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Impurity Transport Measurement and Absolute Radiation Power Evaluation with Tracer-Encapsulated Solid Pellet
トレーサー内蔵ペレットを用いた不純物輸送計測及び定量的放射光強度評価

Shigeru Sudo[1, 2], Naoki Tamura[1], Sadatsugu Muto[1, 2], Tetsuo Ozaki[1], Chihiro Suzuki[1], Hisamichi Funaba[1, 2], and Izumi Murakami[1, 2]

須藤滋[1, 2]、 田村直樹[1]、 武藤貞嗣[1, 2]、 尾崎哲[1]、 鈴木千尋[1]、 舟場久芳[1, 2]、 村上泉[1, 2]

[1] *National Institute for Fusion Science, 322-6, Oroshi-cho, Toki-city, 509-5292, Japan*

[1]核融合科学研究所 〒509-5292 土岐市下石町 322-6

[2] *The Graduate University for Advanced Studies, Hayama, Kanagawa, 240-0193, Japan*

[2]総合研究大学院大学 〒240-0193 神奈川県三浦郡葉山町

The impurity transport property has been studied wtih a diagnostic method of a tracer-encapsulated solid pellet (TESPEL). Using the advantage that the tracers can be deposited locally via TESPEL inside the plasma, the impurity transport characteristics were found to depend on the collisionality and the impurity source location. Furthermore, using another advantage that the total amount of the tracer can be precisely known, the radiation power increase by the tracers per the tracer particle number is obtained. As T_e and n_e are known at the tracer deposition location, the experimentally obtained radiation power loss rate is compared with the model calculation such as FLYCHK.

1. General

In magnetic confinement devices, the impurity behavior in the plasma has been intensively investigated. In particular, the accumulation of impurities is one of the subjects of concern. It can cause substantial radiation power loss in the plasma. Also, a significant amount of impurities, including helium ash, may cause the intolerable level of dilution of the fusion fuel. On the other hand, the localization of the adequate impurity amount in the plasma edge might contribute to the appropriate radiation power in the plasma periphery, which could mitigate the heat load on the divertor plate. Thus, it is necessary to know precisely the transport property of the impurities in the plasma for realizing a fusion reactor.

In order to investigate the impurity transport behavior in detail, we developed a diagnostic method of a tracer-encapsulated solid pellet (TESPEL [1, 2]). TESPEL consists of polystyrene as an outer layer and of specific material as tracers in the core. The advantages of the TESPEL method are: (a) direct local deposition of tracers inside the plasma is possible; (b) the deposited amount of the tracer inside the plasma can be known precisely; and (c) a relatively wide selection of tracer materials is possible.

2. Impurity Transport

The temporal evolutions of the Kα emissions of the tracers (V, Mn, and Co) are measured with the X-ray PHA system, as shown in Fig. 1 [2]. In the case of the PS regime, the Kα intensity is maintained for a long time, while it decays fast in the case of the plateau regime. The green curve fitting is based on the calculation by the 1-D impurity transport code, STRAHL [3] with the assumed particle diffusion coefficient D (spatially flat) and inward pinch V, which is assumed as −2m/s at $\rho = 0.9$, and 0 m/s at $\rho = 0.5$ and $\rho = 1.0$, and these are linearly connected. The negative sign of V means inward convection. In the same shot, the Kα emission intensity of the intrinsic impurities such as Fe was completely suppressed in the PS regime, while it was clearly observed in the plateau regime, as shown in Fig. 2. Thus, it is clear that the impurity location and the plasma density (collisionality) affect significantly the impurity transport property.

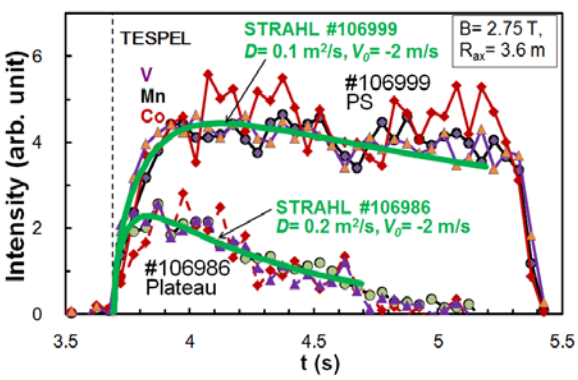

Fig. 1. Temporal evolutions of the Kα emissions of the tracers deposited directly inside the plasma in the cases of the PS and plateau regimes [2]

