MEASUREMENT OF HIGH ENERGY PROTON TEMPERATURE IN LHD

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INTRODUCTION

Measurement of energetic ion spectra has been one of the key diagnostics in fusion plasma experiment. Among various methods, passive measurement of fast neutrals escaping from magnetically confined plasma is widely used[1]. In order to derive ion spectra, possible all neutralization processes and spatial distribution of each particle spices responsible for these processes should be carefully considered and the measured spectra should be modified by sum of these energy-dependent charge exchange probabilities. In a burning plasma experiment, the ion spices are hydrogen isotopes, helium isotopes and impurities, and $H^0(D^0/T^0)$, He^0, He^+, A^{q+} ($q < Z$) are responsible for neutralization of protons. Helium concentration will be high in a D^3He plasma and will be low in a DT plasma[2].

In Large Helical Device (LHD), most of ICRF sustained, or ICRF assisted discharges[3] are produced by He+H admixture. A code to calculate H^0, He^0, He^+ distribution, including 6 charge exchange processes, electron/ion impact ionization and recombination processes in plasma of cylindrical geometry has recently been developed (ACHEN-Code)[2]. Using these results and charge-exchange cross sections, proton energy spectra and energetic tail temperatures (T_{eff}) of two vertical veiwing chords of LHD are derived from the neutral spectra measured by Natural Diamond Detectors (NDD)[4].

With the help of ACHEN-Code, not only the T_{eff}, but also the information on the neutral influx can be obtained from the calibrated NDD counting rates, and that on the neutral source temperature can be obtianed from the comparison of T_{eff} of the two vertical chord in poloidal cross section.

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NEUTRAL FLUX AND SPECTRUM OF HIGH ENERGY ATOMS

The relation of measured neutral flux, $\Gamma_{meas}(E_z)$ to the local proton distribution function $F(E_z,z)$ can be expressed as[1]

$$\Gamma_{meas}(E_z) = \eta_g \int s(z)\, dz\, P(E,z)\, A(E,z)\, F(E_z,z)\ , \qquad (1)$$

where $P(E,z)$: the neutralization efficiency, $A(E,z)$: the attenuation factor*, η_g : the geometrical efficiency, and $s(z)\,dz$: the local observation volume. The neutral efficiency is the summation of contributions from all possible atoms/ions that can transfer one electron to a proton.

$$P(E,z) = \Sigma_i <\sigma^i v>_E n_i(z)\,. \qquad (2)$$

Here we consider only H^0, He^0, and He^+, because the impurity concentration is low in LHD. In the following section the calculation of density distribution of these species is discussed, but the ratio of $n_i(z)$'s do not steeply depend on z and we can approximate as the following,

$$P(E,z) \approx n_0(z_R)[\Sigma_i <\sigma^i v>_E n_i(z)/n_0(z)] = n_0(z_R)\, g(E), \qquad (3)$$

and z_R is a representative point on the viewing line, such as the resonance point of the ICRF wave. We also assume a uniform proton energy spectrum:

$$F(E_z z_R) \approx n_p(z_R) f_p(E). \qquad (4)$$

Then, E-dependent factor can be separated from the z-dependence factor, as

$$\Gamma_{meas}(E_z) \approx \eta_g\, s(0)\, g(E) f_p(E) \int n_p(z)\, n_0(z)\, dz. \qquad (5)$$

In the present analysis procedure, we first calculate the z-dependence factor $\int n_p(z)\, n_0(z)\, dz$, make the velocity(energy) dependent correction, and fit into an exponential line, assuming

$$\begin{aligned} f_p(E)dE &\approx f_p(v)\, v_\perp dv_\perp \\ &\approx v_\perp dv_\perp\, [(m/2\pi)(T_{II}\, T_\perp)^{-1/2} \exp\{-(mv_{II}^2/2\, T_{II}) - (mv_\perp^2/2\, T_\perp)\}] \\ &\approx v_\perp dv_\perp\, [(m/2\pi)^{1/2}(T_\perp)^{-1/2} \exp\{-(mv_\perp^2/2\, T_\perp)\}]\,, \end{aligned} \qquad (6)$$

where T_{II} is assumed to be the ion thermal temperature and $E \approx mv_\perp^2/2$ [2] .

NUETRAL INFLUX CALCULATION

In order to estimate the H^0, He^0, and He^+ distribution, a new code[ACHEN-Code] , including 6 charge exchange processes, electron/ion impact ionization and recombination processes in a plasma of cylindrical geometry has recently been developed. Here all particle spices are grouped into two, a bulk plasma component and a slow component which originates

* The attenuation effect is generally smaller in an He plasma by a factor of 4 -10 than in a H/D plasma.

outside the LCFS (Last Closed magnetic flux Surface) with a density of n^0 coming into a plasma column. He^0 penetration depends on its initial velocity across the LCMS, which is determined by the temperature of neutrals, T^0. The He^+ ion density also depends on T^0, because they are mostly produced through the ionization of slow He^0 atoms. Production of He^+ though the recombination of a bulk He^{++} ion becomes dominant when the density is higher than 3 $x10^{19}/m^3$.

