INTEGRATED MODELLING ACTIVITIES IN SUPPORT OF THE ITER RE-BASELINE

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The ITER Research Plan (IRP) and its recent re-baseline [1] have been continuously supported by Integrated Modelling (IM) activities to help optimize the path towards achieving the ITER mission goals. The ITER IM platform is built upon the Integrated Modelling and Analysis Suite, IMAS [2], which, for the last decade, has been guiding modellers from the international fusion community towards the provision of standard tools, encouraging experts to design IM suites for worldwide usage. The development of ITER IM tools is driven not only by the necessity to build a robust and validated modelling platform for future plasma operation, but also by the constant need to address fundamental physics issues towards finalizing the designs of key systems and of the IRP. Due to the complexity of these short- and long-term objectives, making this development goal-oriented is a crucial aspect for the tools to be built in a reliable and user-friendly way. This is the so-called agile approach. i.e. incremental, iterative, flexible and collaborative, providing rapid, but adequate initial results which can be subsequently refined with the evolution of models and computational capabilities.

The new 2024 baseline comprises a modification of the Heating and Current Drive (H&CD) mix to overcome the increase of radiation losses due to the expected additional tungsten (W) influx caused by the change of first wall (FW) material from beryllium to W [3], and to remain within the neutron fluence budget, limited during the two first phases of operation (the Start of Research Operation (SRO) and DT-1 phases [1]). With these new operational constraints, integrated scenario modelling has been essential to assess the optimal mix between Electron Cyclotron (EC) Resonant Heating (ECRH), Ion Cyclotron (IC) Resonant Heating (ICRH), and Neutral Beam Injection (NBI). The limited neutron budget was the drive for the increase in total installed H&CD power, while the need to overcome the increased W source was the catalyst for making ECRH the dominant heating source. In SRO, the key question related to H&CD is the effect of ICRH on W sputtering, partially addressed by simulating IC coupling and near-field sheath effects [4], although the final decision on its power upgrade will mostly rely on SRO experimental results.

Since the new baseline relies more heavily on ECRH, the operational conditions of the EC system have been reviewed in detail [5], supported by models from the H&CD IMAS workflow [6]. A study has been carried out with TORBEAM [7] to propose an optimal design for the second Equatorial Launcher (EL), needed to inject an extra 20 MW to the plasma, and intended to be non-steerable. Figure 1 shows an example of an angle scan made to choose the appropriate configuration for optimal ECRH and current drive (ECCD). For NBI operation, an extensive analysis has been carried out to assess the shine-through losses in various scenario conditions and to choose the appropriate beam power and energy for all operational conditions of the new IRP [8].

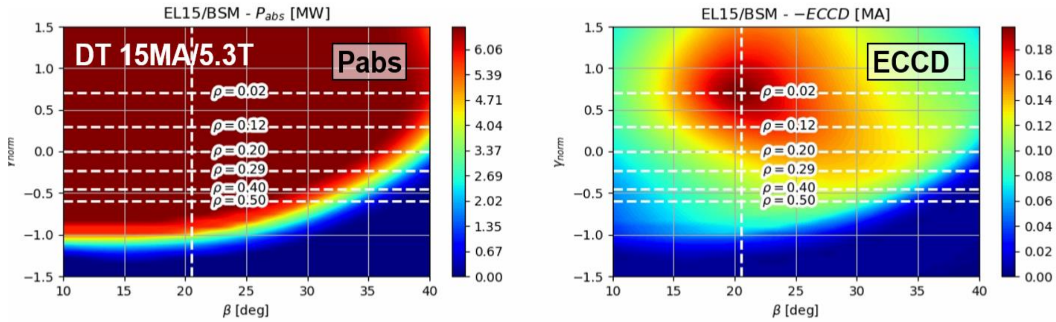

Figure 1: ECRH (left) and ECCD (right) for one EL mirror, with 6.7MW of injected power, for various toroidal angles β and poloidal angles represented by the normalised steering quantity γ_{norm}, for the ITER DT baseline 134173/106 DINA-JINTRAC IMAS scenario. The dashed lines represent the optimal angle values for various radial locations.

The change of FW material brought new constraints in terms of wall conditioning, since a W wall is expected to require boronization to reduce the oxygen contamination during plasma start-up, at least for the very first plasma attempts. For this purpose, a diborane boronization system is included as part of the re-baseline and its design has been supported by unique new modelling of the boronization glow [9], while separate simulations of boron (B) erosion and transport using WallDYN3D migration modelling operating on SOLPS/OSM background plasmas have been deployed to quantify the B coating lifetime and resulting potential dust formation and in-vessel fuel retention [10]. Meanwhile, JINTRAC integrated modelling of limiter ramp-up on W surfaces, accounting for W release and transport, is in very good agreement with higher fidelity, standalone SOLPS-ITER simulations and shows clearly the important role ECRH will play in preventing W core accumulation during this early phase of every discharge [3]. Used in conjunction with W main chamber sources during diverted operation derived from migration code simulations, JINTRAC has been a vital tool to improve confidence that the risks to the Q = 10 objective of switching to W are moderate to low [1,3]. Using these W source estimates as input to DINA, magnetic control scenario modelling has also been performed to deduce the maximum flattop duration in the various operational conditions of the IRP.

In parallel, data processing and analysis modelling tools are being developed for future plasma operation, leveraging the combination of diagnostic models, reconstruction methods and dedicated algorithms integrated in advanced workflows based e.g. on Bayesian or Kalman filter techniques [11] for best estimates of plasma parameters. Synthetic diagnostics are also extensively used for the development of the Plasma Control System (PCS) and its Simulation Platform (PCSSP). Finally, a Pulse Design Simulator (PDS) is being developed to design ITER scenarios and calculate an optimised pulse schedule to be injected in the ITER PCS for the execution of the IRP. The PDS is designed to be highly modular, combining models of varying complexity to provide various computational modes ranging from quick scenario estimates based on prescribed ideal waveforms, to a flight simulator mode relying exclusively on controllers to simulate a pulse from a pre-configured set of waveforms. Such flexibility is achieved by the deployment of advanced multiscale IM methods using a persistent actor framework to facilitate cross-language communication and optimise the simulations.

The development of these tools requires the involvement of the international fusion community, through the sharing of state-of-the-art models optimised for high fidelity or fast plasma simulations. Such code sharing is facilitated when the models are made publicly available for a worldwide contribution of fusion experts, which is the drive for the new open-source software campaign recently launched by ITER Organization.

The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

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