Enhancements to MAST Upgrade to address the EUROfusion Plasma Exhaust Strategy

J. R. Harrison, D. Moulton, M. Carr, I. T. Chapman, D. Keeling, A. Kirk, N. R. Walkden and the MAST Upgrade team

CCFE, Culham Science Centre, Abingdon, OX14 3DB, UK

Introduction

A package of enhancements to MAST Upgrade is proposed to address key issues facing the development of a DEMO device outlined in the EUROfusion plasma exhaust strategy. MAST Upgrade [1] is designed to be a highly flexible facility, capable of operating at higher toroidal field (0.5→0.8T), higher plasma current (1→2MA), longer pulse duration (0.7→5s) and purpose-built closed divertor chambers to explore the Super-X divertor configuration [2]. Early MAST Upgrade operations will be carried out at similar levels of NBI heating and particle pumping as the original MAST device. The enhancements include doubling the neutral beam (NBI) heating power from 5 to 10MW, a cryoplant to feed existing divertor cryopumps, a pellet injector and improved gas fuelling, an expanded suite of diagnostics and an upgraded real-time control system. These upgrades will allow the relative merits of alternative divertor configurations to be assessed at high heating power, in terms of reduction of divertor heat and particle loads, and sensitivity to external control. Furthermore, these enhancements will facilitate detailed studies of detachment physics and transport in the SOL and divertor.

Expanded Divertor Operating Space

The expanded operating space where attached and detached divertor conditions can be accessed has been simulated using the SOLPS5.0 code package. Density ramp studies have been carried out in the code, in a conventional divertor configuration [1] where the outer divertor strike points are at a major radius (R_{target}) of 0.8m and in the Super-X configuration, where R_{target} = 1.54m. The profiles of radial diffusion coefficients for particles and heat used in the code were appropriate to simulate H-mode conditions. The ion flux to the divertors, shown in Figure 1, show that the increased heating power leads to an increase in the ion flux to the divertor and higher neutral density, shown in Figure 2, in both configurations. In the conventional configuration, the divertor remains attached throughout the density ramp.

Conversely, the additional heating power results in a factor ~2 increase in the detachment threshold in the Super-X configuration, and the additional pumping leads to a further increase. This allows for considerable variation in the degree of detachment in the Super-X configuration, thereby increasing the scope for feedback control. Important observations from these simulations are that, without the enhancements, the most deeply detached case is stable with an ionization front ~20cm poloidaly from the divertor target, compared with the 70cm poloidal length of the divertor leg. Also, Figure 2 shows that the neutral compression is maintained at ~100 after the divertor detaches.

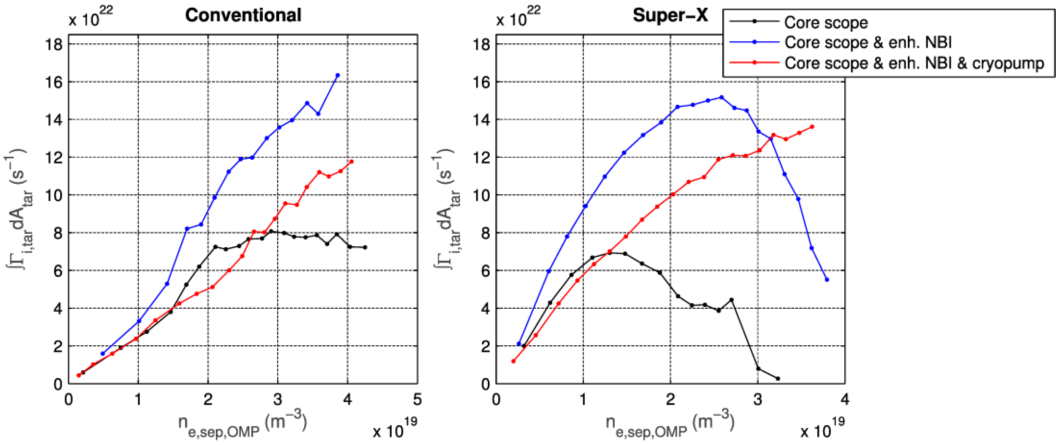

Figure 1: Calculated outer divertor ion flux during a density ramp experiment carried out in SOLPS5.0 in the conventional (left) and Super-X (right) divertor configurations.

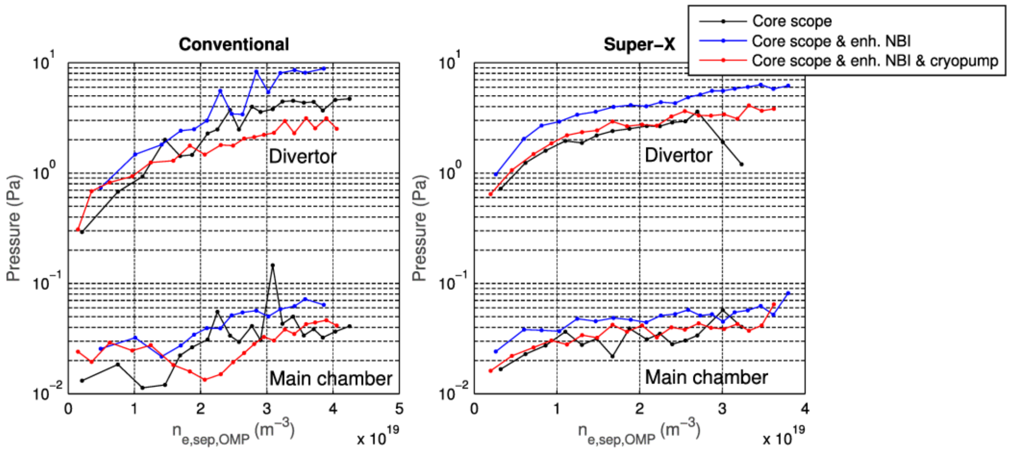

Figure 2: Divertor and main chamber neutral pressures calculated in the cases presented in Figure 1.

