OVERVIEW OF ADVANCED FUSION SCIENCE AND TECHNOLOGY PROGRAM AT UCLA

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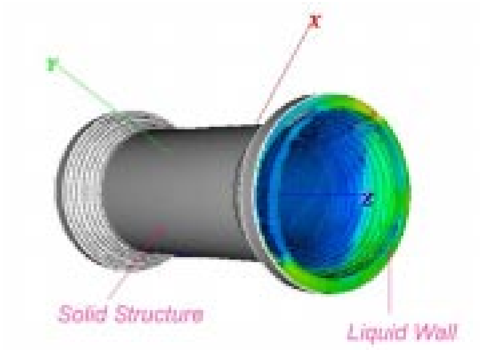
Presentation to Dr. Anne Davies, Director OFES
January 26, 1999

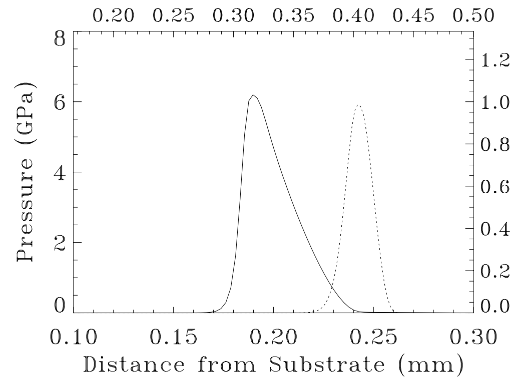
Advanced Fusion Science and Technology Program

Innovative Chamber Technologies that can dramatically improve the vision of an attractive fusion energy product



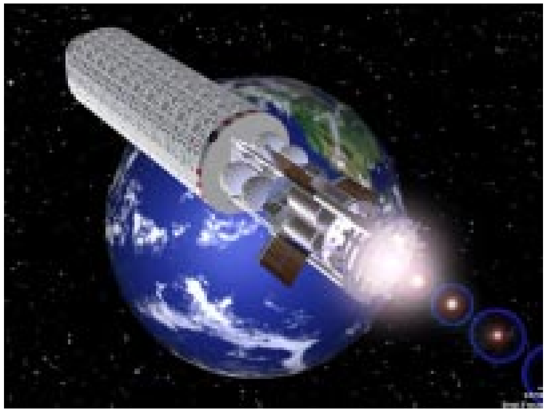
FRC Chamber with Liquid Wall

Basic Science Research in the physical and engineering sciences



Simulation of Ablation Shocks in Thin Liquid Walls for IFE Reactors

Alternative Uses of Fusion: Space Propulsion, Waste Transmutation



MTF Propelled Rocket

Training Students as future fusion scientists

MeSO-Jet Research Staff and Students

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Duel Research Goals:

Developing Fusion Energy Technology and Advancing State of Fusion Sciences

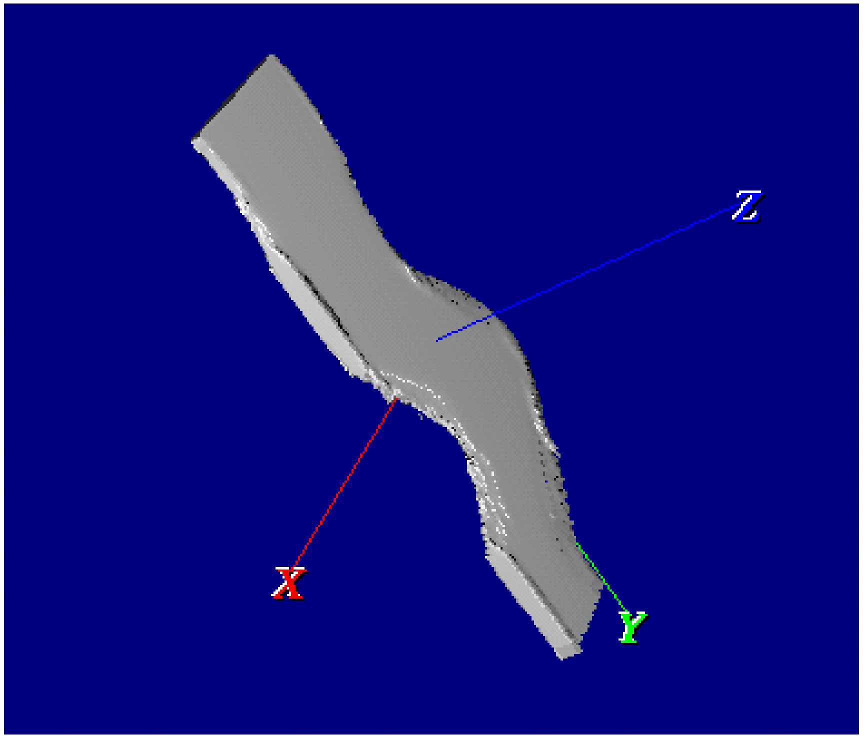
Example: Liquid Walls

APEX Liquid Walls	Basic Science Fields
1. Liquid Wall Formation and Configuration Feasibility	• Turbulent Hydrodynamics • Laminar Magneto-hydrodynamics • Contact Discontinuity Tracking
2. Liquid Surface Temperature and Evaporation Flux	• Turbulent Heat Transfer in High Prandtl Number Free Surface Flow • Laminar MHD Heat Transfer in Low Prandtl Number Free Surface Flow • X-Ray Photon Transport in Low Z Liquids
3. Plasma Edge Shielding of Evaporated Impurities	• Neutral Transport and Ionization in Plasma Background • Edge Plasma Physics
4. High Temperature Liquid Wall Operation	• Corrosion Chemistry • Material Interactions

