PRINCETON PLASMA PHYSICS LABORATORY

Introduction to liquid metal R&D priorities

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2nd MPEX Users Research Forum (SMURF), Sept. 13-14, 2021

Session Goals

- The purpose of this workshop is to get community input into the definition of the MPEX research program for the first 5 years
- The goal is to help formulate research questions, which are
  - appropriate to be addressed on a linear plasma device
  - make use of the unique capabilities of MPEX
    - MPEX will only allow alkali metals < 3.45 moles in vessel (*RM: this needs to be revisited)*

- This input will help the MPEX team to assess:
  - Early exploitation in parallel to high level commissioning
  - Need for target holder assembly modifications
  - Identification of additional diagnostics needs
  - Identification of potential material targets
  - Identification of first batch of irradiated (substrate) materials to be tested, if applicable

PFC development high priority in FESAC LRP

FST Rec: Increase focus on materials/tech

Recommendation: Rapidly expand the research and development effort in fusion materials and technology

- Constructing an FPP requires technology development beyond the burning plasma
- Critical enabling technologies such as plasma facing components structural and functional materials, and breeding blanket and tritium handling systems are currently not advanced enough for an FPP
  - At present levels of support, time to develop these technologies is incompatible with goal of an FPP by the 2040s
- Support foundational fusion materials & technology research
  - Theory and modeling, diagnostics systems, enabling technologies

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Liquid Metal PFC development highlighted in CPP Report

