Design Studies on Advanced Self-Cooled Liquid Test Blanket Modules for JA DEMO

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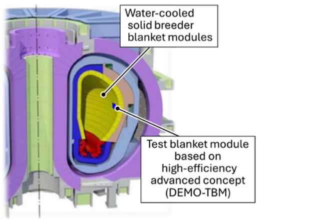
Abstract

- A self-cooled LiPb concept has been selected as the first candidate of a test blanket module (TBM) for a DEMO reactor of Japan (JA DEMO).
- In the present paper, the proposed structure of the LiPb DEMO-TBM and the feasibility evaluations mainly from the viewpoint of first wall cooling and MHD pressure drop are described.

DEMO-TBM for JA-DEMO

- In the Japan's fusion demonstration reactor (JA DEMO), electricity generation will be demonstrated with the water-cooled solid breeder blanket system [1, 2].
- In the later period of the operation, advanced blanket concepts which could achieve higher efficiency power generation are planned to be tested by installing test blanket modules (DEMO-TBMs).

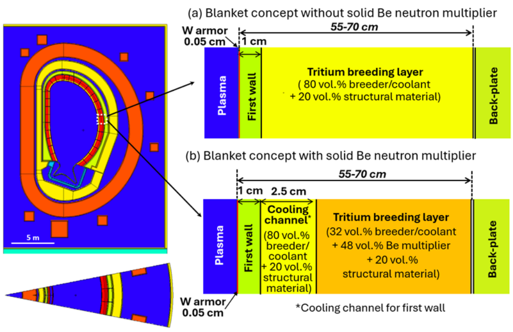
[1] TOBITA, K., et al., "Overview of the DEMO conceptual design activity in Japan", Fusion Engineering and Design 136 (2018) 1024–1031.
[2] SOMEYA, Y., et al., "Development of water-cooled cylindrical blanket in JA DEMO", Nucl. Fusion 64 (2024) 046025.



Test blanket module for JA DEMO (DEMO-TBM) (Position and dimensions have not been decided.)

Tritium breeding performances of liquid blanket concepts

- Tritium breeding ratios (TBRs) of self-cooled liquid blanket concepts were evaluated assuming that all the water-cooled solid breeder blanket modules were replaced by self-cooled liquid blanket modules.

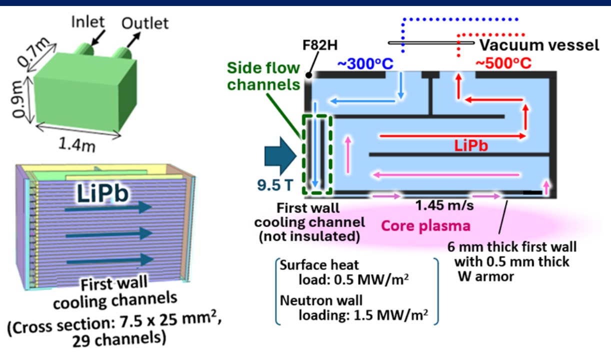


Blanket concept	Tritium breeding ratio
Li/V* (Enrichment of ^{6}Li: 7.5%)	1.08
Li/V (35%)	1.18
Li+Be/V (7.5%)	1.43
Li+Be/V (90%)	1.50
LiPb/RAFMs** (90%)	1.13
FLiBe+Be/RAFMs (90%)	1.31
FLiNaBe+Be/RAFMs (90%)	1.25

* Vanadium alloy
** Reduced activation ferritic/martensitic steel

Calculation geometry for neutron transport and evaluated TBRs.

Proposed structure of self-cooled LiPb DEMO-TBM



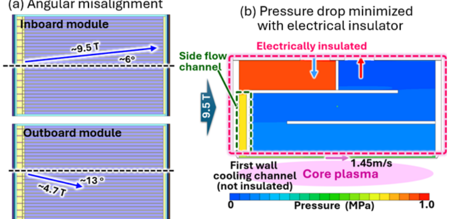
Proposed structure of self-cooled LiPb DEMO-TBM.

- Straight magnetic field lines and cooling channels are assumed to obtain the perspectives on feasibility of the proposed TBM design.
- Since the magnetic field lines in the reactor are curved along the toroidal direction of the torus, <u>the first wall cooling channels in the actual blanket modules would also be curved along the magnetic field lines.</u>

- Design modification on the wall thicknesses, edge shapes of the module and coolant channels, etc. is planned to be performed based on temperature control and mechanical stress analysis.
- Investigation of self-cooled molten salt TBM, i.e., FLiBe and FLiNaBe, has also been started for a similar TBM structure.

