核融合フォーラム・プラズマ物理クラスター
「ＭＨＤ」、「定常運転」、「閉じ込め・輸送」
サブクラスター合同会合
京都テルサ，2007/02/28

ITER 運転シナリオのモデリング

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Contents

- 「定常運転」グループによる ITER 運転シナリオ検討
- TASK コードによる ITER 輸送シミュレーション
- ITER 運転シナリオシミュレーションの比較（Kessel et al）
- 今後の課題

「定常運転」グループにおける ITER 運転シナリオ検討

- ITPA 「定常運転」グループ
  - 元「高エネルギー粒子・加熱・電流駆動」グループ
  - 加熱・電流駆動による定常運転の維持
  - 加熱・電流駆動装置の仕様策定に運転シナリオ検討が必要
- ITPA 「閉じ込めデータベースとモデリング」グループ
  - ITER 物理 R&D 時代に輸送コードのベンチマークテスト
    ⟶ITER Physics Basis
  - IAEA 2004 の際に統合モデリング会合
  - 2006 春から統合モデリングコードの議論

経緯

- **2005/05** (Como):
  - Joint activity to be agreed
  - ITER hybrid scenario, ITER steady-state scenario
  - Optimise scenarios based on their modelling
  - More Heating/CD (NBI, ECRH, ICRH) or install LHCD
- **2005/11** (San Diego):
  - Modelling of ITER advanced scenarios
  - TSC, CRONOS, ONETWO, TASK
  - Starndard set of initial conditions
  - Compare results from different codes

ITER Simulations

- **Using the CDBM and CDBM05 models**
  - Both models could reproduce $T_{e,i}$ profiles for L- and H-mode shots reasonably.
  - The prediction of high performance plasmas is anticipated with the CDBM05 model rather than the CDBM model.
- **Using simple heating and current drive models**
  - Power deposition profile is assumed.
  - Approximate analytic formula is assumed as a current drive efficiency.
- **Searching parameters predicting ITER operation scenarios**
  - Strong self-regulation of the plasma and nonlinearity of the transport model make it more difficult to predict the confinement performance.
- **In this simulation**
  - Density profiles are fixed as H-mode like profiles.
  - **TASK/TR is coupled with the 2-D equilibrium code, TASK/EQ.**
  - It solves the time evolution of the thermal transport and the magnetic diffusion.
  - Radiation losses caused by carbon and bremsstrahlung are taken into account ($Z_{\rm eff} \approx 1.5$).

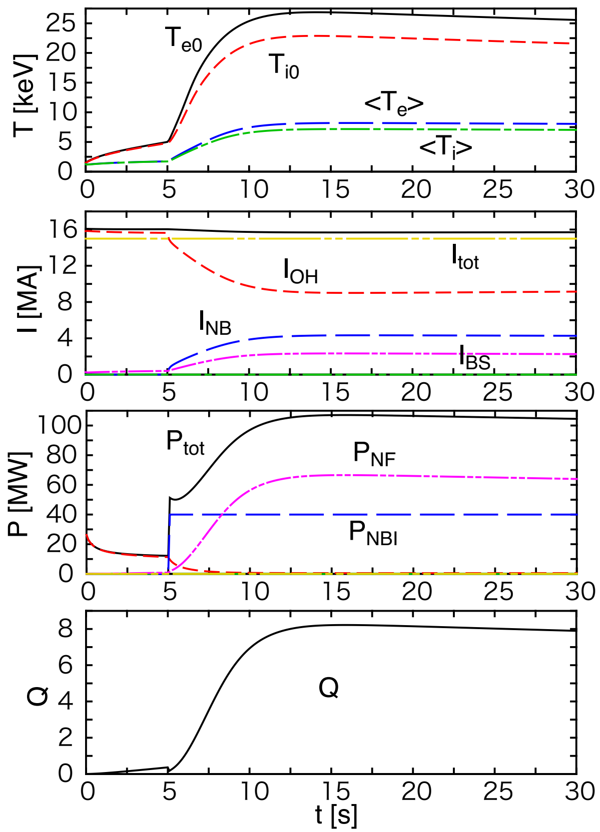
High Q Operational Scenario

- Large plasma current: $I_p = 15$ MA, On-axis heating: $P_{NB} = 40$ MW
- Positive shear profile, Relatively large f_{OH}

