Recent Advances in Chamber Science and Technology

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Outline

- Highlights of Major World Programs on Chamber/Blanket

- Recent Progress on **Liquid Walls**

    - IFE & MFE
    - Basic Principles
    - Plasma-Liquid Surface Interactions
    - Bulk Plasma-Liquid Interactions
    - Fluid Dynamics and Heat Transfer
        - *Modelling*
        - *Experiments*
        - *Analysis & Design*

Highlights of Major World Programs on Chamber (Blanket) Technology

- Several overview and detailed papers at this conference
- Here, only a Quick Summary

Blanket Activities in Europe

- Program emphasis aims for DEMO, w/ test blanket modules (TBM) in ITER
- Emphasis on R&D for two near-term concepts that represent modest extrapolation in technology

1 - Water-cooled Pb-17Li	**2 - He-cooled pebble bed**
$P_{nw} = 2.2\ MW/m^2$	$P_S = 0.4\ MW/m^2$

- R&D Focus
  - Characterization of materials
    - Reduced activation Ferritic-Martensitic steel (EUROFER)
    - Breeding materials (Pb-17Li, Li_4SiO_4, Li_2TiO_3)
    - Beryllium
  - Manufacturing technology (HIP, joining, tritium permeation barrier)

- Other efforts on advanced concepts

A - Intermediate: PbLi with ferritic/martensitic steel
SiC is used only as flow channel inserts

B - Long Term: Other possibilities, e.g. SiC/SiC as structure

Blanket Activities in Japan

- **Main Concepts**
  - **Solid Breeder Blanket** (Key Organization: JAERI)

    Reference: Water cooled blanket with RAFS

    Advanced: He gas cooling system with SiC/SiC
  - **Liquid Breeder Blanket** (Key Organization: NIFS & Universities)

    Research on several advanced concepts: FLiBe, Li, LiPb with ferritic steel, V, and SiC

- **Key Milestones**
  - Demonstration of electrical power generation and tritium breeding in a DEMO-Relevant Test Blanket Module (TBM) in ITER is one of the most important milestones
  - The first TBMs will be installed in ITER around 2015.
  - In parallel with the TBM activity, material R&D should proceed with existing reactors and a fusion neutron source, such as IFMIF

Blanket Activities in Japan (cont'd)

