PARTICLE TRANSPORT STUDY
WITH TRACER-ENCAPSULATED SOLID PELLET INJECTION

S. SUDO, *K. KHLOPENKOV, K. MATSUOKA, S. OKAMURA,
C. TAKAHASHI, R. AKIYAMA, A. FUJISAWA, K. IDA, H. IDEI, H. IGUCHI,
M. ISOBE, S. KADO, **K. KONDO, S. KUBO, H. KURAMOTO, T. MINAMI,
S. MORITA, *S. NISHIMURA, M. OSAKABE, M. SASAO, B. PETERSON,
K. TANAKA, K. TOI, Y. YOSHIMURA
National Institute for Fusion Science, Oroshi, Toki, 509-5292 Japan

*Graduate Univ. for Advanced Studies, Hayama, Kanagawa, 240-0193 Japan
** Graduate School of Energy Science, Kyoto Univ., Kyoto, 606-8501 Japan

Abstract

In order to promote particle transport studies, a tracer-encapsulated solid pellet (TESPEL) is proposed to observe the behavior of tracer particles deposited locally. TESPEL consists of polystyrene as an outer part and LiH as an inner core. For proving the essential concept of the new diagnostics, TESPEL is injected into a neutral-beam-heated plasma of the Compact Helical System. This experiment shows the successful local deposition of the tracer, and the behavior of tracer particles deposited locally in the plasma core region is also observed by a method of charge exchange recombination spectroscopy. Thus, our new diagnostic concept has been proven for the first time from the viewpoints of both the production method of a tracer-encapsulated pellet as well as from the observation of the tracer particles.

1. INTRODUCTION

Transport of a magnetically confined plasma is still one of the key subjects to be clarified because of its importance for fusion reactor development. In order to promote particle transport studies, the concept of a tracer-encapsulated cryogenic pellet (TECPEL) has been proposed [1]. The essential point of this method is based upon the production of a both poloidally and toroidally localized particle source as tracers, which are deposited at first in a very small volume in the plasma in contrast to the conventional methods [2, 3].

After injection of such a TECPEL into a plasma, the locally deposited “tracer” particles (originated from the core of the TECPEL) will be immediately ionized and heated by the bulk electrons and ions. These tracer particles move along field lines at first. Such motion in the direction parallel to the magnetic field lines may be detected with a charge exchange recombination spectroscopy (CXRS) array with high temporal and spatial resolution at the location of the neutral beam. The clear measurement of particle transport in the whole plasma will be possible, and new significant information about transport characteristics will be obtained. This feature makes the transport parallel to the magnetic field line clear in the initial phase, which is usually difficult. And, this can simultaneously make diagnostics about radial transport much clearer because of radially narrow localized tracer particles. Furthermore, with the proposed method, the amount of the deposited particles will be clearly identified because of the known size of the inner core of the TECPEL.

2. EXPERIMENTAL SETUP

Based on the concept described in chapter 1, the technology of a TECPEL injector has been substantially developed [4]. TECPEL, however, needs both a complicated cryogenic system and somewhat large vacuum chamber. So, it is not appropriate to apply TECPEL in a small or medium machine. For the proof of principle of the diagnostic, a tracer-encapsulated solid pellet (TESPEL) instead of TECPEL is used in the Compact Helical System (CHS).

While TECPEL consists of a hydrogen isotope as an outer part and low Z material as an inner core, TESPEL consists of polystyrene (polymer: -CH(C_6H_5)CH_2-) as an outer part and LiH as an inner core [5]. Therefore, TESPEL can be handled at room temperature, and therefore the device can be much simpler, so it is more appropriate to a medium size experimental device such as CHS. The typical diameter and thickness of the typical polystyrene shell are 300 μm and 50 - 100 μm, respectively. The tracer core is a LiH block with a typical diameter of 50 - 100 μm. The schematic of TESPEL is shown in Fig. 1. The hole for tracer insertion is made by a micro-drill. After insertion of the LiH core, the stop is put to keep the core inside of TESPEL.

The method for accelerating a pellet is pneumatic. A typical accelerating pressure of He gas is 25 atm, and the typical pellet velocity with this pressure is about 300 m/s. The rotating disk in the TESPEL injector has 30 holes for holding pellets. In one series of experiments, 29 pellets can be injected one by one by rotating the disk. Such rotating disk can be renewed in less than one hour because of a simple configuration.

The TESPEL injector has a differential pumping system as in case of usual pellet injectors. Such a full TESPEL injection system is installed at CHS. The schematic of the arrangement of the pellet injection line, the neutral beam injector (NBI) line, observation points of Li III in the radial direction, and the other diagnostics for observing pellet ablation are shown in Fig. 2. The Li III emissions are observed at the location on the NBI beam path and at the neighboring port without the NBI beam path. Thus, the difference of these signals can be interpreted as a pure emission from Li^{+2} ions produced through the process of charge exchange of Li^{+3} ions with neutral hydrogen atoms of NBI. Each location is equipped with 10 sets of lens and fibers. The spatial resolution for observing in the vertical chord is 8 - 16 mm. The fibers are connected to photomultipliers through filters for Li III (449.9 nm). In contrast to the conventional CXRS systems using CCD, here photomultipliers for higher time resolution (limited up to 10 μs due to sampling rate of data acquisition) are used.

