WEST wall conditioning operation : baking, glow discharges, impurity powder dropper

A. Gallo, K. Afonin, T. Alarcon, V. Anzallo, E. Caprin,
M. De Combarieu, D. Douai, Ph. Moreau, F-P. Pellissier,
G. Bodner, A. Diallo, R. Lunsford, A. Nagy, the WEST team.

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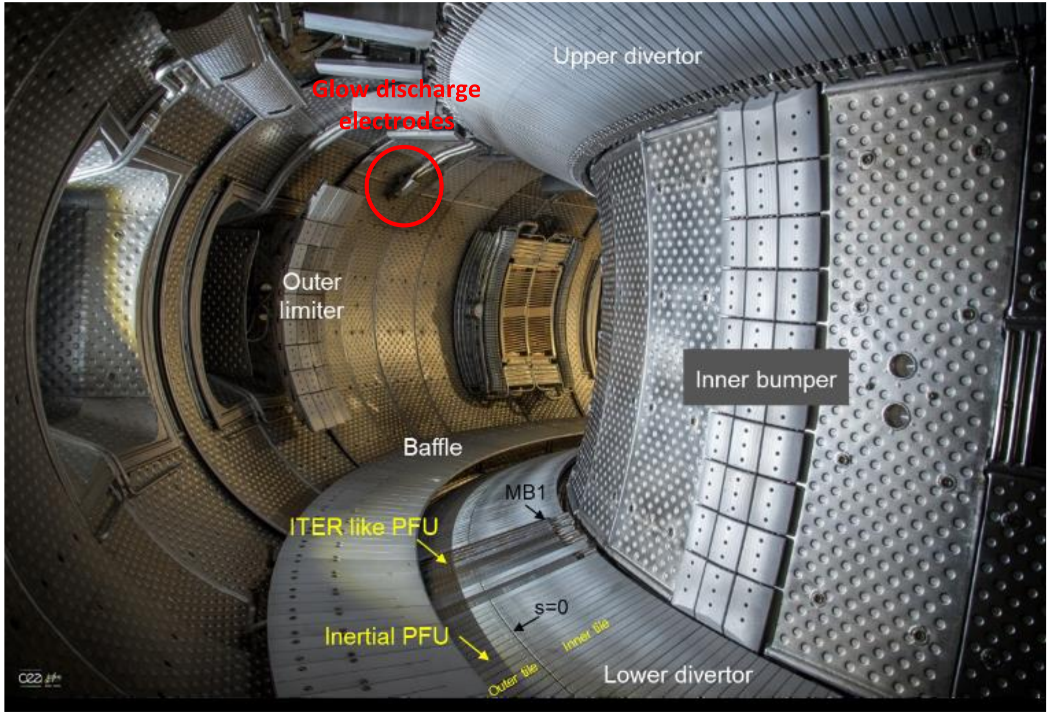
Three (+ one) methods for wall conditioning of WEST

- Baking

- Glow discharge cleaning

- Glow discharge boronization

- Impurity powder dropper



WEST vacuum vessel baked at (up to) $200\ ^\circ\mathrm{C}$

Baking = heating of VV to outgas impurities trapped into/onto FIW and PFCs

==> first, mandatory step after closing VV and pumping down (10^{-5} Pa)

In WEST temperature of PFCs can be ramped from $20\ ^\circ\mathrm{C}$ to $200\ ^\circ\mathrm{C}$ in ~ 50 h via pressurized water cooling loop B30 (ramping max $\sim 7\ ^\circ\mathrm{C/h}$ up, $\sim 10\ ^\circ\mathrm{C/h}$ down)

