§8. D-D Fusion Reactions and Triton Burn-up in the Deuterium Experiment Plasma of LHD

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The deuterium experiment project from 2017 is planned in LHD, where the deuterium NBI heating beams with the power more than 30MW are injected into the deuterium plasma. Principal objects of this project are to clarify the isotope effect on the heat and particle transport in the helical plasma and to study energetic particle confinement in a helical magnetic configuration measuring triton burn-up neutrons.

We have developed an integrated transport simulation code, TASK3D, and applied to the high ion temperature plasma of LHD[1]. Also, to study the kinetic behavior of the energetic particle in helical plasmas, we have developed the GNET[2] code, in which the drift kinetic equation of energetic particles is solved in five-dimensional phase space. In this paper, we study the triton burn-up experiment in LHD by applying the TASK3D and GNET codes.

We perform the triton burn-up simulation of the deuterium experiment of LHD and evaluate the D-T fusion reaction rates to compare with the experimental results of the 14 MeV neutron diagnostic system. The radial profile of the 1 MeV triton production rate due to the D-D fusion reaction between D-beam and D-thermal ions is evaluated by GNET using the radial profiles of T_D and n_D obtained by TASK3D. Figure 1 shows the hows the radial profiles of the evaluated triton production rate due to the D-D fusion reactions in the three density cases $n_e(0) = 0.8, 2.0, 3.5 \times 10^{19}\mathrm{m}^{-}3$. Each of the production rates shows a center peak profiles. It is found that the triton production rate does not simply depend on the density. This is because the population of the energetic beam ions depends on the beam ion birth and slowing-down process. As a result we obtain a center peaked triton production rate about 1.4×10^{14} $\mathrm{m}^{-3}\mathrm{s}^{-1}$ in the $n_{e0} = 2.0 \times 10^{19}$ m^{-3} case.

Next we solve the 5-D drift kinetic equation for the 1MeV tritons by GNET and evaluate the slow down distribution in the real and velocity space. Figure 2-(top) shows the slowing down velocity space distribution of the 1MeV tritons in LHD ($R_{ax} = 3.6$m). We can see a large loss region near the helically trapped particles. About 25% of tritons escape with almost the initial energy of 1 MeV by the prompt orbit loss due to drift motion immediately after their birth ($t < 10^{-5}$ s). After the prompt orbit loss, the collisionless diffusive loss ($10^{-5} < t < 10^{-2}$) and, then, the collisional diffusive loss ($t > 10^{-2}$ s) become dominant.

We evaluate the radial profile of 14MeV neutron production rate using the triton distribution by GNET and T_D, n_D profiles by TASK3D [Fig. 2-(bottom)]. It is found that more than 7.0×10^{11} $\mathrm{m}^{-3}\mathrm{s}^{-1}$ of 14MeV neutrons are generated by the D-T fusion reaction at the plasma center. We also find that the confinement of the 1MeV tritons is improved by the strongly inward shifted configuration of LHD ($R_{ax} = 3.5$m) and that the triton burn-up ratio, which is the ratio of 14 MeV to 2.5 MeV neutron production, is increased to about 0.25%, which is still smaller than that of the large tokamak experiment results.

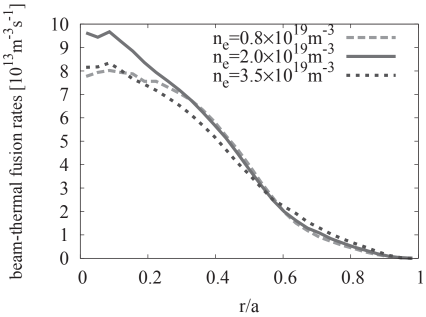

Fig. 1: Radial birth profile of tritons calculated by GNET code.

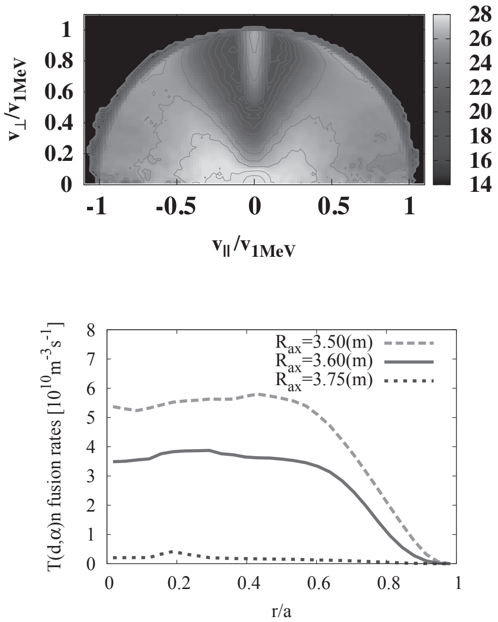

Fig. 2: *Slowing down distribution of 1MeV tritons in the velocity space (top) and radial profiles of 14MeV neutron production rate by the D-T fusion reaction[$P_{tNBI} = 1MW$] (bottom).*

1) S. Murakami et al., Plasma Phys. Control. Fusion **57**, 054009 (2015).
2) S. Murakami et al., Nuclear Fusion **46**, S425 (2006).
3) H. Yamaguchi and S. Murakami, Nucl. Fusion **56** (2016) 026003.