Feasibility evaluations for self-cooled LiPb DEMO-TBM

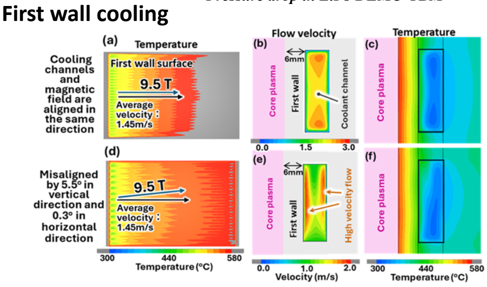
MHD pressure drop



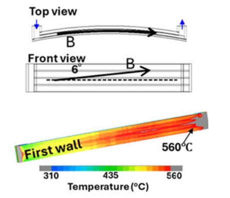
Pressure drop in LiPb DEMO-TBM

- No electrical insulation: ~6 MPa.
- With insulation for the side flow channel : ~2.3 MPa.
- With Insulation for other than the first wall channels: ~1.0 MPa.

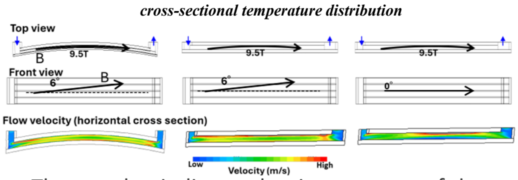
First wall cooling



Surface temperature distribution, flow velocity distribution and cross-sectional temperature distribution



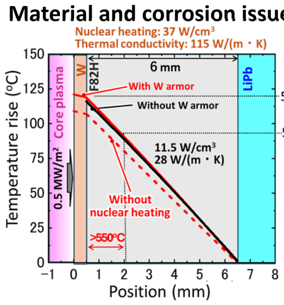
Example of temperature distribution calculated with curved cooling channels and curved magnetic field.



Changes in velocity distribution according to magnetic field direction

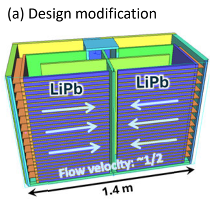
- The results indicate the importance of heat removal enhancement utilizing the characteristics of a liquid metal flow under an intense magnetic field.

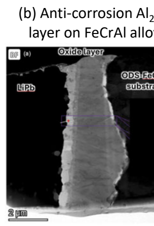
Material and corrosion issues



Temperature distribution in a 6 mm thick F82H first wall

- The front region within ~2 mm from the first wall surface exceeds 550°C.



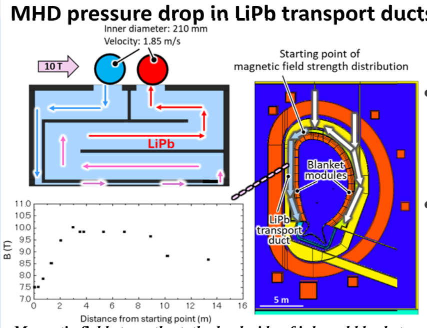


KONDO, M., et al., "Chemical and structural durability of α-Al_2O_3 and γ-$LiAlO_2$ layers formed on ODS FeCrAl alloys in liquid lithium lead stirred flow", Corrosion Science 240 (2024) 112459. (Fig. 11, labels are added).

Efforts to mitigate corrosion in first wall cooling channels

- Corrosion due to the high velocity flows has been one of important concerns.
- Efforts to mitigate the corrosion issue are being conducted.

MHD pressure drop in LiPb transport ducts



Magnetic field strength at the back side of inboard blanket modules

- MHD pressure drop in transport ducts could be suppressed by electrical insulation. (417 MPa ➔ 1.5 MPa)
- Further reduction could be possible by modification in duct configuration (increasing the number of ducts).

Conclusion

- Angular misalignment between the first wall cooling channel and magnetic field induces high velocity flow layers in the coolant flow.➔ This is essential to enhance the heat removal performance.
- The magnitude of MHD pressure drop in the TBM system could be suppressed to an acceptable level with appropriate electrical insulation.

Acknowledgement

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