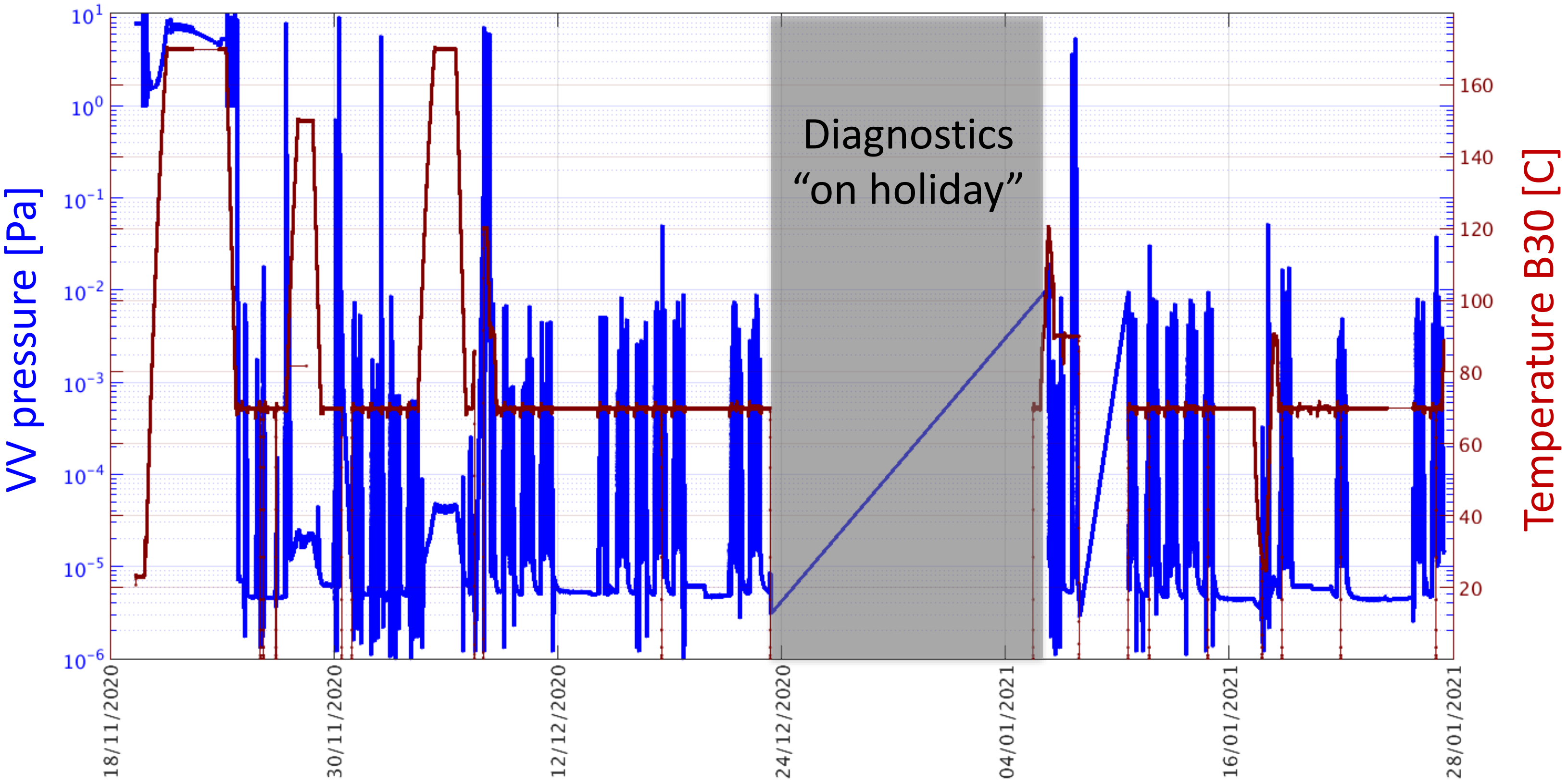
==> During C5 $T_{\mathrm{bake}}^{\mathrm{max}} = 170\ ^\circ\mathrm{C}$ due to minor leaks, C6 goal $T_{\mathrm{bake}}^{\mathrm{max}} = 200\ ^\circ\mathrm{C}$

In parallel, electrical baking via 36 heating cables with $P = 36$ kW each, following set point of water cooling loop B30

Monitoring of baking operations: 24 TC installed on the FIW + 2 midplane QMS

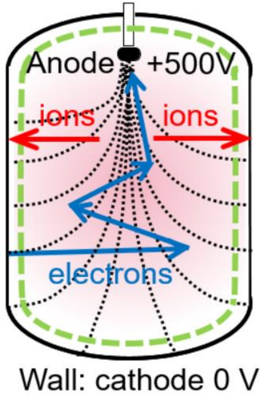
VV = Vacuum Vessel, FIW = First Internal Wall, PFCs = Plasma Facing Components, TC = ThermoCouples, QMS = Quadrupole Mass Spectrometers

Example: baking cycles during WEST campaign 5



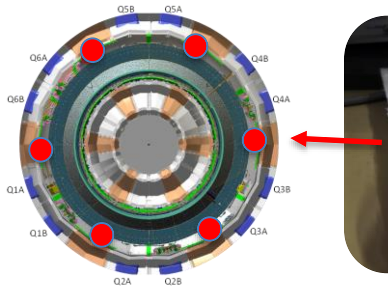
Renewed glow discharge system in WEST

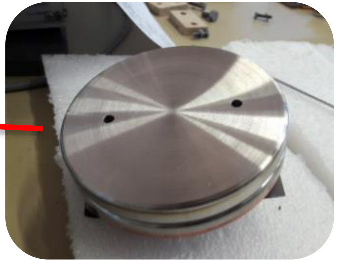
Glow Discharge Cleaning (GDC) = potential difference between VV and six anodes in a D_2 or He atmosphere without a magnetic field ==> sputtering of FIW, PFCs by ions accelerated in potential sheath