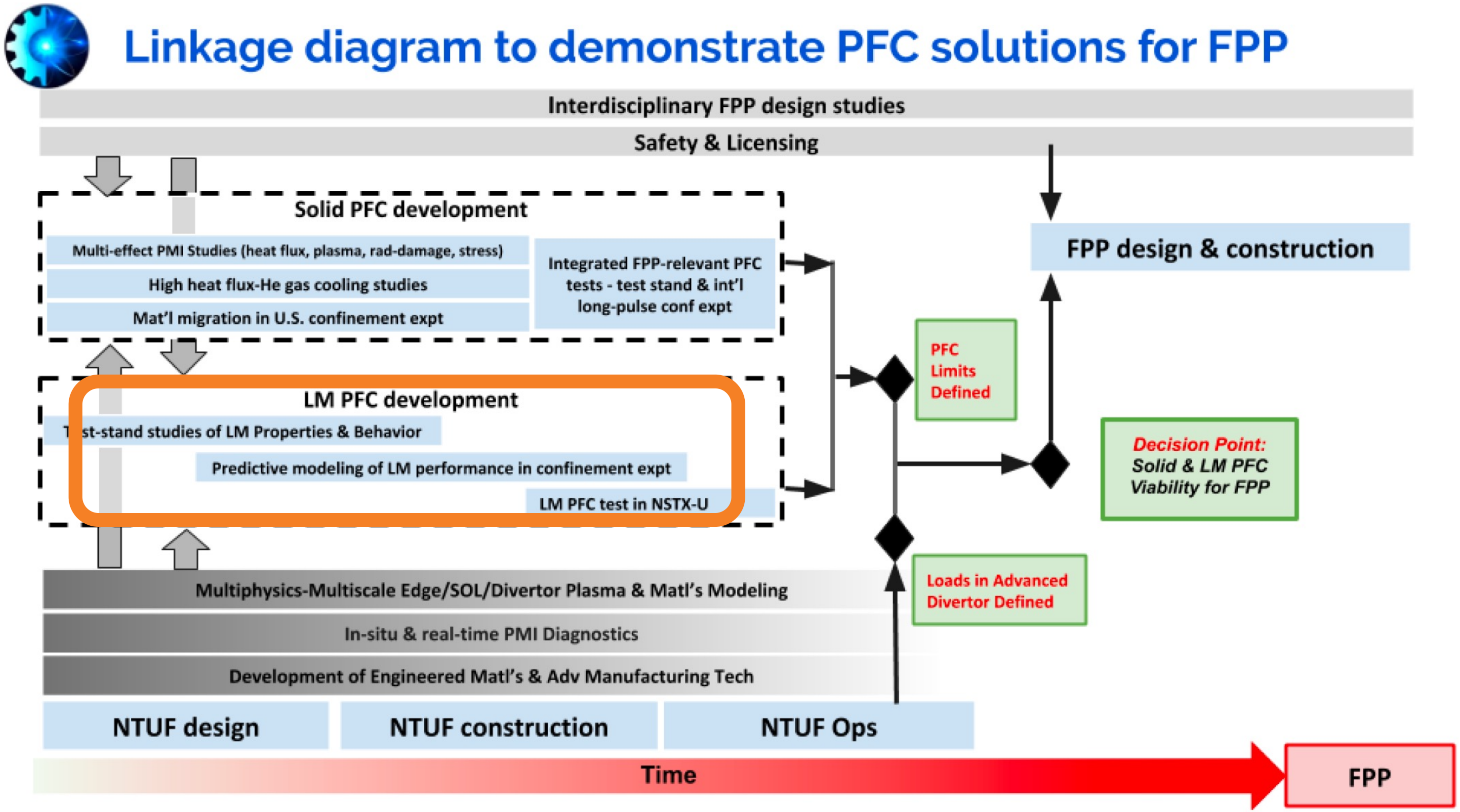

Figure FST-SO-A.1: Linkage diagram for FST-SO-A

Liquid metal PFC R&D recommended as a trnaformative innovation in FESAC LRP (& NASEM Pilot Plant) reports

FST Recommendation: Innovations

Recommendation: Strengthen the innovative and transformative research that offers promising opportunities for fusion energy commercialization: stellarators, liquid metal plasma facing components, inertial fusion energy and alternate concepts

➔ Four innovative areas aim to address key vulnerabilities of a solid PFC tokamak, potentially leading to attractive commercial fusion power by leveraging US leadership

- Stellarators offer intrinsically disruption-free operation with low recirculating power. The quasi-symmetric stellarator concept is unique to US and complemented by international collaboration at the W7-X and LHD stellarators. A new domestic mid-scale US stellarator experiment should be realized.
- Liquid metal PFCs potentially expand reactor wall power limits and alleviate lifetime constraints due to material erosion. Liquid lithium walls may open up pathways to high plasma confinement and compact FPP designs. Development of liquid metal PFC concepts should be targeted.

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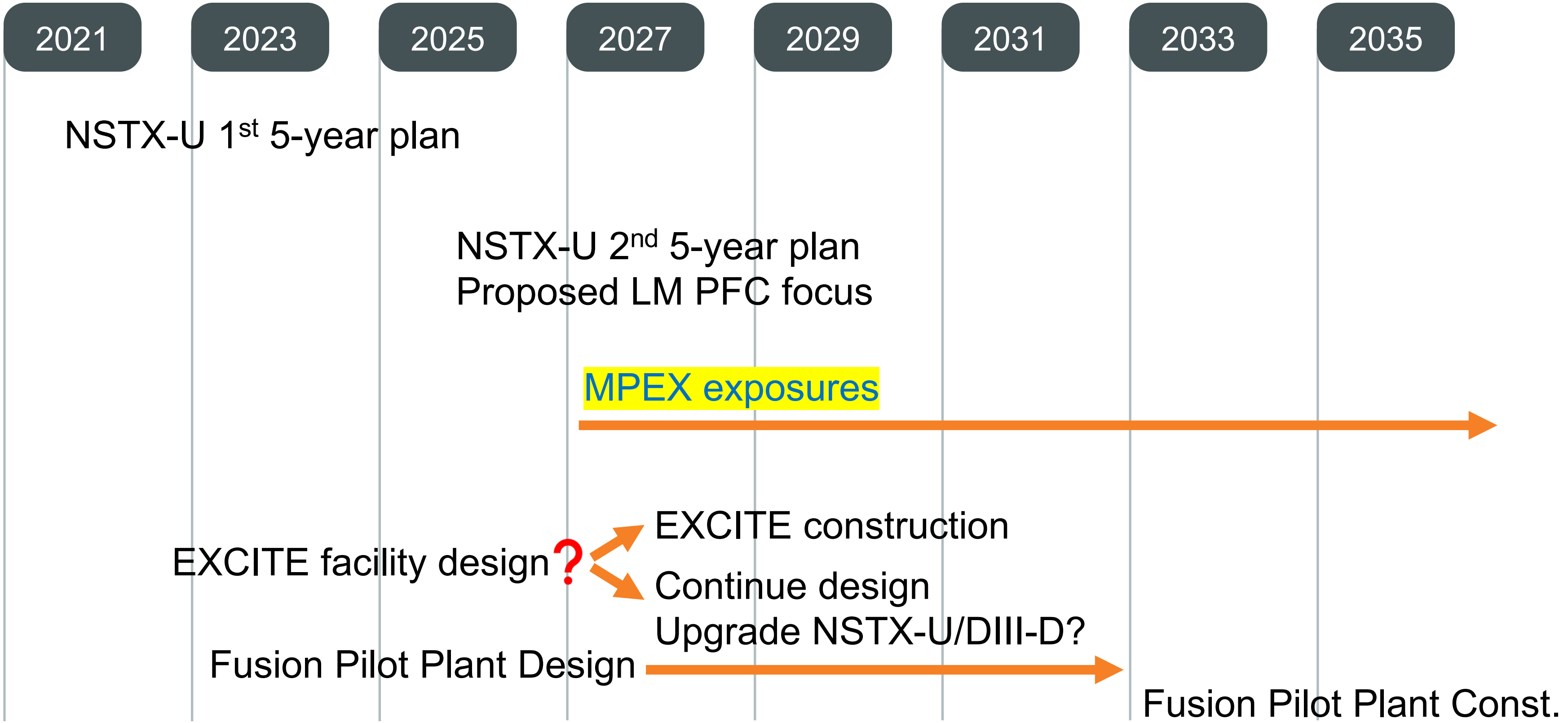
LM Research Needs from 2015 PMI and 2018 TEC reports

