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# MHD STABILITY OF JET HOT-ION H-MODE PLASMAS WITH EDGE RADIATION CONTROL

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## 1 . Introduction

Impurity injection has been used recently to control the plasma edge pressure in JET ELM-free Hot-ion H-modes, Optimised Shear and Steady State ELMy H-modes. This paper reports on experiments with Ar, Kr and Xe injected in ELM-free Hot-ion H-modes. Similar effects were observed in the other regimes.

The objective was to delay edge MHD instabilities which limit confinement in the ELM-free Hot-ion H-mode regime,such as outer modes and giant ELMs [1]. In these plasmas, large pressure gradients and current densities develop at the edge. MHD modelling shows that, at the time outer modes and giant ELMs are observed, the edge plasma is unstable to both external kink and ballooning modes [1]. Impurity injection has been used to decrease the power conducted to the H-mode confinement barrier, thus reducing the edge pedestal temperature. The expected decrease in the edge pressure gradient might improve ballooning stability, and indirectly, increase the stability of external kinks by reducing the pressure driven bootstrap current. Further improvement in the external kink stability might arise from a reduction in the edge Ohmic current.

## 2 . Experimental Results

The effect of injecting Ar, Kr, and Xe in hot-ion H-mode plasmas was studied in discharges heated by 10 MW of NBI power, with $I_p$=2.5 MA, $B_t$ values between 2.5-2.8T and $\delta$~0.37. The impurity was chosen to radiate at the H-mode pedestal ($T_e$~2-3 keV). The impurity was injected from the main chamber (either from the top or the mid-plane) in short puffs lasting $\leq$100ms.

The impurity was injected during the ELM-free period, 800 ms after the start of the heating phase. As predicted, plasmas with Ar and Kr impurity radiation (fig.1 and 2) had a longer ELM-free period. The electron temperature at the top of the pedestal and the edge $\nabla T_e$ are decreased (fig. 3). Although the edge density increased, the rate at which $p_e$ rises has decreased. The giant ELMs in both discharges (i.e. with and without impurity) occur at similar values of the edge electron pressure, estimated at the top of the pedestal. The power flowing through the separatrix was decreased by the bulk radiation (fig. 4). Analysis of SXR emission and bolometer data indicate that the impurities penetrate far into the plasma, producing a wide radiating layer, typically within normalised radii $0.4 \leq \rho \leq 1$, as shown in figure 5

In hot-ion H-mode plasmas without increased radiation, both the neutron yield and the plasma stored energy increase proportionally to the ELM-free period [1]. Impurity radiation did extend the ELM-free period, but did not increase the neutron yield nor the stored energy (fig.1). Nevertheless, with Kr (fig. 2), the edge $T_e$ decreased while the central $T_e$ continued to increase. This suggests that improved performance may still be possible by decreasing the impurity amount. The analysis of these relatively low power discharges (P<12 MW) is made difficult by the presence of sawteeth. Large sawtooth crashes during the ELM-free period cause performance limitation [2]. In addition, sawtooth crashes allow impurity penetration to the plasma core.

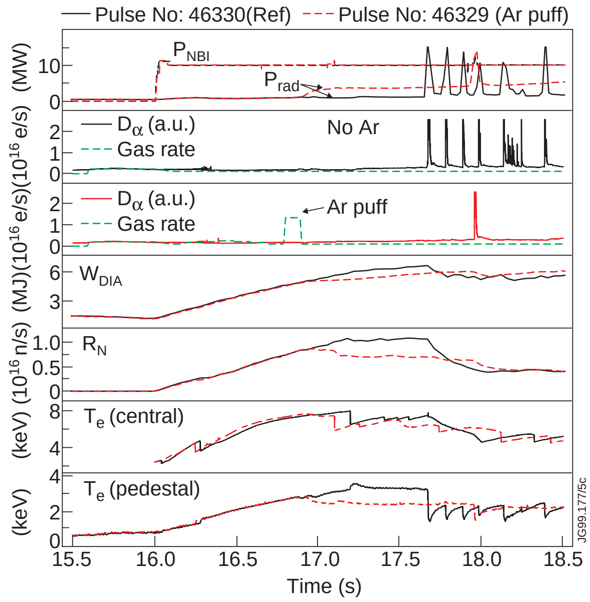


*Fig. 1: Temporal evolution of the $D_\alpha$ emission, plasma stored energy ($W_{dia}$), neutron rate ($R_N$), central electron temperature and electron temperature at the top of the H-mode pedestal for a discharge with an Ar puff at 16.8 s, compared with a reference discharge.*

