OVERVIEW OF THERMOMECHANICAL PROBLEMS IN FUSION REACTOR BLANKETS

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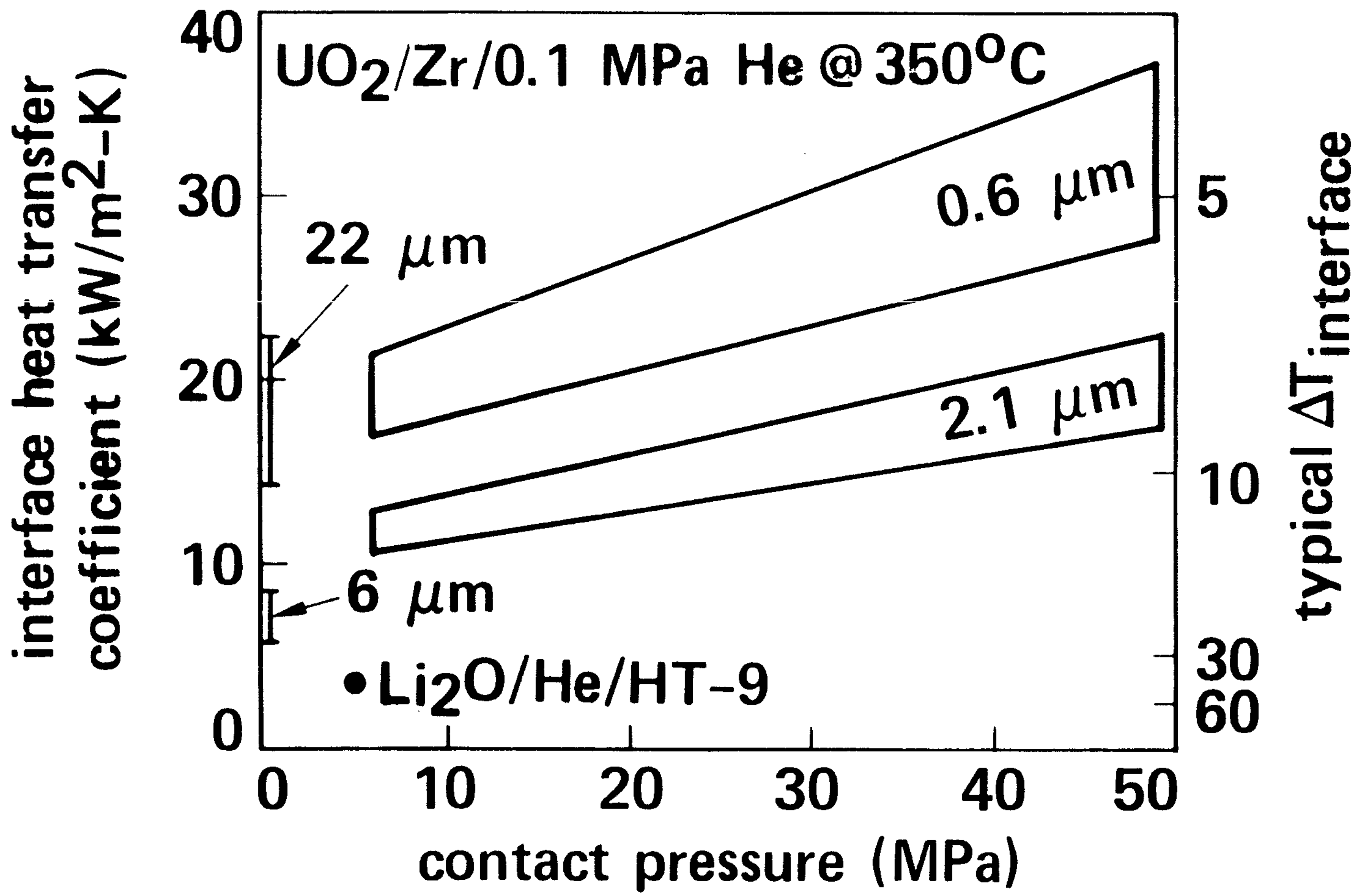
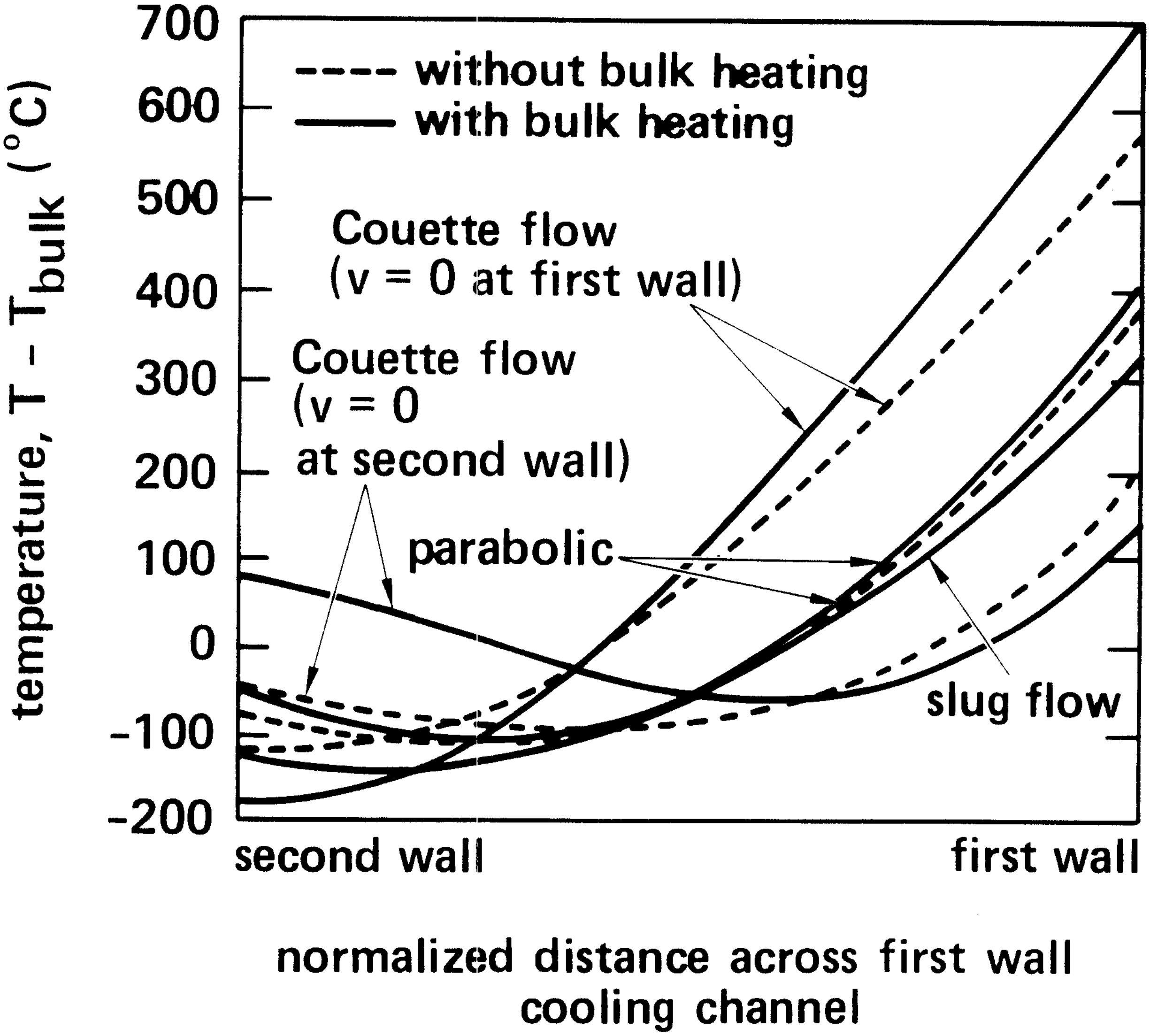
Coolant/breeder interfacial heat transfer is difficult to predict, leading to uncertainties in breeder temperature and tritium inventory.



