Initial Results on Impact of Background Hydrogen Isotope on Impurity Behavior in the EC-heated LHD plasmas

N. Tamura[1, 2], C. Suzuki[1], H. Funaba[1], K. Mukai[1, 2], Y. Yoshinuma[1], K. Ida[1], T. Fornal[3], A. Czarnecka[3], M. Kubkowska[3], and LHD Experiment Group[1]

[1]*National Institute for Fusion Science, National Institutes for Natural Sciences, Toki, Japan*
[2]*The Graduate University for Advanced Studies (SOKENDAI), Toki, Japan,*
[3]*Institute of Plasma Physics and Laser Microfusion, Warsaw, Poland*

Introduction In order to establish a knowledge base necessary for controlling the impurities in magnetically confined plasmas, a better understanding of impurity transport characteristics in such plasmas is still highly required. In LHD, the previous study on impurity transport has been performed mainly in the plasmas heated by a neutral beam injection (NBI), which provides a broad heat deposition profile. On the other hand, the main heating scheme in the possible fusion reactor is an alpha-particle self-heating, which could provide a narrower heat deposition profile. Therefore, it is highly important to investigate the impurity behavior under such a narrower heat deposition condition, which can be modelled by an electron cyclotron resonace heating (ECRH). The first deuterium plasma experiment in LHD has been successfully conducted during 2016-2017. In this experimental campaign, the study of impurity transport in the EC-heated plasmas has been performed also from the viewpoint of the isotope effect in the magnetically confined toroidal plasmas. In this paper, a first initial assessment of the impact of background hydrogen isotope on the impurity behavior in EC-heated plasmas of the LHD is reported.

Experimental setup A combined injection experiment of the argon (Ar) gas and the TESPEL [1] containing vanadium (V) powder has been performed in hydrogen and deuterium plasmas of the LHD. Here, the plasma is initiated and sustained by the ECRH (the injection power of ECRH is 2.1 MW for hydrogen plasmas and 1.7 MW for deuterium plasmas, respectively). In some discharges, a short-pulse (t = 20 ms, $P_{\text{port-through}}$ = 6 ~ 7 MW) perpendicular NBI is used for the Charge eXchange Spectroscopy (CXS) diagnostic. The magnetic configuration use in this experiment is as follows: a major radius R_{ax} = 3.6 m, a magnetic field at a magnetic axis B_{t} = 2.75 T. The outer shell of TESPEL is usually made of polystyrene (-CH(C_6H_5)CH_2-). Then this usual TESPEL could make a hydrogen contamination into the deuterium plasmas. Therefore the TESPEL, which consists of the deuterated polystyrene (-CH(C_6D_5)CD_2-) shell, is used for eliminating such a hydrogen cotamination in the deuterium plasmas. The outer diameter of the TESPEL is set at 0.7 mm and the particle number of vanadium in the TESPEL is around 3.0 ~ 4.0 x 10^{17}. In this experiment, the tracer impurities are deposited inside the LHD plasma, at r_{eff}/a_{99} = 0.75 ~ 0.85, where r_{eff} and a_{99} are the averaged minor radius and the minor radius in which the 99% of the total plasma stored energy is confined, respectively. The VUV spectrometer, SOXOMS is utilized to measure line emissions from the highly-ionized impurity ions with the time resolution of 50 ms.

Experimental results and discussions

Hydrogen plasmas Figure 1 shows a typical results obtained in the low-density (LHD #142659, n_{e_bar} = 1.2 x 10^{19} m^{-3}) and high-density (LHD #142667, n_{e_bar} = 3.0 x 10^{19} m^{-3}) hydrogen plasmas. Here, the line-averaged electron density n_{e_bar} shown is at the time just before the TESPEL injection. As you can see, the injection of the dedicated TESPEL into the EC-heated plasmas is perfectly acceptable. In the low-density case, the V Li-like emission (λ = 24.04 nm) can be hardly observed. On the other hand, in the high-density case, it is clearly observed immediately after the TESPEL injection, and then it is decreased exponentially. The decay time (i.e. confinement time) of the V^{20+} ion is estimated as 0.848 s from the fitted exponetial curve to the V Li-like emission. The V Be-like emission (λ = 15.94 nm, not shown here) is clearly observed in both density cases. The decay time of the V^{19+} ion is also estimated from the fitted exponetial curve to the V Be-like emission, and it is increased with an increase in electron density (0.08 s → 0.778 s). The Ar Be-like emission (λ = 22.12 nm) is also clearly observed in both density cases, and the level of the Ar Be-like emission finally reaches a certain level before the end of discharge. This is considered to be attributed to the recycling. This result clearly shows that a screening effect in the ergodic region [2] seems not to be worked yet. It should be noted here that no impurity accumulation has been observed in the EC-heated hydrogen plasmas under this experimental condition.