- Assess heat and particle exhaust limits of PFC designs: steady & transient *[progress in MAGNUM, EAST]* *
- Develop substrates & coolants for LM surface temperature control *
- Evaluate engineering and materials aspects
  - LM chemistry
  - Wetting and dry-out effects, PFC and wall coverage uniformity
  - Corrosion and embrittlement
  - Neutron damage of solid-based substrate materials
  - Flowing systems: transport of flowing conductive liquids
  - *Some of these issues being considered in **the domestic LM PFC development program***
- Investigate material migration (droplets, etc.) and develop inventory control
- Develop safety procedures in normal and accident scenarios
- Assess tritium transport, retention, and recovery mechanisms
- Assess compatibility with high-performance pedestal and high core confinement
  - Temperature window and vapor pressure limits
  - Reduced particle recycling and access to high confinement with lithium

*** Probable MPEX experiments**

FESAC LRP FPP R&D Timeline: 2021-2035



Initial Thoughts and Feedback

- The limit on in-vessel alkali metals is almost prohibitive. The LM PFC community's understanding was that MPEX was originally intended as a common platform to support both solid and liquid metal PFC evaluations.

- Can the water coolant be replaced by an alternate coolant (liquid or gas) that is not reactive with many alkali metals?
  - Does replacing water with an alternate non-reactive coolant alter the in-vessel limit?
  - Can we use silicone-based fluids, e.g. EC-704 (Tetramethyltetraphenyl-Trisiloxane) used by Youchison?

- Can a more sophisticated analysis be done to quantify the in-vessel alkali metal limit?

Agenda

- Introduction - Maingi (15 + 5 min)
- Needs for flowing systems - Andruczyk, input from Kolemen, Ruzic, Khodak (15 + 5 min)
- Needs for stagnant/creeping systems - Goldston (10 + 5 min)
- Needs for modeling validation of the plasma response to LM - Lore (10 + 5 min)
- Integration aspects with reactor designs - Kessel (15 + 5 min)
- Group input on other needs and feedback on presented material and MPEX assessments listed above - 30 minutes

- Action item: written report of session discussion (Allain and Maingi)

