Contribution ID: **521** Type: **Poster**

Approaches for the qualification of exhaust solutions for DEMO-class devices

Friday 21 October 2016 08:30 (4 hours)

Plasma exhaust is a critical aspect of DEMO-class devices, so there needs to be confidence that it will work. This paper considers the methodology to establish confidence in potential solutions, drawing on approaches inside and outside fusion, including evolving high power computing tools –these approaches could also help find improved solutions, , possibly where all the plasma and materials ingredients operate in known regimes, reducing uncertainty. Crucially, the elements need to be integrated into an overall solution that can meet the demanding performance requirements and constraints of a fusion plant yet also accommodate significant uncertainties in plasma, materials and component behaviour.

A prior full scale test of a DEMO exhaust solution is not feasible, almost by definition. The reference approach is to take the best available design, with various uncertainties and unknowns, and use margins and risk mitigation tools to address these. We explore a complementary approach based on models for the final step to give more confidence in the performance and uncertainty range of the design. The two approaches could be combined.

For the plasma aspects, qualification will be eased if solutions have resilience to uncertainties and variations, ideally with natural "springiness", or damping of transients. These can be tested with integrated models containing all relevant mechanisms and interactions, suitably validated.

Materials and components have comparable modelling and integration challenges, in particular predicting the effects of combined loads (e.g. neutron, thermal, mechanical). A possible strategy is to combine measured and predicted materials properties and failure mechanisms (such as crack propagation, deformation) into a hierarchical multiscale model from atom-scale up. Such a modelling workflow would be well suited to high levels of parallelisation and would improve over use of average material properties.

In-silico qualification of such a large and complex system is very challenging, but has large potential benefits in cost, time, flexibility and optimisation. Fortunately essentially all science issues are being addressed in the community (e.g. in EUROfusion). The computational demands are excessive today, but the rapid development of both computing power and numerical techniques is likely to transform the situation in the next 10-20 years.

Country or International Organization

United Kingdom

Paper Number

FIP/P7-20

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Session Classification: Poster 7

Track Classification: FIP - Fusion Engineering, Integration and Power Plant Design