Study on impurity behaviour by a multiple tracer TESPEL injection

S. Sudo, N. Tamura, S. Muto, C. Suzuki and H. Funaba

National Institute for Fusion Science, Toki, Gifu, JAPAN

Introduction. Impurity behaviours in LHD are studied by a Tracer-encapsulated Solid Pellet (TESPEL) injection [1-2]. By containing multiple tracers in a TESPEL, the different tracer species have been compared simultaneously under the same plasma condition [3]. As the diameter of TESPEL is about 700 μm, the density disturbance on the bulk plasma is typically less than 10 %. The amount of the tracer particles deposited locally inside a plasma is about several 10^{17} particles which is smaller than that of the bulk plasma by a factor of three orders of magnitude. Triple tracers, V (Z=23), Mn (Z=25) and Co (Z=27) are used, because the charges of nuclei of intrinsic impurities, Cr (Z=24) and Fe (Z=26) are in between those of the tracers. Thus, the behaviour of the intrinsic impurity Fe, for example, may be studied quantitatively, by comparing the line intensity of the tracer particles Co and Mn inside the plasma. It has an advantage in compensating the intensity change due to an even slight electron temperature change. Thus, by observing simultaneously the temporal evolution of Kα intensity of the tracers and intrinsic impurities, the difference in transport properties between the intrinsic impurities and the tracers deposited inside the plasma can be studied.

Experimental Setup. A schematic of the composite pellet cross-section is shown in Fig. 1. The tracer amount ranges $(1 - 7)\times10^{17}$ particles, which is practically possible for three different species to be contained inside a polystyrene ball having a hole. This tracer particle number is important to obtain enough intensity of the line emission from tracers compared to the background light with keeping the disturbance to the bulk plasma small. In fact, it has been proven to be adequate under our experimental conditions.

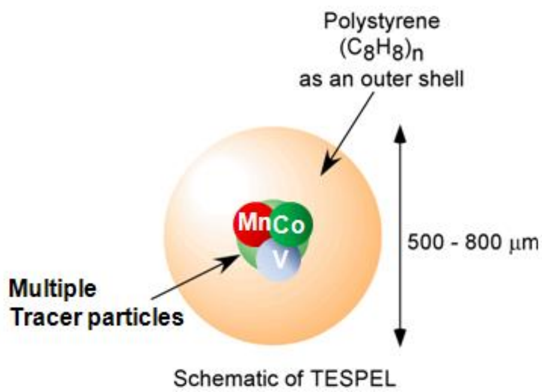


Fig. 1 Schematic of a typical structure of TESPEL containing three different tracers of V, Mn and Co. The outer diameter of the TESPEL is 680 – 720 μm in this series of experiments. The typical equivalent diameter of each tracer lump is about 200 μm.

Experimental Results. The temporal evolution of Kα intensity of Cr and Fe and the line averaged density is shown in Fig. 2a for the medium (#106986, n_e=3.4×10^{19} m^{-3}) and high density (#106999, n_e =6.6×10^{19} m^{-3}) cases. The density disturbance is small by the TESPEL injection as can be seen in Fig. 2a. The intrinsic impurities Cr and Fe in #106986 are contaminated in the plasma, while they are suppressed to get into the plasma in #106999. As shown in Fig. 2b, all the three tracer species are kept for a long time in the high density case in contrast to the case of intrinsic impurities, while the Kα intensity of tracers decays within 1 s in the medium density case. The electron temperature profiles for the two cases at the timing of t= 4.0 s (in the phase of the quasi-steady state of the electron temperature and density) are shown in Fig. 3a, and the electron density profiles are shown in Fig. 3b, and the profiles are hollow. The temperature range for these shots is enough for emitting Kα lines of the relevant atoms. Especially for #106999, it can be said that the electrom tempearture is enough high for the Fe Kα emissions, because we observed the Mn and Co Kα substantially even in the high density case (#106999).

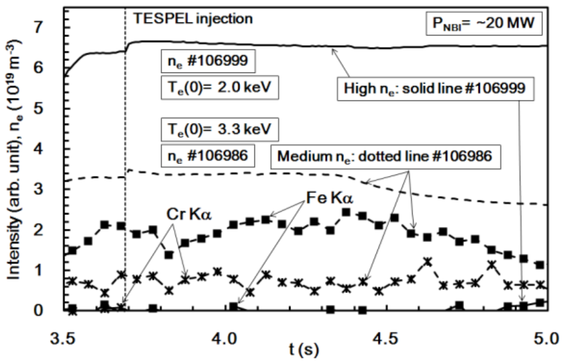


Fig. 2a Temporal evolution of line averaged density and Kα intensities of intrinsic impurities, Fe and Cr for the cases of medium and high density plasmas.

