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ABSTRACT

When working with probes in tokamak plasmas, impurities are always an annoyance. However deliberate seeding with light impurities has shown features which are favourable for a nuclear fusion tokamak reactor, such as high confinement at high density with a radiating belt [1]. Argon and neon have been seeded into a variety of discharge configurations on JET. In these discharges the density build up is produced by a strong gas-puff of D_2, ("puff" phase, see Fig. 1), during which the confinement is degraded. At the same time an impurity is seeded, e.g. argon, in order to raise the radiation level. However the confinement recovers again when the gas valve is closed ("afterpuff" phase). To maintain the density in this phase, small levels of D_2 are applied in addition to a modest extra amount of argon. In discharges limited on the septum of the MkIIGB divertor, this leads to quasi-stationary plasmas at high densities close to the Greenwald level and simultaneously good confinement ($H_{97} \approx 1$). The overall confinement properties of impurity seeded H-mode discharges are discussed in [2]. A new confinement scenario is only attractive as a possible operation scheme, when also the effects caused by ELMs can be handled. Therefore first the link between the global confinement and ELMs will be explored, and then results on changes in the SOL power flux will be given. The afterpuff phase will be the focus of this analysis, since its good confinement properties are particularly attractive. The impurity seeded in the pulses presented here was exclusively argon. A few comparisons of seeded with unseeded puff phases are shown for an enhanced high triangularity configuration.

1. GLOBAL ELM BEHAVIOUR

Strong gas puffing into high power ELMy H-mode discharges leads to a confinement degradation, which is associated with a reversion to Type III ELMs. When argon is puffed in addition to the deuterium, the confinement degradation is even stronger. This can be understood as the result of the enhanced radiation (about 50% higher for seeded pulses) and hence a lowered edge electron temperature (Fig. 2), which reduces the pedestal energy. Note that the diamagnetic plasma energy is also smaller compared to the unseeded pulse, since the density remains about the same. Once the gas-puff is stopped, the ELM frequency decreases until a transition to Type I ELMs appears. This observation is consistent with rising pedestal energy [3], which can be also inferred from Fig. 2 and 3.

During this phase of the discharge ("afterpuff") again a modest amount of argon has been seeded. Depending on the radiation level, ELM-free phases ending with giant ELMs, or Type I ELMs with compound or regular signatures can show up in the afterpuff phase. In Fig. 1 two example time traces of the edge recycling inferred from a horizontal D_α measurement are displayed. The enhanced radiation acts now in two ways: on one hand, the power through the separatrix is lowered; on the other hand, the edge electron temperature is lower and so is the edge pressure gradient. Figure 3 gives a first indication that Ñpe is smaller for seeded plasmas than for unseeded. In [4] an empirical scaling of the ELM frequency has been proposed, which is also confirmed for giant ELMs using a simple model [5], where the temporal sequence of the ELMs is imposed by the reheating time. As shown in Fig. 4 the ELM frequency of unseeded discharges (open symbols) decreases when the power crossing the separatrix is reduced by seeding (closed symbols). For the two pulses illustrated in Fig. 1 about 30-40% has been radiated in the edge (r/a>0.8). This causes a drop in the edge electron temperature and a peaking of the current profile. As a result, the stability regime for the edge profile is enhanced and the ELM cycle prolonged.

Summarising, our observations are a confinement degradation accompanied by Type III ELMs during the puff phase, which recovers after the fuelling has stopped. No matter what the seeding, the pedestal pressure rises from the puff phase to the afterpuff phase. However from comparison of the afterpuff properties from unseeded to seeded discharges, one can report a reduced edge electron temperature, despite a higher edge density a lower pedestal pressure, and a **lower** ELM frequency. A reduced energy pedestal mitigates the energy loss per ELM. $\Delta W/W$ Using the fast magnetic diagnostic the fractional energy loss can be estimated. It is seen that in many cases $\Delta W/W$ is smaller in the seeded discharges (Fig. 5). Shown are the relative decrease of $\Delta W/W$ and P_{sep} of the seeded pulse with respect to the unseeded pulse. Both lower ELM frequency and energy loss per ELM help to maintain or even increase the stored energy despite the high radiation. In [6] the change in collisionality has been proposed as the cause for the drop in $\Delta W/W$.

