Summary and plans for W sources studies within WP TE

Joint WP TE and WP PWIE meeting. Aix en Provence 17-19 septembre 2024

rTFLs: E. Tsitrone, A. Hakola

RTCs: Y. Corre, K. Krieger, A. Widdowson

RT-06 Preparation of efficient Plasma Facing Components (PFC) operation for ITER, DEMO and HELIAS

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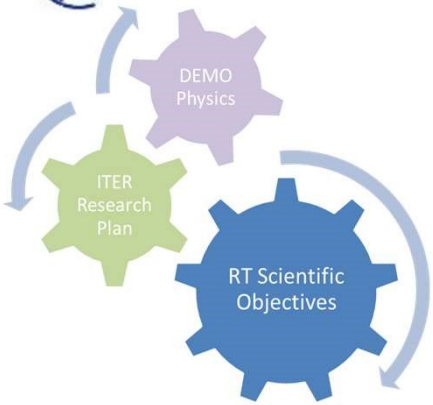
Scope of the talk



- Summarize the plans and ideas related to the TE program covering WEST and AUG and JET analysis.
- Identify the needs for modelling, experiments and wishes to the linear facility community and atomic and molecular data

RT06 activities currently includes analysis of the past experiments (22-23 and 24 WPTE calls) + setting up of new experiments (25)

sessions # or discharges executed/allocated

	JET	AUG	TCV	MAST-U	WEST
2022-23	#14/#12	No exp.	0	0	285/270
2024	0	0/30	0	0	98/105

Call WPTE 2025 deadline 11th of October

RT06 scientific objectives

Impact of power/particle loads on PFC	
D1	Quantify local power load distributions on castellated and shaped PFCs for ITER and DEMO, including melting situations using experimental data and predictive modelling
D2	Assess the impact of sustained high power / high particle fluence plasma exposure of metallic PFCs
Fuel retention, removal and wall conditioning	
D4	Quantify fuel retention in devices with metallic walls, with a focus on long pulse operation (using recent fuel retention diagnostic upgrades such as laser-based diagnostics where available)
D5	Determine fuel-removal and conditioning efficiencies in metallic devices in conditions relevant for ITER PFPO and extrapolate to DEMO
Erosion sources from Plasma Facing Components (impurity content, material migration)	
D3	Quantify material erosion sources from metallic walls under ITER relevant plasma conditions (including high power and impurity seeding plasmas) and determine material migration pathways
D6	Quantify the balance between gross and net erosion of W under different operational conditions

RT06 task 3: E. Pawelec, J. Romazanov

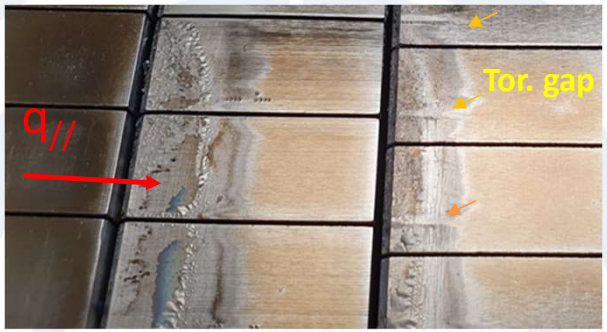
« W source and redeposition » very important topics for RT06 – synergies with RT03 and RT04

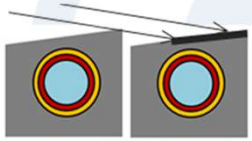
RT-06 WPTE devices & status of knowlegde

Erosion in the divertor *[M. Balden, Phys.Scr. 2021]*

- Net erosion > 0.1 nm.s^{-1} (same range AUG-WEST)
- Gross erosion → impurity intra-ELM (JET-ILW, AUG)
- Helium (fuzz formation, AUG, JET-ILW, WEST phase I)
- ITER-grade PFU (WEST) – thick surface layers (HF C7)
- Toroidal gap (done in AUG, WEST) *[E. Tsitrone, PSI 2024]*

fully actively cooled W divertor - ITER grade PFUs





0.5 mm toroidal bevel

Erosion in the main chamber

- CX flux (AUG), far SOL conditions ?
- Erosion during limiter and ramping phases?

