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Progress towards JINTRAC integrated modelling of X-point radiators

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It has now been demonstrated experimentally in several research tokamaks that a controlled X-point radiator (XPR) under H-mode conditions can not only provide for a fully detached divertor, but also yield a naturally more ELM-stable regime [1-3]. This is therefore a rather attractive scenario for reactors, especially those operating with tungsten (W) divertors, including ITER, since it is well known that ELMs must be mitigated or even entirely suppressed to ensure sufficient target lifetime and W density control [4]. To date, modelling work regarding the XPR regime has been focused on divertor and scrape-off layer characteristics with, in particular, several demonstrations of stable XPR solutions obtained with the SOLPS-ITER plasma boundary code suite for present devices and ITER [5,6]. However, for burning plasmas, a critical question is the core-edge compatibility of these XPR regimes. Such assessments require integrated modelling and efforts in this direction being pursued at the ITER Organization (IO) are the subject of this contribution.
Our approach is to deploy and, where necessary, further develop the modelling code suite JINTRAC, currently the workhorse for high-fidelity integrated simulations at the IO (used extensively, for example, in the recent ITER re-baselining physics activities [7]). As a first step, we focus on existing published SOLPS-ITER stationary XPR simulations obtained for ASDEX Upgrade [5] and try to reproduce them with standalone runs of the JINTRAC divertor/SOL model EDGE2D-Eirene. By utilizing identical grids, a benchmark has been performed in the first instance without drifts and currents or neutral-neutral collisions and with Dirichlet conditions applied at the core boundary on plasma temperatures and ion density. We demonstrate that EDGE2D-Eirene is able to obtain quantitatively similar solutions for the XPR in these nitrogen seeded cases.
As a second step towards the integrated model, we also show that a time-dependent XPR can be obtained using Neumann boundary conditions on the core boundary, where the heat and particle flux from the core are prescribed. Herein, we find that at sufficiently high X_A (i.e. the XPR access parameter [8]), the temperature just above the X-point rapidly drops to a few eV. This indicates bifurcation behaviour between a 'hot'and 'cold'X-point solution as described in the work of Stroth [8]. The impurity radiation steadily rises through the transition, but sees no rapid transition as the temperature above the X-point. Without feedback on nitrogen seeding, the XPR tends to develop over time into an uncontrollable MARFE. A controller is being implemented to actively control the height of the XPR to obtain a fully stationary simulation result, in the same way that the XPR is stabilised in experiment [1]. Regarding the ultimate aim of the full integrated model for the XPR regime, we will discuss the ongoing efforts required to make this possible within the JINTRAC framework. In particular, the need for the 2D boundary code to also describe the pedestal region whilst normally this is taken care of by the core codes in JINTRAC.

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[7] A. Loarte et al., PPCF 2025 accepted manuscript, DOI:10.1088/1361-6587/add9c9
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