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Pellet Injection from Different Locations on DIII-D and Extrapolation to ITER

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1. Introduction

Deuterium pellet injection has been used in experiments on the DIII-D tokamak to investigate fueling in reactor relevant plasmas. The versatile pellet injection system allows injection from two ports on the inner wall, two vertical ports and an outside midplane port as shown in a cross-section view in Fig. 1. The fueling efficiency and mass deposition profiles have been measured from pellets injected from all locations. The inner wall injection locations lead to deeper mass penetration and significantly higher fueling efficiency than the others [1,2]. An outward displacement in major radius of the deposited pellet mass is observed from all injection locations and is hypothesized to occur from ∇B and curvature induced drift effects [3]. Fig. 2 shows this effect by comparing the measured mass penetration depth to the calculated pellet penetration depth from ablation theory for the different injection locations.

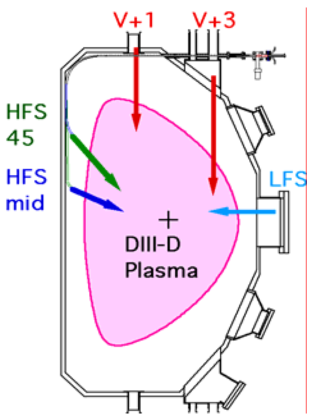

Fig. 1 Cross-section view of DIII-D showing the pellet injection locations.

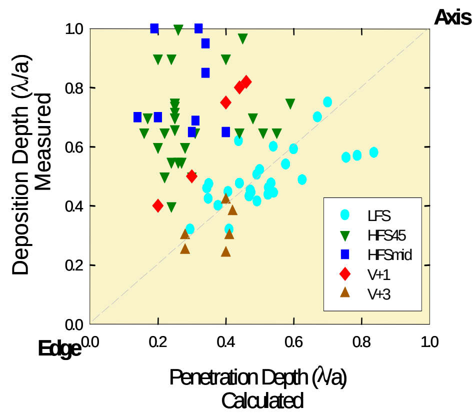

Fig.2 Measured mass deposition depth compared to the ablation model calculated penetration depth for pellets injected from the different locations.

2. Pellet Injection Deposition and Modeling

The pellet mass from inner wall injection is observed to be deposited well beyond the depth reached by the ablating pellet as determined by duration of the D_α light emission and from new fast camera images. The measured pellet mass deposition profiles from Thomson scattering have been compared to those modeled using the numerically solved Pressure Relaxation Lagrangian (PRL) model [3] coupled to the PELLET ablation code [4]. In this model the ablation cloud becomes separated from the pellet and drifts across the field lines due to its polarization and associated ExB force in the curved toroidal magnetic field. New features added to the PRL model include curvature drive from parallel flows, self-consistent plasma pressure profiles, and magnetic shear induced mass shedding. With these new effects included, the modeled deposition profiles are in reasonable agreement with experiment from both inner wall and outside midplane injection [3]. An example from an H-mode discharge comparing the deposition from an inner wall injected 1.8mm pellet with that modeled from the coupled PRL and PELLET codes is shown in Fig. 3.

A database from DIII-D discharges with inner wall injected pellets has been developed experimental data to investigate the scaling of the mass drift distance as a function of pellet and plasma parameters. Regression analysis of the database has shown that the mass drift depth has an inverse edge q dependence and an inverse central electron temperature dependence. The measured pellet penetration depth follows closely that of the neutral gas shielding model without including the drift [5].

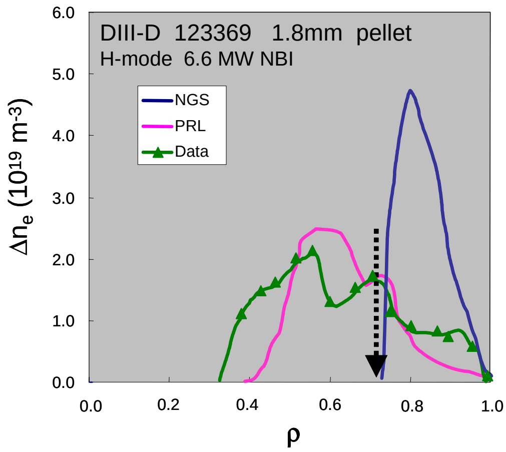

Fig. 3 Measured and calculated deposition profiles for a 1.8mm inner wall injected pellet. The neutral gas shielding ablation model and PRL drift model results are shown with an arrow indicating the measured penetration depth.

3. Extrapolation to ITER

ITER will require efficient pellet fueling to operate at the proposed high density and is designed to have inner wall injection capability [6]. The proposed pellet fueling scenario for ITER has been modeled using the PRL code with realistic pellet sizes and speeds. The modeling shows that inside launched pellets of 3mm and 5mm size with speeds of 300 m/s (limited by the curved guiding tube) have the capabilities to fuel well inside the separatrix as shown in Fig. 4. While not reaching the plasma center, the inner wall pellets of modest size can be expected to provide a significant level of fueling [7].

The scaling of the pellet mass drift distance in ITER from the PRL model has been determined using a regression analysis on a set of ITER pellet injection cases with varied parameters. The drift distance D scales as $B^{-0.15} * T_{e0}^{-0.13} * T_{eped}^{0.5} * r_p^{0.76} * q_a^{-0.15}$ where B is the magnetic field, T_{e0} is the central electron temperature, T_{eped} is the pedestal temperature, r_p is pellet equivalent spherical radius, and q_a is the edge q. The inverse edge q and central temperature dependence follows that from the DIII-D experimental database.