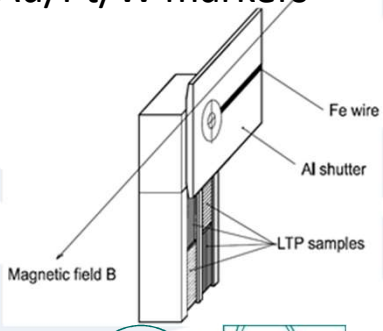
Erosion on the RF antennas (ICRH)

- Fully explored in JET-ILW and AUG
- Important in AUG, WEST (dominate core content) ∝ ROG, RF-fields, coupling… *[L. Colas, NF 62, 2022]*

Prompt redeposition:

- Analyses on going (AUG, JET-ILW, WEST)

Shutter samples with Co/Au/Pt/W markers



Investigation W-He interaction

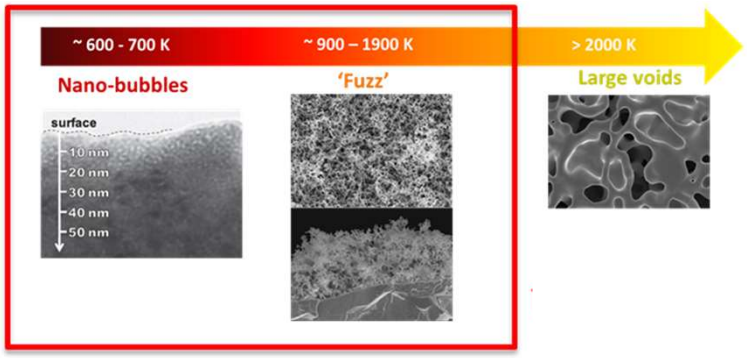
Helium JET interaction with tungsten (2022)

“Tungsten fuzz” experiment

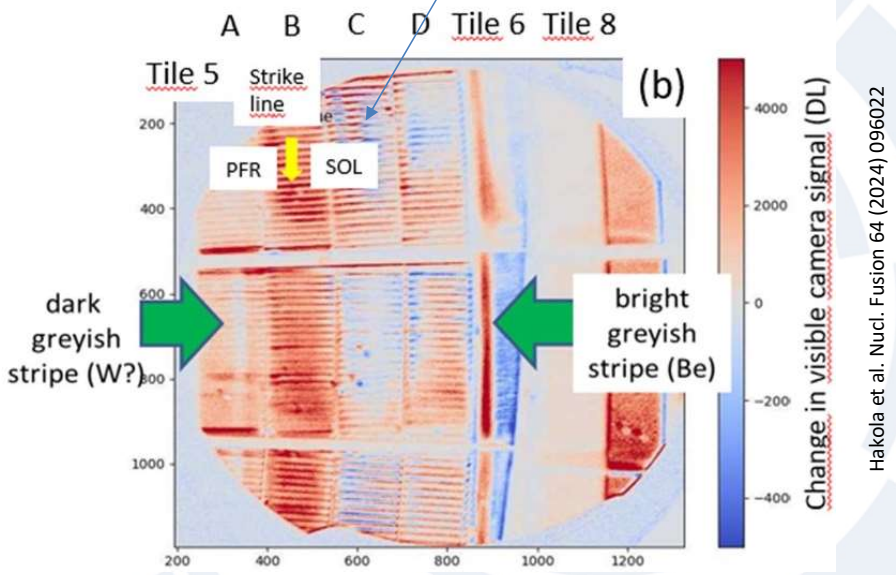
Surface modification from IR camera observed but no visible confirmation of fuzz formation

- Ongoing work in 2024/25: balance between W erosion, growth rate fuzz and co-deposition coverage of the surface with co-deposits ⇒ TE and PWIE

New information needed: **photography (in-vessel 2024) and post-mortem analysis (2025)** needed to confirm modification to tungsten surface ⇒ PWIE



JET - IR Camera: Surface modifications on W after He interaction



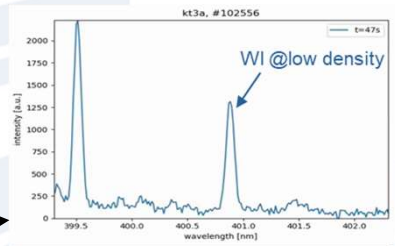
Hakola et al. Nucl. Fusion 64 (2024) 096022

