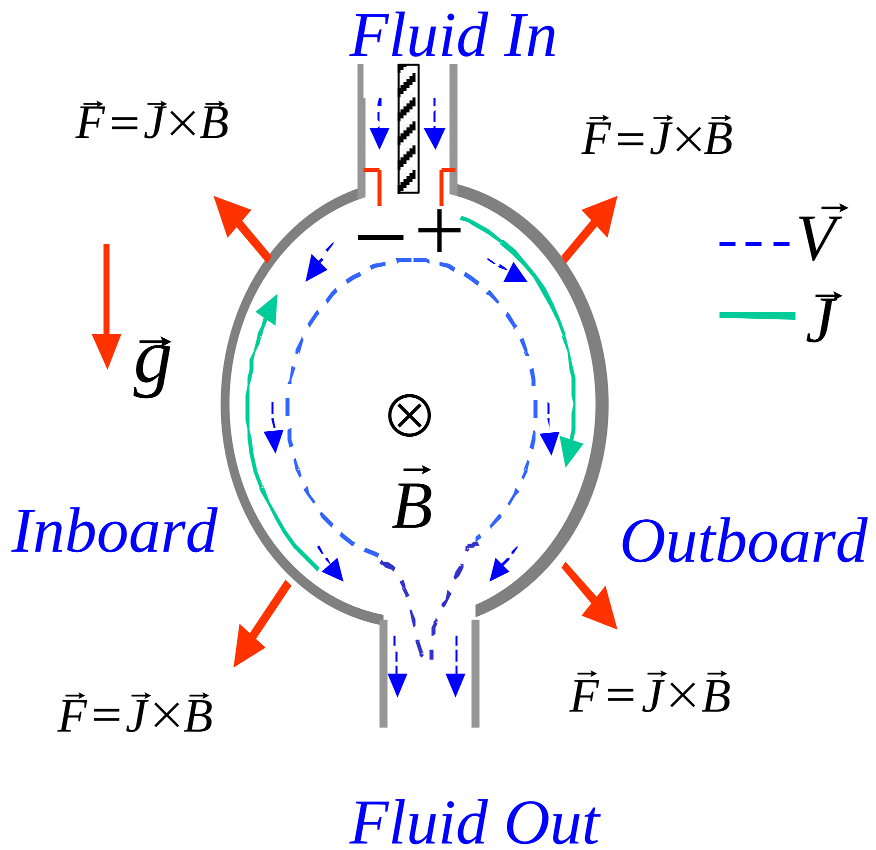
ELECTROMAGNETIC FLOW CONTROL: electric current is applied to provide adhesion of the liquid and its acceleration

Electromagnetically Restrained LM Wall (R.Woolley)

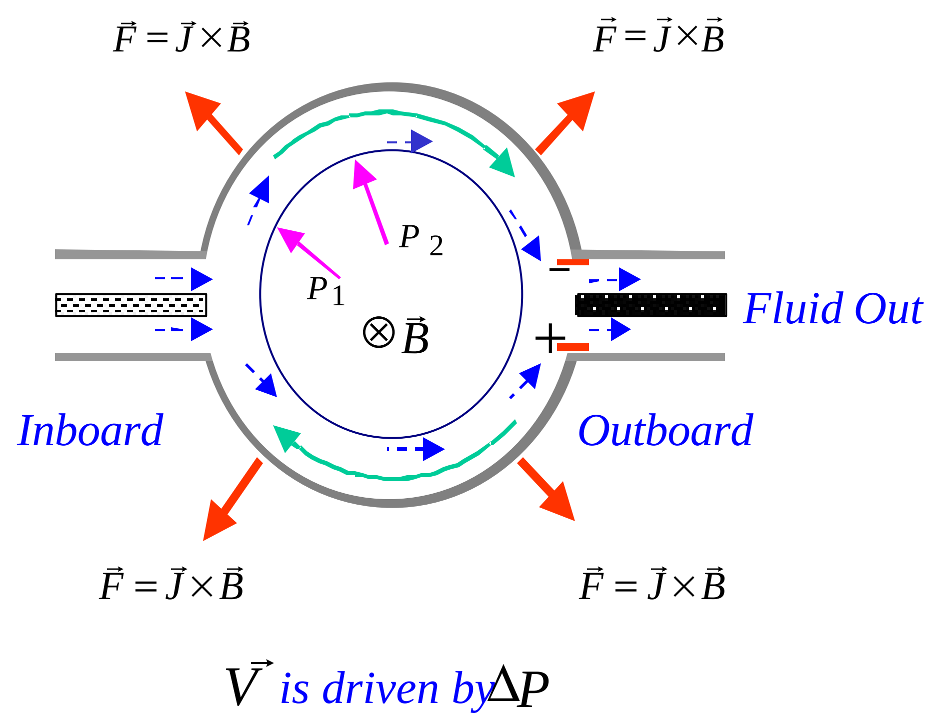
- Adhesion to the wall by $\vec{F} = \vec{J} \times \vec{B}$



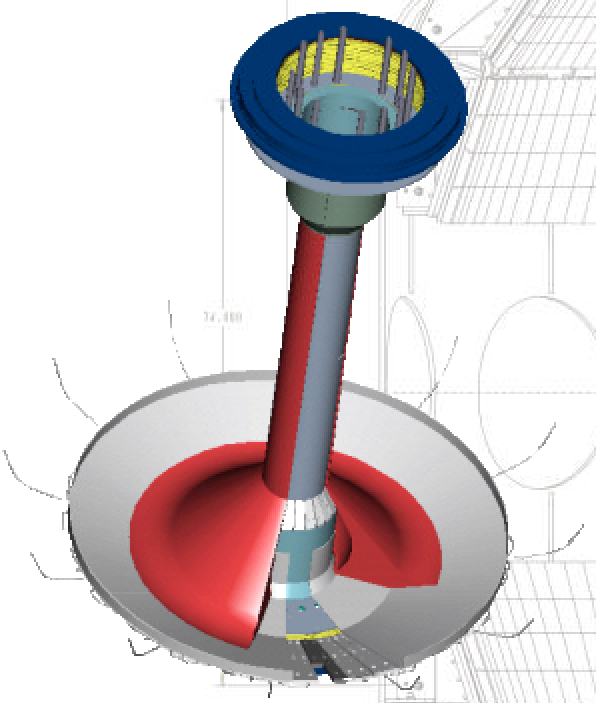
Magnetic propulsion scheme (L.Zakharov)

