ARIES-AT
MATERIAL OPTIONS FOR STABILIZING SHELLS

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Subjects Covered

- Material options for the ARIES-AT stabilizing shells
- Properties such as resistivity, thickness, with and without cladding and mass per toroidal cm, as functions of temperature
- Cooling options
- Recommendations
Material Options for Stabilizing Shells

Requirement as specified by C. Kessel (PPPL):

Assuming 400 C the required thickness for W is 5.5 cm to keep plasma vertical instability growth time in the right range.

What are the options

Tungsten: High temperature refractory metal, high resistivity, high density ($\rho = 19.3$ g/cm$^3$), potential for radiative cooling

Aluminum: Low temperature in solid form, high temperature in liquid form, liquid form resistivity comparable to W, low density ($\rho = 2.7$ g/cm$^3$), requires a cladding material in case of LOCA/LOFA

Copper: High temperature both solid and liquid form, resistivity lowest of all, roughly 50% of Al and much lower than W, medium density ($\rho = 8.9$ g/cm$^3$), in solid form suffers from radiation embrittlement, and resistivity increase with radiation, may require cladding in case of LOCA/LOFA
Electrical Resistivities of solid W and solid and liquid Al and Cu as functions of Temp.

[Graph showing electrical resistivities of Tungsten, Al (solid), Al (liquid), Cu (solid), and Cu (liquid) as functions of temperature]
Thicknesses of Stabilizing Shells Exclusive of Cladding Material

Temperature (°C)

Thickness of Stabilizing Shell (cm)

- Tungsten
- Al (liq.)
- Cu (liq.)
- Al (sol.)
- Cu (sol.)
Overall Thickness of Stabilizing Shells with a 3 mm Cladding Thickness on the Al and Cu
Mass of Stabilizing Shells (Kg) per Toroidal cm Including Mass of W Cladding

Temperature (C)

Mass of each shell per toroidal cm (Kg)

Tungsten
Cu (liq.)
Cu (sol.)
Al (sol.)
Al (liq.)
<table>
<thead>
<tr>
<th>Material</th>
<th>Temp. Range (C)</th>
<th>Shell Thickness w/o Cladding (cm)</th>
<th>Cladding Required</th>
<th>Shell Thickness w/ Cladding (cm)</th>
<th>Mass of Shell kg/cm (tor)</th>
<th>Cooling Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tungsten</td>
<td>200 – 1400</td>
<td>4.0 – 17.5</td>
<td>No</td>
<td>N/A</td>
<td>11.0 – 50.0</td>
<td>Water cooling, He or LiPb cooling, Radiative cooling possible</td>
</tr>
<tr>
<td>Aluminum</td>
<td>200 – 600</td>
<td>2.0 – 3.8</td>
<td>Yes</td>
<td>2.6 – 4.4</td>
<td>2.2 – 3.2</td>
<td>Water cooling, He or LiPb cooling</td>
</tr>
<tr>
<td></td>
<td>(Liquid)</td>
<td>N/A</td>
<td>Yes</td>
<td>9.2</td>
<td>6.2</td>
<td>He or LiPb cooling</td>
</tr>
<tr>
<td></td>
<td>700</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Compatible with W or Mo cladding up to 700 C</td>
</tr>
<tr>
<td>Copper</td>
<td>200 – 1000</td>
<td>N/A</td>
<td>Yes</td>
<td>1.7 – 4.0</td>
<td>3 – 6.2</td>
<td>Water cooling, He or LiPb cooling</td>
</tr>
<tr>
<td></td>
<td>(Liquid)</td>
<td>N/A</td>
<td>Yes</td>
<td>8.0 – 8.5</td>
<td>10.8 – 11.2</td>
<td>He or LiPb cooling, Compatible with Mo cladding up to 1300 C</td>
</tr>
<tr>
<td></td>
<td>1100 – 1300</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Radiative cooling possible</td>
</tr>
</tbody>
</table>
**Recommendation**

**First Option:**

- Liquid Cu in Mo cladding at 1300 C. Mo tubes cooled with He or LiPb. Investigate radiative cooling. 8.5 cm thick and 11.2 kg/tor·cm.

Radiation effect: Ni has a melting point of 1455 C and Co 1495 C. Zr has a liquid density of 6.48 g/cm$^3$ compared with Cu which is 8.2 g/cm$^3$. Ni and Co will precipitate as solids and Zn will segregate by gravity. With the absence of these transmutants, the resistivity will not change.

**Second option:**

- W at low temp. 200 C – water cooled, 4 cm thick, 11 kg/tor·cm
  400 C – He cooled, 6.1 cm thick, 17.5 kg/tor·cm