Temperature Evolution and Light Species Diffusion in Armor and Structural Material for Inertial Fusion Reactor Chambers: a Case for HiPER 4a

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We study the thermo-mechanical response and diffusion of tritium in tungsten coated steels and tungsten coated aluminum under HiPER 4a scenario (bunch of 5 shock ignitions 48 MJ in 10 seconds, 0.5 Hz).

Thermo-mechanical response

Finite element solver ASTER CODE is used to estimate temperature, stresses and deformation in the first wall.

Temporal evolution of the temperature at different depths (\(d\)) in a 1 mm W armor attached to 1 cm SS316 structural material.

• The \(T_{\text{max}}\) < 1400 K on the inner surface is below W melting point.
• \(T\) at the armor-structural interface (\(d=1000 \mu m\)) increases with the number of pulses.
• After 5 pulses \(T\) decreases to RT in hundreds of seconds.

Because of geometrical conditions, the local increase of \(T\) generates material expansion with compression stresses tangential to the radiation direction.

Temporal evolution of longitudinal deformation (\(\epsilon_{\text{xx}}\)) estimated at different depths (W@1mm, SS316 structural material@1cm).

• For \(d < 20 \mu m\) W plastically deforms near the inner surface suffering compression-traction stress cycles. After 5 pulses \(\epsilon_{\text{xx}}\) ≠ 0
• For \(d > 20 \mu m\) material elastically deforms. After 5 pulses \(\epsilon_{\text{xx}}\) = 0

Because of the different expansion coefficient of each material, there is a discontinuity in the tangential stress (\(\Delta\sigma\)) at the junction interface.

Temporal evolution of discontinuity in \(\Delta\sigma\), at the junction for different W armor thickness attached to 1cm SS316

Reducing W thickness increases \(\Delta\sigma\)
• \(\Delta\sigma\) can be diminished by selecting structural materials with:
  o lower expansion coefficient (steel F82H)
  o high thermal conductivity (AI5657)

Tritium diffusion in the first wall

TMAP7 software is used to estimate diffusion of implanted tritium in the first wall. General equations for atomic diffusion into materials and recombination at the surfaces have been used.

• Tritium inventory increases with pulse number (~10^{12} at/m² per pulse).
• 24 hours after the last shot, 98% of tritium escapes to the chamber.

• 10 s after the first shot a Tritium inventory of 6.28 \times 10^{12} at/m² is located at a d < 10 \mu m in W.
• 24 hours after the last shot a Tritium inventory of 1.29 \times 10^{16} at/m² is located at a d < 400 \mu m in W.

Conclusions

The first wall of the reactor chamber can survive the HiPER 4a conditions.

Thermo-mechanical and diffusion of tritium studies show that:
• \(T_{\text{max}}\) at inner surface are below melting point of W.
• To avoid plasticization in structural material the W thickness should be larger than 20 \mu m.
• Discontinuity in the tangential stress at interface is a key parameter to define armor thickness and the structural material type.
• Tritium accumulation in reactor chamber is well below regulations.
• Further calculations are needed to analyze diffusion into structural material.

REFERENCES:

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