Initial Operation of MHD PbLi Facilities at UCLA. Near- and Long-Term Experiments. Research Highlights.

Presented by **Sergey Smolentsev**

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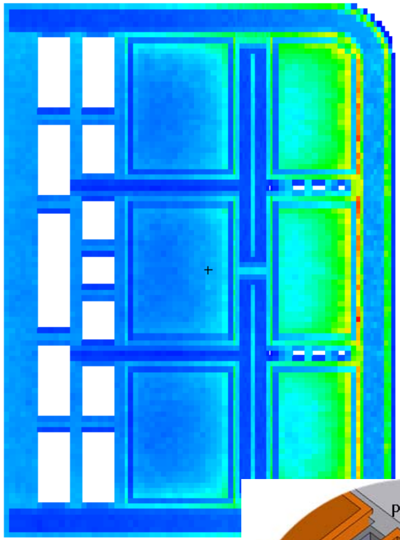

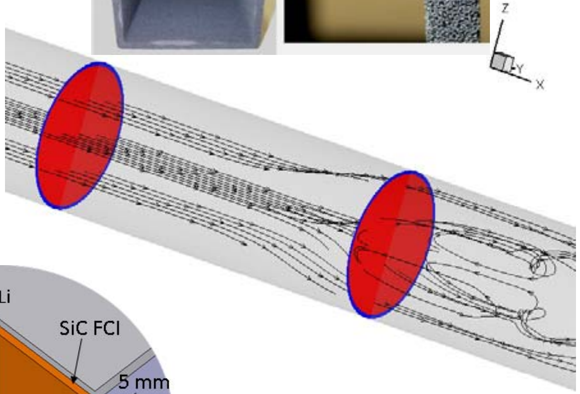

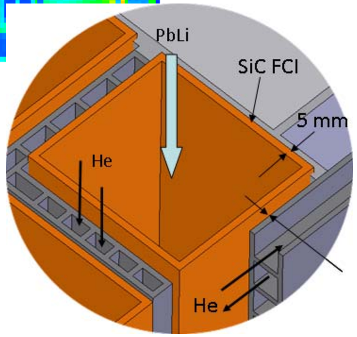

US DCLL

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MHD and heat/mass transfer considerations are primary drivers of any liquid metal blanket design

Issue / phenomena	Self-Cooled	Dual-Coolant	He-Cooled
1. MHD pressure drop and flow balancing	High	Moderate	Moderate
2. Electrical insulation	High	Moderate	Low
3. Flows in a non-uniform B-field	High	High	Moderate
4. MHD instabilities and turbulence	High	High	Low
5. 3D effects in complex-geometry flows	High	High	High
6. Electromagnetic coupling	High	Moderate	High
7. Thermal convection	Moderate	High	High
8. Thermal insulation	Low	High	Low
9. Corrosion/deposition	High	High	High
10.Tritium transport	Moderate	High	High

Blanket type	*Re*=inertial/viscous	*Ha*=(MHD/viscous)$^{1/2}$	*Gr*=buoyancy/viscous
Self-Cooled (Li/V, generic)	3.2×10^4	4.5×10^4	2.0×10^{12}
Dual-Coolant (DCLL, TBM)	3.0×10^4	6.5×10^3	7.0×10^9
Helium-Cooled (HCLL, TBM)	670	1.1×10^4	1.0×10^9

MHD PbLi loop is in operation since July 2011 as a part of MTOR Lab to study MHD/Heat&Mass Transfer processes specific to PbLi flows under blanket-relevant conditions

- PbLi alloy is the main liquid metal breeder/coolant considered for liquid blankets in the US and EU
- This PbLi loop is part of the **MTOR** laboratory at UCLA, and is the only MHD forced-convection PbLi loop in the US, one of a few in the World. Developed as part of the TITAN US-JA collaboration.
- This is a high temperature loop. Many challenges compared to room-temperature LM facilities. New flow diagnostics required. Characterization of PbLi required (composition, impurities, oxidation, structural changes)

