Draft Mission and Specifications for an Integrated PMI-PFC Test Stand

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How Do We Get to Liquid Lithium PFCs on Fusion Energy Systems?

- Laboratory tests of specific effects
- Integrated test-stand to qualify fast-flowing and CPS lithium systems under realistic conditions with high flexibility and extensive diagnostics (focus of this talk)
- Segment tests in non-nuclear confinement facilities
- Full tests in non-nuclear confinement facilities
  - Existing devices
  - Device with Demo-relevant PMI parameters

Need Integrated Capabilities for Liquid Lithium PMI-PFC Tests

- Realistic magnetic field structure and liquid lithium temperature gradients to test lithium flow
- Realistic heating to test evaporation, recondensation
- Realistic steady and transient plasma impingement to test redeposition, thermal self-shielding, pumping
- Realistic steady and transient SOL currents
- Extensive surface diagnostics
- Extensive plasma diagnostics
- Extensive PFC engineering diagnostics
- Extensive modeling
- Would complement other facilities world-wide
    - Combination of PMI + Liquid PFC
- Would require a strong national collaboration.

Phasing of Capabilities will be Required

- **Fusion energy systems have very high requirements**
  - Very long pulse or steady state
  - Parallel power density > 1 GW/m^2
  - High magnetic fields
  - High transients

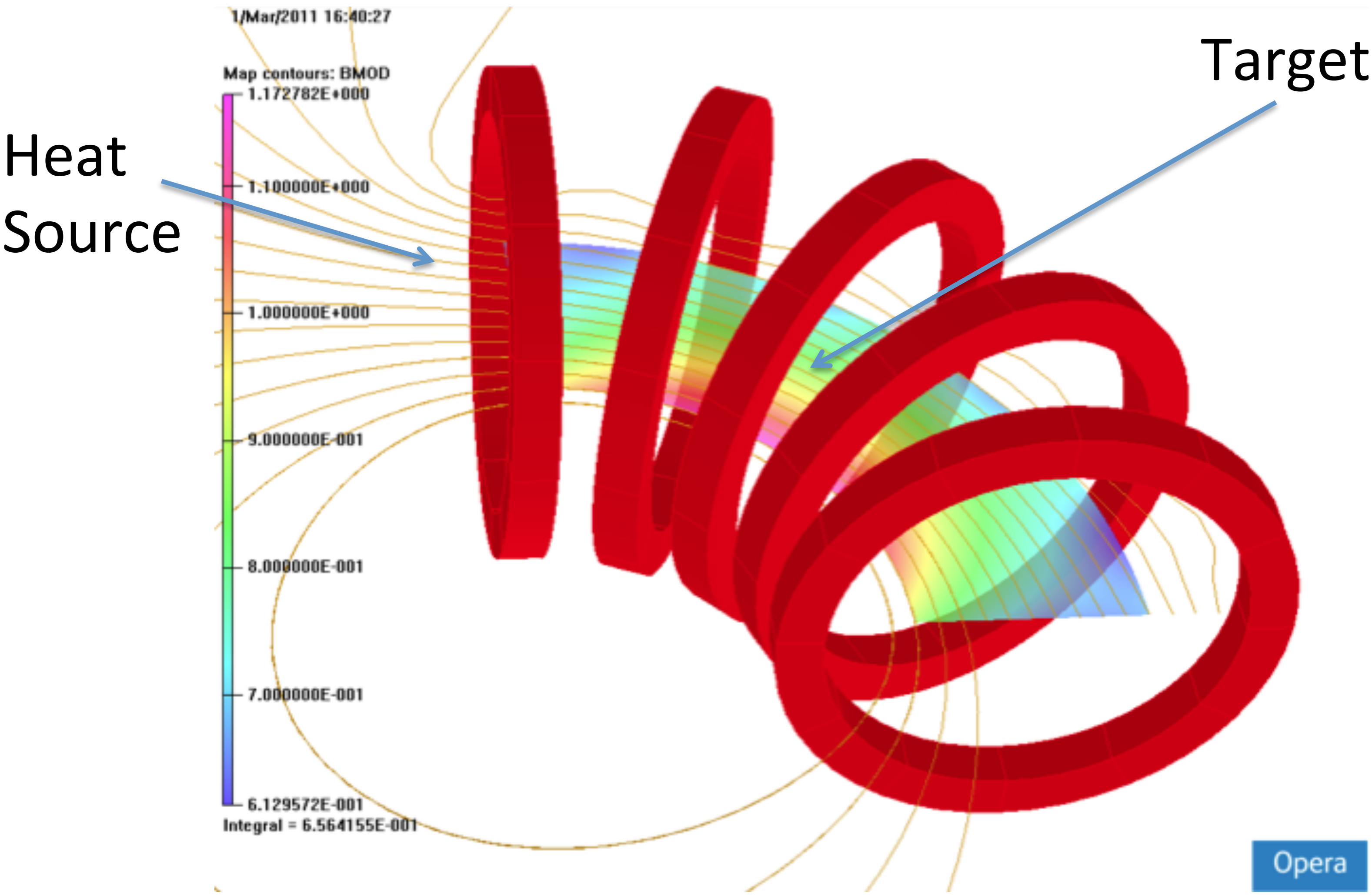
- **Neutron-materials effects are separable**
  - Bulk changes in thermal conductivity, tritium diffusivity, brittleness do not *directly* affect PMI

