*35th EPS Conference on Plasma Phys. Hersonissos, 9 - 13 June 2008 ECA Vol.**32D**, P-4.098 (2008)*

ELMs Triggered from Deuterium Pellets Injected into DIII-D and Extrapolation to ITER

L.R. Baylor[1], T.C. Jernigan[1], N. Commaux[1], S.K. Combs[1], C.R. Foust[1], P.B. Parks[2], T.E. Evans[2], M.E. Fenstermacher[3], R.A. Moyer[4], T.H. Osborne[2], and J.H. Yu[4]

[1]*Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA*
[2]*General Atomics, San Diego, California, USA*
[3] *Lawrence Livermore National Laboratory, Livermore, California, USA*
[4]*University of California San Diego, San Diego, California, USA*

1. Introduction

We report on deuterium pellet injection experiments on the DIII-D tokamak to investigate triggering of edge localized modes (ELMs) in reactor relevant plasma regimes. Previously, ELMs have been observed to be triggered from fueling pellets injected from all locations and under all H-mode operating scenarios in DIII-D [1]. Pellets injected to fuel plasmas with ELMs suppressed by a resonant magnetic perturbation (RMP) can still trigger one or more ELM-like events, but at reduced amplitude compared to H-mode plasmas without RMP applied [2]. Experimental details of the pellet triggering of ELMs on DIII-D have shown that the ELMs are triggered before the fueling pellets reach the top of the H-mode pedestal implying that very small, shallow penetrating pellets are sufficient to trigger ELMs. A new pellet dropper [3] shown in Fig. 1 has been installed to attempt pacing of ELMs [4] with slow (10 m/s), 50 Hz, 1 mm, vertically directed pellets.

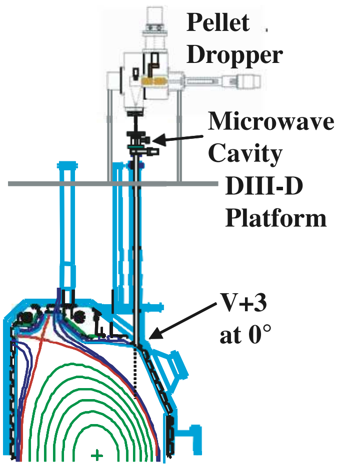

Fig. 1. Cross-section view of DIII-D showing the pellet dropper installation.

2. Pellet ELM Triggering

Fueling pellets from the different injection locations have been observed to trigger ELMs before the pellets reach the top of the pedestal. Fast magnetics signals are used to determine the time of the ELM event and are compared with the pellet ablation D_α emission to determine the location of the pellet when the ELM is triggered. The pellet location as a fraction of the pedestal height is plotted as a function of the pedestal temperature in Fig. 2 for some different operational conditions. We find that the ELMs are triggered well before the fueling pellet reaches half way up the pedestal when RMP is not applied. This is somewhat in contrast to the measurements from ASDEX-Upgrade where it was observed that HFS injected pellets needed to penetrate beyond this depth to trigger an ELM [5]. When RMP is applied on DIII-D, pellets injected from both the inner wall and outside midplane are found to trigger ELM-like events, but the pellet must penetrate deeper than without the RMP applied.

The pellet penetration from pellets injected into DIII-D plasmas has been modeled using the PELLET ablation code [6] using the neutral gas shielding model [7] and agrees well with the measured depth from the lifetime of the D_α emission and fast framing camera studies. Pellets as small as 1mm are predicted to penetrate deep enough to trigger ELMs on DIII-D as shown in Fig. 3.

A device known as a pellet dropper has been installed on DIII-D as shown in Fig. 1 and is now operational for ELM pacing studies. This dropper is designed to introduce 1mm size cylindrical pellets at up to 50 Hz using gravity as the accelerator so that their speed is only ~10 m/s. The dropper pellets have been applied to both L-mode ohmic plasmas and H-mode plasmas with neutral beam injection (NBI). High-speed imaging shows that pellets in the L-mode conditions fall vertically with very shallow penetration into the core plasma. With co-injected NBI H-mode the pellets are swept toroidally and are observed by the tangential viewing fast camera [8] to “skip” along the separatrix. A video frame that shows that the pellet travels toroidally more than 0.5 m while ablating is shown in Fig. 4. The pellets are swept in the direction of the scrape-off layer (SOL) plasma flow, which may be due to drag on the pellet or asymmetric ion ablation. The dropper pellets under these conditions do not penetrate into the core plasma. There is no indication that the dropper pellets trigger ELMs on a reliable basis as is required for ELM pacing. A modification to the injection line to deflect the pellets so that they hit the plasma normal to the plasma surface at