CDBM

$\beta_N = 1.49$

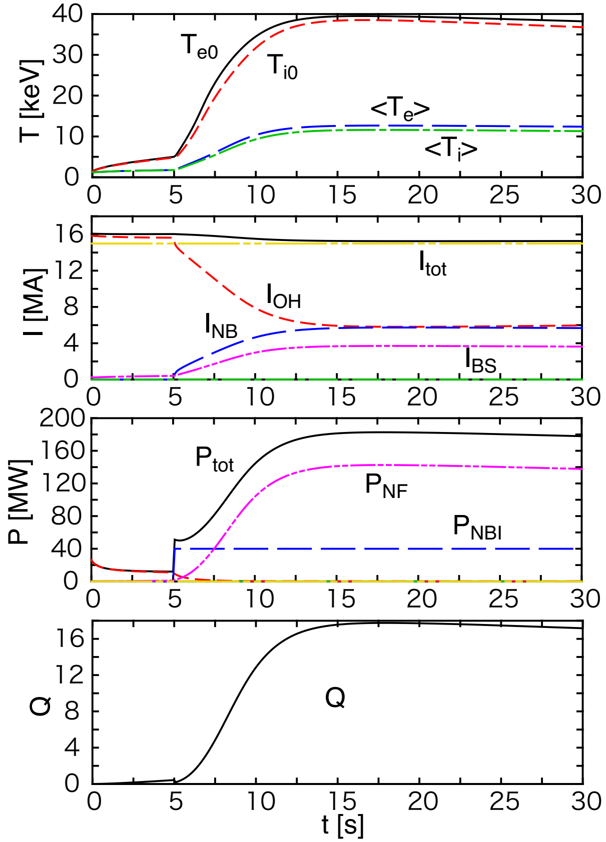
$\tau_E = 3.0$ s

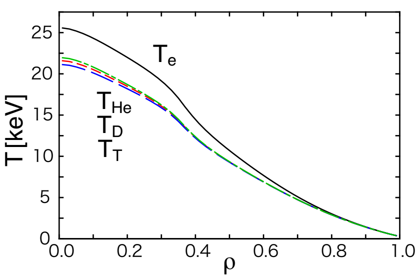


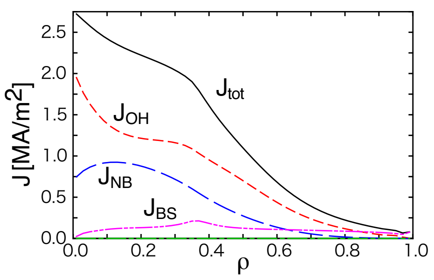
CDBM05

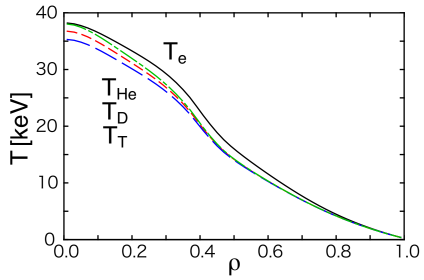
$\beta_N = 2.63$

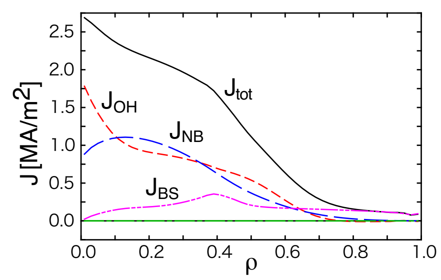
$\tau_E = 3.1$ s











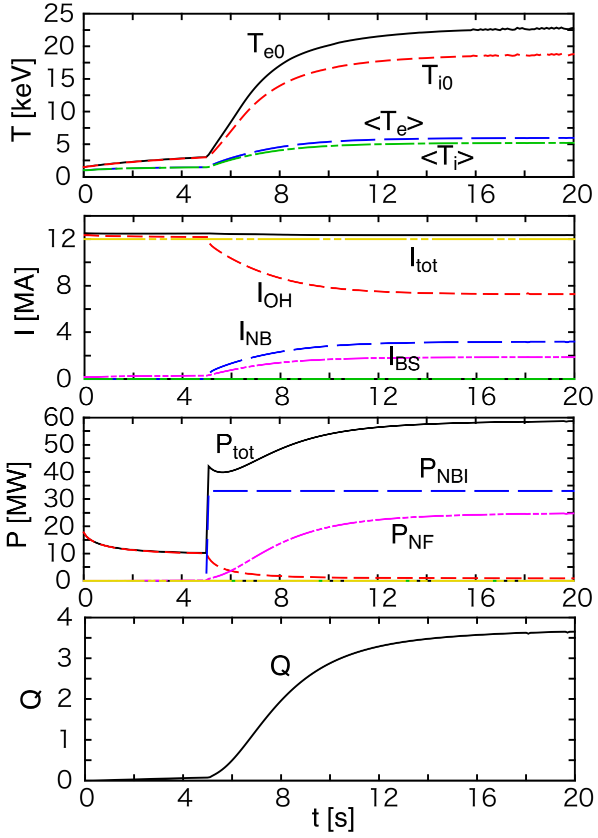
Hybrid Operational Scenario

- Moderate plasma current: $I_p = 12$ MA, On-axis heating: $P_{NB} = 33$ MW
- Flat q profile with small ITB inside $\rho = 0.4$