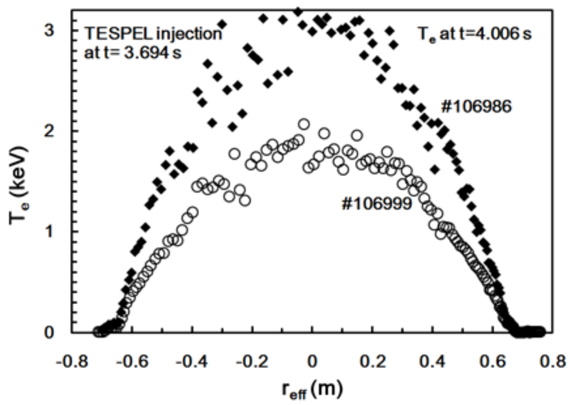


Fig. 3a Electron temperature profiles for the two cases corresponding to Fig. 2a.

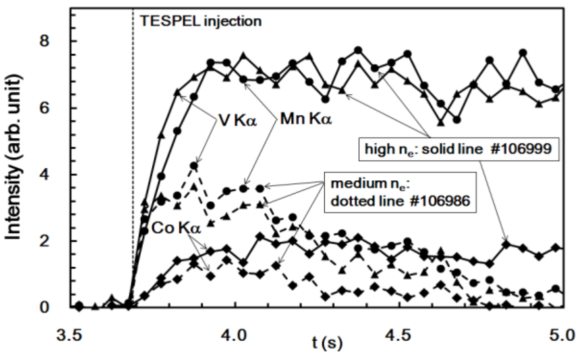


Fig. 2b Temporal evolution of Kα intensities of tracer impurities, V, Mn and Co deposited inside the LHD plasma for the two density cases corresponding to Fig. 2a.

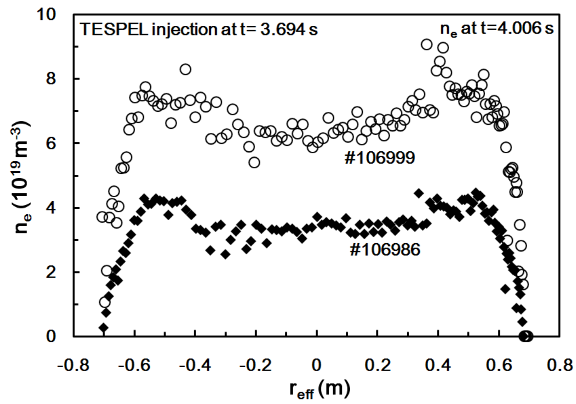


Fig. 3b Electron density profiles at t= 4.0 s for the two cases corresponding to Fig. 2a.

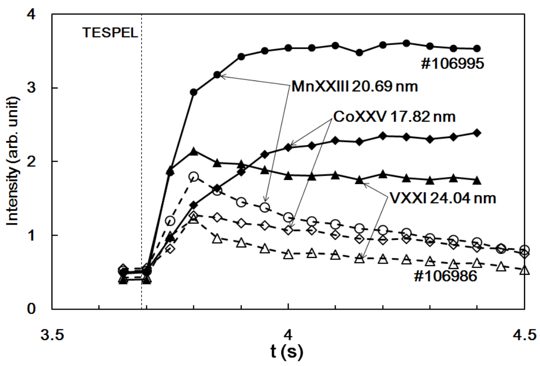


Fig. 4 Temporal evolution of Li-like emission of tracer impurities, V, Mn and Co for #106995 and #106986.

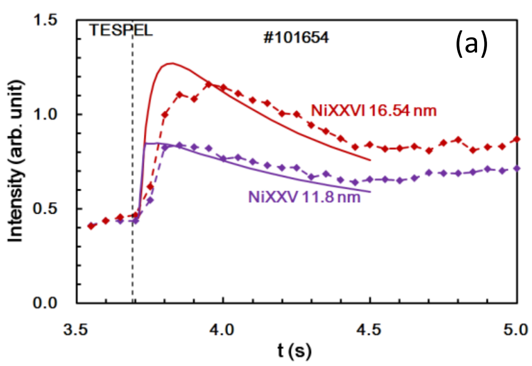
Temporal evolution of Li-like line emission of tracer impurities, V, Mn and Co in the vacuum-ultra-violet region for the density slightly less (n_e=4.8×10^{19} m^{-3} at t=3.7 s and it increases monotonously to n_e=5.3×10^{19} m^{-3} at t=4.0 s) than the case of Fig. 2a is shown in Fig. 4. The feature of the temporal evolution of Li-like line emission of the tracer impurities is just the similar to the case of Kα (long decay time in the high density case) in Fig. 2b. When the density, n_e is higher than 5.0×10^{19} m^{-3}, the impurity line intensities are kept constant, so the confinement time of the tracer impurities becomes very long. The difference of the confinement feature for the tracer impurities, V, Mn and Co is not seen. It should be noted that the Kα emissions in the peripheral chords (outside of ρ (r/a) >0.5) decay in 0.4 s or faster. So, such long conifnement of the tracer impurities occurs in the plasma core region for the high density case. On the other hand, the estimated particle numbers of Fe contaminated in the plasma are decreased when the density is increased. The particle numbers of Fe is estimated by comparing the Kα intensities of Fe with the tracers Co and Mn. The upper value is estimated based on comparison with Co and the lower with Mn, because Z of Co (Mn) is 1 higher (lower) than Fe, the emission intensity of the Fe Kα becomes higher than that of Co at the same temperature in our electron temperature range. The edge electron temperature is almost the same for the two cases as shown in Fig. 3a. So, it seems that the intrinsic impurities like Fe are suppressed in the high density case. But, once the impurity is contaminated in the core, it will be kept for a long time in the high density case. The present results show that the tracers are kept for a long time in the high density regime with the relatively low T_e, while the influx of the intrinsic impurities is suppressed. This simultaneous measurement is new finding owing to the advantage of TESPEL.

