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Mixed hydrogen-neon pellet injection in toroidal plasmas – theory and observation

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Cryogenic solid pellet injection is the most promising technique for fueling magnetically confined fusion reactors. The ablation and assimilation process of injected pellets in dilute high-temperature plasmas is complicated and is an interesting topic not only for its practical aspect of controlling toroidal discharges but also for the physics aspect of plasma-matter interaction. In the last decade, cryogenic solid pellet injection has been applied to a new research area in the field –machine load mitigation during major disruptions in tokamak fusion reactors [1]. Disruptions are a large-scale collapse event that is abruptly triggered when the discharge and/or control system becomes unstable. The present tokamak experiments have demonstrated the possibility that the injection of large-sized pellets can intentionally trigger a disruption while minimizing the thermal impact on the plasma-facing components and the electromagnetic force on the vessel wall. Such a 'disruption mitigation' scheme constitutes a way for the emergency shutdown of future reactors. In ITER, the injection of mixed hydrogen-neon (H_2+Ne) pellets was selected for this purpose. This paper reviews recent developments in theory and experiments on the ablation and assimilation processes of mixed pellets to understand the plasma-matter interactions underlying the ITER disruption mitigation scheme. The key points of this study are summarized as follows.

- **Ablation of mixed pellets:** The ablation cloud self-adopts its thickness to shield the electron particle flux from the ambient plasma. Such self-shielding mechanisms are affected by the introduction of neons to low-Z hydrogen clouds by enhancing elastic scattering. The ablation rate is difficult to measure directly, but experimental data for pellet penetration depths have been well reproduced using the neutral gas and plasma shielding (NGPS) model [2].
- **Plasmoid drift mechanism:** The ablated material forms a plasmoid with an intermediate atom density (10^{22}-10^{24}) between that of solid hydrogen and the background plasma. The plasmoid experiences expansion along the magnetic field and cross-field drift motion. The pellet injection experiment in the LHD steollarator/heliotron [3] demonstrated that the cross-field drift can be controlled by changing the neon concentration in the mixed pellets (see **Figure** 1), which is now a concept that needs to be developed for application in ITER.
- **Disruption trigger**: Hydrogen-neon mixed pellets trigger a disruption within a few milliseconds after injection into tokamaks. Trigger time is crucial for disruption mitigation control. A key process is 'dilution cooling [4]': Hot background electrons are cooled due to equipartition with delivering many cold electrons. Ideally, pure hydrogen injection allows the hot plasma to be diluted to several hundred eV; if such a plasma is maintained at the center of the chamber over the slowing down time of fast electrons, the generation of fast electrons during the disruption can be avoided. The simulation indicated [5] that ITER may realize such a situation by injecting single hydrogen-neon pellets when carefully controlling the neon concentration, injection quantities, and fragment sizes for Shattered Pellet Injection (SPI), which is the baseline scheme for material delivery in ITER. Experimental validation is ongoing with focused efforts.

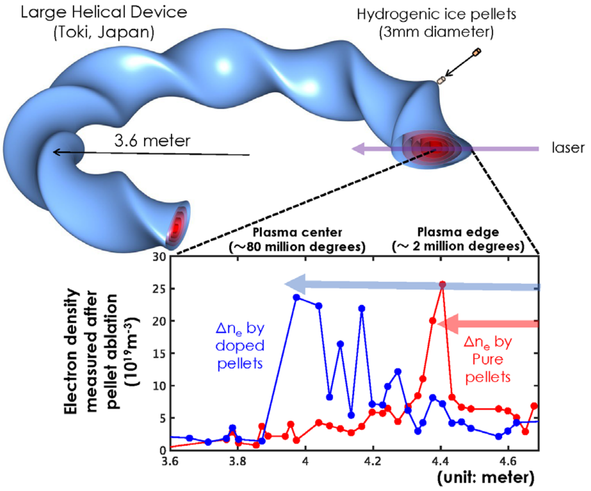

Figure 1. Comparison of the electron density profiles measured by Fast Thomson Scattering (FTS) after pellet injection between pure hydrogen (red) and hydrogen-neon mixed (blue) pellets. The observed deeper material assimilation can be explained by the suppression of the outward drift motion of plasmoids [2,3].

References

[1] M. Lehnen, et al., "R&D for reliable disruption mitigation in ITER", Proceedings for the 27th IAEA FEC (Gandhinagar, 2018).
[2] A. Matsuyama, et al., Phys. Plasmas **29**, 042501 (2022).
[3] A. Matsuyama, et al., Phys. Rev. Lett. **129**, 255001 (2022).
[4] E. Nardon, et al., Nucl. Fusion **60**, 126040 (2022).
[5] A. Matsuyama, et al., Plasma Phys. Control. Fusion **64**, 105018 (2022).