Temperature Profiles Depend Strongly on the Velocity Profile



MAJOR RECENT STUDIES ON BLANKETS IN THE U.S.

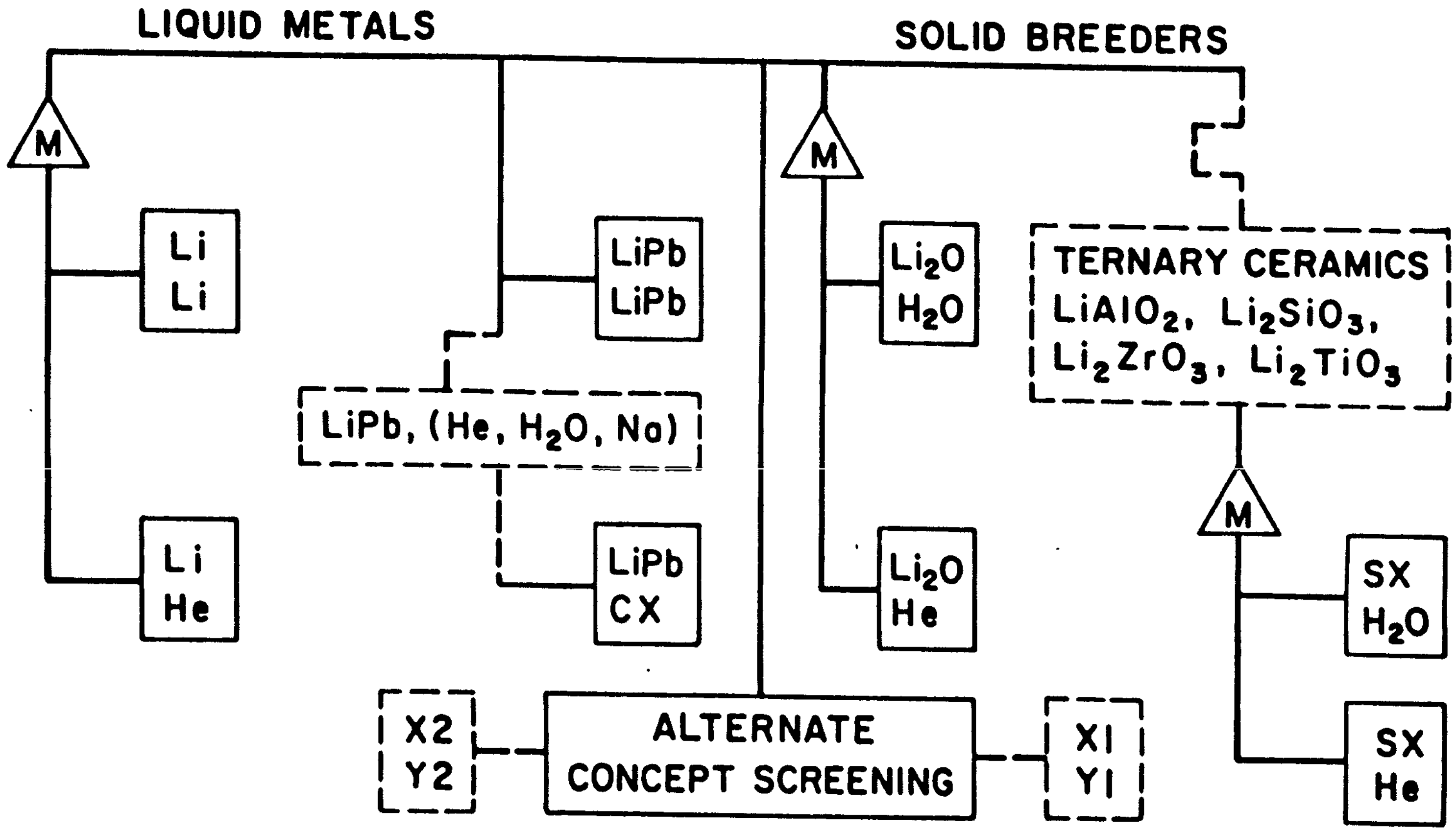
- Blanket Comparison & Selection Study (BCSS) led by ANL
- Fusion Nuclear Technology Issues, Experiments & Facilities (FINESSE) led by UCLA
- Parts of reactor studies carried out b a number of organizations (e.g., TPSS and Mini-MARS)

