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Global JINTRAC Simulations for ITER PFPO Scenario Development

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1.Introduction
The inductive goal of ITER is to produce 500s long burning plasmas with $Q = P_{fus}/P_{aux} \geq$10[1]. This requires the development of operationally robust scenarios that span the whole plasma discharge from start-up to termination not only in Deuterium Tritium (DT) but also in the Pre Fusion-Plasma Operation (PFPO) phase in Hydrogen (H) and Helium (He). In the PFPO phase, subsystems, such as the ELM mitigation system, will be commissioned and important lessons will be learnt about how to optimise and operate ITER plasmas within machine protection limits. As ITER's plasma facing surfaces (PFCs) are made of Beryllium (Be) and Tungsten (W), ITER operation will require applying the ITER heating and fuelling and impurity seeding systems in an optimum way to achieve the best plasma performance while ensuring low power fluxes and low erosion of the PFCs. In particular, the optimisation will include: i) minimising the release of tungsten by plasma-wall interactions; ii) controlling tungsten transport into the core plasma to avoid accumulation; iii) acceptable divertor power loads (<10MWm^{-2}); iv) tolerable Neutral Beam (NB) shine-though loads; and in the Fusion-Plasma Operation (PFO) phase also v) the control of the DT mix in the core plasma. JINTRAC[2], developed by EUROfusion, is in a prime position to tackle this scenario development challenge with its suite of core (JETTO/SANCO/EDWM) and SOL/divertor (EDGE2D/EIRENE) transport codes that concurrently can simulate all these aspects.

2. PFPO-1: 5MA/1.8T H and He H-modes
The ITER Research Plan includes the first H-mode operation in PFPO-1 with 5MA/1.8T H and He plasmas. To maximise the H-mode operational space the plasma density is restricted to a Greenwald density fraction, f_{GW} ~ 0.5 and the heating power available will be 20MW of Electron Cyclotron Resonance Heating (ECRH) (an upgrade of an additional 10MW ECRH in this phase is being studied). Our global JINTRAC simulations starting from L-mode, through L-H transitions to ELMy H-mode indicate that both H and He scenarios are indeed feasible with heating powers in this range. For instance, the H H-mode with Ne seeding has acceptable divertor power loads of <5MWm^{-2}, W sputtering within limits (W sputtering yield<0.002), and steady-state W core concentration of ~1x10^{-6} with less than 1MW of W core radiation due to a very efficient neoclassical screening of W in the H-mode pedestal. It should be noted that while 20MW of ECRH provide robust access to ELMy H-modes in He plasma at 5MA/1.8T, this is not the case for H where a minimum of 30MW is required, due to the isotope dependence of the L-H threshold (P^{He}_{L-H} ~ 0.7P^{H}_{L-H}).

3. PFPO-2: 7.5MA/2.65T H and He H-modes and 15MA/5.3T H L-mode
Later in the PFPO programme, the full complement of auxiliary heating (33MW of Hydrogen Neutral Beams (HNB), 20MW of ICRH and 20MW of ECRH), will be commissioned and exploited, which will allow to explore H-mode discharges up to 7.5MA/2.65T. In this case, H-mode access in H is more challenging as a result of the higher L-H threshold and the lack of a suitable scheme for ICRH heating in these plasmas. To study H-mode access and sustainment in these plasmas, we have considered two cases which both require 33MW of HNB in addition to 30MW ECRH for H plasmas and 20MW ECRH for He plasmas.
For H plasmas, to access H-mode in these conditions one possibility is to reduce the plasma density at H-mode access (n_{el}~3x10^{19}m^{-3}) but this leads to unacceptable HNB shine-through losses on the first wall. To circumvent this issue, we utilise Ne seeding (which increases the HNB stopping efficiency of the plasma compared to one with pure H) up to ~10% core plasma concentration[3]. Despite this high Ne content, the divertor stays semi-detached and the core Ne radiation and W contamination do not deteriorate the H-mode quality. The second option that we have considered is to add ~10% He to a high-density 7.5MA/2.65T H plasma (n_{el}>4x10^{19}m^{-3}), assuming that this will lead to a 15% reduction of the H-mode threshold as seen in the JET experiments[4]. This leads to a viable Hydrogen-dominant H-mode scenario provided that some level of Ne seeding is maintained to ensure acceptable HNB shine-through and divertor power fluxes.

Simulations of 7.5MA/2.65T He H-mode plasma scenarios show that these are less challenging from the integration point of view since He plasmas have a lower L-H threshold and lower HNB losses for a given density. This allows He H-modes with high densities to be sustained (f_{GW} >70%), which keeps the W sputtering yield below 7x10^{-4} and the W core concentration very low~1x10^{-6}, even when we assume no prompt re-deposition of W in our simulations. Even in pure He plasmas the power densities on the targets are very low (<1MWm^{-2}). This restricts the possibility to test the use Ne seeding for divertor power load control in these plasmas; relatively low seeding rates (> 2x10^{20}s^{-1}) can cause full divertor detachment.

The final PFPO phase includes an increase in current and field to those required for Q = 10 operation in DT (15MA/5.3T). The H-mode threshold for 15MA/5.3T H plasmas is in excess of 100MW ($P_{L-H} \sim B^{0.8}$) and with only up to 73MW available auxiliary heating, L-mode operation is foreseen for PFPO-2. As for lower current H-mode H plasmas, a potential issue is the NB shine-through in these plasmas and, therefore, we have performed dedicated modelling both to assess this issue as well other edge compatibility issues (divertor power loads and W contamination). First simulations in these conditions indicate that with pellet fuelling and up to 30MW of RF and 33MW of HNB heating, the plasma can be operated at high enough density (n_{el}> $5x10^{19}m^{-3}$) to allow unrestricted application of NB at full energy (and power). The divertor power loads are maintained under 5 MWm^{-2} without the need of Ne seeding and core W concentration and associated radiation are negligible.

Work is now in progress to model reference plasma scenarios for FPO, which will be described in the paper.

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