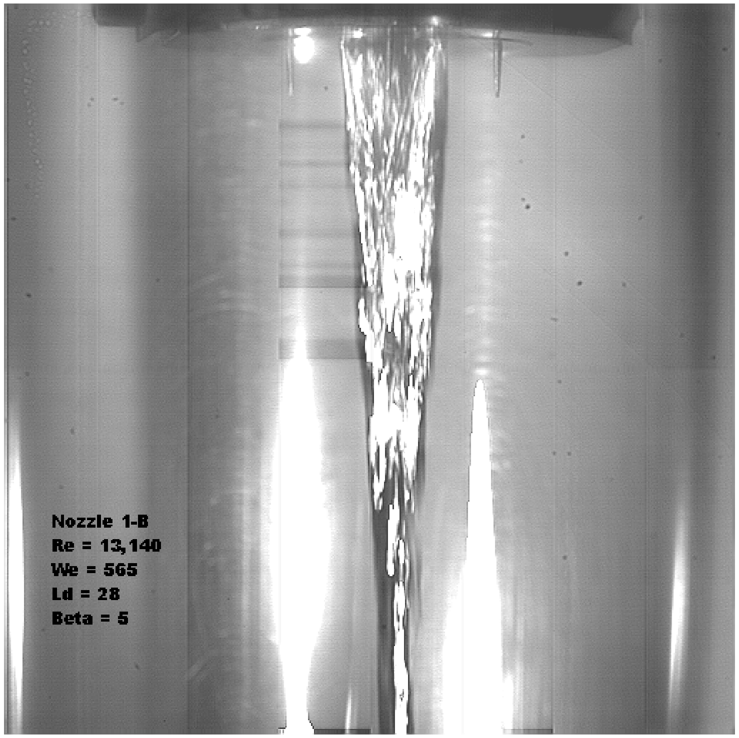
Research Approach:

Sophisticated Numerical Simulations with Scaled Laboratory Experiments

Example: Liquid Jets for IFE Chambers



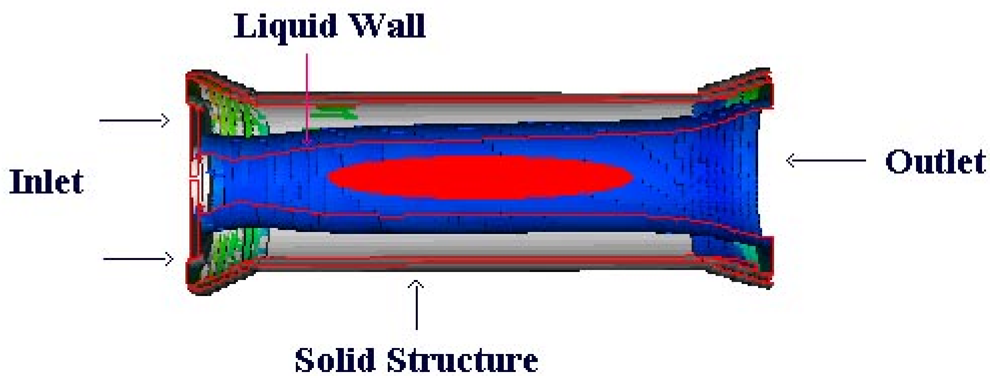
3D Computer Simulation of Oscillating Jet



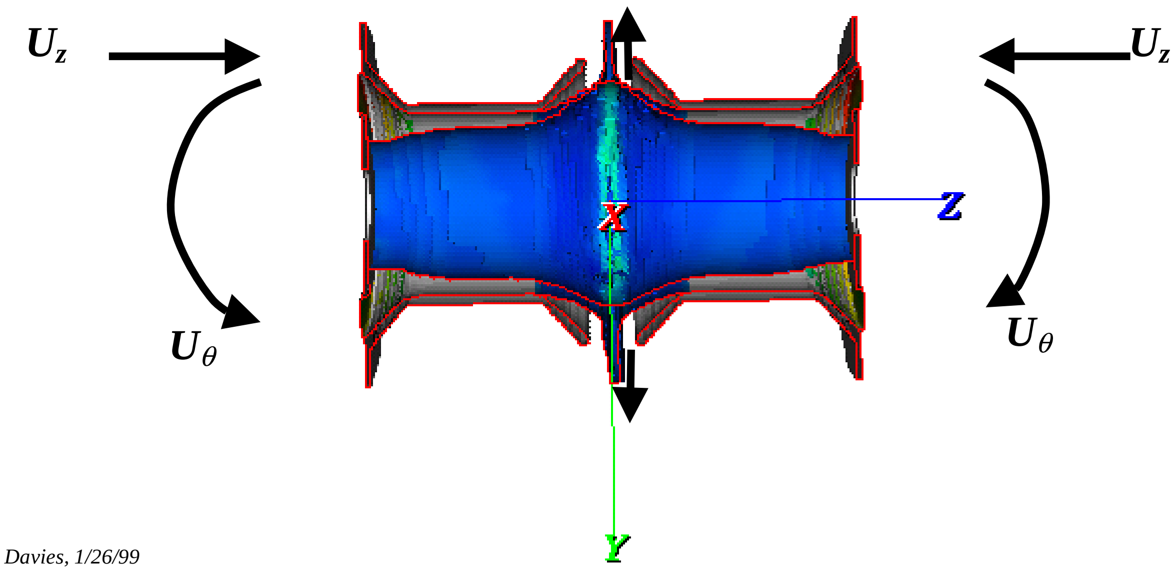
2mm×10mm Stationary LM Jet Experiment

Take Advantage of Facility and Modeling Synergism between MFE and IFE Chambers

Example: Modeling Advanced FRC Chamber with Liquid Walls
and Innovative HIF Cylindrical-Cusp Chamber



Cylindrical FRC



Cusp HIF

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Advanced Fusion Science and Technology Program

Research Projects

- APEX and ALPS
- IFE Chamber Development
- Non-Structural Material Interactions
- Fusion Rocket Propulsion
- Structural Material Research

