EX/P5–24

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Power Handling of the Tungsten Divertor in JET

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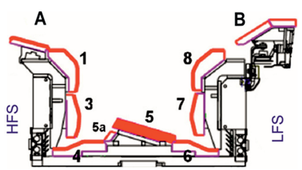
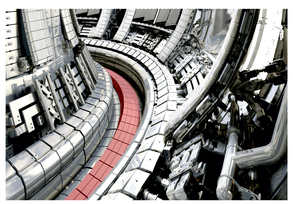
See the Appendix of F. Romanelli et al., Proceedings of the 24th IAEA Fusion Energy Conference 2012, San Diego, USA

1 Introduction

The divertor of the new JET ITER-like Wall (ILW) currently includes tiles of carbon fibre composites (CFC) coated with tungsten and a solid tungsten row (tile 5) [1] in the outer strike point region (OSP) – indicated in red colour below.



The new divertor coating configuration is as follows: Tiles A, 3, 4, 5a –12 µm Mo/W. Tiles 1, 6, 7 and 8 –25 µm Mo/W or Mo/W/Mo/W. Mo layers are ~2µm thick in all cases



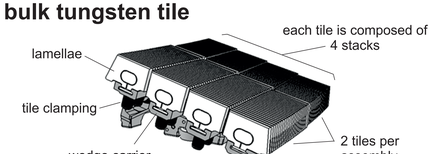
Virtual reality view of the new divertor: the bulk W row is indicated in red

The divertor was designed for power flux densities up to 7 MW/m^2 (on average) and a maximal deposited energy density on the solid tungsten row of 60 MJ/m^2.

2 Coated tiles

- Coating by combined magnetron sputtering and ion implantation (CMSII) in argon
- Low risk of delamination (<1% area) below T_{surf} <1200°C and carbidisation is negligible
- The coatings were tested in the GLADIS (ion beam) and JUDITH (e$^-$ beam) facilities

3 The bulk tungsten tile

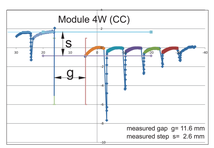


- 48 assemblies of 192 lamellae each. One tile (2 of them per assembly) is composed of 4 stacks aligned with the toroidal direction. Lamella shape (plasma-facing surface) and tilts of stacks to ensure appropriate shadowing
- Operational limit for the temperature of the plasma-facing surface initially set to 1200°C to avoid appreciable grain growth and effects of thermal fatigue, now released to the nominal value ($T_{W,surf} \leq$ 2200°C) with budgetting (4 classes)

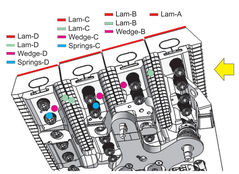
3 The bulk tungsten tile *(continued)*

- Successful installation at JET: tight tolerances for the more than 9000 lamellae of the castellated bulk W design (vertical deviations to neighbours: $\Delta z \leq 150\mu m$ in the torus)
- No leading edges between solid tungsten tiles or even single lamellae: dedicated experiments down to $q_{95} \geq 2.45$: magnetic field scans from B_T= 2.0 T down to B_T= 1.27 T (wetted area on a stack from about f_{wet} = 0.67 (16/24) to f_{wet} = 0.96 (23/24).

Gap Gun (laser) survey in torus



4 Experimental

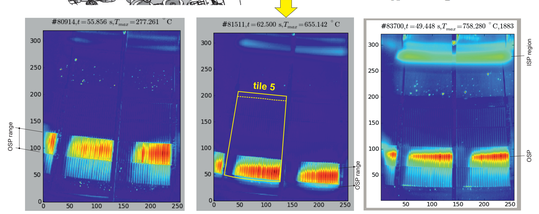


Thermocouple locations in the torus (KD1D)

Top views with infrared camera (KL9B)

Emissivity: $\varepsilon_W \simeq$ 0.18-0.60

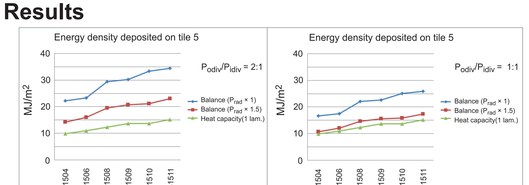
Thermal impact: $\frac{q_0}{A}\sqrt{t} = \frac{\Delta T}{2}\sqrt{\pi k \rho C}$



JPN 80914 (3MW ICRF)-stack C | JPN 81511 (4.5MW NBI)-stack D | JPN 83700 (12MW NBI)-stack C

