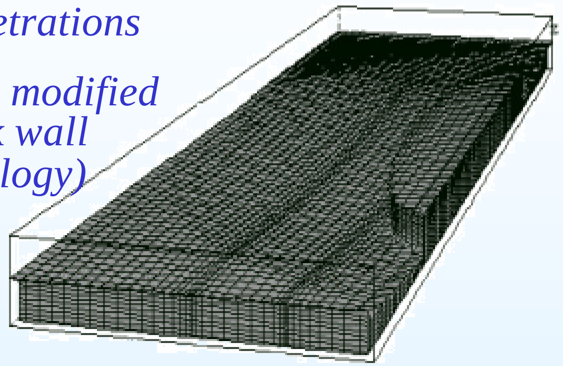
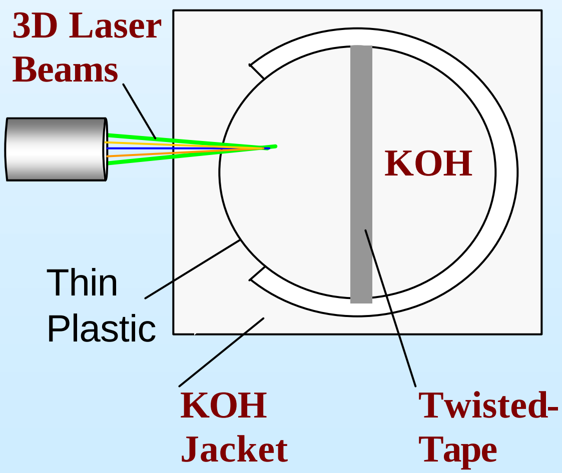
FLIHY constructed as a flexible facility that serves many needs for Free-Surface Flows in low-k, high Pr fluids

Flow Control

Penetrations

(e.g. modified back wall topology)

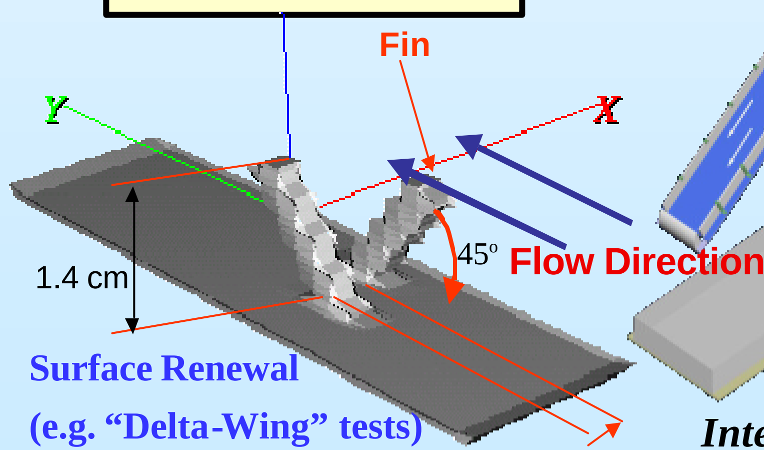




JUPITER-II

US-Japan Collaboration on Enhancing Heat Transfer

- **Large scale test sections with water/KOH working liquid**
- **Tracer dye and IR camera techniques**
- **PIV and LDA systems for quantitative turbulence measurements**



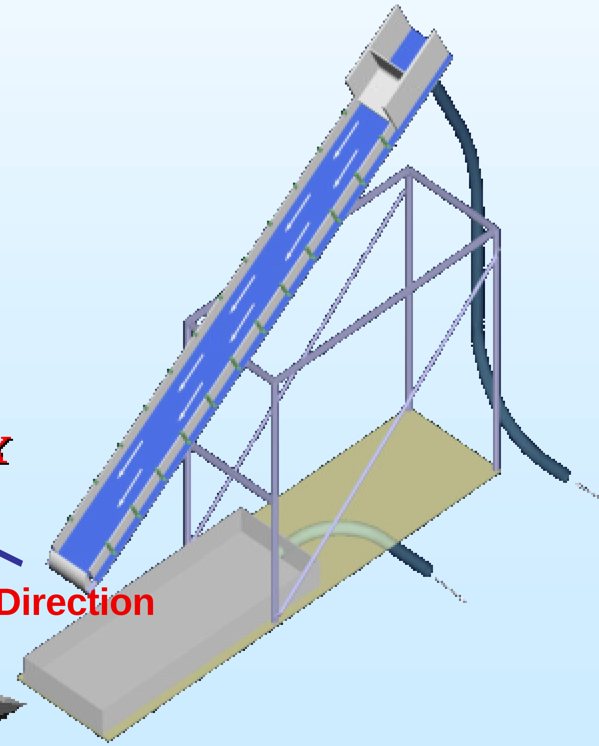
Surface Renewal

(e.g. "Delta-Wing" tests)

