

## Exploring the pathway to the Super H-mode on HL-3 (bold, 14 pt)

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HL-3 is exploring the scenarios with high operation parameter such as super H-mode, where the large edge localized modes (ELMs) should be avoided. Results of EPED reveals that the pedestal density can be less than the Greenwald density limit for the HL-3 super H-mode operation. With the equilibria generated by the integrated framework in OMFIT [1], stability analysis shows that two methods may be used to sustain the super H-mode operation [2]. The first is mitigating the ELMs at the peeling boundary, so that the one single small ELM will not lead to the transition to the high collisionality H-mode. The second is suppressing the ballooning instabilities at the upper ballooning boundary of the bifurcation, which may enlarge the parameter space of super H-mode. Auxiliary techniques such as impurity injection [3] or Resonant Magnetic Perturbation can also be used to control ELMs on HL-3.

According to the simulation results, 2 key issues are studied in experiments on HL-3. The ELM-free H-mode with low density is achieved for more than 600 ms by increasing the triangularity. And the density is further increased during the H-mode by replacing the gas puffing by supersonic molecular beam injection. Moreover, with the ~2 MW neutral beam injection (NBI) heating, super H-mode is firstly achieved in the experiment on HL-3 and the  $\beta_N \sim 3.0$ . The pedestal density  $n_{ped} > 0.5 n_{GW}$  (Greenwald density limit), and the pedestal electron temperature  $T_{e,ped} \sim 1$  keV, which is twice the value of the normal H-mode on HL-3.

### References

- [1] Yiren Zhu et al. Nucl. Fusion 60 (2020) 046014.
- [2] Yiren Zhu et al. Nucl. Fusion 64 (2024) 096019.
- [3] Yiren Zhu et al. Nucl. Fusion 62 (2022) 076011.

Figure 1. Peeling ballooning stability diagram in  $n_{ped}$  and pedestal height of HL-3.

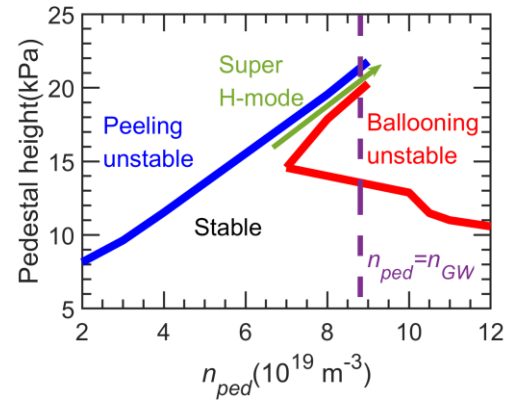


Figure 2. ELM-free H-mode with large triangularity (0.54), and the density ramping up during the H-mode by supersonic molecular beam injection.

