5th Asia-Pacific Conference on Plasma Physics, 26 Sept-1Oct, 2021, Remote e-conference

The UK STEP Programme as Viewed from the Plasma

H Meyer[1] for the STEP Plasma, Control and Heating & Current Drive Team and Contributors
[1] United Kingdom Atomic Energy Authority, Culham Science Centre, Abingdon, Oxon, OX14 3DB, UK
e-mail (speaker): Hendrik.Meyer@ukaea.org.uk

With support from the ITER [1] project and the design of DEMO [2], the international community is now entering an era in which fusion power on the grid could become a reality within the next 20 – 30 years. In this environment the UK has started the ambitious Spherical Tokamak for Energy Production (STEP) programme to develop a compact prototype reactor based on the spherical tokamak (ST) by 2040 [3]. This endeavour is split into three tranches: (1) concept design & supplier base generation; (2) detailed design; (3) build. Whilst tranche 1 (2020-2024) is already entirely publicly funded to provide a concept design for a STEP prototype reactor and define a way forward to a STEP commercial reactor the later tranches will have increasing industry involvement. The STEP programme has taken an innovative approach by embedding a strong central team within one of the world's leading fusion labs and strongly engaging with universities and industry. UKAEA has the unique experience of hosting and operating JET (the only DT capable facility in the world), operating one of the largest spherical tokamaks MAST-U [4] (which prototypes a novel alternative divertor solution), a world leading remote handling lab and world-class material research facilities. The key enabler for a viable concept design is the plasma design. The ST concept makes it possible to maximise fusion power and bootstrap fraction in a compact device at relatively low toroidal field by allowing operation at high normalised pressure $\beta_N \approx 5.5$ and high elongation $\kappa \approx 2.8$ but it also poses unique challenges [3][5]. The compactness restricts significantly the available inductive flux for the plasma pulse and therefore the required plasma current of $I_p \approx 15\,\mathrm{MA} - 25\,\mathrm{MA}$ needs to be predominantly generated, maintained, and ramped-down non-inductively. The non-inductive current must be driven mainly off axis as MHD stability and operation at high κ require broad current profiles with low internal inductance l_i and elevated safety factor $q_{\min} > 2$. At the high density beneficial for fusion, conventional microwave current drive techniques are inefficient and techniques such as electron Bernstein waves (EBW) may need to be employed. To mature this technique for the STEP a 1-2 MW EBW system is being designed for MAST-U with strong university involvement to validate the predictions for STEP. MAST-U will also be key for testing novel divertor concepts needed to handle power exhaust with the relatively small wetted area on the divertor targets – especially at the inner target. Operating in a highly self-organised high β non-inductive scenario with a high radiation and high bootstrap fraction requires sophisticated and novel control concepts. By far the greatest challenge is the prediction of the confinement in the conditions relevant for STEP. Scaling laws and present reduced transport models may give an indication but for a high β ST plasma such as STEP they are well outside their domain of experimental validation. Indeed, parameter dependencies differing from those in the IPB98(y,2) scaling have already been observed in present day large STs and reduced models such as TGLF fail to predict transport in these devices. Linear gyrokinetic (GK) modelling [6] has shown that the turbulence is dominated by micro-tearing modes (MTM) and kinetic ballooning modes (KBM). Including the likely diamagnetic flow, the prevalent MTMs are at low $k_y\rho_s < 0.6$. These modes have very extended eigenfunctions in ballooning space, which make GK modelling very challenging. But optimising these modes could open opportunity for accessing improved confinement. The talk will give a brief overview of the STEP programme and the plasma design process that will lead to the preferred scenario concept being chosen by the end of 2021. It will present the key plasma challenges and assumptions that lead to the scenario choice and discuss the modelling framework that is used to reduce the remaining uncertainties in the plasma solution.

References:

[1] *The ITER Research Plan within the Staged Approach*, ITER Technical Report ITR-18-003 (ITER Organization, 2018)

[2] G. Federici *et al* 2017 *Nucl. Fusion* **57** 092002

[3] H Wilson, et al "*STEP – on the pathway to fusion commercialisation*" Chapter 8 of W J Nuttall "*Commercialising Fusion Energy"* (IoP Publishing, 2020)

[4] H Meyer *The mega amp spherical tokamak,* Chapter 12 of G. H. Neilson "*Magnetic Fusion Energy: From Experiments to Power Plants"* (Elsevier Inc., 2016).

[5] J. E. Menard, in *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* (Royal Society Publishing, 2019), vol. 377.

[6] B. Patel *Confinement physics for a steady state net electric burning spherical tokamak*. Diss. University of York, 2021 https://etheses.whiterose.ac.uk/28991/