Preliminary ARIES-RS-DCLL Radial Build for ASC

L. El-Guebaly
Fusion Technology Institute
University of Wisconsin - Madison
http://fti.neep.wisc.edu/UWNeutronicsCenterOfExcellence

Contributors:
C. Kessel (PPPL), S. Malang, R. Raffray (UCSD)

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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.
ARIES-RS Reference Design
ARIES-RS Reference Design (Cont.)

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)*: 200 dpa - advanced FS or V

**Helium Production @ Manifolds and VV** *(for reweldability of FS)*: 1 He appm

**LT S/C Magnet (@ 4 K):**
- Peak Fast n **fluence** to Nb₃Sn *(Eₙ > 0.1 MeV)*: \(10^{19}\) n/cm²
- Peak Nuclear **heating**: 2 mW/cm³
- Peak **dpa** to Cu stabilizer: \(6 \times 10^{-3}\) dpa
- Peak **dose** to electric insulator: < \(10^{11}\) 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></th>
<th>ARIES-RS-Li/V (Reference Design)</th>
<th>ARIES-RS-DCLL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak NWL @ IB, OB, Div</td>
<td>3.7, 5.6, 2.3 MW/m²</td>
<td>3.7, 5.6, 2.3 MW/m² (to be updated)</td>
</tr>
<tr>
<td>Structure</td>
<td>V-4Cr-4Ti and Tenelon</td>
<td>MF82H FS</td>
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<tr>
<td>Breeder and Enrichment</td>
<td>Li natural</td>
<td>LiPb 90% (or less)</td>
</tr>
<tr>
<td>OB blanket</td>
<td>Two segments</td>
<td>One segment ?</td>
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<tr>
<td>W shells:</td>
<td></td>
<td></td>
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<tr>
<td>Two 5-cm-thick W VS shells on IB: (toroidally continuous)</td>
<td>Between IB HT shield Segments</td>
<td>Between IB blanket &amp; shield ?</td>
</tr>
<tr>
<td>Two 6-cm-thick W VS shells on OB: (toroidally continuous)</td>
<td>Between OB blanket &amp; HT Shield</td>
<td>Behind OB blanket ?</td>
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<tr>
<td>kink shell:</td>
<td>2-cm-thick V Behind OB FW</td>
<td>Thin Cu shell behind OB FW ?</td>
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<tr>
<td>Breeder/coolant manifolds</td>
<td>Discrete</td>
<td>Toroidally continuous:</td>
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<tr>
<td></td>
<td></td>
<td>25 cm He/LiPb manifolds for IB blanket &amp; shield</td>
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<td></td>
<td></td>
<td>35 cm He/LiPb manifolds for OB blanket &amp; shield</td>
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<td></td>
<td></td>
<td>20 cm He manifolds for divertor shield</td>
</tr>
<tr>
<td>HT Shield coolant</td>
<td>Li</td>
<td>He</td>
</tr>
<tr>
<td>LT Shield coolant</td>
<td>He</td>
<td>---</td>
</tr>
<tr>
<td>VV coolant</td>
<td>He</td>
<td>H₂O</td>
</tr>
<tr>
<td>Gaps between HT components</td>
<td>2 cm</td>
<td>---</td>
</tr>
<tr>
<td>VV model</td>
<td>Homogeneous</td>
<td>Heterogeneous with 2-cm-thick plates</td>
</tr>
<tr>
<td>Cross section data library</td>
<td>IAEA FENDL-2</td>
<td>IAEA FENDL-2.1</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 $\Gamma = 5.6 \text{ MW/m}^2$)
(Cross Section through Magnet*)

- 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**

- Peak Fluence or Peak Heating vs. Water Content in IB VV
- Fluence and Heating Limits
- 40% H_2O, 57% WC

**Outboard VV**

- Peak Fluence or Peak Heating vs. Water Content in OB VV
- Fluence and Heating Limits
- 60% H_2O, 23% B-FS

Replacing WC or B-FS with H_2O
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>Distance from Plasma (cm)</th>
<th>Reference</th>
<th>ARIES-RS-DCLL</th>
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<tbody>
<tr>
<td></td>
<td>ARIES-RS</td>
<td>ARIES-RS-DCLL</td>
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</table>

**Vertical Stabilizing Shells:**
- **Inboard** (between blanket and shield)
  - Distance: **47 cm**
- **Outboard** (between blanket and shield)
  - Distance: **61 cm**

**Kink Shells:**
- **Outboard**
  - Distance: **7 cm**
  - (behind OB FW)

**Feedback Coils:**
- **Outboard**
  - Distance: **134 cm**
  - (behind OB shield)

- Distance: **140 cm**
  - (behind OB manifolds)
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>
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</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>$\eta_{\text{th}}$</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>
</tr>
<tr>
<td>Maintenance approach</td>
<td>Sector Maintenance</td>
<td>?</td>
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* Excluding gaps.


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**Note:**

- Sector Maintenance (with coolant pipes attached at bottom)
Observations, Future Work, and Needed Info

**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 Nb$_3$Sn 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.