Liquid Wall Research for MFE

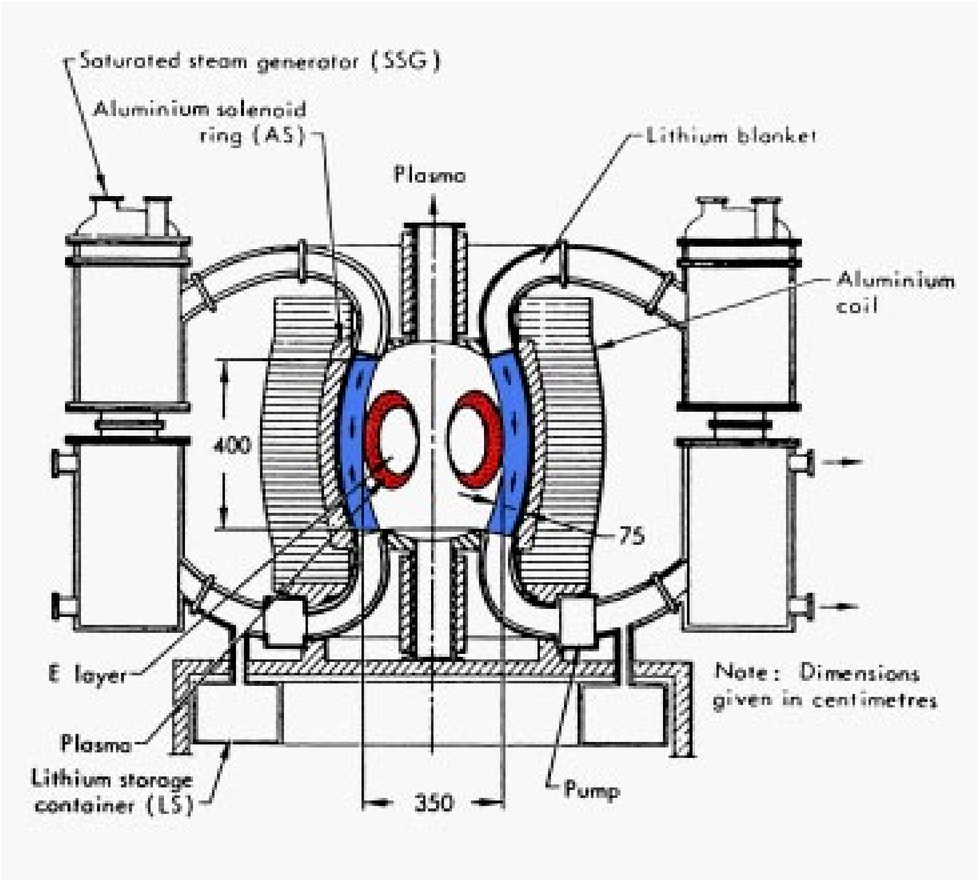
Concept: *Replace first wall, blanket and shield with a thick flowing liquid*

Advantages:

- Replenishable surface facing plasma
- Surface heat transfer directly to coolant, higher average coolant temperature
- Elimation of solid first wall and blanket thermal stress driven failure modes.
- Elimination of significant neutron damage and activation

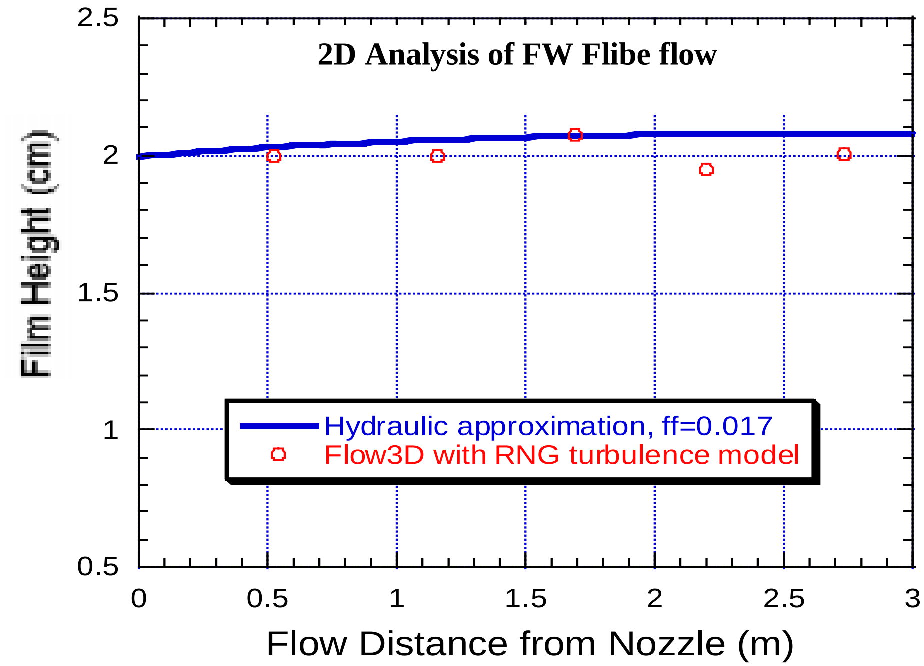
Implications for Fusion Product:

- Higher Power Density
- Higher Thermal Efficiency
- Higher Reliability
- Easier Maintanance
- Reduction of radioactive waste