Deuterium palsmas Figure 2 shows a typical results obtained in the low-density (LHD #140499, n_{e_bar} = 2.0 x 10^{19} m^{-3}) and high-

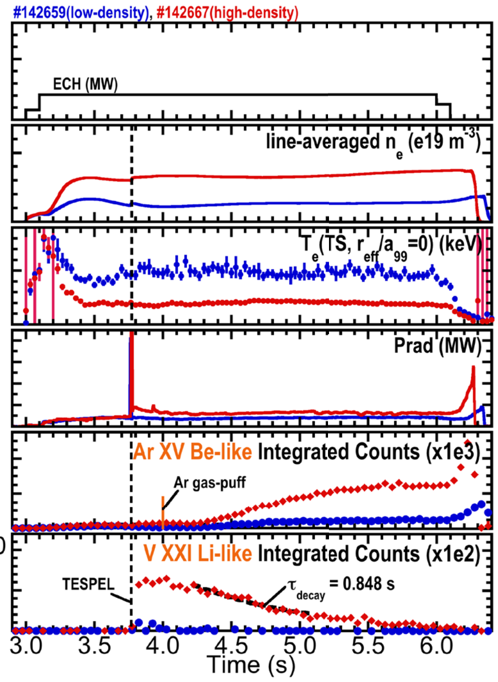

Fig.1. Typical temporal evolution of the major plasma parameters, n_{e_bar}, $T_e(0)$, P_{rad} in low-density (blue, LHD #142659) and high-density (red, LHD #142667) hydrogen LHD plasmas. The temporal evolutions of line emission from the highly-ionized ions of Ar and V are also shown. The vertical dashed line represents the time of TESPEL injection.

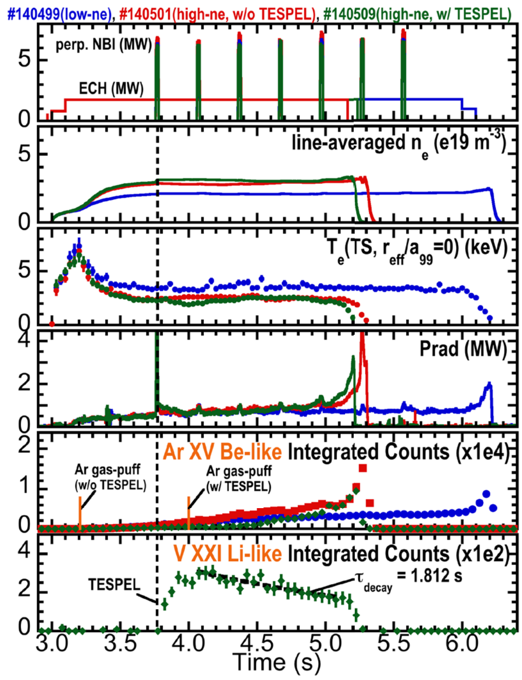

Fig.2. Typical temporal evolution of the major plasma parameters, n_{e_bar}, $T_e(0)$, P_{rad} in low-density (LHD #140499(blue)) and high-density (LHD #140501(w/o TESPEL, red), LHD #140509(w/ TESPEL, green)) deuterium LHD plasmas. The temporal evolutions of line emission from the highly-ionized ions of Ar and V are also shown. The vertical dashed line represents the time of TESPEL injection.

