EVOLVE Lithium Tray Thermal-Hydraulic Analysis

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Overview

- Large heat of vaporization for lithium makes it ideal as a heat sink for blanket
- Need vapor fraction distribution in liquid lithium tray to determine power deposited
  - ♦ Determine volumetric energy deposition
  - ♦ Structural thermal loading
  - ♦ Design for vapor removal
- Scenarios for boiling/evaporation process
  - ♦ No MHD effect, normal boiling in stagnant pool
  - ♦ Moderate MHD effect, channels produced (Malang concept)
  - ♦ Large MHD effect, boiling severely affected
- Review scenarios, provide current best estimate and propose future work

Pool Boiling No MHD Effect

- Divide 50 cm tray into "cells" and predict vapor fraction distribution in each cell
- Cell sizing calculation (Taylor length scale, ~ 10 cm)
  - ♦ Cell width = $2\pi[3\sigma/(g\Delta\rho)]^{1/2}$
- Sawan (UW) provided nuclear heating (W/cm^3) distribution for OB tray
- Uniform vapor fraction distribution of 17% used for first estimate
- 25 zone Li pool (5 radial cells, 5 vertical positions)
- Use energy deposited in Li pool and W wall to determine the vaporization rate
- Lithium vaporized used to determine volumetric vapor flux (jg) and the superficial gas velocity (Jg)

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Pool Boiling No MHD Effect (continued)

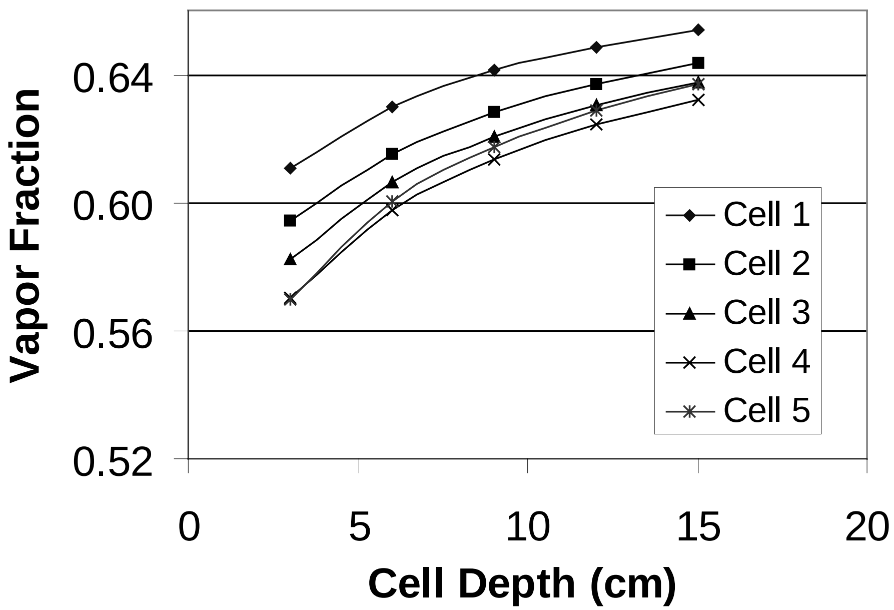
- Drift-flux model

$$< vaporfraction >= \frac{< Jg >}{C_o < Jg > + C_1}$$

- Vapor fractions are driven by Li vapor density and by nuclear heat loads applied to the Li and W
- Vapor fraction must be matched with heating (iteration necessary)
- As first order approximation nuclear heating in the Li is scaled linearly with density
- Once the vapor fraction distribution is finalized, nuclear performance parameters will be updated, and the iteration continued (final vapor fraction distribution on next page)

Pool Boiling No MHD Effect (continued)

- Final cell vapor fractions



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Pool Boiling No MHD Effect (continued)

- "Void Distribution in Boiling Pools with Internal Heat Generation", Kazimi & Chen, (LMFBR core accidents with molten fuel pools forming)

