Kyoto Fusioneering: Materials Compatibility Testing Facilities

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IAEA Technical Meeting on Compatibility Between Coolants and Materials for Fusion Facilities and Advanced Fission Reactors
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31st Oct 2023

Reuben Holmes

Contents

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KF Overview

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- Design and develop **critical path non-plasma-core systems**
- Support fusion developers and **enable an accelerated path to commercialisation**
- Building on a foundation of advanced **fusion plant engineering technology from Kyoto University**
- Bring **Japanese industrial technology** to the global fusion industry

Founded in **2019**

100+ Members

$91m Raised

3 Countries

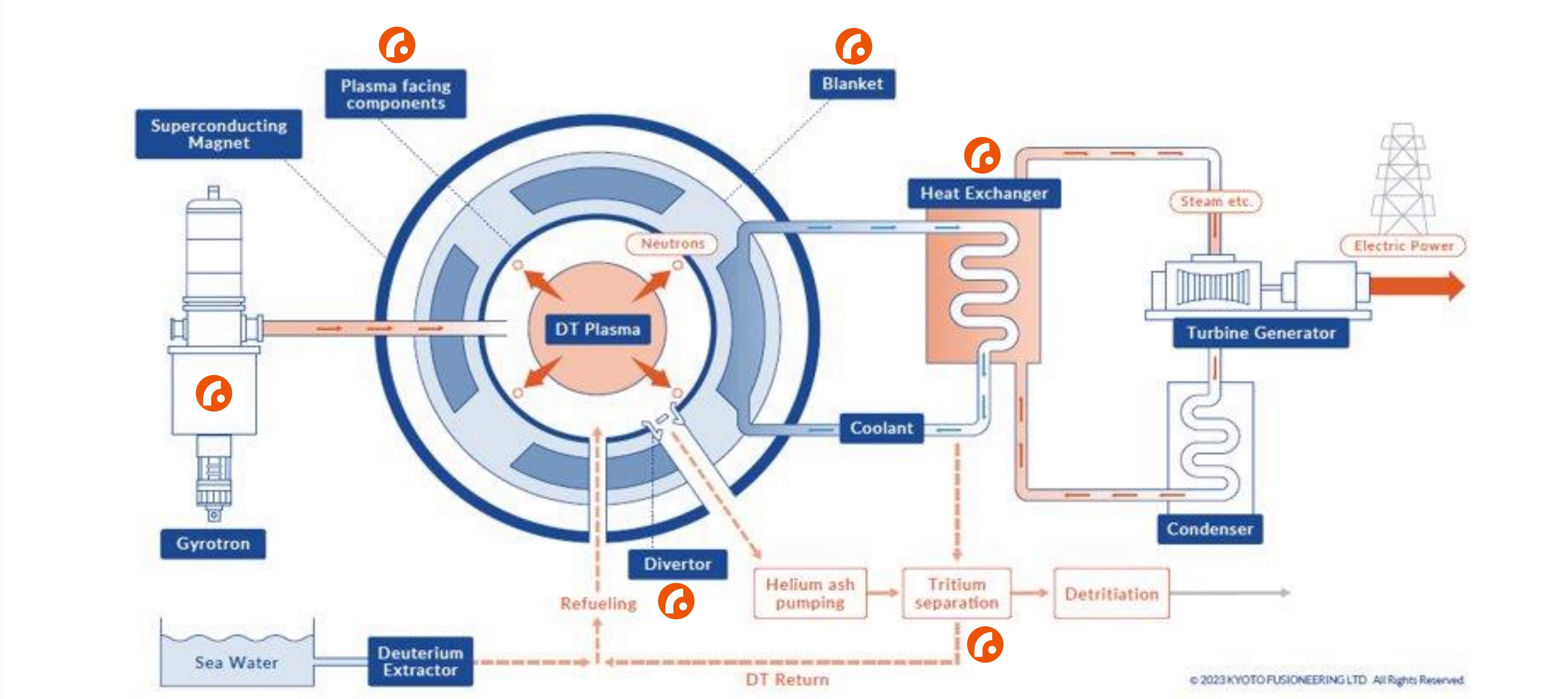
JP

US

UK

FUSIONEERING = Fusion * Engineering

Focus Area



Fusion power plant integrated systems and components: plasma heating, power production, fusion fuel cycle

