Integrated modelling of the main Divertor Tokamak Test facility scenarios

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Introduction

The Divertor Tokamak Test facility (DTT) [1, 2] is a new D-shaped superconducting tokamak under construction in Italy, with the first plasma planned for 2026. It will be equipped with 3 auxiliary heating systems: a 170 GHz ECRH system, a $60-90$ MHz ICRH system, and a negative ion NBI system. The primary task of DTT ($R_0 = 2.19$m, a =0.70m, pulse length $\leq$ 100s, $B_T \leq$ 6T, $I_{\rm pl} \leq$ 5.5MA, $P_{\rm sep}/R \simeq$15) is to study the controlled power and particle exhaust from a fusion reactor, which is a main research topic in the European Fusion Roadmap [3], and test alternative exhaust strategies.

An intensive integrated modelling work of DTT operational scenarios with the Single Null (SN) divertor configuration (Fig.1) is underway, in order to support the machine design, and particularly the definition of the heating mix, the design of the neutron shields, the assessment of fast particle losses and the design of diagnostic systems, as well as to help the elaboration of a DTT scientific work-programme.

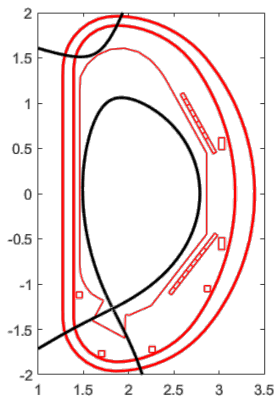

Figure 1: *Plasma shape of the SN DTT scenario.*

Integrated modelling set-up

Simulations of the main operational scenarios in H-mode were performed using first-principle based transport models and state-of-art modules for heating, fuelling and magnetic equilibrium, and are described in detail in [4]. So far, the Full Power (FP), Day-1, and Day-0 scenarios have been simulated, using the JINTRAC[5] suite of codes or the ASTRA[6] transport solver with a mixed ASTRA−JINTRAC approach. These simulations predict steady-state radial profiles of electron and ion temperature, density, current density, rotation, power depositions, and impurities (Ar and W) in $\rho_{tor} \leq 0.94$.

The pedestal was calculated by EPED1[7]. The turbulent heat and particle transport is calculated by the Trapped-Gyro-Landau-Fluid (TGLF)[8] or QuaLiKiz (QLK)[9] quasi-linear transport models. Particularly, TGLF SAT1-geo (released in Nov.2019) and TGLF SAT2 (released in Jan.2021)[10] have been compared to the new QLK release 2.8.1[11] and an "ad hoc" QLK version (specifically developed for DTT to match gyrokinetic predictions in TEM dominant conditions). The results of the modelling performed with the previous device design with R_0 =2.14m and a =0.65m will be presented and discussed.

Full Power scenario

The optimisation of the power distribution in the FP scenario amongst the auxiliary heating systems and of the NBI energy was one of the purposes of this modelling work. By the comparison of several alternatives, the reference heating mix of the FP scenario has been selected: ∼28.8MW of ECRH coupled power, ∼6MW of ICRH coupled power, and ∼10MW of NBI coupled power with a single beam at 510 keV. In the top of Fig. 2 the radial profiles of T_e, T_i, n_e, ω_{tor}, and q obtained for this reference FP scenario using various transport models are compared. We note that, according to all models, DTT operates in a regime with $T_e/T_i > 1$. The 4 models agree reasonably outside $\rho_{tor} = 0.4$, whilst QLK features much flatter density inside ρ_{tor}=0.4, where ECH power density is very high. By a comparison of QLK and TGLF stand-alone runs with gyrokinetic simulations done with GENE, in the inner region the flat QLK n_e peaking is not validated and the TGLF n_e peaking appears a bit overestimated, but qualitatively nearer to GENE predictions.

