Building High Temperature Liquid Lithium Systems: Lessons for Liquid Metal Engineering

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1. Oxford Sigma's interest in liquid metal engineering: Qualifying materials for in-service use in liquid metal environments

ASME Section III Appendix FBB-B – Guidelines and Qualification

ASME Section III Appendix FBB-B addresses the environmental degradation of fusion reactor components exposed to molten metals such as **Li** and **Pb-Li**. This appendix aims to outline key **degradation mechanisms**—including corrosion, erosion, and liquid metal embrittlement—alongside the effects of key **chemical impurities** including **N, O,** and **C**.

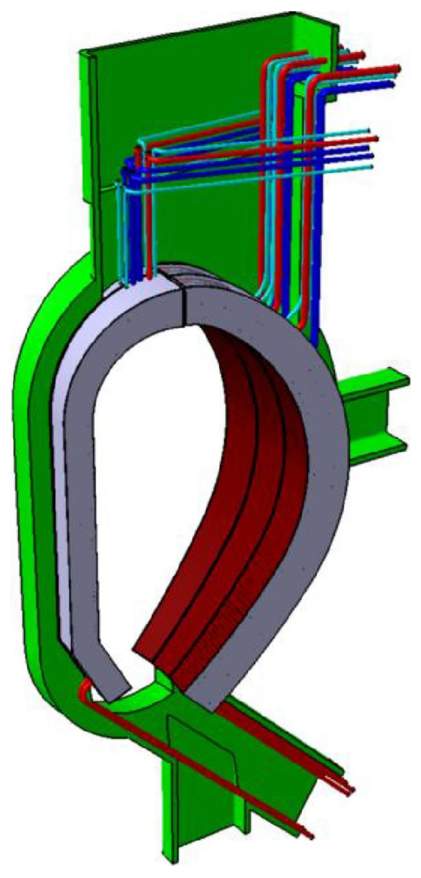
Appendix FBB-B will present recommended **mitigation and monitoring** strategies, such as **impurity control**, material selection, and **in-situ sensing**, to describe standardised testing methodologies used to evaluate material performance under relevant operating conditions, **including:**

Static Tests: Saturation-limited corrosion

Stirring Tests: Enhanced erosion-corrosion

Flowing Tests: Continuous mass loss due to thermal gradients

EU DEMO WCLL BB Sector, Martelli *et al.* (2018)



Key Impurities: $(Li,Na)_2O$, $(Li,Na)_3N$

Degradation Mechanisms: Dissolution; Erosion & Corrosion; Liquid Metal Embrittlement (LME); Phase Transformation; Impurity-Induced Precipitation & Delamination; Grain Boundary Penetration

(100% Li and 17% Li-83% Pb, at.%)

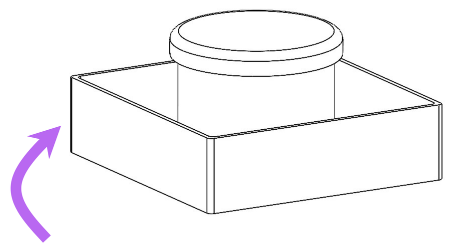
Mitigation & Monitoring Strategies

- Cold traps, getters, and filtration systems
- High-purity material selection and coatings
- In-situ sensors and mass spectrometry
- Sampling techniques (ICP-AES, ammonia titration)

This framework supports the qualification of fusion components and informs design, inspection, and life extension programs.

Informs design, inspection, and life extension → Encourage proactive consideration of degradation → Support future ASME updates based on operational data → Align with ASME Section III Appendix W for **fusion systems**