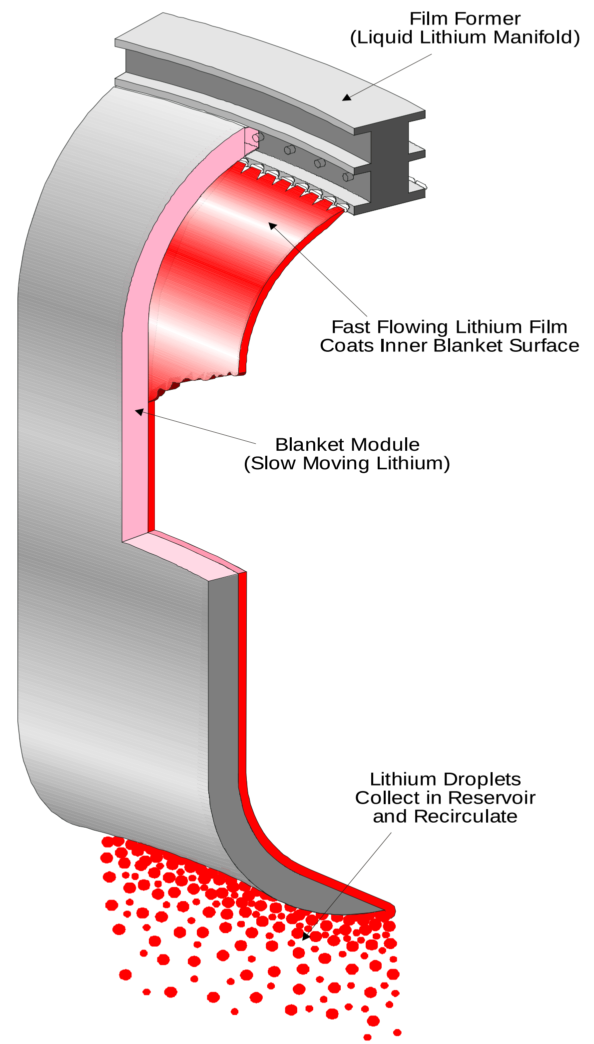


Convective Liquid Flow First wall (CLIFF) Concepts

- Underlying structure protected by a fast moving layer of liquid, typically 1 to 2 cm thick at 10 to 20 m/s.
- Conventional or more innovative liquid breeder blanket located directly behind the CLIFF-wall
- 2D hydrodynamic calculations confirm near equilibrium flow for Flibe at 2 cm depth and 10 m/s velocity (below)



Convective Liquid layer Design



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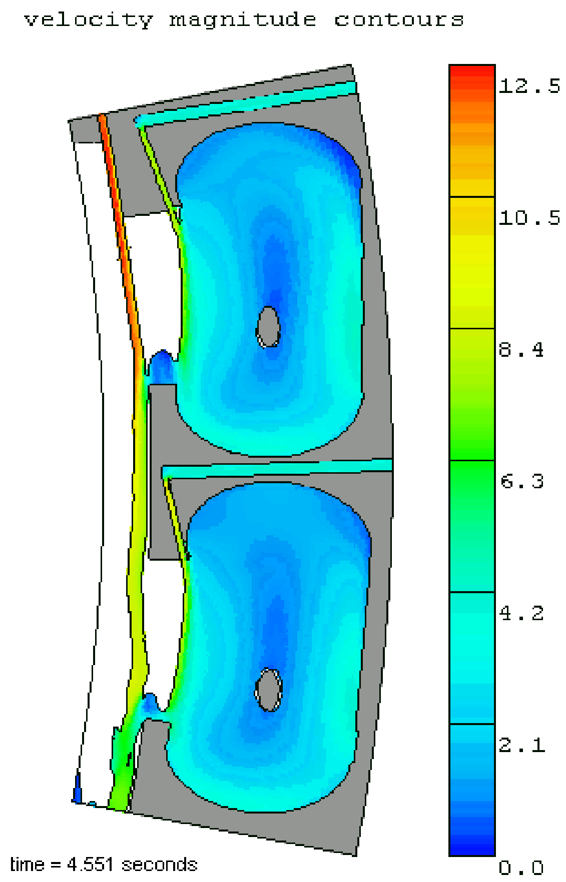
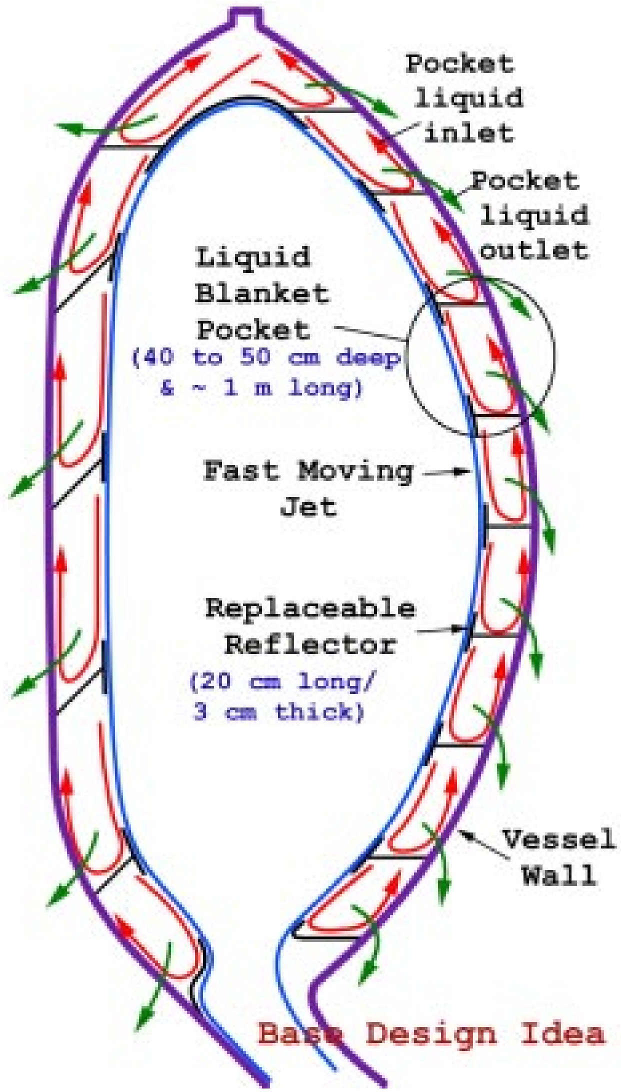
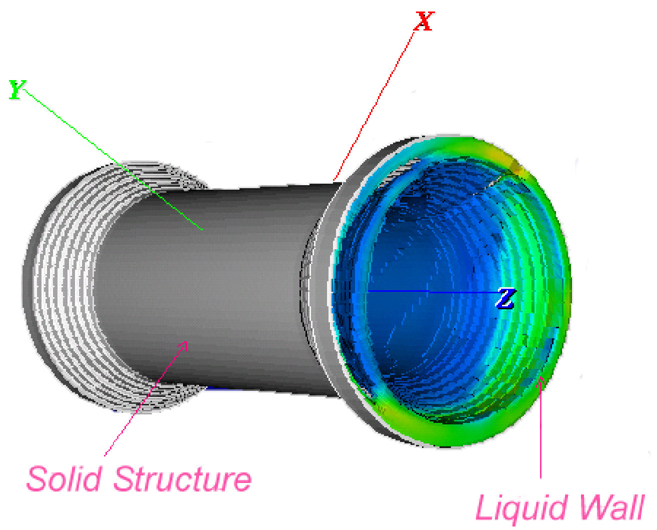
Gravity-Momentum Driven Thick Liquid Wall Concept