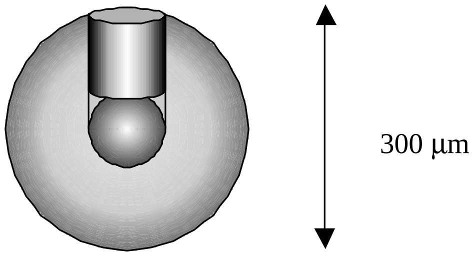

Fig. 1 Schematic of TESPEL. After insertion of the LiH core, the stop is put to keep the core inside of TESPEL.

3. EXPERIMENTAL RESULTS

3.1 Observation of local deposition of tracer particles

The target plasma of CHS is heated by NBI with a power of about 1 MW. This NBI is also utilized as a neutral beam source for the charge exchange recombination spectroscopy (CXRS) as shown in Fig. 2.

The light emission from the pellet is collected with an optical system, and then it is divided by a half mirror to two photomultipliers, each having a filter. Therefore, simultaneously H_α and Li II (or Li I) signals can be registered. Furthermore, two CCD cameras are also installed for observing the images of H_α and Li II (or Li I) emission.

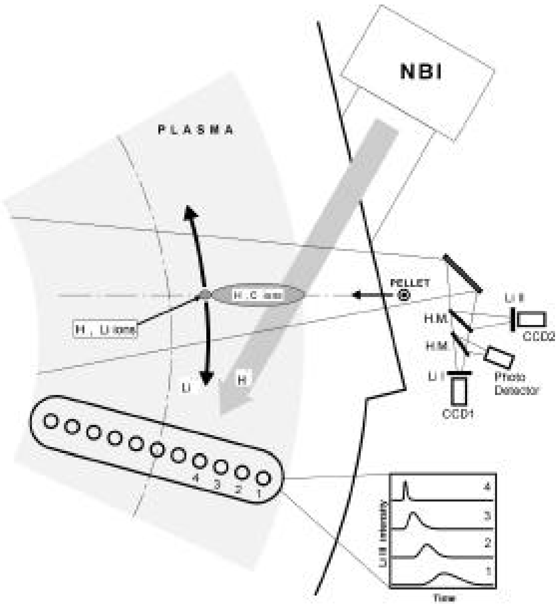

Fig. 2 Schematic of the experimental arrangement.

From the CCD images, it is found that the pellet reaches the central region of the plasma.

An intense emission region of Li II is localized in the central region of the plasma. The thickness of the pellet trace seen as H_α light is less than 10 mm.

Photomultiplier signals of H_α and Li II show that at first H_α appears for about 600 μs and then Li II emits for a short period of around 100 μs in the late phase as shown in Fig. 3 (a). For comparison, signals from H_α and Li II detectors are shown in Fig.3 (b) in case without tracer. In this case, as expected, the peak in the late phase for Li II does not appear. Those results clearly indicate the local deposition of the tracer particles in the core region, although a sharper localization would be preferable.

3.2 Observation of behavior of tracer particles

By TESPEL pellet injection into the plasma with the density of the level of 1.5×10^{19} m^{-3}, the electron density increase of ~ 5×10^{18} m^{-3} is observed, which is consistent with the particle number contained in the polystyrene shell (the contribution from the core is negligible). Under the conditions of such a density increase, the electron temperature is kept higher than the radiation barrier, and the temperature is recovered to the original level in a late phase.

Typical emissions of 449.9 nm (Li III) for CXRS of Li ions near the tracer-deposited radial position (r/a= 0.23) at the location of the NBI path (for CXRS) denoted by "pl3" and at the reference position with the equivalent optical configuration injection denoted by "pl6" are shown in Fig. 4 in the case of R_{ax} = 94.9 cm and B = 1.5 T. Both data are just the same during the RF heating, and some small difference is seen during NBI before pellet injection. After the TESPEL pellet injection, there is a clear difference of Li III intensity. Furthermore, it should be noticed that a clear drop of the CXRS signal "pl3" appears at the timing of NBI turn-off. Thus, it can be firmly confirmed that the difference is due to the Li III CXR emission.

As one example of application to the particle transport study, Li III CXRS signals subtracted by reference signals (which do not see charge exchange with NBI) at the five different radial positions in the case of R_{ax} = 99.5 cm are shown in Fig. 5. Each chord has a

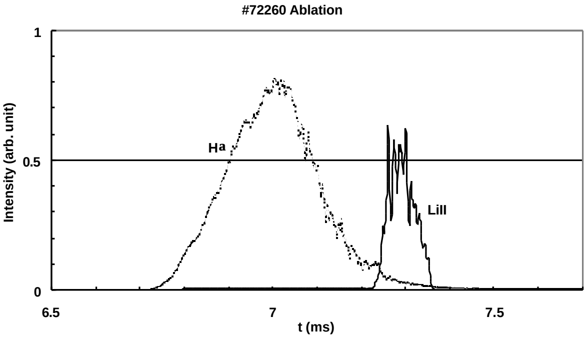

Fig. 3 (a) H_α and Li II emission during pellet ablation in case with tracer of TESPEL.

