Blanket Design Issues for ARIES-AT

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Web address:

ARIES Project Meeting
9 - 10 August 1999
UCSD
# Design Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fusion power</td>
<td>2170 MW (ARIES-RS’’)</td>
</tr>
<tr>
<td>FW location at midplane – OB , IB</td>
<td>6 , 3.5 m</td>
</tr>
<tr>
<td>at top/bottom– OB , IB</td>
<td>4.5 , 3.5 m</td>
</tr>
<tr>
<td>$\Gamma$ : Peak OB , IB</td>
<td>6.6# , 5.1# MW/m$^2$</td>
</tr>
<tr>
<td>Average OB , IB</td>
<td>5.6 , 3.8 MW/m$^2$</td>
</tr>
<tr>
<td>FW poloidal length* – OB , IB</td>
<td>6 , 5 m</td>
</tr>
<tr>
<td>SiC burnup limit</td>
<td>3%</td>
</tr>
<tr>
<td>Machine lifetime</td>
<td>40 FPY</td>
</tr>
<tr>
<td>ARIES-RS’ vacuum vessel configuration</td>
<td>(to be modified)</td>
</tr>
<tr>
<td>ARIES-RS’ LT magnet composition and dimensions</td>
<td>(to be updated)</td>
</tr>
</tbody>
</table>

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# Footnotes

* For same fusion power, smaller radii result in higher wall loading
* Between X points
Preliminary 3-D Nuclear Parameters

• Preliminary 3-D analysis needed at early stage of design to estimate key nuclear parameters:
  – Overall TBR
  – Overall Mn
  – Heat load to components
  – FW lifetime

• 3-D analysis:
  – MCNP code - pointwise FENDL-1 cross section data
  – 10,000 histories - < 1% statistical error in TBR and Mn
  – Neutron source distribution similar to ARIES-RS’
  – Homogenized zones: FW, blanket, HT shield, LT shield/V.V.
  – No radial gaps or RF penetrations (need info)
  – No metallic Kink stabilizing shell (need info)
  – No vertical stabilizing shell (need info)

• FW/Blanket main features:
  – Self-cooled LiPb/SiC system
  – IB and OB blankets only (no blanket behind divertor)
  – LiPb-cooled divertor and HT shields
  – 90% enriched LiPb
  – 10 cm thick separate FW (17% SiC, 26% LiPb, 57% void)
  – 25 cm thick IB blanket (8% SiC, 92% LiPb)
  – 55 cm thick segmented OB blanket (8% SiC, 92% LiPb)

• 3-D results:
  - Overall TBR 1.1
  - Overall Mn 1.1
  - SiC Burnup fraction in OB FW 1.06% per FPY
  - FW EOL fluence 18.5 MWy/m²
  - FW Lifetime 2.8 FPY
## TBR Breakdown

<table>
<thead>
<tr>
<th>Components:</th>
<th>Inboard</th>
<th>Outboard</th>
<th>Divertor</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>FW &amp; DP</td>
<td>5%</td>
<td>11%</td>
<td>2%</td>
<td><strong>18%</strong></td>
</tr>
<tr>
<td>Blanket – Cell I</td>
<td>20%</td>
<td>38%</td>
<td>---</td>
<td><strong>58%</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(20, 18)*</td>
<td></td>
</tr>
<tr>
<td>Blanket – Cell II</td>
<td>---</td>
<td>21%</td>
<td>---</td>
<td><strong>21%</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(12, 10)*</td>
<td></td>
</tr>
<tr>
<td>HT Shield</td>
<td>1%</td>
<td>1.6%</td>
<td>0.4%</td>
<td><strong>3%</strong></td>
</tr>
<tr>
<td>Total</td>
<td><strong>26%</strong></td>
<td><strong>71.6%</strong></td>
<td><strong>2.4%</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

* middle and upper/lower sections
Nuclear Heat Load to In-vessel Components of Self-cooled Design

\( P_n = 1736 \text{ MW - ARIES-RS} \)

<table>
<thead>
<tr>
<th>Nuclear Heating (MW)</th>
<th>Inboard</th>
<th>Outboard</th>
<th>Divertor</th>
<th>Total</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>FW or DP</td>
<td>140</td>
<td>385</td>
<td>46</td>
<td>571</td>
<td>(30%)</td>
</tr>
<tr>
<td>Blanket</td>
<td>250</td>
<td>755</td>
<td>---</td>
<td>1005</td>
<td>(53%)</td>
</tr>
<tr>
<td>HT Shield</td>
<td>80</td>
<td>30</td>
<td>214</td>
<td>324</td>
<td>(17%)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>470</td>
<td>1170</td>
<td>260</td>
<td>1900</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(25%)</td>
<td>(62%)</td>
<td>(13%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Overall neutron energy multiplication is 1.1
Nuclear Heat Load to In-vessel Components of Dual-cooled Design

\(P_n = 1736 \text{ MW - ARIES-RS}\)