Changes in surface in private flux region and far SOL, but not at strike point ⇒ post-mortem analysis and photography needed

RT06 JET Tungsten sputtering (2023)

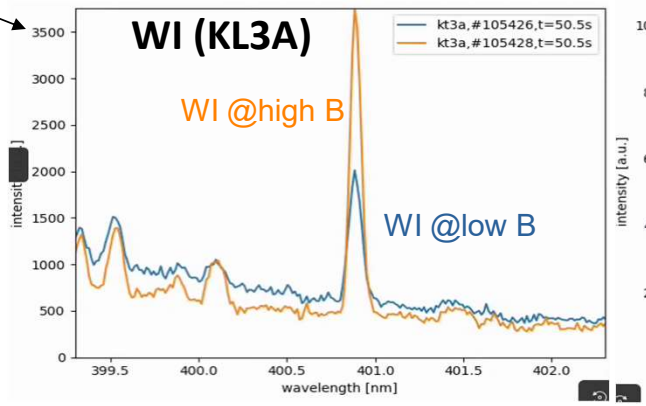
Experiments: W erosion (ions, CXN, impurities), prompt redeposition, screening to understand W sources reaching plasma core

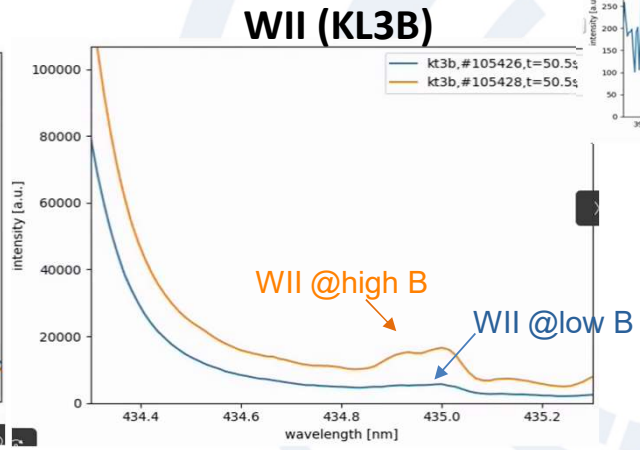
- Fuelling scan (attached vs. detached -> suppressing strike line erosion)
- B-field scan (Larmor radius effect on prompt redeposition)



Reduction WII/WI ratio with increasing B-field (prompt deposition effect)

$$r_L = \frac{\sqrt{2mE}}{ZeB}$$





J. Romazanov, S. Brezinsek

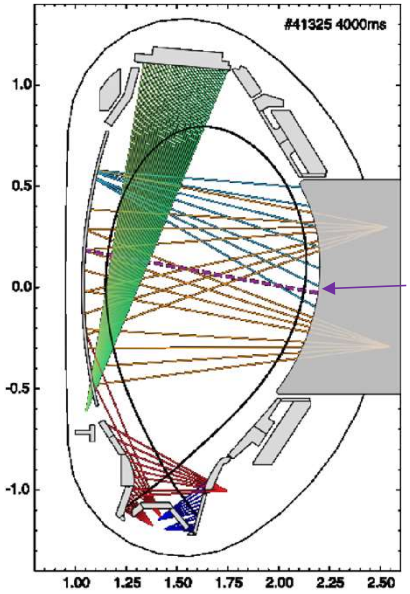
Ongoing work in 2024/25

- Spectroscopy: Relative tungsten states from line ratios (WI, WII, higher charge states) needed for comparison with models
- Modelling effort: ERO, ERO2.0, JINTRAC, PIC

Experimental plan in AUG (up-coming campaign)

- Focus on CX particles → Far Sol condition
- Use the shutter samples with Co/Au/Pt/W markers to measure the erosion in different toroidal and poloidal positions
- W source rates evaluated with VIS spectroscopy

