Comparison of Neutronics Features for Candidate Blankets

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Analysis was presented for two blanket designs in HAPL chamber:

- Self-cooled Li blanket
- He-cooled SB blanket with Be multiplier

LAFS alloy F82H used as structural material

He-cooled steel shield/VV used

Neutronics analysis presented here for a dual-coolant LiPb blanket with the same chamber dimensions and target fusion power

Neutronics features of the three candidate blankets are compared
Basic Assumptions

- 1 mm W armor on ferritic steel (F82H) FW
- Used target spectrum from LASNEX results (Perkins) for NRL direct-drive target
- 70.5% of target yield carried by neutrons with 12.4 MeV average energy
- 1.8 GW fusion power
- Chamber radius 6.5 m at mid-plane

![Graph showing neutron wall loading and surface heat flux](image)

- Average neutron wall loading = 2.2 MW/m²
- Average surface heat flux = 0.92 MW/m²
KEY FEATURES OF DUAL COOLANT LITHIUM-LEAD CONCEPT (DCLL)

● Helium cools the ferritic steel FW and structure and is used for FW/blanket preheating and possible tritium control

● Breeding Li$_{17}$Pb$_{83}$ is circulating at low speed

● No separate neutron multiplier needed

● Use flow channel inserts (FCI) to:
  — Provide electrical insulation to reduce MHD pressure drop in MFE systems
  — Provide thermal insulation to decouple LiPb bulk flow temperature from wall temperature
  — Provide additional corrosion resistance since only stagnant LiPb is in contact with the ferritic steel structural walls

DCLL concept used in several MFE designs (EU Demo, US Demo, ARIES-ST, ARIES-CS) and will be tested in ITER TBM
DCLL Configuration in HAPL Chamber

- Blanket designed to cover the entire vertical length of the chamber
- LiPb is admitted at bottom of blanket module, travels vertically upwards in a large channel behind FW, then makes a U turn at top, and travels down exiting the module on bottom. He coolant connections are also made on the bottom
- Toroidal channels are difficult to implement on the module extremities where it comes to a point. At those locations, at a distance of 2m from the ends, the cooling switches to vertical channels
- A horizontal manifold located near the FW feeds the vertical channels, which in turn exhaust into collector manifolds located at the sides of the module
Example Layout of Chamber with LiPb Blanket

Single module extends the full vertical length of the chamber
## Radial Build and Material Composition

<table>
<thead>
<tr>
<th>Zone</th>
<th>Description</th>
<th>Thick (mm)</th>
<th>% W</th>
<th>% FS</th>
<th>% LL</th>
<th>% SiC</th>
<th>% He</th>
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<tbody>
<tr>
<td>1</td>
<td>Armor</td>
<td>1</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>2</td>
<td>Front wall of FW</td>
<td>4</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>3</td>
<td>FW cooling channel</td>
<td>30</td>
<td>0</td>
<td>17</td>
<td>0</td>
<td>0</td>
<td>83</td>
</tr>
<tr>
<td>4</td>
<td>Back wall of FW</td>
<td>4</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>SiC insert 1</td>
<td>5</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>94</td>
<td>4</td>
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<tr>
<td>6</td>
<td>Front breeding channel</td>
<td>200</td>
<td>0</td>
<td>5</td>
<td>85</td>
<td>4</td>
<td>6</td>
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<tr>
<td>7</td>
<td>SiC insert 2</td>
<td>5</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>94</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>Flow divider plate</td>
<td>15</td>
<td>0</td>
<td>60</td>
<td>0</td>
<td>0</td>
<td>40</td>
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<tr>
<td>9</td>
<td>SiC insert 3</td>
<td>5</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>94</td>
<td>4</td>
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<tr>
<td>10</td>
<td>Back breeding channel</td>
<td>200</td>
<td>0</td>
<td>5</td>
<td>85</td>
<td>4</td>
<td>6</td>
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<tr>
<td>15</td>
<td>SiC insert 4</td>
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<td>0</td>
<td>2</td>
<td>0</td>
<td>94</td>
<td>4</td>
</tr>
<tr>
<td>16</td>
<td>Back wall</td>
<td>50</td>
<td>0</td>
<td>80</td>
<td>0</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>524</td>
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</table>

- Li in LL enriched to 90% $^6$Li

$TBR = 1.176$

Solid angle fraction subtended by beam ports is ~0.4% with minimal impact on overall TBR
Radial variation of nuclear heating (W/cm\(^3\)) determined in the components of the DCLL blanket