- Analytical expressions proposed

  ♦ Bubbly flow

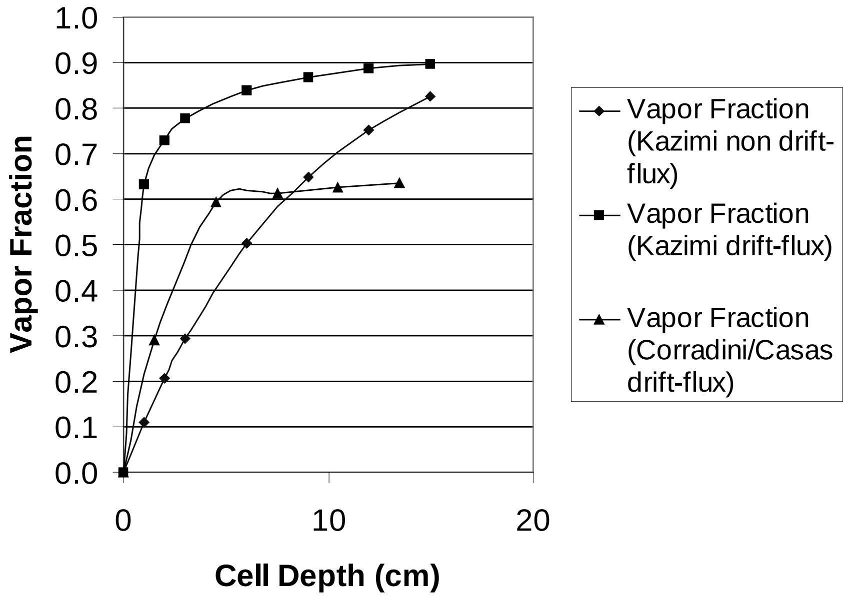
$$\alpha = 1- \exp[-GY/(\lambda\rho_v BV_{inf})]$$

  ♦ Churn-turbulent flow

$$\alpha = 1-1/[1+2GY/(\lambda\rho_v V_{inf})]^{1/2}$$

Pool Boiling No MHD Effect (continued)

- Kazimi and Chen's models are consistent with our drift-flux model (Casas and Corradini)



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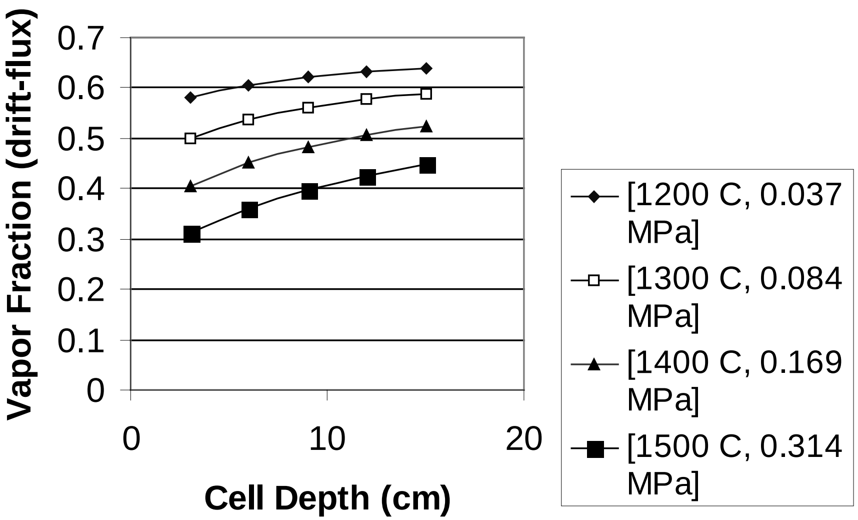
Pool Boiling No MHD Effect (continued)

- Vapor fractions appear to be significant (can be reduced by increasing operating pressure and associated temperature)