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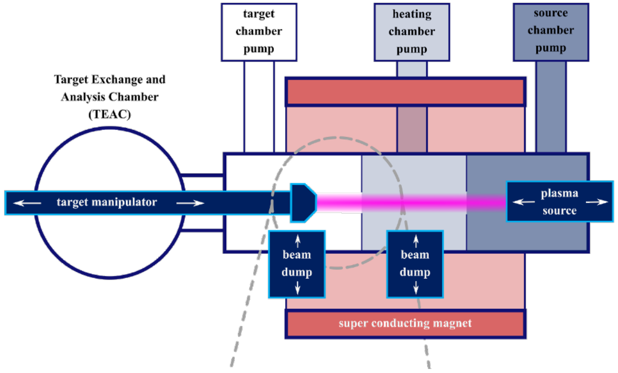
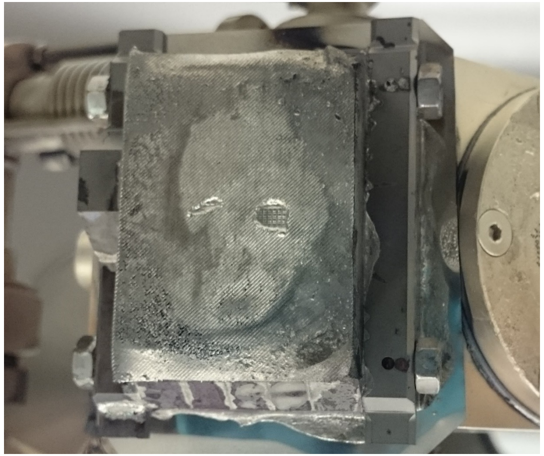
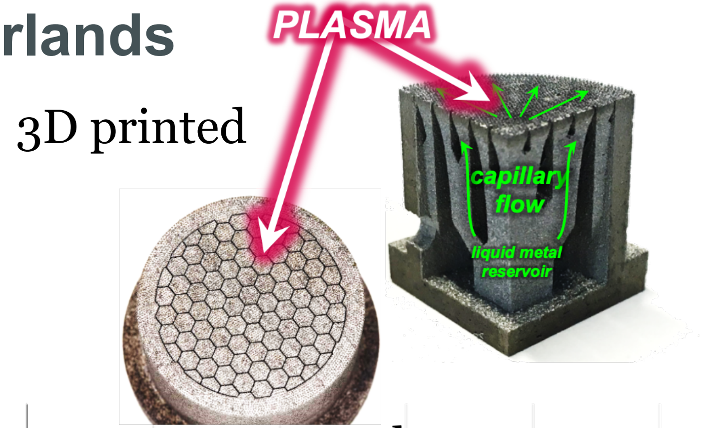
Backup

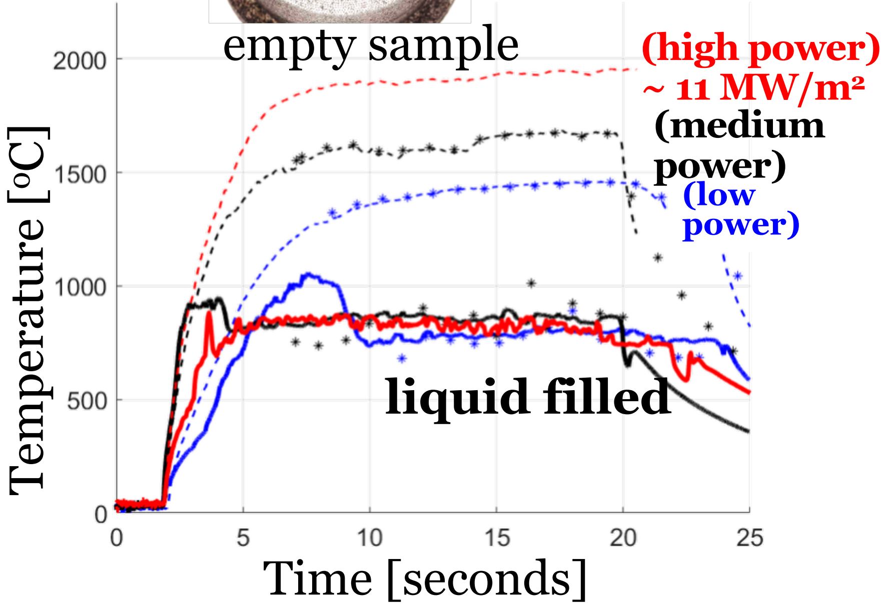
Liquid metal plasma-facing components are being tested in the MAGNUM-PSI test stand in the Netherlands



