EVALUATION OF PLASMA PERFORMANCE IN JA DEMO STEADY-STATE OPERATION

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We have evaluated the plasma performance in the JA DEMO steady-state operation using the integrated modelling code GOTRESS+. The optimal heating and current drive conditions are clarified to maximize the non-inductive current drive per injection power. We examine the dependence of the density profile and pedestal temperature on the plasma performance. We compare the plasma performance evaluated using three different turbulent transport models. The models predict a similar performance whereas they evaluate the different profiles of the temperature and current density. We have obtained the prospect that the plasma operation is possible with the plasma performance required for the power generation in JA DEMO, addressing uncertainties in the modelling and assumption.

1. INTRODUCTION

The conceptual design activity for a steady-state tokamak demonstration reactor, JA DEMO [1], has been conducted in Japan. The plasma operation scenario development is necessary to construct a feasible DEMO concept and to determine the component designs such as the heating and current drive systems. The steady-state plasma operation scenario from the ramp-up to the flat-top burn phases has been developed for JA DEMO [1]. To ensure that the plasma performance required for the achievement of DEMO goals is obtained, the plasma scenario should be developed based on the analyses within a wide range of assumptions considering the modelling uncertainties. The ITER plasma performance has been compared for different turbulent thermal transport models, densities, heating and current drive schemes, and impurity concentrations [2–4]. The dependence of the plasma performance on the turbulent transport model has been examined for EU DEMO [5]. The plasma required for JA DEMO has the characteristics of the larger size and higher performance compared to the ITER plasmas and the fully non-inductive current drive, i.e., the higher non-inductive current drive fraction compared to EU DEMO which supposes no external current drive in the flat-top burn phase. In this paper, we have evaluated the plasma performance in the JA DEMO steady-state operation by conducting integrated modelling simulations with a wide parameter range, addressing uncertainties in the modelling.

2. ANALYSIS MODEL

The plasma performance is evaluated using the integrated modelling code GOTRESS+ [6]. One of the characteristics of GOTRESS+ is to find the steady-state solution directly; therefore, the code is effective for the purpose of this paper. The temperature and current profiles and two-dimensional free boundary equilibrium are calculated, prescribing the electron density profile and ion density fractions. The temperature profile is given in the region of $\rho \geq 0.85$ by the hyperbolic tangent function and solved in the core region ($\rho < 0.85$). Here, ρ is the normalized minor radius. Argon is considered as the impurity species that is injected intentionally to suppress the net plasma loss power across the separatrix, P_{sep}. The Bohm-gyroBohm (BgB) [7,8], CDBM [9], and Coppi-Tang (CT) [10] models are used for the turbulent thermal transport models. The BgB and CDBM models well reproduce internal transport barriers (ITBs) [8] which are supposed to be utilized in the JA DEMO steady-state plasma operation [1]. The CT model has often been used for the ITER scenario studies [3, 4].

3. RESULTS AND DISCUSSION

Table 1 shows the main parameters obtained from a systems analysis (Reference) [1] and the GOTRESS+ simulations for the cases using the BgB, CDBM, and CT models. Figure 1 shows the profiles of (a) the electron density assumed, safety factor, q, (b) ion temperature, and (c) neutral-beam (NB) and electron cyclotron (EC) driven current densities obtained from the GOTRESS+ simulations for the cases using the BgB, CDBM, and CT models. Here, P_{fus} is the fusion power, $P_{\mathrm{NBI(EC)}}$ is the NB (EC) injection power, $Q = P_{\mathrm{fus}} / (P_{\mathrm{NBI}} + P_{\mathrm{EC}})$, f_{GW} is the line-averaged electron density normalized by the Greenwald density limit, β_{N} is the normalized beta, H_{H} is the ratio of the energy confinement time to the IPB98(y,2) scaling, $f_{\mathrm{BS(CD)}}$ is the bootstrap (externally driven) current fraction, and Z_{eff} is the effective charge. The EC and NB injection conditions are determined so that an ITB is maintained at $\rho = 0.6$ by EC current drive, $f_{\mathrm{BS}} + f_{\mathrm{CD}} > 1$ and the minimum value of q is above one for the case

Table 1. Main parameters obtained from a systems analysis (Reference) and the GOTRESS+ simulations for the cases using the BgB, CDBM, and CT models.

