JET HYBRID SCENARIO DEVELOPMENT IN D-T FOR IMPURITY SCREENING STUDY

[1]D.B. King, [1]C.D. Challis, [2]J.Hobirk, [2]A. Kappatou, [3]E.A. Lerche, [1]D. Keeling, [4]M. Baruzzo, [5]I.S. Carvalho, [1]P.Carvalho, [6]E.G. Delabie, [1]A. Field, [7]L. Frassinetti, [1]C. Giroud, [1]K. Kirov, [1]E. Litherland-Smith, [1]M. Maslov, [1]A.Meigs, [1]S.Menmuir, [1]C.Olde, [1]S. Silburn, [1]H.Sun, [8]N. Vianello, [9]JET Contributors and [10]The EUROfusion Tokamak Exploitation Team

[1]UKAEA, Culham Campus, Abingdon, OX14 3DB, UK
[2] Max-Planck-Institute for Plasma Physics, Boltzmannstr. 2, D-85748 Garching, Germany
[3]Laboratory for Plasma Physics LPP-ERM/KMS, B-1000 Brussels, Belgium
[4]Consorzio RFX, Corso Stati Uniti 4, 35127 Padova, Italy
[5]ITER Organisation, Route de Vinon-sur-Verdon, CS 90 046, 13067 St Paul Lez Durance Cedex, France
[6]Oak Ridge National Laboratory, Oak Ridge, USA
[7]Division of Electromagnetic Engineering and Fusion Science, KTH Royal Institute of Technology, Stockholm Sweden,
[8]Consorzio RFX, Corso Stati Uniti, 4, Padova, 35127 Italy
[9]See the author list of C. Maggi et al, 2024 Nucl. Fusion 64 112012
[10]See the author list of E. Joffrin et al 2024 Nucl. Fusion 64 112019

Email: damian.king@ukaea.uk

On fusion devices with tungsten plasma facing components radiation losses can cause significant plasma cooling if the tungsten reaches the core of the plasma [1]. Indeed, this is often the limiting factor in successful plasma discharges. There are a number of effects that prevent or reduce this influx, one such effect is the screening of tungsten from the core due to neoclassical convection in the situation where the ion temperature gradient is sufficiently high compared to the electron density gradient. For ITER plasmas this “temperature gradient screening” is predicted and is important for successful ITER plasma operations [2]. [3]. Hence studies that demonstrate and quantify this effect to help understand the parameter range where it occurs and enable comparison with theory-based models, are important for the development of fusion reactors. The combination of JET’s size, W divertor and tritium handling make it uniquely well suited to address such issues.

Such impurity screening in the periphery of the plasma has been successfully demonstrated on JET as part of the development of hybrid-scenario plasmas [4]. These plasmas provide good conditions for impurity screening thanks to high input power, low collisionality and strong rotation. Peripheral impurity screening was also observed during the DTE2 experiments [5]. Further investigations into this effect were carried out and continued into the DTE3 campaign and bring additional insights into the conditions under which screening occurs, in particular, that effects beyond neo-classical screening may be present.

To access conditions favouring impurity screening on JET, i.e. large $\nabla T/\nabla n$, hybrid scenario pulses have been optimised to achieve low $n_{e,ped}$, and high $T_{i,ped}$(~3keV), which also achieves low pedestal ν^* (~0.1) and strong rotation. To achieve this on JET an optimised gas fuelling timing is used, with a phase of no gas injection at the beginning of the high-power phase to build up a strong temperature pedestal followed by a timed gas puff to trigger the first ELMs. This is to avoid having a very large first ELM that brings in large amounts of tungsten, thereby degrading the pedestal performance. This phase, as the power ramps up and the high-performance scenario is established (referred to here as H-mode entry phase), is very delicate due to the presence of W and the correct approach here is crucial to the high-performance phase on JET. This initial phase will likely also be crucial on ITER, and this phase in the JET hybrid plasmas has been further explored in Ref. [5].