<table>
<thead>
<tr>
<th>Nuclear Heating (MW)</th>
<th>Inboard</th>
<th>Outboard</th>
<th>Divertor</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>FW or DP</td>
<td>32</td>
<td>92</td>
<td>~10</td>
<td>134 (7%)</td>
</tr>
<tr>
<td>Blanket/ manifolds</td>
<td>334</td>
<td>1068</td>
<td>---</td>
<td>1402 (73%)</td>
</tr>
<tr>
<td>HT Shield</td>
<td>114</td>
<td>22</td>
<td>~250</td>
<td>386 (20%)</td>
</tr>
<tr>
<td>Total</td>
<td>480</td>
<td>1182</td>
<td>260</td>
<td>1922 (25%) (62%) (13%)</td>
</tr>
</tbody>
</table>

Overall neutron energy multiplication is 1.1
• To reduce radwaste stream and replacement cost, segment self-cooled FW/B into 3 components: FW, Cell-I, and Cell-II (on OB only)
• Replace each component at end of its service lifetime
• 3% burnup to SiC structure determines lifetime of each component
• Segmentation of dual-cooled blanket is not feasible

<table>
<thead>
<tr>
<th>Component</th>
<th>Lifetime (FPY)</th>
<th>EOL Fluence (MWy/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FW</td>
<td>2.8</td>
<td>18.5</td>
</tr>
<tr>
<td>Cell-I</td>
<td>5.6 – 8.4#</td>
<td>37 – 55</td>
</tr>
<tr>
<td>Cell-II</td>
<td>&gt; 40</td>
<td>&gt; 250</td>
</tr>
<tr>
<td>Shield/V.V./magnet</td>
<td>&gt; 40</td>
<td>&gt; 300</td>
</tr>
</tbody>
</table>

* = lifetime x peak OB n wall loading
# To be determined by 3-D analysis
## FW/B Radwaste Volume and Cost

<table>
<thead>
<tr>
<th>SiC Vol. (m$^3$)</th>
<th>Integral SiC Vol. (m$^3$)</th>
<th>Direct Cost$^*$ (M$$)</th>
<th>Lifetime (FPY)</th>
<th># of Replace. in 40 FPY</th>
<th>Integral SiC Vol. (m$^3$)</th>
<th>Direct Cost (M$$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Unit FW/B</td>
<td>2.8 FPY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14 Replacements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>during 40 FPY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Components:

<table>
<thead>
<tr>
<th></th>
<th>SiC Vol. (m$^3$)</th>
<th>Integral SiC Vol. (m$^3$)</th>
<th>Direct Cost$^*$ (M$$)</th>
<th>Lifetime (FPY)</th>
<th># of Replace. in 40 FPY</th>
<th>Integral SiC Vol. (m$^3$)</th>
<th>Direct Cost (M$$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IB FW</td>
<td>1.7</td>
<td>26</td>
<td>31</td>
<td>2.8</td>
<td>14</td>
<td>26</td>
<td>31</td>
</tr>
<tr>
<td>IB Blkt</td>
<td>2</td>
<td>30</td>
<td>37</td>
<td>8.4</td>
<td>4</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>OB FW</td>
<td>3.8</td>
<td>57</td>
<td>70</td>
<td>2.8</td>
<td>14</td>
<td>57</td>
<td>70</td>
</tr>
<tr>
<td>OB B Cell-I</td>
<td>3.6</td>
<td>55</td>
<td>66</td>
<td>8.4</td>
<td>4</td>
<td>18</td>
<td>22</td>
</tr>
<tr>
<td>OB B Cell-II</td>
<td>6</td>
<td>92</td>
<td>112</td>
<td>40</td>
<td>--</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>17</td>
<td>260</td>
<td>316</td>
<td></td>
<td></td>
<td>117</td>
<td>143</td>
</tr>
</tbody>
</table>

FW/B : Shield Ratio | 0.5 | 0.25

Blanket segmentation reduces cumulative FW/B radwaste volume and replacement cost by factor of ~2

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$^*$ based on 400 $/kg for SiC/SiC composites
Single vs. Dual Loop Cost

- In ASC, Account 22.2 for “Main Heat Transfer and Transport Systems” is function of:
  - Thermal Power
  - Power split between coolants of dual cycle

- Dual loop increases Account 22.2 by 37%, per Miller.

- Example:
  2400 MW thermal power
  50/50 power split between He and LiPb coolants

  Account 22.2:
  - Single Loop: 220 M$
  - Dual Loop: 300 M$

  **He loop increases direct cost by ~80 M$ and COE by 2-3 mills/kWh**

**Question:** Does incremental increase in $\eta_{th}$ of added He loop outweigh drawbacks of high-pressure design, expensive heat transfer/transport system ($\Delta = 2-3$ mills/kWh), high replacement cost ($\Delta \sim 3$ mills/kWh), and high pumping power (>10 MW)?