Parameter	Reference	BgB	CDBM	CT
P_{fus} [MW]	1462	1490	1483	1508
P_{NBI} [MW]	83.7	75	75	75
P_{EC} [MW]	0	40	40	40
Q	17.5	12.9	12.9	13.1
f_{GW}	1.2	1.29	1.28	1.29
β_N	3.4	3.62	3.67	3.65
H_H	1.31	1.51	1.55	1.53
f_{BS}	0.61	0.62	0.61	0.62
f_{CD}	0.39	0.45	0.42	0.43
Z_{eff}	1.84	2.6	2.6	2.6

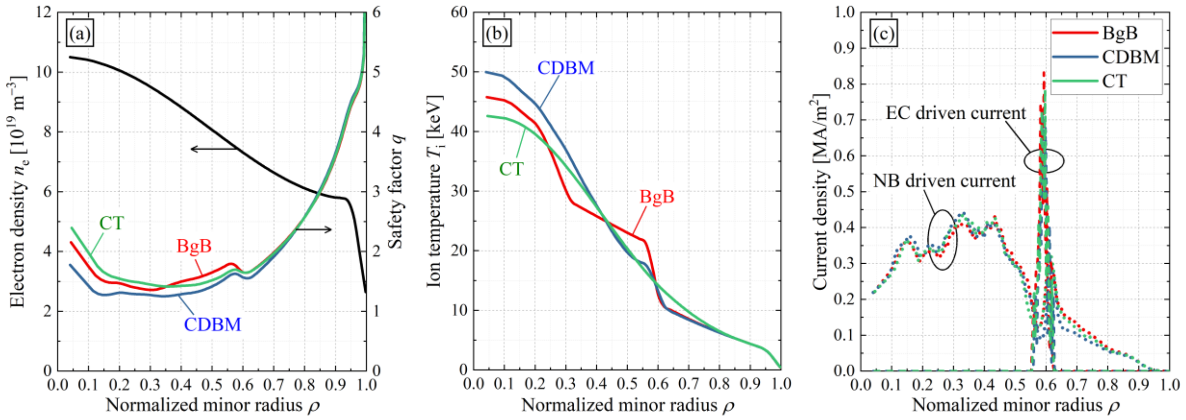

Figure 1. Comparison of the profiles of (a) the electron density assumed, safety factor, (b) ion temperature, and (c) NB- and EC- driven current densities obtained from the GOTRESS+ simulations between the cases using the BgB, CDBM, and CT models.

using the CDBM model. The electron density profile, pedestal temperature, and Z_{eff} are determined to obtain P_{fus} ~ 1.5 GW and P_{sep} ~ 285 MW for divertor protection [11]. The pedestal density and temperature are determined to be 0.85 times the Greenwald density limit and 3 keV, respectively, considering the magnetohydrodynamic stability. The same conditions are assumed for the three cases of the GOTRESS+ simulations except for the transport model, although the optimal conditions depend on the transport model. Because the BgB and CDBM models include the shear effect, ITBs are formed at the positions where the q profile has local minima, whereas no ITB is observed for the case of the CT model. Although the three transport models predict the different temperature and current profiles, the main parameters are evaluated to be similar values. The systems analysis underestimates the power required for the current drive, β_N, H_H, and Z_{eff}.

REFERENCES

[1] SAKAMOTO, Y., et al., Development of physics and engineering designs for Japan's DEMO concept, 27th IAEA Fusion Energy Conf. (2018) FIP/3-2.
[2] POLEVOI, A. R., et al., Assessment of operational space for long-pulse scenarios in ITER, Nucl. Fusion **55** (2015) 063019.
[3] KIM, S. H., et al., Investigation of key parameters for the development of reliable ITER baseline operation scenarios using CORSICA, Nucl. Fusion **58** (2018) 056013.
[4] KIM, S. H., et al., A study of the heating and current drive options and confinement requirements to access steady-state plasmas at Q ~ 5 in ITER and associated operational scenario development, Nucl. Fusion **61** (2021) 076004.
[5] SICCINIO, M., et al., Development of a plasma scenario for the EU-DEMO tokamak reactor, 29th IAEA Fusion Energy Conf. (2023) 1661.
[6] HONDA, M., et al., Development of a novel integrated model GOTRESS+ for predictions and assessment of JT-60SA operation scenarios including the pedestal, Nucl. Fusion **61** (2021) 116029.
[7] ERBA, M., et al., Validation of a new mixed Bohm/gyro-Bohm model for electron and ion heat transport against the ITER, Tore Supra and START database discharges, Nucl. Fusion **38** (1998) 1013.
[8] HAYASHI, N., et al., Transport modelling of JT-60U and JET plasmas with internal transport barriers towards prediction of JT-60SA high-beta steady-state scenario, Nucl. Fusion **57** (2017) 126037.
[9] FUKUYAMA, A., et al., Transport simulation on L-mode and improved confinement associated with current profile modification, Plasma Phys. Control. Fusion **37** (1995) 611.
[10] JARDIN, S. C., et al., TSC simulation of Ohmic discharges in TFTR, Nucl. Fusion **33** (1993) 371.
[11] ASAKURA, N., et al., Simulation studies of divertor detachment and critical power exhaust parameters for Japanese DEMO design, Nucl. Mater. Energy **26** (2021) 100864.