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Integrated time-dependent core-edge-SOL modelling of ITER SRO plasma scenarios

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The ITER Research Plan (IRP) has been updated to incorporate a tungsten first wall and a revised heating mix. [1,2] The planned operational sequence begins with the **Start of Research Operation (SRO)** phase, which foresees the following target scenarios:

- **Hydrogen L-mode scenario** with 40 MW of EC heating, reaching plasma currents up to I_{pl} = 15 MA at B_0 = 5.3 T.
- **Deuterium H-mode scenarios** at I_{pl} = 5 MA / 7.5 MA, B_0 = 2.65 T with $P_{EC} \leq 40$ MW.

In this context, integrated time-dependent core-edge-SOL simulations are required to predict plasma performance and operational constraints with tungsten as the main heavy-ion impurity.

To address this, the High Fidelity Plasma Simulator (HFPS), comprised of the DINA free boundary equilibrium evolution code and the JINTRAC integrated core (JETTO + SANCO + TGLF-SAT2) + edge / SOL-div (EDGE2D + EIRENE) transport solvers embedded in the IMAS workflow environment have been applied, with EC heat deposition and current drive being calculated by GRAY, and the MHD pedestal stability limit in H-mode being determined in a feedback loop with MISHKA.

Comprehensive scenario simulations were performed for the **limiter**, **current ramp-up**, **flat-top**, and **ramp-down** phases. These included scans of tungsten sputtering from the wall as a function of SOL transport conditions, leading to an assessment of operational space constraints.

Key points include:

- **Core contamination pathways:** The relative efficiency of tungsten transport from the wall versus the divertor was quantified, and actuator adjustments for each phase were evaluated to minimise core tungsten accumulation.
- **Limiter phase:** Quasi-stationary operation is possible even with high tungsten self-sputtering–induced core radiation fractions (~70–80%), provided that central EC heating continuously exceeds central radiation losses. [2]
- **Diverted ramp-up:** Tungsten core concentration drops significantly once the plasma is detached from the wall after X-point formation. Tungsten sputtering from the divertor remains negligible due to modest predicted target temperatures and power densities of up to a few MW/m² with $P_{EC} \leq 20$ MW and a Greenwald density fraction $n_{e,lin.-avg.}/n_{GW}$ ~0.4.
- **Flat-top phase:** While H-mode operation shows efficient tungsten screening in the pedestal, divertor heat-flux control via neon seeding may be required at lower densities ($n_{e,lin.-avg.}/n_{GW}$ < ~0.5) with $P_{EC} \leq 40$ MW.
- **Ramp-down phase:** Strategies for optimal H-mode termination - including heating, fuelling, and plasma shape control - were developed to enable a well-controlled shutdown with minimal tungsten contamination.

[1] A. Loarte et al. Plasma Phys. Control. Fusion 67 (2025) 065023
[2] R.A. Pitts et al. Nuclear Materials and Energy 42 (2025) 101854