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Self-consistent predictive core-pedestal ITER scenario modeling*

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Studies are carried out examining the dependence and sensitivity of fusion power production, temperature and density pedestals on edge density fueling strength, current density profile, alpha heating, and magnetic field strength. The goal of these integrated ITER simulations is to identify dependencies that can impact ITER fusion performance.

The self-consistent predictive core-pedestal ITER scenario modeling is carried out. The Weiland anomalous transport model {1} is combined with the NCLASS module in order to compute the evolution of electron and ion temperature, density, toroidal and poloidal rotation, and flow shear profiles from separatrix to the magnetic axis. The nonlinear anomalous transport multifluid model includes ion temperature gradient, trapped electron, kinetic ballooning, peeling, collisionless, and collision dominated MHD modes. The model has been derived from kinetic theory using a small parameter $\epsilon \sim 10^{-2}$. The model can simulate internal and external transport barriers, the L-H transition, the nonlinear Dimits upshift, particle and heat pinches, and poloidal spin up. The other remarkable consequence of model is that it reproduces the experimental power scaling of the energy confinement time, $_E \sim P^{-2/3}$.

The simulations are started with prescribed sources and a guessed L-mode profile and evolve to L-H transition and temperature and density pedestal self-consistently as shown in Fig. 1. There are no assumptions in the simulations that suggest that there will be an L-H transition or where should be the temperature and density barriers. In the simulation shown in Fig. 1, the magnetic-q is just above 2 at the separatrix and density at the edge is below the Greenwald limit. Although, the particle pinch is present in the simulations, a peaked density profile is not obtained. However, there is no problem in reaching the design performance of ITER with fusion Q = 11.5 and with temperature pedestal heights around 3.5 keV.

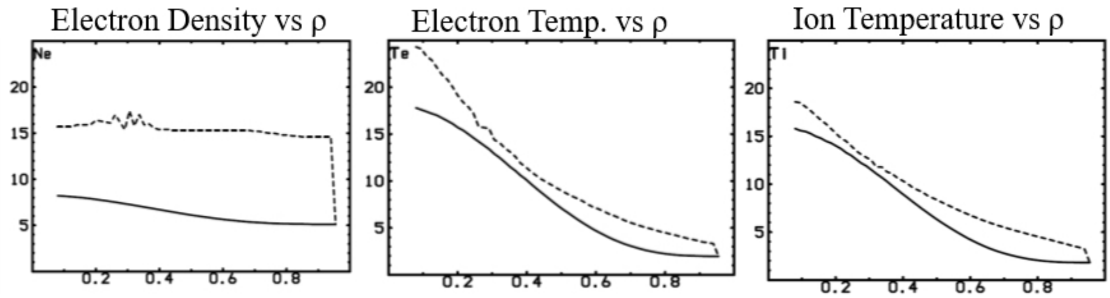

Figure 1: The ITER simulation of density, electron temperature, and ion temperature profiles where the full line is the initial condition and the dotted line is the simulated profile.

The auxiliary heating and current drive profiles are suggested by the central ITER team {2} and the Alpha heating is computed from an analytic formula depending on the local density and the temperature. The neoclassical transport is added to the ion channel.

In general, the ion modes dominate in the interior while electron modes dominate on the barrier. In some ITER simulations both electron and ion modes are found to be stabilized by flow shear in the barrier although the electron mode is considerably stronger without flow shear. There are also cases where the electron channel is not completely stabilized.

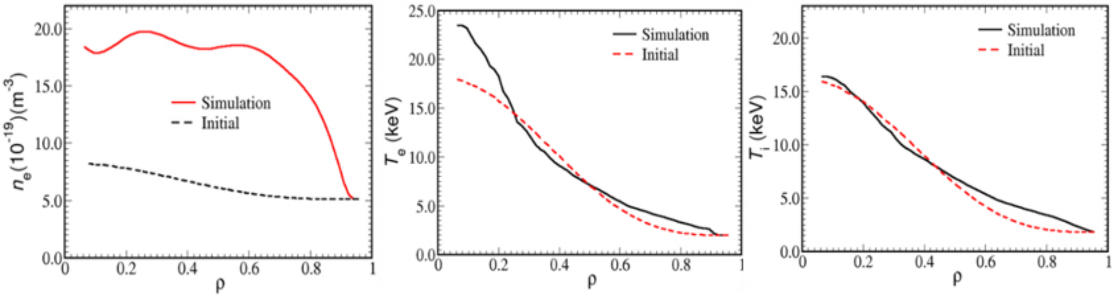

Figure 2: The ITER simulation of density, electron temperature, and ion temperature profiles where the full line is the simulated profile and the dotted line is the initial condition. The edge particle source is increased around 20%. The increase in the edge particle density and weak temperature pedestal barriers are found.

The density and temperature pedestals are found to be quite sensitive to the particle source at the edge as shown in Fig.2. The edge particle source is assumed to be Gaussian in space and its amplitude is increased around 20%. The increase in the edge particle source has two effects. First, it raises the edge density and second it raises the reaction rate close to the edge, thus increasing the temperature fluxes that results in weak temperature pedestal barriers. Clearly, there must be a particle pinch somewhere to get in the particles from the edge source that raises the edge particle density as can be seen in Fig. 2.
The increase in magnetic-q (reducing current density) tend to trigger more kinetic ballooning modes at the edge and decrease in magnetic-q means that peeling gets worse but ballooning gets better. Moreover, it appears that large edge magnetic-q tends to give hollow density (not shown here) while small edge magnetic-q gives normal density profile. This behavior is consistent with the result that n~1/q {3}.
Simulations are carried out with and without Alpha heating. The effects of Alpha heating are found to reduce the slope of the H-mode pedestal. This is expected to significantly ease the problem of ELMs causing damage to the first wall.
Simulations are also performed with B-field increased. A pronounced edge barriers are found when the strength of B-field is increased. The increased B-field have a distinct effect on the MHD modes at the edge. The interesting feature is found that the barrier collapses around q = 2 as MHD stability has reduced to having the barrier replaced by a continuous slope but with about the same fusion Q value. This would actually be good for a reactor.

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{1} J. Weiland, Stability and Transport in Magnetic Confinement Systems (Springer, New York, Heidelberg, 2012); T. Rafiq et al., Phys. Plasmas 20, 032506 (2013).
{2} TER Physics Basis Editors, "Progress in ITER physics basis II confinement"Nucl. Fusion 47, S1–S413 (2007).
{3} Garnier, et. al., Phys. Plasmas 24, 012506 (2017).

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