ABSTRACT

- Some disruptions with short warning times may be unavoidable in ITER
- The Electromagnetic Particle Injector (EPI) is being developed to meet this need (<10 ms overall response time, >1 km/s payload injection speed in ITER)
- Off-line tests have shown attainment of 0.6 km/s in 1 ms
- Because of the large size difference between ITER and present experiments, 3D MHD simulations benchmarked with present experiments is necessary to reliably project to ITER
- M3D-C1 is being modified to model the injection of solid pellets

BACKGROUND

- Shattered Pellet Injection (SPI) has response time of 25 ms on DIII-D, and will have >30 ms response time on ITER [1,2]
- Gas load from SPI impact fracturing [3] could trigger early Thermal Quench (TQ) before fragments penetrate deep into ITER
- Fragmentation, gas load [3] combined with variable fragment size and velocity makes SPI penetration modeling challenging
- SPI overcomes these issues by relying on simple electromagnetic propulsion system without the limitations of gas-based systems
- In SPI, a metallic sabot is accelerated to high velocity (>1 km/s in <2 ms) at which point the sabot releases well-defined particles or a Shell Pellet

Top-down view showing the carbon pellet injection geometry. Case 1 is for pure radial injection, which minimizes the pellet propagation time to the magnetic axis. Case 2 is for a shallow injection cases, such that which is likely to be used in the EPI configuration as in the absence of a plasma, the pellet could leave the vessel through a port at the opposite end of the pellet trajectory. This would avoid the pellet impacting the center stack of the tokamak.

The plasma electron temperature for different time slices (a-d corresponding to 0, 0.235, 0.438, and 1.09 ms respectively) for Case-1 with Velocity of pellet = 1000 m/s. The small circle within the frame shows the pellet position at each time. t = 0.235 ms, the pellet has propagated to the q = 2.4 surface. The core \( T_e \) has dropped from \( \gtrsim 2 \) keV to \( \lesssim 1 \) keV. Central \( T_e \) is falling sharply. Field lines at the pellet position are now linked to the plasma core but not to the plasma boundary. Pellet radiation is coming primarily from the core and, \( T_e \) becomes hollow. At t = 0.438 ms, the pellet has reached the magnetic axis. \( T_e \) at magnetic axis drops to \( \lesssim 200 \) eV. At this point the stochastization spreads to the edge and therefore the temperature at the center starts rising due to the hotter edge plasma. Finally, at t = 1.09 ms, the pellet is almost exiting the plasma. Resulting plasma reforms and has a nearly uniform \( T_e \) above 250 eV.

NEW M3D-C1 Simulations

- New capabilities being added to M3D-C1 [4] will also be capable of modeling SPI penetration for ITER. The target plasma configuration used for these simulations is for the injection of solid carbon pellets is NSTX-U. The ablation model is based on a neutral gas shielding approach (NGS) [5,6] in which the key quantity is the shielding factor \( \delta = q_p/q_0 \), where \( q_p \) is the plasma heat flux that has reached the pellet surface and \( q_0 \) is the plasma heat flux before entering the pellet neutral cloud.

For both strong (\( \delta \ll 1 \)) and weak (\( \delta \approx 1 \)) shielding, analytic expressions can be derived [5,6] and interpolated expression that covers both limits proposed in Ref [5] was incorporated in M3D-C1.

CONCLUSION

- Response time: EPI trigger to core payload deposition would be <10 ms in ITER [7]
- Payload size, composition, and velocity are well defined in EPI permitting reliable modeling
- Core deposition would permit inside-out TQ & Runaway Electron suppression (Konaev, AIAA-FEC 2012, ITR/P1-3B)
- Materials used in EPI are fully compatible with ITER requirements
- M3D-C1 simulations show even 300 m/s carbon pellets do not fully ablate in 2 keV central \( T_e \), plasmas, giving confidence that encasing the payload inside a shell (which could be tungsten for ITER purposes) may be a viable way to transport the radiative payload to the core before initiating a thermal quench that first starts outside the q=2 surface

TOKAMAK TEST AND PARALLEL MHD MODELING EFFORTS ARE NEEDED NEXT STEPS FOR CONCEPT VALIDATION

ACKNOWLEDGEMENTS / REFERENCES

[1] LEHNNEN, M., ITER Disruption Mitigation Workshop Report, ITER HQ, 8-10 March 2017

This work is supported by U.S. DOE contracts: DE-AC02-09CH11466, DE-FG02-99ER54519, AMHR, and DESC00086757REFERENCES