Free Surface Interfacial Transport

- Turbulence at Free Surface

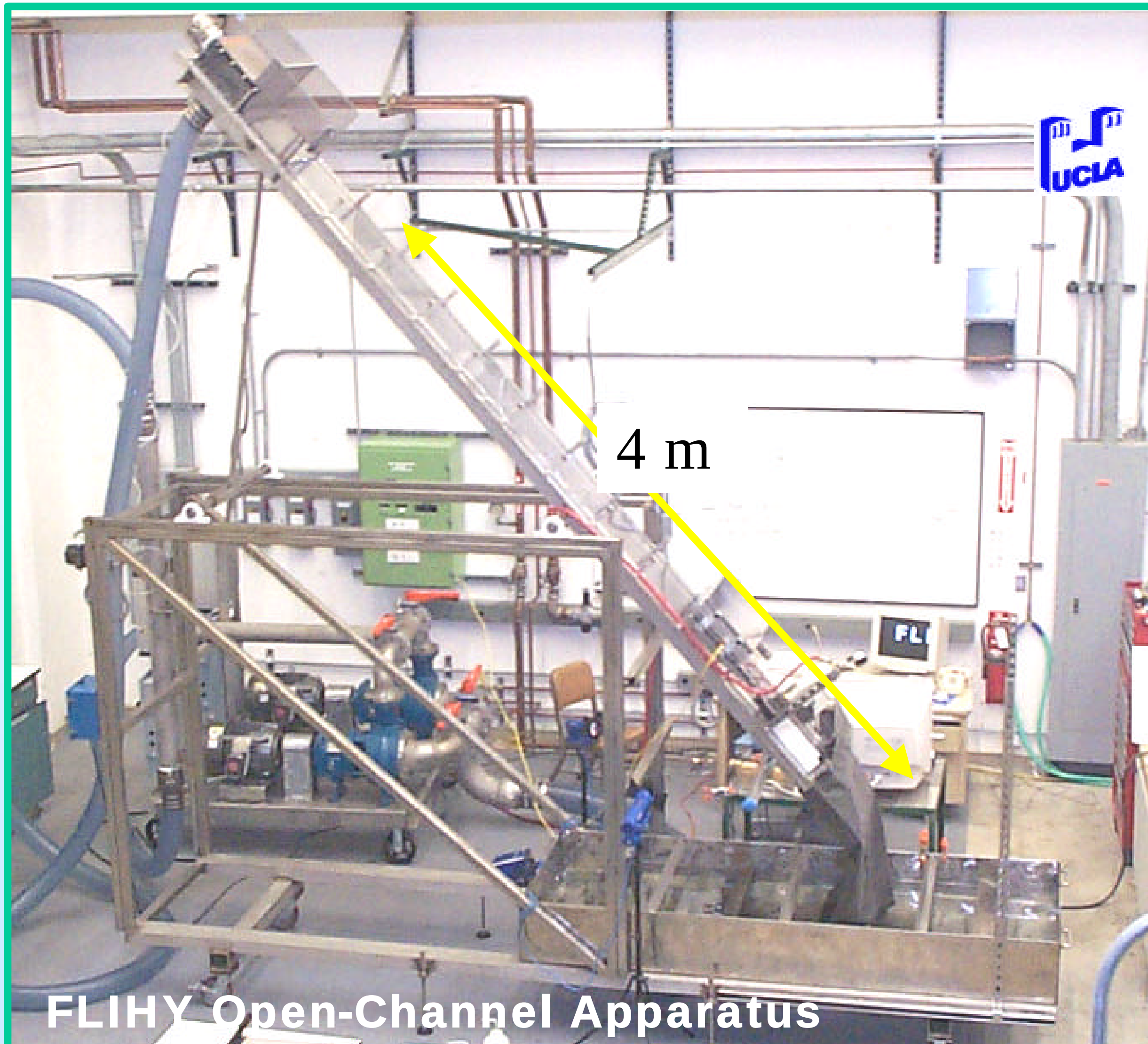
- Novel Surface Renewal Schemes



Interfacial Transport Test section length = 4 m

A Series of Experiments for Free Surface Heat Transfer are under way in FLIHY

- Modular flow systems to accommodate large test article sizes up to 4 m in length
- Large flowrate capability up to 80 liters/sec
- Ultrasonic depth measurement system for free surface wave characterization
- IR surface heating and thermometry systems for surface heat transfer measurements

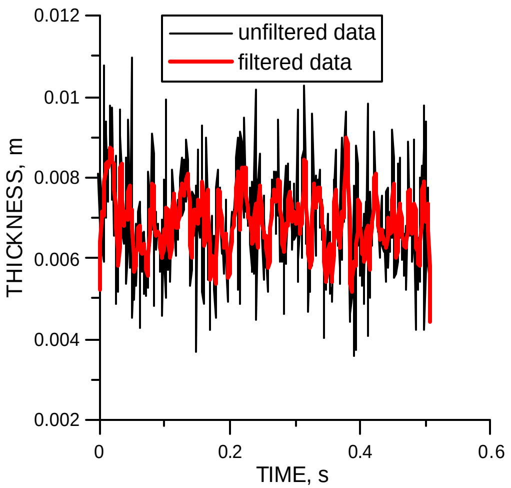


FLIHY Open-Channel Apparatus

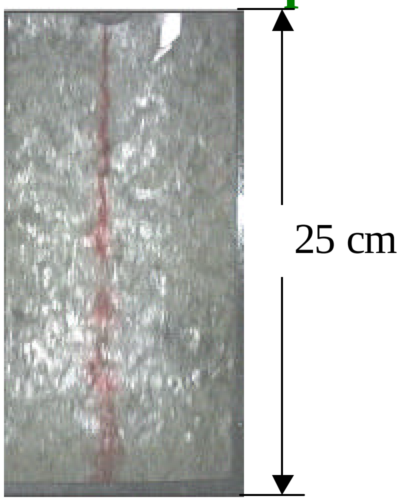
Example of FLIHY EXPERIMENTAL RESULTS: SURFACE WAVINESS is the KEY FACTOR for HEAT TRANSFER in Free-Surface Turbulent Flows

Statistical analysis based on the ultrasound measurements of the flow thickness demonstrates complicated wavy phenomena at the surface

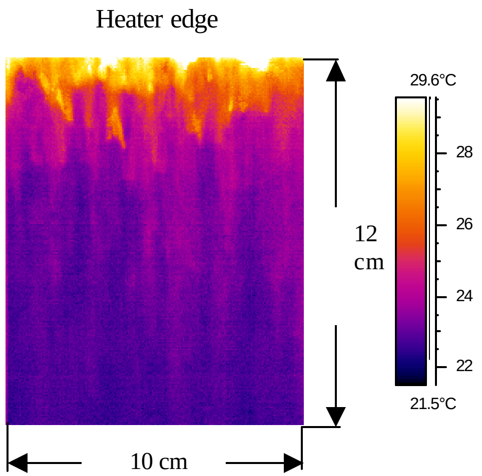
Surface waviness enhances heat transfer through the surface renewal mechanism but leads to pronounced temperature non-uniformity



