Approaches for the Qualification of Exhaust Solutions for DEMO-class Devices

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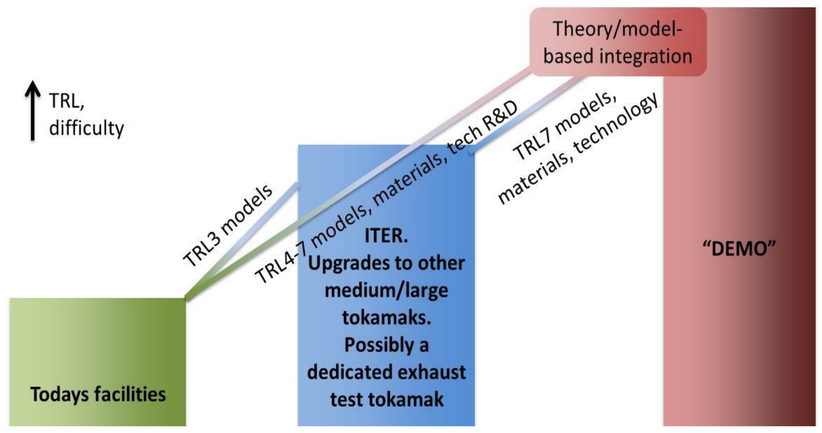
Introduction

- Qualification of exhaust solutions is critical for DEMO-class devices.
- High confidence required for plasma, material and component solutions.
- Stepwise approach to control the time and cost of fusion power development (JET - ITER - DEMO).
- Qualification strategy provides confidence without a fully relevant integrated prototype.
- Theory-based, experimentally validated numerical models used for the final extrapolation.



The Qualification stepladder – a key path to fusion power

- Two examples are investigated: detached divertor plasmas and a plasma-facing component.
- Uncertainty quantification combined with uncertainty minimisation will be vital.
- Qualification issues should be considered from the outset to guide R&D programmes.
- Requires extensive experimental data and advanced computational tools.
- Synergies with virtual engineering and prototyping (used increasingly in other fields).

