A Fusion Development Facility to Test Divertor and PFC Solutions for DEMO


Presented at the ReNew Theme III workshop; Taming the Plasma Material Interface
UCLA, March 4-6, 2009
Significant Gaps from ITER to DEMO for PFC Solutions

- **Erosion and material migration**
  - Higher power density and higher duty cycle
  - More aggressive heat flux control required
  - Tons of PFC material will be eroded and redeposited

- **Tritium fuel cycle**
  - DEMO must breed its own tritium
  - Only small fraction of injected tritium fuel can remain in device

- **High temperature**
  - Blanket temperature $\geq 600$ °C required for efficient electricity generation
  - PFC characteristics fundamentally change at high temperature

- **Off normal events**
  - Disruptions must be eliminated, or substantially mitigated
  - ELMs must be essentially eliminated
A RESEARCH Facility for PFC Development is Needed to Bridge the Gaps to DEMO

A PFC research facility should encompass:

• **Tritium breeding**
  – PFC issues are central to obtaining TBR >1; Thin PFCs for neutron flux to blankets, tritium retention and permeation in PFCs

• **High power density and duty cycle**
  – Tests of heat flux control solutions compatible with high core confinement
  – Test designs to handle large levels of gross and net erosion and redeposition
  – Develop diagnostics for monitoring PFC erosion and integrity

• **High temperature**
  – Tritium retention and permeation change drastically at high temperature
  – PFC surface properties, reworked by the plasma and neutron, may change at high temperature

• **High neutron fluence**
  – Capability to test PFC designs, material and surface properties to >20 dpa

• **Flexibility**
  – Ability to change out and test alternative PFC materials and designs
FDF is a research facility to address the PFC gaps to DEMO

- **Compact**
  - Utilize AT physics for a high power density device at modest size, ~1.3 x DIII-D

- **Helium cooled PFCs**
  - Optimize vessel and PFC temperatures
  - Other options possible

- **Steady state**
  - 2 week discharges, 30% duty cycle over a year

- **High density**
  - Enhanced radiative dissipation

- **Flexibility with removable TF**
  - PFCs assembled outside vessel
  - Divertor and other PFCs can be changed in timely manner
FDF Can Conduct a Broad and Flexible Research Program

- **Test a variety of PFC materials**
  - Possible carbon PFCs for initial operation and discharge optimization; Oxygen bake for periodic cleanup
  - All potential materials can be installed and tested W, Mo, RAFM, engineered BW, flow through C
  - Large volume of PFC material will be eroded and redeposited with unknown characteristics
  - Complete surface inspection, and possible replacement at regular intervals

- **A number of PFC designs can be tested**
  - Swirl tubes and hypervapators for heat removal
  - Joining of PFCs to heat sink; Brazing, mechanical clamping, etc.

- **Heat flux solutions**
  - High density for radiative heat flux dissipation
  - Compatibility of radiative divertors with optimized core confinement
  - Precision divertor alignment to maximize use of flux expansion
  - Innovative divertor configurations for increased flux expansion; Super-X
FDF Research Capability (cont.)

- **Tritium retention**
  - Tritium retention decreases significantly at higher temperature
  - Tritium diffusion, permeation, in high Z metals increases at high temperature
  - Surface properties at high temperature may limit flux of tritium into bulk
  - Optimal operating temperature for tritium control very uncertain

- **Tritium breeding**
  - Credible PFC designs for net tritium breeding can be tested
**FDF Research Capability (cont.)**

- **Component lifetime tests**
  - 20-40 dpa in a 5 year operating period can test material integrity of PFC materials.
  - Effects of neutrons on eroded and redeposited PFC material can be examined.

- **RAMI**
  - High duty cycle over years required high reliability and availability.
  - Maintenance techniques can be developed.
  - Diagnostics important for evaluating erosion, tritium retention and PFC integrity.

*Neutron induced shrink/swell in N3M graphite*  

*End of lifetime*

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Staged Schedule for Experimental Approach

- **Startup phase; 4 years**
  - Shorter pulses for system checkout
  - Optimize performance with PFCs forgiving to off normal events

- **1st experimental phase; 5 years, 12 dpa**
  - Begin steady state operation
  - Conservative PFC and blanket design for initial evaluation

- **Maintenance; 2 years**
  - Install DEMO relevant PFC, divertor and blanket systems

- **2nd operation phase; 5 years, 25 dpa**
  - Test performance of DEMO relevant PFC designs

- **Maintenance; 2 years**
  - Install optimized PFC designs

- **3rd operation phase; 5 years, 40 dpa**
  - Final testing of PFC, divertor and blanket designs for DEMO
A Staged Research Plan for Increasingly Optimized Operation

<table>
<thead>
<tr>
<th>START UP</th>
<th>FIRST MAIN BLANKET</th>
<th>SECOND MAIN BLANKET</th>
<th>THIRD MAIN BLANKET</th>
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<table>
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<tr>
<th>Fusion Power (MW)</th>
<th>0</th>
<th>0</th>
<th>125</th>
<th>125</th>
<th>250</th>
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<th>250</th>
<th>400</th>
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<td>$P_{N}/A_{WALL}$ (MW/m²)</td>
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<td>1</td>
<td>2</td>
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<td>Pulse Length (Min)</td>
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<td>10</td>
<td>SS</td>
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<td>Duty Factor</td>
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<td>$T$ Burned/Year (kG)</td>
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<td>0.7</td>
<td>2.8</td>
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<td>4.2</td>
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<td>5</td>
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<tr>
<td>Net Produced/Year (kG)</td>
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<td>0.56</td>
<td>0.56</td>
<td>0.84</td>
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<td>1</td>
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<tr>
<td>Main Blanket</td>
<td>He Cooled Solid Breeder Ferritic Steel</td>
<td>Dual Coolant Pb-Li Ferritic Steel</td>
<td>Best of TBM RAFS?</td>
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<tr>
<td>TBR</td>
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<td>Test Blankets</td>
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<td>7,8</td>
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<td>Accumulated Fluence (MW-yr/m²)</td>
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