Finite-amplitude surface waves of 10-250 Hz propagate downstream



Dye experiment evidences the surface renewal mechanism



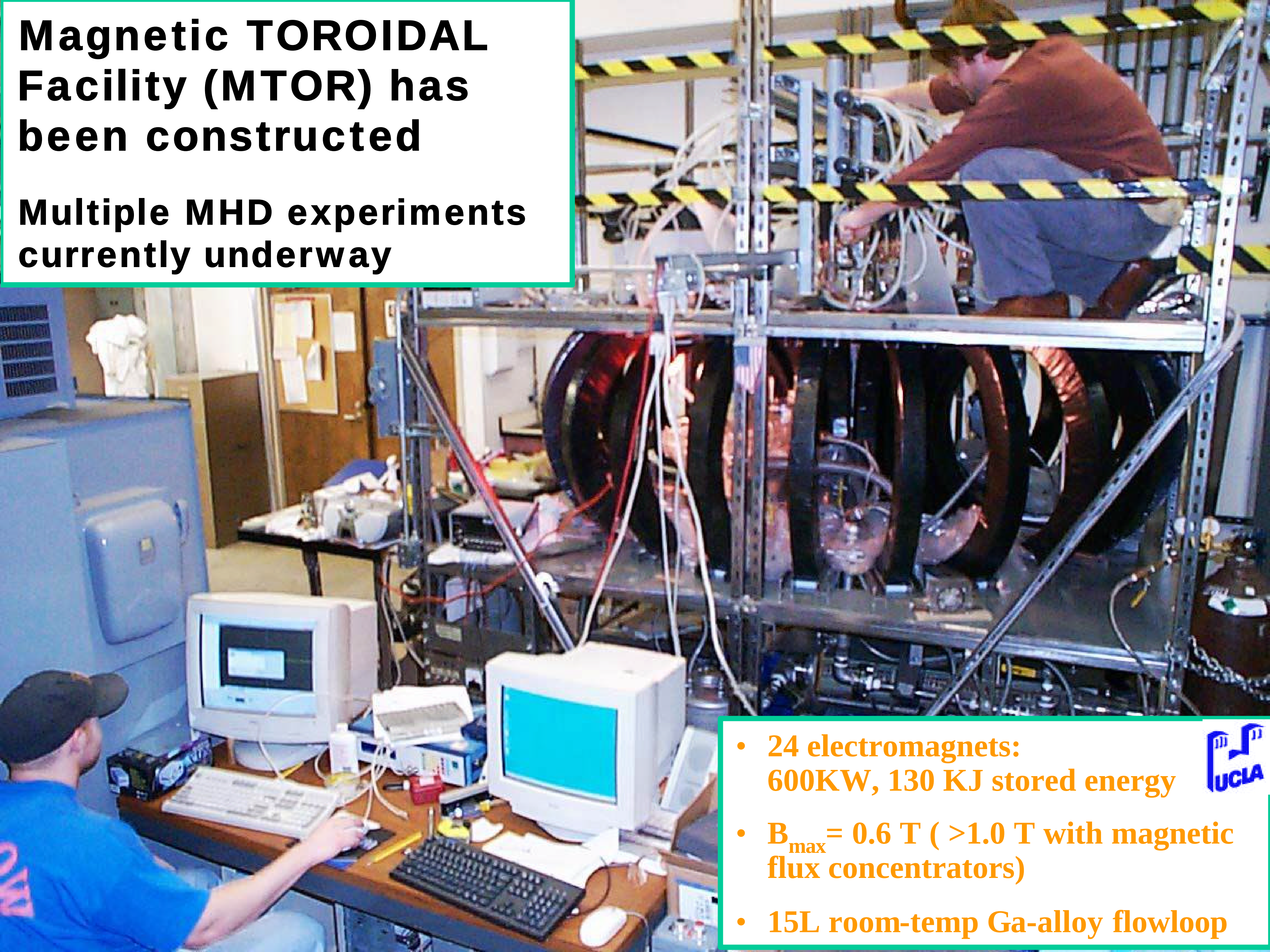
IR images of the surface show "cold" and "hot" strikes $20 kW/m^2$, 30°, 10 L/s flow

Current data analysis and experiments are used for :

- Correlation between hydrodynamic and heat transfer parameters
- Evaluation of Pr_t to be used in "K-epsilon" model

Magnetic TOROIDAL Facility (MTOR) has been constructed

Multiple MHD experiments currently underway



- 24 electromagnets:
  600KW, 130 KJ stored energy
- B_{max}= 0.6 T (>1.0 T with magnetic flux concentrators)
- 15L room-temp Ga-alloy flowloop

UCLA

Exploring Free Surface LM-MHD in MTOR Experiment

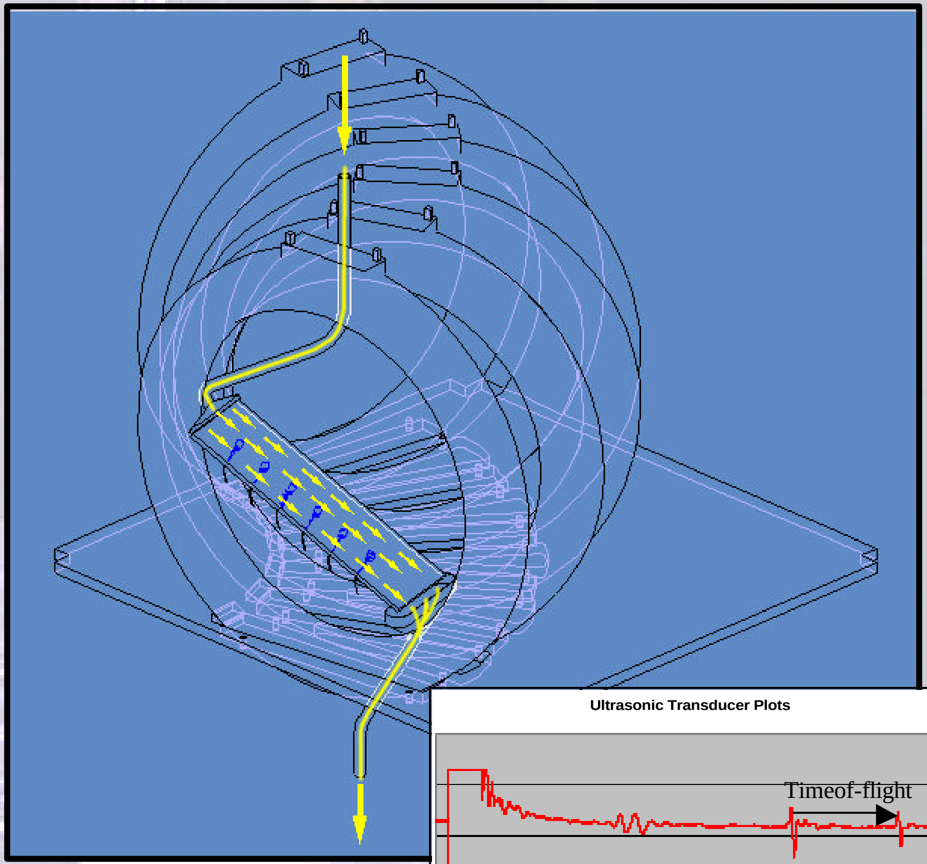
•Study toroidal field and gradient effects: Free surface flows are very sensitive to drag from toroidal field 1/R gradient, and surface-normal fields

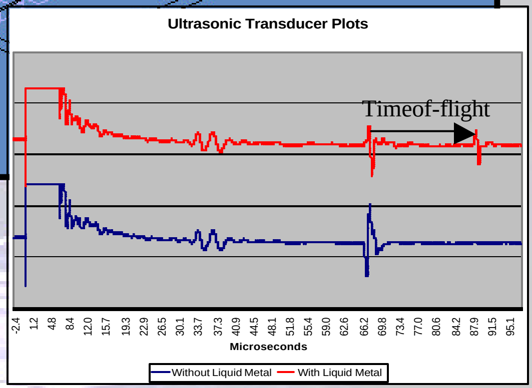
•3-component field effects on drag and stability: Complex stability issues arise with field gradients, 3-component magnetic fields, and applied electric currents

•Effect of applied electric currents: Magnetic Propulsion and other active electromagnetic restraint and pumping ideas