CDBM

$\beta_N = 1.17$

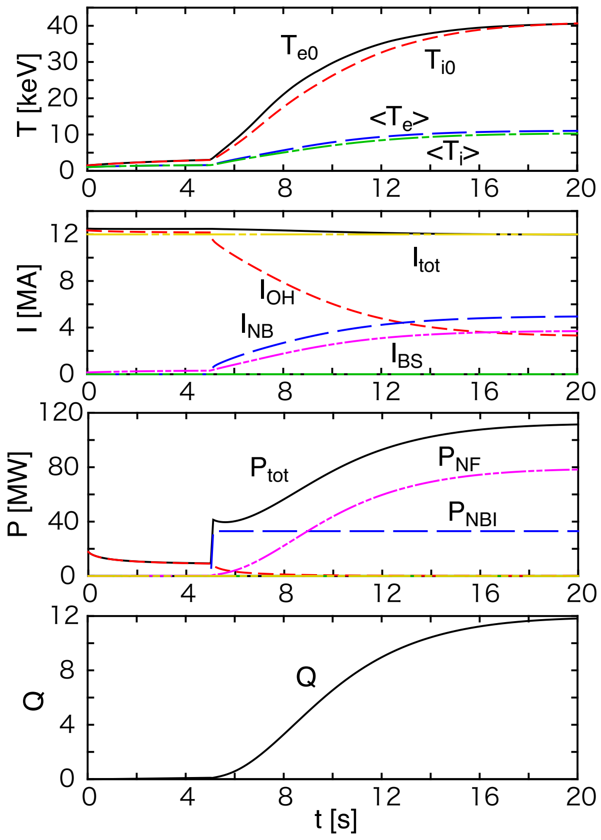
$\tau_E = 3.1$ s

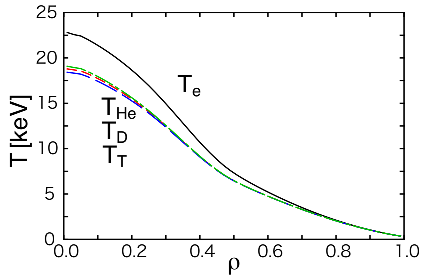


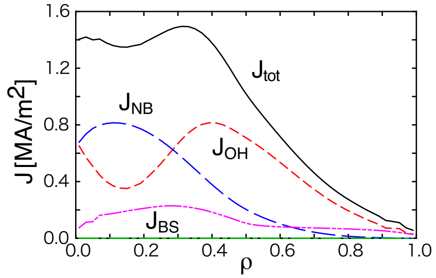
CDBM05

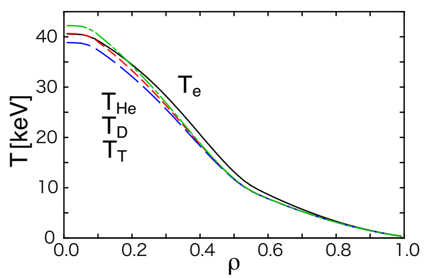
$\beta_N = 2.58$

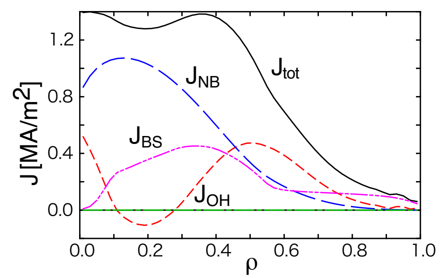
$\tau_E = 3.6$ s











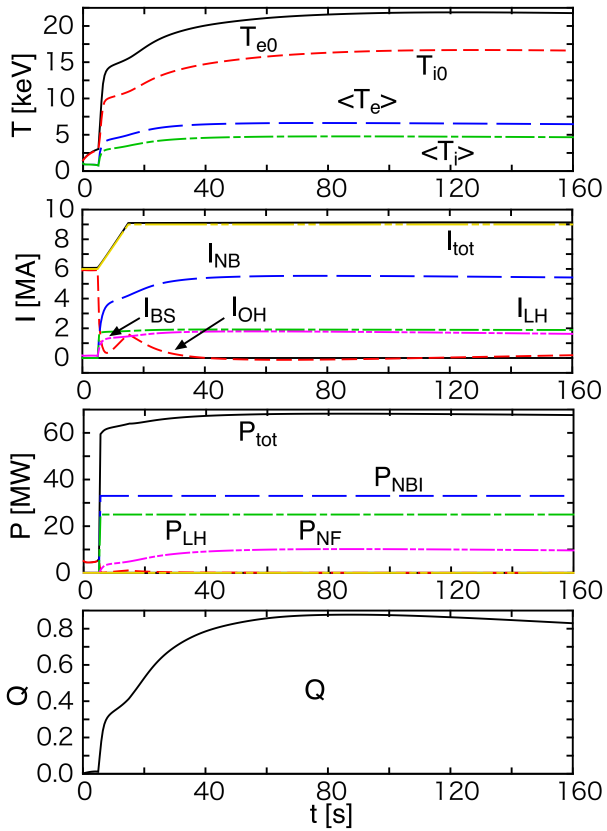
Quasi-Steady State Operational Scenario

- I_p = 6 → 9 MA for 10 s, Negative shear profile, $I_\mathrm{OH} \sim 0$

CDBM

$\beta_\mathrm{N} = 1.2$

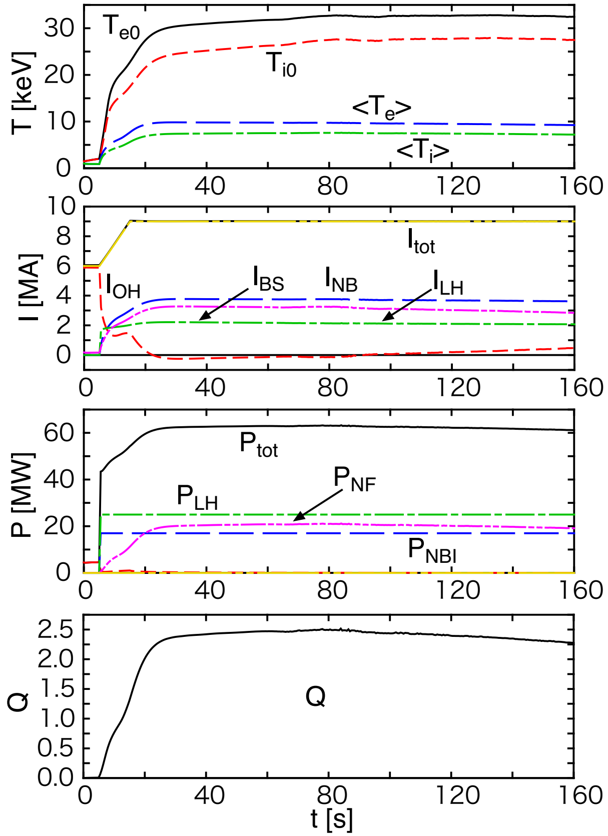
$\tau_\mathrm{E} = 3.0$ s

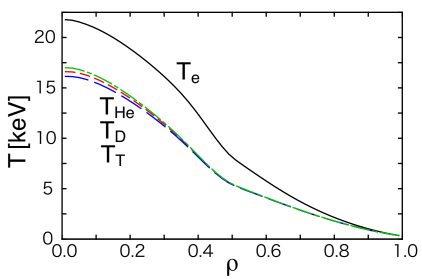


CDBM05

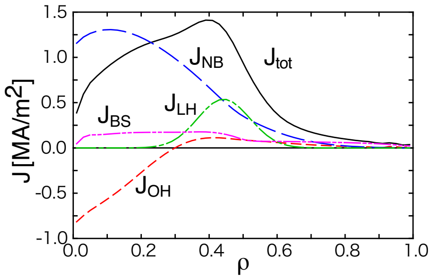
$\beta_\mathrm{N} = 1.55$

$\tau_\mathrm{E} = 3.2$ s

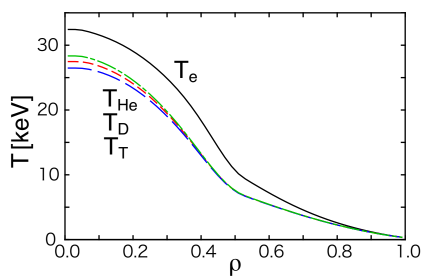




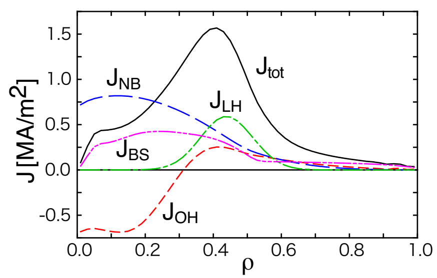
P_NB = 35 MW



P_LH = 30 MW