Adhesion to the wall by $\vec{F} = \vec{J} \times \vec{B}$

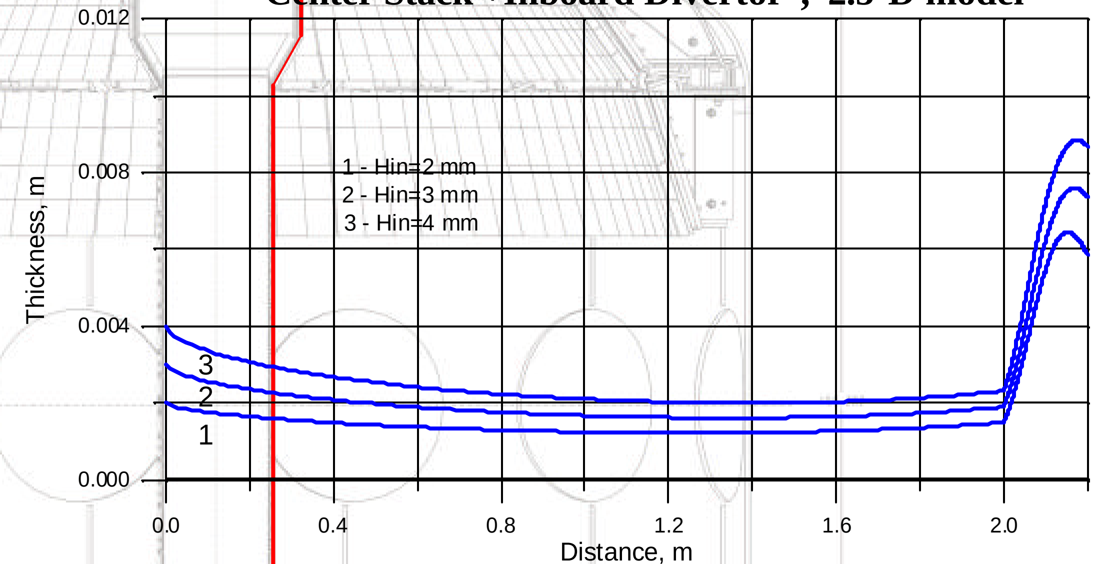
Utilization of 1/R variation of $\vec{B}$ ***to drive the liquid from the inboard to outboard***



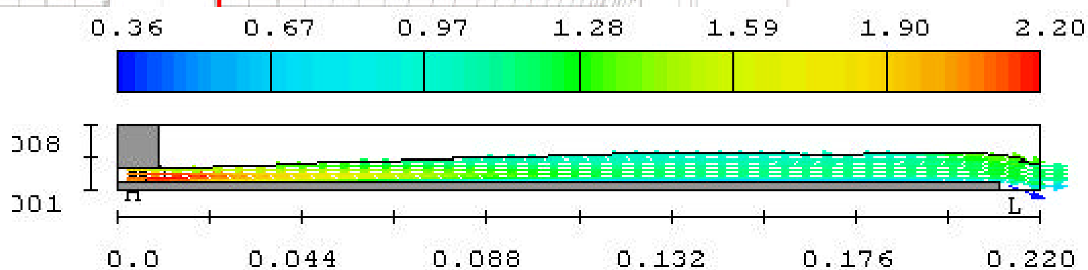
Simulations of Flowing Lithium in NSTX using Newly Developed MHD Free Surface Tools



"Center Stack +Inboard Divertor", 2.5-D model



"Inboard Divertor", Flow3D-M

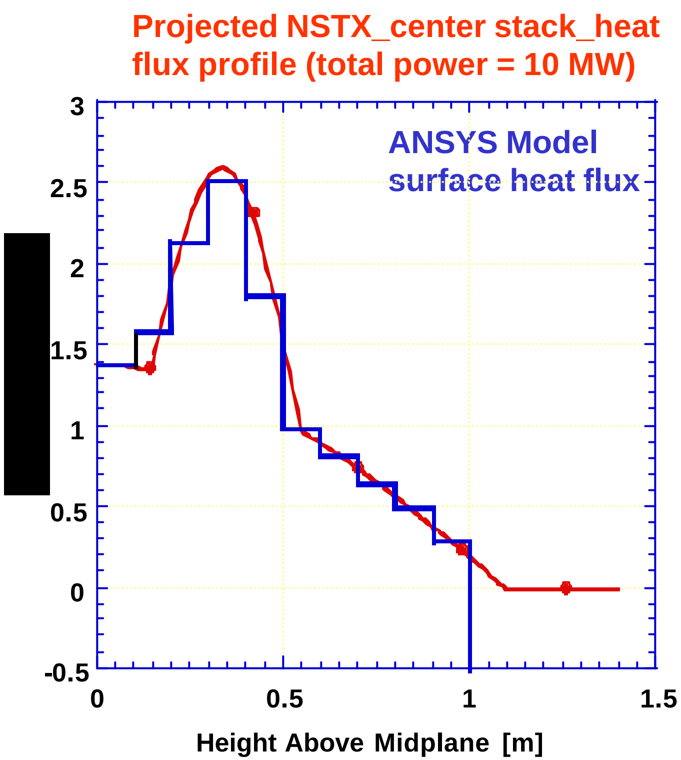


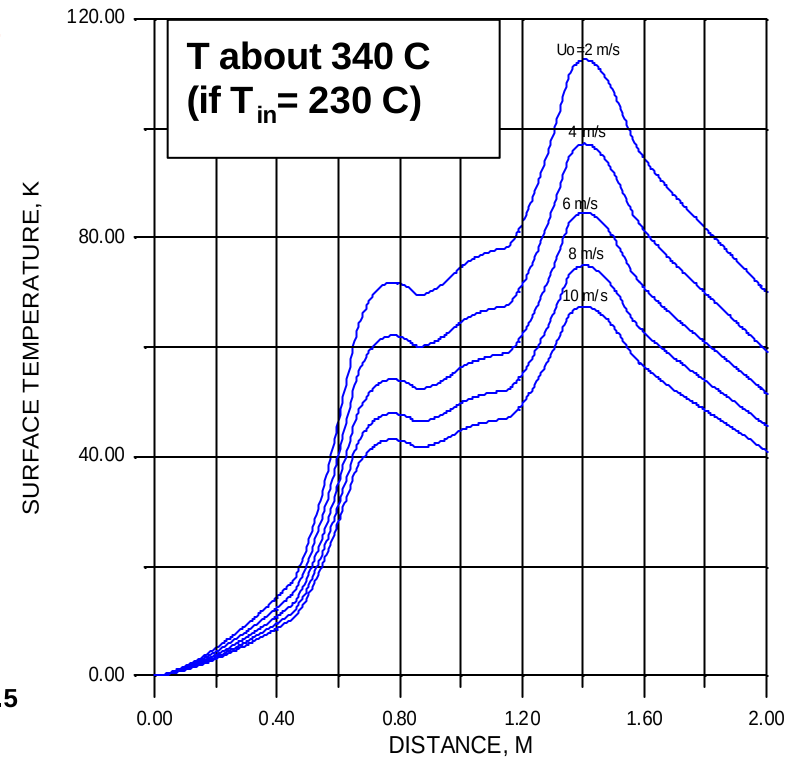
- **Flow3D code was extended to include MHD effects (Flow3D-M)**
- **New 2.5-D model and computer code were developed to calculate MHD free surface flows in a multi-component magnetic field**

