Making Electricity and Hydrogen – the FDF Port Test Blanket Module Program

C.P.C. Wong, R. Stambaugh, V.S. Chan (General Atomics)

White paper for ReNeW, Theme IV: “Harnessing Fusion Power”

US Department of Energy
OFES Research Need
Workshop (ReNeW)
University of California, Los Angeles

March 2–6, 2009
The Greenwald Report states:

Power Extraction: “Understand how to extract fusion power at temperatures sufficiently high for efficient production of electricity or hydrogen.”

Harnessing fusion power: “The state of knowledge must be sufficient to design and build, with high confidence, robust and reliable systems that can convert fusion products to useful forms of energy in a reactor environment, including a self sufficient supply of tritium fuel.”
Test Blanket Modules (TBMs) Enable Research for Electricity and Hydrogen Production

Port blanket sites for fusion nuclear technology development
# Candidate FDF Schedule

<table>
<thead>
<tr>
<th></th>
<th>START UP</th>
<th>FIRST MAIN BLANKET</th>
<th>SECOND MAIN BLANKET</th>
<th>THIRD MAIN BLANKET</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>H D DT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fusion Power (MW)</td>
<td>0 0 125</td>
<td>125 250</td>
<td>250 250</td>
<td>250 400</td>
</tr>
<tr>
<td>$P_{N/A_{WALL}}$ (MW/m²)</td>
<td>1 1 2</td>
<td>2 2</td>
<td>2 3.2</td>
<td></td>
</tr>
<tr>
<td>Pulse Length (Min)</td>
<td>1 10 SS</td>
<td>SS</td>
<td>SS</td>
<td>SS</td>
</tr>
<tr>
<td>Duty Factor</td>
<td>0.01 0.04 0.1 0.2</td>
<td>0.2 0.3</td>
<td>0.3 0.3</td>
<td></td>
</tr>
<tr>
<td>T Burned/Year (kG)</td>
<td>0.28 0.7 2.8</td>
<td>2.8 4.2</td>
<td>4.2 5</td>
<td></td>
</tr>
<tr>
<td>Net Produced/Year (kG)</td>
<td>-0.14 0.56</td>
<td>0.56 0.84</td>
<td>0.84 1</td>
<td></td>
</tr>
<tr>
<td>Main Blanket</td>
<td>He Cooled Solid Breeder Ferritic Steel</td>
<td>Dual Coolant Pb-Li Ferritic Steel</td>
<td>Best of TBMs RAFS?</td>
<td></td>
</tr>
<tr>
<td>TBR</td>
<td>0.8 1.2</td>
<td>1.2 1.2</td>
<td>1.2 1.2</td>
<td>1.2 1.2</td>
</tr>
<tr>
<td>Test Blankets</td>
<td>1,2</td>
<td>3,4 5,6</td>
<td>7,8 9,10</td>
<td></td>
</tr>
<tr>
<td>Accumulated Fluence (MW-yr/m²)</td>
<td>0.06 1.2</td>
<td>3.7</td>
<td></td>
<td>7.6</td>
</tr>
</tbody>
</table>
Port Test Blanket Modules

- FDF will be able to develop fusion’s energy applications including the demonstration of electricity production and possibly hydrogen production. With neutron fluence at the outboard midplane of 1–2 MW/m$^2$ and a goal of a duty factor on a year of 0.3
- FDF can produce fluences of 3–6 MW-yr/m$^2$ in 10 years of operation onto complete blanket structures and/or material sample volumes of about 1 m$^3$.
- This will provide necessary initial RAMI information for the design of DEMO.
- Port blanket modules are for blanket development for both tritium production and electricity production
- Different blanket concepts or variants in 2–3 ports over a 10-year period.
- Another port site should be devoted to the development of blankets that can support hydrogen production, with temperatures of extracted coolant, over 900° C.
- 300 kW electricity and hydrogen production (~one metric ton per week) should be made on test port blankets that are sufficiently successful to warrant that effort.
- FDF will develop the technology necessary for the design of DEMO first wall and blanket components and provide knowledge on the reliability, safety, environmental impacts, and efficiency of fusion energy extraction systems.
FDF can be a High Fluence Facility to Test a Large Number of Blanket Options