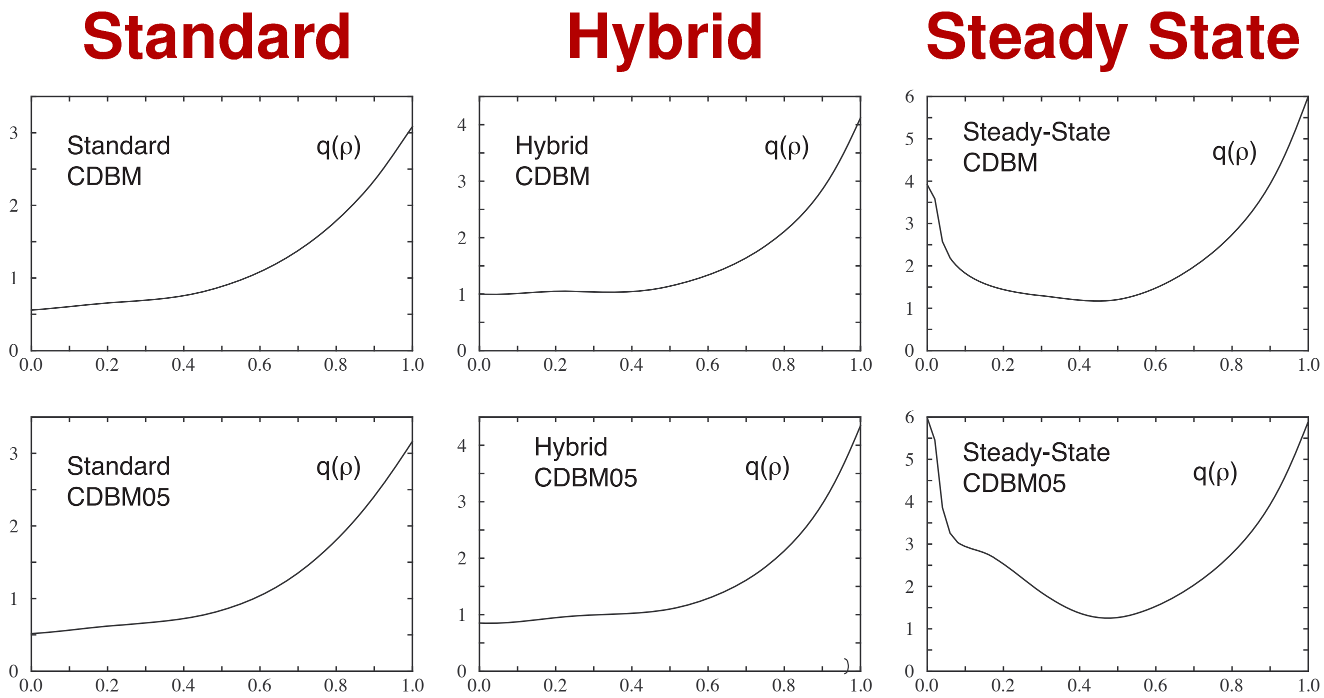


P_NB = 17 MW



P_LH = 25 MW

q Profiles of Previous Shots



- Control of current profile in the hybrid operation requires more improvement to keep $q(0) > 1$.
- Performance of the quasi steady-state operation will be improved if the H-mode plasma edge (edge transport barrier) are included. .

ITPA-SSO: 2006/04 (Naka)

- ITER simulation results
  - TSC (Kessel)
  - ONETWO (Murakami)
  - CRONOS (Giruzzi)
  - TOPICS (Hayashi)
  - TASK (Fukuyama)
- Simulation guideline
  - Hybrid scenario
  - Steady-state scenario

“Guideline” SS Scenario Parameters

April 13 2006

Plasma in flattop phase (as stationary as possible)

Ip = 9 MA
B_T = 5.3 T
τ_P^*/τ_E = 5.0
$f_D/(f_D+f_T)$ = 0.5
f_{Be} = 2%
f_{Ar} = 0.12%

P_{NBI} = 33 MW (1 MeV, off-axis)
P_{ICRF} = 20 MW (40 MHz, FWCD phasing)