Stable Li film flow can be established over the center stack

NSTX: Heat flux can be removed with flowing lithium along the center stack with acceptable surface temperature (even with 4-mm film at 2m/s)

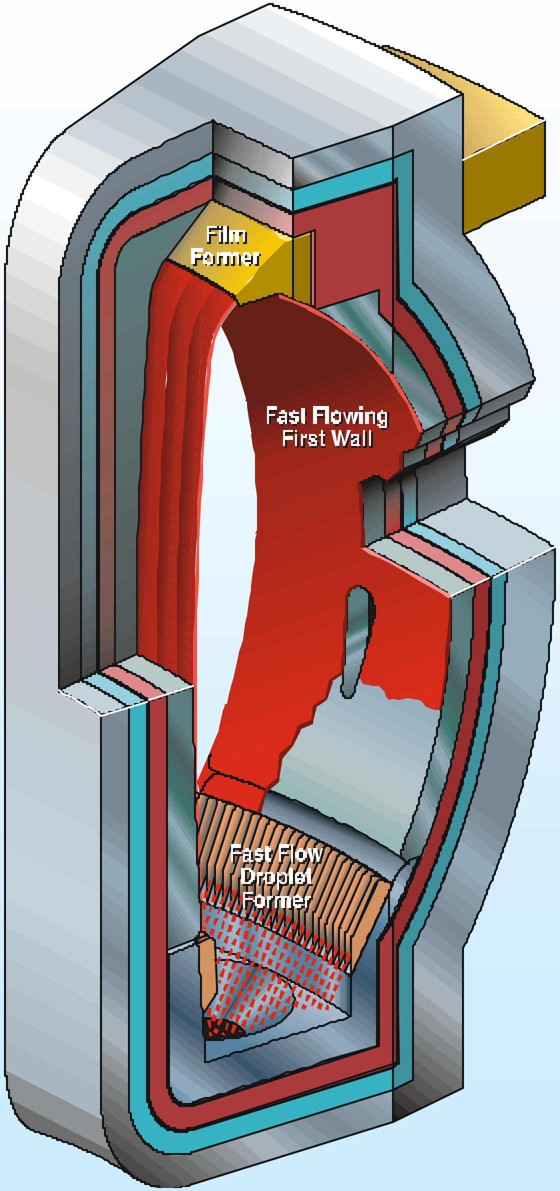
Results of Heat Transfer Calculations for NSTX Center Stack Flowing Lithium Film



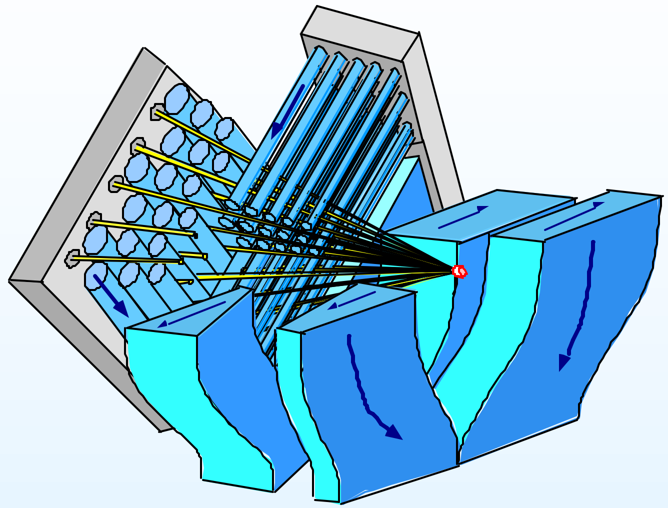


- **Lithium surface temperature increases as flow proceeds downstream as a function of lithium inlet velocity**
- **Two local temperature peaks are related to local maximums in the heat flux profile**

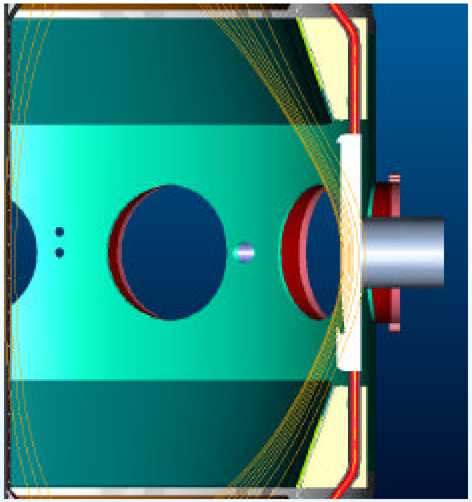
Liquid Wall Science is being Advanced in Several MFE & IFE Research Programs