•Geometric Effects: axisymmetry, expanding / contacting flow areas, inverted flows, penetrations

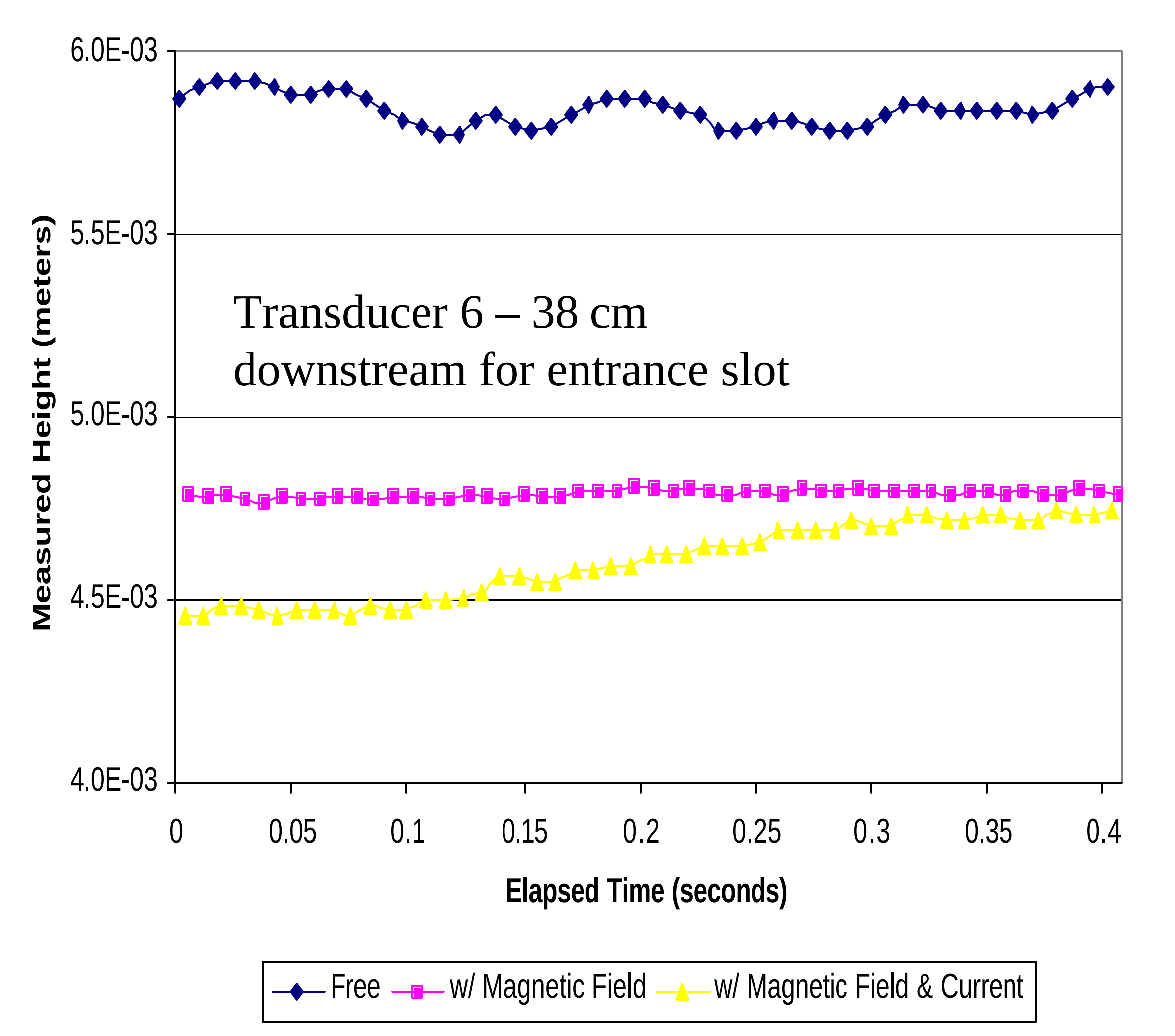
•NSTX environment simulation





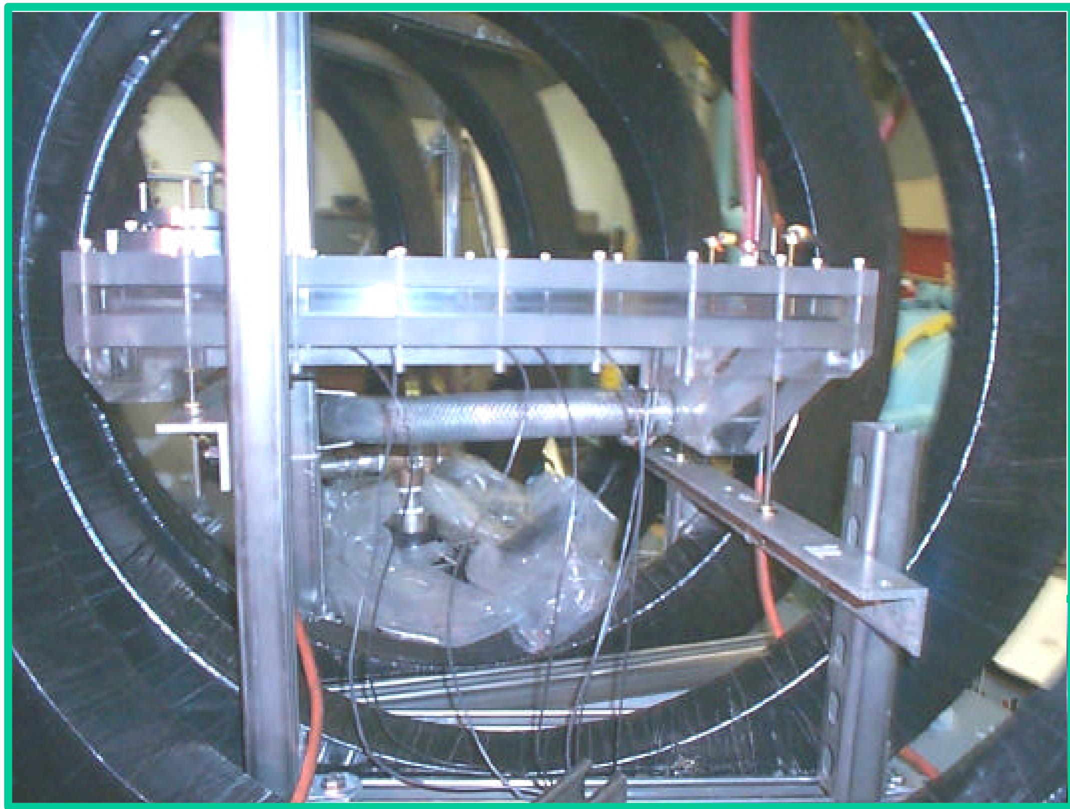
MTOR designed and constructed in collaboration between UCLA, PPPL and ORNL

