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Influence of Neon and Argon Recycling on RI-Mode Confinement in JET

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1. INTRODUCTION

Radiation Improved (RI-mode) plasmas offer an attractive operating regime which has high radiating power fractions (0.5 – 0.9), energy confinement improvements relative to L-mode as measured by the ITERH89P scaling law, H89 $\cong \tau_E/\tau_{H89P}$ [1], and operation near the Greenwald density limit (GW). The TEXTOR tokamak has demonstrated this scenario in a limiter device with steady state conditions [2] for impurity seeding of the plasma discharges with both neon (Ne) and argon (Ar).

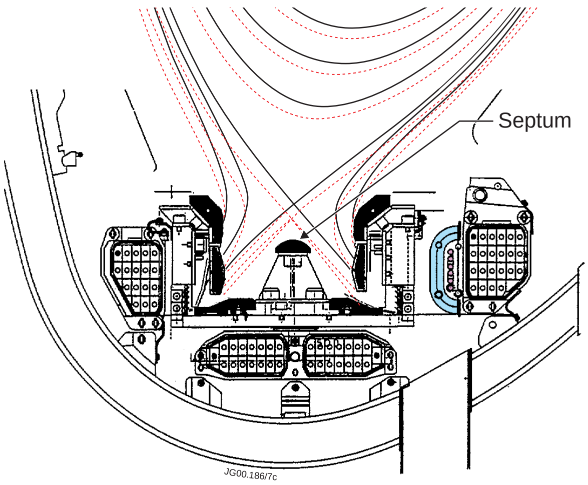
TEXTOR RI-mode experiments suggest that pumping and the control of recycling impurities play an important factor in obtaining the improved confinement of RI-mode. Recent studies on the JET tokamak have been initiated to investigate this mode in a larger non-circular tokamak which has a pumped divertor configuration, where pumping/recycling can be varied, in order to evaluate the importance of impurity recycling on the quality of RI-mode confinement in JET.

2. EXPERIMENTAL RESULTS

RI-mode experiments have been performed on JET with the MkII-Gas Box divertor using Ne and Ar impurity injection into plasmas with $B_T = 2.5$ T, $I_p = 2.5$ MA, and $q_{95} \approx 4.0$ to produce a radiating mantle and improved confinement. Three different divertor configurations are investigated in these studies, as illustrated in Figure 1. The first configuration is the corner configuration (red) in which the x-point is above the divertor septum and the inner and outer strike point is positioned for optimal pumping.

The second configuration is the vertical target configuration (black), where the inner and outer strike point is moved onto the vertical target to reduce the pumping, thereby increasing the impurity recycling in the divertor. The third configuration is the septum configuration, where the x-point is shifted onto the septum, thereby producing a limiter configuration with minimal pumping and very high recycling from the septum. Figure 2 shows the local emissivity versus major radius at the tokamak midplane after Abel inversion of the JET bolometers for both Ne and Ar seeding. A radiating mantle due to the impurity seeding with Ne and Ar is clearly present near the plasma edge.

To investigate the importance of recycling on establishing the RI-mode, Ne and Ar were used to seed two RI-mode deuterium fuelled plasmas with the divertor strike points in the optimal pumping location (corner configuration). The neutral beam power was 12 MW throughout the discharge and Ar or Ne seeding was applied between 17 and 23 s. The results from these discharges are shown in Figure 3. Ne and Ar concentrations are measured in the divertor with a modified Penning gauge, while Charge Exchange Recombination (CER) spectroscopy is used to measure the Ne and Ar concentrations in the core plasma. The ArXV (221.1 Å) and NeVIII (770.4 Å) light intensity is obtained from a VUV spectrometer which views across the midplane of JET.



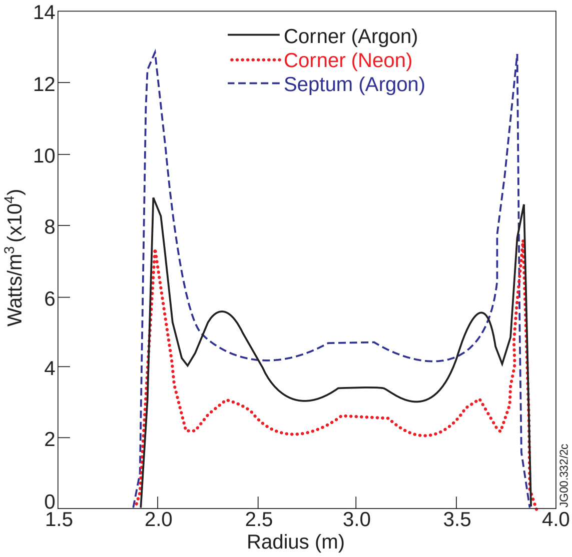


Figure 1: JET MkII-Gas Box divertor with septum. Flux surfaces for optimal pumping are with the strike points in the corner (red). Reduced pumping results when the strike points are moved up on the vertical target (black).

