Impact of Liquid Wall on Fusion Systems

Farrokh Najmabadi
University of California, San Diego

NRC Fusion Science Assessment Committee
November 17, 1999
Seattle, Washington

Electronic copy: http://aries.ucsd.edu/najmabadi/TALKS
ARIES Web Site: http:/aries.ucsd.edu/ARIES

Liquid Wall Concepts Are Among the Few Options Available for IFE Chambers

- About 100 MJ of X-rays and debris Ions are released by the target over about 10 ns. For a practical chamber size, the energy load on an “un-protected” chamber wall is about 2GW/m^2. For each option, the chamber environment should return to its “normal” condition in about 100 to 200 ms.

Options:

- **Gas Protection:** Low-density high-Z gas in the chamber absorbs X-rays and debris and re-radiate the energy in 0.1 to 100 ms.
- **Wetted Walls:** Thin liquid layer on solid walls absorbs the incident energy. The evaporated material recondenses on the chamber wall.
- **Thick Liquid Wall:** Energy yield is absorbed by regenerating liquid walls. Large pumping rate by liquid droplets may allow very low base pressure for the chamber (ideal for ballistic propagation of heavy ion).

⇒All of the above options have several “feasibility” issues and at roughly the same (very early) stage of scientific understanding.

Many Options Are Available for MFE Chambers

- For “conventional” MFE approaches (e.g., steady-state toroidal devices), energy loading on the chamber wall is sufficiently low that there is no requirement for “exotic” technologies.

Options:

- **Structural material:** Ferritic steels, V alloys, SiC composites, and possibly tungsten for divertors.
- **Breeder:** Liquid metal (Li), eutectic compounds (LiPb), salts, solid ceramic breeders, aqueous solutions.
- Most of these options are “well developed”. They are at the “proof-of-principle” stage but sufficient investment is necessary to ensure resolution of remaining issues.

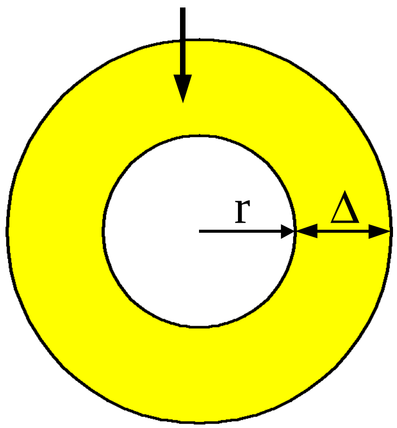
Impact of Liquid Walls on Fusion Systems

- **Claim:** Liquid walls eliminate the need for developing low-activation material.
- By using "neutronically-thick" liquid, it is possible to reduce the neutron dose to a low enough level such that stainless steel structure behind the liquid would qualify as low-level waste.
- **Reality**: Every fusion system includes a large number of penetrations. Structures located at or near these penetration will receive large neutron dose.

⇒**Low-activation material should still be developed**. Some thick liquid walls schemes reduce the amount of low-activation material but will not eliminate them.

Impact of Liquid Walls on Fusion Systems

- **Claims:** Liquid walls can handle high power density and will lead to more compact and economical fusion power plant.
- **Reality:** There is little economic benefit for operating beyond 5-10 MW/m^2 of wall load:

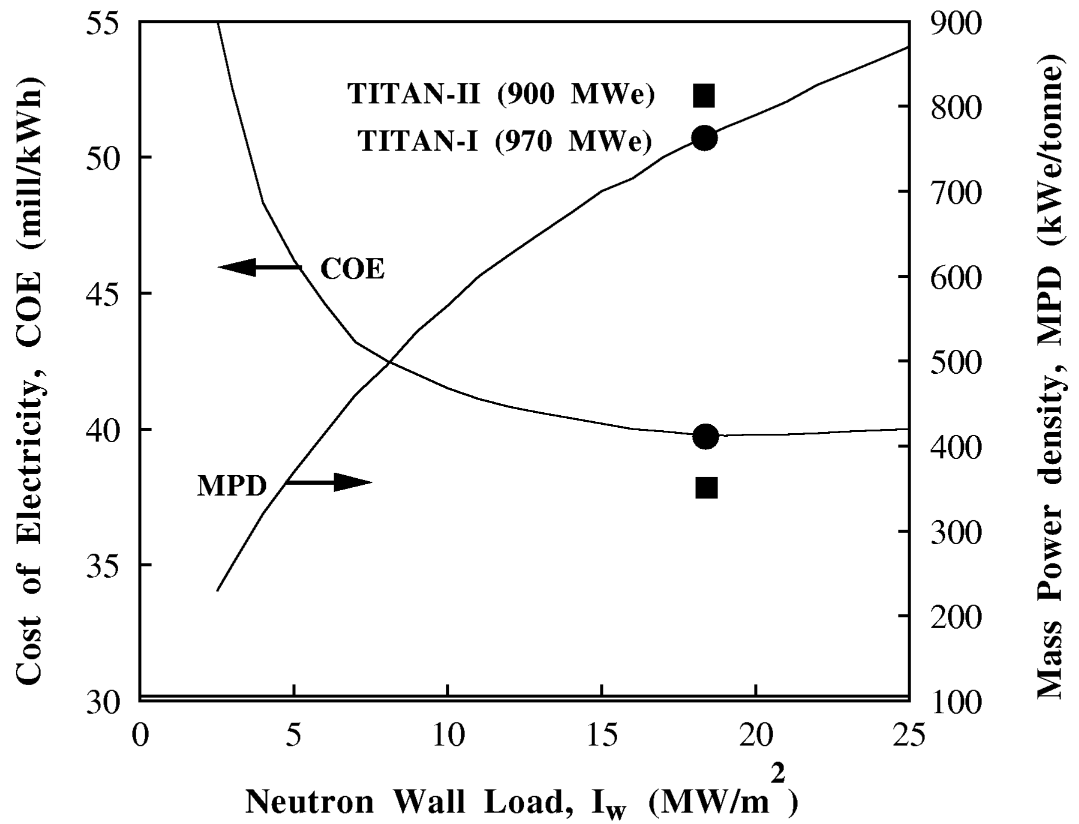


- Simple analysis for a cylindrical plasma with length L:
  $V_{FPC} = \pi L\,(2r\Delta + \Delta^2)$
  Wall loading $I_w \propto 1/(Lr)$
  For $r >> \Delta$, $V_{FPC} \propto Lr\Delta \propto 1 / I_w$
  For $r << \Delta$, $V_{FPC} \propto L\,\Delta^2 \cong$ constant
- "Knee of the curve" is at $r \cong \Delta$ (5-10 MW/m^2 for 1 to 1.5 GW plants)

There Is Little Economic Benefit for Operating Beyond 5-10 Mw/m^2 of Wall Load

- ARIES-RS, ARIES-ST, and ARIES-AT have not optimized at the highest wall load (all operate at around 5 MW/m^2)

- In TITAN reducing wall load from 18 to 10 MW/m^2 resulted in 4% change in COE. (assuming that we use the same technology at both wall loads.)



Improved Performance Can Be Obtained Through High Thermal Efficiency, Cheaper Components, and Enhanced Safety

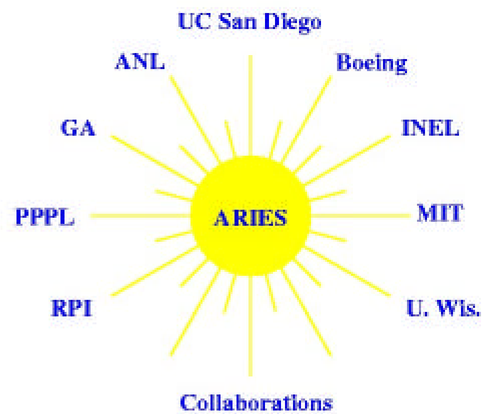
- High thermal efficiency:
  - ∗ Smaller fusion core for a fixed electric output;
  - ∗ cheaper “balance of plant”
- Reduce unit cost of components:
  - ∗ Most of cost of fusion plants is in manufacturing of components. Advanced manufacturing techniques can reduce the units cost drastically.
- Enhanced safety & environmental attributes:
  - ∗ Public acceptance and rapid construction;
  - ∗ Most of the plant components are not nuclear stamped, thus. They would be much cheaper to build and operate.