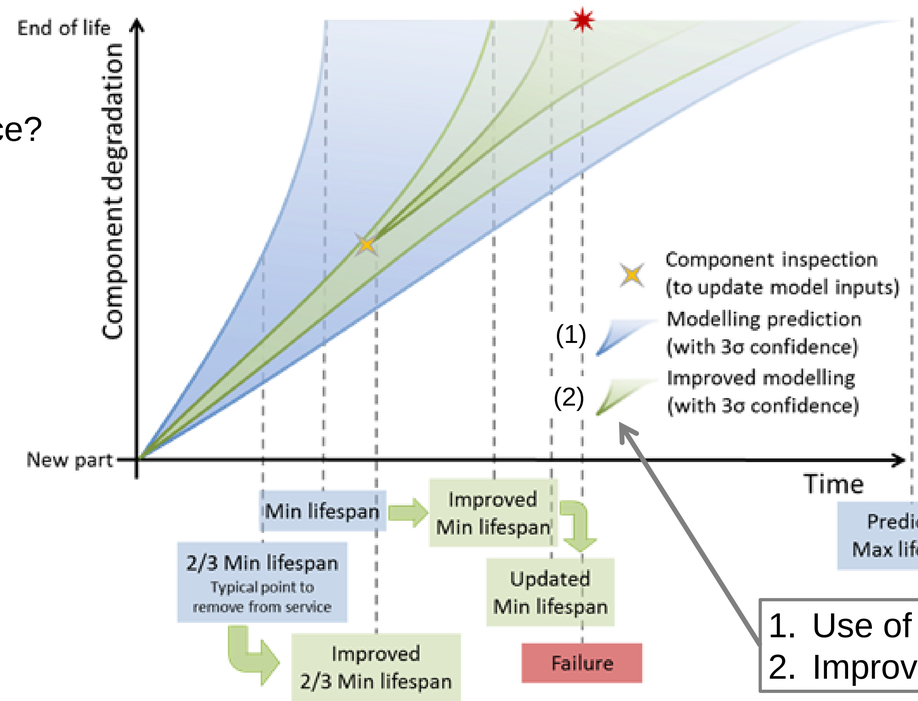
Qualification

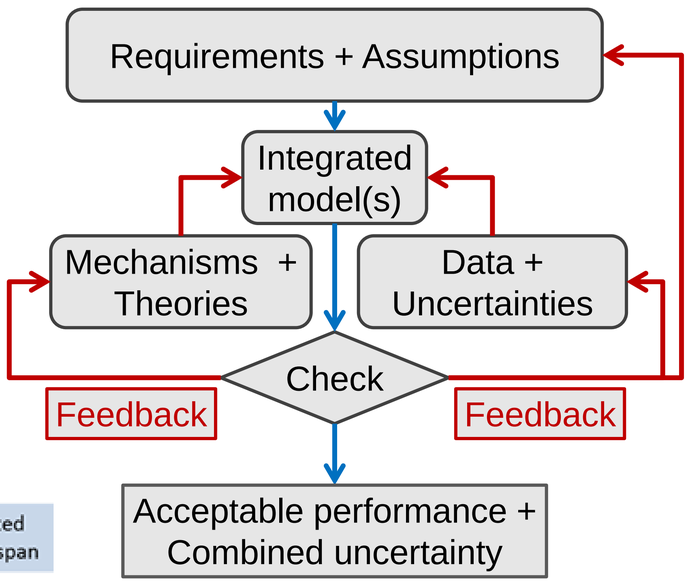
Certainty required that an exhaust scheme will work.
Lower uncertainty more important than higher performance?

- Consider **qualification at start**
- Show uncertainty fits requirements
- Develop qualification stepladder
- **Guide R&D, improve design**

Qualification incorporated into design approach

- Increased modelling confidence allows reduced design margins – improved performance.
- Approach could be critical for finding viable solutions.
- Essential that models correctly capture scale effects.
- Extend component life with combined inspection and modelling.

