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[OV POSTER TWIN] Overview of JET results for optimising ITER operation

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The 2019-2020 scientific and technological programme exploits JET's currently unique capabilities: Tritium handling and ITER-like wall (ILW: Be wall and W divertor). It is the culmination of years of concerted scientific and engineering work, with the ILW installation in 2010, improved diagnostic capabilities, now fully available, a major Neutral Beam Injection (NBI) upgrade providing record power in 2019 (P_{NBI} up to 32MW), and the technical & procedural preparation for safe operation with tritium. Research along three complementary axes yielded a wealth of new results since last IAEA. Firstly, the JET plasma programme delivered scenarios suitable for high fusion power (P_{FUS}) and alpha particle (α) physics in the coming D-T campaign (DTE2), with record sustained neutron rates, as well as plasmas for clarifying the impact of isotope mass on plasma core, edge and plasma-wall interactions, and for ITER pre-fusion power operation (e.g. L-H transition in He plasmas). The efficacy of the newly installed Shattered Pellet Injector (SPI) [ref1] for mitigating disruption forces and runaway electrons was demonstrated, informing ITER disruption management. Secondly, research on the consequences of long-term exposure to plasma in the ILW was completed, with emphasis on wall damage and fuel retention, and including analyses of wall materials and dust particles. This will help validate assumptions and codes for the design & operation of ITER and DEMO. Thirdly, the nuclear technology programme aiming to deliver the maximum technological return from operations with D, T and D-T [ref3] benefited from the high D-D neutron yield in 2019 ($2.26\text{x}10^{19}$n), securing new results for validating radiation transport and activation simulation codes, and nuclear data for ITER. Measuring systems are ready for collecting data in T and in D-T campaigns producing 14MeV neutrons.

Integrated scenarios preparation for high P_{FUS} sustained for 5s (i.e. relevant to energy confinement times in JET) progressed significantly for the two routes investigated: 'Baseline'(q_{95}~3, I_P≥3MA, β_N<2) and 'Hybrid'(tailored q-profile, q_{95}~4.5, I_P ≤2.7MA, β_N≥2.4). Peak neutron rate of $4.2\text{x}10^{16}$n/s ($2.7\text{x}10^{16}$n/s averaged over 5s) are obtained simultaneously with tolerable divertor temperatures and controlled high/medium Z impurity for the full pulse duration in Baseline plasmas at 3.3T/3.5MA, with P_{TOT}=34MW (NBI and Ion Cyclotron Resonance Heating (ICRH)). Pellets help controlling the ELM frequency (f_{ELM}) needed for impurity flushing, with low total D_2 throughput for high confinement. Hybrid plasmas developed to 3.4T/2.3MA reached $4.8\text{x}10^{16}$n/s but MHD avoidance and f_{ELM} control must be optimised for improved, steady performance. The equivalent P_{D-T} for these pulses is consistent with past predictions at same B_T, I_P, P_{TOT} [ref4], giving confidence in the theory-based modelling. Further gains are likely with 40MW now reachable and higher I_P, with divertor heat loads controlled by strike-point sweeping, thus prospects for reaching the target ($5\text{x}10^{16}$n/s) are good. In these conditions P_{D-T}=11-16MW is predicted by theory-based physics models, with range due to uncertainties in the pedestal predictions and to whether isotope effects are included or not. Fast particle diagnostics, significantly improved since DTE1, can now detect small amount of α's, as shown in dedicated experiments making use of 3-ion ICRH scheme (D-(D_{NBI})-3He) to create MeV range particles, with α (≈$10^{16}s^{-1}$) from D+^{3}He reactions. Simultaneous detection of He and hydrogen isotopes with an enhanced high resolution sub-divertor residual gas analyser, as planned for ITER, has been demonstrated.

Experiments and modelling preparing the T campaign. Observations that the impact of isotope on H-mode plasmas comes mainly from the pedestal [ref5] motivated recent gyrokinetic (GK) theoretical investigations of JET pedestals showing that the toroidal branch of the ETG instability can be driven at ion-scale poloidal wavelengths and may be responsible for significant inter-ELM pedestal heat transport. However, in some regimes, isotope effects on core plasma may also be important [ref4]. New experiments in D_2 and H_2 L-mode plasmas and related core GK modelling show that, in plasmas with a strong stabilizing effect of fast particles, differences in fast particle content with isotope mass may lead to strong deviations from the gyro-Bohm scaling of core transport. Recently developed ICRH-only H-mode plasmas (low input torque, dominant e-heating) show the same normalised confinement factor ($H_{98(y,2)}$) and T_e profiles as their NBI-only counterpart at same PTOT, but n_e profile for the NBI case is 50% higher due to NBI fuelling and possibly different particle transport. Work to clarify the impact of edge/divertor was performed. Experiments at 2MA/2.3T, low triangularity (δ) demonstrated that changes in $H_{98(y,2)}$ and pedestal T_e due to divertor configuration can be condensed into a single trend when mapped to the target T_e as the main parameter governing recycling conditions rather than D_2 fuelling rate. A high performance neon seeded scenario (2.7T/2.5MA, high-δ shape) with edge conditions closer to ITER was developed. Neon seeding leads to significant increase (by ≈50%) in pedestal pressure and T_e (from 0.4keV to 0.8keV) and in $H_{98(y,2)}$ (from 0.6 to 0.9) with mitigated divertor power loads. The well diagnosed discharges are used for validating physics-based SOL-edge modelling, increasing confidence in ITER divertor design basis and supporting deployment of neon over chemically reactive N_2 as seed gas in ITER.

JET disruption management programme is in two parts: 1) disruption avoidance based on improved termination techniques and on real-time detection of unhealthy plasmas with jump to controlled termination, causing significant reduction in disruption rate in baseline (60% to 20%) and hybrid plasmas (9%), and 2) disruption mitigation with SPI performed as part of a collaboration between ITER, US and Europe. After successful installation and commissioning, extensive experiments took place with the JET SPI demonstrating very good reliability. By varying the neon content in the SPI pellets, the disruption current quench time can be controlled efficiently in JET, scaling to the range required by ITER. High Z impurity SPI also demonstrated run-away electron suppression. Additionally, it was discovered that D_2 SPI applied to a high current run-away beam leads to benign impacts on the wall, suggesting a new potential solution for run-away electron control in ITER.

Plasma-facing components (PFC) long term exposure in ILW. Retrieval of PFC, wall probes (including test mirrors) and dust for ex-situ studies after three ILW campaigns provide deep insight into material erosion and deposition. Low mobilization of dust during in-vessel operations is shown. Emphasis was placed on material damage such as melting of the Be upper dump plates (UPD) and the identification of factors triggering this process. Comprehensive studies including imaging survey, morphology changes, mass loss and fuel inventory analysis on the most affected UDP tiles was performed. The undisputed reason for melting was unmitigated disruption events which tend to move the melt layers in the poloidal direction resulting in formation of upwards going waterfall-like structures of molten metal. The halo current is believed to provide the j x B force driving the melt layer motion. Global material migration results constitute a unique dataset for modelling and thus improved predictions for ITER.

[ref1] L. R. Baylor, et al., Nucl. Fusion 68 (2019) 211, [ref2] I. Jepu et al., Nucl. Fusion 59 (2019) 086009, [ref3] P. Batistoni et al, Fusion Engineering and Design Vol 109-11, 2016, [ref4] J. Garcia et al. Nucl. Fusion 59 (2019) 086047 [ref5] C. F. Maggi et al., Plasma Phys Control Fusion 60 (2018) 014045

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