density (LHD #140501, w/o TESPEL, n_{e_bar} = 2.8 x 10^{19} m^{-3}, LHD #140509, w/ TESPEL, n_{e_bar} = 2.9 x 10^{19} m^{-3}) deuterium plasmas (there is no TESPEL injection in the low-density case, therefore the n_{e_bar} is at the correspoding time (t = 3.76 s) to the TESPEL injection in the high-density case). In the high-density case, as can be easily recognized from Fig. 2, the plasmas were terminated around at the time of 5.2 s, before a set time (t = 6.1 s) of the ECH-off. This is attributed to a sudden increase of the plasma radiation P_{rad} (i.e. plasma collapse). At that time, the Ar Be–like emission is also abruptly increased. Before the occurrence of the plasma collapse, there is no external fueling except the injection of impurities. Figure 3 shows the temporal evolution of the radial profile of carbon impurity measured with the CXS diagnostic in the cases with and without the TESPEL injection into the high-density deuterium plasma. In both cases, the carbon density is increased with time. As shown in Fig. 4, the decrease of the electron temperature just before the plasma collapse is found to be appeared mainly in the core region (r_{eff}/a_{99} < 0.7). These experimental results clearly show that the impurity accumulation is occurred in the EC-heated deuterium plasmas in LHD. The decay time of the V Li-like emission is estimated as 1.812 s, which is more than double decay time of that in the hydrogen plasma. A rise time (time required to reach maximum) of V Li-like emission seems to be also increased, compared to that in the EC-heated hydrogen plasma. This result strongly suggests that the transport characteristics of impurities in the deuterim plasmas are significantly changed, compared to those in the hydrogen plasmas.

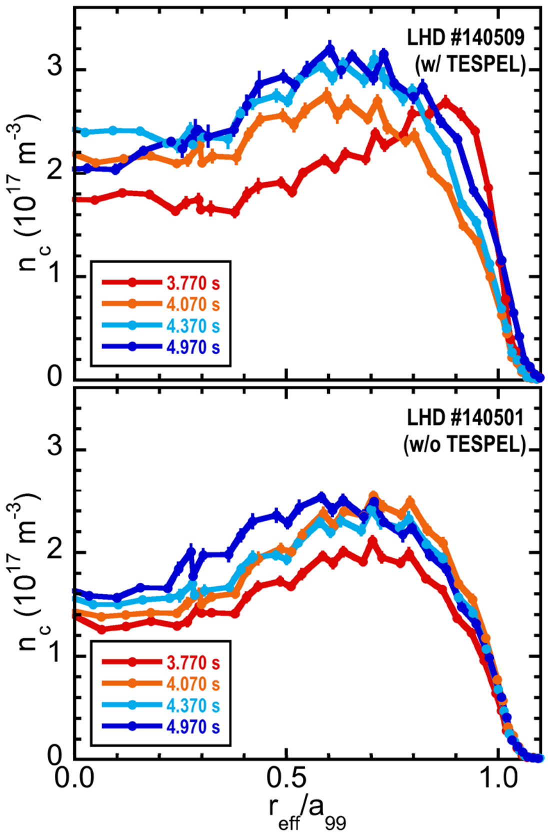

Fig.3. Temporal evolution of the radial profile of carbon impurity measured with the CXS diagnostic in the case with (LHD #140509) and without (LHD #140501) the TESPEL injection into the high-density deuterium plasmas.

The experimental data obtained in this experiment is summarized in the n_e-T_e diagram at the plasma edge, as shown in Fig.5. The impurity accumulation has been observed in the EC-heated deuterium plasmas, not in the EC-heated hydrogen plasmas. Compared to the previous n_e-T_e diagram obtained in the NBI-heated plasmas [3], the n_e-T_e space with the impurity accumulation in the EC-heated plasmas seems to be reduced. This mayt be explained by the difference of the spatial structure of the radial electric field between NBI-heated and EC-heated plasmas.

Concluding Remarks The impact of background hydrogen isotope on impurity behavior in the EC-heated LHD plasmas has been investigated. In the EC-heated hydrogen plasmas, the impurity confinement time is increased with electron density as before, but no impurity accumulation has been observed. On the other hand, in the EC-heated deuterium plasmas, the impurity accumulation has been observed. Therefore the first assessment of the impact of background hydrogen isotope on the impurity behavior in the EC-heated plasmas shows that the deuterium plasma has a better impurity confinement compared to the hydrogen plasmas. As a future work, a further extensive experiment with a higher ECRH power planned to identify the impurity-accumulation-free space and to understand underlying physical mechanisms.