Candidate First–Wall/Blanket Materials

Breeding Materials	Coolants	Structure	Neutron Multiplier
Liquid Metals	H_2O	Austenitic Steel	Be
Li	Li	PCA	Pb
17Li–83Pb	17Li–83Pb	Mn Steel[A]	
	He		
	Salt[C]		
Ceramics		Ferritic Steel	
Li_2O		HT–9	
Li_8ZrO_6		Mod. Ferr. St.[A]	
$LiAlO_2$[B]			
Salt		Vanadium Alloy	
FLIBE[D]		V15Cr5Ti	

[A]Low–activation structural alloys. V15Cr5Ti is inherently low activation.
[B]$LiAlO_2$ is representative of ceramics that include Li_2SiO_3, Li_2ZrO_3, etc.
[C]Nitrate salt.
[D]Fluoride salt

BLANKET OPTIONS



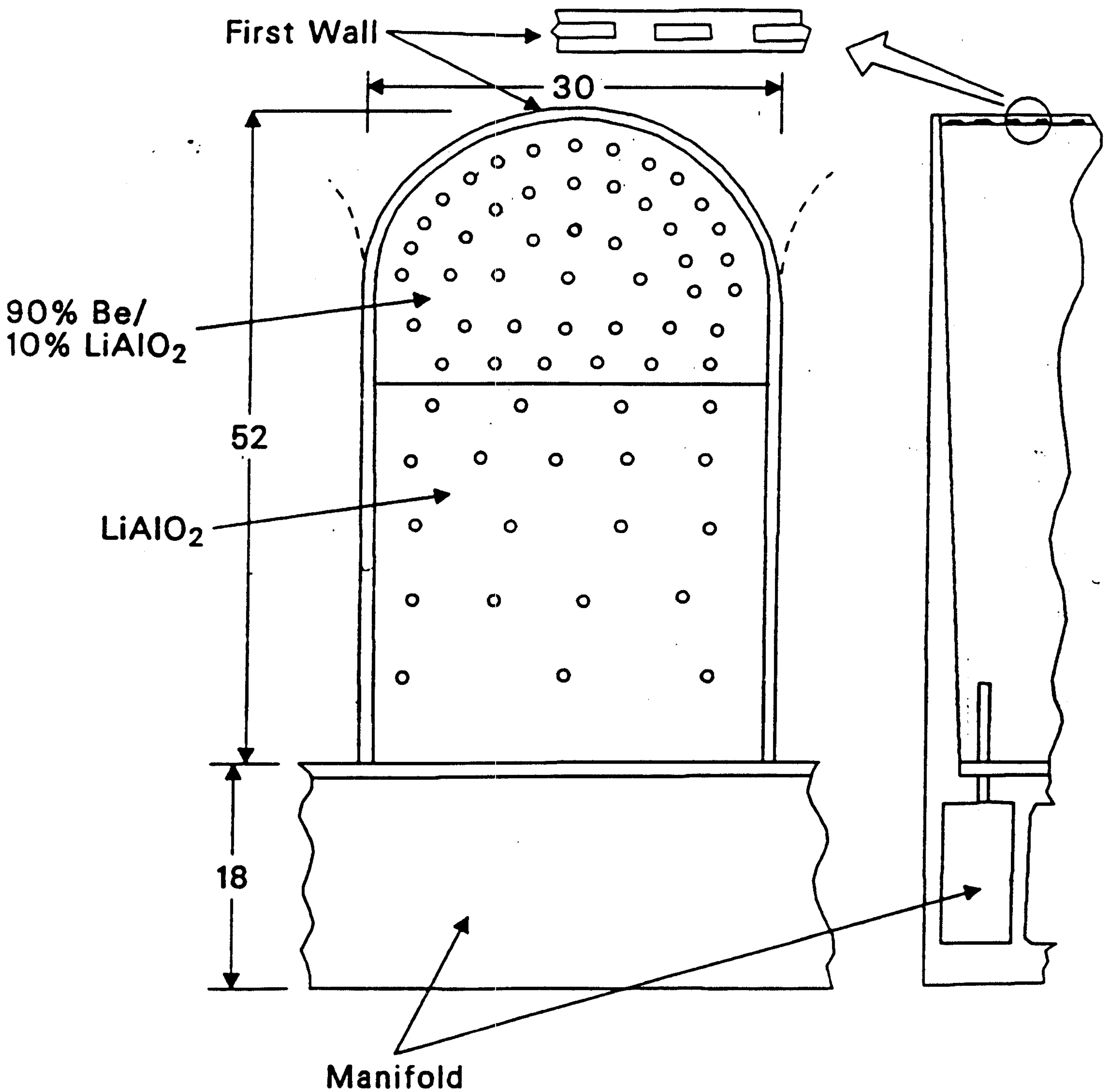
STRUCTURAL MATERIAL

- BIG DIFFERENCE IN R&D
  - (1) PCA
  - (2) FERRITIC
  - (3) VANADIUM ALLOY

M = NEUTRON MULTIPIIER

- ALL BREEDERS (EXCEPT LIPb) MAY REQUIRE MULTIPLIER.
- IS BERYLLIUM THE ONLY CHOICE ?
- BERYLLIUM ASSESSMENT.