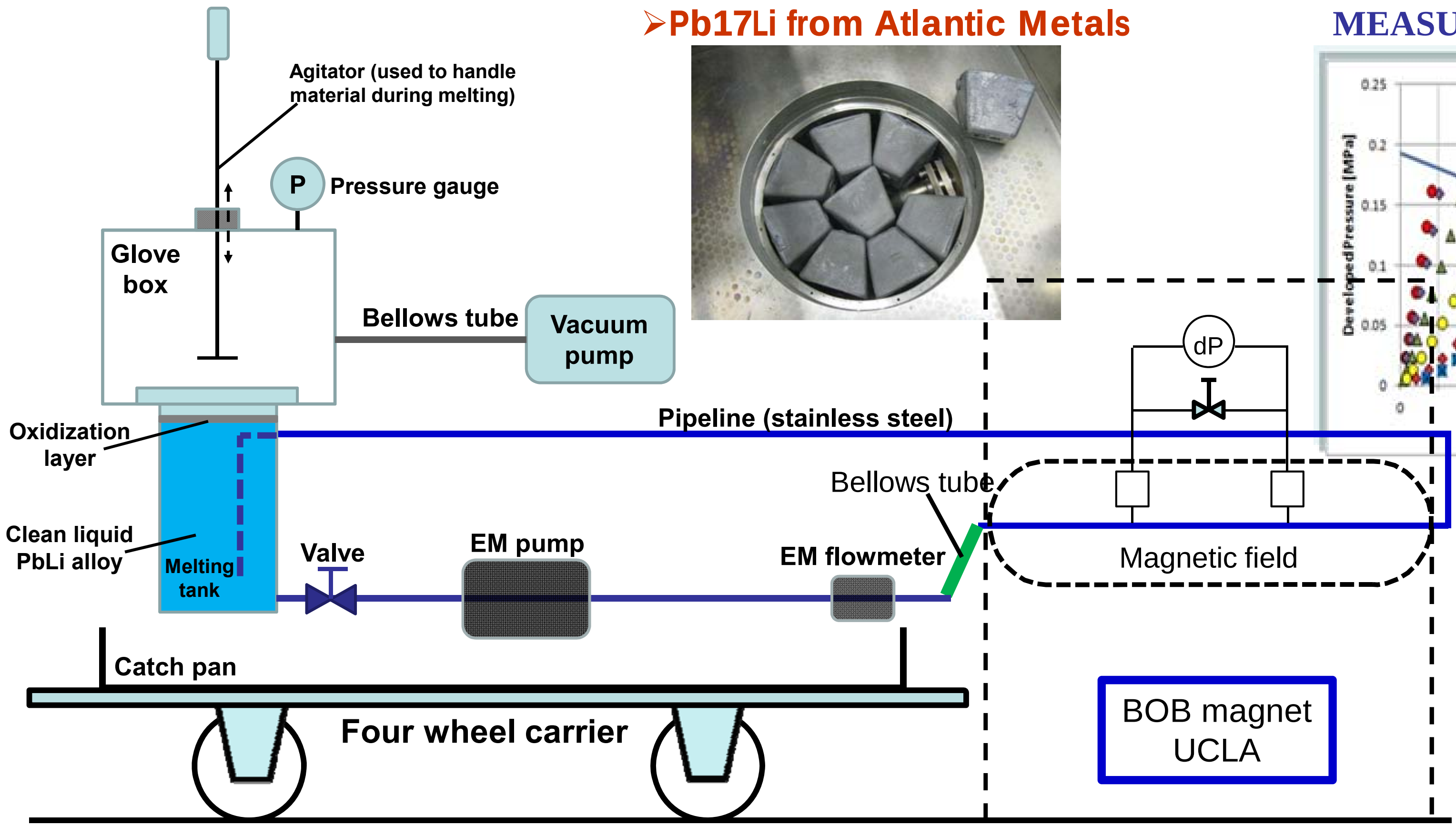
MTOR Laboratory at UCLA

(*Magneto-Thermofluid Omnibus Research*) is a flexible set of flow loops, magnet systems and diagnostics

Working fluids: InGaSn, Hg, PbLi, KOH

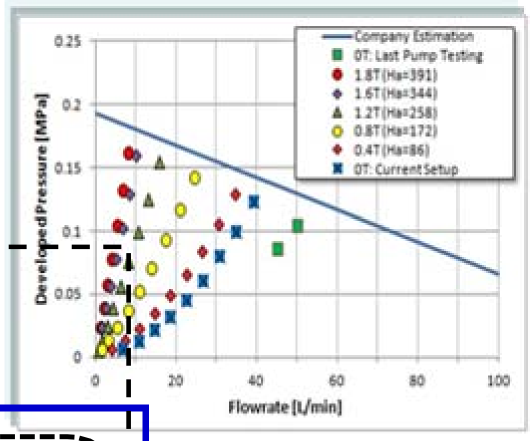
Magnets: BOB (1.8 T), QTOR (1 T, 1/R field)

The new loop has ~ 100 kg PbLi. Operation parameters up to: B=1.8 T, T=400°C, Q=50 l/min, ΔP=0.15 MPa. Fully operating.