P_{EC} = 20 MW (170 GHz, midplane, θ_{tor} = ??)

R_b,Z_b for fixed boundary
(also PF coil currents, li, β_p for free-boundary)

$\rho_{ped}^{density}$ = 0.8
$\rho_{ped}^{temperature}$ = 0.88

n_{ped} = n(ρ = 0.90) = n(0)
T_{ped} = 10.0 keV

n(0) = 0.85 x 10^{20} /m^3
n(ρ = 0.0 - 0.8) = n(0)
Linear drop from ρ = 0.8 - 1.0
n(ρ = 1.0) =1.0 x 10^{20} /m^3
T(ρ = 1.0) = 200 eV

$n_Z(\rho)/n_Z(0)$ same as electrons

$T_e(\rho)$ and $T_i(\rho)$ profiles from GLF23

$T_Z(\rho)$ same as fuel ions

“Guideline” Hybrid Scenario Parameters

April 13, 2006

Plasma in flattop phase (as stationary as possible)

Ip = 12 MA
B_T = 5.3 T
$\tau_P^*/\tau_E = 5.0$
$f_D/(f_D+f_T) = 0.5$
f_{Be} = 2%
f_{Ar} = 0.12%

P_{NBI} = 33 MW (1 MeV, off-axis)
P_{ICRF} = 10 MW (53 MHz, heating only)
P_{EC} = 20 MW (170 GHz, midplane launch, θ_{tor} = ??)