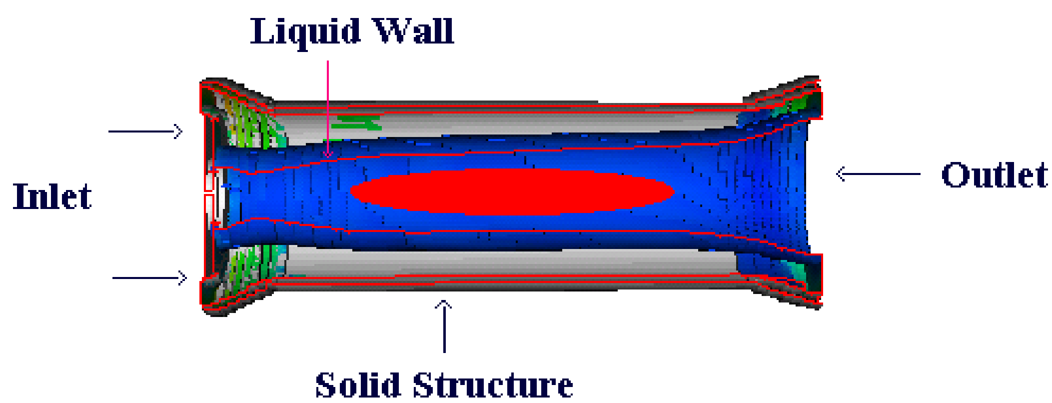
- Utilize mechanically isolated recirculating pockets of liquid Flibe
- Fast liquid layer covers pocket and mechanical "reflector" surface
- Reflectors are easily replaceable



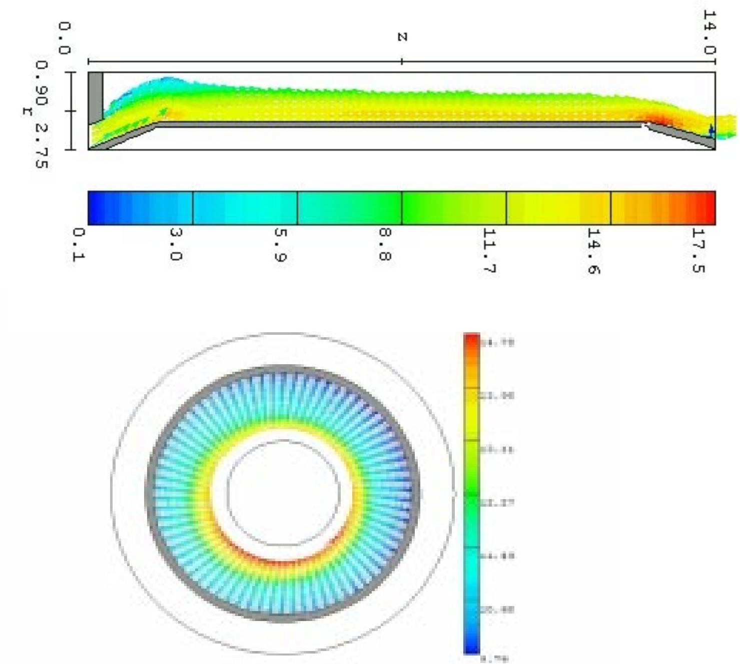


Swirling Thick Liquid Walls for High Power Density FRC





- **Design:** Horizontally oriented structural cylinder with a liquid vortex flow covering the inside surface. Thick liquid blanket interposed between plasma and all structure
- **Computer Simulation**: 3-D time-dependent Navier-Stokes Equations solved with RNG turbulence model and Volume of Fluid algorithm for free surface tracking
- **Results:** Adhesion and liquid thickness uniformity (> 50 cm) met with a flow of V_{axial} = 10 m/s, $V_{\theta,ave}$ = 11 m/s



