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Numerical modelling of underexplored edge plasma cases in tokamaks and linear devices using the SOLPS-ITER code

The study of plasma-material interaction (PMI) in fusion devices relies critically on understanding and controlling the properties of the edge or boundary plasma, which bridges the hot core plasma and the plasma-facing components (PFCs). The accurate modelling of the boundary plasma is a valuable tool to support the interpretation of experimental results and to guide the design of plasma conditions that ensure safe power exhaust, preserve plasma purity, and maintain PFC integrity in future fusion reactors.

Both tokamaks and linear plasma devices (LPDs) play complementary roles in PMI research: tokamaks provide reactor-relevant geometries and conditions, while linear devices offer simplified configurations, more accessible diagnostics, and the cability to achieve integrated fluences comparable to those expected in future reactors. This work presents numerical modelling activities carried out using the SOLPS-ITER edge plasma solver [1, 2], which couples the multi-fluid B2.5 plasma code with the Eirene kinetic Monte Carlo code for neutrals [3]. Three distinct edge plasma cases, relevant to PMI investigations in both device types yet relatively underexplored, are examined, highlighting the modelling choices, limitations, and physical insights gained.

The first case focuses on the edge plasma characteristics of negative triangularity (NT) plasmas in TCV, which offer H-mode-grade confinement in an inherently ELM-free L-mode regime. While NT configurations show potential for reduced transient loads on PFCs, they exhibit more challenging detachment compared to positive triangularity (PT) [4]. Numerical simulations including drifts, currents and carbon impurities demonstrate that the observed differences in target conditions between NT and PT cannot be solely attributed to magnetic geometry. To reproduce the trends observed for electron density and temperature profiles, gas puff rate, and neutral pressure, a suppression of cross-field particle transport in the core and scrape-off layer must be assumed for NT plasmas.

The second case investigates helium H-mode edge plasma in ASDEX Upgrade, heated via hydrogen neutral beam injection (NBI). The relevance of studying helium plasmas arises from the unavoidable presence of He ashes in fusion plasmas, as a product of the fusion reaction, making it essential to assess PFC erosion and impurity transport in a helium environment [5]. SOLPS-ITER simulations, ranging from simple pure helium cases to more complex scenarios including NBI-induced hydrogen, show that a level of agreement with experimental data comparable to that typically achieved in hydrogenic plasmas can be obtained. The ion flux distribution at the divertor is analyzed, highlighting the competition between He++ and He+ species. Furthermore, to improve agreement with the measured divertor temperature profiles, the inclusion of nitrogen traces is discussed as an effective proxy for radiating impurities typically present in the plasma. The resulting validated plasma background will serve as the basis for erosion studies with the ERO2.0 code, aimed at quantifying tungsten migration and redeposition under helium plasma exposure.

The third case examines argon plasmas in the linear device GyM [6, 7], carried out within the framework of the EUROfusion WP PWIE SPB coordinated cross-device experiment, focused on the exposure of tungsten samples with different morphologies. SOLPS-ITER, originally designed for toroidal devices, is adapted to the linear geometry. The sensitivity of plasma profiles to key code parameters for such a non-hydrogenic plasma is analyzed to achieve agreement with experimental data, providing a robust plasma background for subsequent erosion and redeposition modelling. SOLPS simulations highlight that the plasma is weakly ionized and largely dominated by the Ar+ charge state, and that it fully falls within the sheath-limited regime.

Overall, the present contribution highlights the versatility of the SOLPS-ITER code in supporting PMI-relevant plasma studies across different devices, from tokamaks to LPDs, and covering a wide range of operational regimes, from detached plasmas to H-mode helium plasmas and sheath-limited conditions in LPDs.

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Primary author: MOMBELLI, Fabio (Dipartimento di Energia, Politecnico di Milano, 20133 Milan, Italy)

Co-authors: Mr MASTROGIROLAMO, Andrea (Dipartimento di Energia, Politecnico di Milano, 20133 Milan, Italy); Dr TONELLO, Elena (École Polytechnique Fédérale de Lausanne (EPFL), SPC, Lausanne, Switzerland); Dr FÉVRIER, Olivier (École Polytechnique Fédérale de Lausanne (EPFL), SPC, Lausanne, Switzerland); Dr UCCELLO, Andrea (Istituto per la Scienza e Tecnologia dei Plasmi, CNR, 20125 Milan, Italy); Dr ZITO, Antonello (Max-Planck--Institut für Plasmaphysik, Garching, Germany); Dr HAKOLA, Antti (VTT Technical Research Centre of Finland Ltd., FIN-02044 VTT Espoo, Finland); Dr KIRSCHNER, Andreas (Forschungszentrum Jülich, Jülich, Germany); Dr LABIT, Benoit (École Polytechnique Fédérale de Lausanne (EPFL), SPC, Lausanne, Switzerland); Prof. SUBBA, Fabio (NEMO Group, Dipartimento Energia, Politecnico di Torino, Turin, Italy); Prof. PASSONI, Matteo (Dipartimento di Energia, Politecnico di Milano, 20133 Milan, Italy); TEAM (A), TCV; TEAM (B), ASDEX Upgrade; TEAM (C), GyM; TEAM (D), EUROfusion Tokamak Exploitation

Presenter: MOMBELLI, Fabio (Dipartimento di Energia, Politecnico di Milano, 20133 Milan, Italy)