

# Chamber Science & Technology Key Question #1: Liquid Walls in MFE and IFE

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**Chamber Science & Technology Key Question #1:  
Liquid Walls in MFE and IFE**

*What are the merits and issues for liquid walls? What experiments, modeling, and analysis must be done to judge their potential for IFE and MFE? What are the key go/no go issues and how they can be explored quickly?*

Group Leaders:

Ralph Moir (LLNL) and Neil Morley (UCLA)

With Contributions from the Core Working Group:

Rich Mattas and Dai-Kai Sze (ANL)

Ed Lee (LBNL)

Steve Payne and Tom Rognlien (LLNL)

Dick Majeski and Dale Meade (PPPL)

Mike Ulrickson (SNL)

Per Peterson (UCB)

Mohamed Sawan (UWM)

And Other Interested Fusion Community Members

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## Prospectus

For some time now people have thought of liquid walls as an attractive solution to the technology problems of high power density plasma configurations for MFE, and as (nearly) essential for the pulsed wall-loading conditions in IFE. A flowing, renewable surface could be eroded, evaporated and even be broken apart with no permanent adverse effects on a structure requiring frequent maintenance and replacement. Alpha particle energy could be removed without conduction through a solid wall and the associated thermal stress and creep failure modes, and the energy could be extracted at high temperatures for efficient energy conversion. If a liquid wall of sufficient depth could be formed, radiation damage and waste disposal issues for solid structures could be significantly ameliorated.

All these benefits are indeed possible, if only liquid walls could be made to work! As we will see, there are many issues associated with the successful and attractive implementation of liquid walls.

The most obvious issue with liquid walls in MFE, assuming that they can be formed without splash, is that the vacuum required for current successful plasma experiments will be compromised by the relatively high evaporation rate of the hot liquid in the plasma chamber. This concern has led to the formulation of the idea that there is a temperature limit, corresponding to an acceptable evaporation flux, above which liquid walls will kill the operation of the plasma. This temperature limit will be inextricably linked to the ability of the plasma edge to screen neutral atoms and molecules before they enter the core plasma. In determining this screening one must account for the fact that the plasma edge behavior itself will likely be influenced by this large neutral flux.

For IFE, a similar issue stems from the need to clear the chamber of vaporized, splashed, and/or spalled liquid wall material so that targets can be injected and the driver beams can propagate to the targets through the residual vapor and debris at a pulse rate of several shots per second.

Other issues have sprung up as the analysis of liquid walls has advanced slowly over the years, and now more rapidly as part of the APEX and ALPS projects, and IFE development program. For MFE these issues include:

- Feasible liquid flow configurations, including inlet/outlet systems and space for penetrations must be identified
- Conflicting need for low surface temperature for plasma compatibility and high bulk outlet temperature for efficient energy conversion.
- High mass-flow rates needed to form thick liquid walls leads to low bulk temperature rise, and requires large pumping power, significant pumping equipment, and large piping (especially for gravity drainage from the vacuum chamber).
- Electromagnetic fluctuations and currents from the plasma can couple to liquid metal walls and exert a significant influence on its flow behavior. Conversely, stability of core MHD modes and plasma control may be affected differently for conducting and non-conducting liquids

- The liquid walls may act as particle pumps, especially in the limiter/divertor region, which change the effective recycling behavior and plasma-operating regime.
- Effect on other essential reactor systems like vacuum pumping, tritium recovery, plasma fueling, RF antennae, diagnostic and neutral beam penetrations, may require radically redesigned systems.

For IFE the other general issues include:

- Feasible liquid flow configurations, including inlet/outlet systems and space for beam lines must be identified
- Pulsed power deposition can lead to high velocity liquid slugs and droplets that can damage the target chamber structure and beam lines.
- Conflicting need for low surface temperature for driver beam propagation to the target, cryo-target compatibility, and rapid vapor condensation on films and droplet clouds; and high bulk outlet temperature for efficient energy conversion.
- High mass-flow rates needed to form thick liquid walls leads to low bulk temperature rise, and require large pumping power, significant pumping equipment, large piping (especially for gravity drainage from the vacuum chamber), and head recovery systems.
- Effect of liquid and vapor on other essential reactor systems like vacuum pumping, tritium recovery, final optics, diagnostic and driver beam penetrations, may require radically redesigned systems.

### **Main subtopics:**

The subtopic questions posed to the Fusion Community are designed to try to extract from people of various physics and technology backgrounds their views of the precise issues facing liquid walls, and the associated modeling and experiments needed to establish the feasibility and attractiveness of liquid wall concepts as a new paradigm for fusion reactor design.

The following topics will be explored in more detail before and during the Snowmass sessions on this topic. All ideas will be heard and discussed and will be incorporated into the final report along with the opinion (not always unanimous) of the core working group.