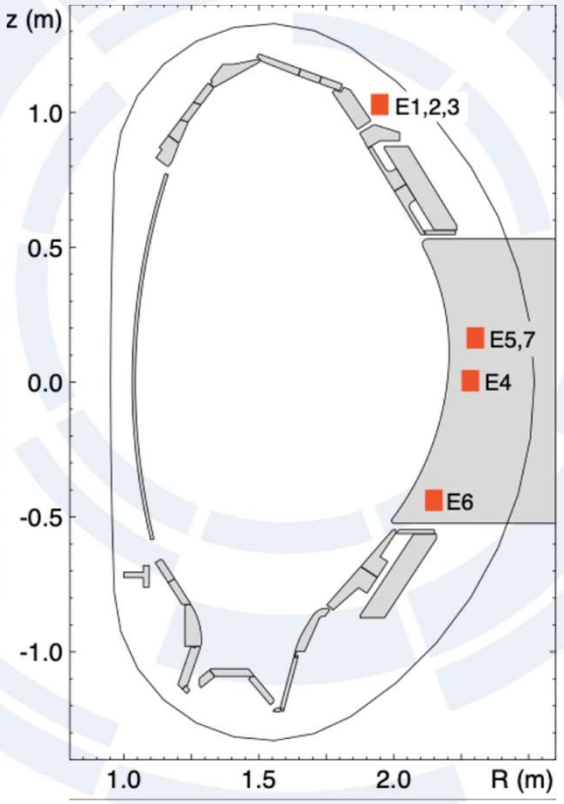
Spectroscopy



Many LOS (VIS | | | | |)

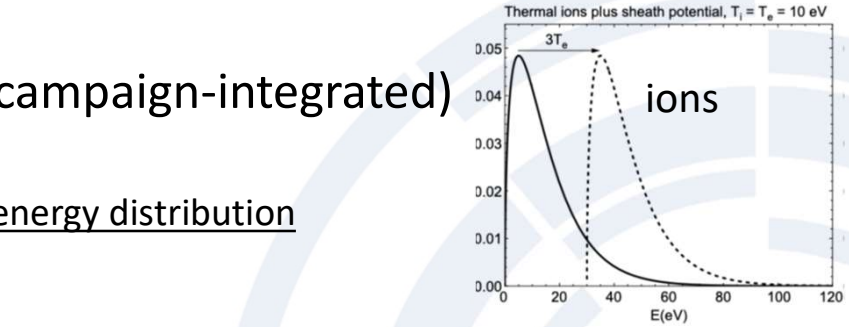
One LOS for impurity concentrations (SPRED – VUV, X-ray)

(campaign-integrated data)