REFERENCE DESIGN CONFIGURATION FOR $LiAlO_2/H_2O$/FS/Be CONCEPT - TOKAMAK



Leading Blanket Concepts Evaluated in BCSS
(Breeder, Coolant, Structure, Neutron Multiplier)

Li/Li/V

Li/Li/FS*

LiPb/LiPb/V*

Li/He/FS

Li_2O/He/FS

$LiAlO_2$/He/FS/Be

$LiAlO_2$/H_2O/FS/Be

$LiAlO_2$/NS/FS/Be

Flibe/He/FS/Be

* Evaluated for TMR only.

MHD PRESSURE DROP

- The MHD Pressure Drop Depends on the Device Parameters and the Blanket Wall Thicknesses

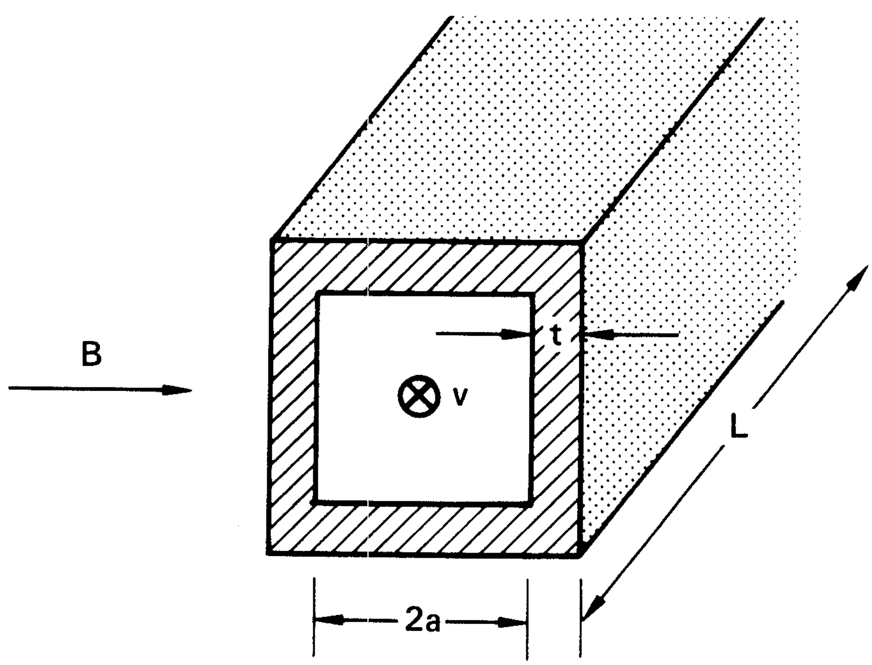
$$\Delta p \simeq \sigma_f v B^2 L \phi$$

$$\phi = \frac{\sigma_w t}{\sigma_f a}$$

- But the Pressure Stress is Relatively Insensitive to the Wall Thickness

$$\sigma = \frac{pa}{t} \sim \sigma_w v B^2 L$$

- The Maximum Allowable Pressure Stress Limits the Flow Velocity. This Conflicts with Heat Transfer Requirements.