➢Pb17Li from Atlantic Metals

MEASURED PUMP CURVE



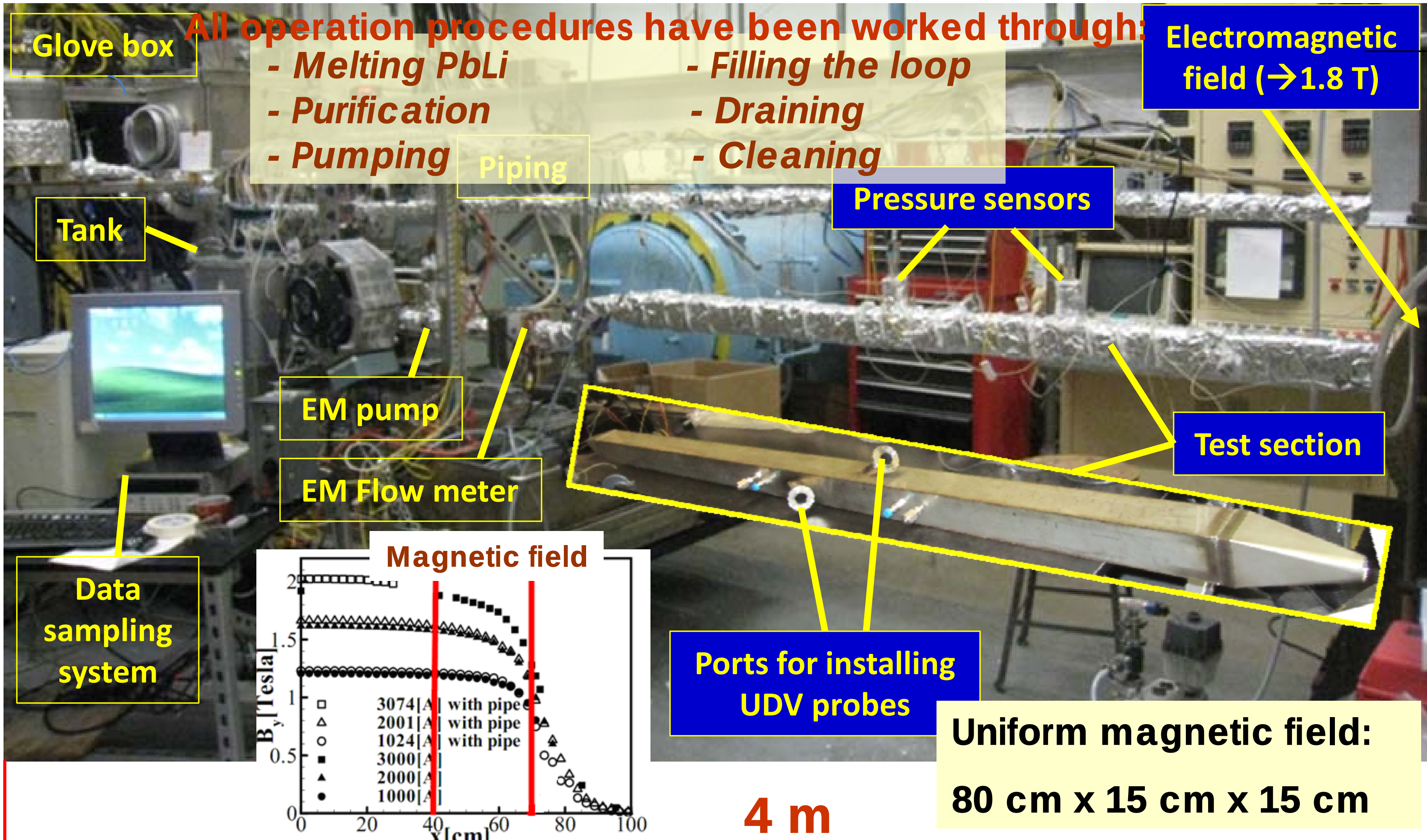
➢Bubbling in PbLi

➢Oxide crust

1. Melting/storage tank – up to 150 kg
2. Series V conduction EM Pump
3. Custom-made EM flowmeter
4. 8-section heater
5. Vacuum pump
6. Gas (Ar) purification system
7. Glove box to access PbLi
8. Movable carrier / catch pan
9. Thermal insulation
10. Temperature monitoring

Since July 2011 there were 5 continuous runs, 3 weeks each

Achievable parameters: **Ha=2500, Re=50,000 (max)**



Uniform magnetic field:

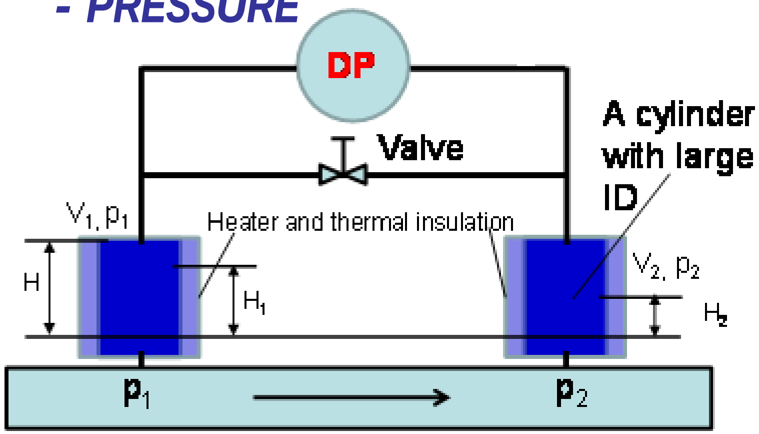
80 cm x 15 cm x 15 cm

4 m

Development of diagnostics tools is ongoing

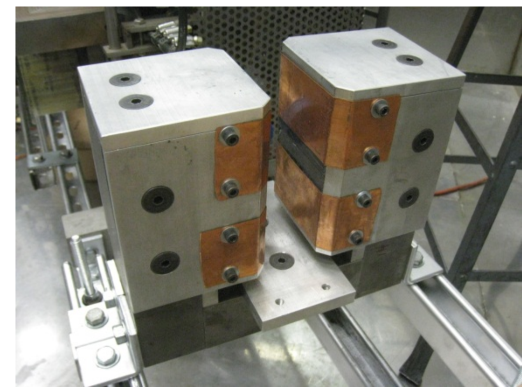
New diagnostics compatible with HT PbLi at T up to 550°C is required

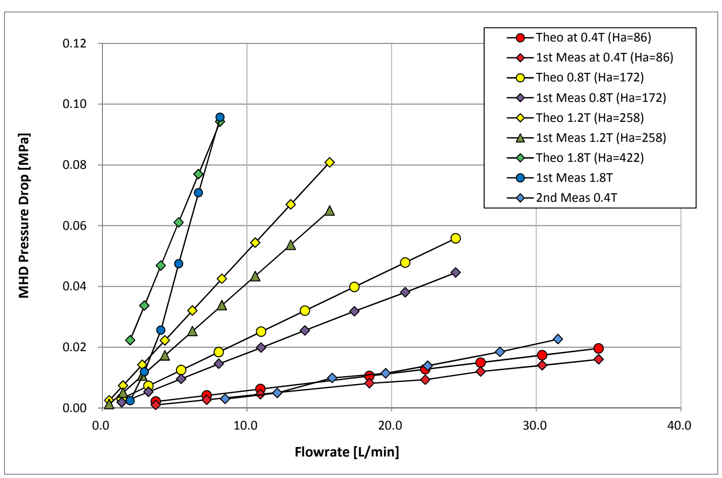
➢ ***Custom-made DP system***
- PRESSURE