2. Corrosion research for mechanistic understanding

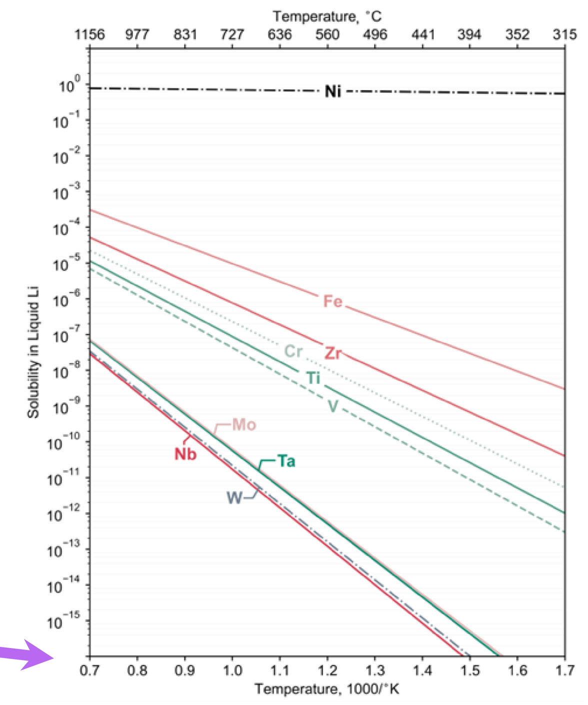


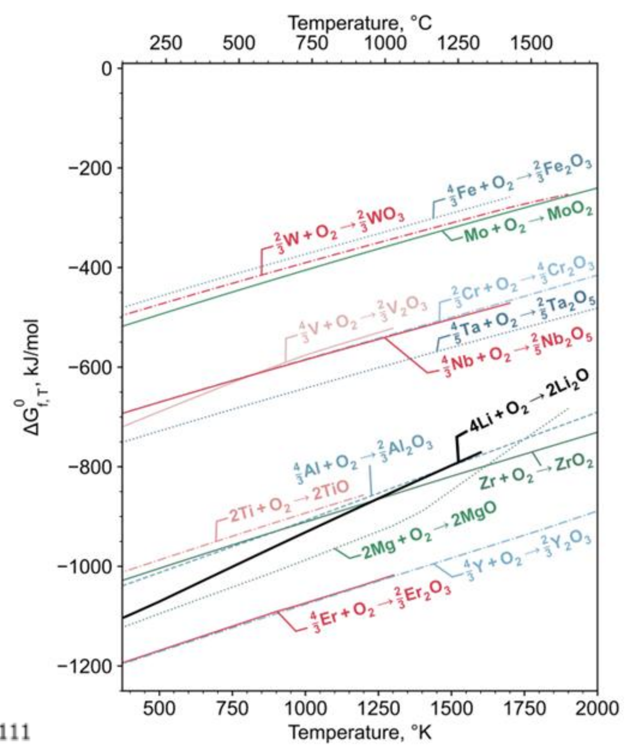
Using existing techniques for the exposure of materials samples to static, high temperature liquid lithium environments, Oxford Sigma is leading efforts to develop fundamental understanding of materials degradation in liquid metals in collaboration with the University of Birmingham.

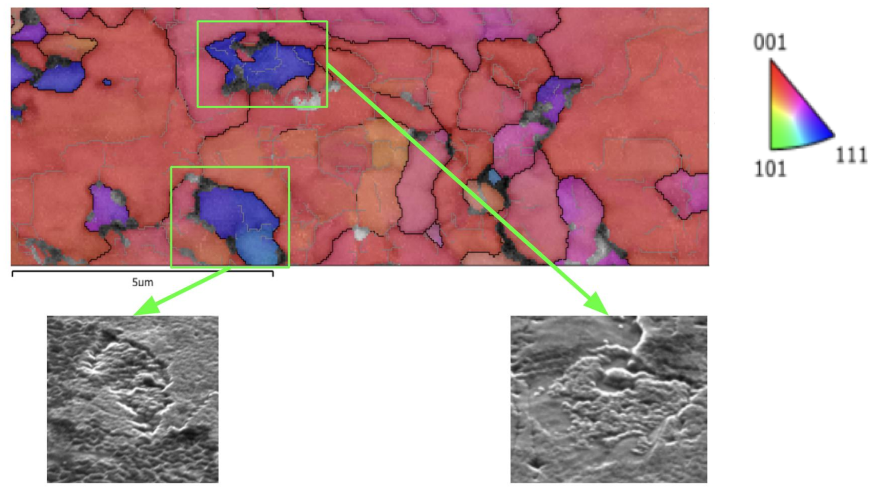
Collating fundamental properties to correlate and gain mechanistic understandings to predict behaviour.

Evaluating the effect of lithium exposure on mechanical properties and structural integrity.

Exploring the effects of crystallographic orientation on the material corrosion to inform preferential component texturing.