2. EFFECTS ON THE DIVERTOR LOAD AND PARTICLE EFFLUX

In order to characterise fluctuations, the steady-state particle losses have been calculated and subtracted from the edge recycling signal. Thereafter the data have been integrated in time and by dividing by the ELM frequency the averaged particle flux per ELM has been determined. The results show this quantity to remain constant or even to increase with higher radiation level. However one should note that due to the continuous seeding, steady-state conditions have not been fully achieved and therefore even after the ELM burst additional particle losses still show up.

Since for the deposited power not only the particle flows are relevant, the surface-facing electron temperature has been measured using the divertor target triple probes. Although the ion temperature is not accessible to the probes, the reduction in the power load on the outer target (not corrected for the magnetic field inclination angle) shown in Fig. 6 is certain, since CXSE measurements indicate lower ion temperatures as well.

For some discharges the power load on the divertor tiles has been measured using an infrared camera. Preliminary results have shown a reduction in the surface temperature on the inner as well as on the outer divertor target tiles [6]. This time-integral measurement implies that in average the heat bursts caused by the ELMs are indeed mitigated.

3. SUMMARY

Impurity seeding in tokamak plasmas has the purpose of forming a radiating belt and diminishing the divertor load. It has been demonstrated that the behaviour of ELMs in the afterpuff phase is affected in various ways: on one hand, the separatrix power is smaller and a lower ELM frequency is achieved; on the other hand, the edge pedestal for argon seeded afterpuff phases is reduced and the heat flux is diminished. The good confinement properties seen in these discharges are augmented by the acceptable energy loss and the lower frequency of ELMs. Presently experimental work is underway to achieve a steady-state phase with benign ELMs by tuning the deuterium and argon gas levels.

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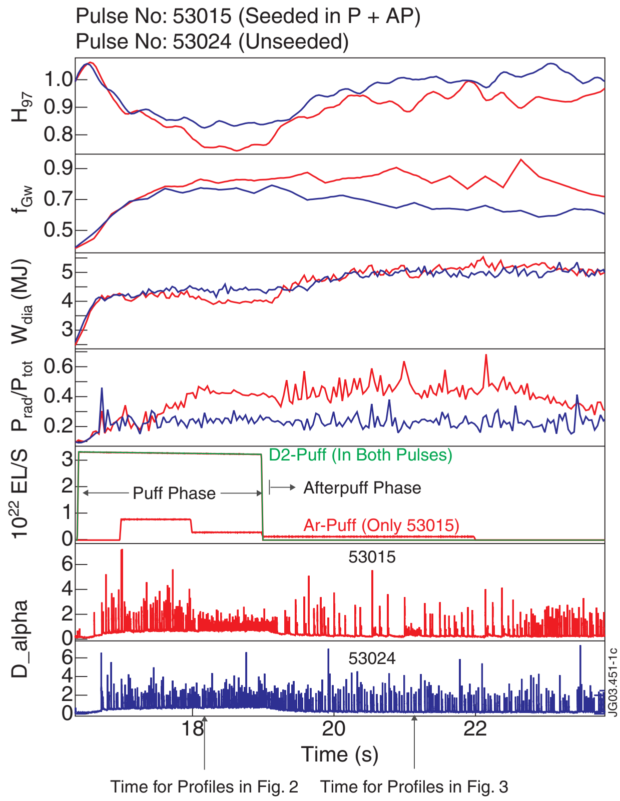

Figure 1: Comparison of unseeded discharge with argon seeded discharge. The seeding has been applied during the "puff" phase as well as during "afterpuff" phase. Shown are a) H97-factor, b) Greenwald fraction, c) diamagnetic plasma energy, d) radiated power fraction, e) gas rate of deuterium and argon puff, f) D_α-trace of seeded pulse, g) D_α-trace of seeded pulse.