- **Existing toroidal experiments can provide good tests**
  - For first phase currently targeting NSTX-U parameters
  - 5 second pulses, ≤ 10 minute repetition period

Draft Magnetic Field and Geometry for First Phase

- Toroidal magnetic geometry is required to simulate flows of liquid metals in the radial direction of a tokamak.
- 1 T toroidal magnetic field, in a toroidal sector
  - dB/dR = 1.25T/m (implies R_o = 0.8m)
  - 0.02 – 0.15 T vertical B-field to model flux expansion
- PFC component 0.5m in toroidal direction (1/10 of torus), 0.5m in poloidal plane.
- PFC surface tilt variable from horizontal to vertical, including inverted.
- Excellent access for plasma, PMI and PFC diagnosis.

A Quarter Torus Provides Required Fields

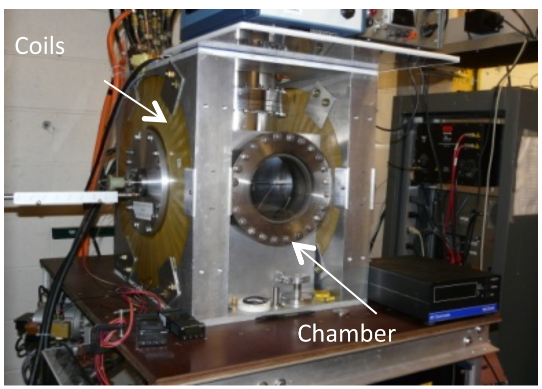


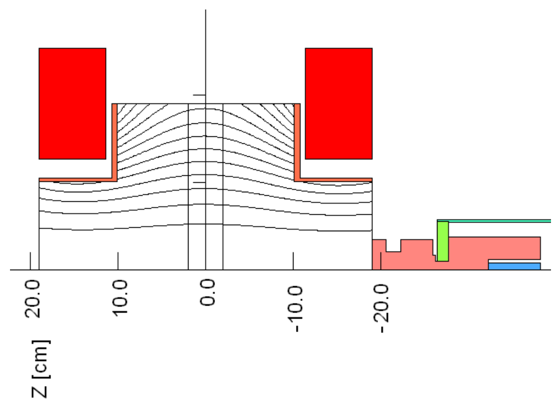
Draft Power and Plasma Flux for First Phase

