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The successful integration of edge localized mode (ELM) suppression using resonant magnetic perturbations (RMPs) with puff-and-pump [1] radiating divertor operation is demonstrated. In addition, because higher gas injection rates are needed to maintain plasma density after the RMP coils have been activated, a radiating divertor with RMP is shown to produce considerably higher levels of radiated power from the divertor and scrape-off layer (SOL)/edge plasma regions than comparable non-RMP discharges at the same density. These new results build on the theoretical and experimental progress made previously in identifying and understanding the underlying physics involved in two distinct topics, i.e., puff-and-pump radiating divertor operation [2] and ELM suppression using RMPs [3].

Recent experiments at DIII-D have studied aspects of the integration between RMP-based ELM suppression and radiating divertor operation, particularly comparing the behavior of injected “seed” argon impurities in both RMP and non-RMP puff-and-pump environments, and identifying what could limit the use of RMP ELM suppression with the radiating divertor. In these puff-and-pump scenarios, argon particles were injected into the private flux region of a single-null configuration, while plasma flow to the divertor was enhanced by a combination of particle pumping near the outer divertor target and deuterium gas puffing upstream. The H-mode plasmas in this study are characterized by $H98(y,2) \approx 0.9\text{-}1.2$, $\beta_N \approx 2$, $\bar{n}_e/n_{eG} \approx 0.3\text{-}0.7$, and $P_{RAD}/P_{INJ} \approx 0.3\text{-}0.8$. Two sets of non-axisymmetric coils (“I-coils”) produce a variety of RMPs in DIII-D [3].

ELM suppression by RMP diminished and was ultimately lost as the deuterium Γ_{D2} and argon Γ_{Ar} gas injection rates were increased. This is shown in Fig. 1 for three values of Γ_{D2}. The activation of the I-coils at $t = 2.0$ s resulted in an immediate decrease in the pedestal density n_{PED}, followed by ELM suppression; $\bar{n}_e/n_{eG} \approx 0.5$ and 0.3 at $t = 1.9$ s (pre-activation of the I-coil) and 2.7 s (post-activation of the I-coil), respectively. Deuterium and argon injection began at 2.8 s and 3.2 s, respectively. Raising Γ_{D2} resulted in an increase in n_{PED} [Fig. 1(Ib-IIIb)] and a drop in pedestal electron temperature T_{PED} [Fig. 1(Ic-IIIc)], but the energy confinement factor *H98(y,2)* remained constant throughout the rest of the discharge [Fig 1(Id-IIId)]. After the initial drop in the edge electron pressure gradient ∇P_e [Fig. 1(Ie-IIIe)] following I-coil activation, ∇P_e recovered gradually over the remainder of the discharge and ELMing activity resumed. Peeling-ballooning mode analysis with the ELITE code suggests that these ELMs were Type-1.

