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Remarks on DD start-up of a fusion reactor

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Initial loading of tritium in a fusion reactor is a serious issue because of availability of tritium. The natural abundance of tritium is almost zero, and resource produced by HWR (Heavy Water Reactor) is limited to several tens kilogram worldwide. Thus, the start-up only from deuterium has been attracting interests. While the previous research of this DD start-up scenario [1] showed the technical feasibility of this scenario, the model of plasma kinetics was so simple that temperature is assumed constant during the start-up. It should be noted that temperature changes during the start-up phase due to the dependence of energy confinement on the fusion power heating as well as the isotope effect by the build-up of tritium concentration. In the present model, the evolution of temperature consistent with power balance including radiation losses and an empirical scaling of an energy confinement time has been simulated. In addition, the profile structures of plasma density and temperature are also discussed.

Operational parameters are based upon the recent tokamak fusion DEMO design by the Joint Special Design Team [2].

Plasma stored energy W_p and accumulation of tritium are calculated using the idea of stock and flow of a system dynamics model. In the model, inflows to the W_p are the alpha heating and NBI heating of 61.9MW; outflows are bremsstrahlung radiation, cyclotron radiation, and the loss due to energy confinement. For energy confinement time, the ITER-98P(y,2) scaling has been used [3],

$$\tau_E = 0.0562 I_p^{0.93} B^{0.15} P^{-0.69} n^{0.41} M^{0.19} R^{1.97} \varepsilon^{0.58} \kappa_a^{0.78}$$

, where I_p, B, P, n, M, R, ε and κ_a are plasma current in MA, magnetic field in T, density in $10^{19}\mathrm{m}^{-3}$, mass number of fuel ions (AMU), major radius in m, inverse aspect ratio and elongation, respectively. The mass number is traced by $(2n_D+3n_T)/n_e$, where n_e is fixed at $5.27\times10^{19}\mathrm{m}^{-3}$. Then temperature is calculated from W_p. Fusion cross sections are calculated by polynomial approximation based upon the well-used model [4].

Three cases such as uniform profile with and without temperature dependence, and parabolic profile with temperature dependence are discussed. In the profile integrated model, profiles of both temperature and density are assumed to have shape of the following equation

$$a(\rho) = (a_0 - a_b)\cdot(1-\rho^2)^{0.6} + a_b$$

where ρ is the normalized minor radius and a_b is the boundary value. This profile is approximated by stepwise shells.

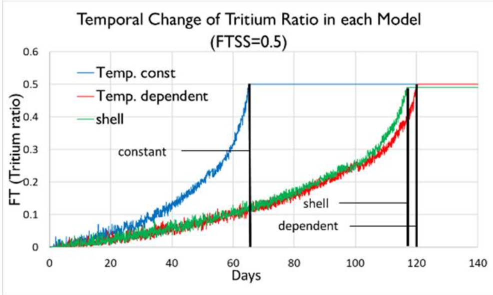

Figure 1 Temporal change of tritium ratio

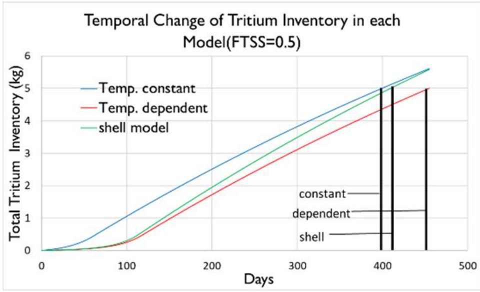

Figure 2 Time development of tritium inventory

Temporal development of tritium ratio (FT) in a plasma is compared between three models in Figure 1. FT is defined by n_T/n_e, and FTSS is a fixed value which defines the tritium ratio in equilibrium state. In the case of the temperature dependent model with uniform profiles (in red), the tritium concentration reaches to the equilibrium state in 120 days, which is 55 days later than the temperature constant model (in blue). In the shell model (in green), equilibrium state is reached in 116 days. Figure 2 shows the development of tritium inventory in a plant. It is notable that tritium inventory in the case of shell model increases faster than in the case of temperature dependent model with uniform profile after the equilibrium is established.

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