The challenge of integrated scenario design for the STEP reactor

F.J. Casson, B. Patel, H. Wilson, H. Meyer, F. Eriksson, F. Koechl, S. Marsden, E. Tholerus, T. Wilson, Y. Baranov, S. Bakes, D. Brunetti, C.D. Challis, T.C. Hender, J. Harrison, S.S. Henderson, F. Militello, D. Moulton, S.L. Newton, R.T. Osawa, C.M. Roach, S. Saarelma, and STEP team

CCFE, UKAEA

The STEP (Spherical Tokamak for Energy Production) reactor design programme is in an early concept phase in which several design families and reactor concepts are under consideration. The main constraints are that the spherical prototype reactor (SPR) must produce net electricity, be smaller than DEMO, and should have an aspect ratio less than 2. The spherical tokamak allows higher beta and elongation than in conventional devices but also presents additional challenges of limited space: The exhaust solution is likely to be double null with an exacting vertical control requirement; even a small distance between the two separatrices in double null can still lead to significant loads on the inner divertor. A compact spherical design also limits the size of a central solenoid with neutron shielding. A spherical tokamak reactor will rely on high bootstrap current fraction and non-inductive current drive, even during the ramp up. The early concepts for STEP have R=2.5m, B_T ~ 2.4 T, Ip ~ 16 MA, A=3/2, κ=2.8, P_{fus}~1 GW, β_N ~5.5, f_{bs} > 70%, and fully non-inductive current drive.

A spherical reactor will face the same reactor integration challenges as DEMO, with additional challenges for predictive modelling, due to the less explored nature of the design space: The anomalous transport is likely to be entirely in the electron channel. To predict the confinement, nonlinear gyrokinetic simulations of microtearing turbulence will be needed (B. Patel, this conference), and a reduced transport model for microtearing turbulence needs to be developed. Since the plasma will operate at a high bootstrap fraction, the current profile may be partly self-organised but still needs to be optimised for MHD stability. The plasma will also need a high radiation fraction, another territory not yet well explored in integrated modelling.

A non-inductive ramp up at reactor temperatures is also quite novel; due to Faraday's law the long ramp up timescale cannot be accelerated just by adding additional current drive. The increase of non-inductive current drive must be carefully managed to avoid the formation of current holes, and techniques are under investigation such as growing the plasma volume in conjunction with the plasma current.

The STEP programme is exploring different design families with different constraints. The integrated modelling is embedded in a wider plant architecture integration programme which seeks to evaluate design space tradeoffs from different areas of plasma and technology at an early stage. Integrated modelling cannot yet reliably predict STEP confinement, since a predictive reduced transport model is not yet available. Even so, integrated modelling forms a key pillar of the concept evaluation workflow by integrating a set of 0D assumptions into a self-consistent plasma description which is then used by later stages of the workflow which analyse exhaust, MHD, fast particle losses, technology, and more.