Figure 2: Abel inversion of Radiated Power versus radius in the RI-mode experiments on JET for the corner and septum configuration with Ar and Ne.

This impurity light emission should be characteristic of the Ne/Ar in the radiating mantle region. Also displayed are the fraction of the Greenwald density, H89 confinement scaling, the divertor enrichment ($\eta = C_{div}/C_{core}$, where C_{div} = divertor impurity concentration and C_{core} = core impurity concentration), and the divertor impurity partial pressure. The discharges are in L-mode from 17.5s to 20.0s and H-mode for the remainder of the discharge. For both the L-mode and H-mode phases the H89 confinement is the same for both Ne and Ar. During the L-mode phase H89 $\approx$ 1.5, while in the H-mode phase it increases to an H89 $\approx$ 2.2. During the L-mode phase the divertor enrichment η(Ar) increases from about 10 to 23, and during the H-mode phase decreases to η(Ar) $\approx$12. On the other hand, the Ne enrichment η(Ne) $\approx$ 5 for L-mode and η(Ne) $\approx$ 4.5 for H-mode. During the good confinement H-mode period the core concentration of both Ar and Ne increases, while the divertor partial pressures of both Ne and Ar both begin to decrease. This is indicative of the sharing of the impurity content between the divertor and the primary plasma volume. This sharing of the Ne or Ar between the divertor and the main plasma chamber can be controlled by modification of the pumping in the divertor.

3. MODIFICATION OF IMPURITY RECYCLING VIA DIVERTOR PUMPING

As seen in Figure 3 during the H-mode phase, the Ar/Ne partial pressures in the divertor and the Ne/Ar spectroscopic signals are decreasing in time. This is indicative that the Ne/Ar is being removed from the divertor and edge plasma via divertor pumping. To investigate this, three discharges are displayed in Figure 4 with Ne impurity seeding. The discharge 50329 has the strike point in the corner for optimal pumping and control of Ne recycling.

Due to significant pumping in this configuration the NeVIII signal (indicative of the quality of the radiating mantle) is decreasing with time as the Ne is removed from the system via the divertor pump. Discharge 50356 begins in the corner configuration until 7.0s and then the divertor strike point is moved to the vertical target position and pumping is thereby reduced. As can be seen by the NeVIII spectroscopic signal the reduced pumping increased the divertor recycling of Ne and resulted in a significant increase in the NeVIII intensity. Similar increases are observed in the divertor Ne partial pressure for the shift to the vertical target.

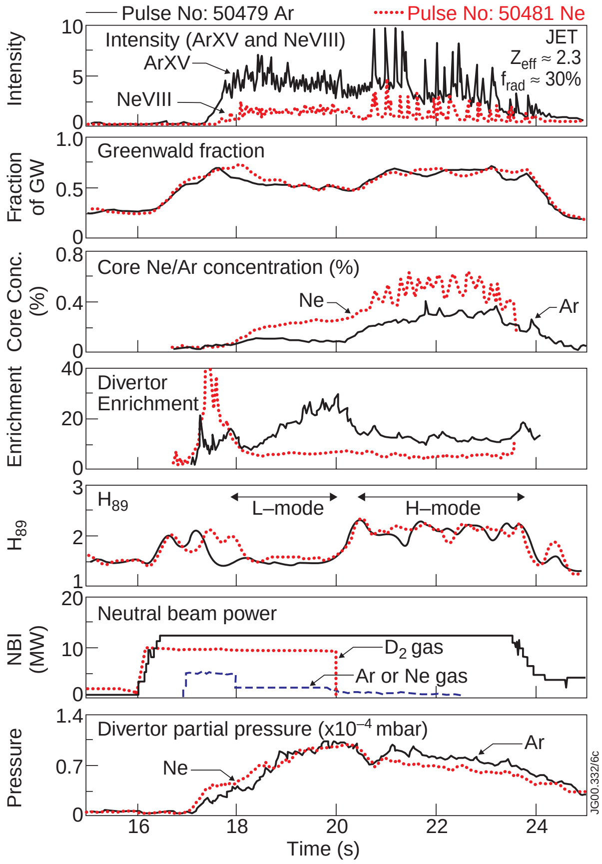


Figure 3: Comparison of the temporal evolution of Ne (50481) and Ar (50479) radiating mantle discharges in the corner divertor configuration. The discharges are L-mode in the early phase and H-mode at the later times. Measurements are described in the text.