Simulation Study. In order to analyze the experimental data, one dimensional impurity transport code, STRAHL [4], is used for calculating the charge state densities and emission line intensities of the impurity ions. It has an advantage of using the atomic data from ADAS (Atomic Data and Analysis Structure) [5] easily. In this series of experiments, V, Mn and Co as well as Ni are used as tracers in the LHD plasmas. However, currently the full atomic data is only available for Ni among these tracers. Thus, here the result of the impurity transport analysis on Ni is shown in Fig. 5a. The temporal evolutions of electron density and temperature are shown in Fig. 5 b and c, respectively. In this case, the position of the tracer deposition is around ρ= 0.7. The impurity diffusion coefficient D and convection velocity V are assumed as 0.25 m^2/s (spatially constant) and V= -1.3×ρ m/s (ρ< 0.8), respectively. The V is interpolated as V= -2.0 m/s at ρ= 0.90 and V = 0.0 m/s at ρ=0.95. The negative sign of V means inward convection. The decay times of the two lines are about 0.5 s for both the experimental and calculated data, although the rise time is not yet well fitted. So, combination of D and V should be optimized further. The temporal evolutions of the line radiations of the triple tracers will be compared systematically with simulation by STRAHL in near future with adopting necessary atomic data.

Acknowledgements. This work is supported by a Grant-in-Aid for Scientific Research (B) (No. 19340179 and 23360415) from JSPS Japan and budgetary Grant-in-Aid No. NIFS09ULHH012, NIFS10ULHH012 and NIFS11ULHH012 from NIFS.

References.

[1] S. Sudo *J. Plasma Fusion Res.* **69** 1349 (1993).
[2] S. Sudo and N. Tamura *Rev. Sci. Instrum.* **83** 023503 (2012).
[3] S. Sudo, N. Tamura, *et al. Nucl. Fusion* **52** 063012 (2012).
[4] K. Behringer "Description of the impurity transport code STRAHL" JET-R(87)08, JET Joint Undertaking, Culham.
[5] H. P. Summers "The ADAS User Manual", version 2.6 (2004). http://www.adas.ac.uk



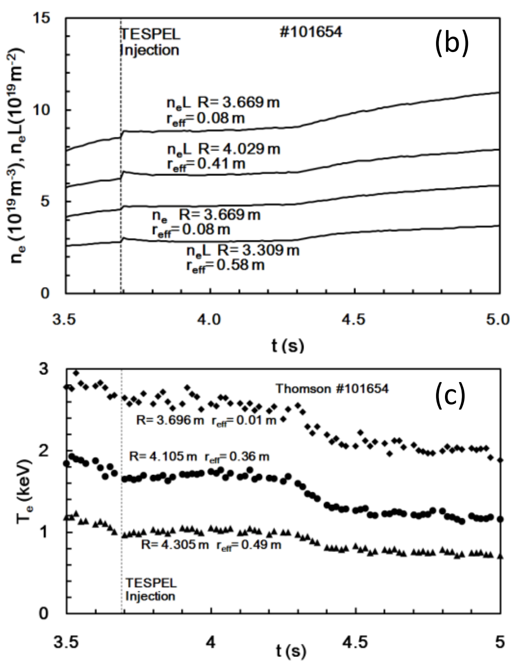


Fig. 5 (a) Temporal evolution of Ni XXVI and XXV emission intensities of experimental and simulation data for #101654. The dotted and solid lines denote experimental and simulation data, respectively. (b) Temporal evolution of electron density. (c) Temporal evolution of electron temperature.