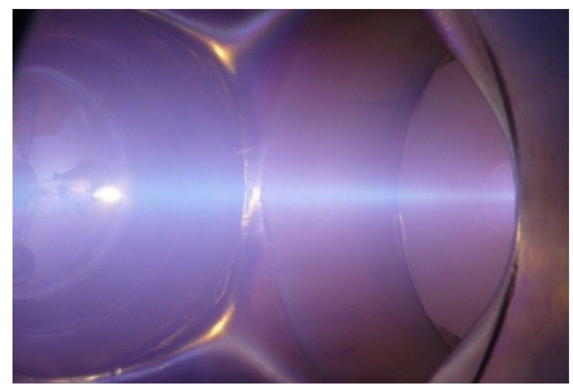
- P/L in the toroidal direction up to 2MW/m.
  Implies up to 1 MW delivered to target.
- Heat flux width variable from 0.04m to 0.2m
  (Greater width goes with lower vertical field)
  - Implies local heat flux of 10 – 40 MW/m^2
- Equivalent to heat flux parallel to **B** $\sim$ 400 MW/m^2
  - 1 MW in 25 cm^2
- Can use separate heat and plasma sources in initial phase.
- Alternatively a powerful upstream plasma may be used to provide particle and heat source, allowing more realistic tests of plasma effects.

Plasma Option: Array of Ferromagnetic Inductively Coupled Sources

- May be cheapest option
- Not fully representative plasma
- Gang together multiple small sources?
- Provide additonal RF heating?





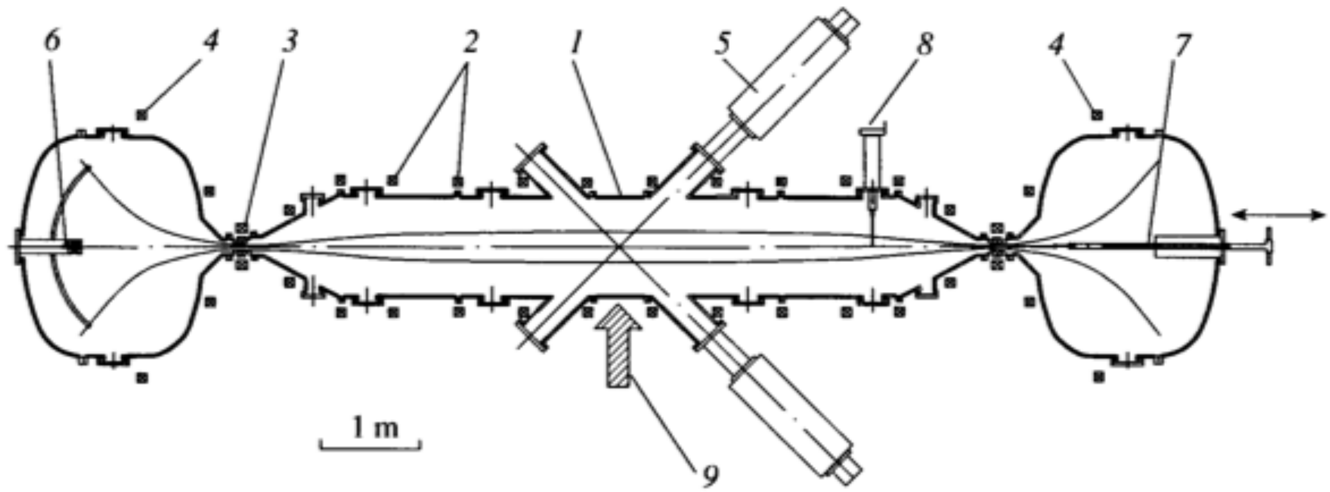


- Couple with other direct heat sources?

Y. Raitses

Mirror Machine Throat Plasmas Approximate Tokamak Edge

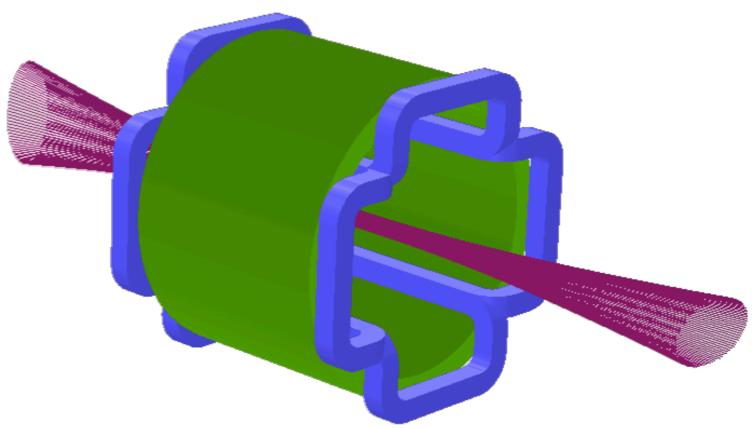
- Upstream parameters of T_e = 50 – 100 eV, n_e = 2 – 5 $10^{19}/m^3$ should provide the right parallel heat flux and collisionality.
- These are achieved in the throat of Gas Dynamic Traps
- Pulse lengths at Novosibirsk are only 5 msec