- Helps plasma initiation and density control by reducing fuel desorption from VV during plasma discharges
- Mitigates impurity content (O, C, N, …) and radiation losses by removing re/co-deposited layers from surfaces

Six glow electrodes on LFS protection panels: new electrode design installed and tested in C5 improved lifetime and current equipartition





Example: impurity content reduced through D_2 GDC

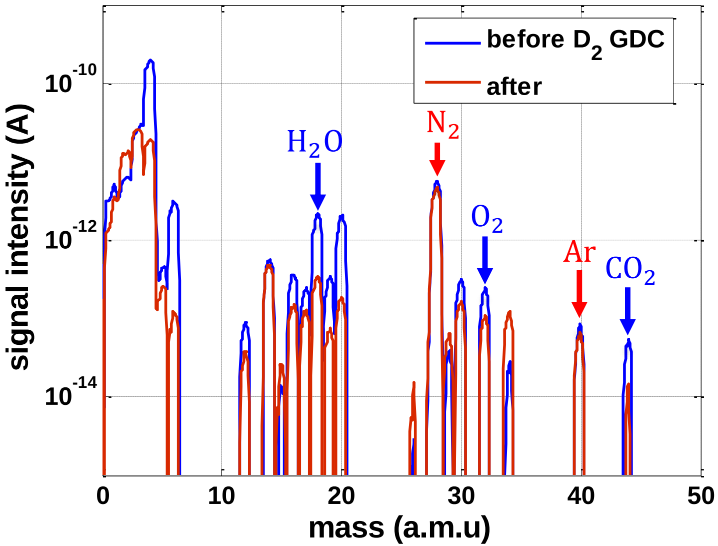
Typical GDC parameters in WEST:

- D_2 torus pressure $= 0.3 - 0.4$ Pa
- Glow current $= 4 - 6$ A
- Glow voltage $= 500 - 600$ V
- Toroidal current < 50 A

Requirements to start GDC:

- majority of H_2 ($p_{H_2} > p_{H_2O}$)
- $p_{H_2O} < 5 \times 10^{-4}$ Pa to avoid oxygen re-implantation

Midplane mass spectrometer

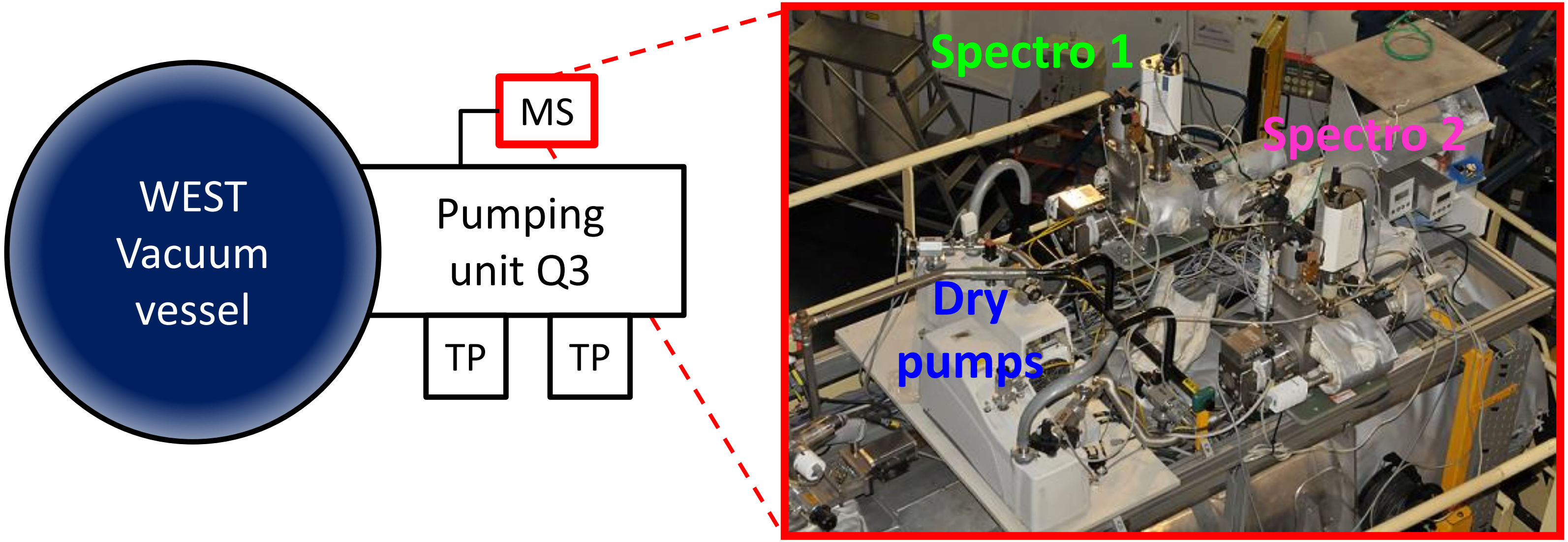


Reduction of masses 18, 32, 44

Masses 28, 40 same ==> air leak

WEST mass spectrometer: experimental setup

Two mass spectrometers (Pfeiffer PRISMA QMS 200) in midplane pumping unit Q3: distinguish species via m/Z ratio using quadrupole filter and channeltron analyzer