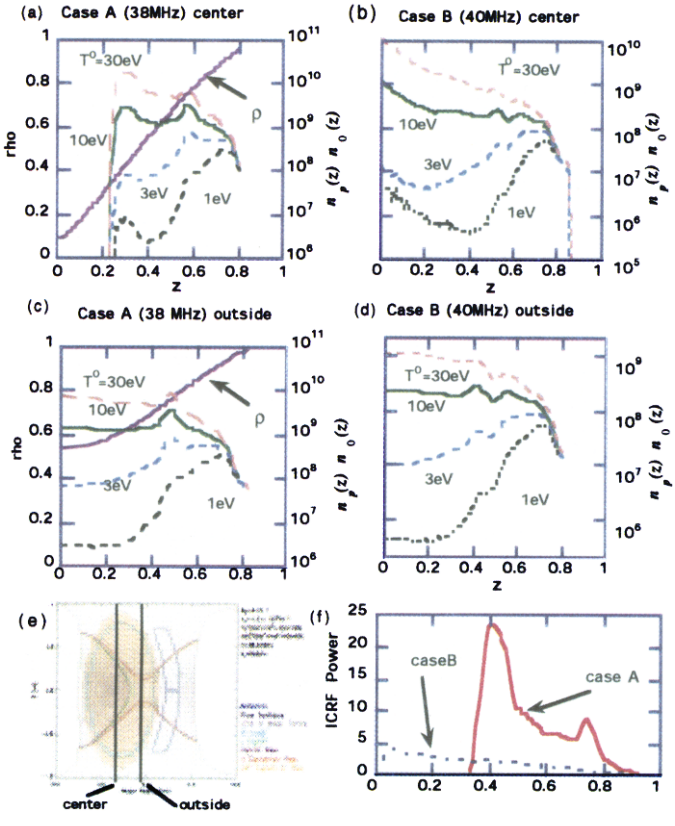

Figure 1. Comparison of two observation lines in ρ and $n_p(z)\ n_0(z)$ for two cases of ICRF power deposition (f), 38.47 MHz(caseA) and 40.47 MHz(caseB). (a), (b) are for Case A and (c), (d) are for Case B. (a), (c) are for the central observation line, and (b), (d) are for the outside observation line, as shown in (e) with the resonace surface structures.

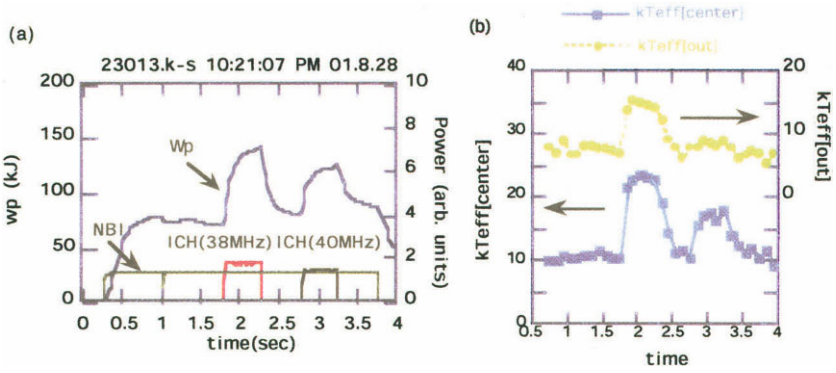

Figure 2 Time evolution of Wp (a) and T_{eff} of central and outside observation chords(b) for ICRF assisted NBI discharge. The changes of T_{eff} are different for two observation lines when the resonance structure changes.

Comparison of two observation lines in ρ and $n_p(z)\ n_0(z)$ are shown in Fig. 1 for two cases of ICRF power deposition, 38.47 MHz (case A) and 40.47 MHz (case B). Here we assume that the high-energy particle distribution function is proportional to that of ICRF power deposition. When T^0 is less than 10 eV, both center and outside chords are not sensitive to the central region, and hence there would not be difference in the T_{eff}.

EXPERIMENTAL RESULTS

Figure 2 shows one of example of ICRF assisted NBI discharges. ICRF of Two different scheme was imposed, from 1.8 – 2.3 sec (case A), and 2.8 – 3.3 sec (case B). For case A, both chords shows increase in T_{eff}, but T_{eff} increases only in the center chord for case B, This happens when the T^0 is higher than 30 eV and the measured spectrum is composed by a substantial contribution from the central region.

If we assume that protons in the ICRF-coupled plasma volume, which is 14% of the total[3,4], are accelerated by ICRF, the information on the neutral influx can be obtained from the calibrated NDD counting rates. Detail study is now in progress.

REFERENCES

1. TESTA, D., GONDHALEKAR, A., Nucl. Fusion, 40 (2000) 975
2. Sasao M. et.al., Proceedings of the 27th European Physical Society Conference on Controlled Fusion and Plasma Physics (June 2000, Budapest), pp.456-459.
   M. Sasao, to be published in NIFS-report.
3. Watari, T., et.al., Nucl. Fusion 41, 325
4. A. V. Krasilnikov, M. Sasao et al., *STUDY OF ACCELERATION AND CONFINEMENT OF HIGH ENERGY PROTONS DURING ICRF AND NBI HEATING IN LHD*, submitted to Nuclear Fusion.
5. M.Sasao, S.Murakami, M.Isobe, A.V.Krasilnikov, et.al. Presented at 18 IAEA Fusion Energy Conference (Sorento, October 2000), IAEA-CN-77/EX9/1