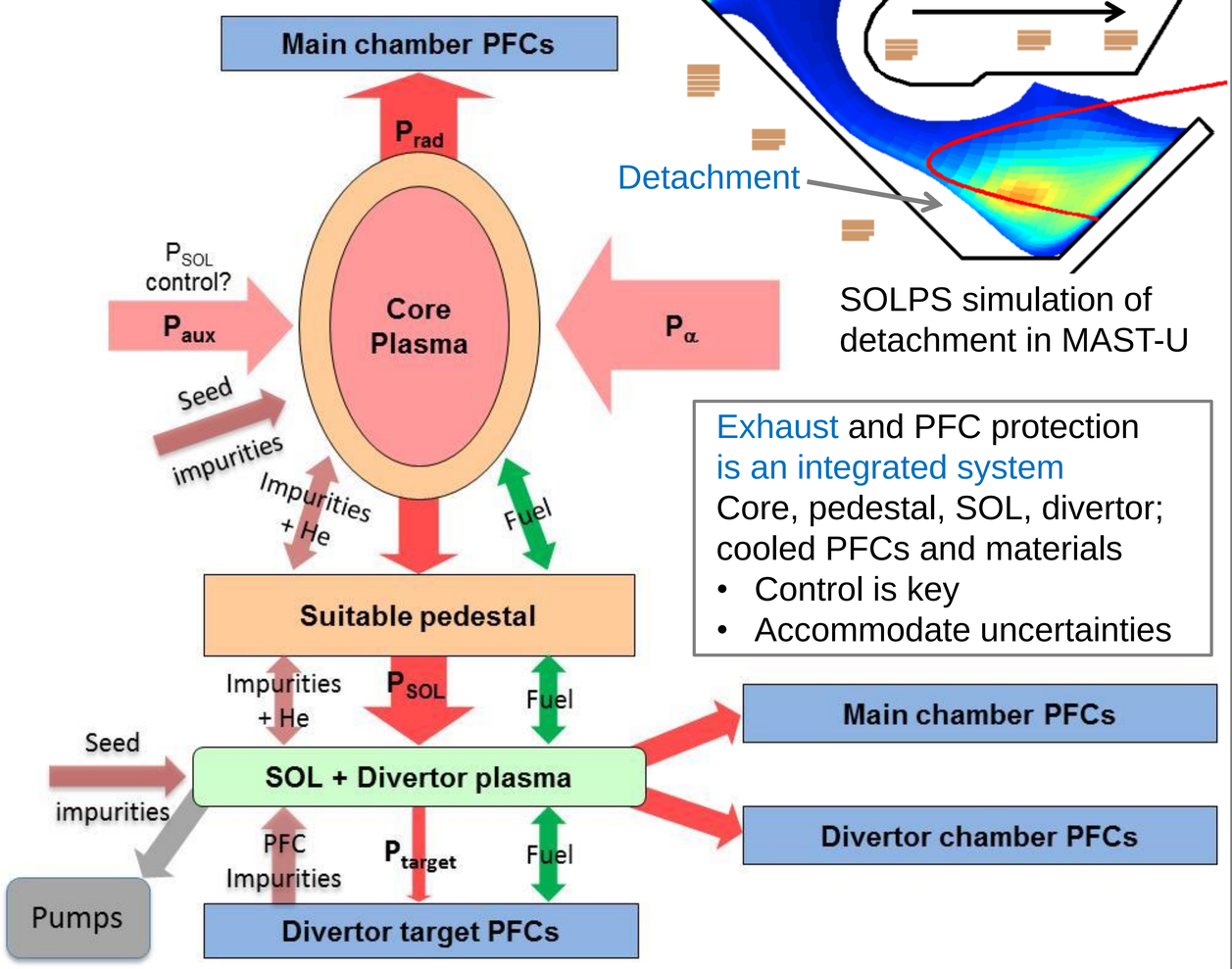


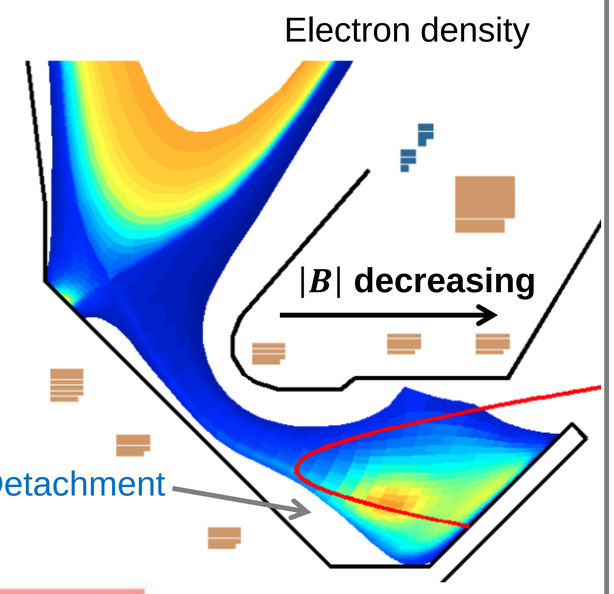


1. Use of a solution that would otherwise be rejected.
2. Improved modelling provides reduced uncertainty.

Power attenuation in the divertor plasma

- Predictable, **controllable** detachment.
- Attenuate **transients.**
- **Integrate** with pedestal (upstream density, 2-D effects if x-point radiation)
- Long-leg helps control if space ($\nabla_{//}|B|$).
- Develop **model framework** to estimate performance and quantify uncertainties.





SOLPS simulation of detachment in MAST-U

Exhaust and PFC protection is an integrated system
Core, pedestal, SOL, divertor; cooled PFCs and materials

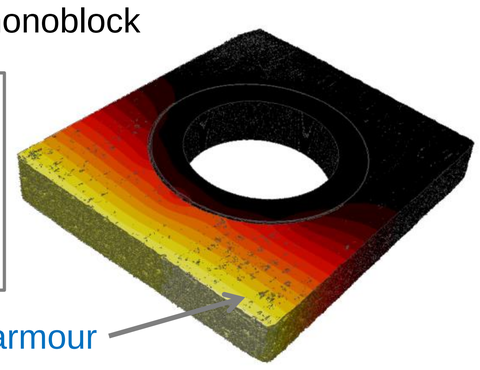
- Control is key
- Accommodate uncertainties