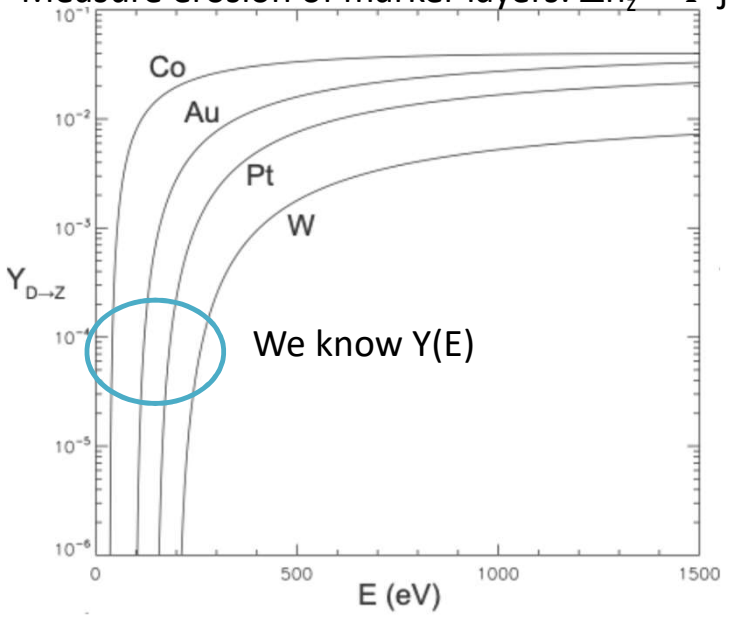


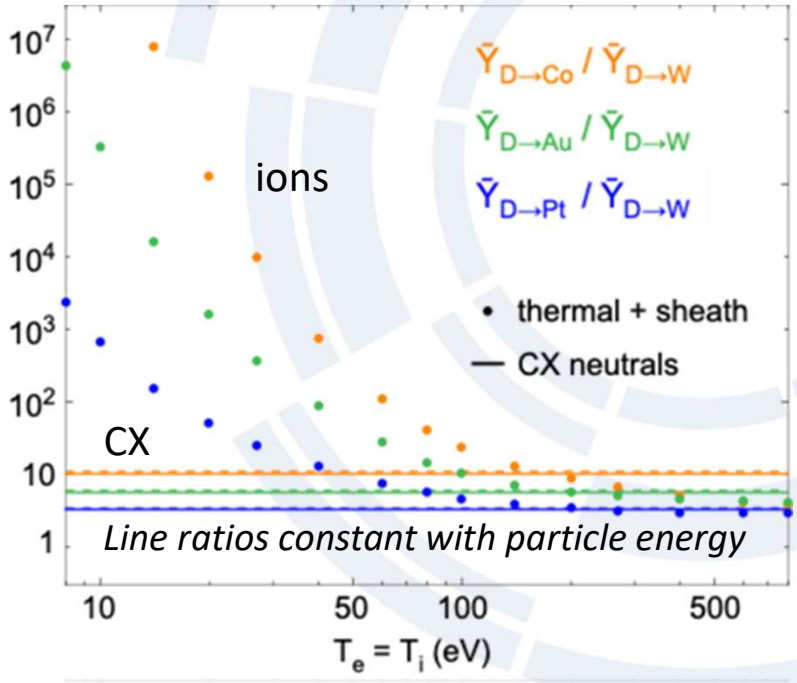
Experimental plan in AUG

- Focus on CX particles → Far Sol condition (campaign-integrated)
  - **Extract (limited) info on particle flux (CX)**
  - Measured ratios $\bar{Y}_{z1} / \bar{Y}_{z2} = \Delta n_{z1} / \Delta n_{z2} \Rightarrow$ approximate energy distribution
  - Measured $\Delta n_z \Rightarrow$ estimate for total incident fluence Φ



Measure erosion of marker layers: $\Delta n_z = \Phi \int f(E)\, Y_z(E)\, dE = \Phi\, \bar{Y}_z$





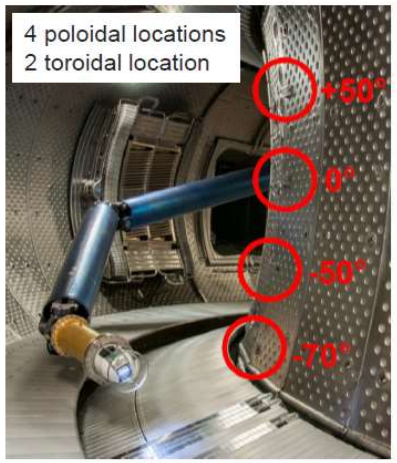
Experimental plan in WEST

- Characterize the W sources (gross erosion) on the ITER-grade divertor during high fluence deuterium campaigns (fixed strike lines):
  - "Attached" plasma condition (C7 HF 2023) RT06
  - Low Te plasma condition (2025) RT06

Red: experiment already performed
Blue = WPTE call for 2025

- Characterize the W sources on main chamber
  - Use of N seeded cooling effect to cut the divertor sources → LH versus ICRH discharges (also look at the W core content) RT06
  - Current ramp-up with W limiter phase – RT03 (synergies with RT06)

[see A. Gallo's talk yesterday]