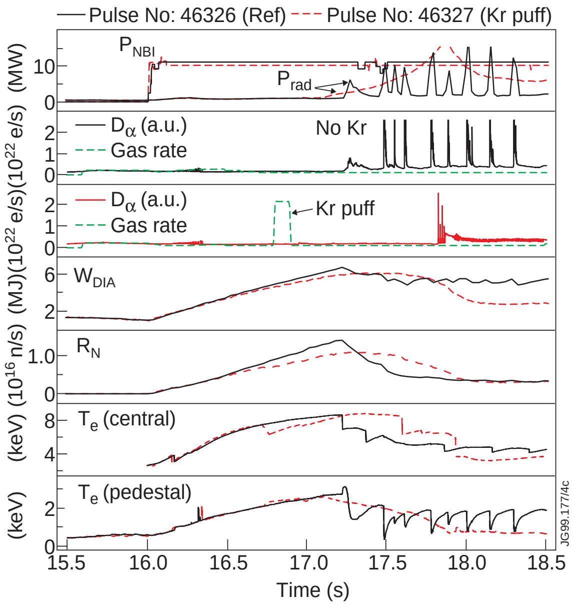


*Fig. 2: As fig. 1, but comparing a discharge with a Kr puff with a reference discharge. N.B In the reference discharge for Kr, $W_{dia}$, $R_N$ and $T_e$ have been limited by an unexpected influx of C from the vessel wall at 17.2 s.*

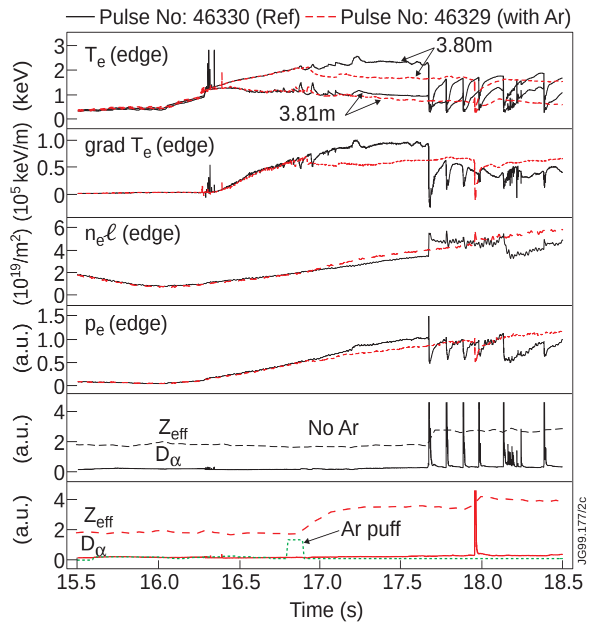


*Fig. 3: With the impurity, $T_e$ at the top of the pedestal decreases, $\nabla T_e$ (edge) decreases, $Z_{eff}$ increases producing a small increase of the edge density. There is a net decrease of $\nabla p_e$ at the edge.*

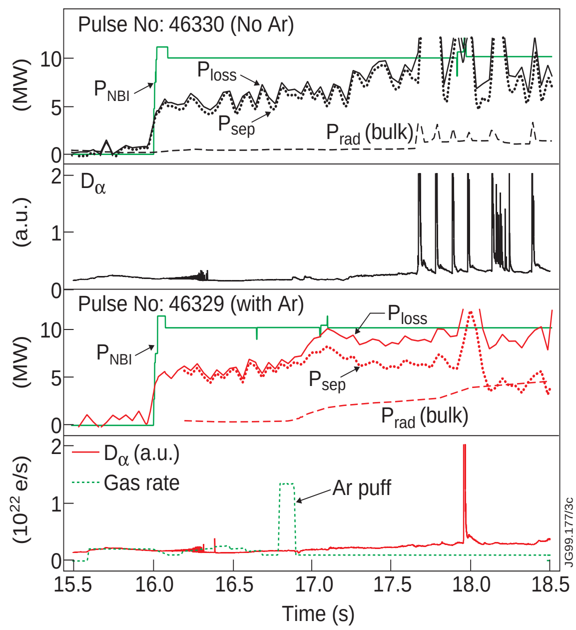


*Fig. 4: Comparison of the power loss ($P_{loss}$=$P_{NBI}$-$dW_{Dia}/dt$), the bulk radiated power ($P_{rad}$ within the flux surface $\rho$=0.95) and the power flowing through the H-mode barrier ($P_{sep}$=$P_{loss}$-$P_{rad}$).*

