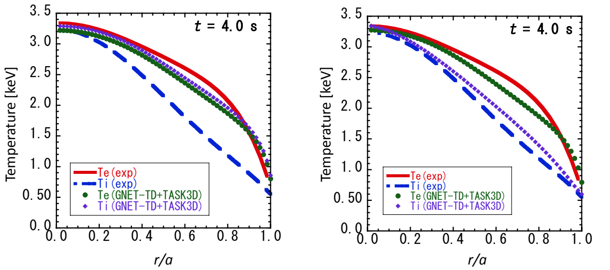
- Simple gyro-Bohm model



- Extended gyro-Bohm with gradT model



- We employed gyro-Bohm and gyro-Bohm+grad T model for turbulent transport coefficients.
- The constant factors for electron and ion were assumed to be equal and chosen to fit the maximum value of T_e to experimental result. ($C_e^{(0)}=C_i^{(0)}=C_i^{(1.5)}=10$, in this study.)
- The simulation results well agreed with experimental results.

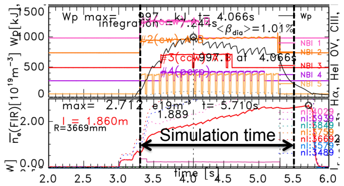


- Development of TASK3D
  - Several turbulent transport models have been installed in TASK3D.
  - Validation of heat transport simulation have been done comparing with the steady-state plasmas in LHD.
  - In order to further improve the prediction accuracy of the code, we have to apply the code to various plasmas.

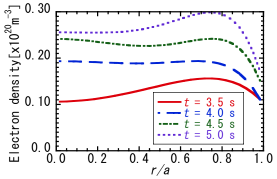
In this study, we apply TASK3D to the time-development LHD plasma to validate the prediction accuracy for time-development plasmas.

Target plasma (LHD #114053)

Time evolution



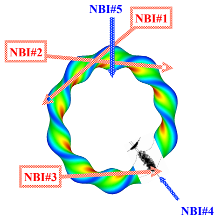
Radial profile of the density



- We apply TASK3D+GNET-TD to the NBI-heated pure H plasma in LHD.
- Rax=3.6m, B0 = 2.75T
- In this shot NBI heating power and plasma density changes in time.
- We compare the time development of Te and Ti.

◆NBI heating systems in Large Helical Device (LHD)

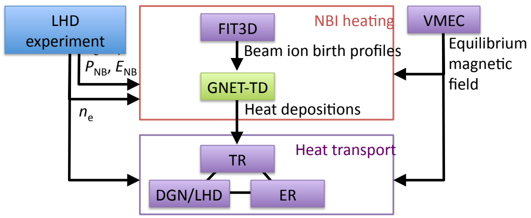
- Five NBI (Neutral Beam Injection) heating systems are installed and applied to experiments in LHD.
- In time-development plasma, birth profiles and slowing-down time of NBI beam ions change with time.
  ➔We have to consider the effect of plasma time development to evaluate the heat deposition of NBI.



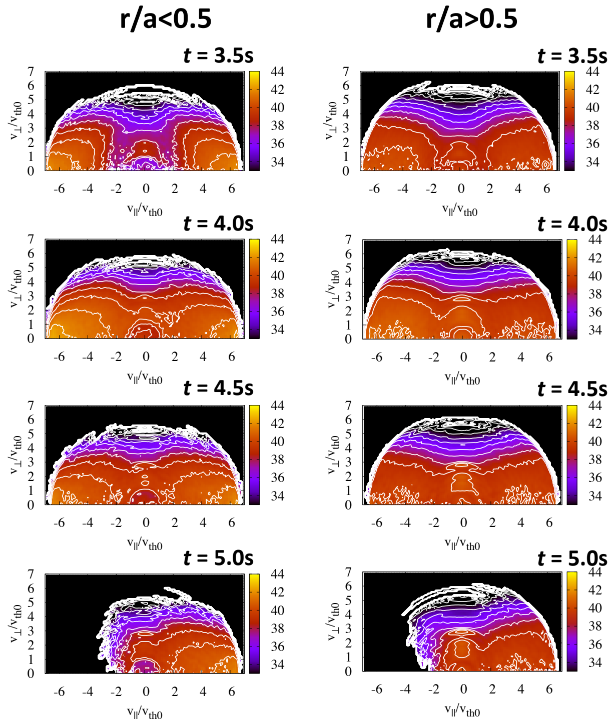
Simulation Models

We perform an heat transport simulation of the time-development LHD plasma using GNET-TD code together with TASK3D.

Flowchart of the heat transport simulation of NBI heated plasma

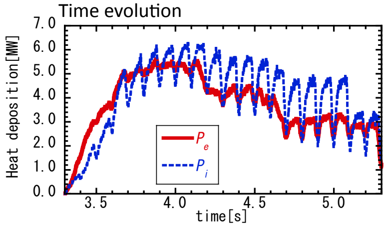


- Beam ion distribution in velocity space



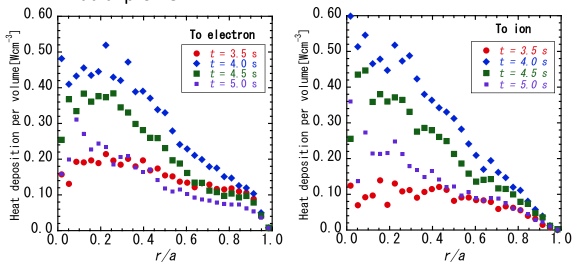
- Heat deposition to electron and ion

Time evolution

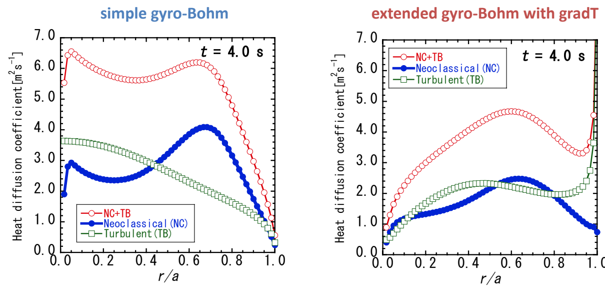


- Beam distribution and heat deposition was obtained by summing each beam component.
- Electron heating changed in response to tangential beam power.
- Ion heating changed in response to perpendicular beam power.

Radial profile

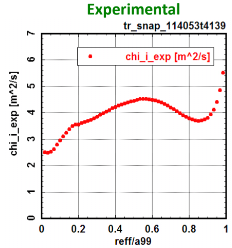


- Heat diffusion coefficient for ion



- We compare ion heat diffusion coefficients χ_i at the time Ti has its maximum value (orange line).
- gyro-Bohm+gradT model well reproduced experimental χ_i.
- With gyroBohm+gradT model for turbulent transport, neoclassical component χ^{NC} became lower.

Experimental



Summary

- An integrated transport cord for helical plasmas, TASK3D, has been developed.
- We performed an integrated transport simulation of time-development LHD plasma using GNET-TD code and TASK3D code.
- Heat deposition to electron changed in response to tangential beam power, while heat deposition to ion changed in response to perpendicular beam power.
- The simulation results of TASK3D well agreed with experimental observations.
- Especially, the extended gyro-Bohm model including temperature gradient well reproduced the radial profile of ion temperature.

Future work

- **Include the effect of impurities (carbon, helium…) in both beam deposition and heat transport simulation.**
- **Development of the turbulence transport model with transport improvements.**
- **Further, we will apply the GNET-TD and TASK3D to various plasmas in wider parameter regime, such as the high-ion-temperature plasma in LHD [4,5]**

References

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