Example results from MTOR Experiments: Film flow height response to toroidal field and magnetic propulsion current



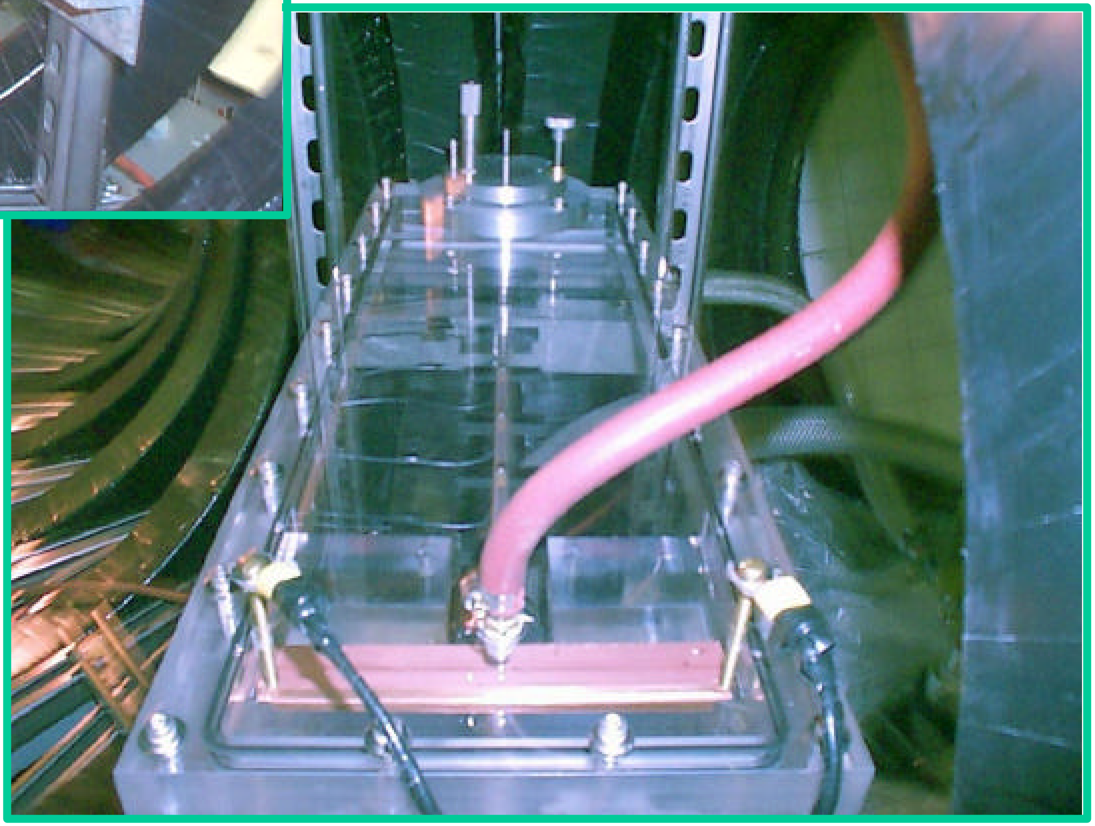
B field acts to laminarize flow – **Reducing flow resistance and eliminating surface waves**

Magnetic propulsion current acts to accelerate flow, but low frequency instabilities observed

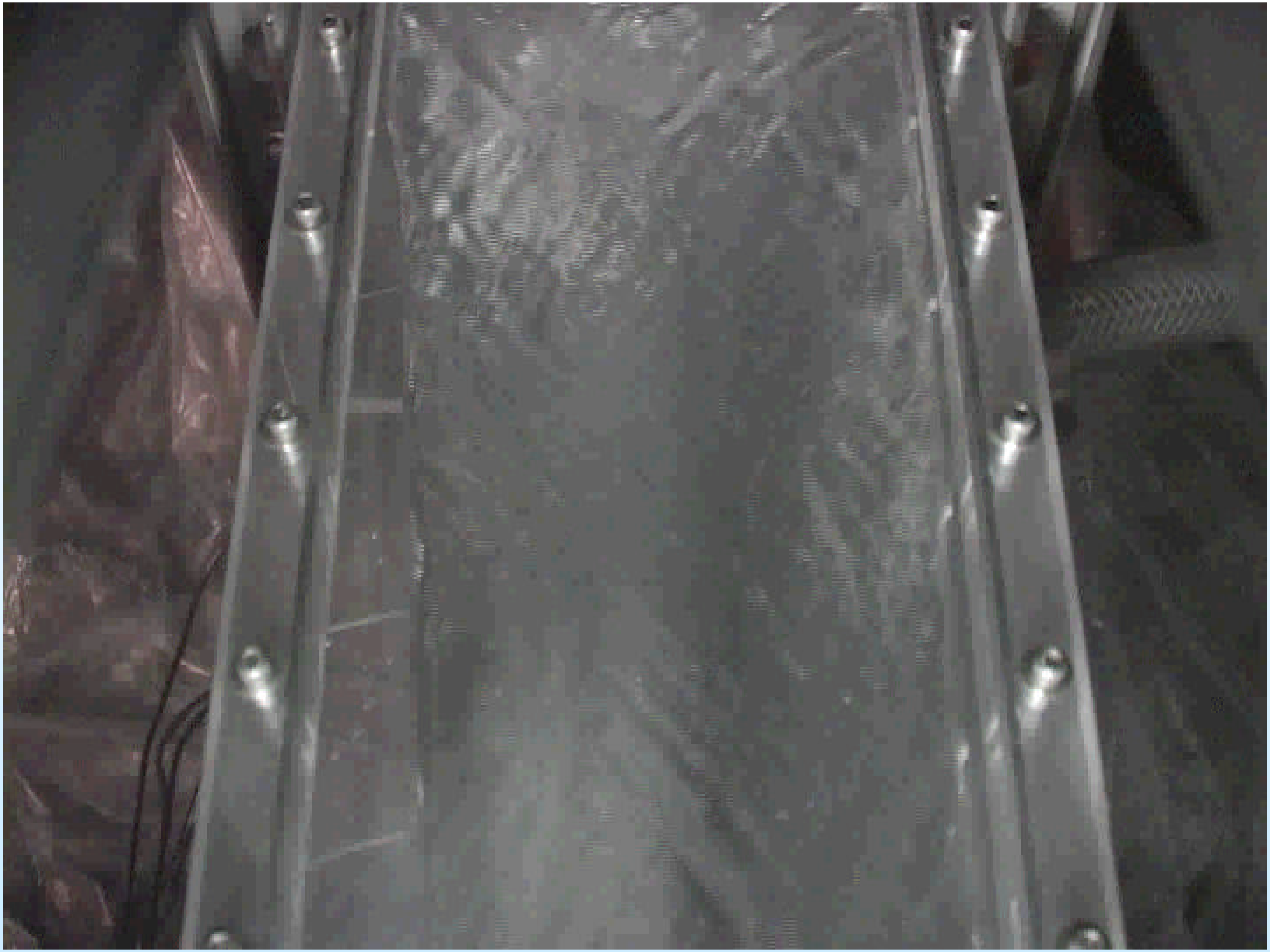


Inclined-Plane Test Section

- Flow area: 20 cm x 60 cm
- Walls are insulated and do not wet Ga alloy



- 300 A available for magnetic propulsion tests
- 7 Ultrasonic Flow Height Transducers
- Variable inclination +5 to –15 deg