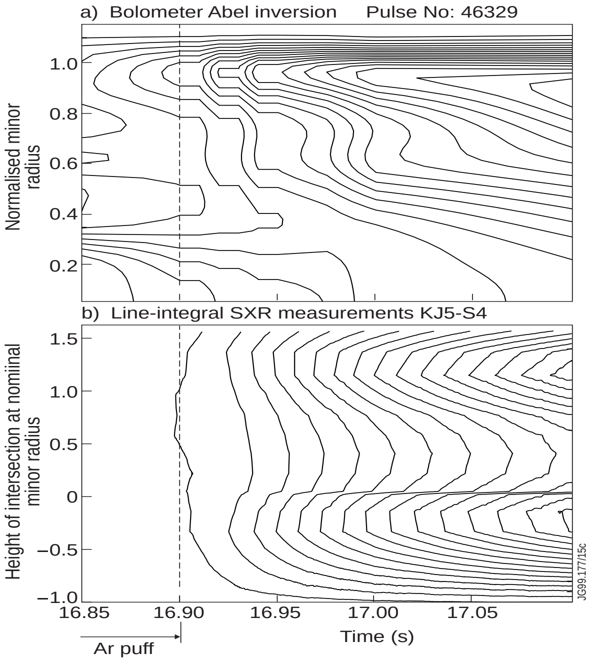


*Fig. 5: a) Flux surface average of the total radiation. b) Line integral SXR emission from horizontal camera.*

## 3 . Observations with Ar

Some observations with Ar were different from Kr and Xe. A few tens of ms after the Ar puff, there is a sudden global $T_e$ collapse (fig. 6). The temperature effects are similar to those observed with MHD outer modes, however no edge MHD mode has been identified. The n=1 magnetic signal in figure 6 corresponds to MHD modes in the core of the plasma. The sudden cooling resulted directly from the radiation. Global $T_e$ collapses are sometimes seen with influxes of C, in discharges that unintentionally touch the vessel wall. (eg. at t=17.2 s in the reference discharge in figure 2.) They have not been observed with the heavier impurities. Spectral analysis (fig.7), indicates that Ar arrived at the separatrix and penetrated the bulk plasma faster than Kr. The fast Ar behaviour however, appears to be a characteristic of hot-ion H-modes, as can be seen from a comparison of the Ar XV line intensity in different H-mode regimes (fig.8). Further analysis is being carried out to see whether this is due to a difference in transport in the scrap-off layer between ELM-free and ELMy regimes.

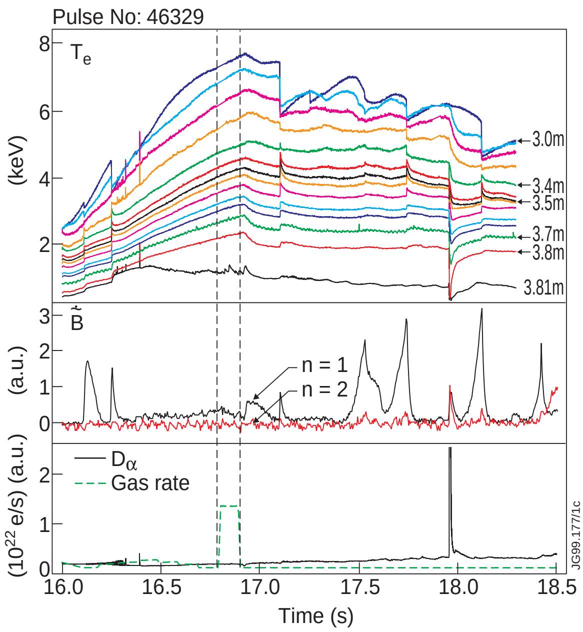


*Fig. 6: $T_e$ at different radii showing a sudden global collapse at t=16.95s, and magnetic perturbations from magnetic pick-up coils.*

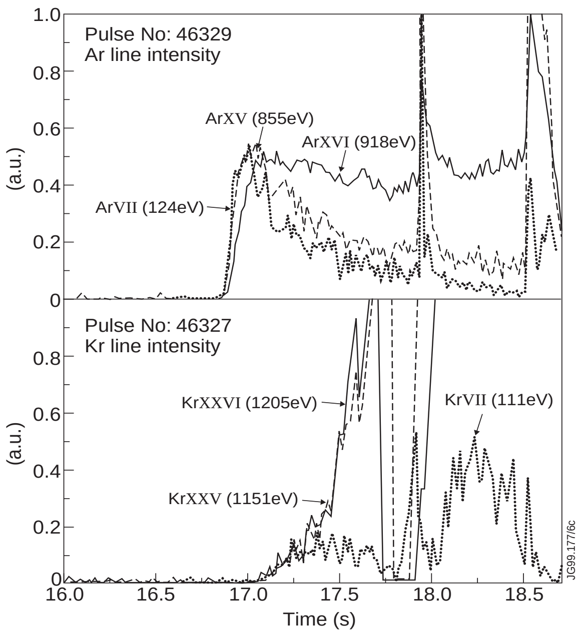


*Fig. 7:– Ar and Kr line intensities from 3 different ionisation stages with comparable ionisation potentials, emitted from or close to the plasma edge.*

