Electrical Resistivity Changes with Neutron Irradiation and Implications for W Stabilizing Shells

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Why Tungsten Shell?

• Per Kessel:
  (Shell thickness (in cm) / Resistivity (in Ohm.cm)) > 15,000
• **Tungsten**: preferred material for ARIES stabilizing shells:
  • Reasonable resistivity ($\rho$) and shell thickness (~0.08 cm for $\rho$ = 5.4 micro Ohm.cm @ RT)
  • High temperature operation (800 - 1200°C)
  • No active cooling
    ⇒ radiate heat to surrounding blanket and shield
    ⇒ simple shell design.
  • Impact on tritium breeding depends on shell location within blanket.
Concerns

• W resistivity increases with:
  – Temperature
  – Neutron irradiation.

• Higher resistivity means thicker stabilizing shell.

• Concerns:
  – Impact on TBR
  – Temperature gradient within shell
  – Thermal stresses
  – Feasibility of radiative cooling?
Unirradiated W:
Variation of Resistivity with Temperature

- Electric resistivity of **unirradiated** W is well established.
- W resistivity (in micro Ohm.cm):
  \[ \rho_W = 4.8 \left( 1 + 4.8297 \times 10^{-3} T + 1.1663 \times 10^{-6} T^2 \right) \]
  for \( 25^\circ C < T < 625^\circ C \)

At 1000\(^\circ\)C, \( \rho_W \) increases 6 times, requiring \(~0.5\) cm thick W shell (\(> 0.08\) cm thick shell at RT).

Tungsten Composition Changes with Neutron Irradiation

- Some W atoms transmute into Re, Ta, Os, and other radioisotopes (see my 5/2010 presentation).
- Transmutation level depends on irradiation time and neutron spectrum (hard near FW or soft behind blanket).
- Example of W transmutations: W armor of ARIES divertor:

  Main transmutation products (Re, Ta, and Os) will increase W electrical resistivity further, requiring thicker W shell.
Variation of Resistivity of Transmutation Products with Temperature

- W, Re, Os, Ta resistivities (in micro Ohm.cm):
  - W: \( \rho_W = 4.8\ (1 + 4.8297e^{-3}\ T + 1.1663e^{-6}\ T^2) \) for \( 25^\circ C < T < 625^\circ C \)
  - Re: \( \rho_{Re} = 17.7\ (1 + 4.5585e^{-3}\ T + 1.2447e^{-6}\ T^2) \) for \( 25^\circ C < T < 900^\circ C \)
  - Os: \( \rho_{Os} = 9.49\ (1 + 4.425e^{-3}\ T) \) for \( 0^\circ C < T < 100^\circ C \)
  - Ta: \( \rho_{Ta} = 12.45\ (1 + 3.83e^{-3}\ T) \) - Ref. 2 - for \( 25^\circ C < T < 100^\circ C \)

Notes:
- Errors in Billone’s memo: marked in red

W and Re exhibit parabolic variations with temperature.

Linear variations assumed for Ta and Os at \( T > 100^\circ C \). Parabolic variation yields higher resistivity.

Q: How much Re, Ta, and Os in W shell?
Re, Ta, Os Atomic Fractions Estimated using ALARA Activation Code

- **Two locations** examined for W shells in ARIES-DB:
  I- 0.5 cm thick W shell behind OB FW
  II- 0.5 cm thick W shell between OB blanket segments.

- **Two lifetimes** considered: **3.4 FPY** and **40 FPY**.

Ave. OB NWL 
~ 4 MW/m²

![Diagram showing different components and locations](image_url)
Transmutation Products in ARIES-DB W Shell

- **W Shell-I (behind FW)** generates **highest** transmutation products.
- Transmutation products **build up with irradiation time**.
Change of W Electrical Resistivity with Transmutation Products

- Experimental data for irradiated W with 14 MeV neutrons does not exist.

- **Per Billone**, electrical resistivity of irradiated W can be estimated by *law of mixtures*:

\[ \rho = f_W \rho_W + f_{Re} \rho_{Re} + f_{Ta} \rho_{Ta} + f_{Os} \rho_{Os} \]

where \( f \) = atomic fraction.
Change of W Shell Resistivity with Irradiation and Temperature

W Shell-I behind OB FW

W Shell-II between OB Blanket Segments
Impact of Change in W Resistivity on W Shell Thickness

\[ \Delta_{\text{shell}} = 15,000 \rho_{\text{shell}} \]

W Shell-I behind OB FW

W Shell-II between OB Blanket Segments
Could LiPb Serve as Stabilizing Shell?

• At 700 °C, $\rho_{LiPb} \sim 150$ micro Ohm.cm* $\Rightarrow$ 2-3 cm LiPb

Options:
– Encase 2-3 cm thick LiPb in FS structure to serve as stabilizing shell
– Cool FS structure with He to remove nuclear heating
– Place LiPb Kink shell behind FW to enhance physics
– T removal in batch process
– Flowing LiPb?
– Start with solid LiPb?

UW experimental Na loop at Forest’s lab could assess feasibility.

* U.Jauch, G.Haase, B.Schulz, Thermophysical properties of Li(17)Pb(83) eutectic alloy, KFK 4144 (1986).
Conclusions

- **W shell thickness** should reflect change in resistivity with temperature and irradiation.

- **Change due temperature** is dominant.

- **Kink shell behind FW** offers physics advantages, but exhibits largest change in resistivity.

- **TBD**: Impact of shell on ARIES-DB TBR.
  Need location and thickness of both shells.

- **Q**: Could “2-3 cm LiPb encased in FS structure” serve as stabilizing shell?