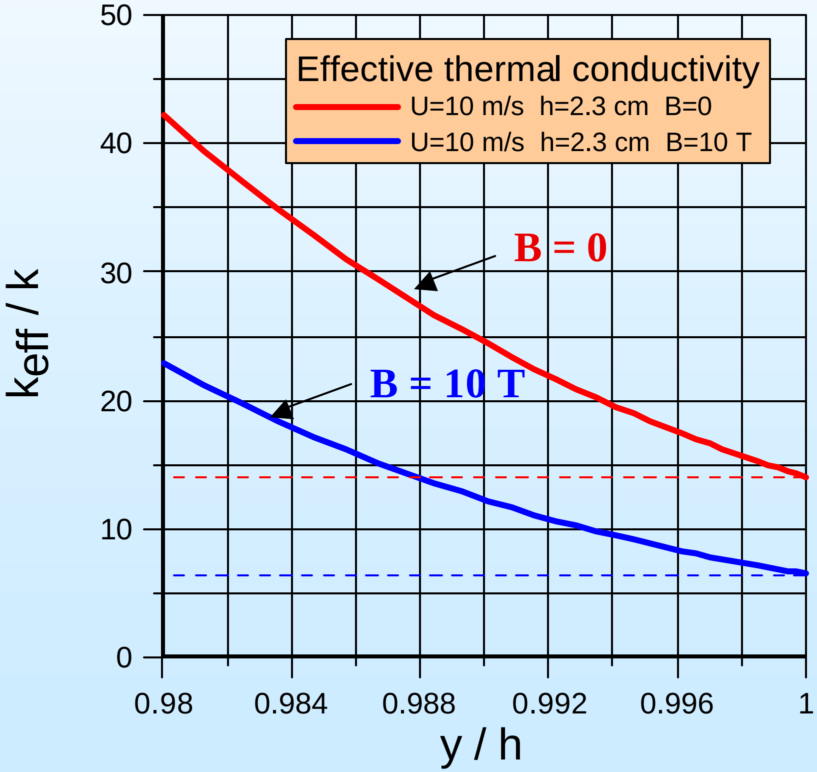
Liquid Metal Integrated Test System

- LIMITS can operate up to 450C and at 150 psi.
- 15 gpm liquid metal flow loop
- Test chamber with either magnet system for MHD testing or electron beam for HHF testing.
- All hardware completed and final commissioning in progress.
- Full diagnostics set: flow, delta P, delta T, surface T, etc.