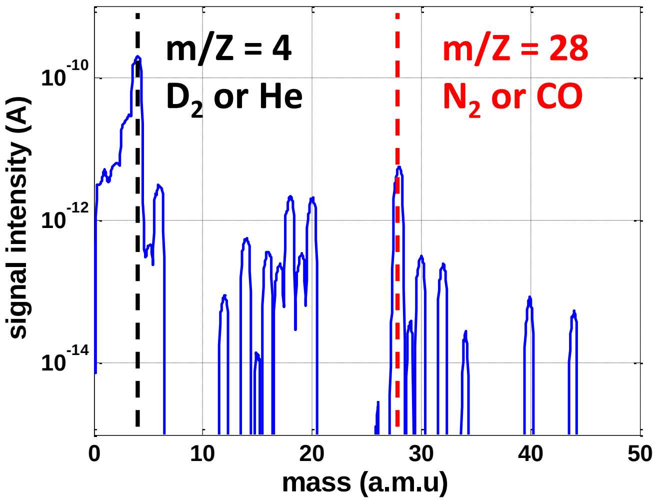


Goal: characterize vessel vacuum during conditioning and plasma operations

WEST mass spectrometry: deliverables (and not)

Species identification based on mass/charge ratio:

- from 1 to 200 amu
- up to 41 masses simultaneously monitored
- mass resolution < 1 amu
- time resolution ~10 s (better if less masses)



Disclaimers:

- species with same m/Z cannot be directly distinguished
- spectrometers not absolutely calibrated: only qualitative/relative information
- unphysical signals from Spectro1 in C5, Spectro2 currently being replaced
- pollution of spectrometer cannot be trivially disentangled from machine signals

Example: D_2 GDC summary in conditioning database

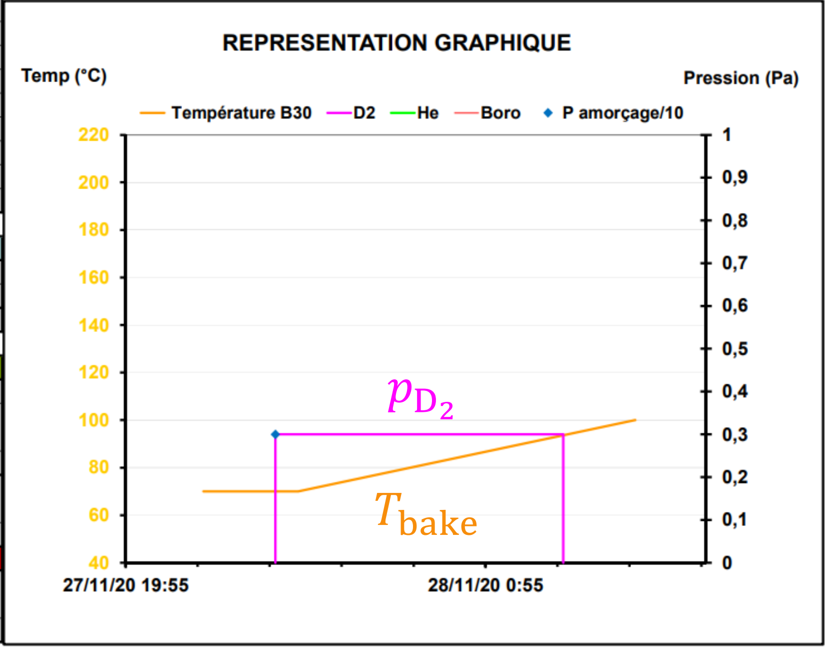
For each GDC:

- Gas type
- Duration
- Injection rate
- Pressure
- Gas consumption
- Electrode current
- B30 temperature