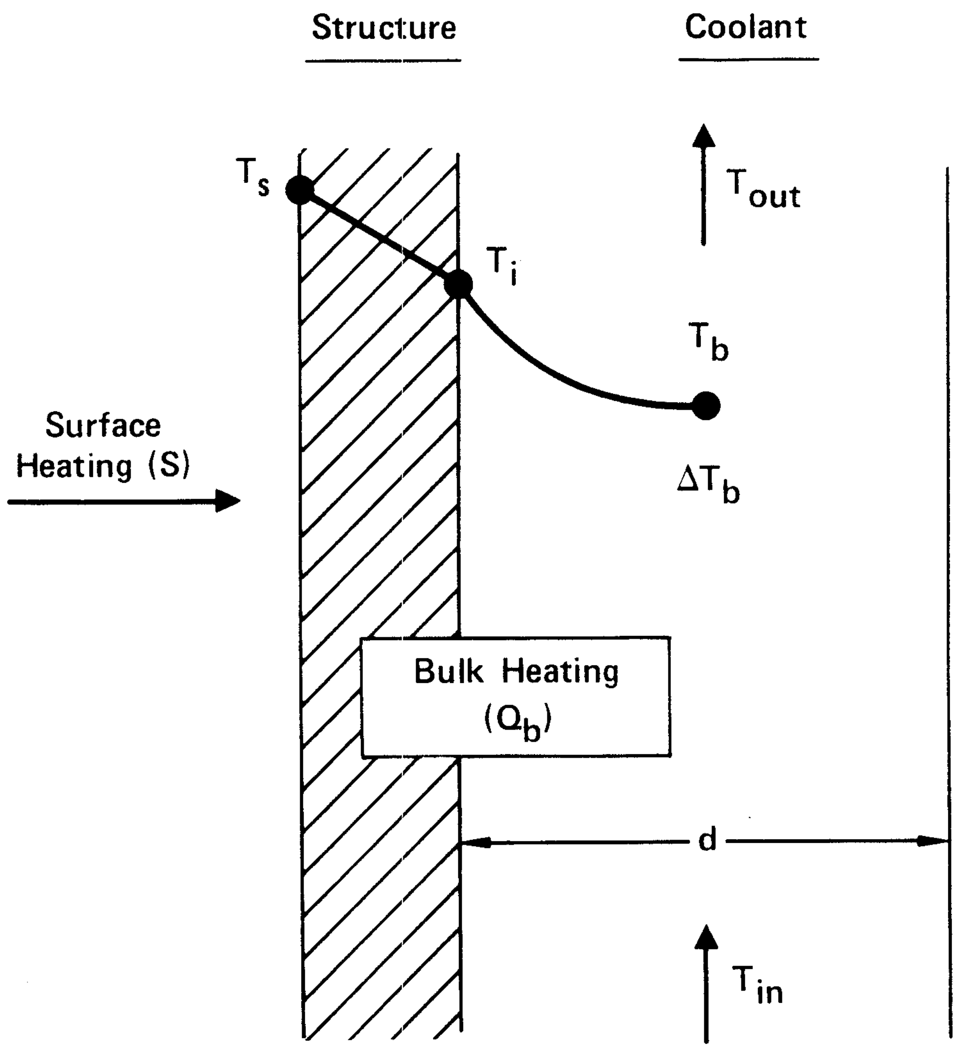


HEAT TRANSFER REQUIREMENTS

The Minimum Inlet Temperature and Maximum Structure and Interface Temperatures Place Upper Limits on $\Delta T_b = T_{out} - T_{in}$

This Translates to a Lower Limit on Flow Velocity.

$$\rho \, c_p \, v \, \Delta T_b = \frac{L}{d} (S + Q_b)$$



$$T_s = T_{in} + \Delta T_b + \Delta T_{film} + \Delta T_s \leqslant T_s^{max}$$

UNCERTAINTIES IN MHD PRESSURE DROP

MHD Flow in Conducting Structures Requires the Simultaneous Solution of Electromagnetic and Fluid Flow Equations in Complex Geometrical Configurations

Uncertainties Arise From:

- Complex Three-Dimensional Flow Effects
  (Internal Channel Geometry)

  Bends, Contractions, Manifolding, etc.

- Complex Magnetic Field Effects

  Sensitivity to Direction of Field

  Field Gradients

- Complex Structure Geometry Effects
  (External Channel Geometry)

  Multiple Channel Effects

  Leakage Currents

MHD FLUID FLOW PHENOMENA

The Magnetic Field Dominates the Velocity Profiles in a Liquid Metal Blanket, Resulting in