Calculated velocity and surface depth

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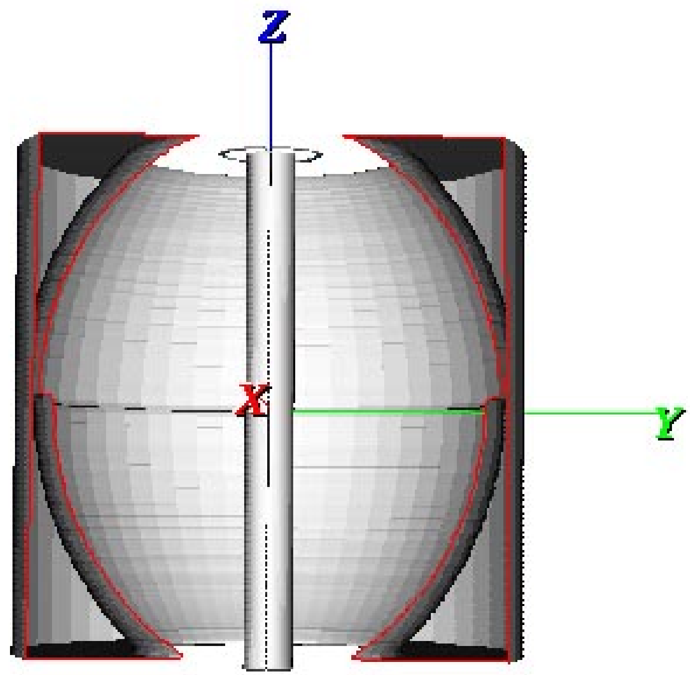
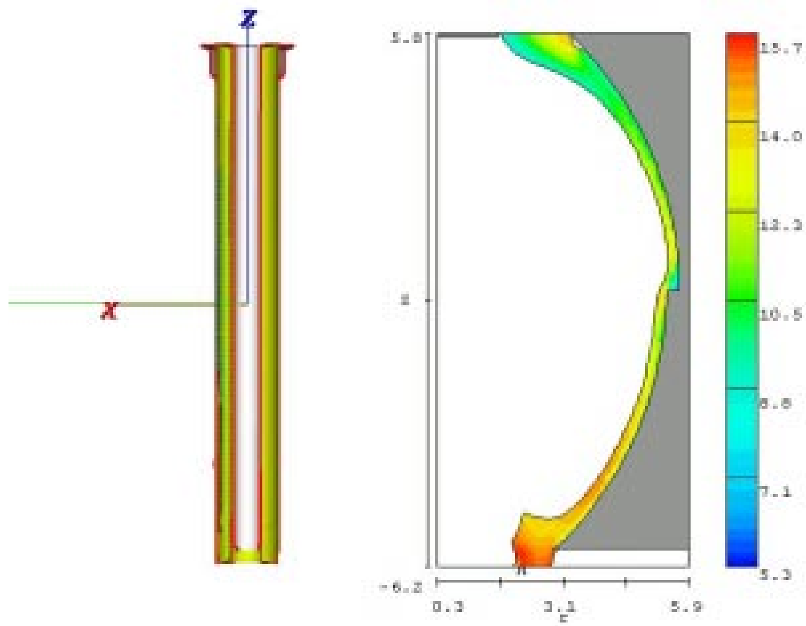
Toroidally Rotating Thick Liquid Wall for the ST





Design Concept:

- Thick liquid flow from reactor top
- ***Outboard***: Fluid remains attached to outer wall due to centrifugal acceleration from the toroidal liquid velocity
- ***Inboard***: Fast annular liquid jet

Simulation Results:

- Step in outboard vacuum vessel topology helps maintain liquid **thickness > 30 cm**
- Calculated outboard inlet velocity, $\mathbf{V_{poloidal} = 4.5\ m/s,\ V_{toroidal,ave} = 12\ m/s}$
- Inboard jet $\mathbf{V_z = 15\ m/s}$ is high to prevent excessive thinning, < 30%

IFE Chamber Phenomena Research:

Analysis, Modeling and Experiments for Liquid Wall Protection and Chamber Clearing Schemes

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University of California, Los Angeles

Objectives and Strategy

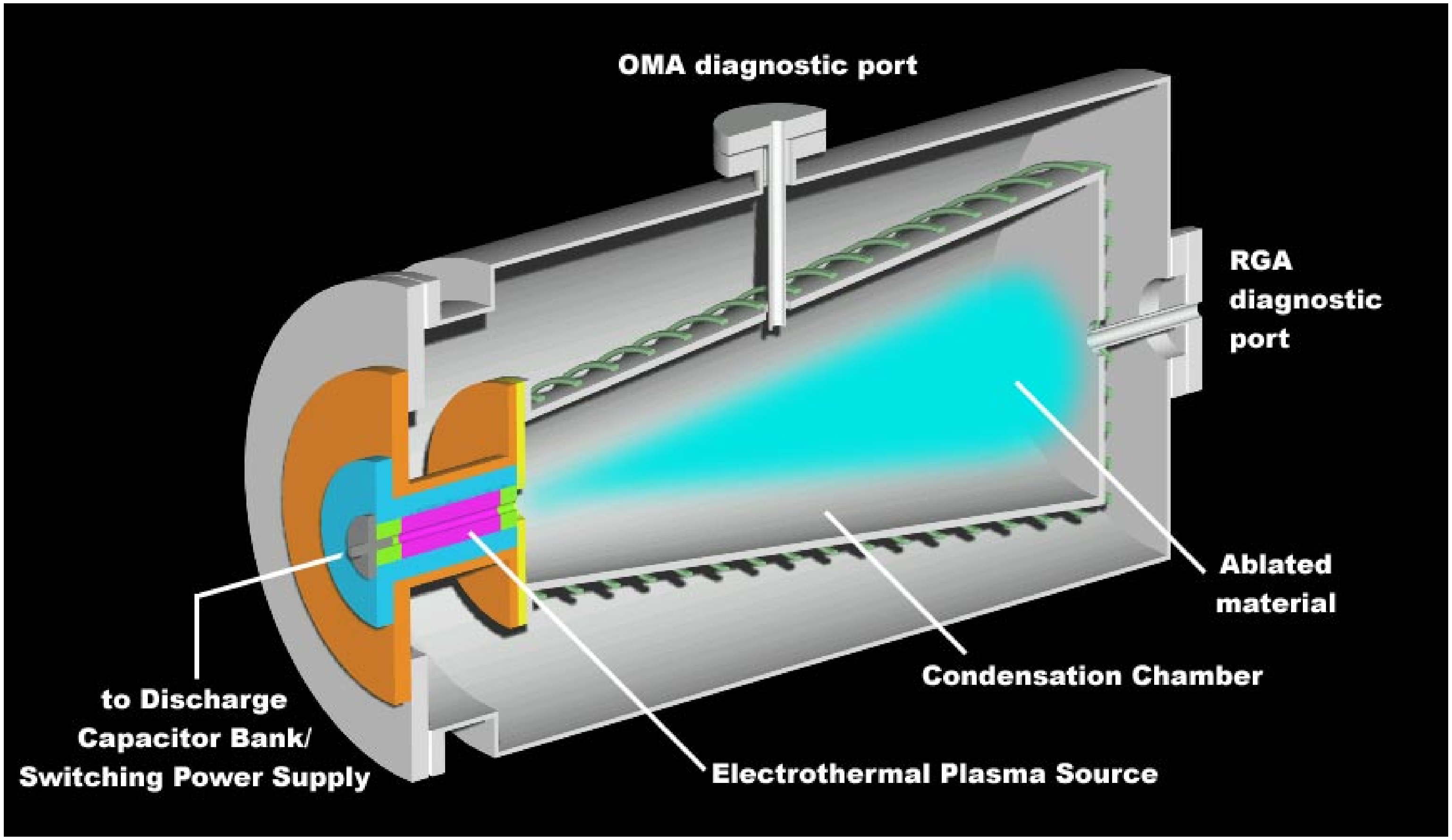
- **Understanding the relevant phenomena and underlying science** of challenging IFE chamber physics and engineering issues, resulting in the development of an attractive energy product.
- **Combination of analysis, model development, and small-scale single and multiple effect experiments** to advance the current state of understanding and predictive capability for liquid wall IFE schemes. This strategy is designed to progress to full-scale integrated experiments for the most attractive chamber technologies in the next 20 years

