Multiscale Whole-Device Modeling in the ITER Era

S. Kruger, A. Pankin, and J. Cary

International experiments and the construction of ITER is bringing about a new era of plasma physics. This new era of long plasma discharges at high plasma performance and burning plasmas requires a reevaluation of theoretical and computational models. For modeling the plasmas on the longest time scales and for answering engineering-level optimization questions, the whole device model [1], which couples all regions as well as all spatio-temporal scales, has proven to be a useful and widely used tool. The long time scale and burning plasma physics requires a rethinking of the level of fidelity required for accurate simulations, as well as the numerical methods used to achieve them.

In recognition of this fact, the Europeans have embarked on the Integrated Tokamak Modeling (ITM) effort, with the development of the European Transport Solver (ETS) as its core [2]. The Japanese fusion program has the Burning Plasma Simulation Initiative (BPSI) to answer these challenges. In the United States, there is currently no effort to develop a whole device modeling code that can be competitive to the European and Japanese efforts. This is true despite the investment in the proto-FSP projects, SWIM and FACETS, which had given the US the only parallel integrated modeling capability. In addition, the US has been at the front with its development of predictive fluxes (e.g., GLF23 and TGLF), its ability for fully kinetic and nonlinear RF modeling, and the ability to model walls on

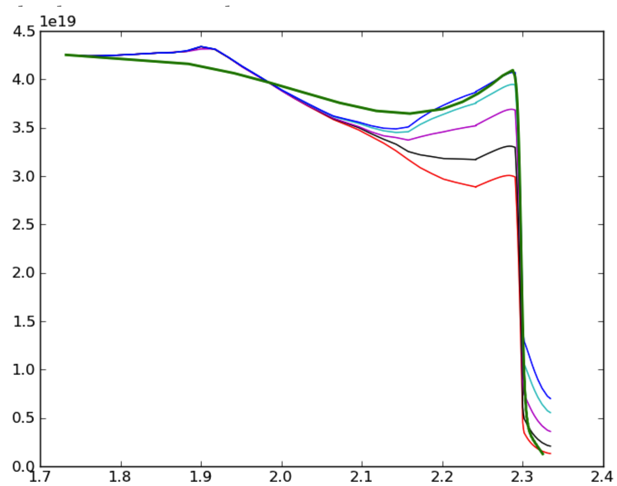

Figure 1: Plasma density profiles as functions of discharge major radius for different values of gas-puff strength specified as equivalent amperes. The different lines are as follows. Red: no gas-puff, black: 100, magenta: 250, light-blue: 400 and blue: 500. The dark green line is the experimentally measured density profile.

The ideal whole device modeling code includes:

- Coupling between different regions of tokamak such as the coupling between plasma core, plasma edge, and tokamak wall;
- Coupling between different physical processes covering different spatial and temporal scales, such as the coupling between anomalous and neoclassical transport, auxiliary heating and current drive, and large scale instabilities.

These two aspects of integration have a number of applied math and computational challenges related to the large range span of spatial and temporal scales, the 1D and 2D nature of transport in different regions of plasmas, and the need to use high-performance computer resources in a cost-effective way. Valuable experience has been accumulated in the area of integrated modeling of tokamak plasmas over the last 40 years. However, until recently many aspects of integrated modeling have not been addressed. These aspects include the use of high-fidelity gyro-kinetic codes for microturbulence in a full-featured predictive transport code, coupling of 1D transport in the plasma core and 2D transport in the plasma edge, and self-consistent plasma-wall interactions. Recently using an advanced whole-device modeling approach, significant progress has been made on the better understanding of plasma edge effects on the H-mode pedestal properties and plasma confinement. It has been demonstrated that sources both in the plasma edge and in the plasma core influence the H-mode pedestal structure which has a key role on the overall discharge confinement, pedestal stability, and fluxes on tokamak walls and divertor plates. Fig. 1 shows the plasma density profile variation with different parameters of gas puff.

Integrated modeling is important in every aspect of tokamak analysis, but it remains critical for the following research areas:

- Long-pulse scenario modeling;
- High-fidelity modeling of interaction between turbulence, MHD instabilities, RF source, and fast particles;
- Control and mitigation of large scale instabilities and discharge disruptions;
- Transient and intermittent effects in tokamaks including wall material response to the transient effects;
- Plasma wall interaction, material degradation, erosion and material mixing due to extended discharge operation.

Therefore, the time is ripe for the US program, with its limited budget, to take advantage of its leadership position in computation/modeling by providing the most advanced multiscale integrated modeling. Doing this would ensure that the US has a significant position in the interpretation, planning and execution of the near and far term experiments at ITER and DEMO allowing the U.S. to reap the major research results as the international program moves forward.

[1] S. Hirshman and S. Jardin, Phys. Fluids **8** 1388 [1976]

[2] `http://portal2.efda-itm.eu/itm/portal/`

[3] `http://p-grp.nucleng.kyoto-u.ac.jp/bpsi/en/`