§ 23. Ignition Condition of Proton-Boron Fusion Reactor[1)]

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Proton-Boron fusion reactor (p-^{11}B reactor)

$$p + {}^{11}B \rightarrow 3\alpha + 8.7\ MeV$$

has a potentiality for the ultimate energy resource on the earth. Because, the fuels (proton and boron) are ubiquitous on the earth and fast neutrons are not generated. It has been, however, considered, in the p-^{11}B reactor that bremsstrahlung power loss is too large to satisfy the ignition condition, because the atomic number of boron is so large ($Z_B = 5$). But, the progress of LHD experimental and theoretical studies have brought a new prospect for the p-^{11}B reactor.

A remarkable loss of the high energetic particle is not found in the ICRF experiment of LHD and the energy spectrum of the accelerated protons has extended even to 500keV-range. This result agrees with the prediction clarified by the particle orbit calculation, which show that MeV-range protons are produced and confined by ICRF heating in LHD ($B_{ax} = 3$T). It is shown that accelerated protons can selectively absorb the energy from ICRF wave. Then, runaway ion heating process occurs in ICRF heating in LHD[1)].

The plasma disruption caused by the high beta is not yet observed in LHD, even if the beta value go beyond the traditional theoretical limit. It is shown theoretically that LHD has potentiality of the high beta plasma confinement[2)]. The chaotic field line-layer plays a key role for an efficient plasma confinement in LHD. Steep density gradient in peripheral region can be stabilized by the line-tying effect of lines of force (Fig.1). Stabilizing effect of conducting end plates is studied by the variational principle. The critical pressure gradient in chaotic field line region in LHD is estimated as follows.

$$\frac{P_{lcfs}}{B_0^2/2\mu_0} \simeq \left(\frac{\Delta}{L}\right)^2 \frac{U}{\delta U}\pi^2 = 0.15\cdots, \quad (\beta_{lcrs} \simeq 15\%)$$

$$(L = 1.5\ \mathrm{m}\ ,\ \Delta = 0.1\ \mathrm{m}\ ,\ U = 0.7\ ,\ \delta U = 0.2\ )$$

where P_{lcfs} is the plasma pressure at the last close flux surface, Δ the width of chaotic field line region, L the field line length to vacuum vessel wall, U the specific volume, B_0 the magnetic field intensity, respectively.

It was theoretically predicted that steady state distribution of ICRF heated proton become quasilinear plateau distribution function (QPDF) due to runaway ion heating process[1)]. The fusion reaction rate of p-^{11}B is calculated assuming QPDF for protons and ignition condition for p-^{11}B reactor is estimated (Fig.2). Possibility for ICRF sustained p-^{11}B reactor is shown.

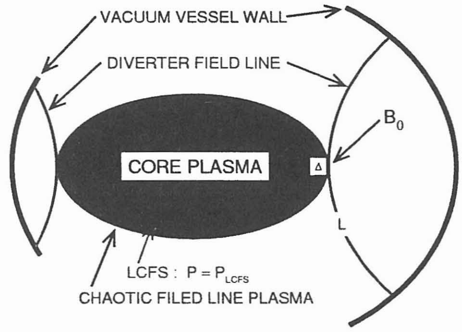

Fig.1 Line-tying effect for stabilization of LHD plasma.

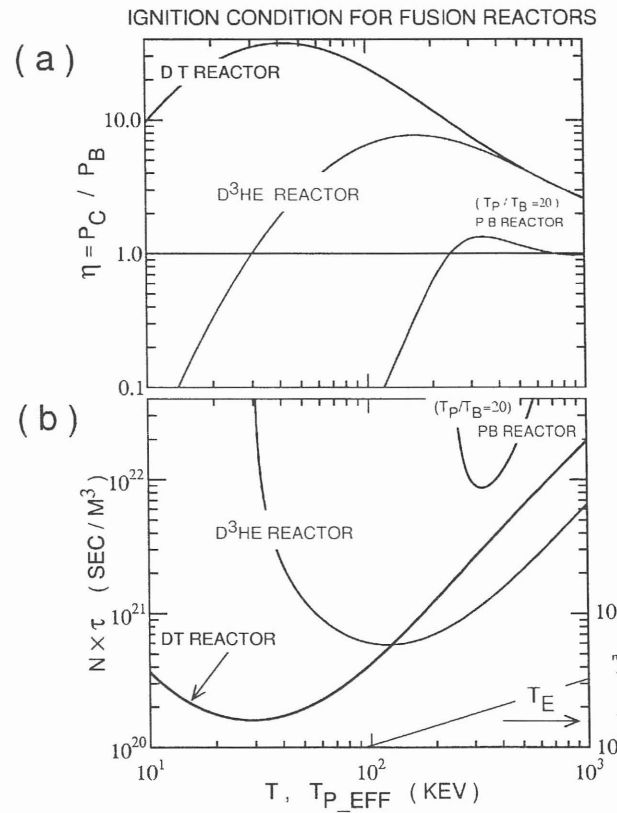

Fig.2 Ignition condition for fusion reactors. P_c and P_B are power densities released by charged particles and by bremsstrahlung. Boron temperature T_b is assumed to be $T_b/T_{p\_eff} = 1/20$. The region of $\eta > 1$ (colored part) shows that the ignition is possible.

Reference

1) Watanabe, T., et al., NIFS-PROC-53, 24 (2003)

2) Watanabe, T., J. Plasma Fusion Res. SERIES, 5, 487 (2002)