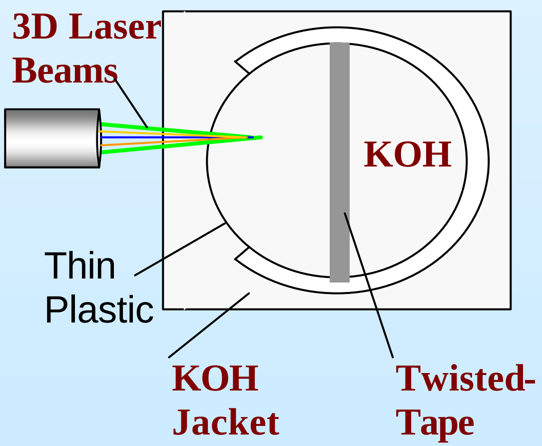
APEX CLiFF



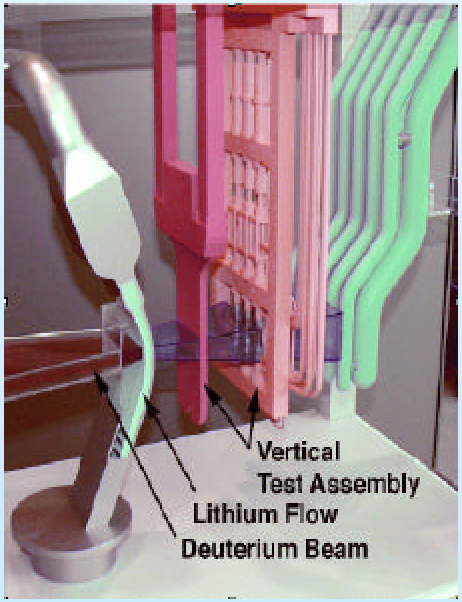
HYLIFE-II



NSTX Li module



JUPITER-II



IFMIF

Liquid Wall Science is important in many scientific pursuits and applications

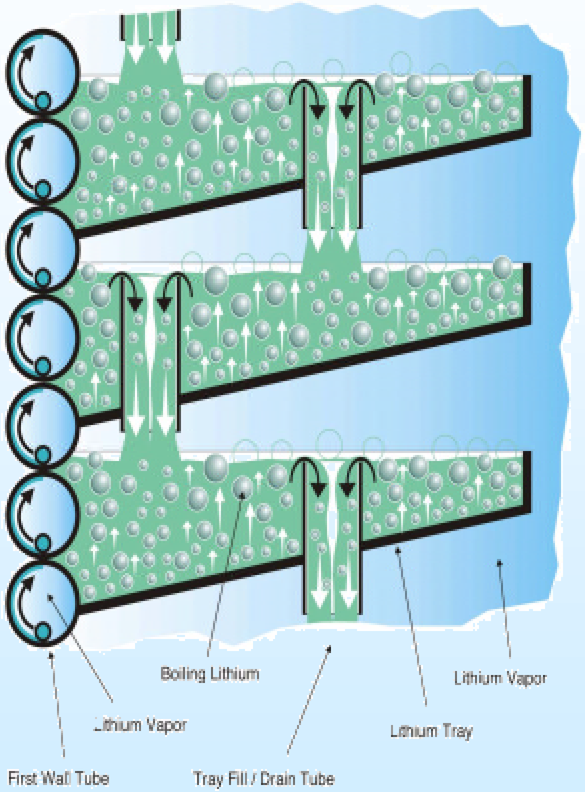
(For details: *Appendix, *Science presentation on APEX Website)

- **Liquid Jet and Film Stability and Dynamics:** fuel injection, combustion processes, water jet cutting, ink jet printers, continuous rod/sheet/ribbon/sphere casting, flood/jet soldering, ocean waves, hull design, ocean/river hydraulic engineering, surfing, liquid walls for fusion reactors
- **Liquid MHD / free surface interactions:** melt/mold stirring and heating, liquid jet/flow control and shaping, crystal growth, astrophysical phenomena, liquid metal walls for particle accelerators and fusion reactors
- **Liquid MHD / turbulence interactions:** microstructure control in casting, boundary layer control, astrophysical dynamos and plasmas, liquid walls for particle accelerators and fusion reactors
- **Free surface heat and mass transfer:** oceanography, meteorology, global climate change, wetted-wall absorbers/chemical reactor, condensers, vertical tube evaporator, film cooling of turbine blades, impurity control in casting, liquid walls for particle accelerators and fusion reactors

Watermark: Turbulent flow effect on dendrite formation in casting - LANL simulation

Progress on Addressing Key Issues for Promising **Advanced Solid Wall** Concepts

EVOLVE



1. Material Issues

Assessment of Material Issues for high-temperature refractory alloys “operating temperature” range and areas of uncertainties

- Sparked great interest in the materials community

  (comprehensive Journal Paper by Zinkle, Ghoniem, Sharafat)

- R&D needs identified for the material program

2. Heat Transfer/Transport for 2-phase flow with MHD

- Experiments at Univ. of Wisconsin
- Modeling at UCLA, UW, FZK

3. Engineering Issues

- Analysis and Innovative Solutions

  (GA, FZK, UW, SNL, ORNL, ANL, UCLA)