Progress in FY98

- ***Turbulent Slab Jet Flow Experiments and Modeling***: Experimental and numerical analysis of stationary and oscillating liquid jets, needed to establish the *basic feasibility of thick liquid pocket wall protection concepts*
- ***Compressible Response and Fracture of Liquid Films:*** Modeling and experiments to determine the fracture strength of shock loaded liquid surfaces, needed to predict the *post-explosion dynamics of liquid jets and films*
- ***Wall Protection and Cavity Clearing Schemes Design and Analysis:*** Design of chamber vapor condensation experiments for benchmarking against numerical models, needed to determine the *achievable rep-rate.*

"ALiCE" – Advanced Liquid Condensation Experiment

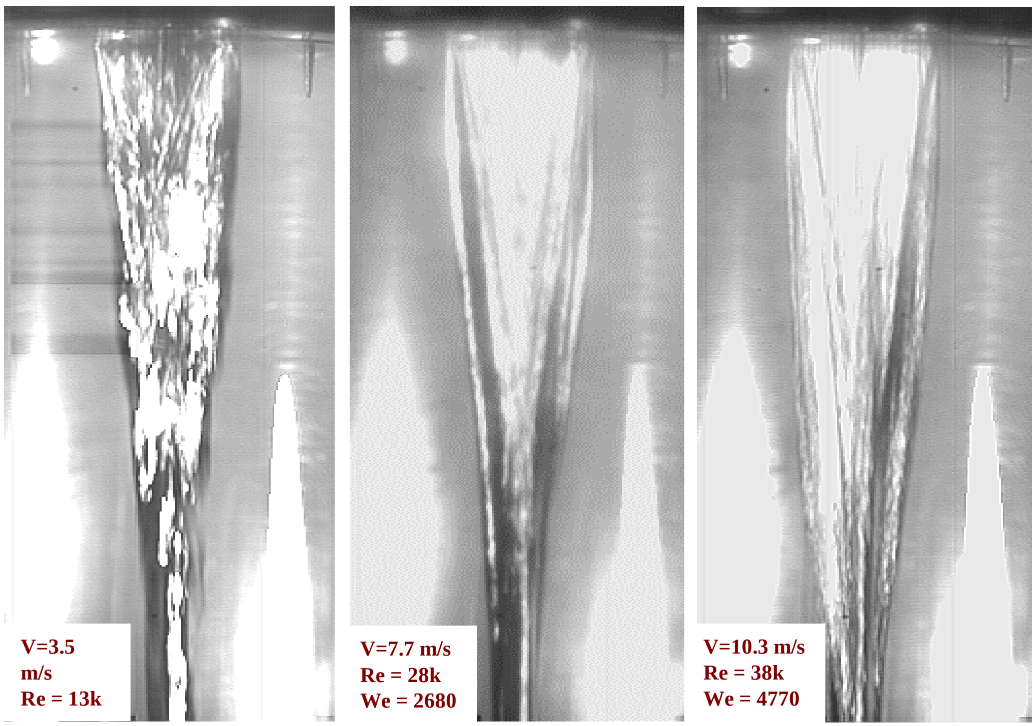
Goal: *to measure the condensation rate of ablated and partially ionized wall-protection liquids with similar particle and energy densities to IFE chamber designs*