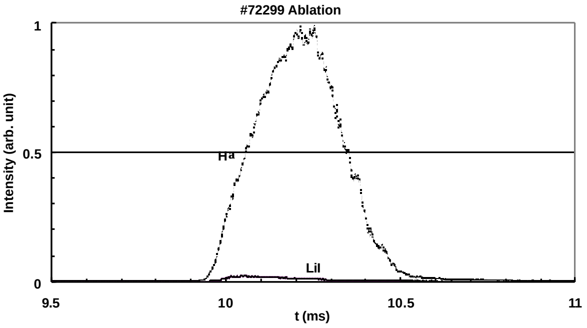

Fig. 3 (b) H_α and Li II emission during pellet ablation in case without tracer of TESPEL.

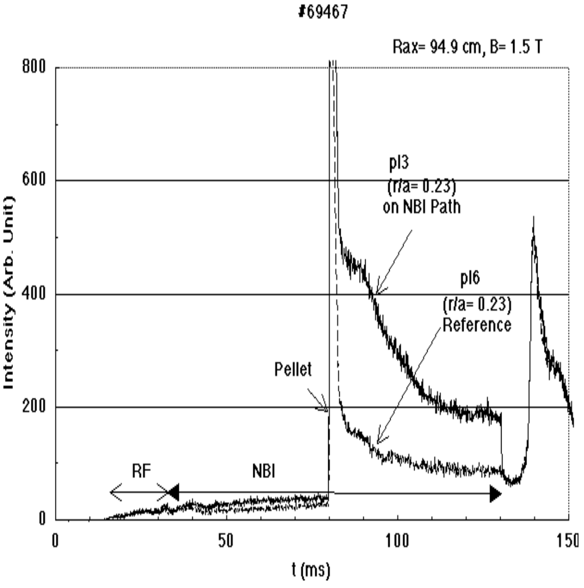

Fig. 4 One example of Li III emissions near the tracer-deposited radial position (r/a= 0.23) at the location of NBI path (for CXRS) and at the reference position for TESPEL injection.

diameter of 8 mm for observing area.

At first the peak appears near the center denoted by C in Fig. 5. As indicated by two arrows, the peak appears later in the outer radius, which is qualitatively reasonable. The delay of the peak between C and D is about 5 ms in the distance of 3.6 cm. In the inner radius, the delay is 10 ms in 7.2 cm, while 7 ms in 7.2 cm in the outer radius.

Based on the equation (*n* means the density of the fully stripped Li ions) without source term:

$$\frac{\partial n}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left(r D \frac{\partial n}{\partial r} + V n \right)$$

the simplified analysis shows that the diffusion coefficient D is 0.13 ~ 0.19 m^2/s at r/a = -0.2 ~ 0.3 (inward pinch V is neglected here, and there is no significant source in the outer radius at the initial phase).

Although a detailed comparison between the experimental data and transport simulation is necessary, this experimental result shows that the local transport analysis is possible.

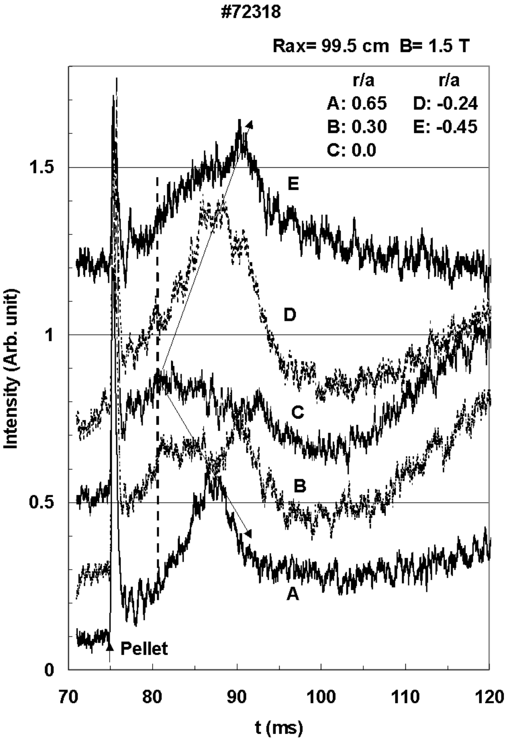

Fig. 5 Li III CXRS signals subtracted by reference signals at different radial positions.

4. CONCLUSION

In conclusion, a new diagnostic method for particle transport study with TESPEL has been experimentally implemented for the first time. The results from CHS have shown the successful local deposition of the tracer, and the behavior of tracer particles deposited locally in the plasma core region is also observed by a method of charge exchange recombination spectroscopy. Therefore, our new diagnostic concept has been proven for the first time from the viewpoints of both the production method of TESPEL and the observation of the tracer particle behavior.

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