Plasma Facing Components

(The Path to DEMO)

Michael Ulrickson
Presented at FESAC Development Path Meeting
January 13-14, 2003
San Diego, CA
Outline

• Solid Surface PFCs
  – Plasma Facing Materials Development
  – Heat Sink Development
  – Joining Technology
  – Manufacturing and Reliability

• Liquid Surface PFCs
  – Electromagnetic Forces
  – Plumbing Issues (corrosion, supply and return)
  – Interfaces (diagnostics, heating, pumping, …)

• Common Themes and Conclusions
Solid Surface PFCs
Plasma Facing Materials Development

• Required Characteristics
  – High thermal conductivity
  – Reasonable activation
  – Thermal fatigue and creep resistance
  – Low erosion under edge plasma conditions
  – Low tritium retention

• Candidate Materials
  – Carbon, Copper, Molybdenum, Tantalum, Tungsten
  – Copper is not a good choice because of sputtering
  – Carbon is not a good choice because of T retention (?)
Magnetic Fusion Energy Heat Fluxes

Heat Flux (MW/m²)

Duration (s)

- Fusion Disruption
- Fusion ELM
- Radiant Flux at Sun Surface
- Fast Breeder
- Rocket Nozzle
- Fusion Divertor
- Fusion First Wall
- Fission Reactor

Sandia National Laboratories

MAU 5 2/19/2002
Heat Flux Capability

Material

Limiting Heat Flux (MW/m²)

Typical Minimum

Typical Maximum

Normal Operation
Heat Sink Development

• Coolant Choices
  – Water is primary now but has issues of steam interactions with hot activated refractory metals
  – Helium gas is the prime candidate in the future

• Heat sink designs
  – For water swirl tapes, hypervapotron, screw tube, … are all well established
  – Porous metal heat sinks are in the initial stages of development for He gas cooling (Cu alloys now)
Porous Metal Heat Sinks (He)

- Promising designs have been found for Cu alloys
- Heat removal is approaching water values
- Pressure drop is ok.
- Refractory metal research just starting.
- Helium gas purity is a key issue but there appear to be solutions.
- Refractory alloy development is needed.
Joining Technology

• Joining of W PFM to Cu heat sinks is well developed because of ITER R&D
• Refractory to Refractory joining
  – Initial scoping studies conducted jointly with Russians using Zr and Nb alloys.
  – Work terminated by the technology budget cuts in 1998-99
• This is a key issue that is not being addressed.
Manufacturing and Reliability

- PFC R&D is conducted on relatively small samples (~100 cm²)
- Thousands of such parts must be reproducibly produced for a fusion device like ITER or CTF
- Tore Supra has fabricated the largest actively cooled PFC but had great difficulty with production because of repeatability, QC
- Involvement of large high-technology industries is essential to achieving practical PFCs for such machines.
Liquid Surface PFCs
Benefits of Liquid Surfaces

- High heat flux removal capability (up to 50 MW/m²)
- No thermal stresses, no radiation damage
- Some liquids have strong hydrogen pumping and will radically alter divertor recycling
- No erosion or neutron flux limits on component lifetime
- Prime candidates for PFC applications are Li, Ga, Sn, In, and perhaps (LiFBeF₂NaF)
Allowed Duration for High T Limit

Heat Flux (MW/m²)

Allowed Duration (s)

Heated Length (cm)

10 m/s

100

10

1

Lithium

Indium

Gallium

Tin
Measurement of H Retention in Li

- High flux exposure on PISCES
- Retention is 100% up to complete formation of LiH over two orders of magnitude in fluence.
- These data have been used to determine the surface recombination rate.
- This means a flowing lithium surface will be an excellent pump.
Electromagnetic Forces

- Currents are created in flowing conducting liquids by
  - Plasma thermoelectric effect (temperature differences)
  - Halo currents
  - Spatially varying magnetic fields
  - Temporally varying magnetic fields

- Codes for computation of the effect of such currents is in progress (UCLA, Hypercomp, ...)

- This is a fundamental issue for liquid surface PFC
Motion Induced Currents

- Liquid Metal
- Perpendicular Currents
- Streamwise Currents
- Voltage
Other Issues

- Nozzle designs with smooth exit flow have to be designed
- Liquid metals are highly corrosive (T limits)
- External liquid metal loops are highly conducting and may have B-dot issues during current ramps.
- Electromagnetic restraint could be used to counteract EM forces
- Non-conducting liquids require special turbulence promoters
- Diversion of flow (antennas, diagnostics)
Common Themes and Conclusions

• A long term relationship with a high technology manufacturing company will have to be matured to successfully deploy PFCs on DEMO or CTF
• Scaling R&D size prototypes to the large sizes needed is a key issue
• Materials development is needed on both paths
• The solid surface path is well defined but second priority now
• Liquid surfaces will be a cheaper development path if fundamental issues are favorably resolved