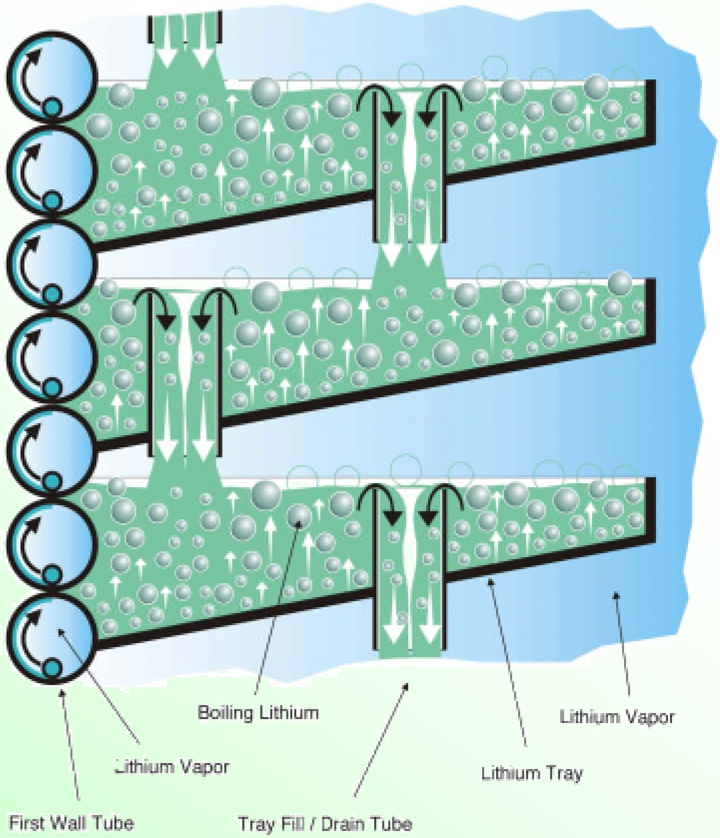
Key R&D items under investigation

- **Solid Breeder Blanket**
  - Development of base manufacturing technology for TBMs
  - Development of manufacturing technology of breeding material and neutron multiplier, such as $Be_{12}Ti$
  - Irradiation performance of RAFS, and ODS
  - Thermal/mechanical and irradiation performance of pebble beds
  - Supercritical water cooled blanket system for higher thermal efficiency
  - High temperature gas cooled blanket system with SiC/SiC
- **Liquid Breeder Blanket**
  - Development of FLiBe-based blanket with RAFS
  - Research on thermal hydraulics/heat transfer
  - Research on Tritium recovery technology
  - Research on Insulation/Tritium-permeation coating technology
- **JUPITER-II**
  - Collaborative program between Japan (mainly Universities) and USA covers materials, tritium, thermofluids, and pebble bed/SiC thermomechanics

Chamber Science & Technology in the USA

- Distinct, but collaborative Chamber Programs for IFE & MFE
- Last 3 years: strengthened interactions among Materials, PFC, and Chamber Programs
- The effort on “conventional” blankets is limited to:
  - Thermomechanics of pebble bed beryllium and ceramic breeders (IEA, JUPITER-II)
  - Insulators for liquid metal blankets (part of JUPITER-II)
- The major emphasis in Chamber Science & Technology over the past 3 years has been on Innovative Concepts that:
  1 - In the near-term: enable plasma experiments to more fully achieve their research potential
  2 - In the long-term: substantially improve the attractiveness of Fusion as an Energy Source
- Key research programs initiated: APEX (Chamber) and ALPS (PFC)
- Innovative concepts proposed: 1) Advanced Solid Walls 2) Liquid Walls

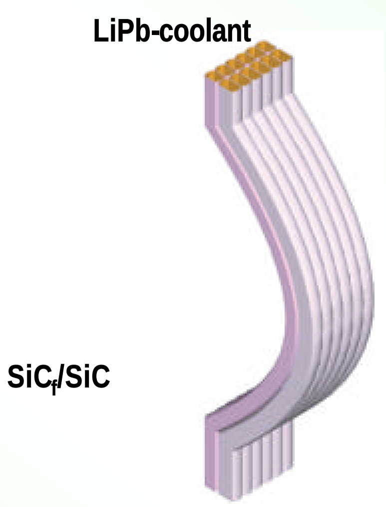
Innovative Solid Wall Concepts



EVOLVE (APEX)

- Novel Concept based on use of high temperature refractory alloy (e.g. tungsten) with innovative heat transfer/transport scheme for vaporization of lithium
- Low pressure, low stresses
- Low velocity, MHD insulator not required
- High Power Density / Temperature / Efficiency
- Key Issues Relate to Tungsten

ARIES-AT FW/Blanket Segment



- **SiC/SiC-LiPb proposed by ARIES**
  - SiC allows high temperature, but power density may be limited
  - Low activation
  - Key Issues relate to SiC/SiC

Reflections on Advanced Solid Walls

- Attempts to extend the capabilities and attractiveness of solid walls have required very advanced structural materials
- EVOLVE requires W alloy for high power density, high temperature

  But the Material Community is not enthusiastic (risky, costly, very long-term)
- High temperature with LiPb or other coolants/breeders relied on SiC/SiC

  Recent advances in SiC/SiC development are remarkable

  But some scientists are asking: Is SiC/SiC appropriate for FW?

  <u>A Viewpoint:</u> SiC cannot address all the issues of the first wall: heat load, pressure boundary, erosion, helium retention issue, etc.

  <u>A Suggestion:</u> Focus on utilizing SiC for suitable applications such as inserts (for insulation), and deeper regions of the blanket.
- Emerging Trend:

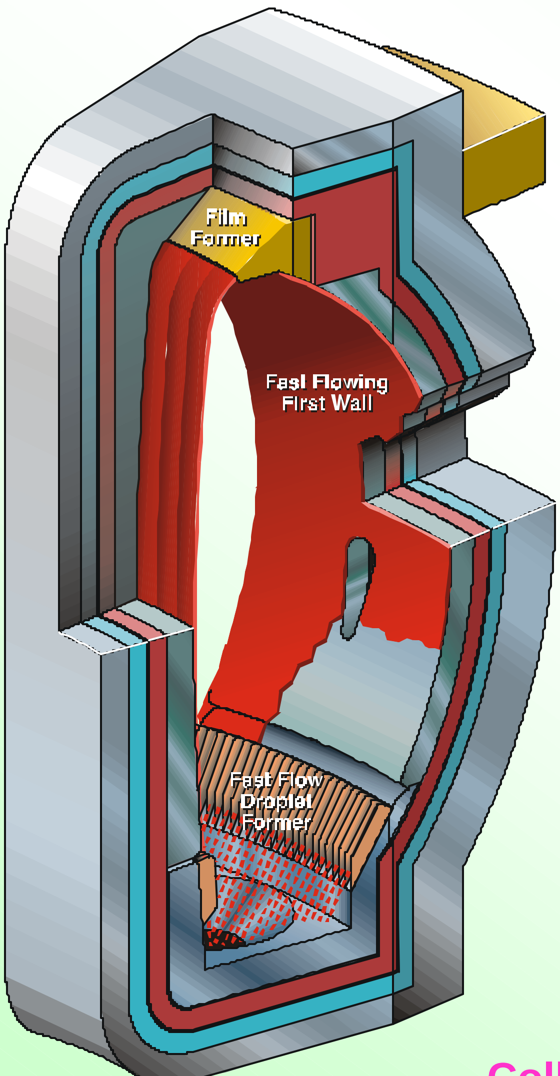
  - Emphasize advanced higher-temperature ferritic steels
  - EU/J/US: ODS
  - US: Nano-Composited Ferritic Steel (max. temp ~ 800 C)

Recent Progress on

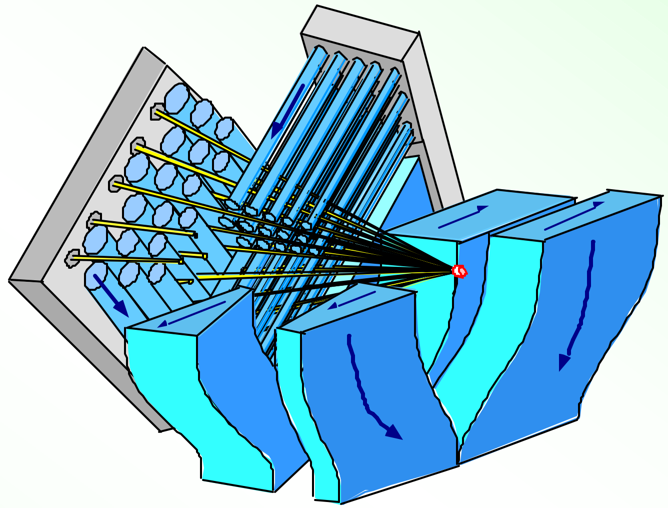
LIQUID WALLS

The remainder of this presentation will focus on Liquid Walls

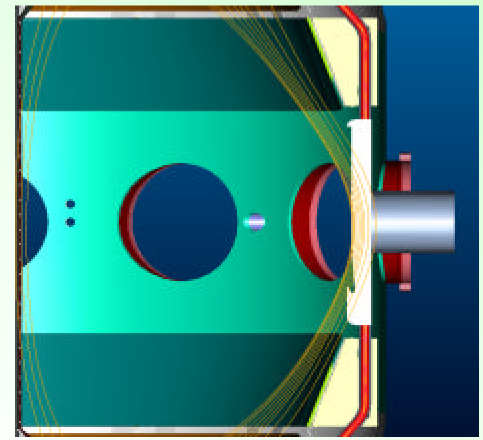
Liquid Wall Science & Technology are being Advanced in Several MFE & IFE Research Programs



