Demonstration of the ITER Power Exhaust Solution Using the "Puff and Pump" Technique on DIII-D*

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In future, high power density fusion devices, the need to prevent local deposition of the plasma energy efflux on the first-wall surfaces is a critical design consideration in order to maintain the integrity of such surfaces. This requirement must be met without significant impact on plasma purity or overall plasma confinement. For the International Thermonuclear Experimental Reactor (ITER), these constraints have led to the following design criteria [1]: $P_{rad}/(P_{input}+ P_{\alpha}) = 83\%$, $P_{rad,core}/(P_{input}+ P_{\alpha}) = 33\ \%$, $P_{target}/P_{loss} = 17\%$, $Z_{eff} < 1.8$, and $\tau_E/\tau_{E,ITER93H} > 0.85$. Here, P_{loss} is the power flowing out of the core (i.e., $P_{input} + P_{\alpha} - P_{rad,core}$) and P_{target} is the power conducted to the target plate. These criteria represent a compromise between maintaining sufficient power flow through the edge plasma to maintain H–mode confinement and obtaining sufficient radiation. Past experiments have had difficulty achieving these conditions simultaneously when using seeded impurities, and therefore there has been some concern regarding the viability of the ITER design. However, recent experiments in DIII–D using the "puff and pump" technique with argon as the seeded impurity have demonstrated the compatibility of these design constraints. In particular, steady-state plasma conditions have been achieved with $P_{rad}/P_{input} = 72\%$, $P_{target}/P_{loss} = 17\%$, $P_{rad,core}/P_{input} = 16\%$, $Z_{eff} = 1.85$, and $\tau_E/\tau_{E,ITER93H} = 1.05$.

The plasma solution produced as part of these stuides has many interesting features. In terms of power exhaust, significant radiation is obtained from both the core and divertor plasmas with $P_{rad,div}$: $P_{rad,SOL}$: $P_{rad,core}$ (MW) = 4.3:2.4:1.8 at $P_{input} = 11.9$ MW. Argon line radiation provides the preponderance of the core radiation with the total radiation found to be consistent with argon concentrations (~ 0.20%) inferred from CER measurements. This level of argon concentration (along with ~1% carbon concentration) leads to $Z_{eff} = 1.85$, which is significantly below the Z_{eff} (~2.25) predicted by the multi-machine scaling law developed by Matthews *et al*. [2]. Carbon line radiation provides the bulk of radiation from the divertor region with a small fraction (~20%) coming from argon. Energy confinement is not grossly affected by the increased radiation with $\tau_E/\tau_{E,ITER93H}$ ~1.0 achieved at both high density (n_e/n_{GW} ~1) and high radiated power fractions (P_{rad}/P_{input} ~1). Interestingly, the ELM energy loss during the "puff and pump" phase of these discharges is ~ a factor of 4 lower than typically observed in similar plasma conditions. As a result of the high level of radiation, the peak heat flux on the divertor target is reduced by a factor of 4 from that expected in non-radiative conditions at similar input power levels and exhibits signs of detachment with the peak in the heat flux ~ 5 cm away from the separatrix. However, there is still appreciable particle flux in the strike point region. Also, there is no evidence of volumetric recombination suggesting that significant heat flux reduction can be achieved without recombination playing an important role in the power exhaust.

[1] G. Janeschitz *et al., Proc. 16th IAEA Fusion Energy Conference, Montreal, Canada, 1996* (IAEA), Vol. 2, pp. 755.
[2] G. Matthews *et al.,* J. Nucl. Mat. **196–198**, 450 (1997).

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