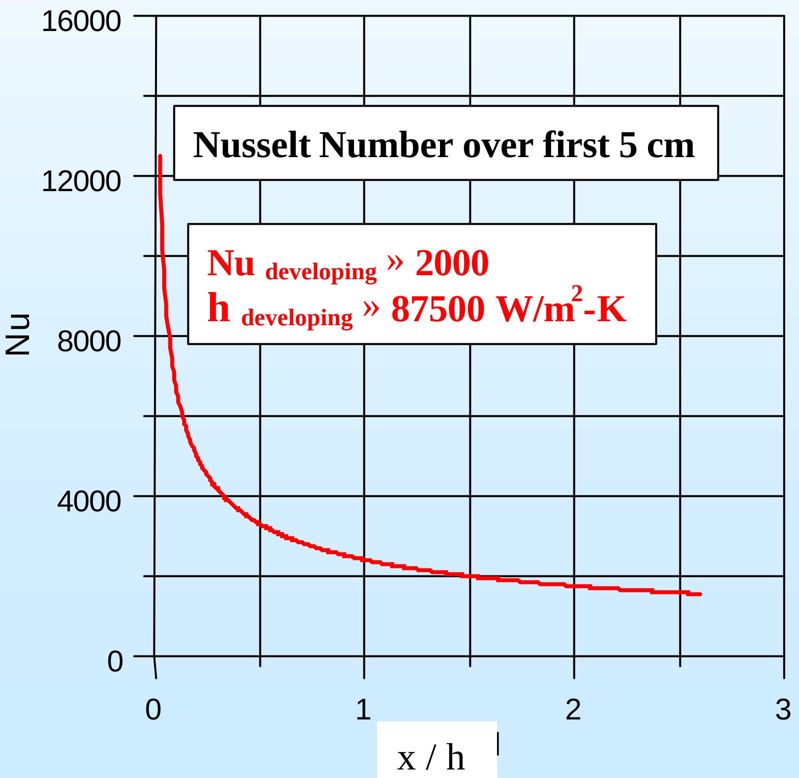
Sandia National Laboratories

Results of Modeling Heat Transfer in Flinabe

Magnetic Field Reduces Turbulence



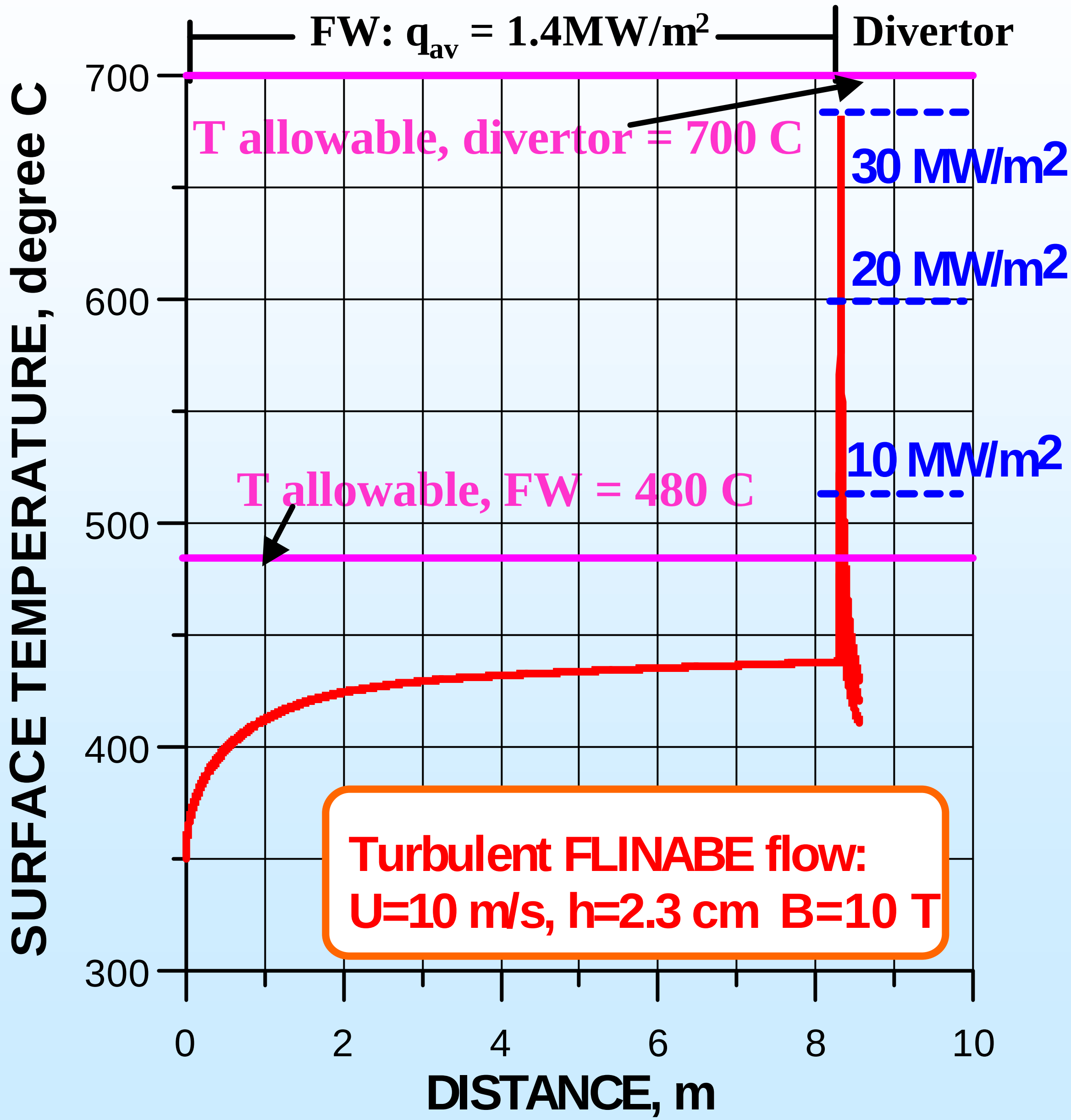
Heat Transfer is higher in the developing region (can help in divertor region)



HEAT TRANSFER - EDGE PLASMA MODELING FOR FLINABE FW SHOWS HIGH HEAT LOAD CAPABILITIES

Flinabe

- **Melting Point = 240 - 310 C**
  Inlet T ~ 350 C
- **From Plasma-edge modeling**
  T (allowable) = 480 C - FW
  = 700 C - Divertor
- **Turbulent FLINABE layer can tolerate high heat fluxes:**
  FW: ***1.4 MW/m^2 (averaged)***
  Divertor: ***30 MW/m^2 (peak)***
  (accounting for B effect with no flow mixing)
- **Further improvements are possible through, for example, mixing the liquid right before the divertor inlet**



Heat Transfer Calculations for Sn Cliff Demonstrate a Wide Design Window

Temperature Limits

	Li	Sn-Li	Sn	Flinabe
FW	420	630	840	480
Div.	475	700	1600	700

TIN

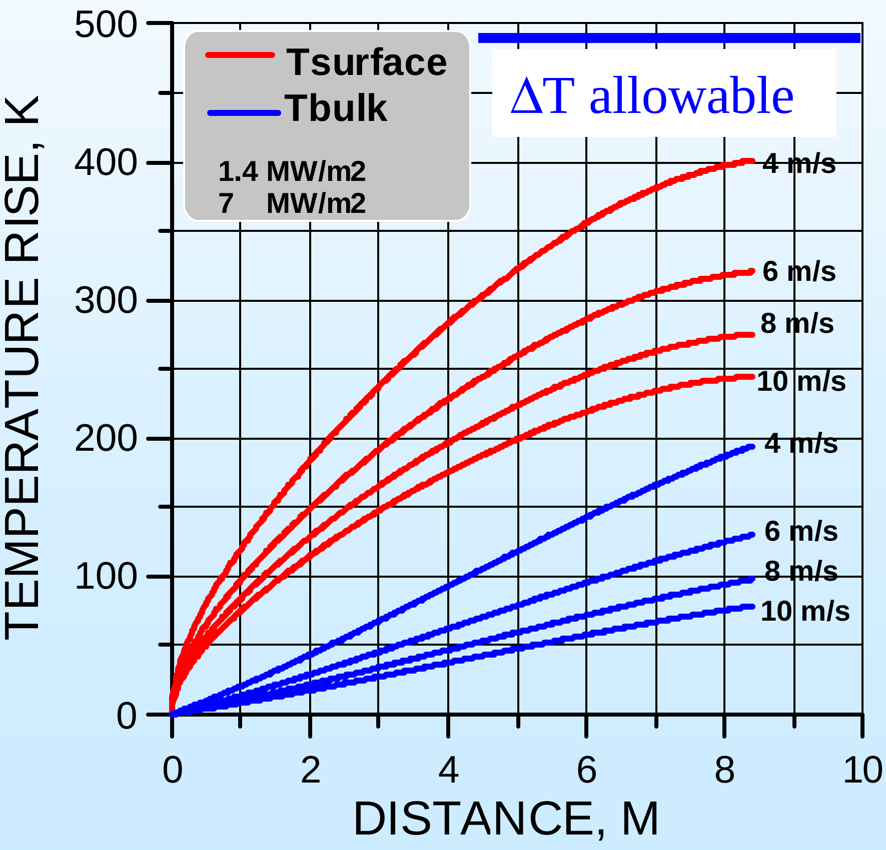
Melting T=**232°**

Inlet T=**300-350°**

$T_{allowable}$=**840°** (FW)

$T_{allowable}$=**1600°** (Divertor)