SCYLLA© Breeder Blanket

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Silicon Carbide Composites – Ceramic fibres in a ceramic matrix

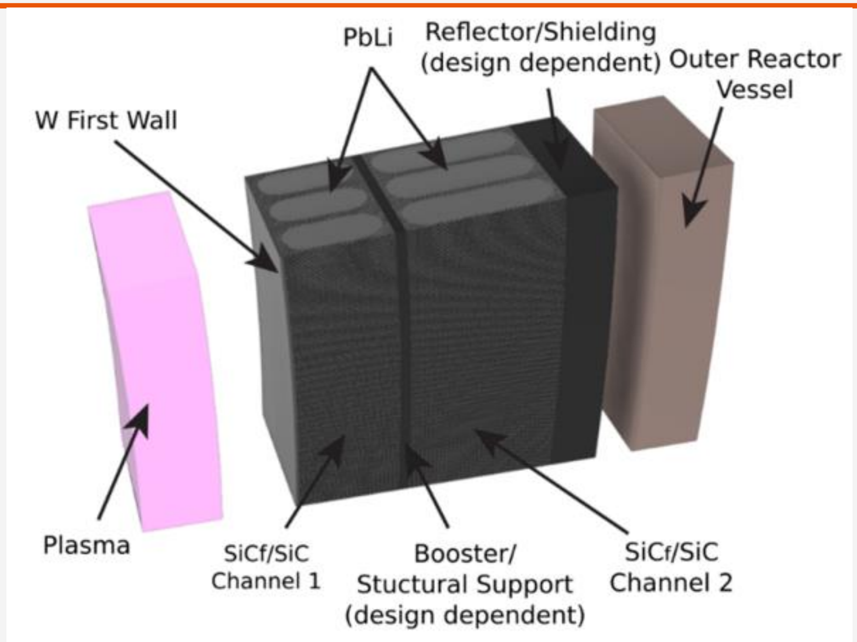
- High temperature operation – increased efficiency
- Relatively low neutron absorption cross-section
- Relatively low neutron activation and shorter half-lives
- Relatively low tritium permeability

SiC_f/SiC Development

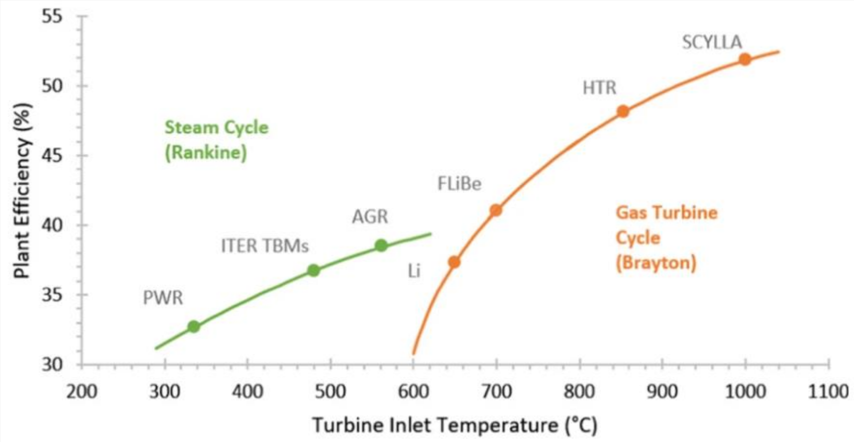
- Different processing methods: CVI, PiP, CVD, NITE, etc.
- Different properties: density, crystallinity, hermeticity, thermal conductivity, and chemical stability
- Challenges remain for characterising, joining, etc.

