First observations of tungsten PFCs after the first phase of operation of the WEST tokamak

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CONTEXT
WEST tokamak operation with tungsten plasma facing components (PFCs)

► W coated PFCs (inertial & actively cooled)
Qualification and validation according to spec. (i.e. HIF tests up to 10MW/m²)

► Bulk W ITER-like PFCs (actively cooled)
Installed onto one sector of the lower div. sector Non-beveled PFCs

- 6 PFUs during C1 & C2 (ASIPP, JADA)
- 12 PFUs during C3 (ASIPP, JADA, F4E)
PFUs not vertically aligned within ITER spec. (max $m_{ap}=0.8$ mm)
- 14 PFUs during C4 (ASIPP, JADA, F4E)
4 PFUs with unchamfered edges
1 intentionally-damaged PFU
1 PFU dedicated to melting experiment PFUs vertically aligned within spec.

INSPCTION OF THE W-COATED PFCs

► Lower divertor (W/Mo coated graphite)
Coating delamination observed on the trailing edges of the tiles after C2 -> disruptions

After 3 years of operation, the plasma pattern was clearly visible on the tiles. No surface alteration was detected.

WEST phase II: will be replaced by ITER-like PFUs

INSPCTION OF BULK W ITER-LIKE PFUs

► Erosion/deposition pattern clearly identified
Cracks observed on every misaligned PFU with ISP/OSP exposed leading edge. Some cracks formed during C3, some others during C4

► A change of surface morphology appeared near the exposed leading edge (OSP only). This was also detected by IR camera during operation [A. Grosjean et al., Nucl. Mat. And Energy 27, 2021]

CONCLUSION

- A new design of the outer limiter was developed for C4. W-coated tiles were replaced by bulk W tiles to resist against impacts of runaway electrons.
- No major damage was observed on the W-coated PFCs after 3 years of operation. Only localized coating delamination occurred due to transient events or arcing. Erosion and reposition mechanisms have been evidenced on the W-coated graphite tiles of the lower divertor (post-mortem analyses).
- Cracks, OHS and melting were observed on misaligned ITER-like PFUs, likely caused by disruptions. It did not hamper the operation. The damage observed after C3 barely evolved during C4. The new divertor with beveled PFUs is under installation in WEST.

WE S T O P E R A T I O N

<table>
<thead>
<tr>
<th>No pulse</th>
<th>Nb pulse</th>
<th>Ml. exposed</th>
<th>Swell</th>
<th>Swell max</th>
<th>Dursat max</th>
<th>Contal</th>
<th>Contal avg</th>
<th>Dursat avg</th>
<th>W of total</th>
<th>W of total</th>
<th>Echo</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1/C2</td>
<td>Oct. 2017</td>
<td>1283</td>
<td>716</td>
<td>56%</td>
<td>805</td>
<td>10.5</td>
<td>1553</td>
<td>282</td>
<td>76%</td>
<td>95.5</td>
<td>0</td>
</tr>
<tr>
<td>C3</td>
<td>Jul.-Oct.</td>
<td>1304</td>
<td>1010</td>
<td>82%</td>
<td>818</td>
<td>37.5</td>
<td>7302</td>
<td>730</td>
<td>74%</td>
<td>4947</td>
<td>105</td>
</tr>
<tr>
<td>C4a</td>
<td>Jul.-Aug.</td>
<td>1257</td>
<td>1157</td>
<td>91%</td>
<td>1204</td>
<td>55</td>
<td>5968</td>
<td>755</td>
<td>72%</td>
<td>7823</td>
<td>1128</td>
</tr>
<tr>
<td>C4b</td>
<td>Sep.-Nov.</td>
<td>372</td>
<td>345</td>
<td>85%</td>
<td>309</td>
<td>29</td>
<td>1991</td>
<td>375</td>
<td>94%</td>
<td>4300</td>
<td>3</td>
</tr>
<tr>
<td>All</td>
<td></td>
<td>4216</td>
<td>3294</td>
<td>78%</td>
<td>1004</td>
<td>55</td>
<td>21514</td>
<td>2042</td>
<td>17185</td>
<td>1247</td>
<td>13</td>
</tr>
</tbody>
</table>

- 6h of plasma exposure, including 45 min in He
- Max plasma duration =1min
- Significant use of boronization during C4
- Divertor peak flux 5MW/m² but large number of transients

INSPCTION OF BULK W ITER-LIKE PFUs

► PFU with sharp poloidal edges – comparison of damage after C3 / after C4

<table>
<thead>
<tr>
<th>C3</th>
<th>C4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toroidal position on the sector</td>
<td>#12</td>
</tr>
<tr>
<td>Vertical misalignment with upstream PFU(OSP)</td>
<td>$m_{ap}=0.8$ mm</td>
</tr>
<tr>
<td>Bulk W melting event</td>
<td>Impact of RE on the trailing edge of MB14-17 during C3. Did not evolve during C4</td>
</tr>
<tr>
<td>Optical hot spots (OHS) on the exposed poloidal edges</td>
<td>Position of the OHS and melting are in good correlation with PFUs vertical and radial misalignments</td>
</tr>
<tr>
<td>Cracks on the top surface</td>
<td>Cracks still visible but did not propagate further during C4</td>
</tr>
</tbody>
</table>

WEST phase II: new design under investigation

► Baffle, Inner bumpers, upper divertor Pattern of the plasma clearly visible on the PFCs, but no major damage observed despite 30min operation on the upper divertor