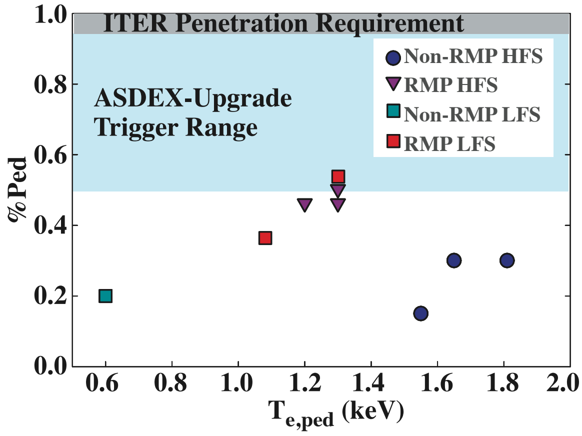

Fig. 2. The pellet position where an ELM is triggered, plotted as a fraction of the pedestal height, vs the pedestal temperature. All the pellets are 1.8 mm and injected from either the inner wall (HFS) or outside midplane (LFS).

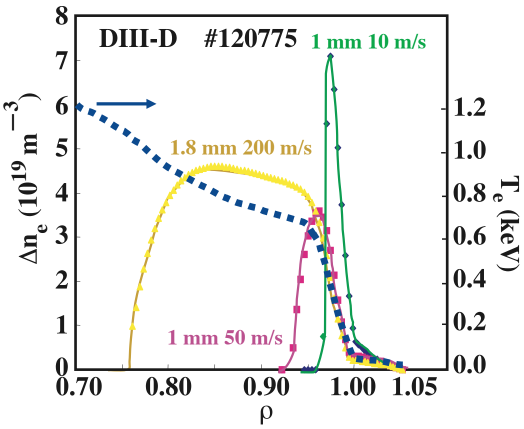

Fig. 3. Pellet mass deposition profiles calculated with the PELLET code for typical H-mode profiles. No mass drift in included in the deposition calculation.

10 m/s instead of 3.5 m/s is planned for the future to learn if this size and speed pellet can trigger ELMs with a more normal trajectory.

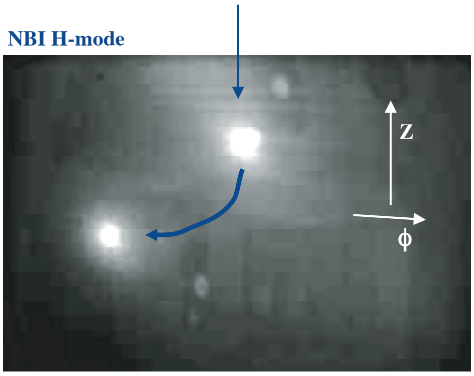

Fig. 4. A tangentially viewing fast camera image showing the light emitted by two dropper pellets. The top pellet has just started ablating in the scrape off layer. The lower pellet is an earlier pellet that has been swept toroidally while ablating by effects from the SOL plasma.

3. Pellet Injection into RMP ELM Suppressed Plasmas

The application of RMP on DIII-D has been successful at suppressing ELMs completely in otherwise ELMing H-mode plasmas [2]. The density is reduced when RMP is applied, due to increased transport compared to cases without the RMP. Therefore pellet fueling has been applied in an attempt to raise the density during the RMP ELM suppressed phase. Individual pellets were found to induce recycling bursts similar to ELMs [2]. When strings of inner wall injected 1.8 mm fueling pellets were injected at 150 m/s during an otherwise fully ELM suppressed discharge, ELM-like events were found to return when the density was increased by the fueling. After the pellet fueling ends and subsequent density decay occurs, the ELM-like events were found to largely disappear as is seen in Fig. 5. These ELM-like events have about half of the divertor D_α spike magnitude as the pre-RMP ELMs. They also produce a rapid decrease in the total plasma stored energy that is approximately half the decrease from the pre-RMP ELM events as determined from high temporal resolution MHD equilibrium reconstructions. Lower frequency pellets with partial ELM suppression has led to only a few ELMs coincident with each pellet as shown in Fig. 5.