- Turbulence Supression

    Long Entry Lengths for Heat and Mass Transfer

    Reduced Heat and Mass Transfer in the Coolant

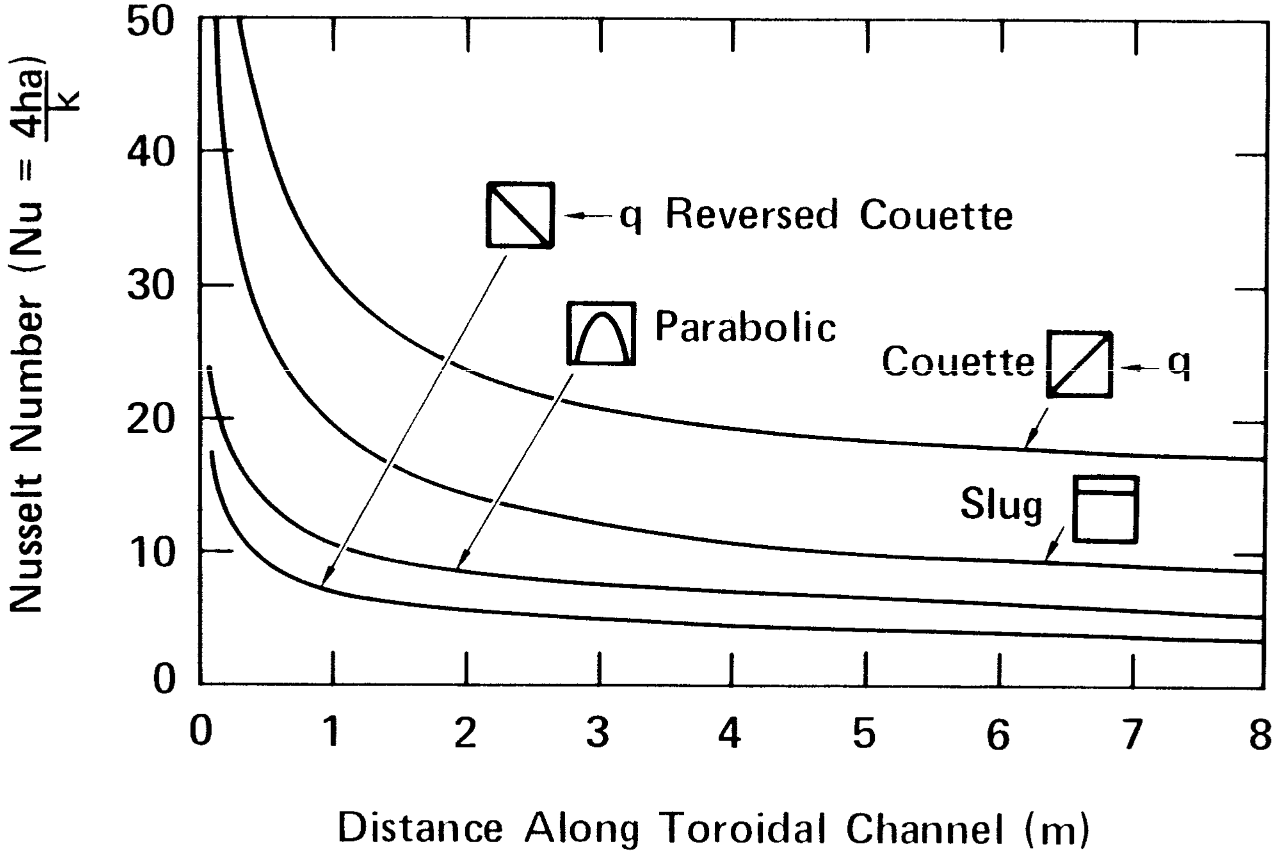
- Very Thin Boundary Layers

    Enhanced Corrosion

- High Velocity Fluid Jets

The Uncertainties in MHD Fluid Flow Are Similar to Those for MHD Pressure Drop i.e., Geometric Complexities in Flow, Magnetic Field, and Structure Geometry

In Laminar Flow, the Heat Transfer Coefficient Depends on the Velocity Profile and Varies Throughout the Entire Blanket



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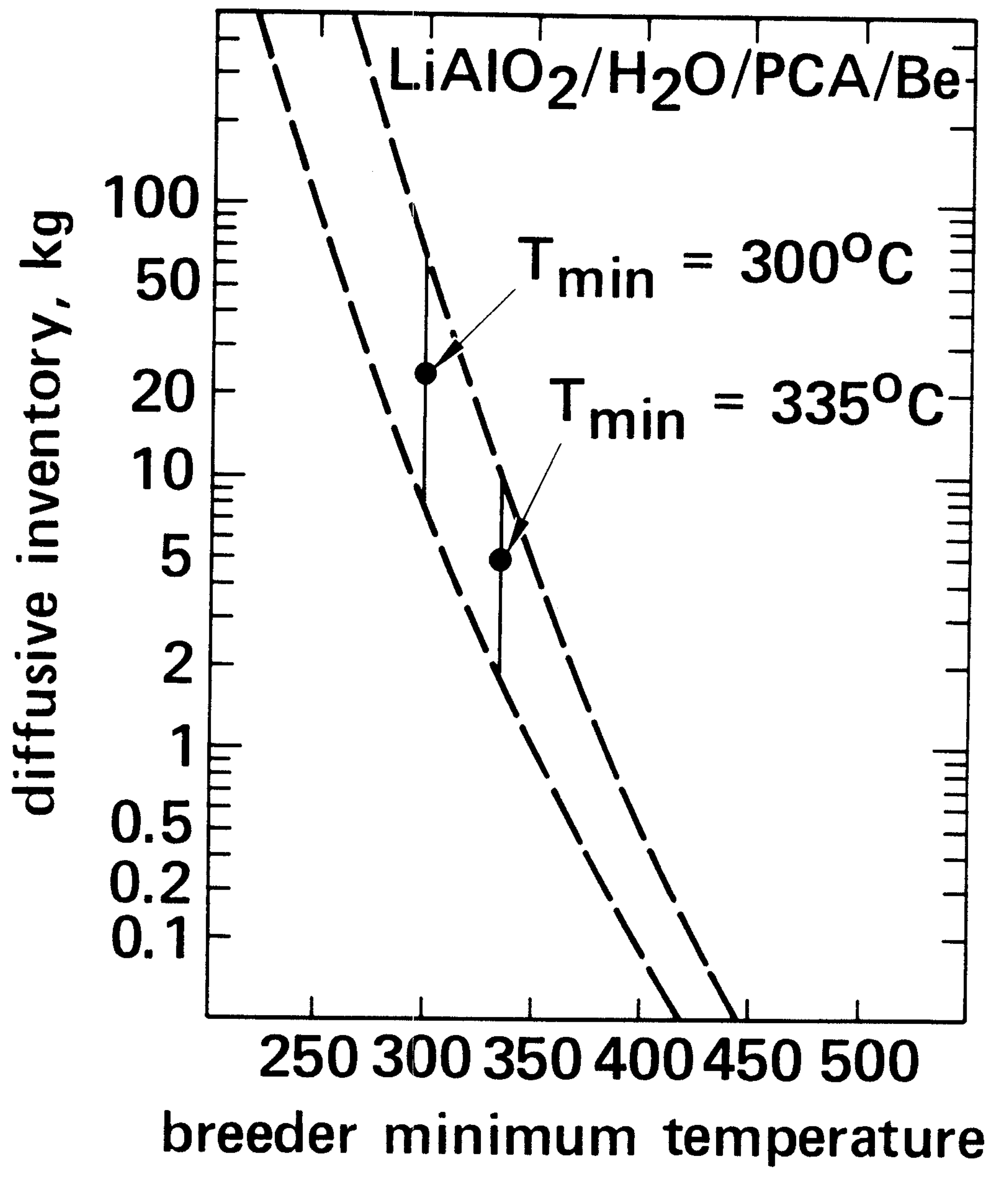
Issue