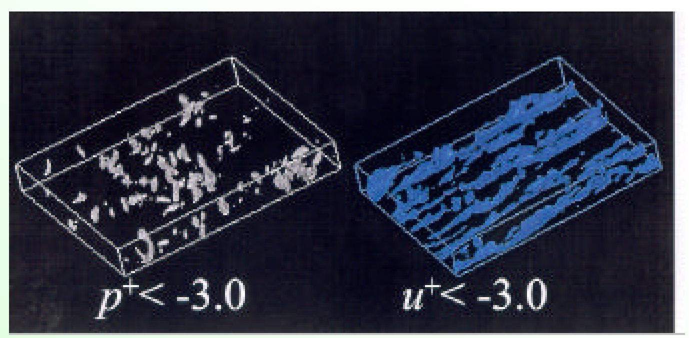
APEX CLiFF



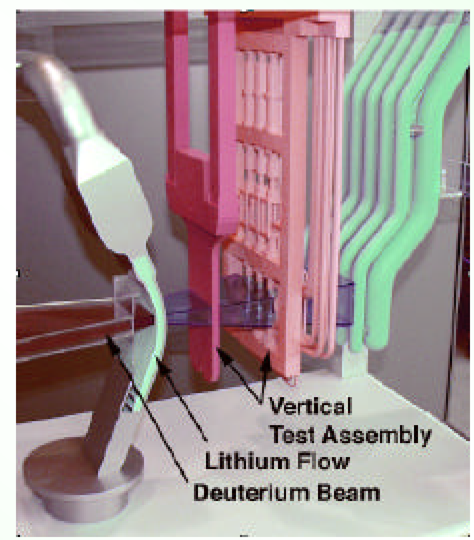
HYLIFE-II



ALPS/APEX NSTX Li module

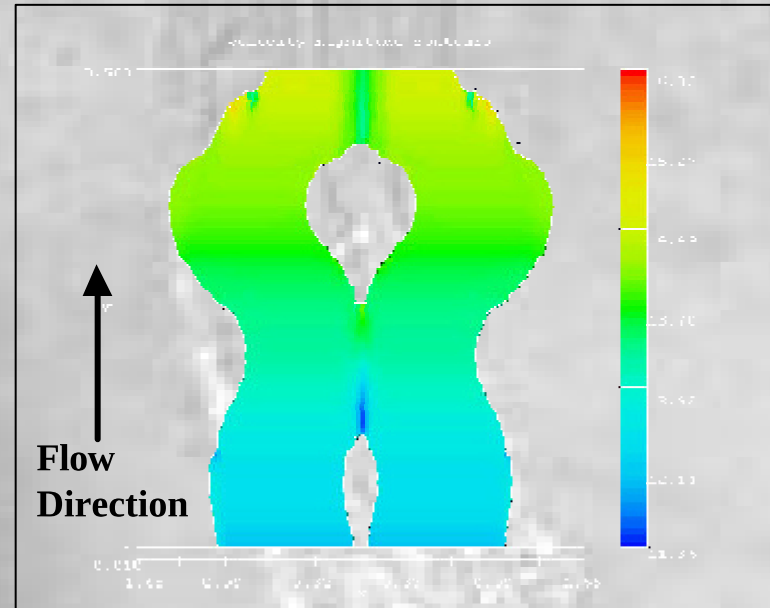


DNS Free Surface Simulation
Collaboration with non-fusion scientists
US-Japan Collaboration

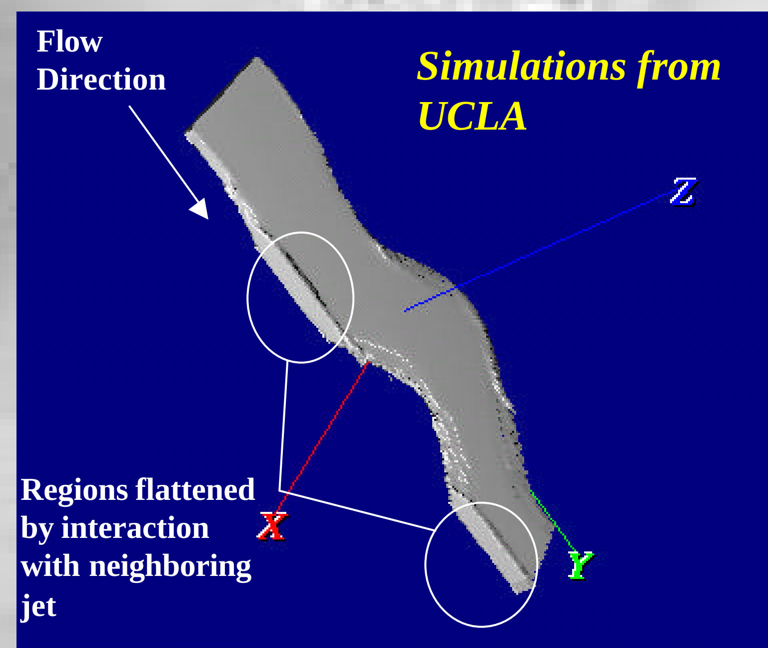


IFMIF

Oscillating IFE jet experiments and simulations



•**Single jet water experiments and numerical simulations demonstrate control of jet trajectory and liquid pocket formation at near prototypic Re**