Improved Core Plasma Performance

The improvement in the performance of the core plasma with the proposed enhancements estimated using TRANSP simulations is shown in Figure 3. The achievable β_N, P_{heat}/R_{target}, P_{heat}/A_{surf} (where P_{heat} is the total heating power and A_{surf} is the area of the last closed flux surface) and P/R (not shown) are predicted to double. The collisionality in the core and SOL are expected to strongly decrease as a result of increasing T_e with higher heating power. This allows for detailed studies of confinement and instabilities at high β_N, and for the development of integrated scenarios with good core confinement and detached divertors.

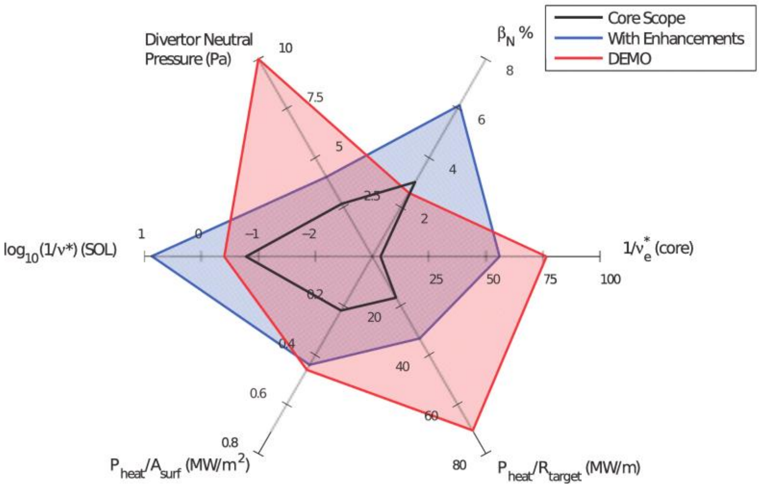

Figure 3: Operating space of core scope MAST Upgrade and after the enhancements, compared with those of a possible DEMO device [3].

Improved Suite of Diagnostics

One of the main objectives of the MAST Upgrade physics programme is to develop and validate models used to predict the distribution of heat and particle loads to plasma-facing surfaces at the divertor and first wall. To this end, improvements in the diagnostics capabilities are intended to resolve, both spatially and temporally, areas most important for code validation. Measurements of the divertor heat flux to all divertor strike points in all foreseen divertor configurations will be possible with 3 additional infra-red cameras, and fast imaging of the main chamber and divertor with >100kHz frame rate with 2 fast cameras for tracking the propagation of filaments. A new X-point Thomson scattering system, to complement the mid-plane and divertor systems, will provide n_e and T_e profile measurements at 10 spatial locations and 33ms time resolution. Measurements of the 2D radiation emissivity around the X-point will be made using an IR imaging bolometer and AXUV diodes will be used to estimate the radiation losses in the divertor chamber with 2μs time resolution. Spectral line emission in the visible spectrum will be measured with multi-spectral imaging cameras and a new divertor grating spectrometer to infer n_e and T_e in the divertor volume using line intensity and shape measurements, as well as for comparison with synthetic diagnostics from transport codes.

Improved Plasma Control

Upgrades of the real-time control system will concentrate on the vertical position control of the plasma to a level of precision required in a DEMO device, around 0.3mm, and the development and use of model-based controllers of detachment. Detachment control will be studied using a combination of Langmuir probes, bolometry, Thomson scattering, core interferometer, fast ionization gauges and imaging cameras, all with high bandwidth real-time data output.

Conclusions

A package of enhancements to MAST Upgrade has been proposed to address key issues in the EUROfusion plasma exhaust strategy, made up of 2 neutral beam injectors, cryoplant, pellet injector, improved gas fuelling, new and improved diagnostics and an upgraded real-time control system. They will allow for the exploration of conventional and alternative divertor configurations at higher heating power and with improved particle control. The extended suite of diagnostics will allow for extensive model validation in order to improve predictions of particle and heat loads in a future reactor, and improved real-time control systems will aim to control the vertical position of the plasma to the high precision required in a double-null reactor, and to control detachment with model-based controllers and a several divertor diagnostics.

Acknowledgements

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053 and from the RCUK Energy Programme [grant number EP/I501045]. To obtain further information on the data and models underlying this paper please contact PublicationsManager@ccfe.ac.uk. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

[1] G. Fishpool et al., J. Nucl. Mater. **438,** S356-S359 (2013)

[2] P. M. Valanju, M. Kotschenreuther, S. Mahajan, J. Canik, Phys. Plasmas **16**, 056110 (2009)

[3] G. Federici et al., Fusion Engineering and Design (in press), doi:10.1016/j.fusengdes.2015.11.050