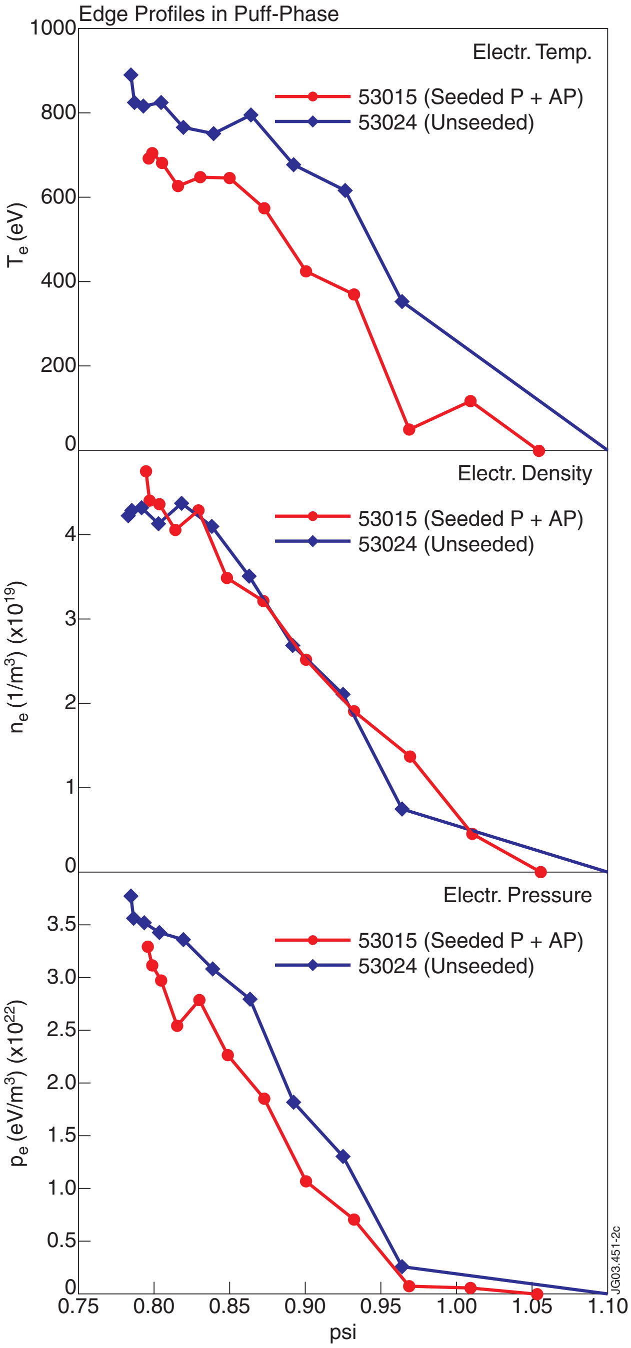

Figure 2: Edge profiles of seeded and unseeded pulse. The profiles are taken during the puff at the time as indicated in Fig. 1.