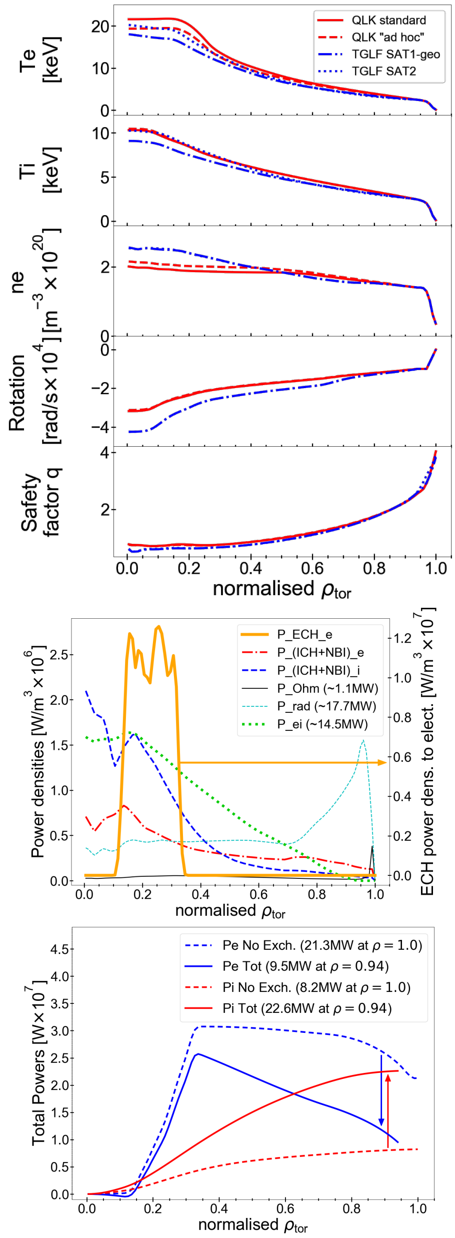

Figure 2: *FP reference scenario profiles.*

To have a reference $q_{95} > 3$, the device has been enlarged to R_0 =2.19m and a =0.70m. The updating to the

new DTT size of the modelling work is underway. Globally, the Ohmic power $P_{\rm Ohm} \approx$1.1MW is quite negligible, the core radiated power $P_{\rm rad} \approx$15$-$18MW is about the 35% of the total power, and a large amount of power ($P_{\rm rad} \approx$14$-$15MW) is exchanged from electrons to ions because of the collisional coupling. Some impurity penetrations into the core is observed with both models. In the FP reference scenario, the energy fraction owned by the energetic particles due to both NBI and ICRH systems amounts to $W_{\rm EP}/W_{\rm tot} \approx 6.5 - 7.7\%$.
The neutron rate resulted $\leq$1.5x10^{17}/s, i.e. compatible with the present design of neutron shields.

Fuelling issues

To investigate the edge neutral level required to operate in the FP scenario without pellets, the standard QLK run has been extended up to the separatrix, including an edge transport barrier tuned to reproduce the previous pedestal. Since the neutral density rate, shown in Fig.3, is significant up to $\rho_{\rm tor} \sim$0.8, the neutral penetration into the plasma evaluated by FRANTIC[12] is adequate for fuelling. The NBI contribution to the neutral source is small. To reach the required density value at the top of barrier, we need at the separatrix a neutral flux level of $\sim$ 0.36x10^{22} particles/s, which corresponds to a D fuelling of $\sim$5x10^{22}/s. Being near to the feasibility limit, a pellet injection system is deemed useful as a fuelling method in DTT to avoid degrading the edge plasma with extremely high gas puff rates and to minimise the operational risk.