Coolant Options – High T, Breeding, Corrosion

- LiPb
- FLiBe
- Li



SCYLLA © Breeder Blanket Concept (Pearson, 2022)



Plant Efficiency vs Temperature (Baus, 2023)

SiC_f/SiC Coolant Compatibility – LiPb

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Conditions

- 400 – 1200 ºC, 100 – 5000 hours
- Static and flowing (up to ~0.5 ms^{-1})
- Various types of SiC_f/SiC

Key Conclusions

- **Below 1000 ºC**, corrosion is generally low, with CVD-type SiC composites seemingly the most stable
- At **1100 and 1200 ºC**, Si conc. in LiPb increased, suggesting corrosion
- **Impurities in LiPb** greatly influence the character of the corrosion layer: Li_2O, Al and Y (sintering), Ni, Cr and Fe (alloys), C forming carbides
- Seemingly low impact of **flow velocity**

Reference Study	SiC Composite Material	Static/Flowing LiPb	Time	Temperature
Barbier (2002)	CVI SiC: as-received and scratched surfaces	Static	3000 h	800 ºC
Pint (2007)	Monolithic CVD β-SiC	Static	5000 h 2000 h 1000 h	800 ºC 1100 ºC 1200 ºC
Zhu (2009)	PiP SiC with CVD SiC coating	Static	500 h	700 ºC
Zhao (2010)	PiP SiC with and without CVD β-SiC coating	Static (Fe, Cr and Ni impurities)	500 h	700 ºC
Ling (2011)	PiP SiC with and without CVD β-SiC coating	Static	200 h 1000 h	800 ºC 800 ºC
Park (2011)	NITE SiC with fibre coated with C	Flowing (0.1-0.37 ms^{-1})	1000 h	900 ºC
Tosti (2013)	CVI SiC	Static	100 h	400 ºC
Pint (2013)	CVD SiC	Static	1000 h 1000 h 1000 h	500 ºC 600 ºC 700 ºC
Park (2018)	CVD SiC and CVI SiC	Flowing (~0.1-0.5 ms^{-1})	1800 h 3000 h	900 ºC 700 ºC
		Static	1000 h	900 ºC
Pint (2021)	CVD SiC	Flowing (~0.95 cms^{-1})	1000 h	600-700 ºC
Romedenne (2023)	CVD SiC	Flowing (~0.07 cms^{-1})	1000 h	550-650 ºC

SiC_f/SiC Coolant Compatibility – FLiBe

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Conditions

- 550 – 750 ºC, 24 – 1000 hours
- Static
- Various types of SiC_f/SiC
- Due to difficulties in handling Be, data is sparse (more data available for FLiNaK)

Reference Study	SiC Composite Material	Static/Flowing FLiBe	Time	Temperature
Nishimura (2000)	Monolithic SiC	Static	24, 72 and 240 h	550 ºC
Cao (2016)	CVI and CVD SiC	Static(?)	1000 h	700 ºC
Pint (2020)	Various CVD SiC: CVD SiC, High-resistivity, Low-resistivity, α-SiC, Graphite + pyrolytic C Various CVI SiC: Hi-Nicalon Type 2 fibres, Tyranno SA3 fibres	Static	500 h 1000 h 1000 h	750 ºC 650 ºC 750 ºC

Key Conclusions

- **Little difference** in corrosion rates in the range 650 – 750 ºC
- Generally, the **CVD SiC composites** seem to be more resistant to corrosion than CVI SiC
- **Impurities in FLiBe** appear to cause degradation of SiC (formation of $Ni_{31}Si_{12}$ due to Ni impurities)