Blanket options can start with the ITER TBM program candidates:

- Helium-cooled Lithium-Lead blanket (1)
- Dual-Coolant (He and LiPb) type Lithium-Lead (DFLL and DCLL) blankets (2)
- Dual-Coolant (He and LiPb) Lithium-Lead Ceramic Breeder (LLCB) blanket (1)
- Helium-cooled Ceramic/Beryllium blanket (3 designs)
- Water-cooled Ceramic/Beryllium blanket (1)

These are 8 blanket main options being evaluated by the ITER TBM program, and with detailed variations and graduate improvements of preferred concepts, judicious selection will be needed to focus on the selection of ~10 blanket concept designs to be tested in FDF.
FDF Test Module Program: Four Key Ancillary Systems Based on ITER TBM Systems

(Some details will be dedicated to the specific TBM)

1. Port Cell Area

2. Hot Cell Area

3. Heat Removal Area

4. Tritium Plant
Power Extraction: High Neutron Wall Loading (Neutron wall loading ~ 2 MW/m²)

- FDF will make the definitive contribution here since it will be designed for \( \Gamma_n \sim 2 \text{ MW/m}^2 \) into the mid-plane test port blanket modules and will have a goal of duty factor 0.3 for an integrated fluence of 3–6 MW-yr/m²

- These are essential capabilities for fusion nuclear technology development

- ITER's goals are 0.5 MW/m² mid-plane neutron flux and a lifetime fluence of 0.3 MW-yr/m²

- FDF will be about 1/10 and ITER about 1/100 of reactor fluence
Test Blanket Module Program Will Also Enable Research on Optimizing Tritium Production

- The limited pulse length on ITER (perhaps as high as 3000 seconds) may not allow an adequate demonstration of continuous extraction and accountancy of tritium from the test blanket modules.

- FDF will develop test blankets in port modules at 1–2 MW/m² neutron flux operating durations of up to 2 weeks will enable demonstration of the kind of actual continuous closed loop tritium extraction to be used in fusion systems.

- FDF will demonstrate the whole fuel cycle that of the plasma and tritium breeding blanket, including extraction, accountability, and safety issues of a steady-state DT device to pave the way for DEMO.
This issue could be phrased much more broadly. Fusion has yet to capture its first fusion neutron in a blanket. Everything in combined first wall/blanket development remains to be done experimentally.

FDF will test whole, real size first wall/blanket structures as main-blankets and test blankets with significant neutron fluxes and fluences, relevant first wall heat and plasma fluxes, and in a real system with mitigated disruptions and other challenges.

FDF will be designed with the flexibility and maintainability to allow ten test blanket variations to be tested in ten years.

FDF will be a test bed for learning how to engineer reliable first wall/blanket structures and make first efforts on reliability growth.
High Temperature Blankets (Hydrogen Production)

- FDF will have reactor relevant neutron fluxes and fluences to develop such blankets in test port modules.

- FDF should extrapolate from the knowledge of main-blanket design development and work in concert with the latest development of advanced high performance structural material like SiC/SiC composite and/or refractory alloys to design a module for the demonstration of high helium outlet temperature suitable for hydrogen production.
The FDF Program will be a test bed for learning how to engineer and operate reliable first wall/blanket structures and gain first information on reliability growth for the blanket system.

The machine must be reliable to achieve two week continuous operation and the availability to achieve a 30% duty factor on a year. It must be maintainable because it is a research environment and failures must be repairable and the blankets must be changeable.

Inspection of the components is an integral part of the research; we need to find out what is happening to these components and provide data to fusion reactor RAMI data base.
Conclusions

FDF program on Power Extraction will lead to the understanding on how to extract fusion power at temperatures sufficiently high for efficient production of electricity or hydrogen.

(Satisfying what is stated in The Greenwald Report)

FDF will acquire sufficient knowledge to design and build, with high confidence, robust and reliable systems that can convert fusion products to useful forms of energy in a reactor environment, including a self sufficient supply of tritium fuel.

(Satisfying the requirement from the Harnessing Fusion Power Theme)