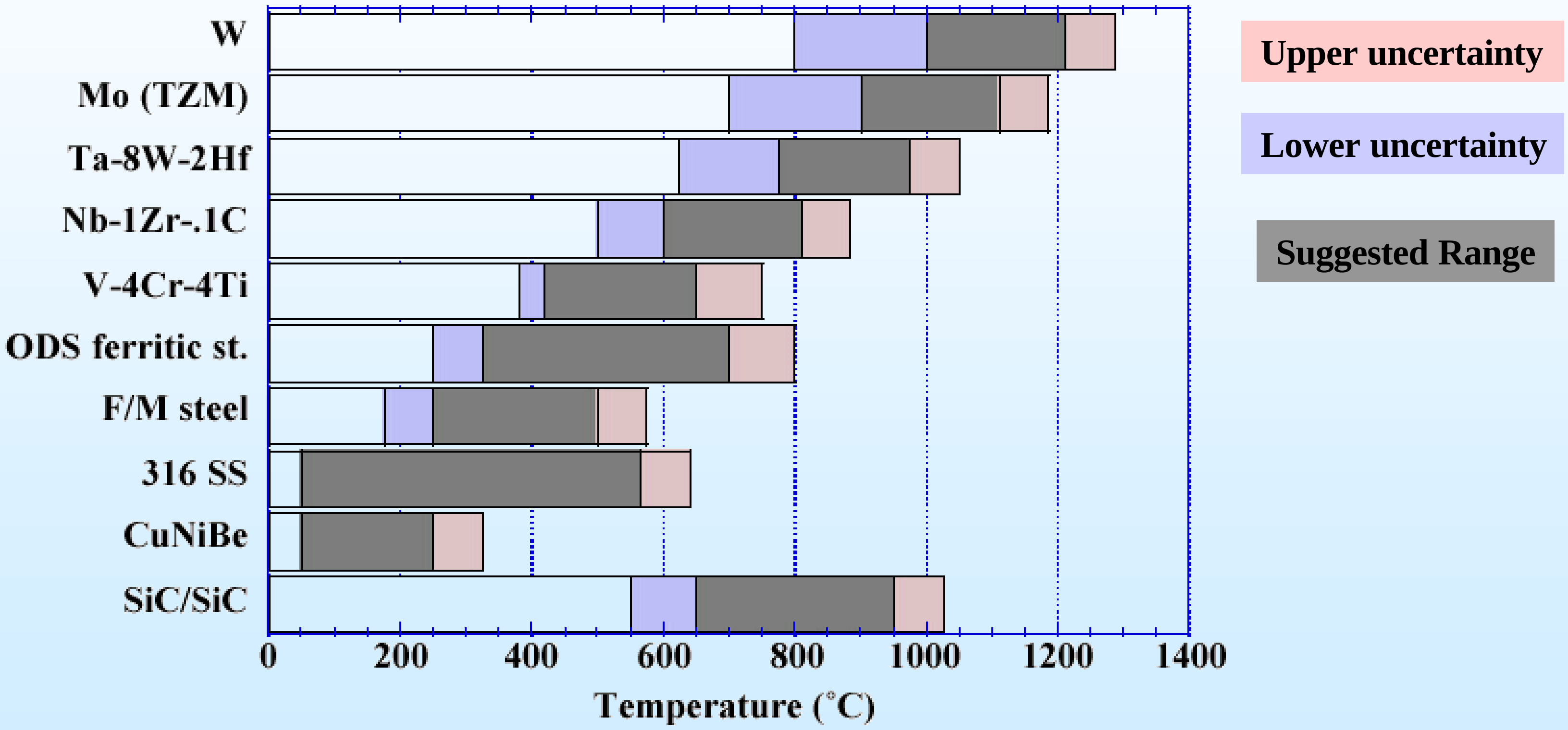
4. Safety & Environmental

- Decay Heat and Waste Disposal (INEEL)

5. Reliability

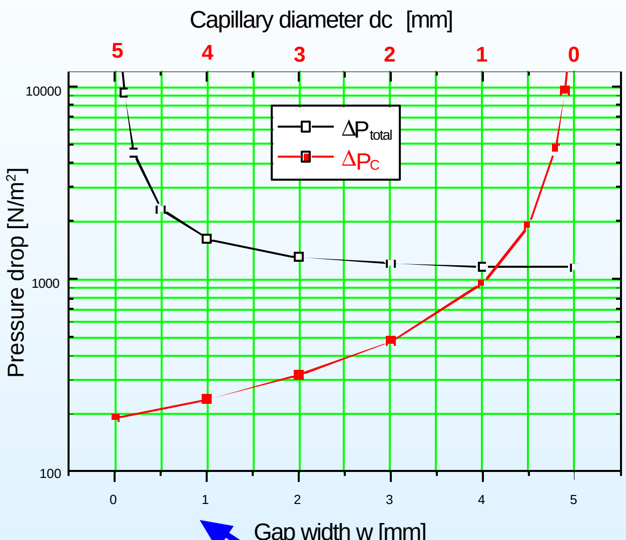
- Leak Tolerance (Majumdar/ANL)
- Reliability is a critical issue for fusion; discussed often, but very difficult to address

Our EVOLVE Concept stimulated considerable interest in the material community to investigate high-temperature refractory alloys (e.g. W)

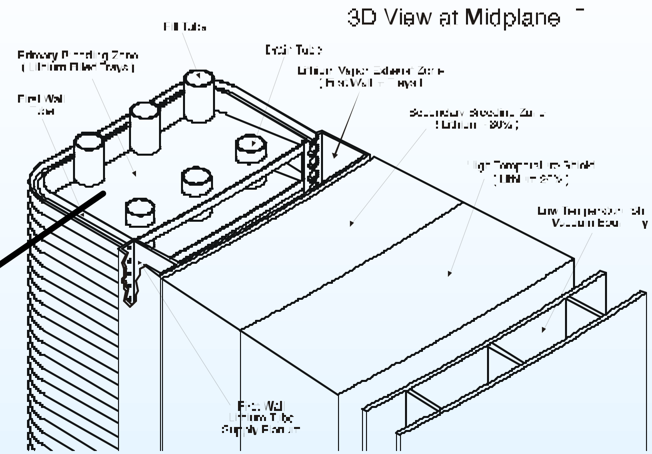


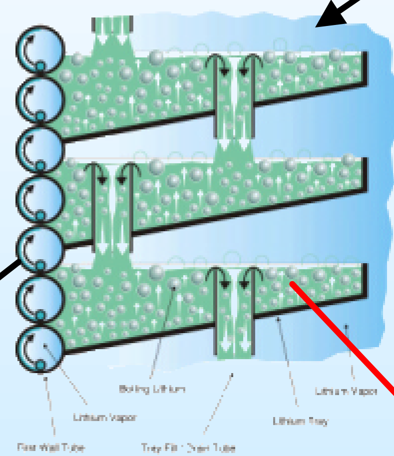
Operating Temperature Windows (based on radiation damage and thermal creep)

