JET hybrid ramp-up integrated modelling accelerated by QuaLiKiz neural network and predictive analysis for JET tritium discharges

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Recent developments of neural network (NN) surrogates of the reduced gyrokinetic turbulent transport model, QuaLiKiz [1, 2], have accelerated the evaluation speed from $\sim$10 s per radial point to $\sim$1 ms. The resulting model, named QLKNN, achieves this increased computational speed while retaining sufficient accuracy for meaningful integrated modelling simulations [3, 4]. This combination enables a rapid iteration of the integrated transport solvers, such as JINTRAC [5], both for post-discharge analysis and sensitivity studies.

This work applies the coupled JINTRAC + QLKNN model to develop a dynamic simulation of a recent JET deuterium hybrid scenario ramp-up discharge, representing conditions not explicitly included in the NN training dataset. This phase of the discharge exhibited a characteristic hollow T_e profile, a phenomenon observed to be amplified by increasing the isotope mass and suspected to result from increased core impurity accumulation [6]. Experimentally, the feedback of this lower core temperature on the current diffusivity can lead to reverse shearing in the central core plasma, potentially causing disruptions via MHD instabilities [7]. The dynamic simulation evolves n_e, T_e, and T_i over 7 s starting from the time of X-point formation, including a self-consistent fixed boundary equilibrium calculation and 3 predictive impurity species (Be, Ni, W). The impurity boundary conditions were set to match measured 0D Z_{eff} and P_{rad} signals. These results reveal the relative impact of impurity transport mechanisms on the temperature hollowing, including a study on local Z_{eff} and Q_{rad} contributions. In addition, the simulated arrival of the $q = 1$ surface at the sawtooth inversion radius is also within 500 ms of the experimentally observed onset of the sawtooth crashes.

Once the deuterium reference settings were validated, further investigations were performed on the isotope effect on the ramp-up scenario and the impact of n_e and n_{imp} boundary condition modifications. This exercise was aimed to assist the JET experimental teams in preparing for the tritium campaigns. The simulation results both affirm the trends identified from previous hydrogen experiments and provide reasonable engineering targets to recreate the desired q-profile in tritium experiments. Although the inclusion of plasma edge physics are still required for a fully predictive simulation, this work demonstrates the potential of using NN surrogates for fast routine discharge analysis and experimental design.

References

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