DECHARGES LUMINESCENTES de CONDITIONNEMENT (DLC)										
SPECTROS	Température B30		D2		He		Boro		P amorçage/10	
Acquisition	Date	temp. (°C)	Date	P (Pa)	Date	P (Pa)	Date	P (Pa)	Pirani ☑ Baratron ☑	
Spectro 1 OK ☑	27/11/20 21:00	70	27/11/20 22:00	0,3	23/11/20 9:10	0	23/11/20 9:10	0		
Spectro 2 OK ☑	27/11/20 22:19	70	28/11/20 2:00	0,3	23/11/20 9:10	0	23/11/20 9:10	0	Date	P (Pa)
Spectro MKS OK ☐	28/11/20 3:00	100	☑ DUREE (h):	4:00:00	☐ DUREE (h):	0:00:00	☐ DUREE (h):	0:00:00	27/11/20 22:00	3
Remarques: ☐										

ALIMENTATIONS ELECTRIQUES						
Consigne courant:	Alim. N°1			Alim. N°2		
	3A			2A		
Electrodes utilisées:	1A	3A	5A	2A	4A	6A

STATION DE GAZ:		
GAZ	PRESSIONS (b)	CONSO (b/h)
D2 début:	147,4	
D2 fin:	143,3	
B50 conso D2:	4,1	1,02
He début:		
He fin:		
B50 consom. He:	0	0,00
CASEMATE DIBORANE: B8 à 15% B2D6		
B2D6 début:		
B2D6 fin:		
consom. B2D6 :	0	0,00



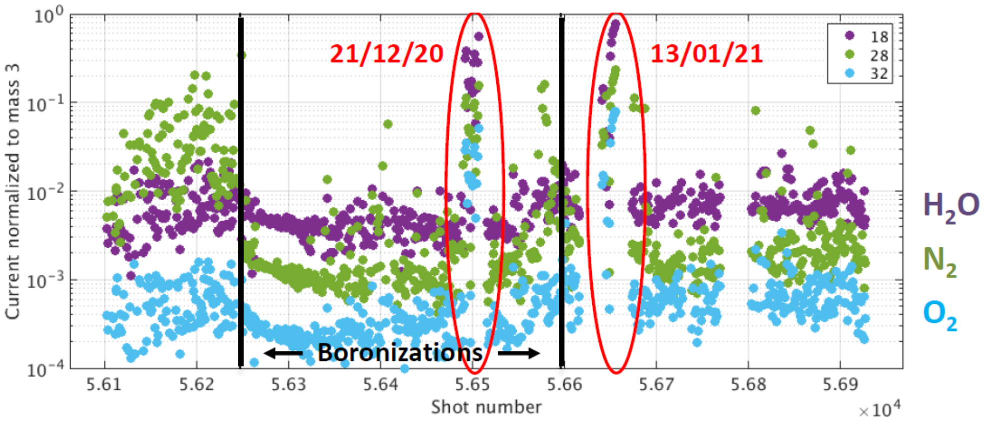
Glow discharge boronization: opens operational space

Glow discharge boronization (GDB) re-introduced during WEST campaign 3 after initially trying to avoid B to have real all-W machine (nobody managed)

- GDB dramatically widened operational space (n) by reducing O, C, N et cetera

- Aggressively performed in campaign 4 to reduce f_{rad} and increase T_{core}, P_{sep}

- **Necessary in campaign 5 to perform plasma discharges:** mitigated strong outgassing of newly installed BN tiles at in/outboard OMP limiters



OMP = Outer MidPlane

Example: B_2D_6 GDB summary in "Conditioning History"

GDB = same as GDC but using a B_2D_6-He 15%-85% gas mixture

Preceded and followed by He-only GDC phase:

1) He cleans surfaces

2) B_2D_6 creates B-rich layers filled with D_2

3) He removes some D_2

DECHARGES LUMINESCENTES de CONDITIONNEMENT (DLC)

SPECTROS		Température B30		D2		He		Boro	
Acquisition		Date	temp. (°C)	Date	P (Pa)	Date	P (Pa)	Date	P (Pa)
Spectro 1 OK	☑	8/12/20 7:17	120	8/12/20 8:17	0,3	8/12/20 8:17	0,35	8/12/20 10:00	0,5
Spectro 2 OK	☑	8/12/20 12:40	120	8/12/20 8:17	0,3	8/12/20 9:27	0,35	8/12/20 14:30	0,5
Spectro MKS OK	☐	8/12/20 16:15	90	☐ DUREE (h):	0:00:00	☑ DUREE (h):	1:10:00	☑ DUREE (h):	4:30:00
Remarques:	☐	8/12/20 17:15	90						
	☐								