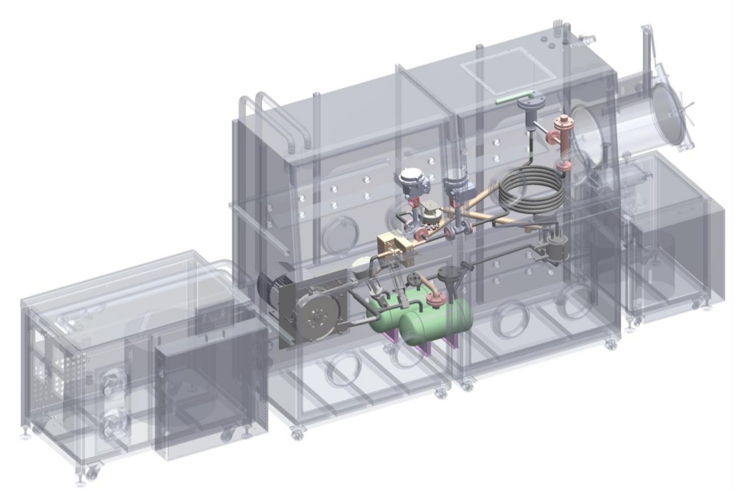


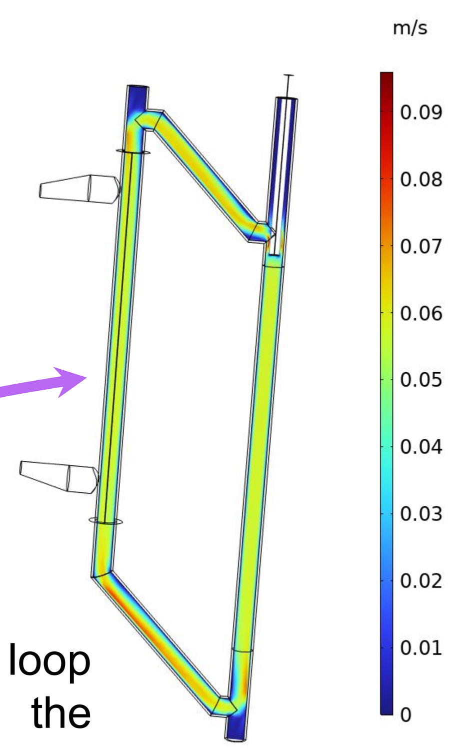




Data collated from:
Knacke et al., 1991
Muroga & Pint, 2010
de Boer et al., 1988

3. Concept and engineering design of systems

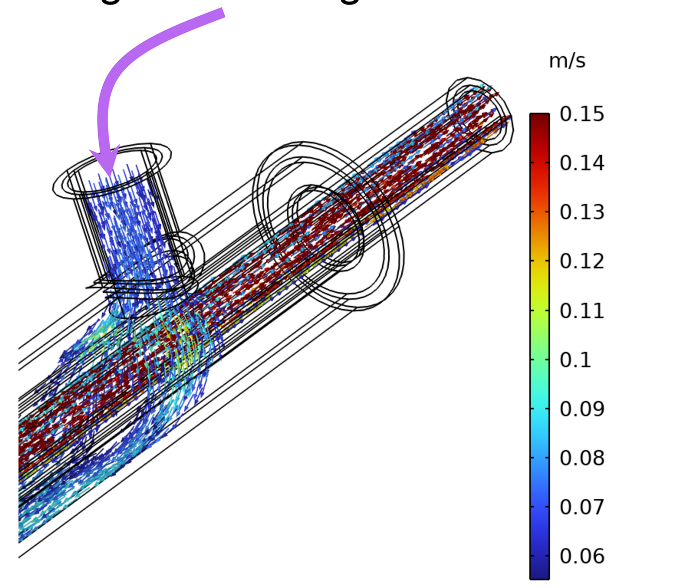




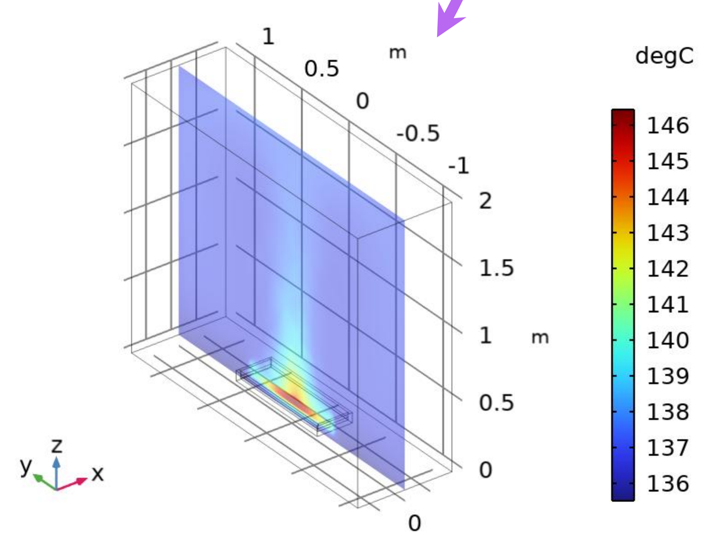
Concept design for a natural, thermal convection loop and a pumped, forced convection loop to enable the testing of materials samples in representative conditions.

Detailed **component design** to enable operation of the loops, such as safe and effective heat exchangers for fluid heating and cooling.

Analysis for substantiation of the **safety case** for operation of experimental facilities.



Pipe-in-pipe heat exchanger modelling



Analysis of heating effect due to fire

4. Experimental de-risking activities

Operational needs for system diagnostics and monitoring. For example, calibrating and verifying the performance of **level sensors** in the operational system. Or, verifying the sealing of the joint design to be used in piping systems.

Corrosion screening tests to demonstrate the expected structural integrity of key parts over the testing duration.

Assessing the integrity of barriers for the purpose of maintaining the purity of the environment.

5. Primary recommendations

Community-wide need for **off-the-shelf sub-components** such as specialist sensing and purity testing equipment.

Standardised methods for comparable testing across facilities.

Collaborative approach to **safety case** development for safe and reliable operation of systems across the industry.

Targeted development of understanding to address key barriers to end application deployment including identification of the necessary allowances in structural design.