R_b,Z_b for fixed boundary
(also PF coil currents, li, β_p for free-boundary)

$\rho_{ped} = 0.925$

$n_{ped} = n(\rho = 0.925) = n(0)$
T_{ped} = 7.0 keV

$n(0) = 0.95 \times 10^{20}$ /m^3
$n(\rho = 0.0 - 0.925) = n(0)$
Linear drop from $\rho = 0.925 - 1.0$
$n(\rho = 1.0) = 0.35 \times n(0)$
$T(\rho = 1.0)$ = 200 eV

$n_Z(\rho)/n_Z(0)$ same as electrons

$T_e(\rho)$ and $T_i(\rho)$ profiles from GLF23

$T_Z(\rho)$ same as fuel ions

ITPA-SSO: 2006/10 (Chengdu)

- IAEA Fusion Energy conference
  - Simulation of the Hybrid and Steady State Advanced Operating Modes in ITER
    - C. E. Kessel et al. (ITPA-SSO TG)
    - Benchmark test:
    - CRONOS, ONETWO, TSC/TRANSP, TOPICS, and ASTRA
- ITPA SSO TG
  - Modelling of ITER advanced scenarios
    - TSC/TRANSP (C. Kessel)
    - CRONOS (G. Giruzzi)
  - Actuator benchmark test
    - ECCD, LHCD, ICRH, NBI

ITER Hybrid Benchmark Simulations

(more work is needed to strictly enforce these prescriptions for the simulations)

Plasma in flattop phase (as stationary as possible)

$Ip = 12$ MA
$B_T = 5.3$ T
$t_P^*/t_E = 5.0$
$f_D/(f_D+f_T) = 0.5$
$f_{Be} = 2\%$
$f_{Ar} = 0.12\%$

$P_{NBI} = 33$ MW (1 MeV, off-axis, $Z_{NBcenter} = -0.42$ m @ R = 5.3 m)
$P_{ICRF} = 20$ MW (53 MHz, heating only, 2T)
$P_{EC} = 20$ MW (170 GHz, midplane launch, $\alpha_{1,2,3} = 0^o$, $\beta_{1,2,3} = 30^o$, $P_{1,2,3}$ = 6.67 MW)

R_b,Z_b for fixed boundary (also PF coil currents, l_i, β_P for free-boundary)

$\rho_{ped} = 0.925$

$n_{ped} = n(\rho = 0.925) = n(0)$
$T_{ped} = 5.0$ keV

$n(0) = 0.85 \times 10^{20}$ /m3
$n(\rho = 0.0 - 0.925) = n(0)$
Linear drop from $\rho = 0.925 - 1.0$
$n(\rho = 1.0) = 0.35 \times n(0)$
$T(\rho = 1.0) = 200$ eV

$n_Z(\rho)/n_Z(0)$ same as electrons

$Te(\rho)$ and $Ti(\rho)$ profiles from GLF23

$T_Z(r)$ same as fuel ions

Hybrid #1) NB + IC

Hybrid #2) NB + IC + EC

ITER Hybrid NB + IC

	li(1)	q(0)	W_{th} (MJ)	β_N	H_{98}*	Te(0) (keV)	Ti(0) (keV)	Z_{eff}	I_{BS} (MA)	I_{NB} (MA)	P_α (MW) Q
ONETWO	0.72*	0.58	295	2.10	1.10	27.2	33.4	1.70	3.87	2.07	69 6.5
TSC/ TRANSP	1.05	0.44	340	2.18	1.41 1.18	33.8	33.8	1.71	3.39	1.42	80 7.5
CRONOS	0.70*	0.69	339	2.30	1.43	26.3	25.6	1.69	4.26	0.92	87.6 8.3
TOPICS	0.61*	0.99	359	2.24	1.05	30.4	31.6	1.70	3.93	2.62	82.2 7.8
ASTRA	0.77*	0.53	327	2.12	1.18	34.3	34.5	1.71	2.82	1.92	99.7 9.4

*These are li(3)

*Higher H_{98} values use P_{input} and lower values use (P_{input}-P_{rad})

Benchmark Test for ITER Hybrid Scenario

- **C.E. Kessel et al.: IAEA2006 IT/P1-7** (ITPA/SSO)
- Codes: **CRONOS, ONETWO, TSC/TRANSP, TOPICS, ASTRA**