Average neutron wall loading = 7 MW/m²
Average surface heat flux = 1.4 MW/m²



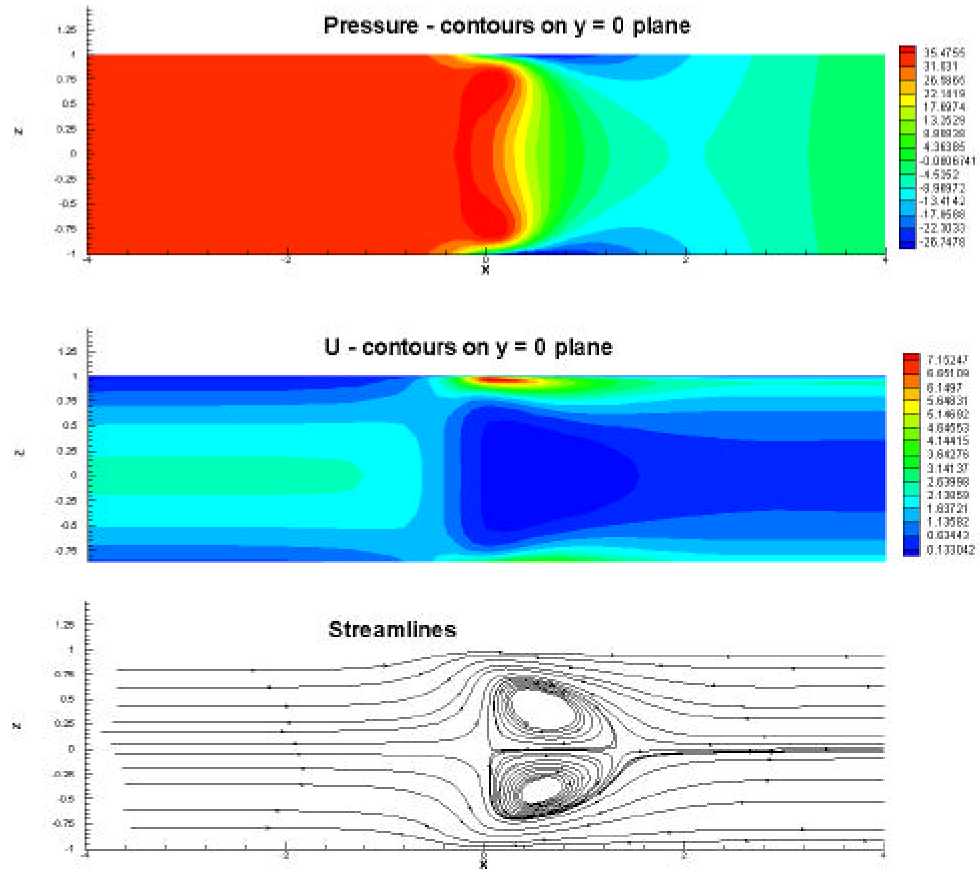
EFFECT OF MAGNETIC FIELD GRADIENTS ON LM FLOW IS VERY IMPORTANT

LIQUID WALL WITH AXIAL SYMMETRY:

- Is affected through spatial variations of the toroidal field
- MHD drag can be reduced by applying a current (magnetic propulsion)

LIQUID WALL WITH NO AXIAL SYMMETRY (sectioned):

- Is affected through spatial variations of the wall normal field
- Still needs more quantification



Channel flow in a fringing magnetic field: Ha=1000.
3-D calculations by HIMAG code.
Two trapped vortices can be seen.

WALL ELECTRICAL CONDUCTIVITY HAS A STRONG IMPACT ON LIQUID WALL DESIGN

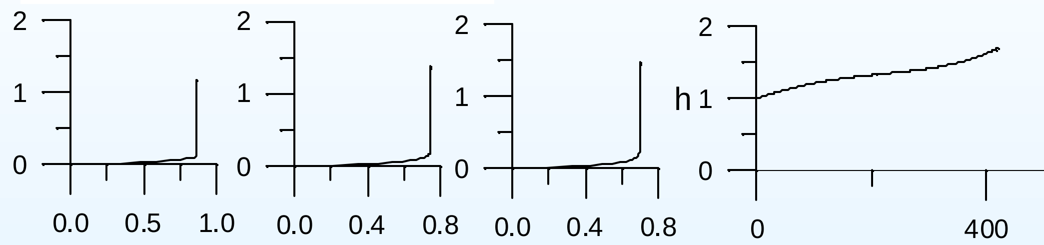
INITIAL CONCLUSIONS

(ACCOUNTING FOR BOTH TOROIDAL AND NORMAL FIELDS)

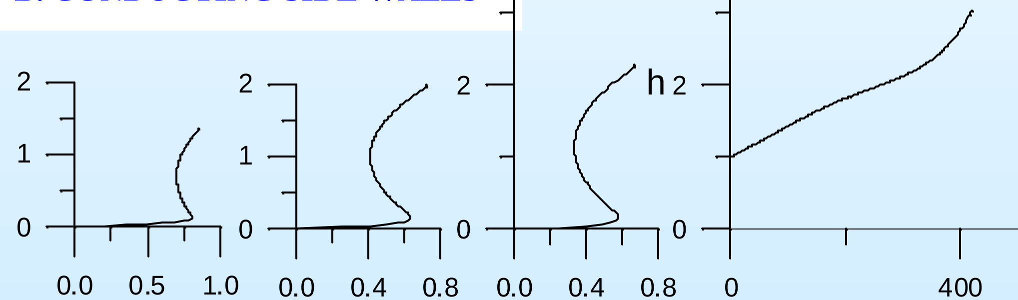
- **METALLIC SIDE-WALLS ARE UNACCEPTABLE**
- **SIC SIDE-WALLS ARE ACCEPTABLE PROVIDED THEY ARE FAR APART (2B > 8 M) INSULATORS ALLOW SMALLER SPACING**
- **IN AN AXI- SYMMETRIC FLOW (no side-walls), THE MAXIMUM ALLOWBALE WALL-NORMAL FIELD IS (Bn)max=0.015 T**
- **IN A SECTIONED FLOW WITH ISOLATED SIDE-WALLS,**
  - **- (Bn)max=0.1 T (metallic back-wall)**
  - **- (Bn)max=0.2 T (SiC back-wall)**
  - **- (Bn)max=0.5 T (isolated back-wall)**

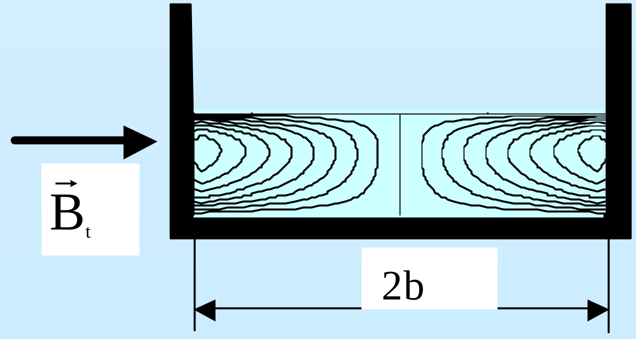
VELOCITY PROFILES AND DOWNSTREAM FLOW THICKNESS VARIATION IN LiCLiFF.

A. ISOLATED SIDE-WALLS



B. CONDUCTING SIDE-WALLS





I am Done !