Contribution ID: **33** Type: **Talk**

Systematic development of breeder blankets using model-based systems engineering (MBSE) and a new systems-simulation library

Thursday 5 February 2026 17:10 (30 minutes)

The development of fusion power is heavily dependent on performant breeder blankets. They are key to achieving both fuel self-sufficiency and net power for a continuously operating powerplant. Yet breeder blankets remain at a low technology readiness level, with none yet tested in an operational tokamak environment. Achieving these key blanket functions, while also withstanding multiple thermal, structural and neutronic loads, provides an integrated design challenge for the blanket itself. This challenge must be fulfilled within the highly constrained environment of a tokamak, while integrating the blanket with the tritium-handling and power-generation functions of the powerplant.

In this work we demonstrate the development and down-selection of a blanket concept through the application of systems-engineering processes and systems simulation. Systems engineering is an industry-standard approach to enable the successful development of highly complex and integrated systems, such as a fusion powerplant. Here we apply model-based systems engineering (MBSE) to systematically gather requirements, evaluate risk for designs and define the verification activities to qualify a design. The outputs from this focus analysis work around risk reduction, and define the required virtual and physical qualification activities.

The definition of the blanket and its risks feeds into the down-selection of blanket concepts. We demonstrate this down-selection, initially from material choices and potential architectures to a shortlist of concepts. This shortlist is evaluated in a fast, consistent and repeatable manner using systems simulation and automated workflows. A new systems-simulation library, ARTEMIS, has been developed using Modelica to quickly enable representation of new concepts and their assessment for a wide design space. The systems simulations are linked in automated workflows to neutronics simulations in OpenMC to enable, in this first stage, integrated neutronic-hydraulic-thermal-structural analysis. The analysis workflow is then linked directly back to the set of requirements for the blanket, defined using MBSE. This provides a comparative assessment between blanket architectures and designs to enable design-driving decisions.

We demonstrate the analysis and down-selection process for a pin-breeder
architecture, demonstrating how this approach enables quantitative assessment of the trade-offs inherent in the designs and the size of the design space, as well as optimisation for a best-performing design.

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Session Classification: Session 3-12

Track Classification: LIBRTI Conference