1. Do liquid walls really have the potential to yield a more attractive fusion energy product? What is the research and development path required to address feasibility and, subsequently, engineering design issues in a timely, economically realistic manner? What is the real impact on other reactor technology systems? (Moir, Sawan)
2. What modeling and experiments are required to establish the hydrodynamic feasibility of various thick liquid wall configurations for MFE and IFE? (Morley, Peterson)
3. What plasma modeling and experiments are required to determine the criteria of compatibility of liquid walls with acceptable tokamak or emerging concepts plasma

operation (e.g. allowable surface temperature?) Will plasma operation with liquid walls be fundamentally different than with dry walls? Does it make sense to have a liquid divertor only, with solid first walls or solid divertor with liquid walls? (Rognlien, Majeski, Meade, and Ulickson,)

4. Are there driver propagation, focusing modes, and final optics more compatible with liquid walls? Will residual liquid vapor and droplets affect target and driver propagation? What modeling and experiments are needed to determine the real limits on residual amounts of vaporized wall material in IFE reactors? (Lee, Moir, Payne)
5. Is there a clearly superior choice of working liquid? Is Flibe a feasible liquid based on plasma contamination (MFE), molecular recombination and condensation (IFE), tritium breeding, and structural material compatibility? Is lithium vapor pressure simply too high to make an attractive liquid wall? Will MHD effects and interaction with the plasma exclude either Flibe or liquid metals as viable working liquids? How important are activation and chemical reactivity properties in affecting materials compatibility, waste disposal, and accident response? (Mattas, Sze)

Three 1-hour 45-minute discussion periods during the first week of Snowmass (Tuesday, Wednesday, and Thursday afternoons, July 13<sup>th</sup>, 14<sup>th</sup>, and 15<sup>th</sup> in the *Top-of-the-Village* Tent) are anticipated for the subtopics. Moir and Morley will act as chairmen for these two discussion sessions.

- Each subtopic is allotted 45 minutes.
- Statements not to exceed 10 minutes in length precede each subtopic discussion. These remarks will introduce the issues associated with the subtopics and state the opinion of the core working group on these questions, and will be given by the core working group members assigned to each subtopic (above)
- Guided discussion will continue after the introductory remarks for 35 minutes. The chairmen will have the option of extending the length of the discussion period if it seems particularly useful.
- If there is time remaining near the end of each two-hour period, the chairmen will bring up any additional points for consideration gleaned from the discussions.

A summary of key issues and required modeling and experiments will be prepared by R. Moir and N. Morley and will be presented at the end of the second session and during the second week of Snowmass. Before the one-hour session in the second week, the core working-group will modify the preliminary report to reflect the conclusions (or opinions) of the discussion sessions. Following the summer study, the final report will be prepared based on the discussion at Snowmass, with contributions accepted from ALL interested community members.

### **Preliminary Report Outline:**

A draft of the core working group opinion on the above subtopics is given on the following pages and has been distributed before the meeting so as to elicit comments from the community. Comments can be registered via the Snowmass technology website hosted by UCLA at [www.fusion.ucla.edu/Snowmass](http://www.fusion.ucla.edu/Snowmass). Look in "Hot Topics and Commentary" to see all Chamber Technology Hot Topic Questions, and use the "view comments | add

comments” link under each question to register your opinions via email. Your comments will be automatically posted on the website and distributed to the core working group. Please feel free to contact Neil Morley ([morley@fusion.ucla.edu](mailto:morley@fusion.ucla.edu)) directly if you have any problems with the website system.

### **Philosophy**

This particular question is specifically about liquid walls and their potential attractiveness in fusion power plants. Other questions on different technologies are being held as part of the afternoon Cross-Cutting sessions and can be viewed at the Snowmass technology website cited above. It should also be noted that there are other Snowmass sessions with overlapping interest in liquid walls, especially the morning IFE session headed by Craig Olson ([www.columbia.edu/~mem4/wg\\_ife.html](http://www.columbia.edu/~mem4/wg_ife.html)).

The discussion here is meant to be frank and honest about the potential and problems of liquid wall concepts for MFE and IFE power reactors, and the R&D necessary to substantiate this potential. Many variants of liquid wall systems are possible that capitalize differently on the potential strengths outlined in this prospectus. They are not discussed here in detail. Many variants of advanced solid wall and particulate wall systems are also possible which may also be attractive for energy producing reactors. They also are not discussed here. But, some information is available at the APEX website at [www.fusion.ucla.edu/APEX](http://www.fusion.ucla.edu/APEX). All participants are encouraged to educate themselves on the current state of plasma chamber technology research.

**Liquid Walls Subtopic 1**

*Do liquid walls really have the potential to yield a more attractive fusion energy product?*

*What is the research and development path required to address feasibility and, subsequently, engineering design issues in a timely, economically realistic manner?*

*What is the real impact on other reactor technology systems?*

**Ralph Moir and Mohamed Sawan**

**Liquid Walls Subtopic 1 – R. Moir and M. Sawan**

Do Liquid Walls have the Potential to be Attractive?