4. Summary

Fueling pellets have been found to trigger ELMs before they reach half way into the pedestal, which implies that the ITER requirement for pacing pellets to reach the top of the pedestal may be overly conservative. Pellets dropped from a vertical port on DIII-D with low speed and at a glancing angle with respect to the plasma surface do not have enough momentum to cross into the H-mode plasma and reliably trigger ELMs. This implies that pellets need to penetrate well inside the separatrix in ITER in order to guarantee triggering of an ELM. Future studies will elucidate just how far inside the separatrix the pellets need to penetrate. Pellet fueling of H-mode plasmas with RMP applied is a scenario under test for operation of ITER without strong type-I ELMs. Thus far testing on DIII-D has shown a return to a reduced amplitude ELMing state when strong pellet fueling is applied. Some cases with partial ELM suppression have led to fewer ELMs with the pellets. Thus further optimization of the RMP technique is needed to be able to fully suppress ELMs during pellet fueled H-mode scenarios for application to ITER.

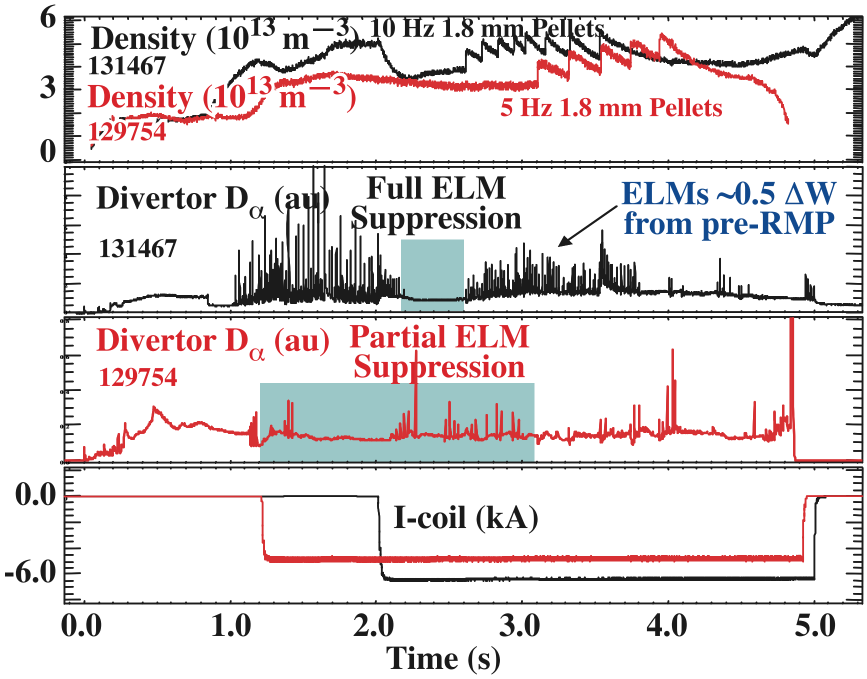

Fig. 5. Two cases of 1.8 mm fueling pellets injected from the inner wall into H-mode plasmas with RMP applied. In the full ELM suppressed case with 10 Hz pellets, frequent ELMs are observed after the pellets start. The partial ELM suppressed case (lower coil current) shows only a few ELMs with the 5 Hz pellets.

This work was supported by the Oak Ridge National Laboratory managed by UT-Battelle, LLC for the US Department of Energy under DE-AC05-00OR22725, DE-AC05-00OR54698, Lawrence Livermore National Laboratory under DE-AC52-07NA27345, and General Atomics under DE-FG02-04ER54758.

References

[1] L.R. Baylor, *et al.,* Nucl. Fusion **47**, 1598 (2007).
[2] T.E. Evans, *et al.,* Nucl. Fusion **48**. 024002 (2008).
[3] S.K. Combs, *et al.,* Proceedings of 22nd Symposium on Fusion Engineering, IEEE Cat. #07CH32901C.
[4] P.T. Lang, *et al.,* Nucl Fusion XX
[5] G. Kocsis, *et al,* Nucl. Fusion **47**, 1166 (2007).
[6] W.A. Houlberg, S.L. Milora, and S.E. Attenberger, Nucl. Fusion **28**, 595 (1988).
[7] P.B. Parks and R.J. Turnbull, Phys. Fluids **21**, 1735 (1978).
[8] J.H. Yu, *et al.,* Phys. Plasmas **15**, 032504 (2008).