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TASK コードによる原型炉起動時における燃料同位体に注目した輸送研究
Research about fuel isotope transport during DEMO start up using TASK code

宮前　健人 [1], 山田　弘司 [1], 福山　淳 [2]
K. Miyamae[1], H. Yamada[1], A. Fukuyama[2].

[1] 東京大学新領域創生科学研究科, [2] 京都大学
[1] Graduate school of Frontier Sciences, The University of Tokyo, [2]Kyoto University.

It is important to develop a reliable operation scenario during startup phase for DEMO. In JA DEMO, ignition scenario for ohmic plasma initiation has been developed [1]. In EU DEMO, steady state scenario with q profile of hybrid shear is considered [2]. Startup scenarios of DEMO are still in research, with many different assumptions over plasma physics. In this research, a startup scenario of JA DEMO is developed, focusing on the diffusive transport of ions and electron in transient state. Also, along with the scenario development, the isotope effect of ions against evolution of fusion power output is analyzed.

In this research, the integrated tokamak modeling code, TASK/TR, is used to calculate temporal evolution of tokamak core plasmas [3]. In the TASK code, following one dimensional diffusion equations are solved.

$$\frac{\partial}{\partial t}(n_s V') = -\frac{\partial}{\partial \rho}(V'\Gamma_s) + S_s V',$$

$$\frac{\partial}{\partial t}\left(\frac{3}{2} n_s T_s V'^{3/5}\right) = -V'^{2/3}\frac{\partial}{\partial \rho}(V' Q_s) + S_{Es} V'^{5/3},$$

$$\frac{\partial}{\partial t}\left(\frac{\partial \psi}{\partial \rho}\right) = \frac{\partial}{\partial \rho}\left[\frac{\eta_{\parallel}}{\mu_0}\frac{I}{V'\langle R^{-2}\rangle}\frac{\partial}{\partial \rho}\left(\frac{V'}{I}\left\langle\frac{|\nabla\rho|^2}{R^2}\right\rangle\frac{\partial \psi}{\partial \rho}\right) - \frac{\eta_{\parallel}}{I\langle R^{-2}\rangle}\langle (J_{CD}+J_{BS})B_{\phi}\rangle\right],$$

where

$$\Gamma_s = \langle|\nabla\rho|\rangle n_s V_s - \langle|\nabla\rho|^2\rangle D_s \frac{\partial n_s}{\partial \rho},$$

$$Q_s = \frac{5}{2}\langle|\nabla\rho|\rangle n_s T_s V_{Es} - \langle|\nabla\rho|^2\rangle \chi_s \frac{\partial (n_s T_s)}{\partial \rho} - \langle|\nabla\rho|^2\rangle\left(\frac{5}{2}D_s - \chi_s\right)T_s\frac{\partial n_s}{\partial \rho}$$

and s denotes each species such as electron and bulk ions. For particle and heat diffusion, CDBM model [4] was used.

Fusion reactor parameters are based upon the recent tokamak fusion DEMO design by the Joint Special Design Team [5]. During the operation, fuel ions are injected continuously from outer side of minor radius, which is deposited at $\rho = 0.8$.

The development of plasma current and fusion power output in the base case scenario is shown in Fig. 1. Plasma current was raised to 14.5 MA, and fusion energy gain value Q reached 10 at the end. However, as shown in Fig. 2 (a), He ash builds up in the center and fuel ions are diluted to form hollow profile, resulting in limitation of Q value at early stage of operation.

To enhance the fusion output and Q value, anomalous particle pinch was added to the diffusion equation. With particle pinch, profiles of fuel ions are improved, and Q value successfully reached 15. This indicates that without particle pinch, at least in early stage of operation, fueled ions could not reach center and fusion output is degraded.

Isotope effect of ions are modeled based on the CDBM [4], with Alfven velocity of each ion species

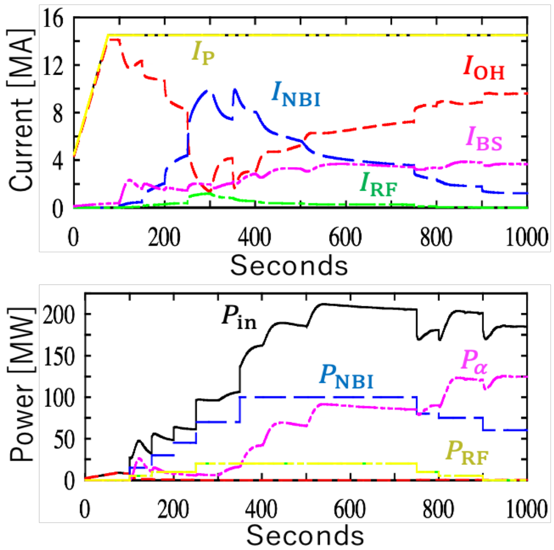

Figure 1. Temporal evolution of plasma current and fusion output in the base case scenario. After 750 seconds, auxiliary powers are decreased and hence Q value rises.

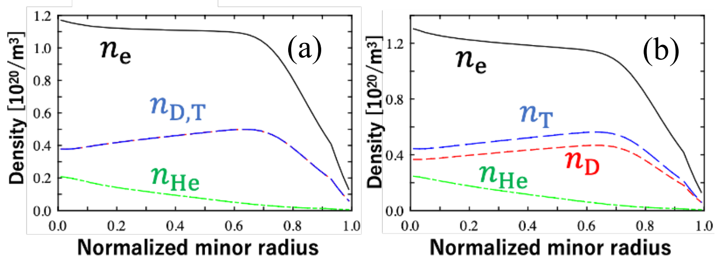

Figure 2. Density profile of ions and electron in (a) the base case scenario and (b) the case with isotope effect of CDBM integrated.

calculated separately for the following equation.

$$\chi_{CDBM} = CF(s,\alpha)\alpha^{3/2}\frac{c^2}{\omega_{pe}^2}\frac{v_A}{qR}$$

The difference in profile of deuterium and tritium is shown in Fig. 2 (b). Due to the isotope effect, heavier ions have less diffusion coefficient, resulting in difference of density profile. Although He ash built up more and fuel ratio deviated from 1:1, its effect to the fusion power output was relatively small (less than 5%).

References

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