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[REGULAR POSTER TWIN] Scenario preparation for the observation of alpha-driven instabilities and transport of alpha particles in JET DT plasmas

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Good confinement of the fusion-born alpha particles is essential to ensure adequate burning plasma performance in next-step fusion devices. Among the processes determining this confinement, instabilities triggered by energetic particles (EPs) may play a major role, and are currently being studied in various tokamaks using auxiliary power sources to sustain EP populations. Instabilities resulting from fusion-born alphas, on the other hand, can only be observed in deuterium-tritium (D-T) plasmas. Since DTE1, the D-T campaign conducted in the Joint European Torus (JET) in 1997, the device has undergone significant changes, among which the installation of a Be/W ITER-like wall (ILW) and the development of new diagnostics directly relevant to the physics of energetic ions, in particular alphas. The preparation of a new D-T campaign (DTE2) in JET [Joffrin2019] thus includes various developments relevant to burning plasmas [Sharapov2008]. As JET is currently the only tokamak in which D-T plasmas can be produced, DTE2 constitutes the only opportunity to experimentally document the physics of alphas, and validate the numerical tools used to simulate their effects before ITER comes into operation.

Among the instabilities related to the presence of EPs, alpha-driven Toroidal Alfvén Eigenmodes (TAEs) have received some attention in the past. The rationale is that the features of the alpha population differ significantly from those of energetic ions created by external sources. As a result, the instability itself differs and its impact on the plasma performance remains to be evaluated. Because of the relatively low values of normalized alpha pressure (β_α) attained in the only two magnetic confinement fusion devices capable of D-T operation to this day, TFTR [Nazikian1997] and JET [Sharapov1999], core-localized alpha-driven TAEs have been difficult to observe unambiguously. From these experiments and from results obtained during the present effort in JET [Dumont2018], it has been established that their observation requires i) a sufficient alpha pressure, ii) an elevated safety factor (q), iii) an "afterglow phase"consisting of abruptly switching off all external EP sources and rely on the longer slowing-down of alphas compared to other ions present in the pulse to isolate their impact, including the destabilization of TAEs. The afterglow has been key to the success of the experiments performed in TFTR [Nazikian1997]. In terms of scenario, these conditions translate into i) low density to favour large electron and ion temperatures, ii) large NBI power to maximise the fusion yield, iii) no ICRH power before the afterglow phase to exclude any contribution from ICRH-driven ions to the TAE drive, iv) an elevated q-profile. In preparation for DTE2, advanced scenarios fulfilling these requirements have been under development in deuterium plasmas during the last experimental campaigns. In pulses at 3.4T/2.5MA, NBI waveforms have been fine-tuned to inject the power early in the pulse and thus obtain elevated q-profiles, while fulfilling the requirements of the ILW in terms of beam shine-through. Operating at line-integrated densities in the range $5-9\times10^{19}\mathrm{m}^{-2}$ has allowed clear Internal Transport Barriers (ITBs) to be observed in JET-ILW.

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The resulting ion temperatures in the range $10-15$keV at peak performance yield large neutron rates from D-D reactions in NBI+ICRH discharges ($2.8\times10^{16}\mathrm{s}^{-1}$) and in NBI-only discharges ($2.5\times10^{16}\mathrm{s}^{-1}$). On the other hand, in some instances, phases during which ELM-free/type-I ELM alternate set in before the period of interest, and result in impurity influxes deleterious to the performance and possibly inducing early pulse terminations. A large effort has thus been devoted to ELM and impurity control without resorting to ICRH power. Pellet pacing has been found to be the most efficient method for these plasmas, and has allowed pulses with no ELM-free/type-I ELM periods to be obtained. Despite the use of these methods, predicting the time of peak performance remains difficult because it results from a trade-off between ITB build-up and impurity accumulation. A real-time control algorithm has therefore been developed and successfully tested to start the afterglow at the best possible time during the pulse, i.e. when the neutron rate reaches its peak value. Finally, discharges entirely fuelled by the Tritium Injection Modules (TIMs) relevant to the upcoming TT and D-T campaigns have been successfully demonstrated.

In order to produce EP populations and probe the TAE stability in these D plasmas, ICRH power has been employed. Hydrogen (H) minority heating at 51MHz results in the destabilization of core-localized TAEs with properties approaching those expected for alpha-driven TAEs in DTE2.

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Modelling the stability in these discharges allows predictive simulations for DTE2 to be refined. Helium 3 (^{3}He) minority heating at 33MHz has also been tested. Although it requires more fine-tuning compared to H minority heating, the advantage of this scheme is that it results in the creation of energetic ^{3}He populations which are particularly well diagnosed by the EP and neutron diagnostics installed in JET. As a result, this type of pulse provides essential information regarding EP transport in the presence of elevated q-profiles, a topic fully relevant to the preparation of robust and performant advanced scenarios for ITER [Sips2005].Overall, the extrapolation of the best-performing NBI-only pulses obtained so far to D-T predicts that $\beta_\alpha(0) > 0.1\%$ should be attained, which is compatible with the observation of core-localized alpha-driven instabilities and measurement of resulting induced EP transport, thus encouraging the completion of the present developments in view of DTE2.

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