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First-principle based multi-channel integrated modelling in support to the design of the Divertor Tokamak Test Facility

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The Divertor Tokamak Test facility (DTT) [1-3] is a D-shaped superconducting tokamak (R=2.14 m, a=0.65 m, BT≤6 T, Ip≤ 5.5 MA, pulse length ≤ 100 s, auxiliary heating ≤ 45 MW, W first wall and divertor), whose construction is starting in Frascati, Italy. Its main mission is to study the controlled exhaust of energy and particle from a fusion reactor, which is a top priority research item in the European Roadmap [4] towards thermonuclear fusion power production. This will be possible in DTT by achieving large PSEP/R values (where PSEP is the power flowing through the last closed magnetic surface) using 45 MW of auxiliary heating in a high performance machine characterised by high flexibility in the choice of the divertor and of the magnetic configurations. The characteristics of the machine will allow to address many ITER and DEMO relevant physics issues besides plasma wall interaction in a fusion relevant range of plasma parameters. The heating mix foresees the use of 170 GHz ECRH, 60-90 MHz ICRH and 400 keV negative ion beam injectors, with ECRH being the main system, although the precise sharing between the three systems has still to be optimised.

In order to help with the heating system definition, and to provide scenarios for the design of diagnostics and pellet injector, or for the evaluation of issues such as ripple losses or neutron shields, it is a key priority to achieve multi-channel integrated modelling of DTT scenarios based on state-of-art first principle quasi-linear transport models, whose reliability stems from an extensive validation work against experiments and high fidelity gyrokinetic simulations carried out within the EUROfusion and ITPA frameworks (see e.g. the recent overview [5] and references therein). It is also important that the integrated modelling results for some cases are validated against gyrokinetic simulations with the specific DTT parameters, to corroborate the validity of the reduced models in the particular case of DTT. In this paper, we summarise the first results of this activity, which extends the preliminary predictions reported in 1.

The integrated modelling of DTT has been carried out with the JINTRAC suite [6] and covers the region inside the separatrix, whilst the values of temperature and density at the separatrix are taken consistently with the scrape-off layer simulations described in 1. The pedestal has been determined with the EPED1 model [7] implemented in the Europed code [8], and core-edge coupling has been taken into account on an iterative basis. The pedestal density has been set to achieve a volume averaged density <ne>˜ 0.43 nGW (Greenwald limit). The region in-side the top of the pedestal has been modelled using the QuaLiKiz [9] or the TGLF [10] turbulent transport models and NCLASS [11] for the neoclassical transport. The simulations pre-dict steady-state profiles of ion and electron temperature, density, rotation, current density, impurity (Ar, W) density, and calculate a self-consistent equilibrium starting from a fixed boundary taken from [12]. The heating has been modelled self-consistently using PENCIL[13] for NBI, PION[14] for ICRH and GRAY[15] for ECRH. SANCO [16] has been used to calculate impurity ionisation and recombination and radiation. The rotation has been predicted using a semi-empirical estimate of Prandtl and pinch numbers [17] due to numerical issues using the turbulent momentum transport from the quasi-linear models.

Fig.1 shows profiles obtained for the SN full power H-mode scenario with 32 MW ECRH, 15 MW NBI and 3 MW ICRH using QuaLiKiz for turbulent transport, which is mainly driven by ion-scale ITG/TEM. The strong central ECRH peaks Te far above Ti in the central part. Ions are rather stiff and Ti stays below Te also in most of the outer region, in spite of a large amount of thermal exchange power from electrons to ions. The ne profile is moderately peaked. A peaked rotation profile with central value of 50 krad/s does not provide a significant ExB stabilisation of the ion heat transport. Global plasma parameters are βN=1.6, τE=0.28s, total DD neutron rate˜1.4 1017 s-1 (30% thermal). Total radiation is 15 MW. Both Ar and W show peaked profiles, with hints of W central accumulation, however a better treatment of W neoclassical transport using NEO [18] is in plan to check this prediction. In this simulation MHD has not been included, but some considerations on MHD stability will be discussed. Similar simulations for the half-power DAY1 heating configuration yield very similar profiles and double confinement time, which is also an indication of the high stiffness. Simulations with TGLF are being finalised with the latest release of the model [19], and differences between the predictions by the two models will be assessed against gyrokinetic simulations using GENE [20].

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