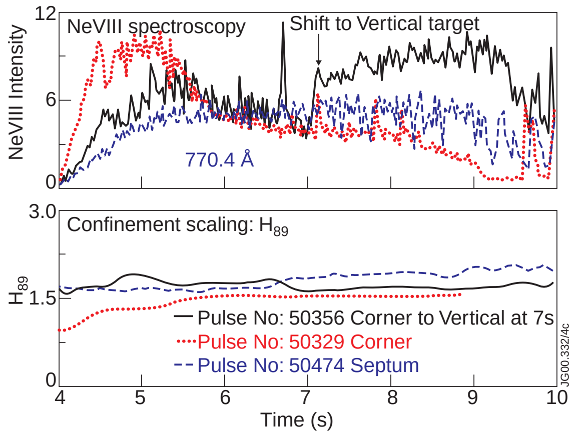


Figure 4: Temporal evolution of NeVIII intensity and H89 confinement improvement for the corner, vertical target, and septum configuration with Ne impurity seeding.

Comparing the H89 confinement at ≈ 8s, the reduction in Ne pumping for the vertical target configuration slightly improved the confinement relative to H89 in the corner configuration. Finally, in discharge 50474 the x-point is placed on the septum (see Figure 1) to form a limiter plasma, which has very minimal pumping, due to the poor connection to the pumping slots in the divertor. This produces a high degree of Ne recycling from the septum and provides a steady source of Ne to maintain the radiating mantle with only a moderate amount of pumping (perhaps similar to the RI-mode limiter configuration found in TEXTOR). The NeVIII intensity for the septum limited case is intermediate between the corner and vertical target configuration, but the H89 confinement is significantly improved over the corner and vertical target configuration.

4. COMPARISON WITH DIII-D RESULTS

The divertor enrichments for Ne and Ar measured in these experiments are similar in magnitude to those observed during induced scrape-off layer flow (‘puff and pump’) experiments on DIII-D [3]. In the present experiments the divertor enrichment values are: η (Ar) $\approx$ 10-23 (L-mode), η (Ar) $\approx$12 (H-mode); η (Ne) $\approx$ 5 (L-mode) and 4.5 (H-mode). Comparable enrichment values were found in DIII-D, η (Ar) = 17 , η (Ne) = 2.3 both in ELMy H-mode. In the DIII-D experiments strong D_2 fuelling was introduced at the top of the tokamak and the enrichment values were reduced in the case of D_2 fueling from the private flux region. However, the DIII-D experiments correlated the effect of induced scrape-off layer flow (produced in the top gas-puff case) with the increased enrichment, whereas such an effect is not seen in JET [4]. It should be noted, though, that much of the fuelling of D_2 in these JET RI-mode discharges was also introduced from the top of the tokamak. However, a direct comparison of the regimes on the two machine is outside the scope of this RI-mode study.

5. CONCLUSIONS

These experiments have focused on the importance of controlling the Ar and Ne recycling in JET plasmas through variations in the divertor pumping for the current MkII-Gas Box Divertor. The quality of RI-mode confinement (higher values of H89) is found to marginally improve when Ne and Ar recycling are allowed to increase for the reduced pumping cases (vertical target and septum configurations). For the reduced pumping cases, both the Ne and Ar radiation increase in the mantle region, and similarly corresponding Ar/Ne partial pressures increase in the divertor. When maximum pumping is applied (corner configuration), the impurity radiation from the mantle and impurity content in the divertor are continually decreasing; thereby, resulting in a less robust radiating mantle and poorer RI-mode confinement properties. These results show that the impurity content of the radiating mantle can be controlled via modifications in the divertor pumping (i.e. positioning of the divertor strike points). These configuration modifications within the MkII-Gas Box geometry lead to steadily increasing or steadily decreasing impurity content, but the optimum RI-mode confinement is found under steady conditions for the septum configuration. Additional optimization will be needed to produce the best RI-mode confinement in the vertical target/corner configurations, since the septum will be removed in 2001.

ACKNOWLEDGEMENTS

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