- Power density in W armor: 43.8 W/cm\(^3\)
- Peak power density in FS structure: 15.6 W/cm\(^3\)
- Peak power density in LiPb: 34.2 W/cm\(^3\)
- Peak power density in SiC FCI: 11.9 W/cm\(^3\)
Plant Thermal Power
for 1800 MW Fusion Power

Total Thermal Power = 2096 MW

- 1231 MW removed from blanket by LiPb
- 865 MW removed from blanket and VV by He
  - 742 MW from blanket (531 MW surface + 211 MW volumetric)
  - 123 MW from VV
Peak Radiation Damage in Blanket

<table>
<thead>
<tr>
<th></th>
<th>dpa/FPY</th>
<th>He appm/FPY</th>
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<tbody>
<tr>
<td>W armor</td>
<td>8.2</td>
<td>4.8</td>
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<tr>
<td>FW</td>
<td>26.3</td>
<td>174</td>
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</table>

Blanket lifetime is ~7.6 FPY

Peak EOL (40 FPY) Radiation Damage in 30 cm VV

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<th>dpa</th>
<th>He appm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front of VV</td>
<td>58</td>
<td>35.2</td>
</tr>
<tr>
<td>Back of VV</td>
<td>8.4</td>
<td>0.5</td>
</tr>
</tbody>
</table>

- VV is lifetime component
- Rewelding is possible at back of VV
Self-Cooled Li Blanket Configuration

1 mm W Armor

2 mm ODS FS Inner Wall

1 mm W Protection Layer

3.5 mm ODS FS

5 mm Li FW Channel

3.5 mm ODS FS

Large Li Inner Channel
Solid Breeder Blanket Configuration

Be Peeble Beds
Coolant Channel
First Wall
Stiffening Plate
Ceramic Pebble Beds
Inlet/Outlet Manifolds

Neutrons
# Comparison between Nuclear Performance of Li, SB, and LiPb Blankets in HAPL

<table>
<thead>
<tr>
<th></th>
<th>Li Blanket</th>
<th>SB Blanket</th>
<th>LiPb Blanket</th>
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<tbody>
<tr>
<td>Overall TBR</td>
<td>1.12</td>
<td>1.17</td>
<td>1.17</td>
</tr>
<tr>
<td>Blanket thickness (cm)</td>
<td>47</td>
<td>65</td>
<td>52</td>
</tr>
<tr>
<td>Total Thermal power (MW)</td>
<td>2103</td>
<td>2302</td>
<td>2096</td>
</tr>
<tr>
<td>(12% He)</td>
<td></td>
<td>(100% He)</td>
<td>(40% He)</td>
</tr>
<tr>
<td>Power density in FW structure (W/cm³)</td>
<td>13</td>
<td>20</td>
<td>16</td>
</tr>
<tr>
<td>Peak FS damage rate (dpa/FPY)</td>
<td>19</td>
<td>20</td>
<td>26</td>
</tr>
<tr>
<td>Peak EOL (40 FPY) dpa in VV</td>
<td>170</td>
<td>19</td>
<td>58</td>
</tr>
<tr>
<td>Blanket lifetime (FPY)</td>
<td>10</td>
<td>10</td>
<td>7</td>
</tr>
<tr>
<td>Required VV thickness (cm)</td>
<td>50</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Thermal Efficiency</td>
<td>~45%</td>
<td>~30-35%</td>
<td>~40-45%</td>
</tr>
</tbody>
</table>
Thicker SB blanket with significant amount of Be required for tritium breeding (due to low breeding capability of SB and large amount of structure needed)

The large amount of Be in SB blanket yields ~10% more thermal power and 20-40% higher power density in FW

While all of the thermal power is carried by He in the case of SB blanket, only 12%, and 40% is carried by He in cases of Li and LiPb blankets, respectively, with the rest carried by the breeder

While FW radiation damage is similar for Li and SB, it is about 30% higher for the LiPb blanket which is reflected in shorter blanket lifetime

Thicker VV is required with Li blanket (due to poor shielding capability of Li) to allow rewelding at back of VV

VV is a lifetime component in three cases but the margin is smaller for the Li blanket

Other considerations (material compatibility, safety, tritium retention/control, thermal efficiency, complexity, fabrication, weight, cost, development risk and R&D cost, …) should be accounted for in the blanket selection