An Effect That Imposes a Limit on Design Window Represents an Issue

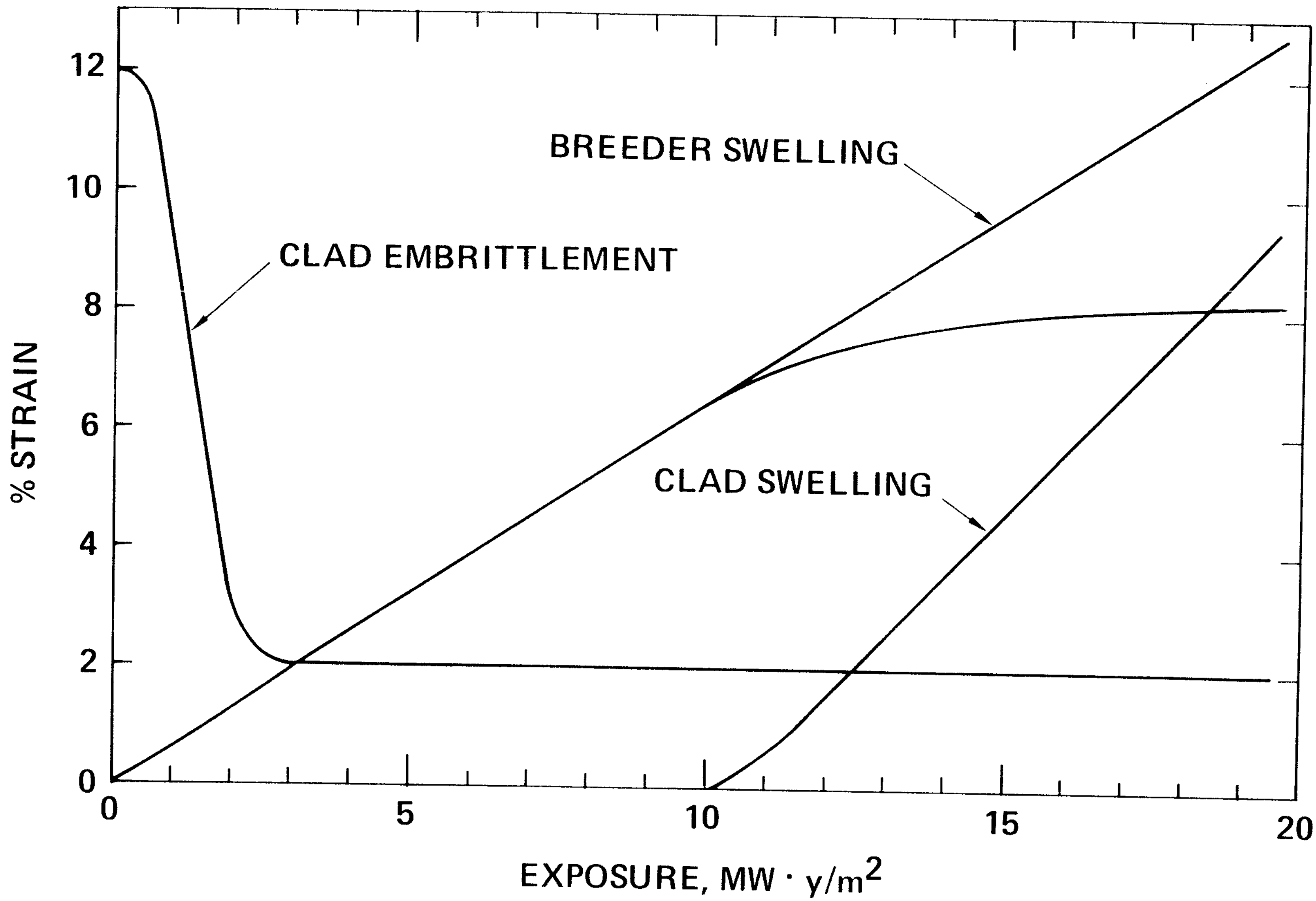
Important

If Uncertainty in Defining the Limit is Wider Than Design Window, the Issue is Important

