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Latest developments on the commercial self-cooled lithium-lead fusion reactor blanket SCYLLA©

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Introduction

The breeding blanket is a vital component for any demonstration and commercial fusion reactor that uses D-T fuels (D:deuterium, T:tritium). T needs to be bred by neutrons reacting with lithium mainly via the ^{6}Li(n,α)t neutron reaction. The Self-Cooled Yuryo Lithium Lead Advanced (SCYLLA©) blanket is a Self-Cooled Lithium Lead (SCLL) commercial concept in development at Kyoto Fusioneering (KF) [1]. Liquid lithium lead (molten metal, LiPb) will flow in silicon carbide composite (SiC_f/SiC) coolant channels at very high temperatures, generating heat and T from mainly thermal neutrons generated with DT fusion reaction.

Research and development (R&D) programme

SCLL blankets have several advantages over other blanket concepts:

- Easy access to the breeding material during operation, e.g. for replacement/addition of Li.
- Only one fluid as coolant and breeding material simplifies the auxiliary systems.
- Low T solubility may allow simpler extraction.
- Very high temperature allows for other processes (hydrogen, process heat, etc).

SCLL sees several challenges, which are addressed by the KF research and development program:

- SiC_f/SiC manufacturing including interfacing with first wall (FW) materials and piping is expensive and/or at low technical readiness.
- Unknowns regarding T extraction efficiency, magneto-hydrodynamic effect due to high B-field of magnets, heat transfer at FW, and heat exchanger (HX) design and permeation.
- Primary coolant has high T concentration and T transport; permeation has to be studied carefully.

Status and Outlook

Currently the main effort is driving the industrial capabilities to manufacture large component parts and complex shapes using SiC_f/SiC. A 10x10x10 cm³ box has been manufactured and currently a flow channel divider is being inserted (cf. Fig. 1). In the first phase of SCYLLA© development the box will be connected to a LiPb loop on the UNITY facility for experimentation [2], which will also address the additional issues of T extraction, T processing, and heat exchange. The SiC_f/SiC box will be exposed to 1 MW/m² surface heating. Additionally volumetric heating can be added which, in combination, simulates the heat flux experienced at the equatorial plane in an EU DEMO-type reactor. A temperature increase of about 500 K is expected to occur. Currently flow channel optimisations are performed via simulations (see Fig. 1) making use of buoyancy to reduce the pressure drop. The LiPb flow and heat distribution, including impact on FW temperature, will be verified in the experiment.

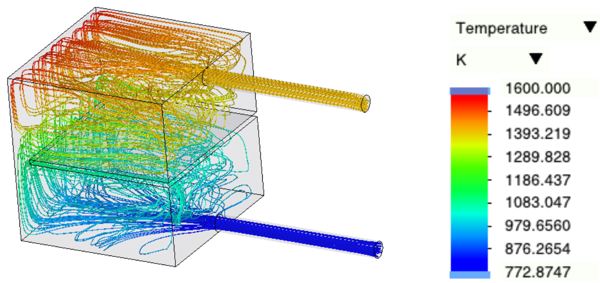

Figure 1: Thermal flow analysis of SCYLLA© blanket module showing the LiPb temperatures.

Only two materials, molybdenum and SiC_f/SiC, have been identified that can work for the piping to connect the ~1000°C LiPb stream to the HX of the UNITY experiment. Both materials will be tested as piping materials, which is also the first time large SiC_f/SiC tubes will be used for the coolant. SiC_f/SiC samples have been produced with a proprietary grade that resolves the degradation of pyrolytic C-interface under strong irradiation. Tungsten has been bonded to this grade of SiC_f/SiC. The samples are planned to be irradiated with Si^+ ions in the UK, starting at the end of 2022. Larger blanket modules reaching Test Blanket Module size are planned for phase 2 and 3 until 2026. This presentation will provide details on all technical aspects as well as commercialisation.

[1] R. Pearson et al., 2022, IEEE Transactions on Plasma Science, DOI: 10.1109/TPS.2022.3211410
[2] S. Takeda et al., 2022, Fusion Science and Technology TOFE 2022 Special Issue (under review)