- Vapor fractions in excess of 50% could be observed

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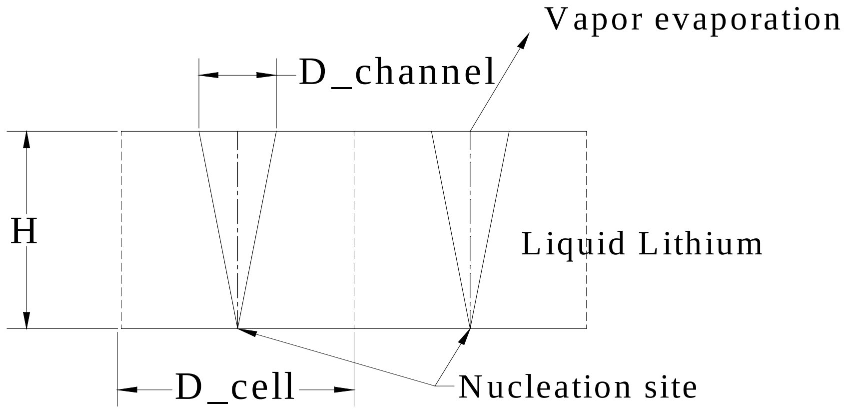
Moderate MHD Effect

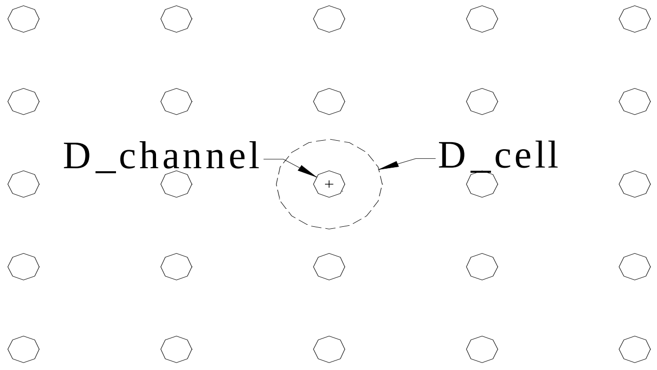
- Alternative boiling flow regime proposed by S. Malang (FzK)
  - ♦ MHD effects could hold channels open with minimal liquid lithium movement with smaller vapor fractions and stable channels
  - ♦ Moderate interaction where magnetic field dampens bulk liquid lithium movement but does not affect nucleate boiling process
    - ▪ Channels initiated at preferred nucleation sites and spaced as needed for heat removal
- Potential for smaller vapor fractions with stable liquid/vapor channels

Moderate MHD Effect (continued)

Schematic of vapor channels (side view)



Schematic of vapor channels
(top view)



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Moderate MHD Effect (continued)

- Conduction heat transfer analysis and liquid superheat would determine maximum spacing of channels
  - ♦ To avoid liquid nucleation channels could be spaced ~ 8 cm apart (200K superheat)
- Mass, pressure and energy balances are combined to determine vapor flow geometry and spacing
  - ♦ Balancing static head of liquid lithium with kinetic force from vapor, frictional force from vapor and magnetic pressure drop of liquid lithium in channel
  - ♦ ΔP(static liquid head) = ΔP(kinetic) + ΔP(friction) + ΔP(magnetic)

$$\Delta P(static) = \rho_l g H \qquad \Delta P(kinetic) = \frac{\rho_v v^2}{2}$$

$$\Delta P(friction) = 0.03 \rho_v (H/D) v^2 \qquad \Delta P(magnetic) = \sigma v_l B^2 (L/2)$$