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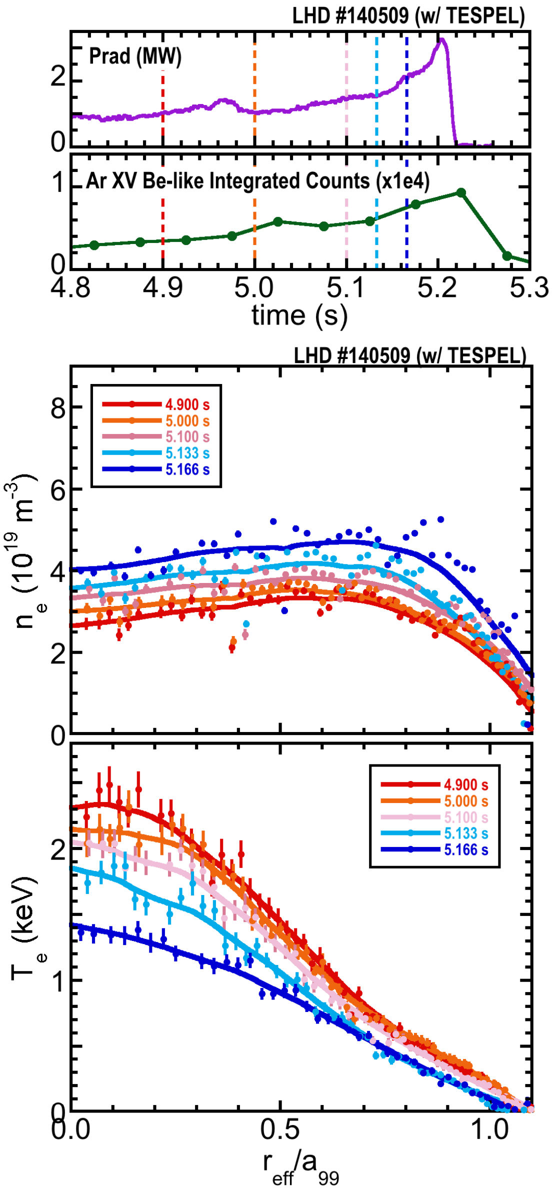

Fig.4. Temporal behavior of the plasma radiation, Ar Be-like emission and the electron density and temperature profiles just before the plasma collapse. The colors of dashed lines in the upper two frames correspond to those of solid symbols and lines in the lower two frames.

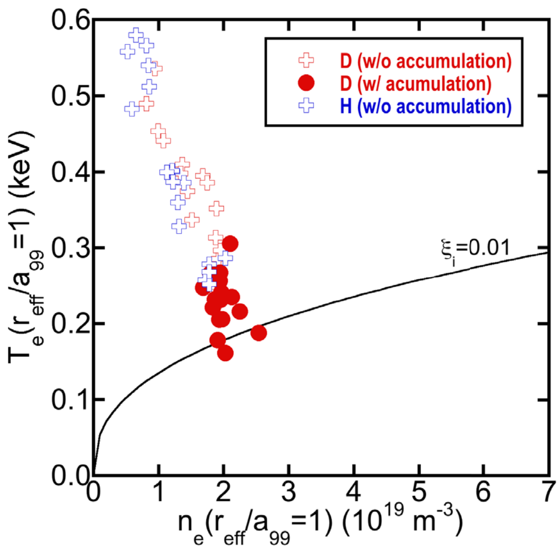

Fig.5. The *n*-*T* diagram at the plasma edge for impurity behavior in hydrogen and deuterium EC-heated discharges with R_{ax} = 3.6 m, which is obtained in the 19th LHD experimental campaign. The open red and blue cross symbols indicate the deuterium and hydrogen discharges without impurity accumulation, respectively. The closed red symbols indicate the deuterium discharges with impurity accumulation (No impurity accumulation is observed in the hydrogen EC-heated discharge). The solid line indicate the critical boundary condition for the impurity retention in the edge ergodic region at R_{ax} = 3.6 m.