Progress on Modeling, Analysis & Experiments for EVOLVE

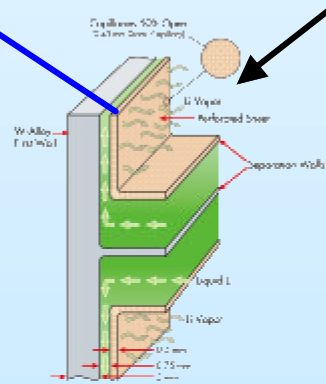


W-alloy EVOLVE Design
Li-vapor @ 0.037 MPa



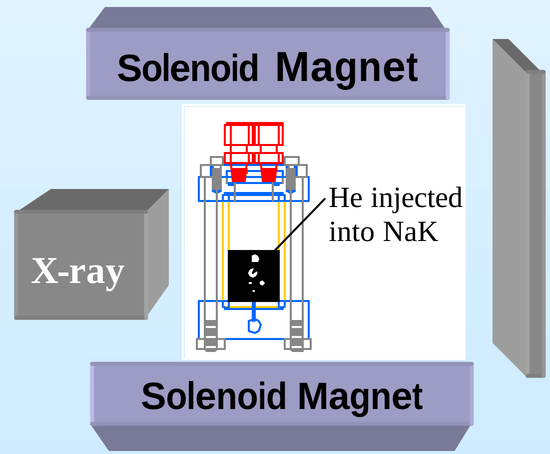


Detail analysis defines design details



Capillary FW

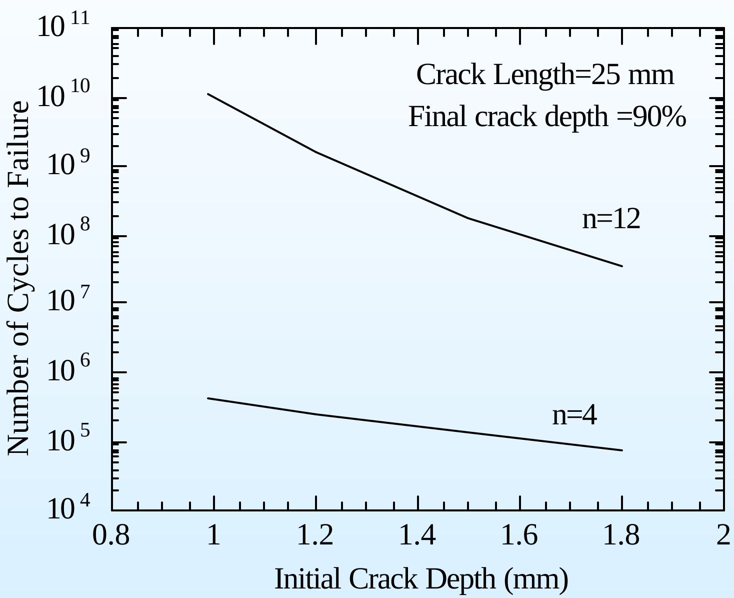
MHD Li-boiling being investigated

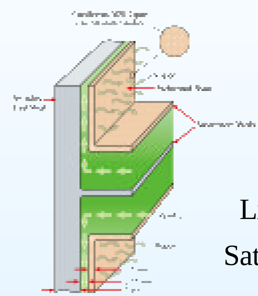


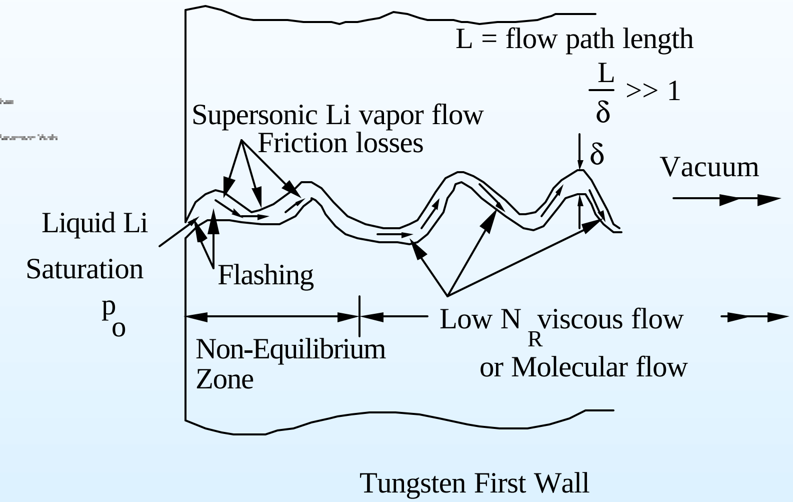
Identify and Address Fundamental Issues

Fatigue and leakage analyses Indicate that the 3 mm W-alloy wall of EVOLVE could tolerate a large number of Cycles and Cracks

(Initial non-through crack assumption: 25 mm long, 10 µm width)





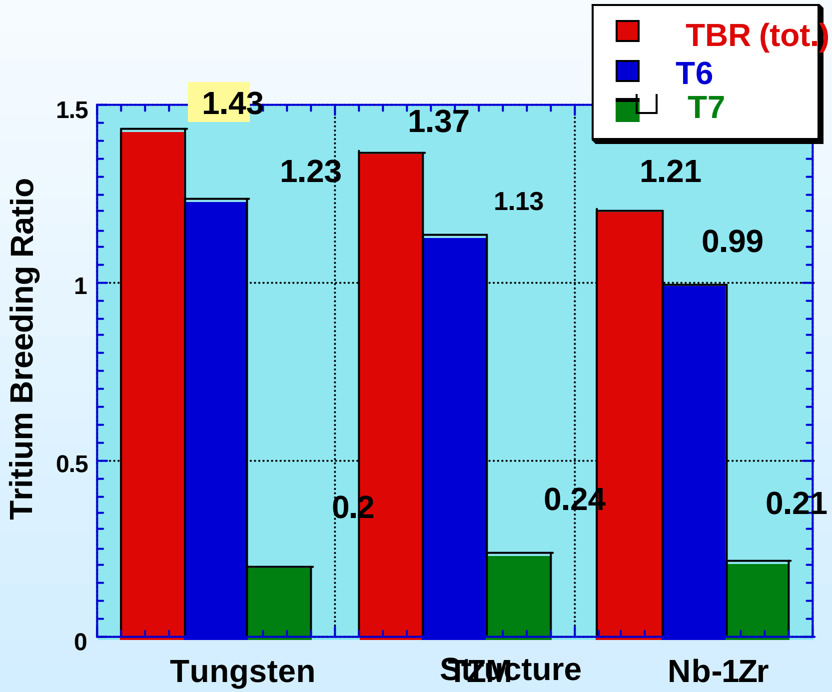


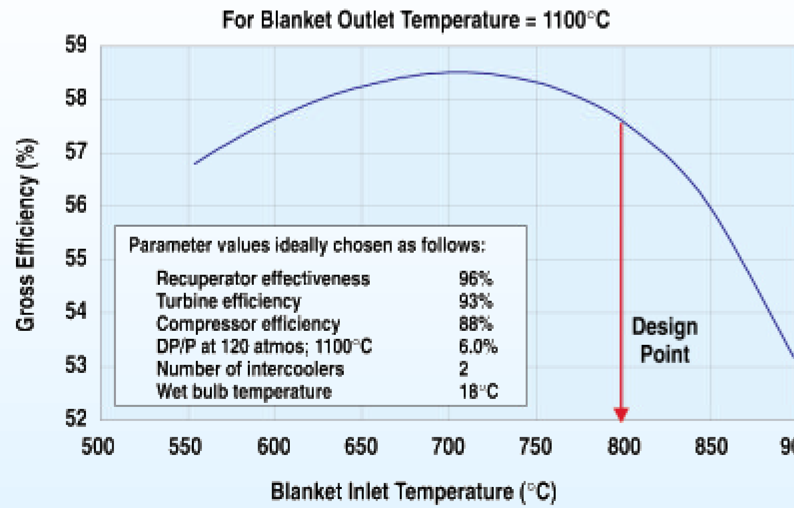
Large number of cycles could be tolerated before a through crack would occur

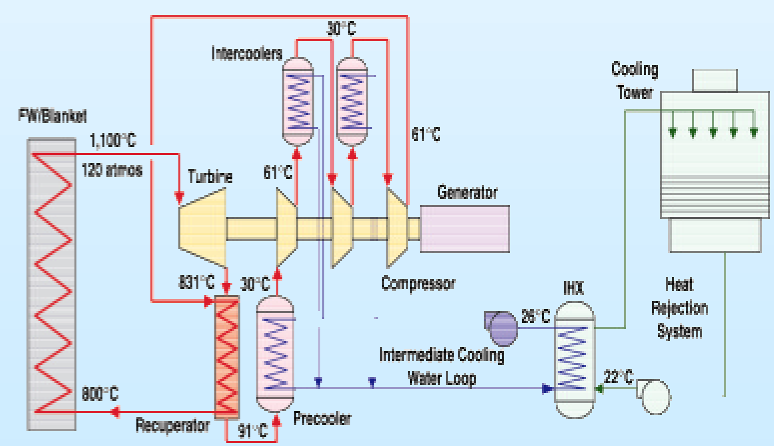
At a leak rate of 5×10^{-4} g/s, the leak would not impact local heat transfer and large number of cracks can be tolerated by the plasma depending on the regime of plasma operation.

