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Preparing the Systems Code PROCESS for EU-DEMO Conceptual Design

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As the EUROfusion EU-DEMO design programme approaches the transition between the pre-conceptual and conceptual design phase the systems code PROCESS has been improved to incorporate more detailed plasma physics, engineering and integration models. Unlike many systems codes PROCESS combines the physics modelling with both technology and costs analysis. Key to the conceptual design phase are detachment, toroidal field magnet design, double-null power sharing, operational sensitivity and economic uncertainty analysis. All of these have been integrated into PROCESS [1.], [2]. During the pre-conceptual design systems codes are an essential tool for exploring fusion power plant concepts. They allow one to model the interaction of the plant systems and quickly perform reactor optioneering. To be able to carry out these large scoping studies the fidelity of the models can be restricted to reduce the computational time. The EUROfusion EU-DEMO baseline designs are created using the systems code PROCESS and the ability to measure these trade-offs has led to important design choices being examined during the DEMO pre-conceptual design phase. Ruling out unfeasible designs allows EUROfusion to efficiently identify where in the design space to carry out detailed design work. This contribution describes how PROCESS has been retooled for EU-DEMO conceptual design.

To allow optimisation of the underlying plant systems for a more fixed plant design greater detail had to be integrated into PROCESS. For EU-DEMO a 1-D scrape-off layer (SOL) model has be implemented to capture the power loss mechanisms in the SOL, to validate the core plasma power balance and to determine if the plasma is in a detached state –a key design requirement for EU-DEMO [3]. In combination with the SOL model PROCESS can now allow power sharing in a double-null configuration. The choice of single versus double-null is a fundamental choice for EU-DEMO so capturing the behaviour is essential for a systems code. A 1-D plasma transport solver has been integrated into the code to produce a self-consistent plasma model with plasma profiles for correctly calculating heating and current drive power deposition and determining the plasma radiation by integrating over the profile [4].

As the design space of EU-DEMO becomes smaller there is a need to understand what the sensitivity of the design is given some uncertainty on the performance and engineering parameters. PROCESS is an ideal tool for this analysis due to its breadth of scope and computational speed. It has given insight into the likelihood of a given EU-DEMO design achieving the high-level goals of EUROfusion, such as reaching the net electric power target [5] (the same analysis has been used on CFETR [6]). The PROCESS uncertainty tools have been used to analyse the cost sensitivity of DEMO designs to determine the primary cost drivers. This information will contribute to the decisions during concept down-selection.

One of the primary drivers of machine design, performance and cost are the superconducting magnets. Therefore, correctly calculating the space required, the achievable field and cost is essential for PROCESS. High temperature superconductors (HTS) can potentially offer a performance, engineering and cost benefits. A REBCO (rare earth barium copper oxide [7]) HTS model has been written for PROCESS for the TF coils. The operating temperature of the TF coil for both LTS and HTS is 4.5 K for the analysis presented here as it is often preferable to go to higher field to achieve large net electric power, as the fusion power is proportional to $\beta^2 B^4$. This is done rather than increase the operating temperature to save on electrical power needed for the cryogenic system or use an alternative to helium as a coolant.

PROCESS has been used to analyse the impact of toroidal field coil stress on machine design with LTS [8] and can now compare with HTS. Figure 1 shows the effect of the allowable Tresca stress in the TF coil steel. The LTS model includes a quench calculation with a variable copper fraction, while the HTS model imposes a maximum superconductor current per unit area of copper, chosen as 100 A/mm2 or 200 A/mm2. PROCESS was set to minimise the major radius and to produce 500 MW net electric power for 2 hours. Figure 1 shows that one can achieve higher fields at smaller machine size with HTS. The reduction in major radius depends on the copper requirement and is in the range 0.25-0.5m. At higher allowable stress the HTS PROCESS runs start to prioritise smaller machine size over further increasing the field.

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Further detail will be added to reduce uncertainty in the models and allow more robust design scoping studies, such as an equilibrium solver. All systems codes will need to be comprehensively rebuilt to make them relevant for the conceptual design phase. The UKAEA power plant technology group is revising PROCESS to make improvements and collaboration easier.

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