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Verification and validation of plasma burn-through simulations in preparation for ITER First Plasma

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The development of tokamak start-up operation scenario often relies on operator's experiences, rather than more robust approach based on numerical modelling. Such a trial-and-error approach has fortunately worked to find start-up recipes in small or medium size devices, but increases the risk of delays to experiments. Moreover, it would not be appropriate anymore for a large superconducting tokamak like ITER. First plasma operation in ITER is planned in 2025, and it is of crucial importance to ensure robust successful start-up. However, ITER has a risk of failure in full ionization of the prefilled gas (i.e. plasma burn-through), which is an essential condition for the start-up operation, because the toroidal electric field available is limited to 0.33V/m, much lower than the value typically used in now-a-days tokamaks i.e. 1 V/m. In order to assist the heating power in the plasma burn-through phase, a few MW of ECH power is planned for ITER First Plasma, but there still is a large uncertainty as the ECH absorption efficiency is very low (˜ a few %) due to the low Te during the plasma burn-through phase. Therefore, it is now important and timely to develop a reliable plasma burn-through modelling tool including ECH to further optimize the operation scenario for ITER First Plasma.

This paper presents the summary of the code benchmark of plasma burn-through modelling codes, which was a joint modelling activity in ITPA-IOS for 2018 ˜ 2020. For the first time, there was an extensive comparison between the plasma burn-through modelling codes presently available - DYON 1 [2] [3] [4], SCENPLINT [5] [6] [7], and BKD0 [8] [9] [10]. The benchmark activities were done in three steps, adding more complexities to the modelling in each step.

The first step was to verify the energy balance, particle balance, and circuit equations used in the three codes. With simple settings in the modelling e.g. constant plasma volume, no impurity, no ECH, etc, and with the parameter set foreseen in ITER First Plasma e.g. Hydrogen, Vloop =12V, Bt=2.65T, Bp=2mT, Vv=1000m3, R=5.65m, a=1.6m, ITER First Plasma was simulated, and the calculated threshold value of prefill gas pressure required for plasma burn-through was compared. Without any adjustment in the source codes to provide similar simulation results one another, interestingly, the three codes already predicted the same value of the threshold prefill gas pressure i.e. 0.8mPascal (see Figure 1), implying the overall consistency between the codes for the simplified modelling case. Each term in energy balance, particle balance, and circuit equation has been compared in detail, and the differences in the detailed simulation results were identified. The three codes were adjusted to match the detailed simulation results each other, and could successfully provide almost identical values for all the simulation results, such as time evolution of the plasma current, temperature, and density. This confirms the identified terms are the main differences for the simplified modelling case.

The second step was to validate the modelling against experimental data. For this, experimental data at JET such as loop voltage, plasma volume, and prefill gas pressure were used as input data, and impurity content evolution was also modelled in the codes. In this exercise, it was found that the plasma volume evolution and electromagnetic modelling of the eddy current in passive structure are important. Some differences were also found between codes which turned out to result from different atomic data. DYON and BKD0 use ADAS data, while SCENPLINT uses V. E. Zhogolev's data [11]. Adjusting the term related to plasma volume evolution and eddy current, DYON and BKD0 were able to provide the same results, but SCENPLINT had different results, in particular, the impurity content evolution and radiation due to the different atomic data. The difference of the atomic data was investigated, and it was found that the radiation due to transitions without changing of main quantum number is taken into account in V. E. Zhogolev's data, while ADAS does not include it.

The third step was to validate the modelling codes against ECH-assisted plasma burn-through discharges. Stand-alone simulations of ECH modules in each code were compared, and only small difference in the ECH absorption efficiency was found. Together with the ECH modules, the three codes simulated KSTAR discharges, and provided similar results until the carbon impurity become important for energy balance. This confirms that the three codes are consistent for ECH-assisted plasma burn-through, except impurity evolution because of the different atomic data.

After summarising the findings in the above joint benchmark activities, this paper will present the plans to develop reliable plasma burn-through modelling tool, in preparation of operation scenarios for ITER First Plasma.

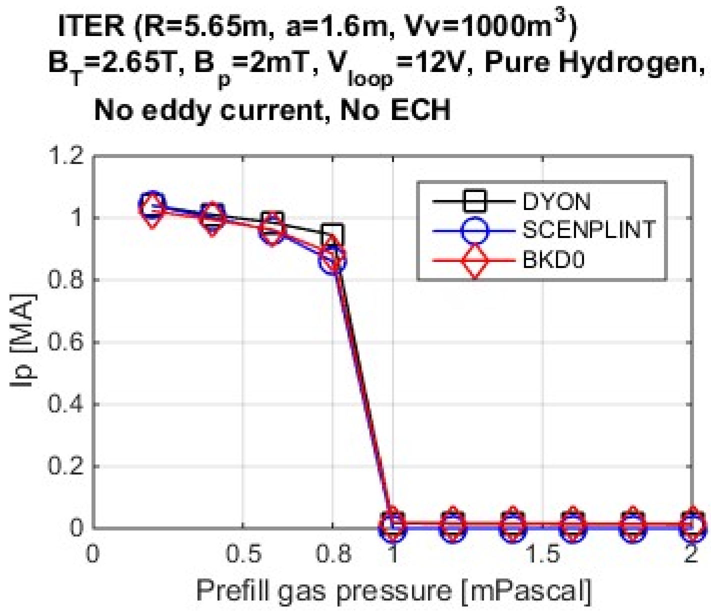

Figure 1: Plasma current at 1 second after loop voltage applied, calculated by DYON, BKD0, and SCENPLINT

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