- **Calculated life is strongly dependent on extrapolated data**
- **Relevant crack growth data is needed**

W-alloy shows highest tritium breeding performance and CCGT thermodynamic efficiency >57%







Material System Thermomechanics Interactions

Modeling and Experiments

Material System Thermomechanics Interactions
(Non-Structural Materials Science)

***Mission**: Advance the engineering science knowledge base necessary for understanding the thermomechanical performance and material interactions, and possibly extending technology limits, of ceramic breeders and beryllium material systems.*

Objectives: Perform laboratory experiments and modeling for:

a) fundamental thermal-physical-mechanical properties for packed beds

b) material system thermomechanics interactions and deformations

This research is conducted as part of international collaboration (IEA, JUPITER-II)

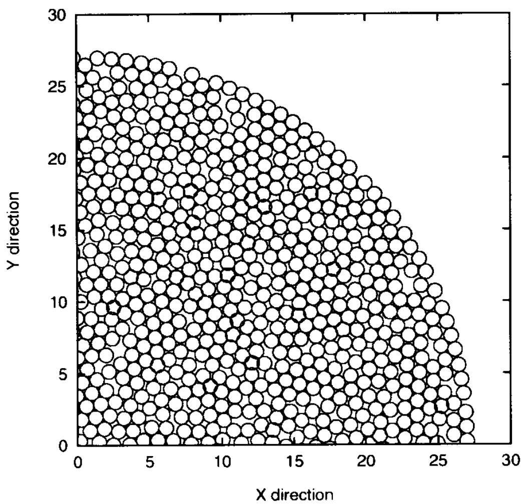
- It is part of US strategy to participate in selected areas of R&D to contribute and gain access to data from the larger international community (EU and Japan)

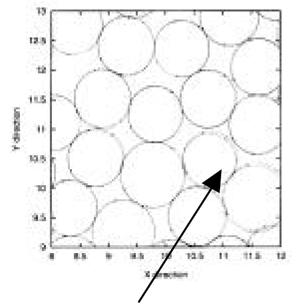
Excellent area of research for University

Material System Thermomechanics Interactions Studies at UCLA

Phenomenological and Numerical Modeling

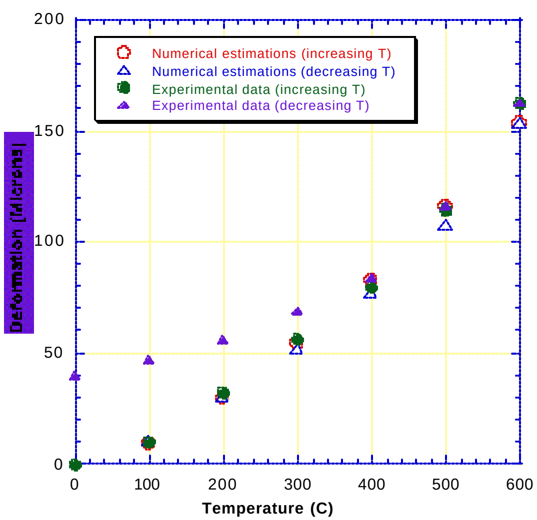
Packing characteristics of the bottom layer of packing (mean particle diameter = 1 mm total number of particles = 26,010)

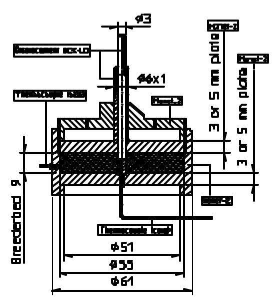




Particle relocation

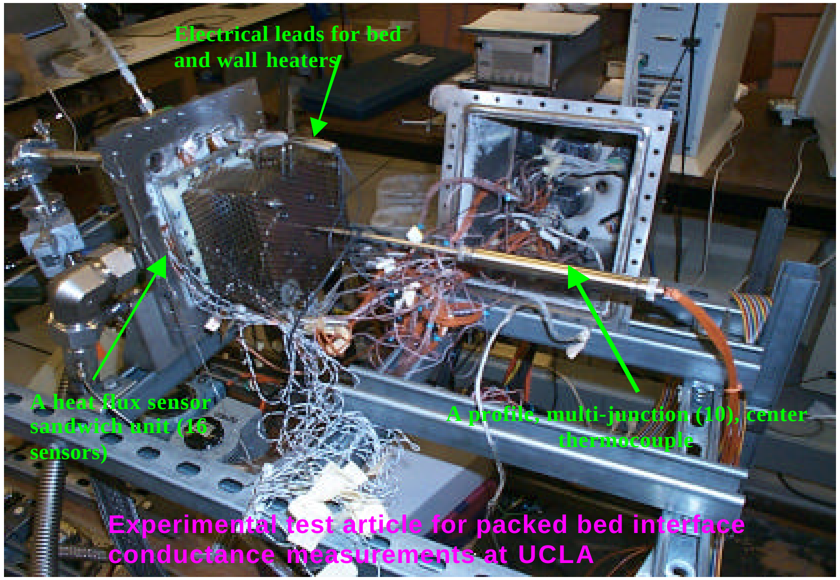
Experimental data is reasonably predicted by the numerical estimations based on fixed boundary conditions