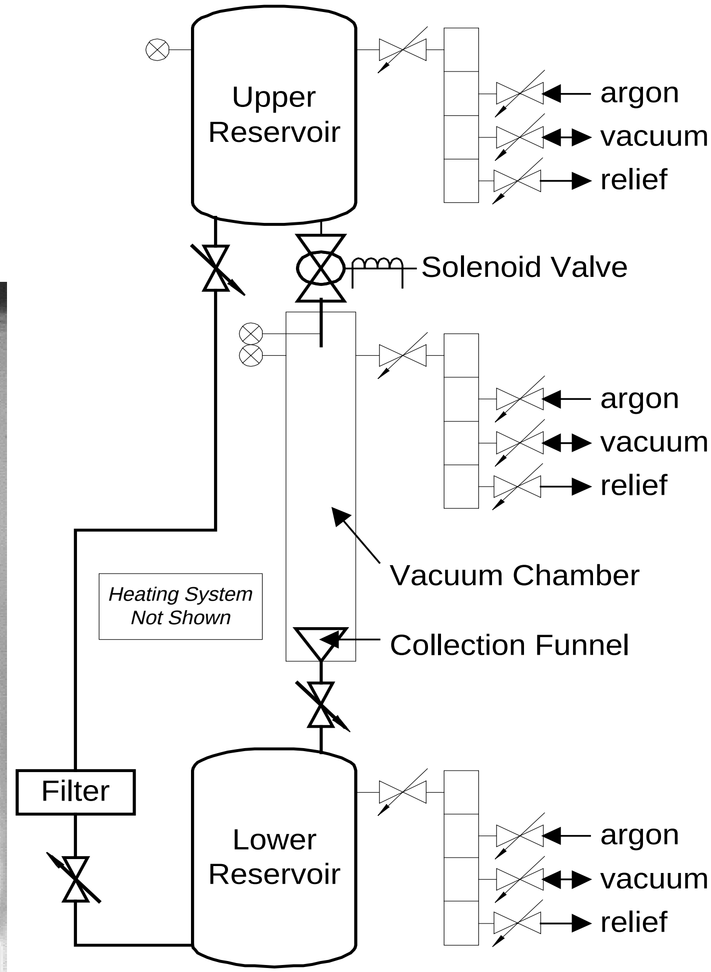


“MeSO Jet” - Turbulent Slab Jet Flow Experiments

Goal: *to determine surface wave character, slab contraction length, and ultimate breakup length of stationary and oscillating liquid slab jets - optimize nozzle design for IFE applications*

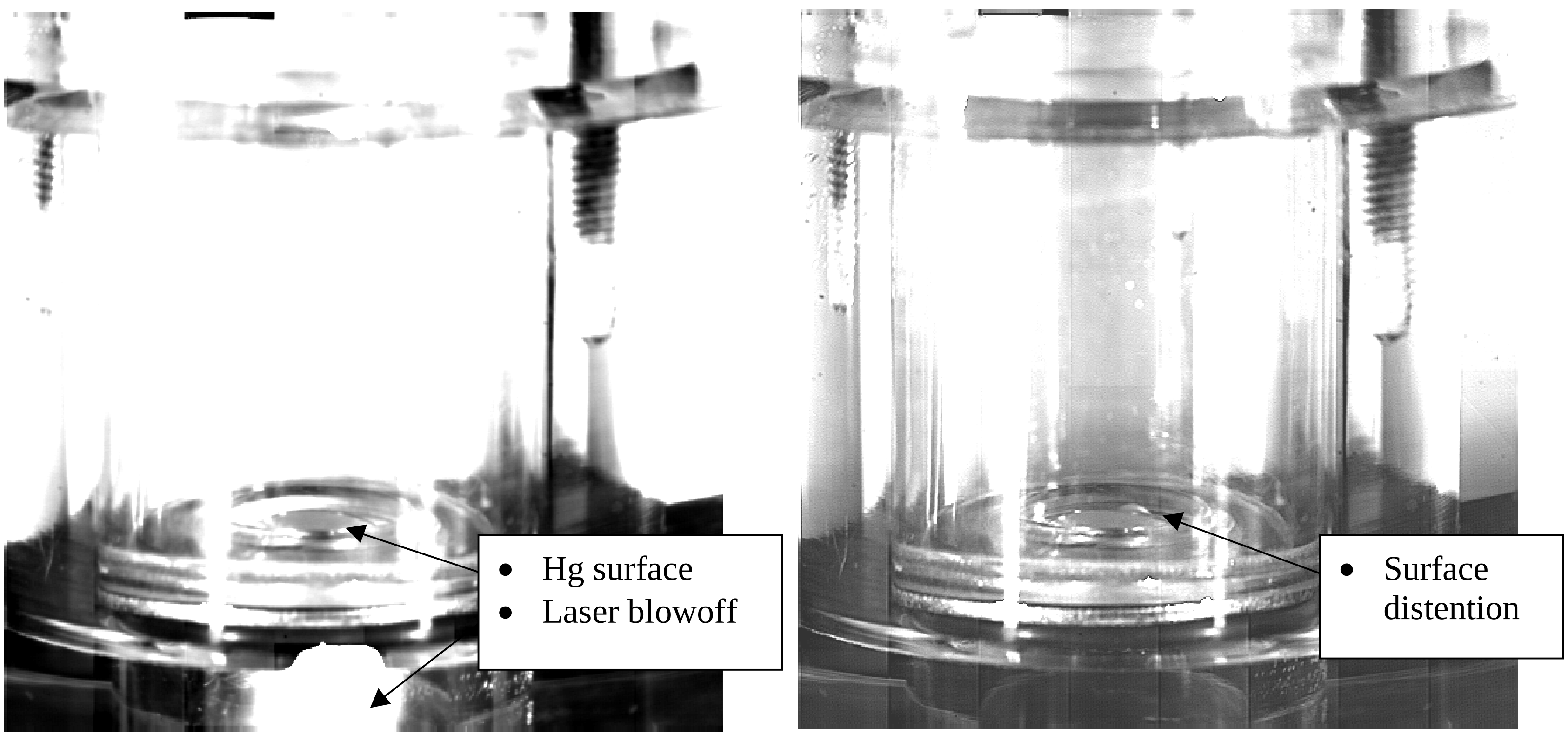
- Low volatility liquid metal is driven through interchangeable nozzle assembly into transparent vacuum chamber by variable pressurization of upper reservoir
- Jet image is recorded with high speed digital camera
- Photographs are analyzed with motion analysis software





"POPOFF" - Liquid Fracture Experiments

Goal: *to measure the fracture strength of various chamber relevant liquids (Li, Flibe Pb-Li, Pb) to fast tensile waves generated from X-ray ablation induced shocks and neutron isochoric heating*



Liquid fracture experiment photographs:
(a) Laser impact at time zero and
(b) 0.5 mm bulbous distention of the free surface 3.5 ms later