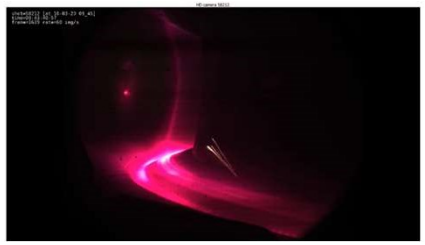
only CX neutrals

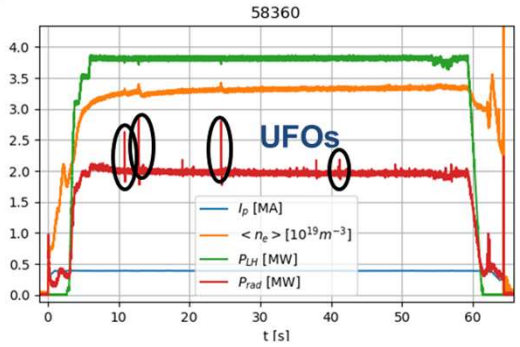
Other topics in piggy-back

- W-sputtering in the far SOL (sample holder, collector probes)
- Post-mortem to characterize the net erosion over the exp. campaigns.
- Understand the W migration pathways (surface layers build-up)
  - Large scale: impurity transport (drifts, turbulence)
  - Local scale: prompt redeposition (Larmor rad., sheath), bevel effect, gaps…

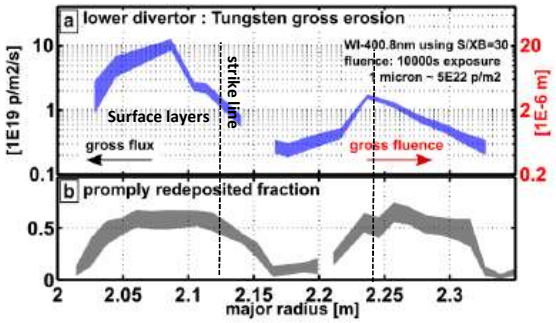
Experimental plan in WEST

High fluence C7: ”attached” plasma condition





N. Fedorczak, PSI 2024]



WEST C7 HF:

- ~ 380 repetitive shots run for 1 month, cumulating ~3 hours of plasma / 30 GJ of energy
- ITER relevant fluence reached (~2 PFPO shots): ~5 10^{26} D/m^2
- UFO detected with IR originate mostly from HFS (thick deposits area)

[E. Tsitrone, PSI 2024]

- UFO data analysis: *[J. Gaspar, NME 2024]*
- W gross erosion: *[N. Fedorczak, NME 2024]*
- Surface-layer build-up: *[J. Gerardin, NME 2024]*
- Modelling: on-going *(PHD A. Huart)*
- Post-mortem: on-going *[C. Martin, NME 2024]*
- Thick W deposited layer studies→ Magnum PSI

[see T. Morgan’s talk this morning]