Experimental test article

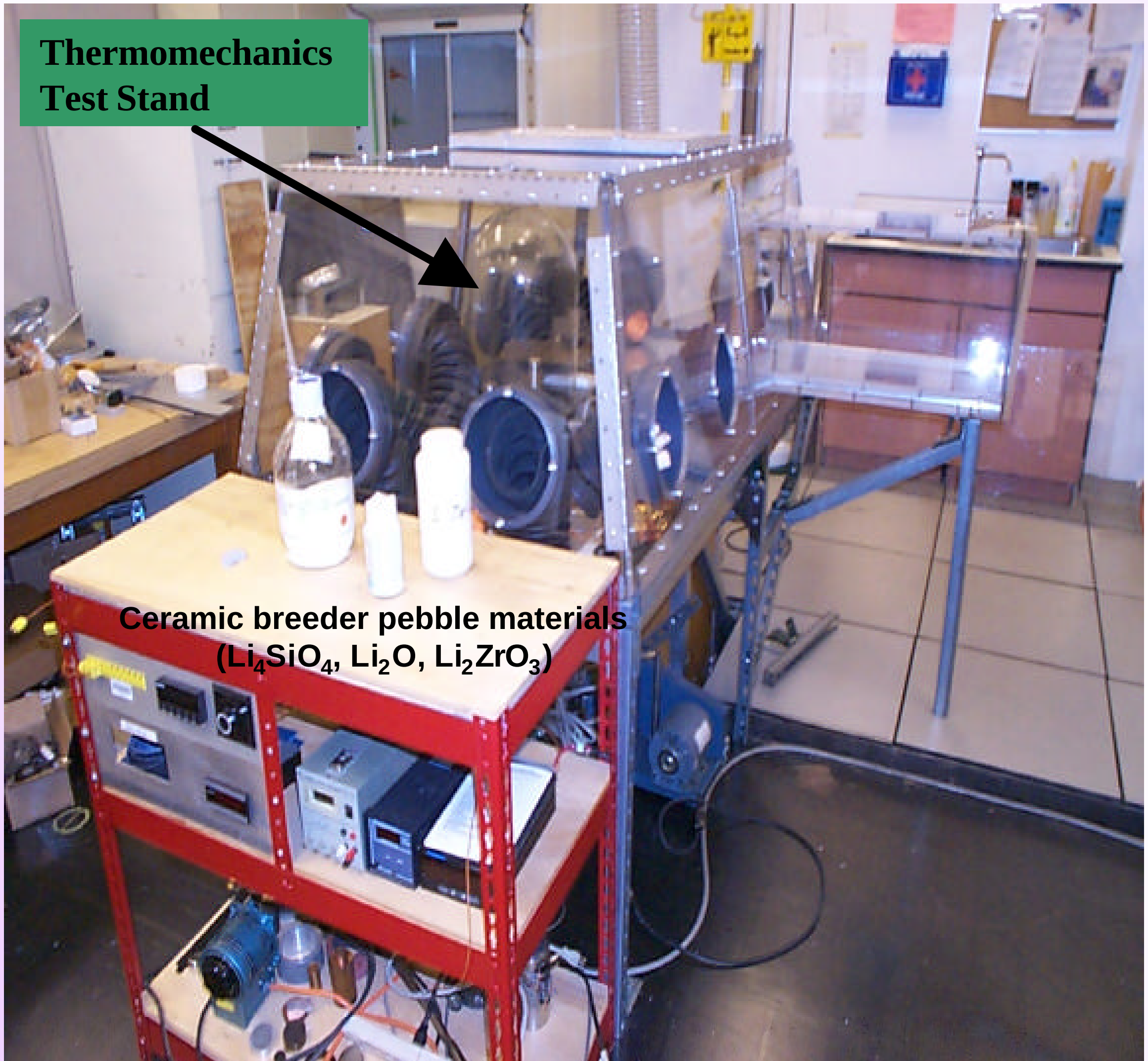
Small Scale Experiments

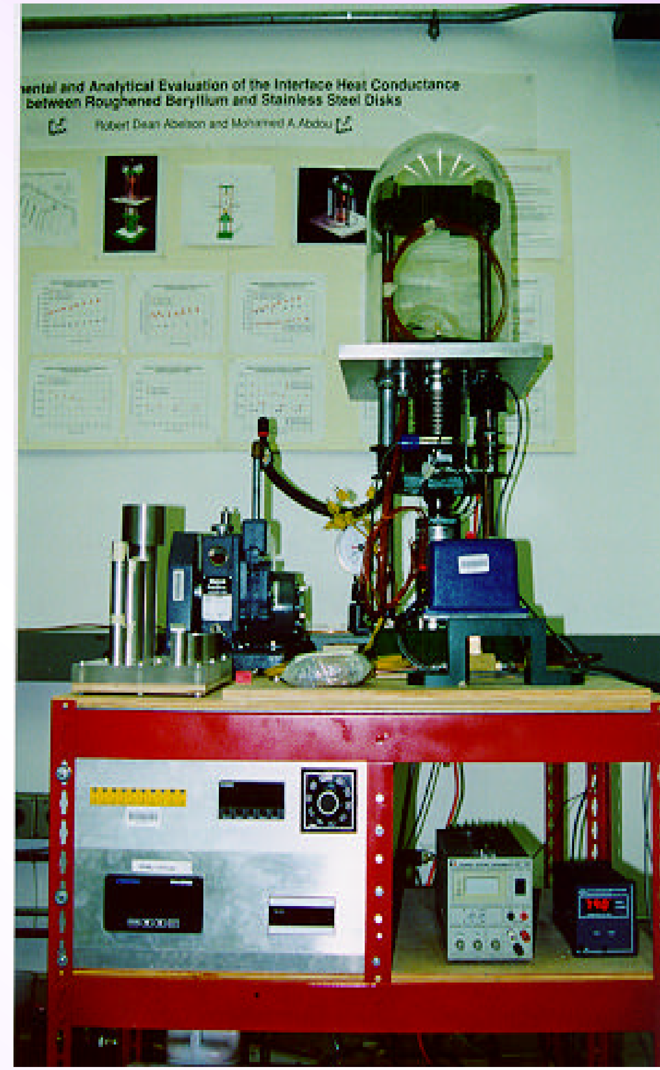


International Collaboration

JAERI scientists observing and discussing real-time experimental data in Japan

Beryllium Handling and Particulate Materials Thermomechanics Test Stand





Material System Thermomechanics Interactions

- **Remarkable Progress and Achievements**

e.g. - 3D Discrete Numerical Simulation micro-mechanics models/codes to simulate and predict the effective thermophysics properties and mechanical characteristics of packed beds under imposed and induced loads.

The models were validated against experiments

The models were used for analysis leading to important conclusions about the behavior of ceramic breeders and beryllium under fusion conditions

- Models and experiments to predict the interface heat conductance between “non-conforming” beryllium and steel surfaces subject to non-uniform thermal deformation.

Good agreement between model and experiments

Understanding the variation of interface conductance and thermal deformation with various loading and operating conditions