Conventional manufacturing



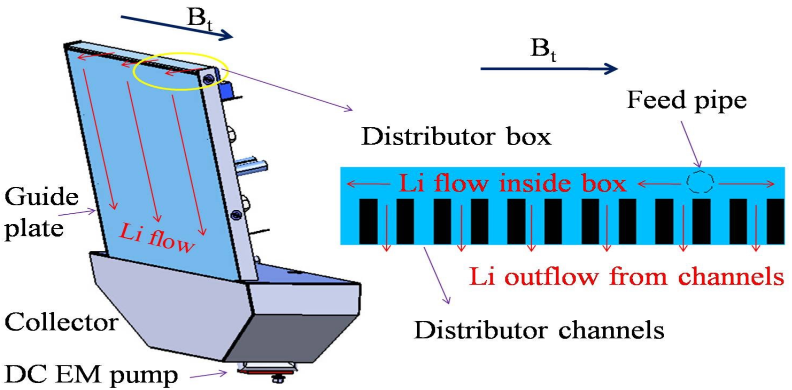


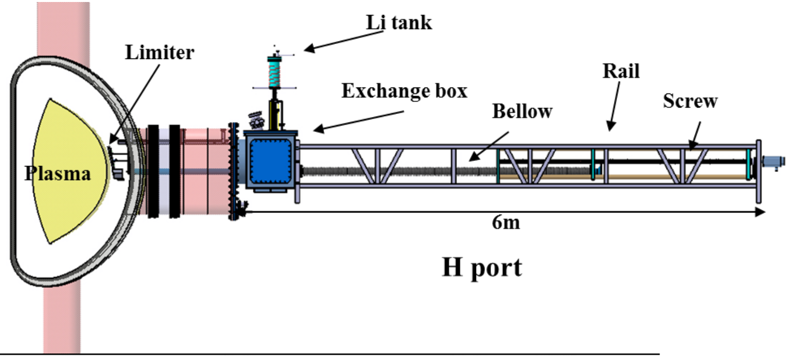


P. Rindt: Ph. D. thesis 7/2019; PPPL seminar 11/12/2019

Liquid metal plasma-facing components are being tested in EAST fusion device in China

- Four generations of midplane liquid lithium limiters tested in EAST
  - Prototype SS plate tested in HT-7
  - Gen. 1 (12/2014) tested in EAST
  - Gen. 2 (12/2016) tested in EAST
  - Gen. 3 (8/2018) tested at UI-UC and PPPL and then EAST
  - Gen. 4 (1/2020) tested in EAST
    - Increasing P_{aux}, W_{MHD}





Generation	Heat Sink	SS thickness (mm)	JxB pumps	Max. P_{aux} (MW)	Max. q_{exh} (MW/m^2)	Max. W_{MHD} (kJ)
1	Cu + SS	0.1	1	1.9	3.5	120
2	Cu + SS	0.5	2	4.5	4	170
3	Mo (TZM)	NA	2	8.3	TBD	280

J. Ren, Rev. Sci. Instrum. **86** (2015) 023504
G.Z. Zuo, Nucl. Fusion **57** (2017) 046017
J.S. Hu, Nucl. Fusion **56** (2016) 046011
R. Maingi, IAEA FEC 2018 paper FI/3-5Ra

A liquid metal campaign entails installing a large area, flowing liquid Li PFC into NSTX-U

- The NSTX-U tiles were re-designed during the recovery project
  - **HHF** regions are castellated graphite
  - **LHF** regions are in far scrape-off layer and private flux region
- A liquid metal campaign entails replacing some portion of outer divertor HHF tiles with liquid Li PFCs
  - Recommended by 5-year plan review committee
    - In the next 5-year plan 2026+
  - Three concepts : Li vapor box, divertorlets, and fast-flow in a capillary porous system
    - All three discussed in domestic LM program