**Yes**

**Attractive Liquid Wall Features**

- Elimination of first wall (divertor, and blanket) structure resulting in reduced thermo-mechanical problems related to thermal stress, embrittlement, and creep, *etc.*
- Neutron attenuation by liquid in front of most (possibly all) solid structures, reduced parasitic capture of neutrons in solid structure

**Potential Impact on Attractiveness (compared to generic solid wall)**

- Higher power density capability – results in smaller and lower cost components (magnets, chambers, vacuum vessel)
- Elimination of erosion lifetime limitations at divertor and FW/Limiter surfaces
- Reduced volume of radioactive waste (reduced size, increased lifetime)
- Reduced radioactive hazard from accidental releases
- Increased tritium breeding potential without the use of massive amounts of Beryllium multiplier
- Higher availability due to increased lifetime and reduced failure rates
- Lower capital cost by reduction in first wall and blanket replacement, number of hot and cold cells, amount of handling equipment, *etc.* (Highly design dependent)
- Reduction in costly materials development needs with expensive 14 MeV neutron testing facilities (IFMIF = ~\$1B, VNS=~\$3B, Operation=~\$.25B/yr, *etc.*)

**IF WE ARE CLEVER – The above attractive features could lead to significantly lower COE**

How much: by ~30%? ~50%?

## Liquid Walls Subtopic 1 – R. Moir and M. Sawan

### Can Liquid Walls be made to work and still remain attractive?

**There are serious issues needing resolution by R&D before we can say yes.**

#### Primary Issues needing R&D:

- Evaporation threatens to put out plasma burn in MFE systems limiting the blanket operating temperature and affecting the attractiveness of the power conversion system. Low temperature operation of liquid walls may be feasible, but might not be attractive.
- Evaporation and liquid debris threatens pulse rate in IFE systems. Limits on pulse rate and liquid temperature will impact the attractiveness of liquid walls designs. Low temperature low pulse rate operation of liquid walls may be feasible, but might not be attractive.
- Nozzles must form the liquid flow pattern required and exit nozzles (or drains) must receive the flow without drips and other liquid debris that threatens the plasma burn or chamber clearing.
- MHD effects with liquid metals might preclude the desired open channel flows for MFE systems and insulators are integral parts of the concept.
- Penetrations for MFE systems and beam port protection for IFE systems have serious design issues

**Feasibility and attractiveness is not assured and may come out negatively, different conclusions are possible for different plasma confinement schemes (MFE) and drivers (IFE).**

**Rethinking of optimum plasma confinement and driver propagation should proceed hand-in-hand with liquid wall development to achieve both a feasible and attractive vision of a fusion reactor**

## **Liquid Walls Subtopic 1 – R. Moir and M. Sawan**

**APEX and ALPS Projects and IFE Program  
are taking the right steps toward establishing feasibility.**

**Some questions are being addressed in the APEX project (for liquid walls) and ALPS project (innovative divertors) and as part of the IFE development path**

- Various designs implementations for liquid walls and divertors have been proposed and explored
- Information available at APEX website [www.fusion.ucla.edu](http://www.fusion.ucla.edu) , and as part of the interim APEX report due out in August
- IFE plan described by W. R. Meier, editor, “Chamber and target technology development for heavy-ion inertial fusion,” UCRL-ID-133629 (draft Mar 15, 1999).

**At this point the ultimate feasibility and attractiveness of liquid walls has not yet been shown.**

**The Modeling and Experimental R&D program needed to resolve the issues will be part of the continuing APEX, ALPS programs**

- Hydrodynamic feasibility
- Plasma operation and interaction with liquid walls
- Surface and bulk temperature control
- Fundamental data measurements: sputtering and recycling rates from the liquids, dissociation cross-sections for molecules such as those from Flibe, liquid vapor pressure and composition

**and IFE program**

- Hydrodynamic feasibility
- Chamber clearing ready for the next shot in about 1/5 s

**Liquid Walls Subtopic 1 – R. Moir and M. Sawan**

**What is the Needed R&D to demonstrate  
the attractiveness of Liquid Walls**

**Must demonstrate feasibility - R&D needs for various feasibility issues are described in the following subtopics**

- Hydrodynamic Feasibility
- Plasma Compatibility
- Driver Compatibility
- Choice of Working Liquid

**R&D needs to demonstrate ultimate Attractiveness**

- System code for liquid walls in Tokamak, Emerging Concepts, and IFE: with specific assumptions for liquid wall issues. Where do Liquid Walls optimize?
- Design study exploring impact of liquid walls on all reactor systems with detailed COE calculations with both conservative and liberal assumption sets
- **Liquid Wall DEMO**

**Liquid Walls Subtopic 2**

*What modeling and experiments are required to establish the hydrodynamic feasibility of various thick liquid wall configurations for MFE and IFE?*

**Neil Morley and Per Peterson**