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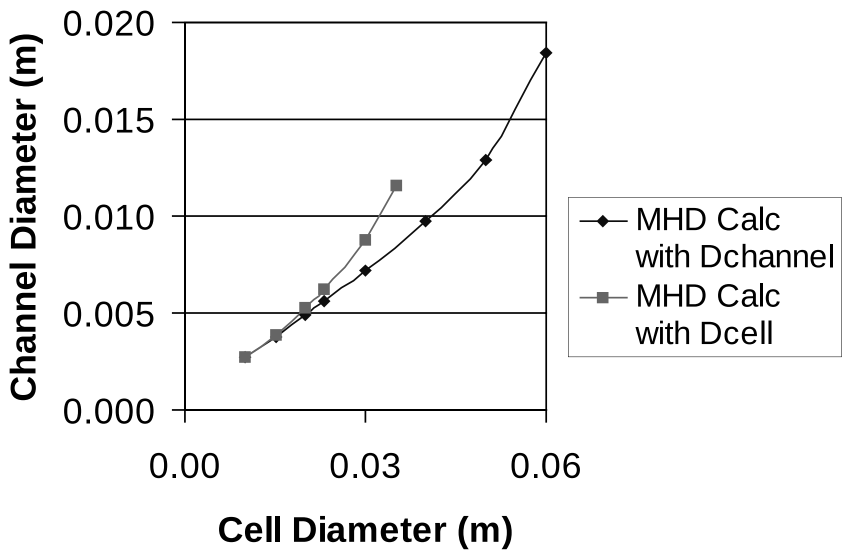
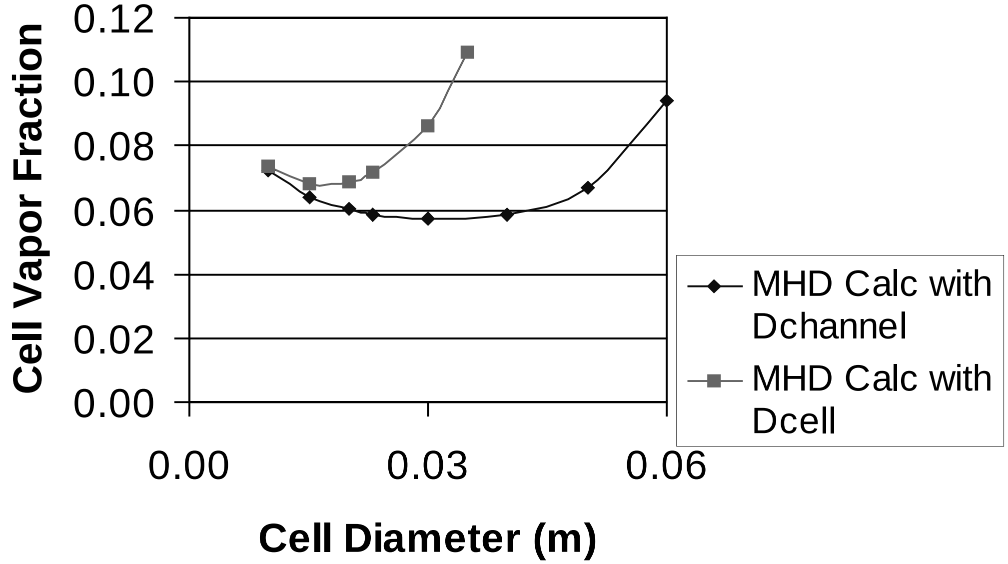
Moderate MHD Effect (continued)

- Parametric analyses performed to illustrate the effect of cell size on vapor channel size, and vapor fraction



Moderate MHD Effect (continued)