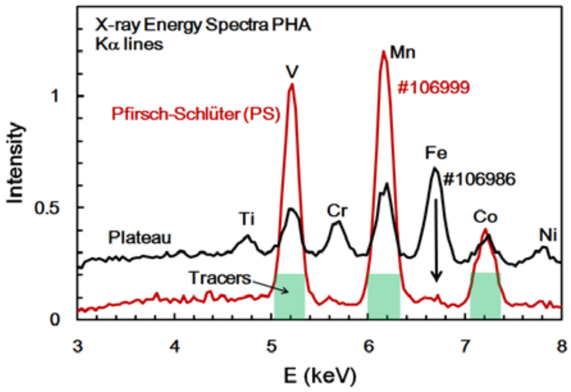

Fig. 2. The Kα emissions of the tracers and the intrinsic impurities in the cases of the PS and plateau regimes [2].

There was observed a narrow impurity accumulation window in the plateau regime. This was for the case of the intrinsic impurities entering from the outside of the plasma. But, the impurities deposited directly inside the plasma by a TESPEL injection are observed to be confined for a long time in the high density case. On the other hand, in the high density case, the impurities entering from the outside of the plasma are prevented from entering into the plasma core by the friction force in the scrape-off layer (SOL) [5]. The difference of the density is understood as the discrimination of the collisionality between the PS and plateau regimes. In the extreme high density case, SDC (super dense core plasma), the central electron density reaches n_e=1×10^{21}m^{-3}. TESPEL injection experiments also showed the long tracer confinement in the SDC plasma [6]. This is consistent with the above results in the high density case by the TESPEL injection.

3. Absolute Radiation Power Evaluation

For a certain impurity, the total radiation power P is written as:

$$P = \int L_{rad}(T_e(r))n_e(r)n_z(r)dV \qquad (1)$$

where L_{rad} is the radiative power loss rate, and n_z is the impurity density. Utilizing the advantage of the localized deposition of the tracer, the deposition location is assumed as r_* in the early phase,

$$\begin{aligned} & n_z(r) = n_z\delta(r - r_*) \\ & \int n_z(r)dV = N_z \end{aligned} \qquad (2)$$

The total amount of the tracer deposited by a TESPEL is precisely determined as N_z (which is also due to the advantage of TESPEL), then,

$$P \sim L_{rad}(T_e(r_*))n_e(r_*)N_z \qquad (3)$$

Thus, simple comparison between the experimental data and the above atomic data can be made. For the analysis of the results, the bolometer power is taken at the peak value in 20 – 30ms after TESPEL injection. Although this is a rather rough estimate, most of the experimental results agree within the scattering of 50%, and the scaling is roughly written as:

$$\Delta P(\mathrm{MW}) = 0.6\, N_z(10^{18}\mathrm{particles})n_e(10^{20}\mathrm{m}^{-3}) \times L_{rad}(T_e(r_*))(10^{-38}\mathrm{MWm}^3) \quad (4)$$

The possible candidates for radiation cooling in a form of gas are Kr and Xe. If we take L_{rad}= 23 and 5.6 for Xe and Kr at T_e= 1 keV based on the FLYCHK data [7], the radiation power will be 140 and 34 MW for Xe and Kr, respectively, under the condition of the particle amount of 1×10^{19} and the electron density of n_e= 1×10^{20} m^{-3}. Thus, such a quantity will be within the scope for planning the radiation cooling in the plasma periphery by adjusting the particle amount.

A new property of the impurity behavior was revealed owing to the advantage of the direct deposition of the tracers by TESPEL. In the plateau regime, the multiple tracers deposited in the plasma flow away faster than in the case of the PS regime, while the intrinsic impurities can enter easily into the plasma core in the plateau regime. In the PS regime, the multiple tracers deposited in the plasma are maintained for a long time, while the impurities coming from the outside of the plasma are prevented from entering into the plasma core. The power radiation loss by impurities for radiation cooling is also quantitatively measured using the advantage of TESPEL.

References

[1] S. Sudo *et al Rev. Sci. Instrum.* **83** (2012) 023503.
[2] S. Sudo *et al Plasma Fusion Res.* **9** (2014) 1402039.
[3] K. Behringer, Rep. JET-R(87) 08, JET Joint Undertaking, Abingdon (1987).
[4] Y. Nakamura *et al Nucl. Fusion* **43** (2003) 219.
[5] Kobayashi M *et al Fusion Sci. Technol.* **58**(2010) 220.
[6] TAMURA, N. *et al Proc. of ITC/ISHW2007, nifs-proc.* **69** (2007) 422.
[7] http://www-amdis.iaea.org/FLYCHK/