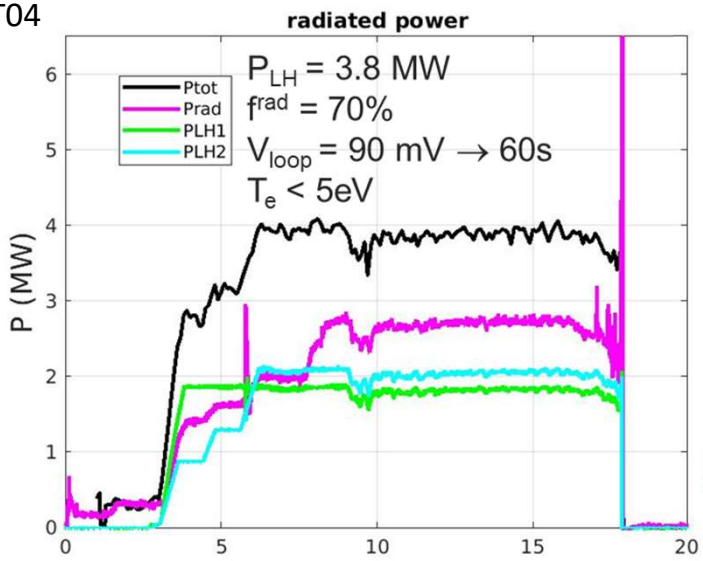
Experimental plan in WEST

High fluence @ low Te

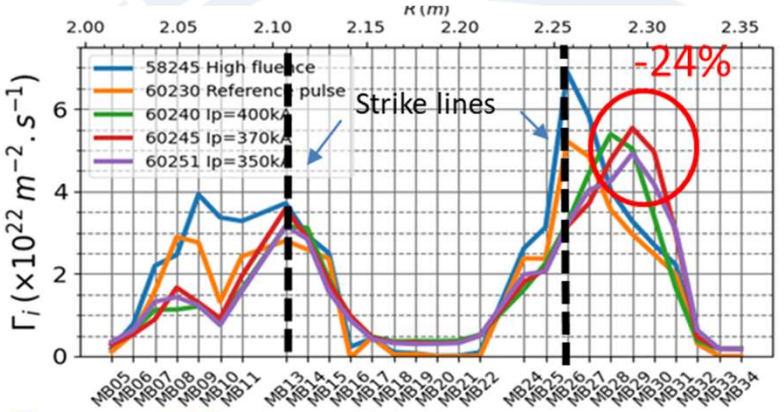
XPR scenario developed in RT04

Scenario X-point radiator dans WEST

high fluence XPR C9 @ 350kA

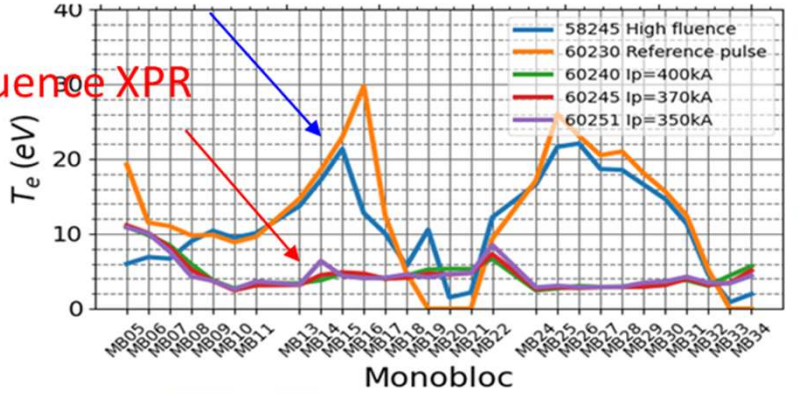


Ion particle flux



High fluence C7

High fluence XPR

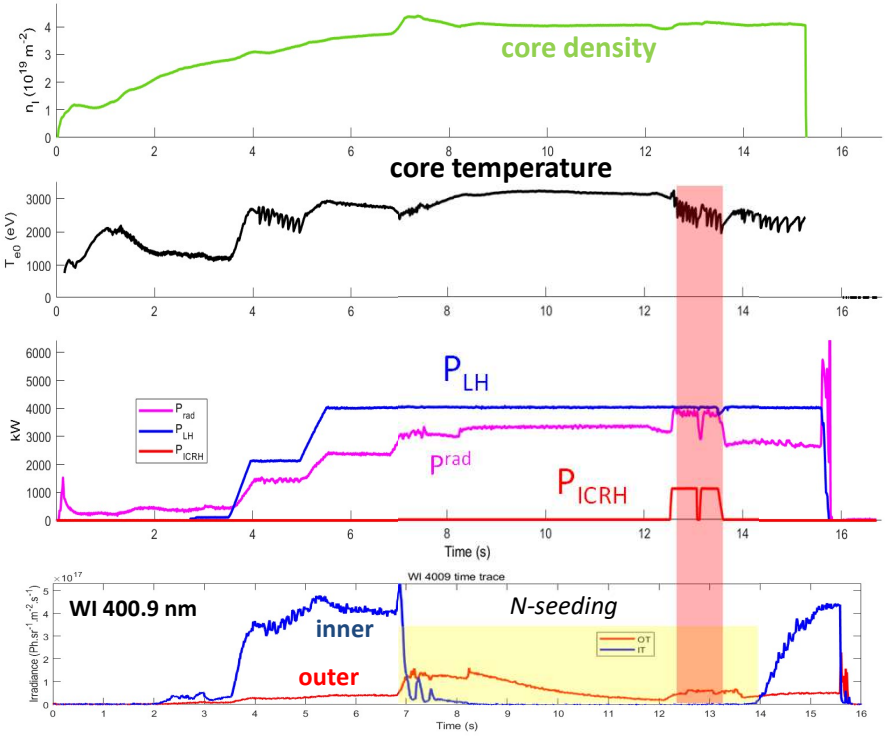


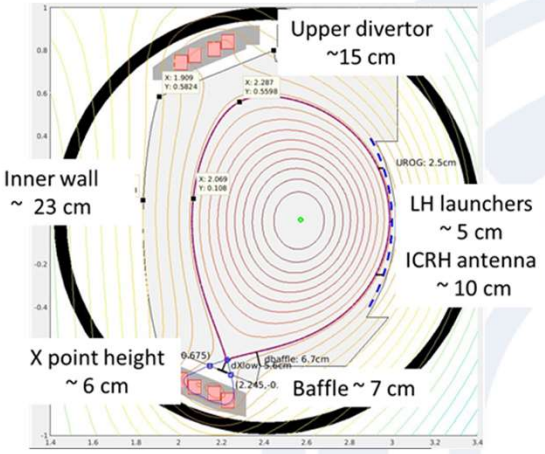
- HF XPR plasma scenario developed in C9 up to 15 s (LH1 uncooled)
- Test the scenario in C11 up to 60s
- Run the high fluence campaign at low T_e in C12 (1 month)

Experimental plan in WEST

W sources in the main chamber: RF E-fields, ROG?

use of N seeded detachment to turn-off divertor source
→ W core content LH versus ICRH discharges





- ~1 MW/1s of ICRH over a stable plasma with 4 MW of LH power
- W sources extinguished on the inner, reduced on the outer side