Issues to be Resolved

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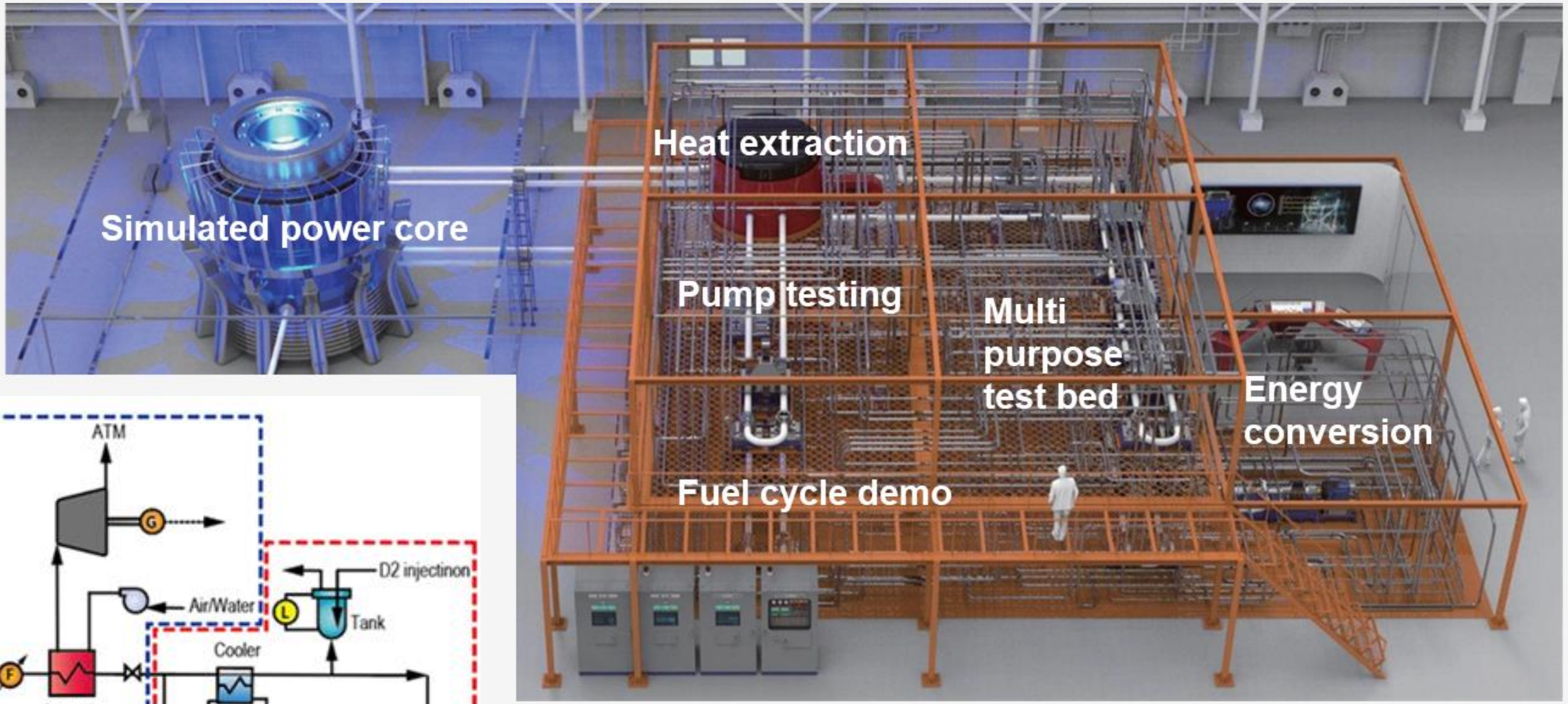
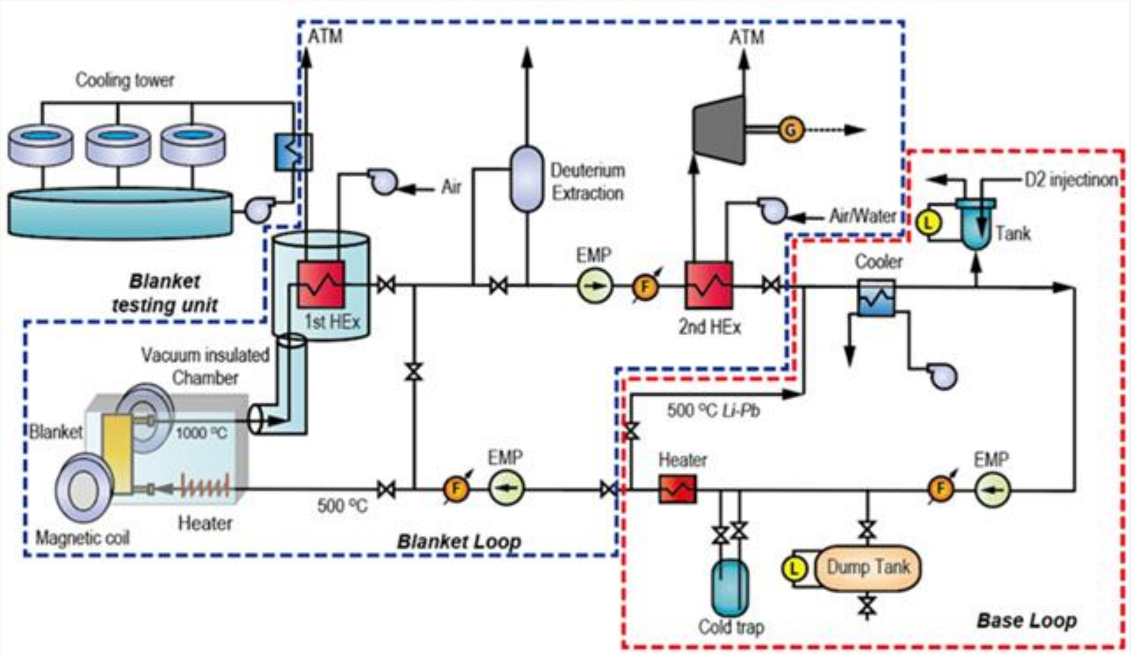
- **Long-term corrosion** experiments in flowing coolant under **neutron irradiation**;
- Flowing experiments with a **temperature gradient** and including SiC composites and structural alloys where **dissimilar interactions** may occur between SiC and Fe, Ni and Cr;
- Correlation between chemical degradation or corrosion and propagation of **micro-cracks**, and the time-dependent slow **crack growth** failure of fusion-grade SiC composites;
- **Cover gas solubility** and the expected **oxygen activity** during service;
- The impact of **irradiation on the behaviour of H isotopes** in SiC composites;
- The impact of adjusting the **Li:Pb ratio** on corrosion behaviour;
- The effect of **SiC composite microstructure** (e.g. grain boundary effects) on corrosion and susceptibility to form **localised attack**.