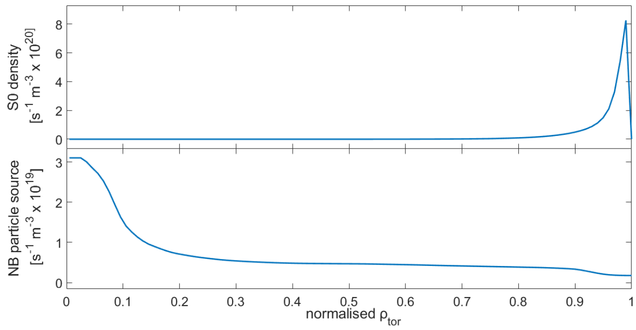

Figure 3: *Profiles of neutral sources in the FP case.*

Day-1 scenario

In the Day-1 scenario (with $B_{\rm tor}$ =6T and $I_{\rm pl}$ =4.0MA), about 25MW of external power is coupled with the plasma: 14.4MW from ECRH in first harmonic O-mode, 3MW from ICRH, and 7.5MW at plasma from NNBI with 1 beam at 400keV. According to both TGLF and QLK, T_i values are similar in Day-1 and FP scenarios, due to the high ion stiffness, while the n_e peaking is less pronounced in Day-1 than in the FP case. Some discrepancies in the T_e and T_i profiles appear between the

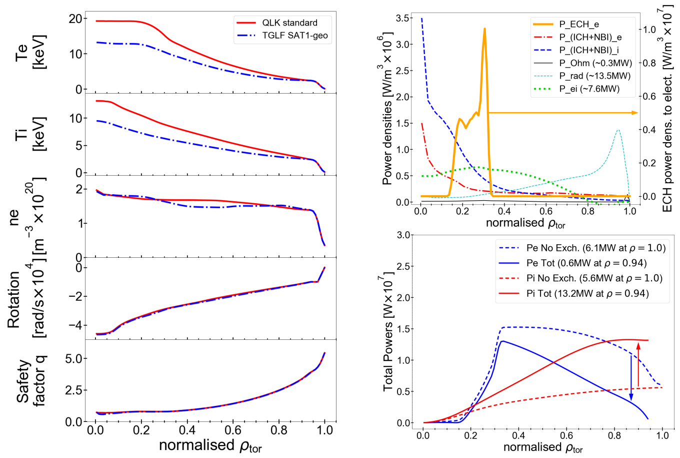

Figure 4: *Radial profiles for the Day-1 phase.*

two models. We notice that T_e is significantly reduced in the Day-1 TGLF run with respect to the FP profile.

Day-0 scenario

The day-0 phase (with B_{tor} =3T and I_{pl} =2.0MA), i.e. the first experimental plasma, features only 8 MW of ECH power in second harmonic X-mode to maximise the absorption. Since the day-0 scenario is a purely electron heated case, this is the scenario where QLK validity is most affected by the dominant TEM regime. Therefore, modelling results displayed in Fig.5 refer only to the TGLF SAT1-geo simulation.

Due to having only electron heating and low density, T_e is much larger than T_i ($T_{e_0} \approx 12$ keV and $T_{i_0} \approx 4$ keV).

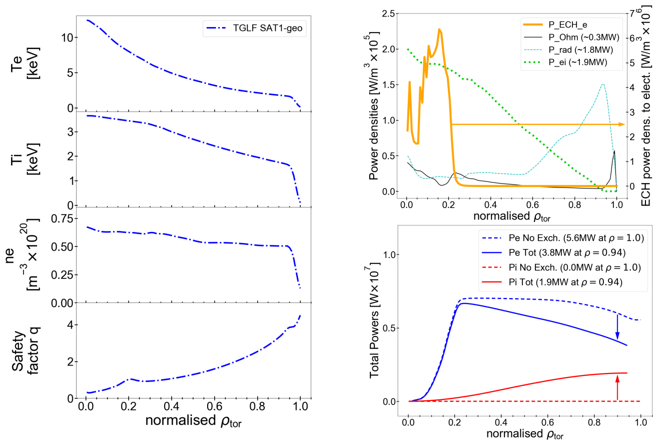

Figure 5: *Radial profiles for the Day-0 phase.*

Conclusions

Integrated steady-state simulations of the main DTT scenarios are now available. The machine size has been increased, the heating mix has been defined, neutron shields have been confirmed, and a pellet injection system is deemed useful as a fuelling method in DTT.

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