Preliminary ARIES-AT-DCLL
Radial Build for ASC

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Objectives

• Define preliminary radial builds for ARIES-AT-DCLL with:
  – Stabilizing shells
  – LiPb/He Manifolds (tentative composition/dimension/location).

• Highlight impact of DCLL system and stabilizing shells on ARIES-AT engineering and physics.
ARIES-AT Reference Design

- Fusion Power: 1755 MW
- Major Radius: 5.2 m
- Minor Radius: 1.3 m
- Peak $\Gamma$ @ IB, OB, Div: 3.1, 4.8, 2 MW/m$^2$

- SiC/SiC Composite Structure
- LiPb/SiC Blanket
- Discrete LiPb Manifolds
- HT S/C Magnet @ 70-80 K
- No W on FW

- Calculated Overall TBR: 1.1
- $\eta_{th}$: ~ 60%
- Availability: 85%

- Plasma Control:
  - 5 W Shells on IB and OB
  - 2 Vertical Position Coils
  - 2 Feedback Coils
ARIES-AT Radial Builds: IB, OB, Div (SiC Structure)
## Changes, Updates, and Assumptions

<table>
<thead>
<tr>
<th></th>
<th>ARIES-AT-LiPb/SiC (Reference Design)</th>
<th>ARIES-AT-DCLL</th>
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<tbody>
<tr>
<td><strong>Peak NWL @ IB, OB, Div</strong></td>
<td>3.1, 4.8, 2 MW/m²</td>
<td>3.1, 4.8, 2 MW/m² (to be updated)</td>
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<tr>
<td><strong>FS structure</strong></td>
<td>ORNL FS</td>
<td>MF82H FS</td>
</tr>
<tr>
<td><strong>LiPb:</strong></td>
<td></td>
<td></td>
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<tr>
<td>Li enrichment</td>
<td>90%</td>
<td>90% or less</td>
</tr>
<tr>
<td>Average temp</td>
<td>700 °C</td>
<td>~580 °C</td>
</tr>
<tr>
<td>Density</td>
<td>8.8 g/cc</td>
<td>9 g/cc</td>
</tr>
<tr>
<td><strong>OB blanket</strong></td>
<td>Two segments</td>
<td>One segment</td>
</tr>
<tr>
<td><strong>LiPb/He manifolds:</strong></td>
<td>Discrete</td>
<td>Assumed toroidally continuous in OB and Div regions</td>
</tr>
<tr>
<td>W shells:</td>
<td></td>
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<tr>
<td>Two 4-cm-thick VS shells on IB:</td>
<td>Between IB blanket &amp; shield</td>
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<tr>
<td>(toroidally continuous)</td>
<td></td>
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<tr>
<td>Two 4-cm-thick VS shells on OB:</td>
<td>Between OB blanket segments</td>
<td>Behind OB blanket (or use FS cooling channels of blanket)</td>
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<tr>
<td>(toroidally continuous)</td>
<td></td>
<td>FW could serve as RWM shell</td>
</tr>
<tr>
<td>1-cm-thick RWM shell on OB:</td>
<td>Between OB blanket segments</td>
<td></td>
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<tr>
<td>(discrete)</td>
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<td></td>
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<tr>
<td><strong>Shield coolant</strong></td>
<td>LiPb</td>
<td>He</td>
</tr>
<tr>
<td><strong>IB Blanket-shield gap</strong></td>
<td>1 cm</td>
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<tr>
<td><strong>VV model</strong></td>
<td>Homogeneous</td>
<td>Heterogeneous with 2-cm-thick plates</td>
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<td><strong>TF &amp; PF magnets</strong></td>
<td>YBCO HT S/C</td>
<td>Nb₃Sn LT S/C</td>
</tr>
<tr>
<td><strong>Cross section data library</strong></td>
<td>IAEA FENDL-2</td>
<td>IAEA FENDL-2.1</td>
</tr>
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</table>
Recommended ARIES-AT-DCLL
IB Radial Build

- No LiPb/He Manifolds on IB.
- Upper/lower W Shells located between Blanket & Shield.
Recommended ARIES-AT-DCLL OB Radial Build
(Cross Section through Magnet*)

- 35 cm LiPb/He Manifolds placed behind shield (thickness/composition to be updated by Rene/Siegfried).
- Upper/lower W Shells located between Blanket & Shield.
- Could FW serve as RWM (kink) shell? Thickness? Impact on TBR?