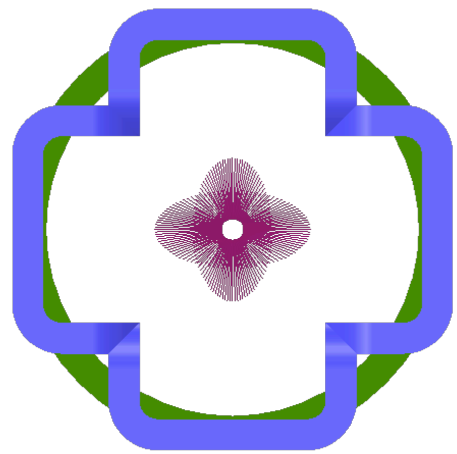


- Cost?
- Can we direct the outflowing plasma to the target?

Need to Control Heat Flow Path

- At fixed parallel heat flux, need to adjust strike zone
  - Strike zone correlated with varying vertical field
  - Wide and tangential for large flux expansion
  - Narrow and vertical for small flux expansion
- Plasma source → quadrupole → guide field → target





I. Zatz / A. Brooks

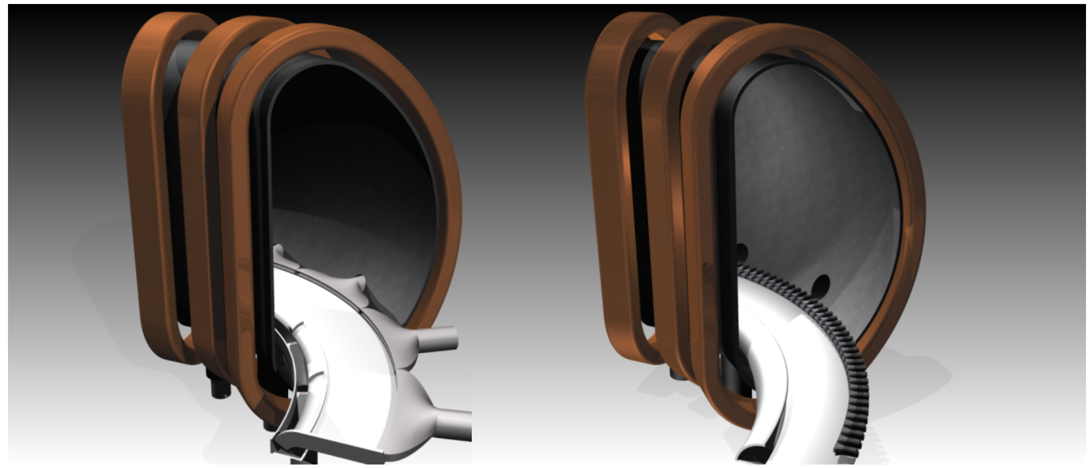
Draft Pulsed Heat and Current Sources for First Phase +

- **Heat fluxes**
  - 20x the continuous heat flux to simulate ELMs in 0.25 msec pulses
  - 20x the continuous heat flux to simulate disruptions, in 2.5 msec pulses

