§21. Parameter Range of ICRF Heated Plasma

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Various experiments using ICRF heating were succeeded in the additional heating and the plasma sustenance at the 3rd experimental campaign. In this section, parameter ranges of ICRF heated plasma are described.

1) Plasma density vs. ICRF heated power

A scaling of the density limit on Helical system was derived from experimental data obtained at medium size devices. That is given as a function of the heating power, the magnetic field strength and the size of device, i.e. P, B, a, and R [1]. A relation between the average line electron density and the heating RF power, P_{ICH} was examined regarding ICRF heated plasmas. The maximum average electron density so far achieved was $1.9\times10^{19}m^{-3}$ at ICRF heating power of 1.3 MW. The density limit on the LHD derived from the scaling [1] is

$$n_{ec}\ (m^{-3}) = 2.7\times10^{19}\ P(MW)$$

The highest density can be deduced $3.5\times10^{19}m^{-3}$ at 1.3MW of ICRF heating power. All the operated density is lower than the limit predicted by the scaling. The fraction of the radiated power to the heating RF power, P_{rad}/P_{ICH} was no more than 40 % even in n_e=$8.7\times10^{18}m^{-3}$ at P_{ICH} =0.41MW, in which the density was 80 % of the density limit. In the highest density discharge, i.e. $1.9\times10^{19}m^{-3}$ the ICRF heating power was gradually reduced from 1.3MW to 0.4MW before turn-off of RF power. During this period the density was about the same. Then the fraction of P_{rad}/P_{RF} increased with the decrease in the RF power and it could be consequently estimated that the limit density (P_{rad}/P_{RF}=0.9) was n_{ec}=$1.9\times10^{19}m^{-3}$ at P_{ICH} =0.40MW, which is about 1.8 times larger than that of the above-mentioned scaling. Another discharge with the high density of $5.0\times10^{19}m^{-3}$ could be achieved at NBI heated plasma with 1.4MW, which did not exhibit the density limit yet [2]. The higher density will be achieved in the 4th experimental campaign, considering the same heating quality of the ICRF heating as that of the NBI heating.

2) High temperature plasma

A relation between the plasma stored energy, W_p and the average electron density was examined at the heating power of 1.2~1.4MW in ICRF and ECH heated plasmas, extracting data from the wide range of the electron density, i.e. from $4.0\times10^{18}m^{-3}$ to $1.9\times10^{19}m^{-3}$. The relation fits to the scaling of the density of ISS95, in which W_p is proportional to $n_e^{0.51}$. The electron temperature at the magnetic axis $T_e(0)$ increases with the decrease in the average electron density. The maximum electron temperature of $T_e(0)$=3.8keV was obtained at n_e=$4.5\times10^{18}m^{-3}$. The electron temperature scales with $n_e^{-0.41}$, which is the same scaling of ISS95.

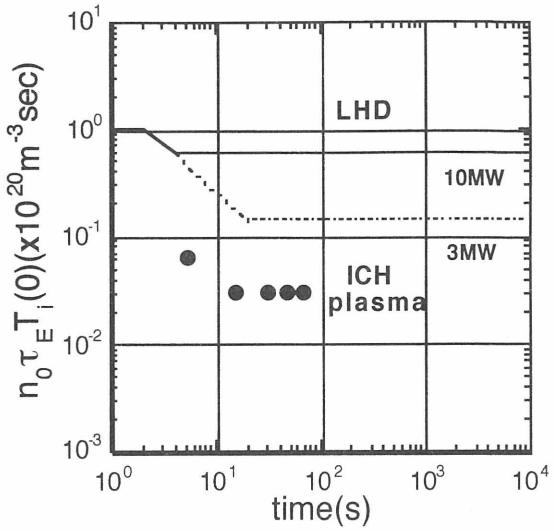

Fig.1 Achieved range in diagram of fusion triple product vs. operation time.

3) Fusion triple product at long pulse operation

One of the main objectives of the LHD project is the long pulse operation. The long pulse operation for 68 seconds was achieved in the plasma of 110kJ, n_e = $1.0\times10^{19}m^{-3}$ and T_{e0}~T_{i0}=2.0keV with the ICRF heating power of 0.85 MW. This is described in the other section titled as "Long pulse plasma sustenance by ICRF heating". The energy confinement time τ_E was 0.16 seconds and the fusion triple product was $n_e(0)\,\tau_E T_i(0)$ =$3.2\times10^{18}m^{-3}$keVsec (see Table 1). This was plotted in the diagram of fusion triple product vs. operation time of Fig.1. Here other long pulse discharges were also plotted; 15, 30 45 seconds operation at the same fusion triple product as that of the 68 seconds discharge. The higher fusion triple product, i.e. $n_e(0)\,\tau_E T_i(0)$ = $6.5\times10^{18}m^{-3}$keVsec (see Table 1) was also plotted, which was obtained at the highest plasma stored energy of 200kJ with 5 seconds. The final goal of the LHD steady state operation is at the high fusion triple product, i.e. $n_e(0)\,\tau_E T_i(0)$= $1.5\times10^{19}m^{-3}$ keVsec at 3MW and $6.0\times10^{19}m^{-3}$keVsec at 10MW as also shown in Fig.1. As the triple fusion product increases with the plasma density, these goals will be achieved at higher plasma density, i.e. n_e=4.5×10^{19} ~$1.7\times10^{20}m^{-3}$.

Table 1

$n_e(\times10^{19}m^{-3})$	τ_E (sec)	$T_i(0)$(keV)	$n_e\tau_E T_i(0)$ ($\times10^{18}m^3$keVsec)	pulse length(sec)
1.0	0.16	2.0	3.2	68
1.9	0.2	1.7	6.5	5

References
[1] S.Sudo et. Al., Nuclear Fusion 30, 11(1990).
[2] Y.Takeiri, private communication.