Preliminary ARIES-RS-DCLL Radial Build for ASC

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Objectives

- Define preliminary radial builds for ARIES-RS with:
  - DCLL blanket and shield
  - LiPb/He Manifolds (tentative composition/dimension/location)
  - Stabilizing shells.

- Identify potential locations for stabilizing shells and feedback coils and assess impact on TBR, if any.

- Compare reference ARIES-RS with ARIES-RS-DCLL and highlight impact of DCLL system on overall design.
Fusion Power 2167 MW
Major Radius 5.52 m
Minor Radius 1.38 m
Peak $\Gamma$ @ IB, OB, Div 3.7, 5.6, 2.3 MW/m$^2$

V-4Cr-4Ti Structure
Li/V Blanket
2.5, 7.5, and 40 FPY Components
Discrete Li Manifolds
LT S/C Magnet @ 4 k
No W on FW

Calculated Overall TBR 1.1
$\eta_{th}$ 46%
Availability 76%

**Plasma Control:**
5 cm W Shells on IB
6 cm W Shells on OB
2 cm V Kink Shell behind OB FW
Design Requirements

Calculated Overall TBR* 1.1
Net TBR* (for T self-sufficiency) ~1.01

Damage to Structure
(for structural integrity)

Helium Production @ Manifolds and VV
(for reweldability of FS)

LT S/C Magnet (@ 4 K):
Peak Fast n fluence to Nb₃Sn (Eₙ > 0.1 MeV) 10¹⁹ n/cm²
Peak Nuclear heating 2 mW/cm³
Peak dpa to Cu stabilizer 6x10⁻³ dpa
Peak dose to electric insulator < 10¹¹ rads

Plant Lifetime 40 FPY
Availability 85%

Operational Dose to Workers and Public < 2.5 mrem/h
ARIES-RS Radial Builds: IB, OB, Div
(V Structure, Li Breeder, Li/He Coolants)
## Changes, Updates, and Assumptions

<table>
<thead>
<tr>
<th>ARIES-RS-Li/V (Reference Design)</th>
<th>ARIES-RS-DCLL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Peak NWL @ IB, OB, Div</strong></td>
<td>3.7, 5.6, 2.3 MW/m²</td>
</tr>
<tr>
<td><strong>Structure</strong></td>
<td>V-4Cr-4Ti and Tenelon</td>
</tr>
<tr>
<td><strong>Breeder and Enrichment</strong></td>
<td>Li natural</td>
</tr>
<tr>
<td><strong>OB blanket</strong></td>
<td>Two segments</td>
</tr>
<tr>
<td><strong>W shells:</strong></td>
<td>Between IB HT shield Segments</td>
</tr>
<tr>
<td><strong>Two 5-cm-thick W VS shells on IB:</strong> (toroidally continuous)</td>
<td>Between OB blanket &amp; HT Shield</td>
</tr>
<tr>
<td><strong>Two 6-cm-thick W VS shells on OB:</strong> (toroidally continuous)</td>
<td>2-cm-thick V Behind OB FW</td>
</tr>
<tr>
<td><strong>kink shell:</strong></td>
<td>(discrete)</td>
</tr>
<tr>
<td><strong>Breeder/coolant manifolds</strong></td>
<td>Discrete</td>
</tr>
<tr>
<td><strong>HT Shield coolant</strong></td>
<td>Li</td>
</tr>
<tr>
<td><strong>LT Shield coolant</strong></td>
<td>He</td>
</tr>
<tr>
<td><strong>VV coolant</strong></td>
<td>He</td>
</tr>
<tr>
<td><strong>Gaps between HT components</strong></td>
<td>2 cm</td>
</tr>
<tr>
<td><strong>VV model</strong></td>
<td>Homogeneous</td>
</tr>
<tr>
<td><strong>Cross section data library</strong></td>
<td>IAEA FENDL-2</td>
</tr>
</tbody>
</table>
Recommended ARIES-RS-DCLL
IB Radial Build (Peak $\Gamma = 3.7 \text{ MW/m}^2$)

- IB radial build increases by 12-17 cm.
- Upper/lower W VS shells could be placed between blanket & shield (50 cm from plasma).
- Shells embedded in replaceable shield ?!
- Shield will be segmented into replaceable and permanent components.
- Manifolds are reweldable at top/bottom, not around midplane.
Recommended ARIES-RS-DCLL
OB Radial Build (Peak $\Gamma = 5.6$ MW/m$^2$)
(Cross Section through Magnet*)

Reference ARIES-RS

ARIES-RS-DCLL

- OB radial build increases by 5-7 cm.
- Upper/lower W VS shells could be placed between blanket & shield (85 cm from plasma).
- Feedback coils could be placed behind manifolds (140 cm from plasma).

* Cross section between magnets TBD.
Optimization of VV Composition and Thickness

**Inboard VV**

- **Fluence**
- **Heating**

```
20 cm Thick VV
```

- Water Content in IB VV (%)
- Fluence Limit
- Heating Limit

Replacing WC or B-FS with H$_2$O

**Outboard VV**

- **Fluence**
- **Heating**

```
20 cm Thick VV
```

- Water Content in OB VV (%)
- Fluence Limit
- Heating Limit

Replacing WC or B-FS with H$_2$O
Recommended ARIES-RS-DCLL Divertor Radial Build (Peak $\Gamma = 2.3$ MW/m$^2$)

- 20 cm replaceable shield (every 6 FPY).
- 20 cm He manifolds.
- Div radial build decreases by 1-5 cm.