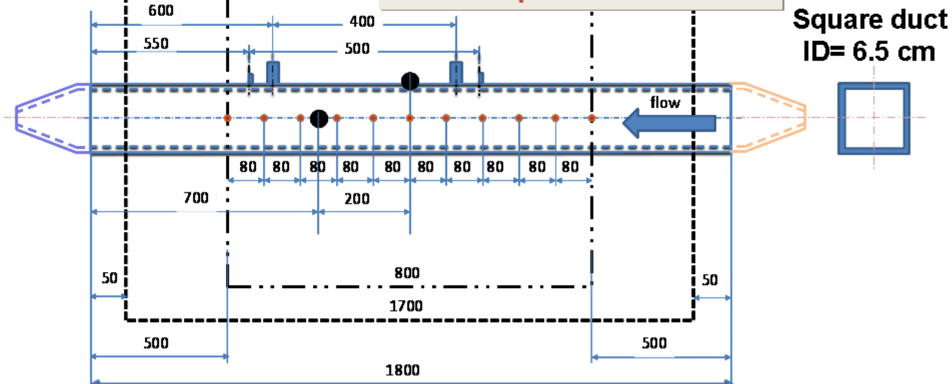
➢ ***HT UDV System***
- VELOCITY

➢ ***EM flowmeter***
- FLOWRATE





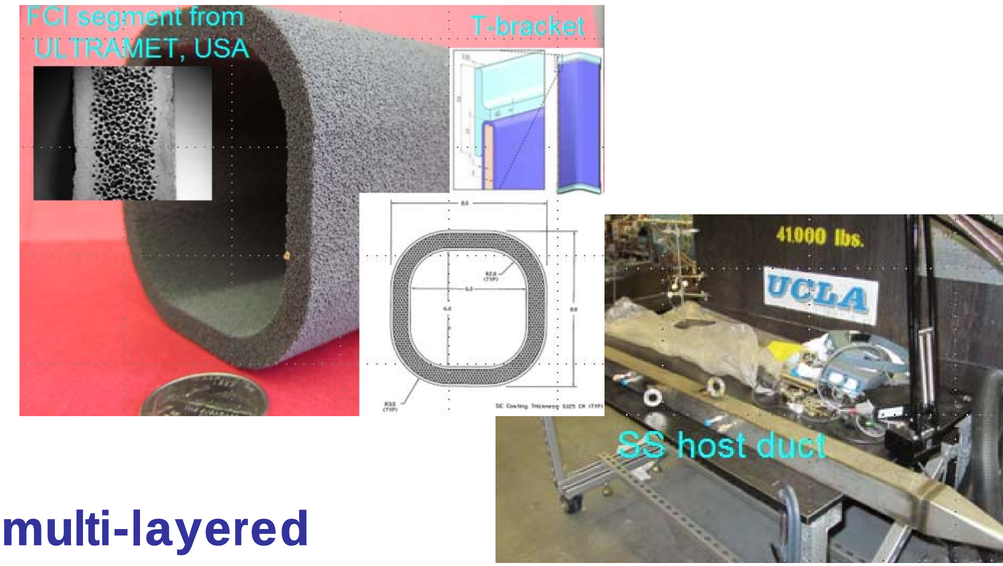
-Rectangular duct test-section
-Ports for 2 UDV sensors
-Ports for pressure sensors



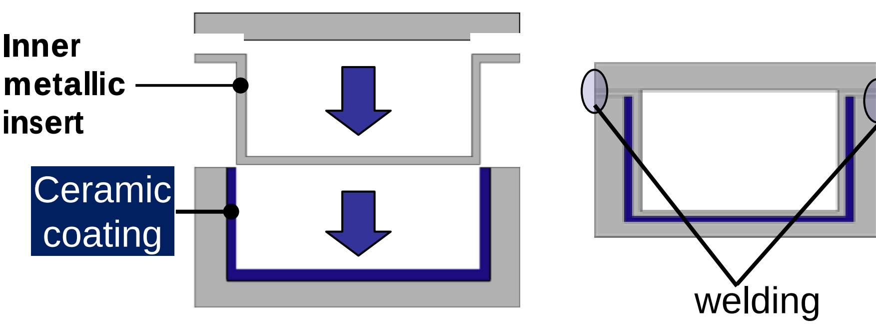
Current experiments address : (i) compatibility of structural materials with PbLi and (ii) MHD pressure drop reduction

1. Static testing of foam-based SiC FCI (Ultramet): T=700°C , P=0.1-0.5 MPa, 100 hrs

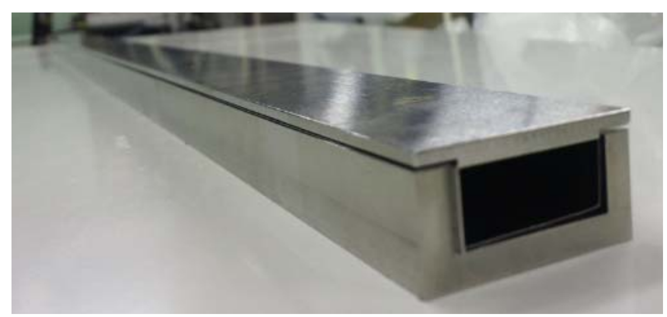
2. Dynamic testing of FCI (Ultramet): T~350°C, V~5-20 cm/s, B=0-1.8 T



