High performance Ne-seeded baseline scenario in JET-ILW in support of ITER

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The first goal of the ITER device is to produce “burning” deuterium-tritium (DT) plasmas with ~500 MW of fusion power for durations of 300-500s. A large fraction (typically 60-70%) of the thermal plasma exhaust power (~100 MW) crossing the magnetic separatrix under these conditions needs to be radiated via impurity-seeding to remain within the power handling capability of the metallic (tungsten, W) divertor targets. The required energy confinement (τ_E) on ITER necessitates an H-mode, with high pedestal pressure and temperature, usually associated with high transient heat loads (ELMs) on plasma-facing components. These loads need to be mitigated or eliminated since otherwise W target erosion will be both inconsistent with the ITER divertor lifetime and will lead to excessive W core plasma contamination.

Previous, well documented impurity seeding experiments in JET with the ITER-Like Wall have clearly shown that for input powers up to P_{IN} ~ 21 MW, peak outer target (OT) heat loads could not be significantly decreased without substantial pedestal degradation and periodic loss of H-mode. Only with nitrogen (N) seeding was it possible to secure the dual requirement of OT partial detachment with high pedestal pressure. New experiments, reported here, with record values of P_{IN} ~35 MW, have shown for the first time that Ne-seeding can be compatible with high performance H-mode.

Although it has not yet been possible to achieve OT partial detachment with Ne at this higher P_{IN}, the pedestal pressure improvement with respect to unseeded plasmas found previously with N has now been obtained with Ne, as well as a factor 2 decrease in effective heat diffusivity χ_{eff} in the core. An additional and key finding of these new Ne-seeding experiments is that, at the highest achieved radiative fraction ($f_{rad} = P_{rad,tot}/P_{in} = 0.8$), high performance stationary conditions with small ELMs or even with no ELMs were obtained, delivering a very attractive scenario. These discharges have H_{98}~0.9, β_N~2.3, Greenwald fraction $<n>/n_{GW}$~0.68, Z_{eff}~2.7 and a neutron rate $R_{nt}=1.6\text{x}10^{16}$ n.s^{-1}, parameters not achieved with N under the same conditions. Integrated modelling carried out with QuaLiKiz within the JETTO/JINTRAC suite of codes identifies that the increased central T_i, T_e and R_{nt} with Ne-seeding are due equally to reduced core transport (via stabilization of ITG and ETG instabilities) as well as an increased pedestal T_i and T_e. The simulations also find that the higher value of pedestal electron density, $n_{e,ped}$ and lower T_i/T_e ratio of N versus Ne-seeded plasmas are the key reason for the lower R_{nt} with N. These new results are extremely encouraging for ITER, indicating that the preferred baseline Ne-seeded Q_{DT} = 10 scenario is practical and that the complications associated with the use of N (ammonia formation and the resulting impact on plant duty cycle) can be avoided.

An important as yet unresolved issue with these higher P_{IN} discharges, is the apparent lack of clear OT partial detachment with Ne. Plasma boundary simulations using the SOLPS-ITER code suite (the workhorse for the ITER divertor design), with all drifts and currents included, find little difference between Ne and N, with both impurities leading to partial and even full detachment. Experimentally, this is only clearly found with N-seeding whilst simultaneously maintaining high confinement. The reasons for this discrepancy are being investigated and will be reported in this paper.

As part of the current JET DTE2 campaign, Ne-seeded pulses are being run for the first time with DT fuel. Predictions with QuaLiKiz expect a fusion power mostly dependent on $n_{e,ped}$ and ranging from 4 MW to 9 MW if $n_{e,ped}$ is varied from 6.6 - 4x10^{19} m^{-3}. In preparation for DT, pulses have been run in pure T, finding an increased W source in comparison with D (due to the higher sputtering yield of T vs. D) causing low ELM frequency, or ELM-free conditions prior to the Ne-seeding phase and requiring a significant increase in the gas rate in T to achieve stationary conditions. Fortunately, in DT, stationary conditions have been easily obtained for unseeded plasmas even with an increased W source with respect to D. The higher performance Ne-seeded counterparts have now been performed for the first time in DT and will be discussed.