## 4 . Comparison with other H-mode regimes

Figure 8 shows that in Optimised Shear [3] as well as in steady state ELMy-H-modes [4], impurity injection delays or totally supresses giant ELMs. As in the ELM-free hot-ion H-mode case, the giant ELMs in ELMy-regimes occur at a critical pedestal pressure [5], which would be lowered when the radiation is increased. Analysis of impurity effects in these regimes, also with respect to a less understood effect on the amplitude of grassy ELMs, is in progress.

a) Hot-ion H-mode b) Optimised shear c) ELMy H-mode

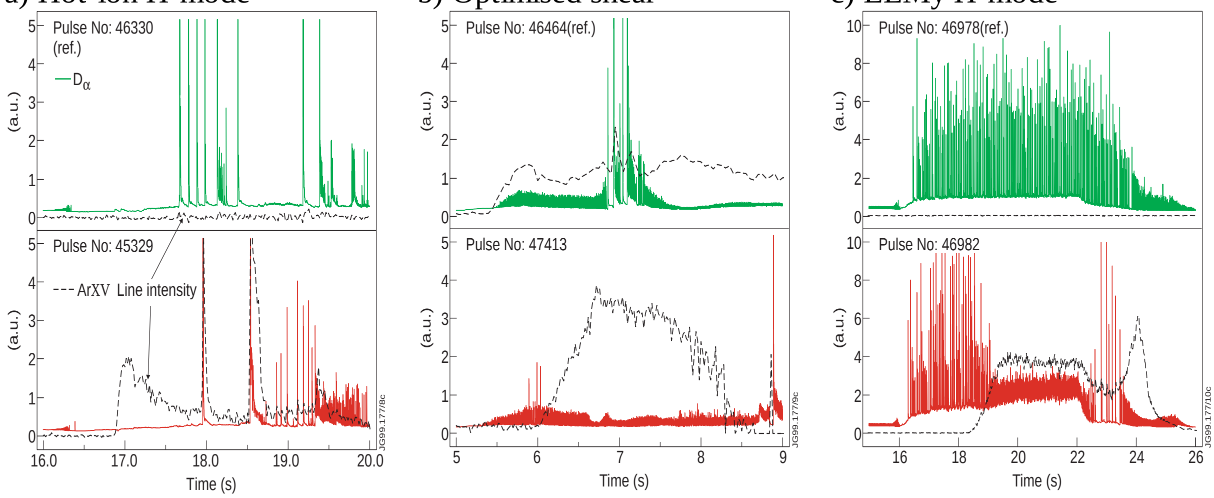


*Fig .8: Comparison of ELM behaviour with Ar injection in different H-mode regimes. The figures show the $D_\alpha$ emission and the intensity of the Ar XV line emitted close to the plasma edge. The $D_\alpha$ signals show that: a) In the Hot-ion H-mode the 1st Giant Elm is delayed; b) in Optimised shear the amplitude of grassy ELMs is decreased, while the giant ELMs are delayed (the two discharges shown are discussed in detail in references [6-7]. c) In the ELMy H-mode, the repetitive giant ELMs are substituted by a period of grassy ELMs.*

## 5 . Conclusions

Experimental confirmation of improved edge MHD stability was obtained in ELM-free hot-ion H-mode discharges where either Ar, Kr or Xe were injected into the plasma during the heating phase. In those experiments the edge temperature gradient was kept low, by creating a wide radiating region and decreasing the power conducted through the H-mode confinement barrier. As expected, the first giant ELM has been delayed. However, since the density continues to increase, the high performance phase is still limited by a giant ELM. Further decrease in the rate of rise of the edge pressure, leading to a steady state regime could be envisaged by a better control of the edge density. Delaying the ELM by impurity injection has not lead to higher values of plasma stored energy and neutron yield. Further experiments are required to obtain the optimum amount of impurity injection. In the hot-ion H-mode experiments, Ar was found to behave differently from Kr and Xe. The Ar enters the bulk plasma in a few tens of ms, similar to observations in Laser Ablation experiments [8]. Increased edge stability with respect to ELMs has also been observed when the radiation level is increased in optimised shear and steady state ELMy H-mode plasmas.

## References


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