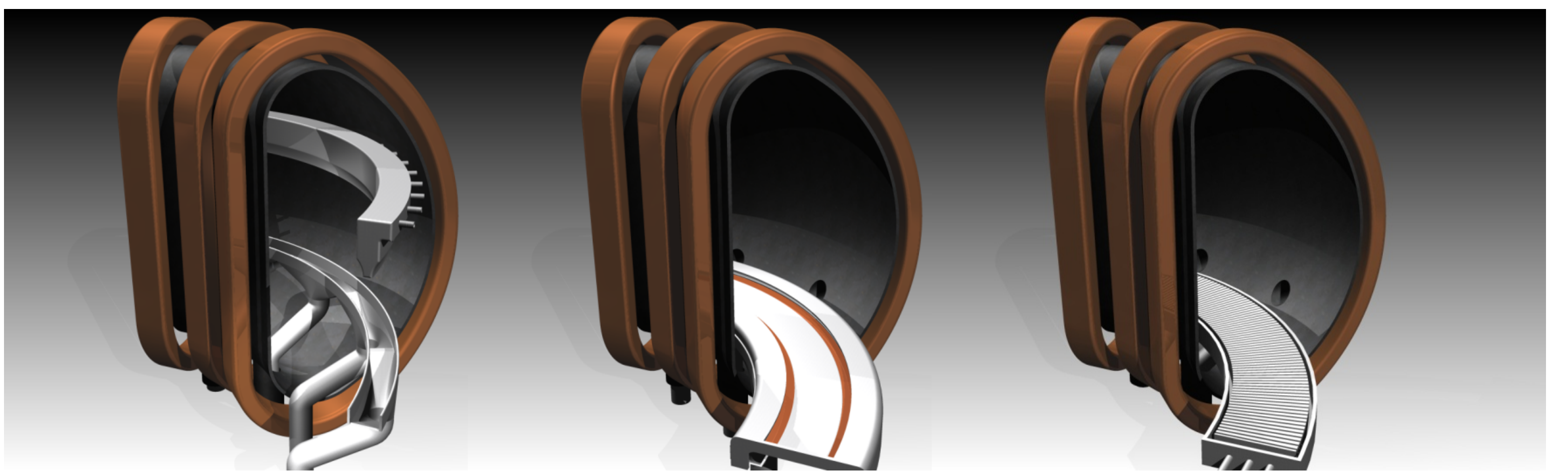
- **Parallel SOL current density**
  - 0.1 MA/m^2 continuous
  - 1 MA/m^2 to simulate ELMs in 0.25 msec pulses
  - 10 MA/m^2 simulate disruptions in 2.5 msec pulses

Test Heat Removal with Fast-Flowing Li

- Designs use convection to exhaust incident power
- $v > 1$ m/s
- Thickness ≈ 1 cm