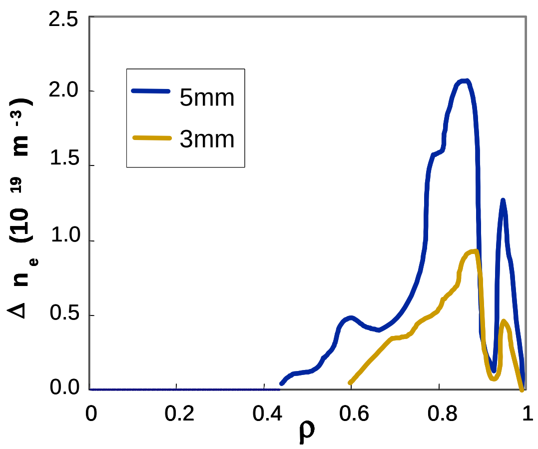

Fig. 4 Calculated deposition profiles from the PRL code for ITER 3 and 5 mm pellets injected from the inner wall for 20 keV central and 4 keV pedestal electron temperatures.

The expected fueling efficiency for ITER burning plasmas from gas puffing is much less than 1% [7,8], while that calculated from inner wall pellet injection approaches 100%. Outside midplane pellet injection on ITER has also been modeled for ITER and was found to have significant drift of the pellet mass outside the separatrix and thus a fueling efficiency less than 10%. However, such pellets may be useful for triggering edge localized modes (ELMs) to limit the heat flux to the divertor [9].

The expected source fueling profile on ITER from gas fueling has been calculated and shown to have very limited neutral penetration compared to present day tokamak experiments [7,8]. This implies that gas puffing and recycling will have a very limited ability to fuel the ITER core in the burning plasma scenario. The scrape off layer (SOL) plasma screens the core plasma from the puffed and recycled neutrals. It is clear from this result that a core fueling source other than gas and neutral beam injection will be needed to reach and maintain high density operation and provide efficient tritium fueling in ITER. The gas puff will therefore be a means of controlling the SOL and divertor plasma density rather than controlling the core plasma density.

4. ELM Triggering

Pellets injected into DIII-D from all the injection locations have been found to trigger ELMs in H-mode plasmas presumably due to localized pressure excursions beyond ballooning mode stability. Differences in the ELM characteristics triggered from the different pellet injection locations have been measured. The ELMs triggered from outer wall pellets have the largest edge perturbation and longest duration and therefore seem to be the most sensitive location to trigger the ELM. Interestingly, the power deposited in the divertor by ELMs is significantly lower for those triggered by the inner wall pellets than for the ELMs occurring naturally as shown in Fig. 5. A system designed specifically to trigger rapid small ELMs by injecting small slow speed pellets is planned for use on DIII-D to test its applicability for ITER.

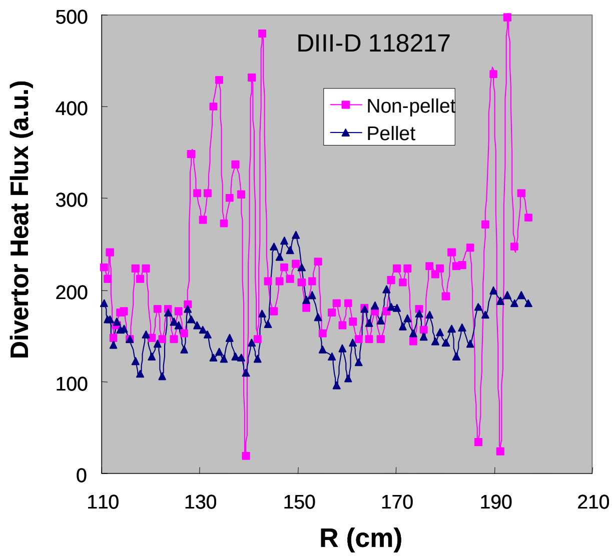

Fig. 5 Divertor heat flux measured by infrared camera in an ELMing H-mode plasma from an inner wall pellet compared to an ELM just before the pellet was injected. The time between the pellet and previous ELM is approximately the same as that from the natural ELM rate.

5. Summary

Pellet injection into DIII-D plasmas has demonstrated deeper fueling from inner wall ports than from vertical or outside midplane locations, even at much lower pellet speeds. The difference in fuel deposition has been successfully modeled by taking into account ∇B and curvature drifts. When using this model for ITER we have achieved fuel deposition well beyond the scrape off layer for inner wall injected pellets and this scheme promises to provide sufficient fueling for operating ITER at high density. ELMs triggered from small outer wall (low field side) injected pellets may prove to be a useful means to limit the ELM magnitude.

Acknowledgements

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[1] L.R. Baylor, *et al.*, Phys. Plasmas **8** 1878 (2000).

[2] P.T. Lang, *et al.*, Phys. Rev. Lett. **79**, 1478 (1997).

[3] P.B. Parks, L.R. Baylor, Phys. Rev. Lett. **8**, 1968 (2005).

[4] W.A. Houlberg, S.L. Milora, and S.E. Attenberger, Nucl. Fusion **28**, 595 (1988).

[5] P.B. Parks and R.J. Turnbull, L.R. Baylor, Phys. Fluids **21** 1735 (1978).

[6] ITER Physics Basis, Nucl. Fusion **39** 2175 (1999).

[7] L.R. Baylor, *et al.*, Phys. Plasmas **12** 56103 (2005).

[8] A.S. Kukushkin and H.D. Pacher, Plasma Phys. Control. Fusion **44**, 931 (2002).

[9] P.T. Lang, *et al*, Nucl. Fusion **44** 665 (2004).