UNITY-1 Facility Development

UNITY-1 (under construction)

- Blanket test section (1000 °C)
- 300 L LiPb inventory
- FLiBe and Li loops to be added later
- 4T NbTi magnet
- Two heat exchangers and power conversion (*first electricity generation from a blanket module*)





Materials Testing

- Compatibility in flow conditions (up to 50 $Lmin^{-1}$)
- Impact of changing Li:Pb ratio
- FLiBe and Li piping material tests

Other Facilities – LiPb and FLiBe

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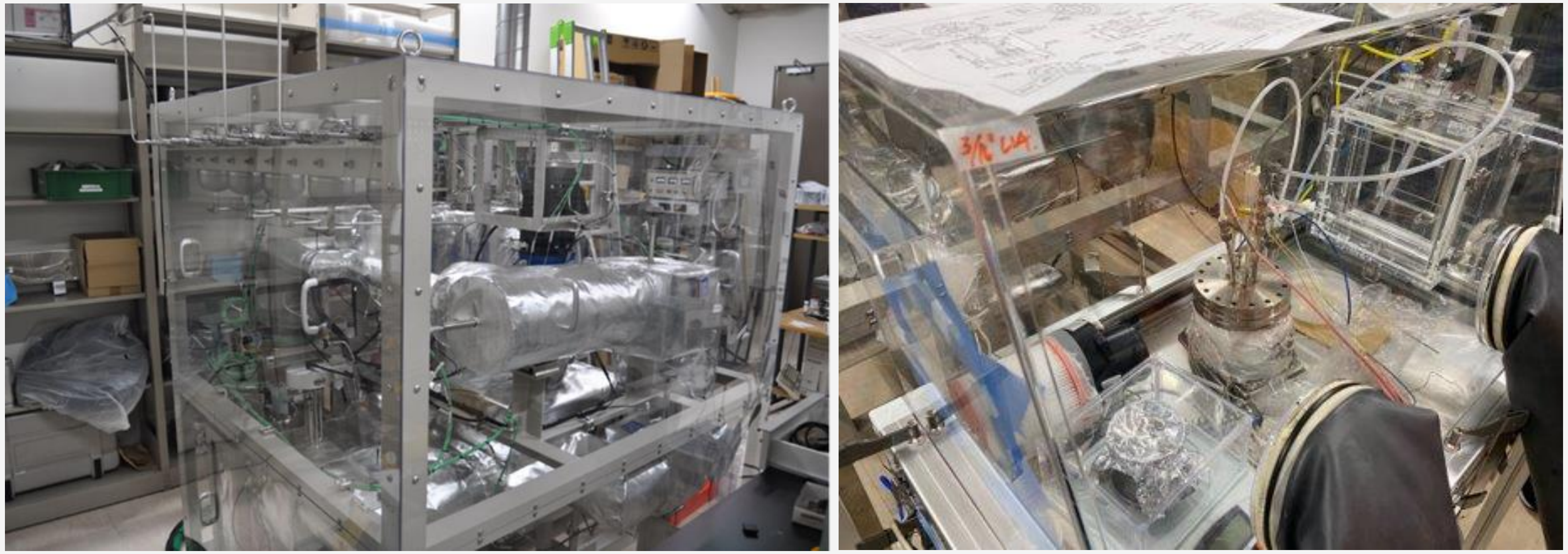
1) LiPb Loop (historic)

- Up to 926 ºC
- 10 L LiPb
- ~3 $Lmin^{-1}$
- Corrosion under flowing conditions

2) FLiBe Loop (commissioning)

- Up to 650 ºC
- 7 L FLiBe
- FLiBe refining system
- Coolant purification, corrosion under flowing conditions, tritium extraction (using D as proxy)

LiPb Loop, Kyoto University



FLiBe Loop (left), FLiBe Purification Glovebox (right)

Other Facilities – Li

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3) Li Loop (under construction)

- Up to ~600 ºC
- 3.7 kg Li
- ~10 $Lmin^{-1}$
- 9Cr-1Mo ferritic steel, Ni-free steel (SS430)

- SiC and Li are incompatible, but other materials offer promise for high-temperature applications: V, W, Mo, Ta, No and their alloys
- Could be suitable for heat exchangers and smaller components
  - Superior resistance to corrosion (up to 1300°C)
- Issues remain to be investigated:
  - Scarcity of raw materials
  - Manufacturability
  - Reactivity with impurities

Conclusions

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Understanding Corrosion in the SCYLLA© Breeder Blanket

- Existing literature provides a baseline for understanding corrosion of SiC_f/SiC composites in LiPb and FLiBe
- Further works include: long-term corrosion behaviour, impact of impurities, irradiation and temperature gradients, etc.

KF SiC_f/SiC Development

- SiC_f/SiC composites are still being optimised – existing corrosion data is a guide only
- Characterisation of SiC_f/SiC composites requires further work, and joints may require special attention for corrosion

KF Facility Development

- UNITY-1 is being built in Kyoto, Japan: High temperature LiPb flow loop with 4T magnetic field
- Additional experimental loops available or planned: LiPb and FLiBe loops (existing), Li loop (planned)

Scope for Collaboration

- KF is keen to work with others to share knowledge and experimental facilities

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ありがとうございます
Thank you

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