- Cell vapor fraction versus cell diameter



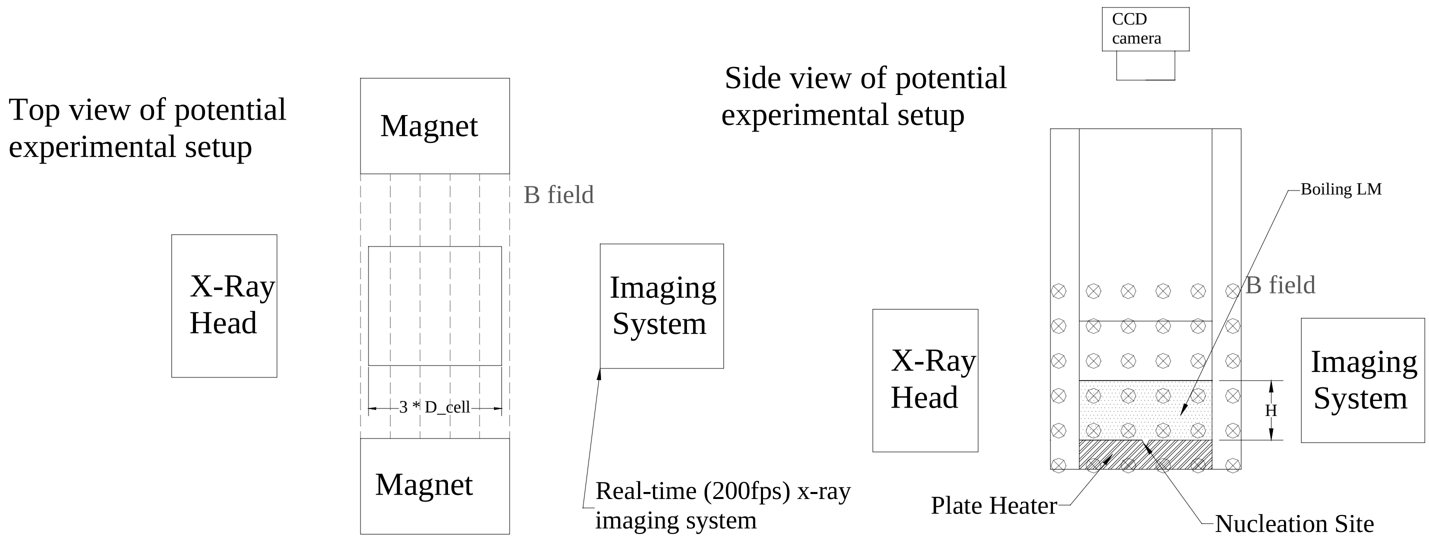
Large MHD Effects

- It is possible that MHD has a large effect on liquid metal boiling: bubble size and frequency (Lykoudis et al. Int. J. Heat Mass Transfer 41 (1998) 3491-3500)
- If this is confirmed for large magnetic fields (>> 1 T) boiling could be severely affected
- Current judgement is that this is not the case, but it must be experimentally confirmed by boiling flow regime visualization experiments
- These experiments are also needed to confirm the expected flow regime with moderate MHD forces

Proposed Future Work

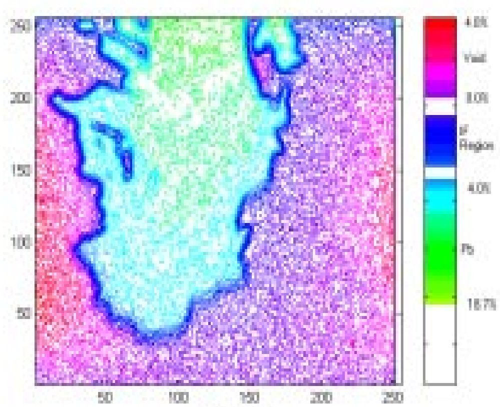
- According to previous work and the current state of knowledge regarding pool boiling of liquid metals in the presence of a magnetic field, experiments are required to accompany further analysis.
  - ♦ Determine the onset of nucleate boiling and its characteristics for a conductive fluid (lithium) at different magnetic field strengths to quantify the suppression of boiling.
  - ♦ Real-time visualization of flow patterns developed when boiling is achieved in the liquid metal as a function of magnetic field strength.
  - ♦ Develop a physical model explaining the effects of the magnetic field for onset of boiling for liquid metals and boiling flow regime. This will allow us to determine the boiling rate and heat transfer for a given volumetric heat flux and will lead to the required depth of the pool needed to balance heat generation and heat removal.

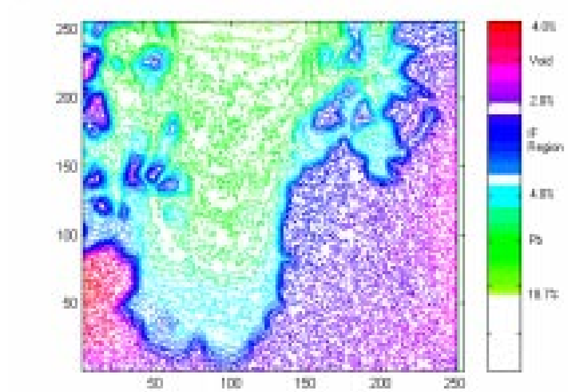
Cartoon of Proposed experimental arrangement:



Example of Liquid metal/void images from high speed X-ray system

(Taken at UW-Madison Liquid metal laboratory by: E. P. Loewen*) *now at INEL





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