Experimental Data from UCB

Remarkable Progress on Liquid Wall Research in the Past 3 years

- New Design Ideas for Liquid Walls in MFE Have Evolved
  (Elaborate Liquid Wall Designs for IFE have long existed)
- Key Technical Issues Identified & Characterized
- R&D Effort on Top Issues Initiated: Significant Progress
  - Modeling
    - Plasma Physics Edge & Core
    - Fluid Mechanics, MHD, Heat Transfer
  - Experiments
    - Laboratory Experiments on Thermofluids (w/ & w/o MHD)
    - Laboratory Experiments on Sputtering & Particle Trapping, etc.
    - Tokamak Experiments: Liquid Lithium in Actual Plasma Devices

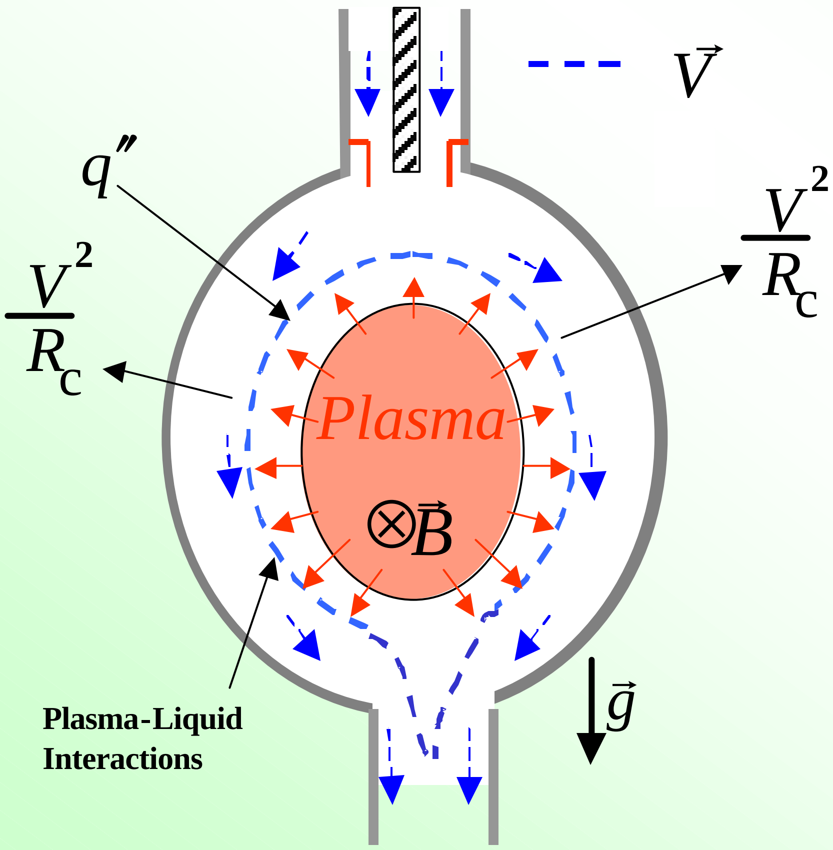
Potential Benefits if we can develop good liquid walls:

- Improvements in Plasma Stability and Confinement
  - Enable high ß, stable physics regimes if liquid metals are used
- High Power Density Capability
  - Eliminate thermal stress and erosion as limiting factors in the first wall and divertor
  - Results in smaller and lower cost components
- Increased Potential for Disruption Survivability
- Reduced Volume of Radioactive Waste
- Reduced Radiation Damage in Structural Materials
  - Makes difficult structural materials problems more tractable
- Potential for Higher Availability

No single LW concept may simultaneously realize all these benefits, but realizing even a subset will be remarkable progress for fusion

"Liquid Walls" Have Many Design Options

1) Type of Flow Control ***2) Working Fluid*** ***3) Liquid Thickness***



- **Gravity-Momentum Driven (GMD)**
  - Fast liquid adheres to back wall by centrifugal force
  - Applicable to LM's or molten salts
- **GMD with Swirl Flow**
  - Add rotation
  - Good for cylindrical geometry (e.g. FRC or IFE)

Swirl Flow in **FRC**