

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

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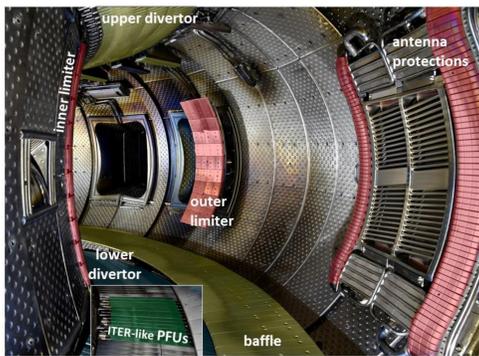
CONTEXT

WEST tokamak operation with tungsten plasma facing components (PFCs)

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

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

- 6 PFUs during C1 & C2 (ASIPP, JADA)
- 12 PFUs during C3 (ASIPP, JADA, F4E)
PFUs not vertically aligned within ITER spec. (max m_{PFU} =0.8mm)
- 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.



■ W/Mo coated CFC ■ W/Mo coated graphite ■ W coated CuCrZr
■ Bulk W

WEST OPERATION

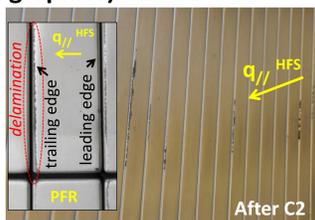
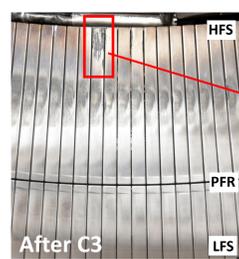
	Nb pulses	Nb Plasma	Sustained	Ip max (kA)	Duration max (s)	Cumul (s)	Disrupti ons	Disrupti vity	W LH total (MJ)	W IC total (MJ)	Boro
C1/C2 Oct. 2017 - Feb. 2018	1283	716	56%	805	10.5	1553	282	76%	95.5	0	0
C3 Jul.-Dec.18	1304	1076	82%	818	37.5	7302 (≈2h)	730	74%	4947	105	3
C4a D2 Jul.-Aug19	1257	1157	92%	1004	55	9968 (≈2h45)	755	71%	7823	1139	5
C4b He Sep.-Nov.19	372	345	83%	709	29	2991 (≈50min)	275	96%	4300	3	8
All	4216	3294	78%	1004	55	21814 (≈6h)	2042		17165	1247	13

- ≈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

INSPECTION OF THE W-COATED PFCs

► **Lower divertor (W/Mo coated graphite)**

Coating delamination observed on the trailing edges of the tiles after C2 → disruptions



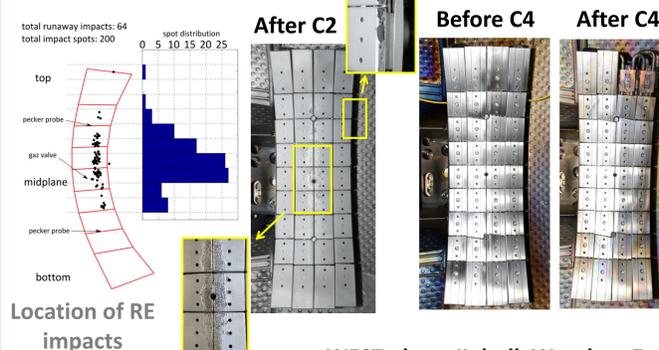
Impact of arcs lead to the delamination of the coating on the HFS of the tiles

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

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

► **Outer limiter (W/Mo coated CFC then bulk W)**

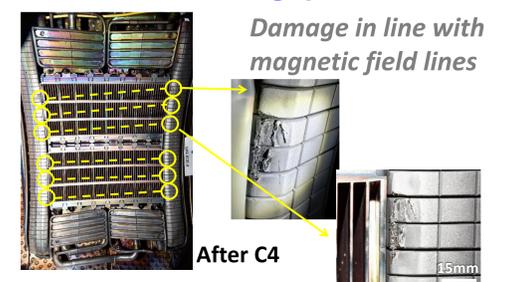
W coating delamination and W melting were observed after C2 and C3 due to impacts of runaway electrons in the absence of a control scheme (C2, C3). For C4, bulk W tiles were developed and proved to be a robust solution.



WEST phase II: bulk W or low-Z BN tiles. Under discussion

► **Antenna protections (W/Mo coated CFC)**

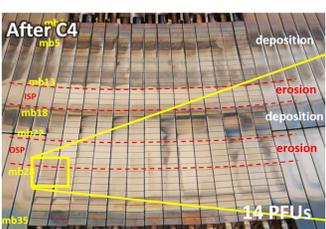
Damage observed on the antenna protections due to arcing after C4.



WEST phase II: new design under investigation

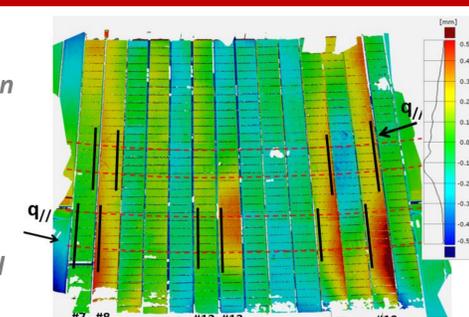
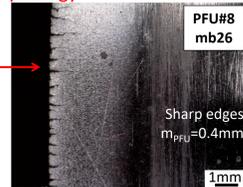
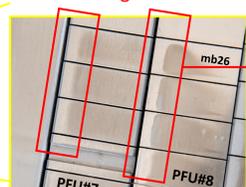
► **Baffle, Inner bumpers, upper divertor**
Pattern of the plasma clearly visible on the PFCs but **no major damage** observed despite 30min operation on the upper divertor

INSPECTION OF BULK W ITER-LIKE PFUs



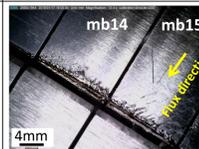
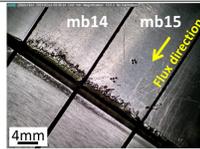
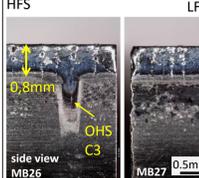
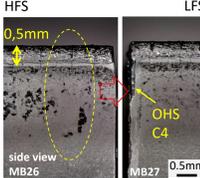
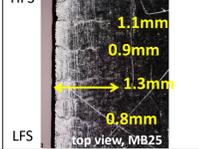
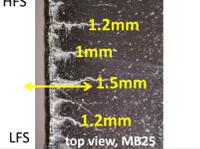
- Erosion/deposition pattern clearly identified
- Cracks observed on every misaligned PFU with ISP/OSP exposed leading edge. Some cracks formed during C3, some others during C4
- A change of surface morphology appeared near the exposed leading edge (OSP only). This was also detected by IR camera during operation [A. Grosjean et al., Nuc. Mat. And Energy 27, 2021]

Change of surface morphology



Metrology map obtained by laser scanning showing the relative misalignments of the PFUs with their theoretical position (CAO model) during C4. The black lines indicate the cracks location

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

	C3	C4
Toroidal position on the sector	#12	#8 (max outer flux)
Vertical misalignment with upstream PFU(OSP)	m_{PFU} =0.8mm	m_{PFU} =0.4mm
Bulk W melting event Impact of RE on the trailing edge of MB14-17 during C3. Did not evolve during C4.		
Optical hot spots (OHS) on the exposed poloidal edges Position of the OHS and melting are in good correlation with PFUs vertical and radial misalignments		
Cracks on the top surface Cracks still visible but did not propagate further during C4		

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.