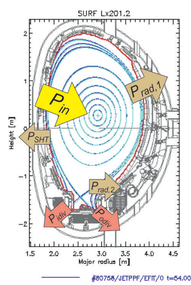
Infrared camera(s) – esp. KL9B (Octant 8)

5 Results



NB pulses with both ISP and OSP on the vertical targets tend to confirm a 2:1 power sharing between the legs

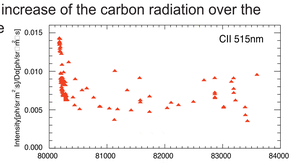
5 Results *(continued)*



- Power balance with corrections in the order of 10%; deposited energies in the outer divertor ~ 20-30 MJ/m^2

Coatings:

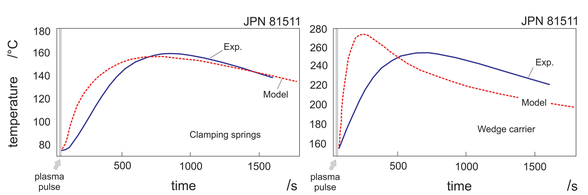
- Neither Ar traces in the discharge are of concern (<2% at. in the layers), nor the W-radiation events observed (~ Ø100 µm particles penetrate the main plasma) which become scarce;
- No significant increase of the carbon radiation over the campaign; see P5-04 and [2] for details



- No damage detected during campaigns C28-C30. Inspections with IVIS (In vessel Inspection System) have not revealed any definitive evidence of delamination. Hot spots seen on the coated tiles are believed to be debris from other sources but tiny blister-like damages cannot be fully ruled out.

Bulk W tile:

- Experimental behaviour close to design values, e.g. T_{surf} <1100°C for power to the outer strike point 5-10MW/m^2, E_{dep} =20-30 MJ/m^2



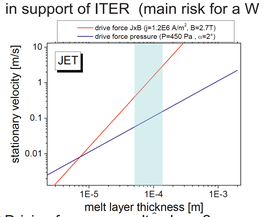
(Highest permitted load determined in the first place by the carrier)

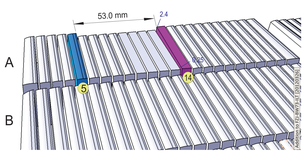
- No damage of divertor tiles observed.
- Sweeping over 2 stacks of the segmented tile effective for spreading out the load.
- Impurity seeding is another technique to lower the load on the divertor targets that will be applied in the next campaign.

6 Melt experiment *(contribution to the decision on the day 1 divertor in ITER)*

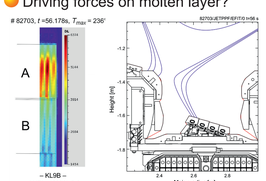
- Special design installed to expose leading edges and investigate deliberate melting in support of ITER (main risk for a W divertor [3]).

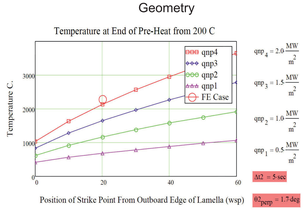
Vertical step ≥ 0.3mm





- Driving forces on molten layer?





Operation on 'stack A' Unique: Melting in 2 steps, steady state pre-heating + large ELMs

- Evolution of melt damage and power handling? The dedicated experiment planned in JET may provide *in fine* a significant contribution to the decision on a full W divertor [3] from the very beginning in ITER.

7 Conclusions

- The divertor tiles perform very closely to the design specifications (to $T_{surf} \leq$1200°C for the coatings / for the bulk material: $P \leq$9MW/m^2 and, so far, $E_{dep} \leq$35MJ/m^2, pulses up to 20s). No significant damage was detected, neither on the coatings, nor on the solid tungsten row.
- Full exploitation of the divertor will start in the next campaign (2013).
- The experimental behaviour of the row of bulk tungsten tiles during plasma operation is close to design values in a wide range of operational parameters with deposited energy densities around and slightly above 30 MJ/m^2.
- Tile 5 is designed for a maximum local temperature of the plasma-facing tungsten of 2200°C and a maximal energy deposition of 60 MJ/m^2 (+0/-10%).

[1] Ph. Mertens et al., Physica Scripta **T145** (2011) 014002 (7pp)
[2] S. Brezinsek, PSI-2012, submitted to J. Nucl. Mat.
[3] R. Pitts, PSI-2012, submitted to J. Nucl. Mat.

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