3. Dynamic testing of three-surface-multi-layered channel (Japan): T~350°C, V~5-20 cm/s, B=0-1.8 T

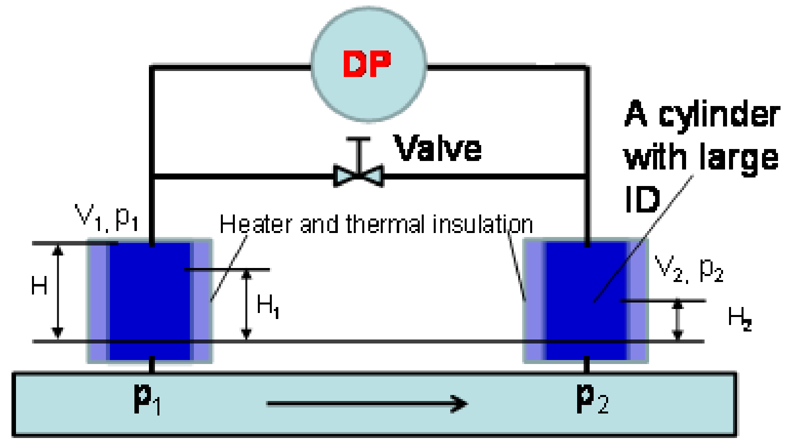


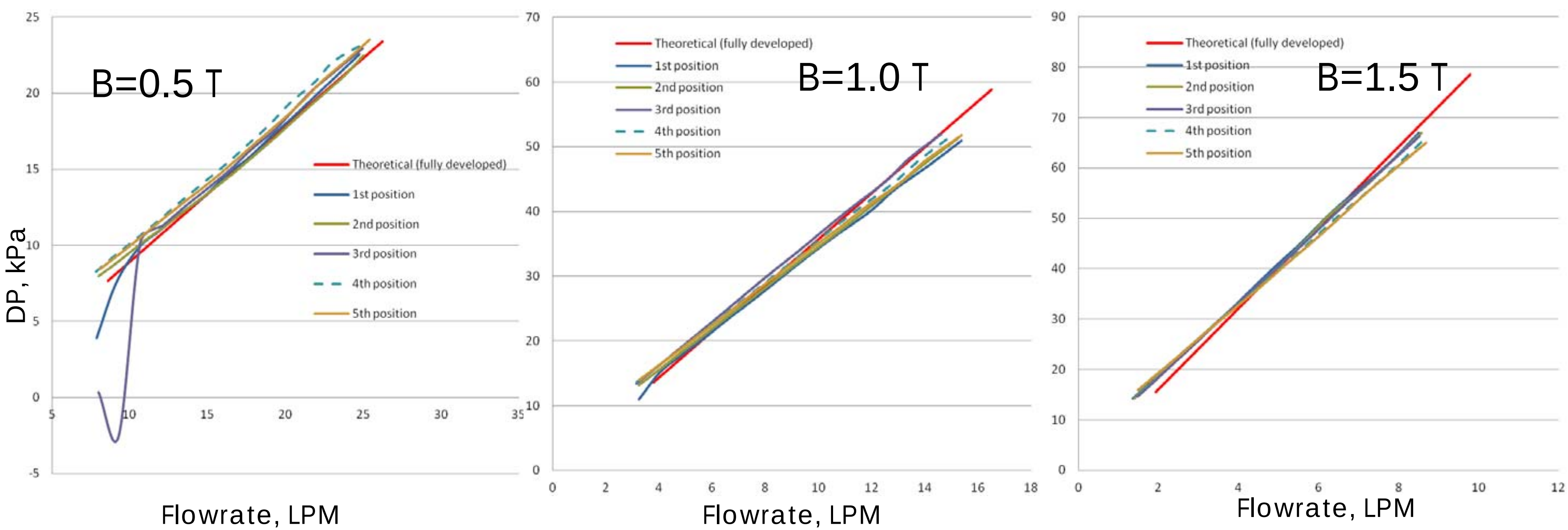
Fabrication process



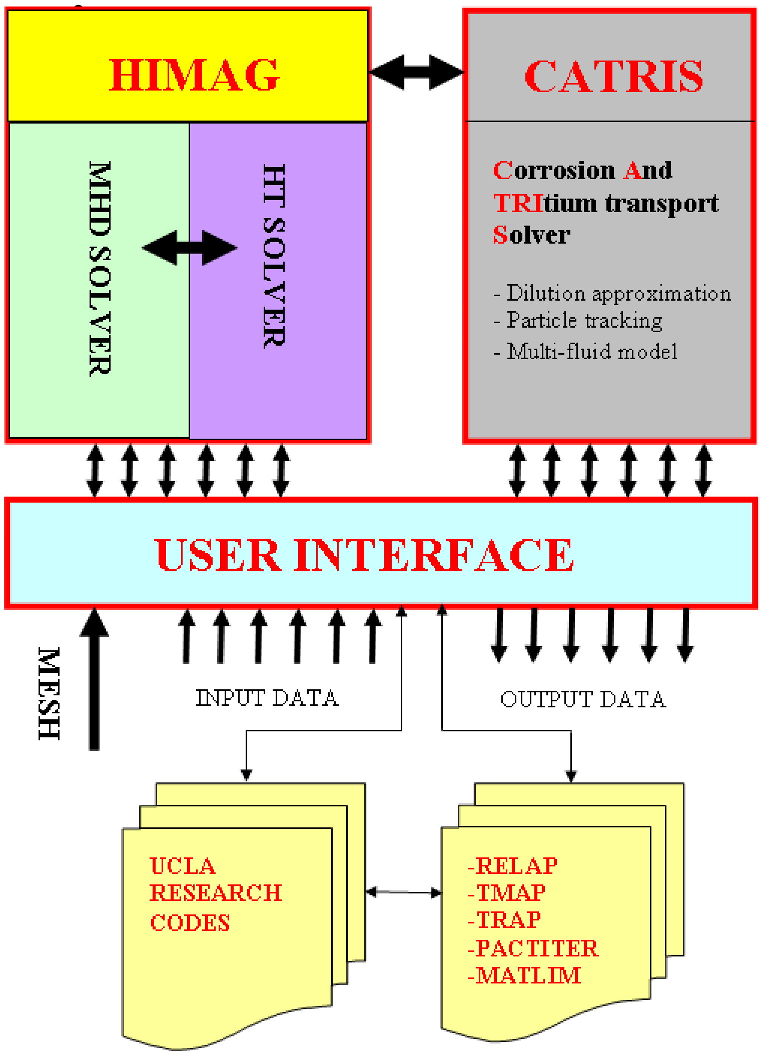
A new DP system has been developed to extend MHD pressure drop measurements to PbLi flows at T>300°C