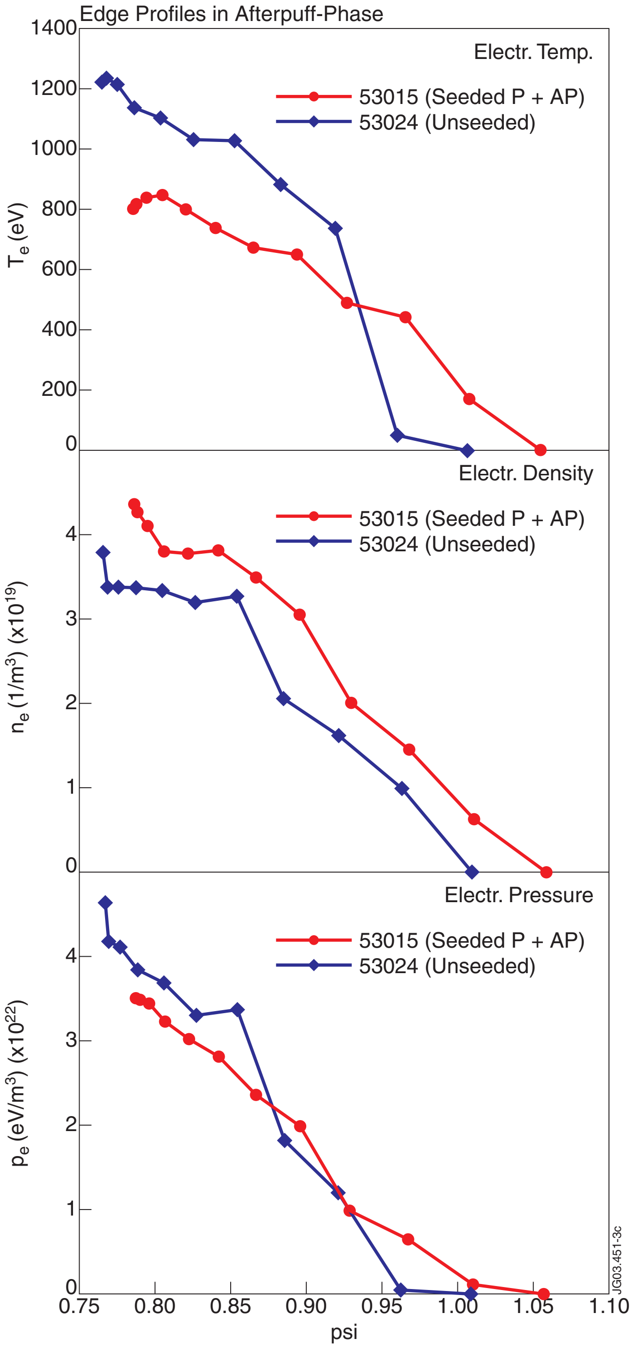

Figure 3: Edge profiles of seeded and unseeded pulse. The profiles are taken during the afterpuff phase at the time as indicated in Fig. 1.

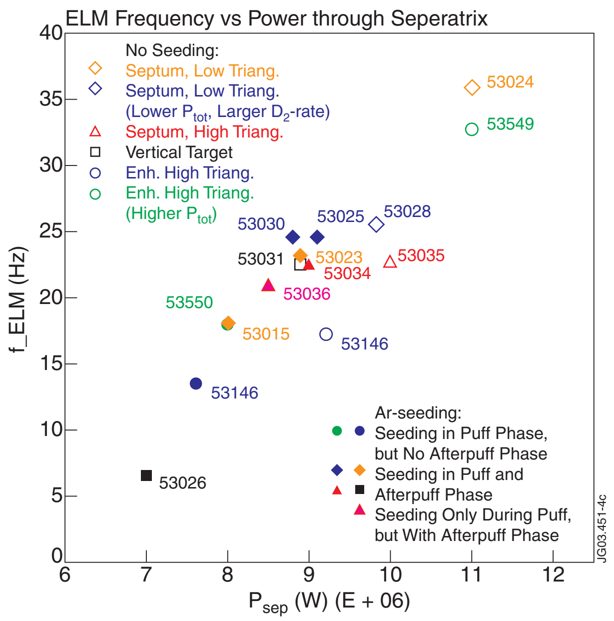

Figure 4: ELM frequency versus power crossing the separatrix. The open symbols correspond to unseeded pulses, the closed to seeded.

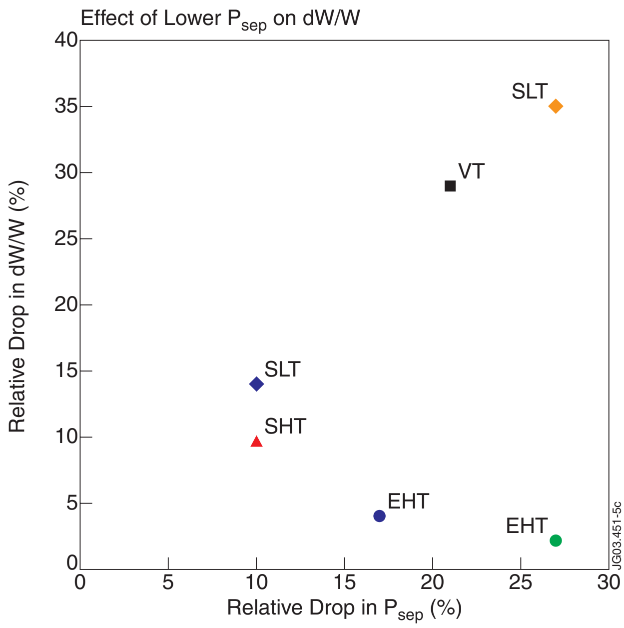

Figure 5: Relative drop in ELM energy loss fraction and separatrix power of seeded with respect to the unseeded pulse.