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Design Exploration and Technology Development of the STEP Li2O Ceramic Breeder Blanket

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The breeder blanket for the STEP Prototype Powerplant (SPP) must provide high performance breeding for a spherical tokamak without inboard breeding, materials and coolant compatible with a 600 ℃ outlet temperature for net power confidence, and a system deliverable on the targeted timescales of the STEP programme. Following a comprehensive assessment of all breeder, coolant, and structural material options, solid ceramic lithium oxide (Li2O) has been selected together with a Ti-modified austenitic stainless steel structural material, CO2 coolant, and beryllium-based multiplier. This combination is considered to give the highest confidence of successfully meeting the SPP requirements.

However, engineering realisation of a deployable blanket on SPP timescales still requires rapid progress in design alongside fail-fast testing and technology demonstration, with continuous iterative feedback between the two. Underpinning this must be a clear definition of requirements, constraints, and areas of uncertainty to drive robust performance development. This paper details initial scoping of the design space and the technology development needs of the chosen system.

For the chosen palette of materials, identifying a performant architecture presents initial design challenges around achieving sufficient tritium breeding performance, respecting material temperature limits through robust heat management and hydraulic design, and ensuring compliance against availability and reliability requirements. We first present and explore these constraints for the SPP blanket. For an assumed annular pin geometry, analysis revealed that peak temperatures of breeder material below 900 ℃ can be achieved by varying pin dimensions, but this has a consequent trade-off with structural volume content (and hence tritium breeding ratio), and total part number (and hence reliability performance). A wider exploration of potential blanket architectures is being pursued, informed by this learning, with a view to downselection of a preferred architecture.

Meanwhile, use of Li2O as a breeder material has been well documented in literature to present challenges with material degradation, most frequently citing irradiation swelling, LiOH formation, and structural material compatibility. However, these issues have a strong dependence on temperature, environment, and operational duty cycle. The issues have therefore been reviewed from first principles and revisited in the context of the SPP requirements. From this, SPP-specific design constraints and opportunities have been identified that further refine understanding of the Li2O breeder blanket design space and feed back into the design process. Remaining uncertainties and risks have led to a set of prioritised steps for testing and technology demonstration. Preliminary screening of the extent of degradation mechanisms (and sensitivity to operationally controllable parameters) can be carried out in unirradiated environment, before more costly and time-intensive irradiation tests are required. In the longer term, scale-up towards component-level functional testing is required, aiming for proof of mechanical, thermal, and electromagnetic performance demonstration, in parallel with nuclear and tritium transport performance demonstration. A timeline for this suite of development needs will be presented to give an overall outlook for development of the Li2O blanket concept.

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