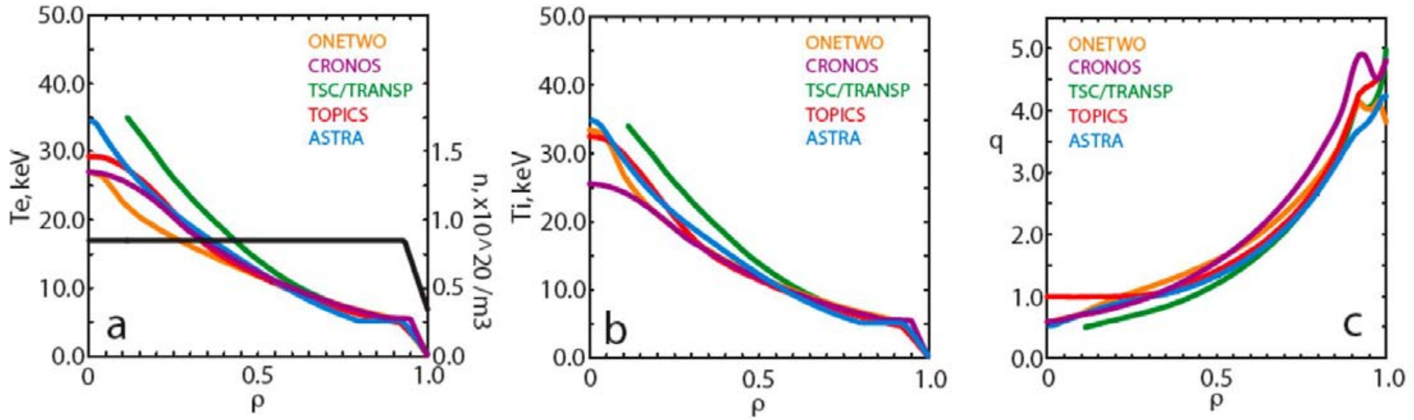


Figure 1. Electron temperature profiles and density profile (a), ion temperature profiles (b), safety factor profiles (c), for the NB+IC ITER Hybrid simulations.

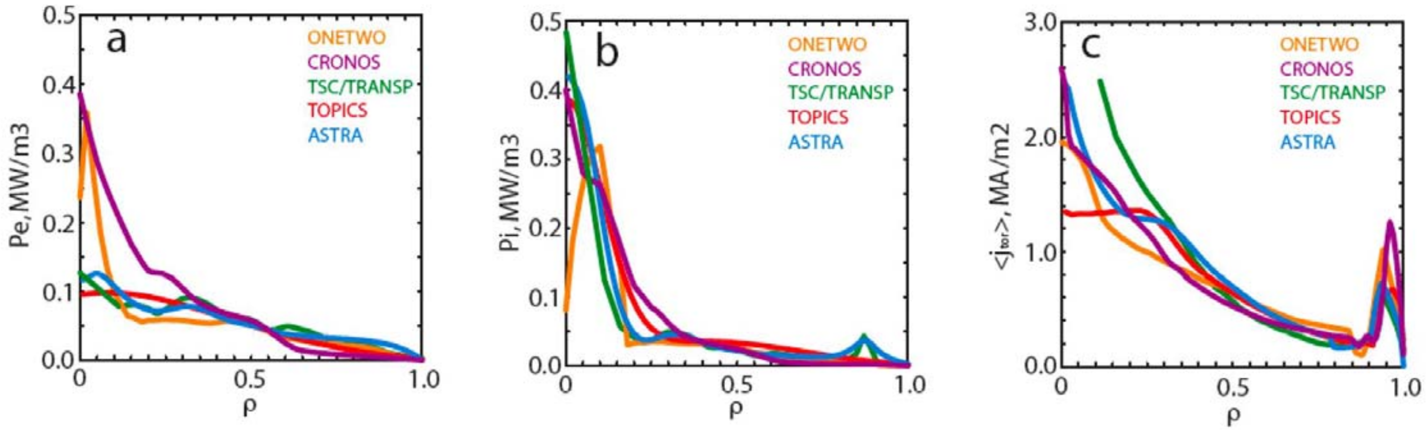


Figure 2. External power deposition profiles to electrons (a) and ions (b) and the toroidal current density (c) for the NB+IC ITER Hybrid simulations.