The goal of the experiments discussed here was to develop hybrid plasmas so that the peripheral impurity screening could be explored further and to prepare for possible experiments in D-T with improved diagnostic coverage compared to that in previous experiments. This included the optimisation of the scenario at different plasma current, toroidal field and improvements to the D-T scenario to better study this topic rather than optimise for fusion power. Although many aspects of the scenario are JET specific, the delicate path to the conditions where high performance and W screening occur provides useful information for the preparation of future reactors.

The presence of impurity screening in JET plasmas is assessed by analysis of bolometry data as described in Ref [3]. This analysis has revealed W impurity screening in many of the pulses performed, including those in DTE3. Due to the dependence of the study on this bolometry data, further development to ensure good quality data was required. One aspect of this is that if f_{ELM} is too high then there is insufficient time for the inter-ELM analysis of the data to be performed. Analysis of neo-classical W transport using the FACIT code [6] can be used to reveal if at a given timepoint, the profile gradients provide the conditions required for Ti gradient W screening.

The development of the hybrid scenario in deuterium following DTE2 focused on achieving lower pedestal density and preparing the scenario for D-T. The variation in pedestal density was attempted via multiple routes but the clearest results can be seen from a reduction in the plasma current, which required further adaptation of the gas fuelling to achieve an appropriate ELM frequency and the plasma shape to avoid uncontrolled termination of the plasma. The comparison of relative changes in the W content of the plasma $\Delta n_W/n_W$, due to ELMs (y-axis) and during the inter-ELM periods (x-axis), for the 2.1MA and the 2.3MA plasma is shown in Fig. 1 in the same format as used in Ref. [4].

To optimise the scenario in D-T the primary difficulties were in adapting the H-mode entry to account for the isotope effects on the L/H-threshold power [7] and in optimising the gas fuelling to account for the slower response of the tritium injection modules [8], D:T isotope ratio, plasma density, first-ELM timing, ELM frequency and the consideration of the bolometry diagnostic in the gas fuelling used. Further details on the development work will be presented with a focus on how the scenario was optimised for D-T. The comparison of the D vs' D-T impurity screening is shown in Fig. 2, in both cases the pulses are primarily in the screening regime.

The optimisation of the scenario allowed for improved bolometry data compared to DTE2 and higher pedestal temperatures compared to DTE3 (~3.5keV compared to ~2.5keV), hence this work provides vital evidence of impurity screening in a high fusion power, DT plasma. Modelling work has been carried out and is ongoing to interpret the results and determine the nature of the screening seen in these plasmas and this is the subject of further work.

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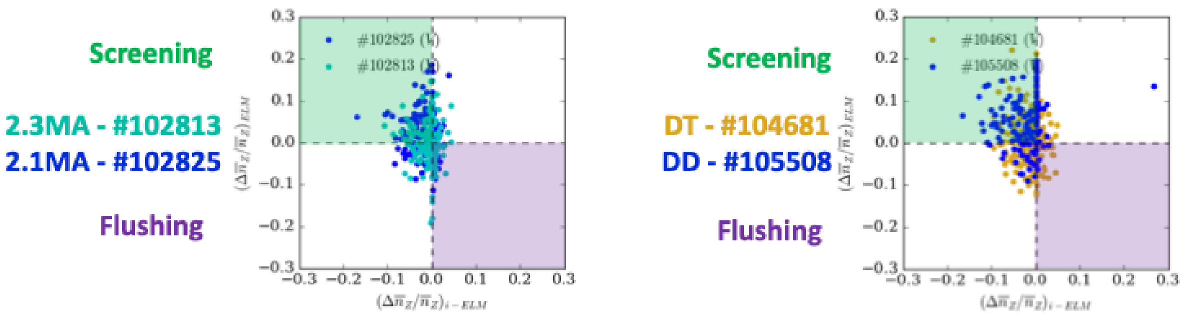

1: Screening vs flushing analysis of bolometer data for 2.1MA (blue) and 2.3MA (green) plasma (left figure) and for a DD plasma (blue) and a DT plasma (gold) plasma (right panel). Screening and flushing regions of plots indicated by colour.