* Cross section between magnet TBD.
35 cm LiPb/He Manifolds located behind shield (thickness/composition to be updated by Rene/Siegfried).
Impact of Stabilizing Shell Location on ARIES-AT Physics

- Preliminary assessment on stability and control without much detailed analysis.

- For vertical stability, parameters of interest is distance of stabilizing shell from plasma boundary normalized to minor radius (a=1.3 m), and growth rate of instability that must be restrained by feedback coils behind shield/manifolds.

- In reference ARIES-AT:
  - IB stabilizers $d/a = 0.31$
  - OB stabilizers $d/a = 0.28$
    $\Rightarrow$ Plasma elongation $= 2.2$ and significant increase in beta
    $\Rightarrow$ Feedback coils behind OB shield (@ 96 cm from plasma boundary)

- In ARIES-AT-DCLL (assuming shells between blanket and Shield):
  - IB stabilizers $d/a = 0.38$
  - OB stabilizers $d/a = 0.65$ <-- too high!
    $\Rightarrow$ Plasma elongation $= 1.5 - 1.6$ – unacceptable
  Assuming feedback coils at same normalized location as in reference ARIES-AT (meaning coils embedded in shield!).
  - Impacts on physics and design of placing feedback coils outside manifolds (@ 140 cm from plasma) need to be assessed.
Impact of Stabilizing Shell Location on ARIES-AT Physics (Cont.)

- **For RWM (kink stability)**, 3.8 cm FS/He FW (containing 1.3 cm FS) will probably be adequate to slow the resistive wall mode down for feedback control.
  (Laila: scaling from 2 cm V kink shell of ARIES-RS ⇒ ~5 cm FS kink shell ⇒ Breeding problem)

- **Steel vs Tungsten Kink Shell:**
  - Steels have resistivity ~12 times higher than W (and 50 times higher than Cu).
  - FS do **not** slow down plasma as efficiently as W.
  - This means **voltage and power** required for feedback system will be **360 MVA** (12 times higher than 30 MVA of reference ARIES-AT).
  - 360 MVA is **very high** regardless of the fact that it is mostly reactive power.

**Overall conclusions:**

- FS RWM (kink) shell requires **very high voltage and power** for feedback system (360 MVA).
- 5 cm thick FS RWM shell @ FW degrades TBR significantly. May examine Cu or W shell behind FW.
- Locating vertical stabilizing shell outside OB blanket results in major hit to plasma operating point and is probably **unacceptable**.
- This assessment assumes same geometry for plasma, which may **not** be the case.
Feasibility of using FS Cooling Channels for Plasma Stabilization

- Can central cooling channel be modified and connected from module to module (as in ARIES-AT) to create toroidally continuous stabilizing shell?
- If so, d/a = 0.35 for ARIES-CS-DCLL – much better than 0.65 for shell outside 80 cm blanket.
- Could modified cooling channel be moved 5 cm inward to attain d/a = 0.31?
- Thickness of steel shell >> thickness of W shell.
- Impact on TBR of modified cooling channel should be assessed.
Observations:

– LiPb/He manifolds increase radial standoff and should **not** be placed at IB.
– Initial assessment indicated **unacceptable physics parameters** for locating W stabilizing shells outside OB blanket.
– **Steel RWM (kink) shell** requires very **high voltage/power** (360 MVA) and fairly thick steel (~5 cm). This may not be economically acceptable and will degrade TBR significantly.

Questions:

– Could central 1.5 cm FS/He cooling channel within blanket be modified and connected toroidally to serve as vertical stabilizing shells?
– Does modified cooling channel call for more steel? If yes, more steel will degrade TBR.
– Could feedback coils be embedded in OB shield? If not, impacts on physics and design of placing coils outside manifolds should be assessed.
– Do W, Cu, and FS resistivities increase with neutron fluence? If so, assess impact on shell parameters.

To do:

– Replace HT YBCO TF/PF magnets by LT Nb₃Sn magnet.
– Breeding with < 90% enrichment (for larger breeding margin) will be assessed. It may require fairly thick IB and OB blankets. Impact on stabilizing shells and physics?
– OB radial build for Xn between magnets will be provided.
– **IB replaceable shield** will be divided into replaceable and permanent components to minimize radwaste stream.
– **Boride material** will be added to OB VV to reduce magnet heating and activation.
– **Penetration shield** should surround pumping ducts to limit radiation damage at VV and magnet.
– **NWL distribution** will be updated using actual neutron source profile within plasma, per Wilson (UW).

Needs:

– Practical solutions for RWM shells, vertical stabilizing shells, and feedback coils.
– Compositions of LT **magnets and** coil cases.
– Size, composition, and location of **manifolds**.