- Available pressure sensors (*e.g.* by Keller) are limited to 300°C
- New DP system works at T>300°C
- DP measurements taken: fully developed MHD flow in a SS pipe, 5 locations
- T=350°C, B=0.5, 1.0, 1.5 T, Q=2-25 LPM
- Good match with theoretical predictions





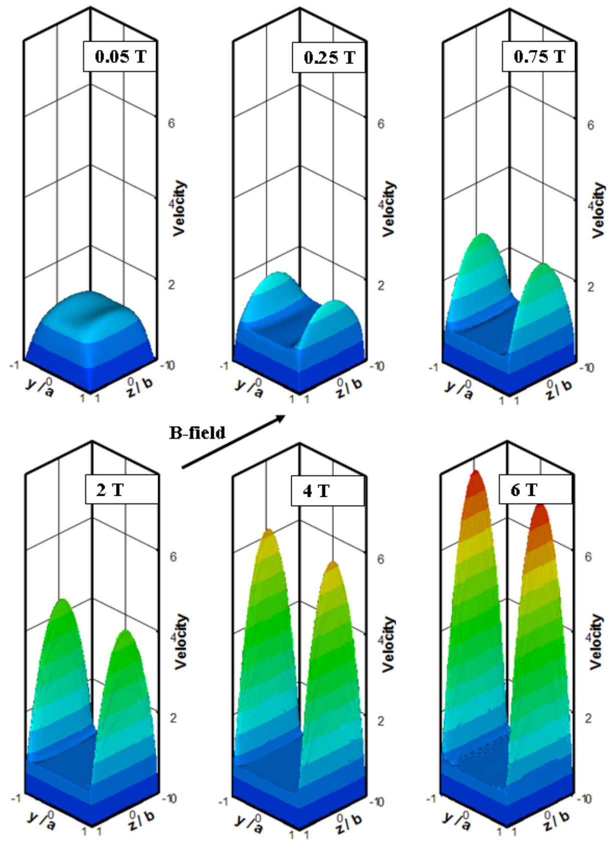
Integrated modeling tools to couple MHD with Heat & Mass Transfer are developed along with experiments $Ha \sim 10^4$, $Re \sim 10^4$, $Gr \sim 10^9$