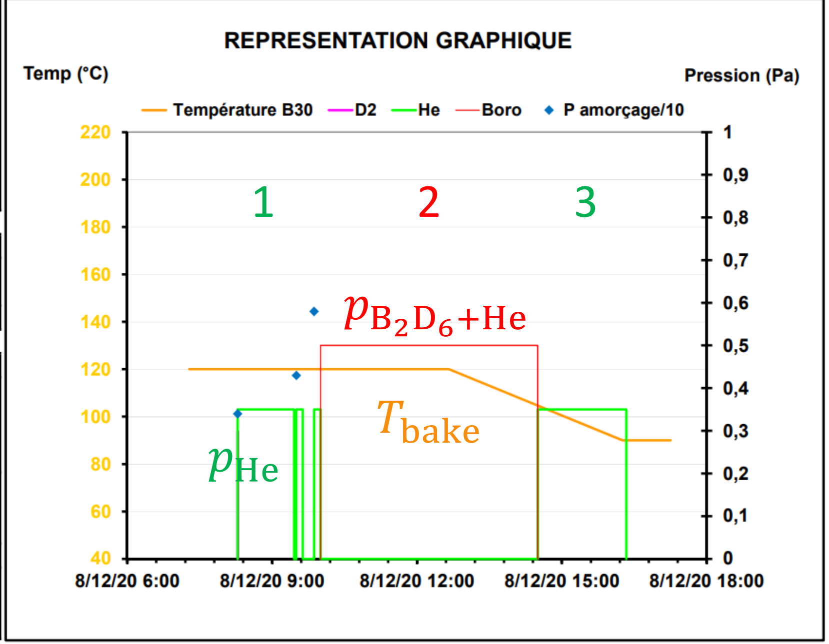
P amorçage/10	
Pirani	☑
Baratron	☑
Date	P (Pa)
8/12/20 8:17	3,4

ALIMENTATIONS ELECTRIQUES

Consigne courant:	Alim. N°1			Alim. N°2		
	3A			2A		
Electrodes utilisées:	1A	3A	5A	2A	4A	~~6A~~

STATION DE GAZ:

GAZ	PRESSIONS (b)	CONSO (b/h)
D2 début:	0	
D2 fin:	0	
B50 conso D2:	0	0,00
He début:	87	
He fin:	81	
B50 consom. He:	6	5,14
CASEMATE DIBORANE: B8 à 15% B2D6		
B2D6 début:	20	
B2D6 fin:	10	
consom. B2D6 :	10	2,22



Real-time wall conditioning with powder dropper

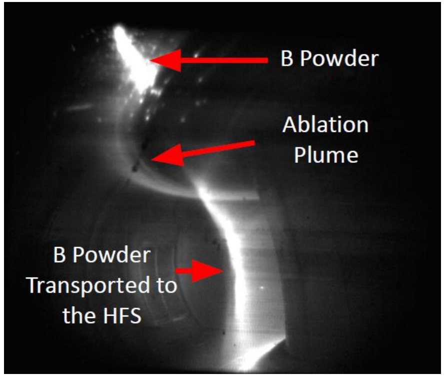
Impurity Powder Dropper (IPD) by PPPL first deployed in C5 (2021)

[A. Nagy, RSI, 2018]
[A. Bortolon, NME, 2019]

Scientific goal: study effect of B powder dropping on conditioning of WEST plasma-facing components in long pulses

Experimental strategy:

- B powder dropped in 10 LSN, L-mode WEST discharges
- $I_P = 0.5$ MA, $n_{core} = 4 \times 10^{19}$ m^{-2}, $P_{LHCD} = 4.5$ MW
- Drop rate scan from 0 to 17.3 mg/s (total 310 mg)
- Continuous drop duration up to 16.5 s



[G. Bodner EPS 2021] [A. Gallo APS 2021] [G. Bodner NF submitted]