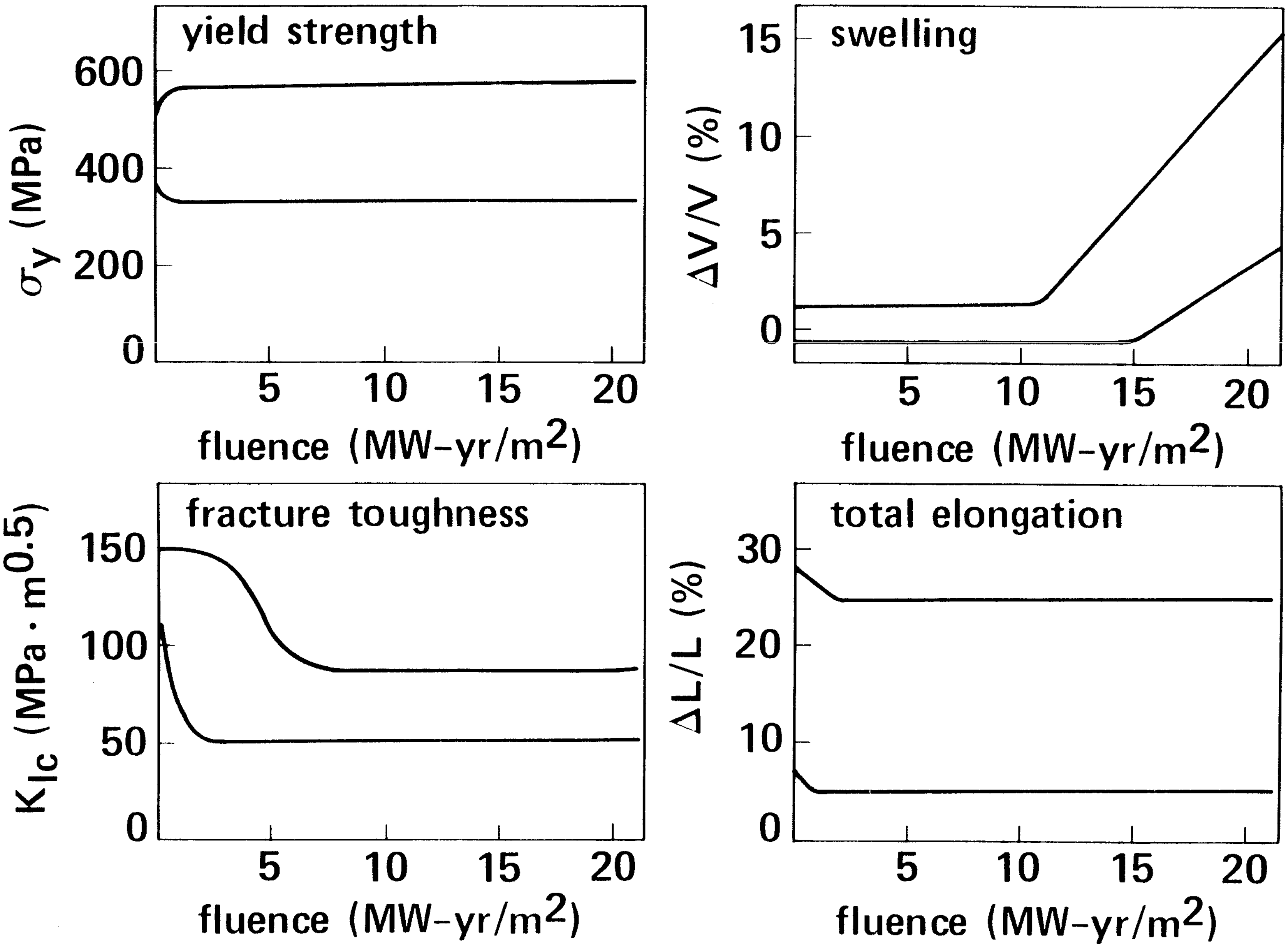
Uncertainties in tritium diffusion rate and breeder temperature affect blanket inventory.



CLAD/BREEDER MECHANICAL INTERACTION
(ESTIMATES FOR Li_2O/HT-9/He)



Effects of irradiation on basic structural material properties are uncertain. (HT-9 @ 500°C)



What Have We Learned From Blanket Design Studies?

- Present Uncertainties Are Too Large To Permit Selection Of Only One Option
- Substantial Experimental Data Needed Before Selection

Problem of R&D Cost

- R&D Cost Is Greatly Affected By Number Of Options Pursued
- Similar Problems For Many Fusion Nuclear Components
- Need Carefully Planned Experiments

How Do We Plan
An Effective Experimental Program?

SUMMARY

- Selection between liquid metal and solid breeder blankets requires more experimental data

- Many of the blanket issues relate to thermomechanical performance

- For liquid metals: the dominant issue is MHD effects

- For solid breeders: the main issues relate to tritium inventory and clad/breeder/multiplier interactions