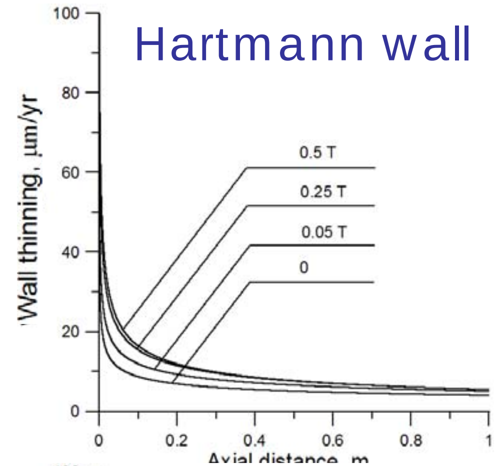


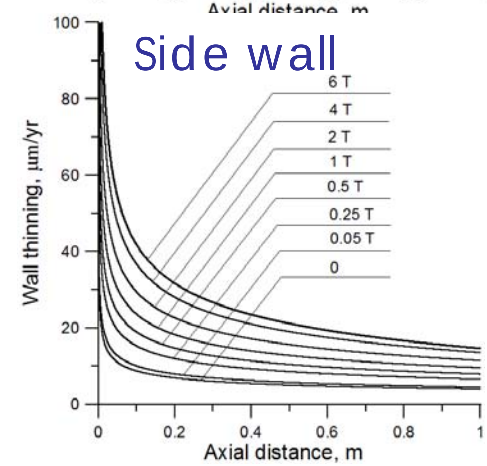
- **HIMAG** (HyPerComp Incompressible MHD Solver for Arbitrary Geometry) is a 3D, unstructured mesh, MHD/Heat Transfer parallel code. Developed by HyPerComp and UCLA. Started 10 years ago. Ha numbers up to 10,000.
- **CATRIS** (Corrosion and Tritium Transport Solver) is a *new mass transfer solver* coupled with HIMAG –started 2 years ago. Various models, such as "dilution approximation" and "particle tracking".
- **TRANSMAG** (Transport Phenomena in Magnetohydrodynamic Flows) – a new UCLA research code to address corrosion and transport of corrosion products in laminar and turbulent MHD flows.

Example: *Very strong effect of B-field on corrosion of RAFM in flowing PbLi*

- Existing data on the effect of B-field is limited and inconsistent.
- **Riga experiment (2009):** *corrosion is doubled due to the B-field effect*.
- **Computations**: either increase or decrease in the corrosion rate with B.
- Various effects of B-field, (non-uniform field, field direction, Q2D MHD turbulence) on corrosion are complex and need to be addressed via experiments and theory.







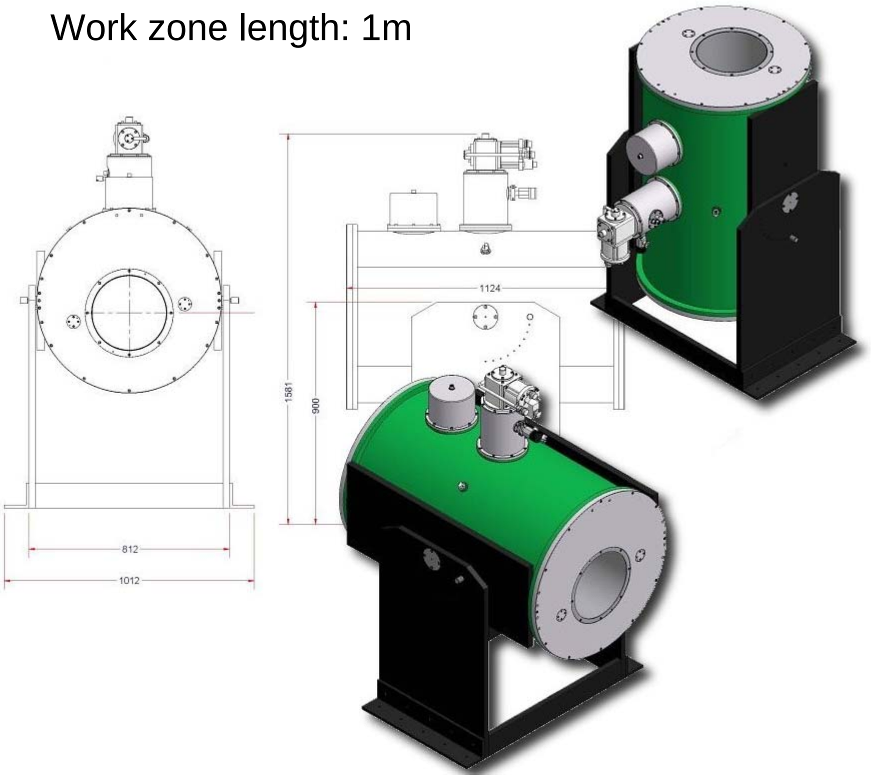
TRANSMAG: *Side walls* experience 2-3 times higher corrosion rate compared to *Hartmann walls* due to velocity jets.

Additional facility upgrades can substantially expand experimental capabilities

- A **hot temperature (550°C) leg** could be added for MHD flow-induced corrosion experiments / SiC FCI testing ~ $ 150 K
- A companion **He loop** could be included for combined liquid metal / helium cooling capability for liquid metal blankets and first wall experiments ~ $ 200 K
- A **stronger** (3-4 T) / **bigger** size (1m x 30 cm x 30 cm) **magnet** could be added for mock up testing of a LM blanket and its components (1/4-1/2 of full size) at Hartmann numbers up to 10,000

  > $ 1 M

- Maximal magnetic field induction: 5 Tesla
- Work zone diameter: 30 cm
- Work zone length: 1m



5 T superconducting magnet has been intensively used in IPUL (Latvia) over the last decade in MHD experiments