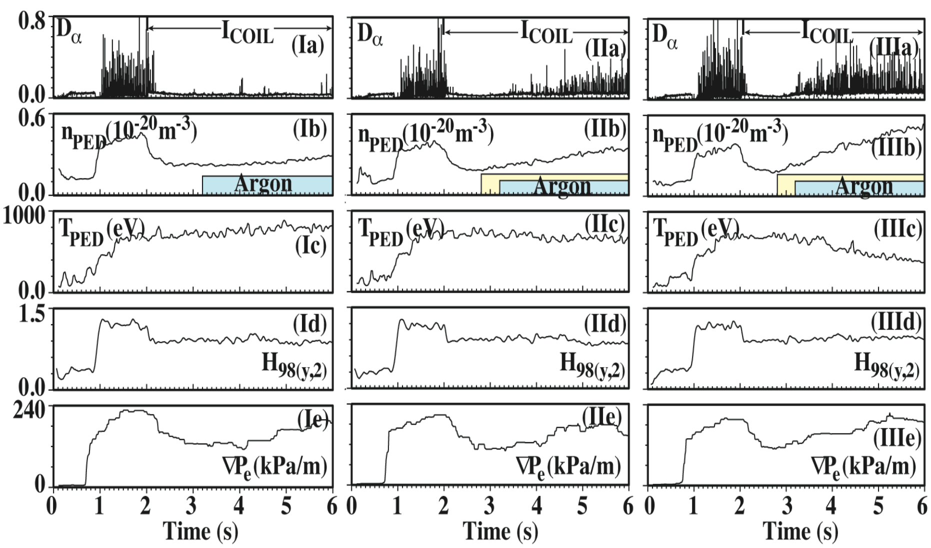

Fig. 1. The re-emergence of ELMing activity for three distinct values of Γ_{D2}: zero (Col. I), 5.0 Pa m^3/s (Col. II), and 10 Pa m^3/s (Col. III). Γ_{Ar} = 0.05 Pa m^3/s was used in each case: (a) Deuterium recycling D_α, (b) n_{PED}, (c) T_{PED}, (d) *H98(y,2)*, and (e) ∇P_e. I-coil = 5.8 kA in each case. Note that the argon (blue) and the deuterium (yellow) boxes in (b) represent only their injection times and are not to scale.

Differences in argon accumulation in the core between RMP ELM-suppressed and similar non-RMP ELMing H-mode plasmas were less than 20%, as shown in Fig. 2. It is important to note that the core concentration of argon in the RMP cases decreased as the deuterium gas puff rate increased in a way similar to that of comparable non-RMP cases. This would suggest that the physical processes detailed in the modeling reported previously [2] for non-RMP radiating divertor plasmas may also apply to corresponding RMP cases, i.e., the importance of particle drifts in the SOL and divertor in "fueling" the core plasma. This is a key point, because the extensive studies in optimizing performance of radiating divertor plasmas in *non-RMP* cases may provide direction as to how radiating divertor cases *with RMP* can be optimized. We note that the return of Type-1 ELMing activity at higher densities in RMP plasmas may have been responsible for the similarity in argon impurity accumulation in the core plasma.

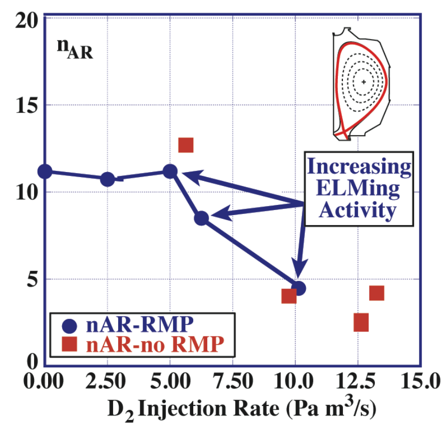

Fig. 2. Less argon accumulates in the core plasma (n_{AR}) as Γ_{D2} is increased, in both RMP and non-RMP radiating divertor discharges. The plasma shape used in this study is shown in the inset.

RMP was also found to enhance plasma radiated power during puff-and-pump operation. For example, a comparison of similarly-prepared H-mode plasmas with and without RMP (but with the same pedestal density) showed that the radiated power was ≈30% higher in the RMP case. This was largely due to the additional deuterium (and argon "seed" impurity) gas puffing needed to maintain the pedestal density after the I-coil had been activated, and this, in turn, produced a thicker SOL plasma and lower plasma temperatures in both the plasma edge and SOL/divertor that were favorable to enhancing radiated power. While *H98(y,2)* was reduced ≈20% after the I-coil was activated, the energy confinement time of these plasmas during subsequent puff-and-pump operation remained representative of a good H-mode [i.e., *H98(y,2)* ≈ 1] and was insensitive to changes in n_{PED} over a wide range.

From the preceding results we can draw important conclusions for the direction of this research. In terms of low impurity contamination and energy confinement degradation with flexible control of core density, we expect the most effective way to apply RMP ELM suppression to radiating divertor plasmas would be to maximize divertor pumping and operate with the ion $\boldsymbol{B}x\nabla\boldsymbol{B}$ drift directed away from the X-point. This is based on our previous work in non-RMP radiating divertors. A discussion of the technical issues that were encountered in executing these experiments (e.g., 2/1 locked modes at low density) will be presented.

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