He-cooled Divertor: Study on Low-Temperature Design Using Ta Alloy as Thimble Material

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Reference design HEMJ [1] (Fig. 1)

- Nominal heat flux 10 MW/m^2.
- Cooling: impinging multiple helium jets (10 MPa, 600°C).
- Hex. W tile (18mm A/F) brazed to WL10 thimble (Ø15 x 1 mm), joined with ODS Eurofer back bone structure.

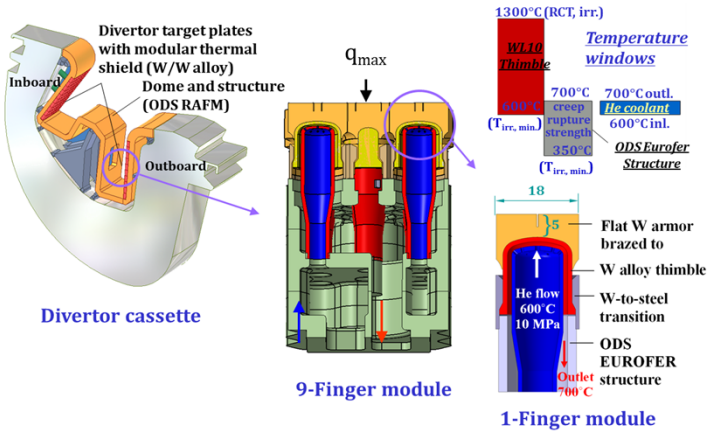


Fig. 1: Reference HEMJ design: Heat removal by helium jet impingement (10 MPa, 600 ° C)

Problem: unknown irradiated data for W materials

Material	DBTT$_{unirr.}$ (°C)	ΔDBTT @ dpa/T$_{irr.}$ (°C)	T$_{irr.,\ \Delta DBTT,\ minor}$ * (°C)
Eurofer [3]	-90	235 @ 70/330	350
W [4]	~650 (rod, Ø20 mm)	unknown	unknown
WL10 [4]	400–450 (rod, Ø20 mm)	unknown	unknown
T-111 [2]	-190	unknown	unknown

*above which only minor DBTT shift is expected

Alternative HEMJ design with T-111 thimble (Fig. 2)

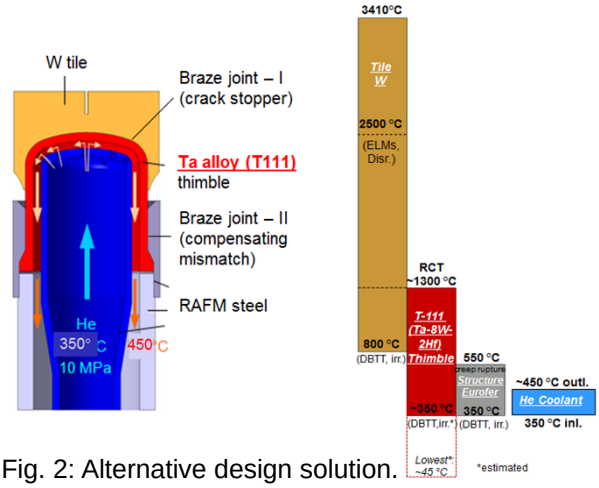


Fig. 2: Alternative design solution.

[1] P. Norajitra et al., Fusion Eng. Des. 83 (2008) 893–902.
[2] NASA Technical Note, NASA TN D-5873, Survey of Properties of T-111.
[3] E. Gaganidze et al, J. Nucl. Mater. 355 (2006) 83–88.
[4] M. Rieth, http://bibliothek.fzk.de/zb/veroeff/79094.pdf, http://bibliothek.fzk.de/zb/veroeff/81120.pdf, retrieved 03.06.2013.

Advantages of T-111 [2] as alternative thimble material

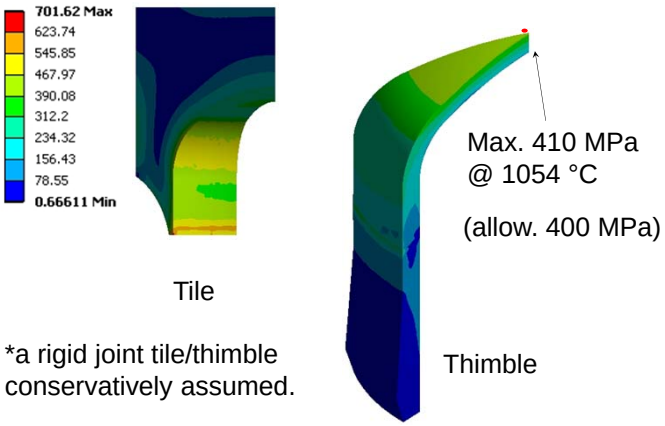
- High creep resistant at T ~ 980 – 1310 °C.
- Extremely low DBTT of -196 °C.
- Good formability and weldability.
- Corrosion resistance to liquid alkali metals (Li, Na, K).

Design Verification by CFD and FEM Analyses

Table 1: Boundary conditions (top) and result summary (bottom) of CFD analysis.

	Reference case (Thimble WL10)	Thimble T-111
Mass flow rate per finger (g/s)	6.8	6.8
He inlet temperature (°C)	634	350
He pressure (MPa)	10	10
He density (kg/m^3)	5.2	7.0
Heat flux (MW/m^2)	10	10
Volumetric heat generation (MW/m^3)	17	17

	Reference case (Thimble WL10)	Thimble T-111
Max. tile temp. (°C)	1783	1606
Max. thimble temp. (°C)	1201	1055
He outlet temp. (°C)	712	429
Max. He velocity (m/s)	245	~170
Pressure loss (MPa)	0.12	0.08



*a rigid joint tile/thimble conservatively assumed.

Fig. 3: Von Mises equivalent stress* (MPa) by ANSYS for T-111 case, (heat flux 10 MW/m^2, T$_{He}$ 350 ° C).

Conclusion

- An alternative solution with T-111 material may satisfy the requirements on the ductility of thimble structure.
- The chosen coolant temperature of 350 °C allows for the simplistic application of Eurofer base material instead of ODS Eurofer.