PFCs - combined neutron and thermomechanical loads

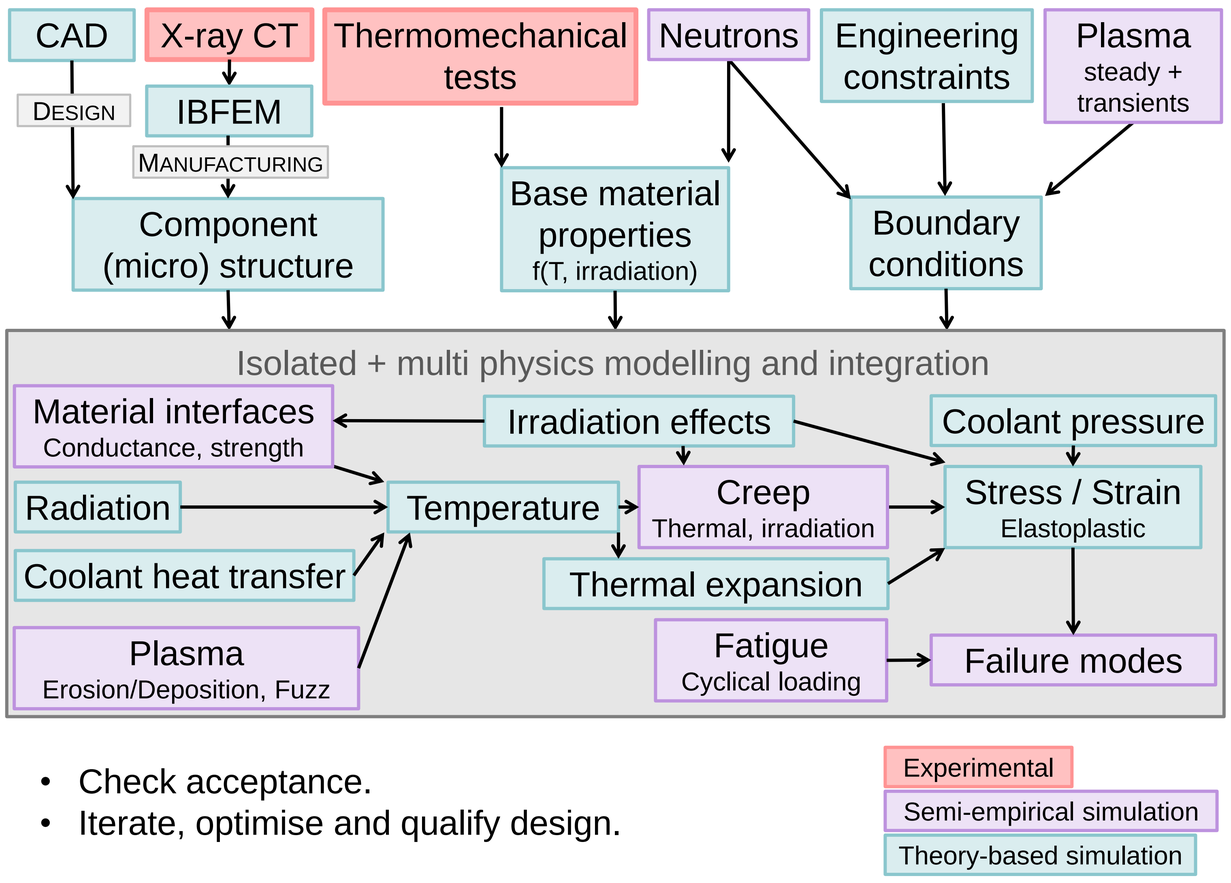
Temperature distribution in a CFC-copper pipe monoblock

Example of uncertainty reduction
Image-Based FEM analysis (Virtual Prototype)

- Understand **'as built'** performance in detail.
- **Optimise manufacture** processes.
- **Mitigate risk** in components life-cycle.



Traceable performance calculations assist component qualification:



- Check acceptance.
- Iterate, optimise and qualify design.

Summary

- Development of the 'qualification stepladder' + the tools to climb it is key.
- Include qualification factors in concept choice and design phases.
- Theory and modelling will play a critical role in qualification at all stages.
- Validate theory and modelling with experiment.
- Use theory and modelling to assess final integration of multiple sub-systems.
- Quantify the impact of untested (untestable) aspects of the final environment.
- Aim to qualify integrated design without full scale functional tests.

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To obtain further information on the data and models underlying this paper please contact PublicationsManager@ccfe.ac.uk.