Integrated modeling of tokamak plasma confinement

T. Luda[1], C. Angioni[1], M. G. Dunne[1], E. Fable[1], A. Kallenbach[1], N. Bonanomi[1], T. Lunt[1], P. A. Schneider[1], M. Siccinio[1], G. Tardini[1], the ASDEX Upgrade Team*, and the EUROfusion MST1 Team**

[1] Max–Planck–Institut fuer Plasmaphysik, Boltzmannstrasse 2, D–85748 Garching, Germany

*See the author list in H. Meyer et al. 2019 Nucl. Fusion 59 112014

**See the author list in B. Labit et al. 2019 Nucl. Fusion 59 086020

e-mail (speaker): teobaldo.luda.di.cortemiglia@ipp.mpg.de

A new integrated model based on engineering parameters (IMEP) [1] has been developed to predict the confinement and temperature, density and rotation profiles of H-mode plasmas. A new edge pedestal transport model is included into the ASTRA [2] transport code, which, together with the TGLF [3] and NCLASS [4] turbulent and collisional transport models, simulates the evolution of the profiles. A simple scrape-off layer (SOL) model has been also implemented, providing the boundary conditions at the separatrix. No profile measurements are required as input, and the only inputs of the model are the magnetic field, the plasma current, the heating power, the fueling rate, the impurity seeding rate and the plasma geometry.

The adopted pedestal transport model, which is based on multi-device experimental observations, sets a transport constraint for the pedestal evolution between edge localized modes (ELMs). This provides the electron and ion temperatures and densities at the top of the pedestal for a given pedestal width. Many ASTRA simulations are run in parallel, each with a different pedestal width, providing a scan of the pedestal pressure. The MISHKA [5] MHD stability code is run on each ASTRA simulation result, to find the highest pedestal pressure which is stable to peeling-ballooning modes, corresponding to pre-ELM conditions. The kinetic profiles associated to this pedestal width are the final result of the workflow and are used to calculate the plasma stored energy and the energy confinement time.

This automated modeling framework has been extensively tested by simulating 50 stationary phases of ASDEX Upgrade discharges. The database selected for this validation includes wide variations in the operational parameters, such as heating power, current, magnetic field, triangularity, and fueling. IMEP reproduces the main dependencies which are captured by multi-device scaling laws, such as those on the plasma current and on the heating power. Moreover, the stored energies predicted by the model are in significantly better agreement with the experimental observations than those obtained by scaling laws. As an advantage over the scaling laws, IMEP also describes the change in confinement caused by fueling, triangularity, and magnetic field. It can also provide physical insights on the origin of these dependencies in the different radial domains, core, pedestal and SOL, as well as the respective limitations and device specific elements of the various modeling components.

The pedestal transport model gives an accurate estimate of the pedestal structure, providing for the first time the capability of separately predicting the pedestal profiles of electron and ion temperatures and densities. IMEP also reproduces plasmas in the small ELM regime and ITER baseline scenarios, demonstrating that this approach has the potential to improve the prediction of the fusion performance in future tokamak reactors.

[1] T. Luda et at, 2020 Nuclear Fusion 60 036023

[2] G.V. Pereverzev, P. N. Yushmanov, IPP-report 5/98, 2002, E. Fable et al 2013 Plasma Phys. Control. Fusion 55 124028

[3] G.M. Staebler et al, 2007 Phys. Plasmas 14 055909

[4] A. Houlberg et al 1997 Physics of Plasmas

[5] A. B. Mihailovskii et al. 1997 Plasma Phys. Rep. 23 844