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Integrated simulations of CFETR steady-state scenario with METIS code

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A quasi steady state scenario of CFETR with 1GW fusion power has been recently designed by using the METIS code[1], a fast integrated tokamak modelling tool for scenario design. The target of 1GW fusion power has been reached with auxiliary heating of 50MW NBI and 30MW ECRF at 90% of the Greenwald density limit. A desired reversed shear q-profile has been obtained by careful tailoring of the current density profile by the external heating and current drives during the current ramp-up phase. The bootstrap current fraction is more than 60% and the non-inductive current fraction is more than 90%. This well-designed METIS result is then used as the input set for more precise 1.5D simulation by the full CRONOS suite code and the calculation is in progress.

As the original part of CRONOS, METIS is fully integrated in the CRONOS suite of codes, but it can be used on a stand-alone basis. The METIS code has been developed to simulate tokamak plasma evolution using an almost always convergent computing scheme that allows to simulate a full plasma discharge in a time of the order of one minute. It combines 0D scaling-law normalised heat and particle transport with 1D current diffusion modelling and 2D equilibrium. It contains several heat, particle and impurities transport models, as well as heat, particle, current and momentum sources, which allow faster than real time scenario simulations. The fusion products and effects are described with a particular care and various non-linear couplings between physical quantities are taken into account.

METIS includes a complete current diffusion solver (as in CRONOS but on a 21 points radial grid only). The MHD equilibrium is computed using a fast solver based on moments of the Grad-Shafranov equation. The bootstrap current and resistivity are computed using the Sauter formulation. The shapes of the current sources are based on simplified analytical formulations and efficiencies are given either by a scaling law (Fast Wave Current Drive), an analytical prescription (Lower Hybrid), analytical Fokker-Planck 0D integration (Neutral Beam Injection Current Drive), or simplified adjoint method solution (Electron Cyclotron Current Drive). The density profile is described by means of a peaking factor that is given by a scaling law or prescribed. The line-averaged density is prescribed and the edge density is given by a scaling law. The energy content of the plasma is given by a scaling law that depends on the scenario. The 0D solver takes into account the time evolution (equations are solved using an ODE solver). The temperature profiles are computed using time-independent transport equations. Transport coefficients have a simple analytical shape (1+a*x^2) and are normalized to retrieve the correct energy content. The ratio between ion heat diffusion coefficient and electron heat diffusion coefficient is prescribed. Shapes of the sources are computed with the help of analytical formulation. The NBI and ICRH (Ion Cyclotron Resonance Heating) deposition repartition on ions and electrons are computed using an analytical Fokker-Planck 0D solution. The D-T fusion power is computed using realistic cross-sections. The plasma composition is deduced from prescribed line average effective charge (Z_{eff}) and prescribed minority ion fraction. The accumulation of He ashes is taken into account separately. The line radiation is computed on the basis of coronal equilibrium (Post's formulation), the bremsstrahlung is corrected for relativistic effects and the cyclotron radiation is computed following the Albajar scaling.

References

[1] J.F. Artaud, F. Imbeaux, J. Garcia, et al. Nucl. Fusion 58 (2018) 105001

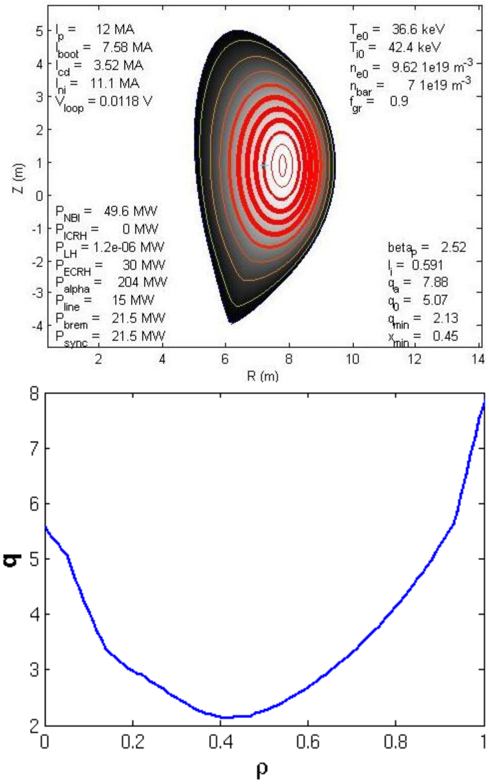

Figure 1 The equilibrium and q-profile of a quasi steady state scenario of CFETR calculated by METIS.