Effect of boron drop on global plasma parameters

Same scenario without B powder
and with 9.2 mg/s

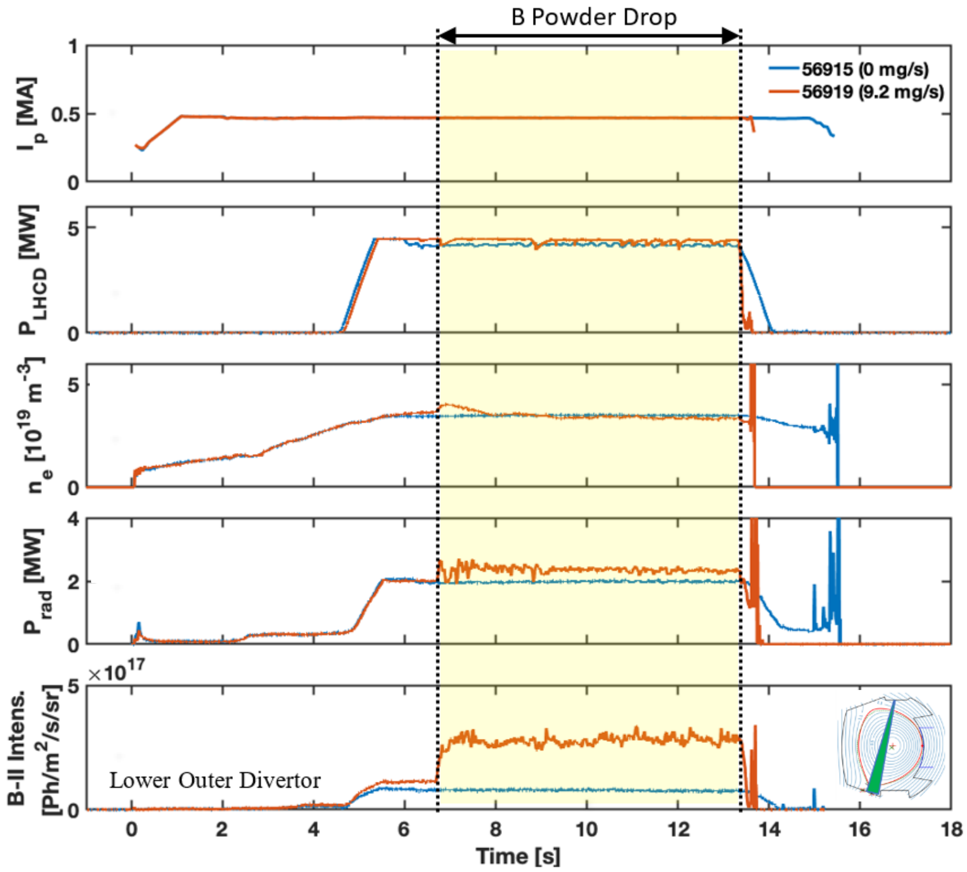
- LHCD coupling not perturbed

- density maintained (low drop rate)

- radiated power increases slightly, remains higher throughout drop

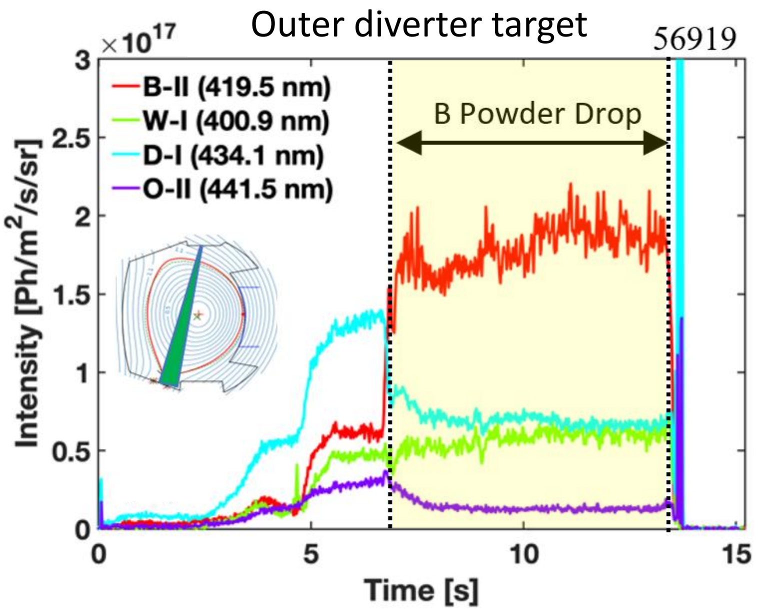
- B signal near lower outer diverter constant throughout drop phase

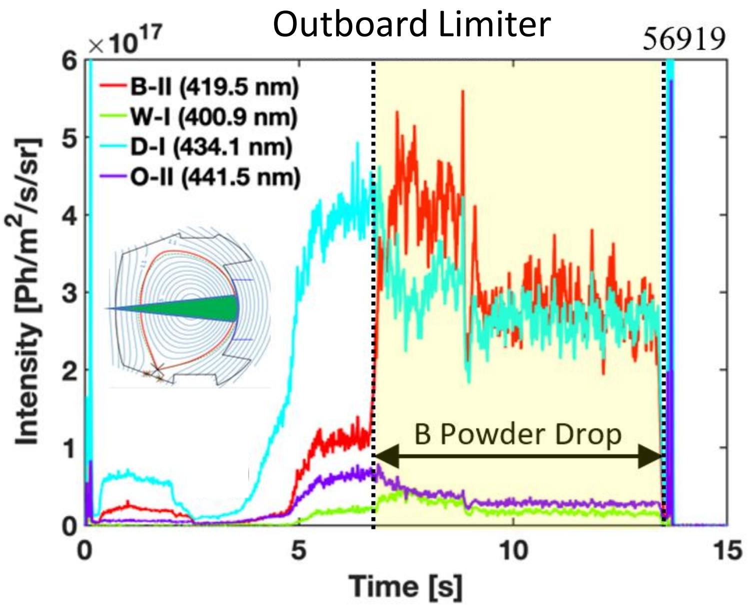
[G. Bodner EPS 2021] [A. Gallo APS 2021] [G. Bodner NF submitted]