Main Features of ARIES-AT

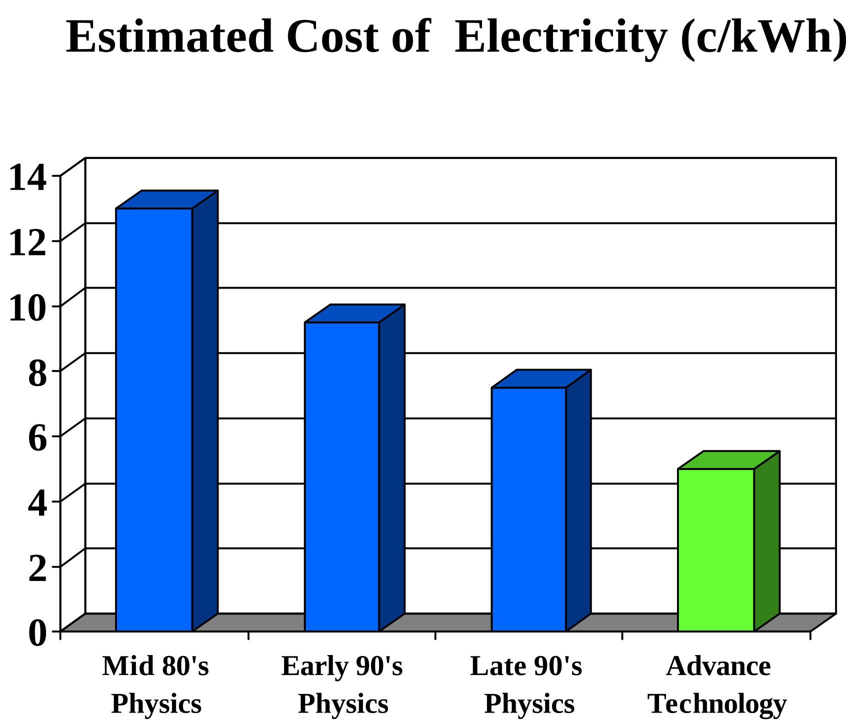
- **Higher Performance Physics:** RS equilibria have been developed with up to 50% higher β than ARIES-RS and reduced current-drive power.
- **Higher Performance Magnets:** High-temperature superconductors.

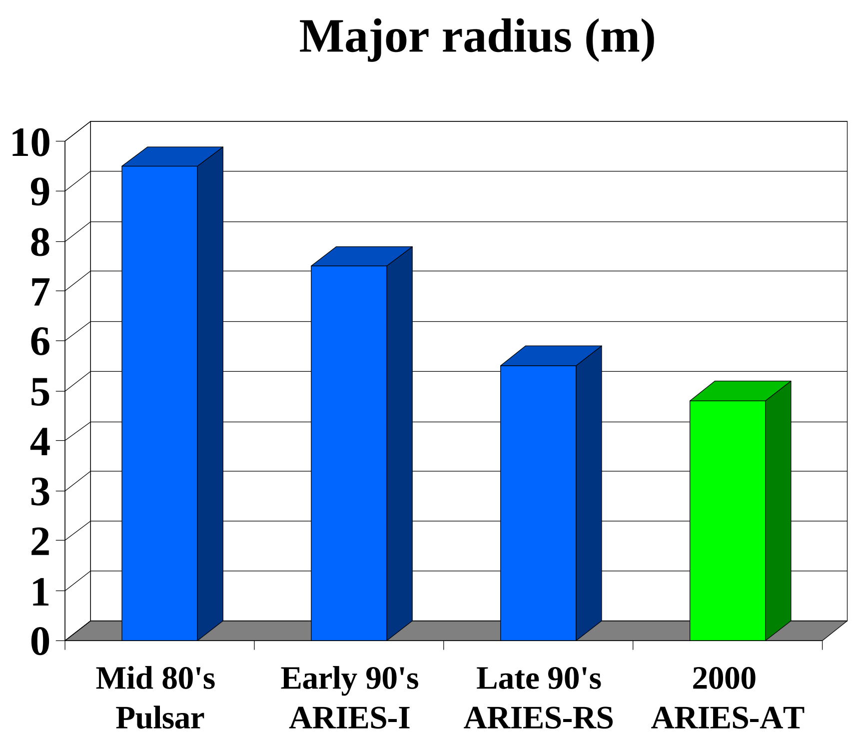
⇒ Design optimized at the same power density as ARIES-RS, higher β was used to reduce the peak field at the magnet.

- **High Performance Blanket:** New high-temperature SiC composite blanket design capable of achieving ~60% thermal conversion efficiency.
- Reduce unit cost of components through **advanced manufacturing techniques.**



Our Vision of Magnetic Fusion Power Systems Has Improved Dramatically in the Last Decade, and Is Directly Tied to Advances in Fusion Science & Technology





Preliminary ARIES-AT parameters:

Major radius:	4.8 m	Fusion Power	1740 MW
Toroidal β:	6.4%	Net Electric	1000 MW
Wall Loading:	4.3 MW/m^2	COE	5 c/kWh

Value of Liquid Wall Research

- Liquid walls do not improve the performance of fusion systems dramatically;
- Liquid walls do not reduce the cost of fusion chamber technology development. They do not eliminate the need for low-activation material.

However:

- Liquid wall concepts are among the few options available for IFE chambers.
- The MFE solid wall concepts are in “proof-of-principle” stage and it is too early to narrow the options.
- Liquid wall system and interaction of liquids with plasma represent intriguing scientific issues.
- We need a <u>balanced program</u> to study fusion energy sciences of fusion chamber technologies.