§7. Control of Radiation Process in LHD-type Fusion Reactor

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The LHD-type magnetic field configuration has chaotic field line region outside of the last closed flux surface. The connection length of lines of force become very long in an LHD-type configuration because of the high magnetic shear. Then, an LHD-type fusion reactor would become possible surrounding the high-temperature core plasma by a high-Z, low-temperature ($T \lesssim$ a few KeV), and high-density plasma in the peripheral chaotic field line region. Presence of the low-temperature and high-density plasma in the periphery brings the following three benefits to the fusion reactor: reduction of the bremsstrahlung loss from the core plasma, reduction of divertor heat flux and convert of the fusion energy to visible radiation.

i) Reduction of the bremsstrahlung loss

Proton-Boron fusion reactor ($P^{11}B$ reactor) [1] probably offers the ultimate energy resource. The fuels (Proton and Boron) are ubiquitous on the earth and fast neutrons are not generated. Main reaction

$$p + {}^{11}B \rightarrow 3\alpha + Q_\alpha \,, Q_\alpha \simeq 8.7 \text{ MeV} \qquad (1)$$

is neutron-free. The side reaction

$$p + {}^{11}B \rightarrow n + {}^{11}C - 2.8 \text{ MeV} \qquad (2)$$

is an endothermal reaction and produces only slow neutrons when energy of proton exceed about 3 MeV or more. It has been, however, considered, in the $P^{11}B$ reactor that bremsstrahlung loss is too large to satisfy the ignition condition, because the atomic number of boron is so large ($Z_B = 5$). One possibility of $P^{11}B$ reactor was suggested by a combination of LHD type magnetic configuration and ICRF heating scheme [2, 3].

We have estimated the ignition condition of fusion reactor

$$\frac{W_p}{\tau} + \eta_{sc} P_B = P_c \qquad (3)$$

under the assumption of screening effect $\eta_{\rm sc}$ of the bremsstrahlung loss P_B , and have confirmed the possibility of a $P^{11}B$ reactor (Fig.1).

ii) Study for physical mechanism of the impurity hole

A good balance between a high-temperature core plasma and a low-temperature and high-density peripheral plasma is necessary for the application of the radiation process in a fusion reactor. LHD experiments have founded the impurity hole: high Z and high mass impurities are automatically exhausted from a core plasma.

We have studied the orbits of high-Z impurities in the LHD magnetic field taking into account the change of ionic charge, which cause the diffusion process by the change of the Larmor radius. In high-temperature plasma, the ionization process increase the ionic charge and the Larmor radius become small. Then inner diffusion speed becomes slow. But, if a high-Z and high energetic ion moves toward peripheral low temperature region, the recombination process reduce the ionic charge of the ion. Then, outer diffusion speed becomes fast because of large Larmor radius of the ion. Furthermore, in LHD magnetic configuration, large poloidal Larmor radius of a low ionic charge and high energy make the ion be a direct loss particle. We have confirmed numerically as shown if Fig. 2.

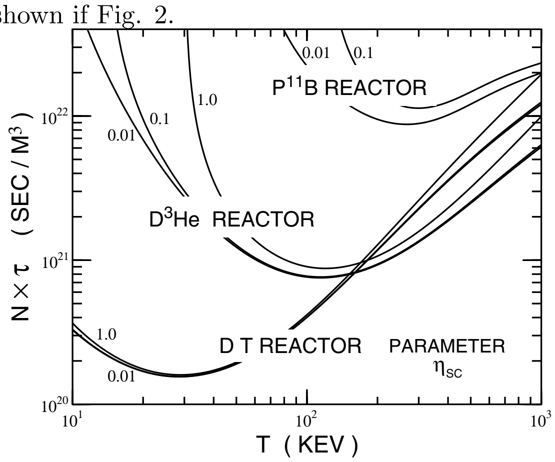

Fig. 1: Effect of $\eta_{\rm sc}$ for the ignition conditions of DT, D^3He and $P^{11}B$ reactors

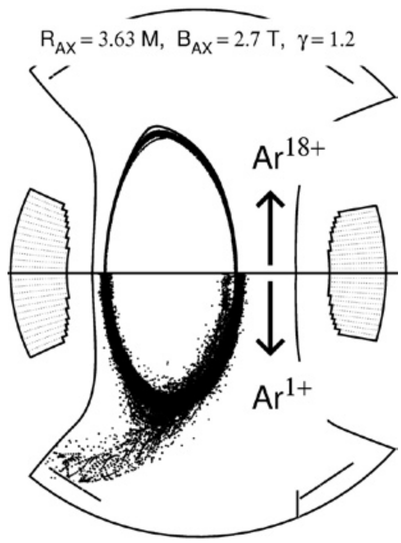

Fig. 2: Relation between ionic charge and particle orbits near the LCFS in LHD. Upper (lower) half represents the Poincaré plot of Ar^{18+} (Ar^{1+}) of $E = 10$ KeV.

1) J. M. Dawson, RPG-273, University of California, Los Angels (1976).

2) Watanabe, T., et al, J. Plasma Fusion Res. Series, **6** (2004) 630.

3) Hojo H., Watanabe, T., and Todoroki J., *Theoretical study of $P^{11}B$ reactor with LHD-Type magnetic field configuration*, KAKEN(15540480) (2004).