B powder makes it to limiters and diverter targets

- O and D signals reduced during drop: less light impurities and fuel recycling
- W signal increases slightly: balance between B coating and W sputtering



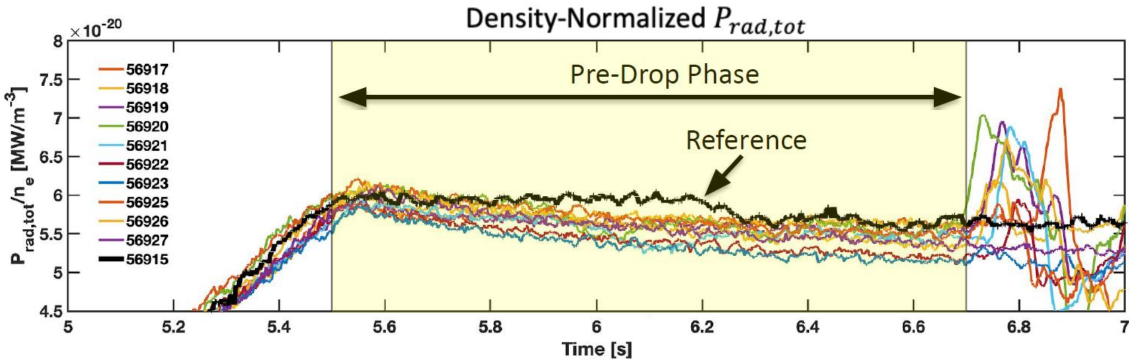


[G. Bodner EPS 2021] [A. Gallo APS 2021] [G. Bodner NF submitted]

Cumulative effect on radiated power and light impurities

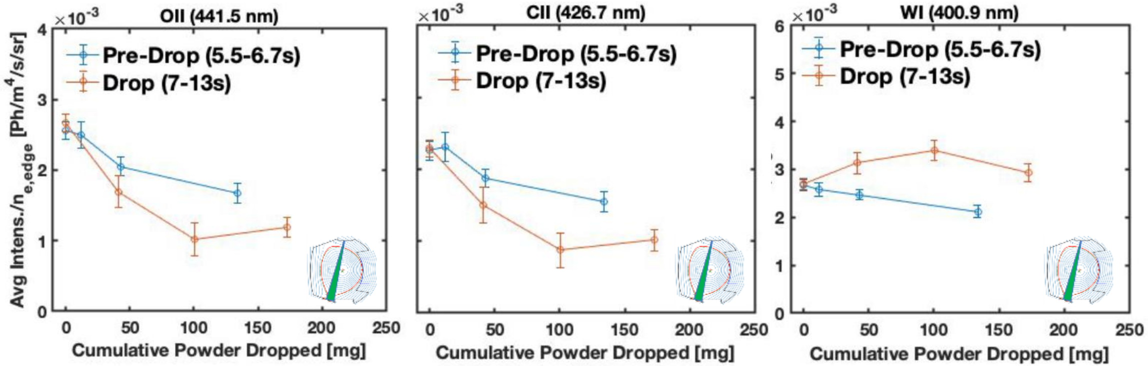
First signs of conditioning as more powder dropped:

normalized radiated power in pre-drop phase reduced



Impurity line intensities at lower diverter target reduced in both drop and pre-drop phases

(same for outboard limiter)



[G. Bodner EPS 2021] [A. Gallo APS 2021] [G. Bodner NF submitted]

Conclusions and future perspectives

- Classic conditioning methods allowed for good performance in WEST but commissioning of pristine full-W machines extremely challenging

- Long pulse devices and especially future steady state reactors require development of real-time viable conditioning methods and strategies

- First experiments with an impurity powder dropper in WEST showed encouraging signs of wall conditioning and big margin of improvement

- More drop experiments planned on WEST in 2022 to compare B to BN powder and develop feedback controlled, adaptive drop strategies

Wall conditioning strategy for campaign 6

- Improved QMS baking insulation to reduce intrinsic H2O contamination

- GDC until D2 and H2 signals > H20 signal (**as long as needed at 200 C**)

- Start operations without GDB to assess effect of conditioned BN tiles (vs C5)

- If machine startup difficult during day 1, **we go for GDB directly on day 2**

- Ideally GDB every 2 weeks, to be adjusted according to bolometry, quadrupole mass spectrometers, visible spectroscopy, VUV spectroscopy measurements

- **First discharge of every day (08:00) should be a reference Ohmic discharge: assess that all basic systems are operational and monitor wall conditioning**