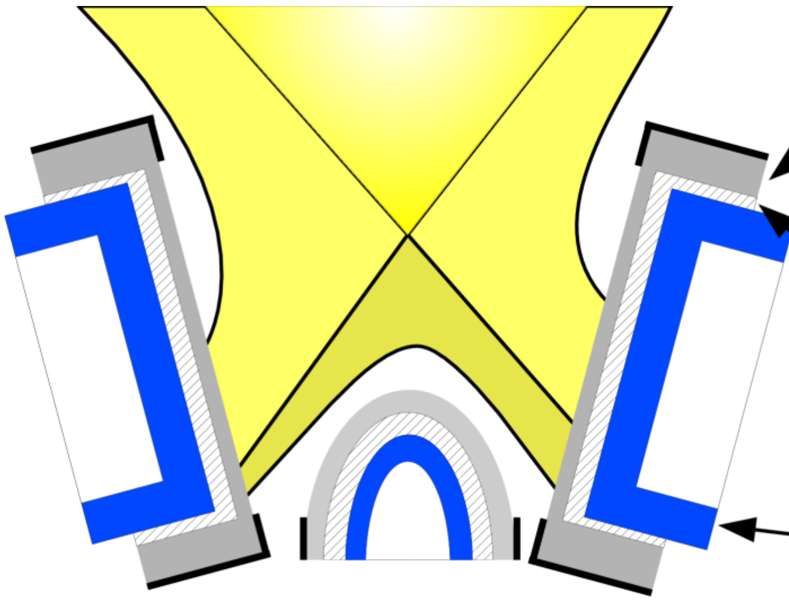
Pressure driven Jets



Curtain Limiter JxB TEMHD

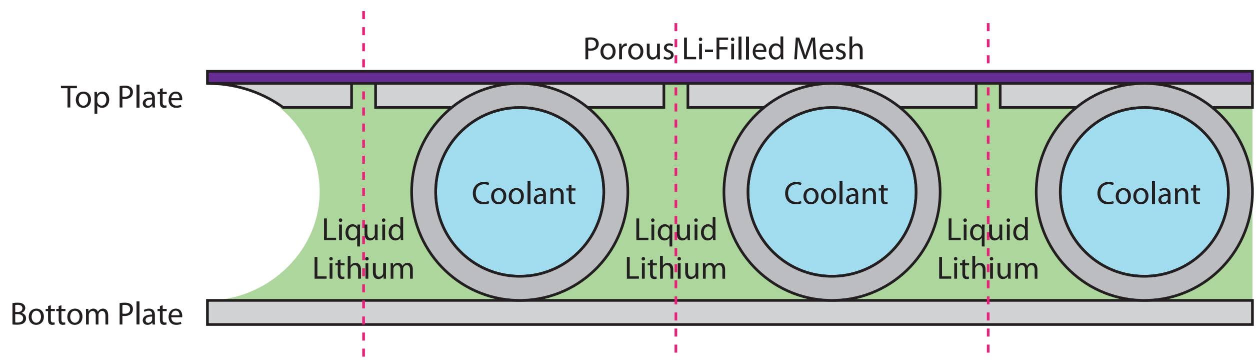
H. Ji, J. Rhoads

Test CPS Lithium with Active Coolant



- Lithium “soaker-hose” wets plasma-facing surface
- Gas coolant + evaporation + radiation removes heat

See Next Talk by J. Goh



M. Jaworski

Extensive Surface Diagnostics Needed

Diagnose chemical composition and morphology of top nm's of PFC surface (plasma sputtering range) including local in-vacuo measurements:

X-ray Photo Electron Spectroscopy (XPS).
Low Energy Ion Scattering (LEISS), SEE measurement
Vacuum 'suitcase' for remote analysis if necessary to avoid B field effects.
Remote analysis facilities including:
Direct Recoil Spectroscopy (DRS).
Auger microprobe
SEM, XRD, HREELS, ALISS etc…

Diagnose chemical composition of sub-surface layers to investigate D pumping, diffusion, segregation and intercallation including local in-vacuo measurements:

In-situ thermal desorption spectroscopy:
In-situ laser ablation spectroscopy
In-situ passive spectroscopy.
Rutherford backscattering

Diagnose PFC surface temperature:

2-color thermography.
(install heaters to control PFC temperature independently of plasma flux).

C. Skinner

Extensive Plasma Diagnostics Needed

- **Electron Density and Temperature**
  - Fixed and Insertable Langmuir Probes
  - Thomson Scattering

- **Ion Parameters**
  - Retarding Field Analyzers
  - Plasma Ion Mass Spectrometers

- **Radiation**
  - Spectrometry
  - Filtered Visible Detector Arrays
    (rotational and vibrational temperature and molecular ion mass)
  - Filtered Fast Visible Cameras
  - Bolometry

R. Kaita

We Welcome Your Collaboration!

Sample Test Modules	Free surface flow, jets Ji *et al.*	Actively wetted and cooled CPS Jaworski *et al.*	Coatings, engineered surfaces Kugel *et al.*
Heat and Plasma Sources	Commercial e-beam, plasma sources Zweben *et al.*	RF, thruster, helicon etc Raitses *et al.*	Intense NBI/ plasma source Goldston *et al.*
Diagnostics and modeling	Surface, including pumping Skinner *et al.*	Plasma Kaita *et al.*	Modeling Stotler *et al.*
Test Chamber	Vacuum system, location options Gentile *et al.*	Magnets Zatz *et al.*	Liquid metal services Jaworski *et al.*

Conclusions

- **An integrated PMI-PFC test stand would be a major step along the route to implementing liquid lithium systems in fusion energy systems**

- **It is not a simple undertaking to simulate even current experiments**

- **Implementing a PMI-PFC test stand will need to be a collaborative undertaking**

- **We are taking a first look, and welcome your collaboration.**