Reference ARIES-RS

ARIES-RS-DCLL
# Potential Locations for Stabilizing Shells and Feedback Coils

<table>
<thead>
<tr>
<th>Vertical Stabilizing Shells:</th>
<th>Reference</th>
<th>ARIES-RS-DCLL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inboard (between blanket and shield)</td>
<td>47</td>
<td>50 ?</td>
</tr>
<tr>
<td>Outboard (between blanket and shield)</td>
<td>61</td>
<td>85 ?</td>
</tr>
</tbody>
</table>

**Kink Shells:**

<table>
<thead>
<tr>
<th>Kink Shells:</th>
<th>Reference</th>
<th>ARIES-RS-DCLL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outboard</td>
<td>7</td>
<td>9 or 45 ?</td>
</tr>
<tr>
<td>(behind OB FW)</td>
<td>(behind OB FW or between blanket segments)</td>
<td></td>
</tr>
</tbody>
</table>

**Feedback Coils:**

<table>
<thead>
<tr>
<th>Feedback Coils:</th>
<th>Reference</th>
<th>ARIES-RS-DCLL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outboard</td>
<td>134</td>
<td>140 ?</td>
</tr>
<tr>
<td>(behind OB shield)</td>
<td>(behind OB manifolds)</td>
<td></td>
</tr>
</tbody>
</table>
Kink Shell Behind OB FW?

- Could Cu (or W) kink shell be placed behind OB FW?
- Integration of kink shell with blanket?
- Impact on breeding?

ARIES-RS-DCLL OB Blanket with kink shell behind FW

IB and/or OB Blanket should be thickened to compensate for breeding losses
Kink Shell Between OB Blanket Segments?

- Could OB blanket be segmented into two segments?
- **Benefits:**
  - Cu (or W) kink shell placed between OB blanket segments
  - Less integration problems
  - Less impact on breeding
  - Lifetime of back segment > 3 FPY (~15 FPY)
  - Notable reduction in lifecycle radwaste volume.
- If feasible, revisit ARIES-AT-DCLL? d/a ~ 0.35 for VS shells

ARIES-RS-DCLL OB Blanket
With Cu kink and VS shells between blanket segments
(blanket Temp < 700 °C)
## Impact of DCLL System on ARIES-RS Overall Design

<table>
<thead>
<tr>
<th></th>
<th>Reference ARIES-RS</th>
<th>ARIES-RS-DCLL</th>
</tr>
</thead>
<tbody>
<tr>
<td>IB, OB, Div radial standoff*</td>
<td>173, 214, 183</td>
<td>185, 219, 178</td>
</tr>
<tr>
<td>Limit for max NWL (m)</td>
<td>~ 6</td>
<td>&lt; 5.5 ?</td>
</tr>
<tr>
<td>R (m)</td>
<td>5.52</td>
<td>&gt; 5.52</td>
</tr>
<tr>
<td>Overall energy multiplication</td>
<td>1.2</td>
<td>~ 1.15</td>
</tr>
<tr>
<td>$\eta_{th}$</td>
<td>46%</td>
<td>40–45%</td>
</tr>
<tr>
<td>Structure unit cost#</td>
<td>300 $/kg of V</td>
<td>~ 60 $/kg of FS</td>
</tr>
<tr>
<td>Blanket/divertor/shield/manifolds cost*</td>
<td>~ $80M</td>
<td>&lt; $80M</td>
</tr>
<tr>
<td>Cost* of heat transfer/transport system</td>
<td>$260M</td>
<td>$400-500M</td>
</tr>
<tr>
<td>Pumping power</td>
<td>12 MW$_e$</td>
<td>~ 150 MW$_e$</td>
</tr>
<tr>
<td>LSA factor</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Cost of Electricity#</td>
<td>76 mills/kWh</td>
<td>&gt; 76 mills/kWh</td>
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</table>

**Maintenance approach**

Sector Maintenance

(with coolant pipes attached at bottom)

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* Excluding gaps.


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Observations:

- DCLL system increases IB and OB radial standoff
- Kink shell degrades breeding
- Resistivity increases with neutron fluence. Impact on stabilizing shell parameters?

To do:

- Adjust blanket dimensions to accommodate kink shell and estimate TBR for one OB blanket segment or two, if feasible
- Assess breeding potential with < 90% enrichment. This may require fairly thick IB and OB blankets. Impact on locations of vertical stabilizing shell and feedback coils?
- Divide IB shield into replaceable and permanent components to minimize radwaste stream
- Provide OB radial build for Xn between magnets for ASC
- Pay special attention to location and configuration of He-access pipes for upper/lower divertors
- Surround pumping ducts with penetration shield to limit radiation damage at VV and magnet.

Need:

- Info on new fluence limit for Nb₃Sn and reference
- Physics parameters for ARIES-RS-DCLL system to estimate peak IB and OB NWL
- Locations of kink shells, vertical stabilizing shells, and feedback coils
- Blanket composition
- Size, composition, and location of manifolds.