Benchmark Test for ITER Steady-State Scenario

- Codes: **TOPICS, CRONOS, TSC/TRANSP**

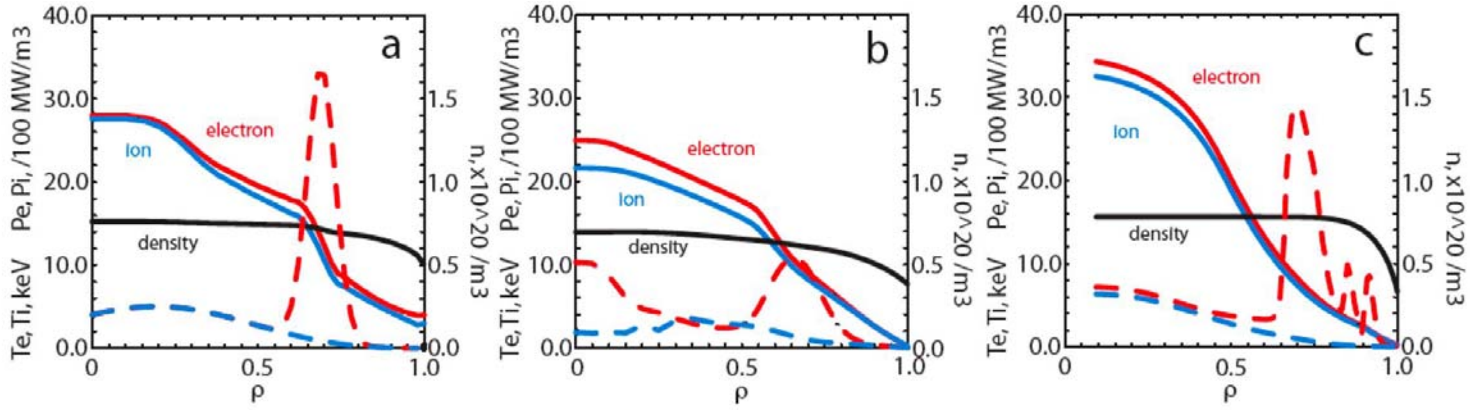


Figure 5. Electron and ion temperature, density, and external power deposition profiles for Steady State ITER simulations, (a) TOPICS (NB+EC), (b) CRONOS (NB+IC+LH), and (c) TSC/TRANSP (NB+IC+LH).

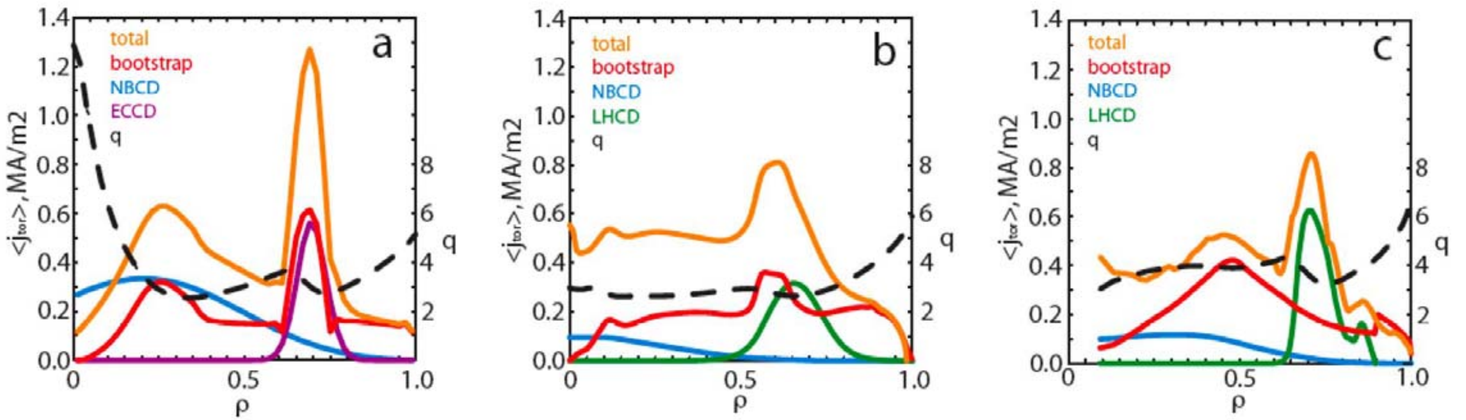


Figure 6. Safety factor and toroidal current density profiles and its contributions for Steady State ITER simulations, (a) TOPICS (NB+EC), (b) CRONOS (NB+IC+LH), and (c) TSC/TRANSP (NB+IC+LH).

今後の課題

- ITER 運転シナリオのモデリング
  - CDBM Modeling group との連携
  - シミュレーション ガイドラインの再検討
  - 加熱機構モデリング
  - ベンチマークテストの意義
- 日本の貢献
  - 運転シナリオモデリング： TOPICS, TASK
  - 加熱機構ベンチマークテスト：ECCD, NNBI
  - SSO-TG 会合に出席しつづけることが必要
- 次回：2007/05/9-11