- ICRH power too low → cooling of the core temperature – Te > 3 keV required to evaluate the core W content with UV spectroscopy

IC

ICRH system (3 antennas)
- Frequency: 45 - 60 MHz
- Capability:
- 9 MW / 30 s
  6 MW / 60 s
  3 MW / 1000s

Repeat with more ICRH power (at least 3 MW)

Needs in support of the Tokamak experiments: modelling

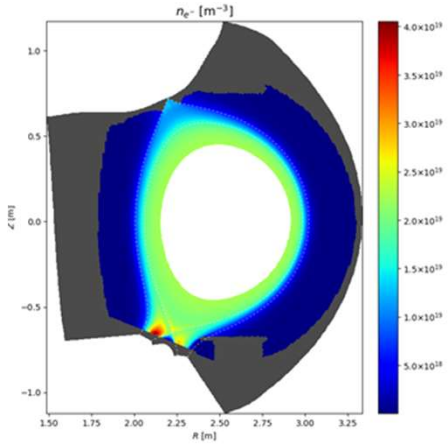
[previous talk A. Kirschner]

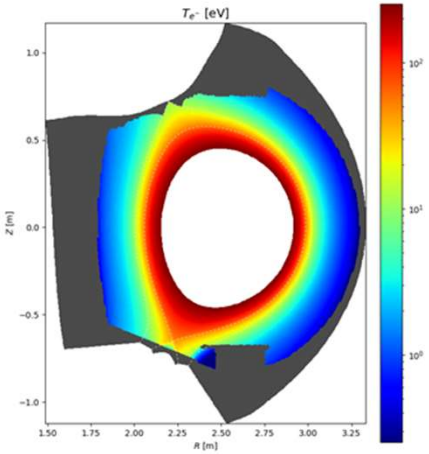
1 WP TE

PLASMA BACKGROUND MODELING

- plasma background with SOLEDGE2D/EIRENE, SOLPS → DRIFT effect, turbulence (ballooning) SOLED3X, impurity transport
- PIC modelling (transients) in gaps
- Based on plasma diagnostics : reflectometry, Langmuir probes, bolometry, IR data…

RT06 task 3: E. Pawelec, J. Romazanov





2 PWIE

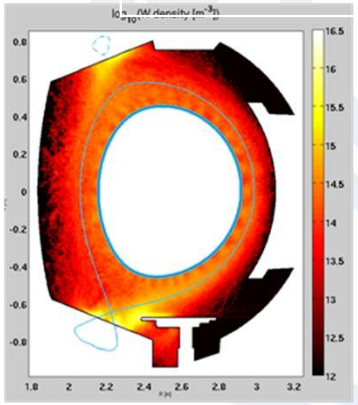
ERO2.0 MODELING

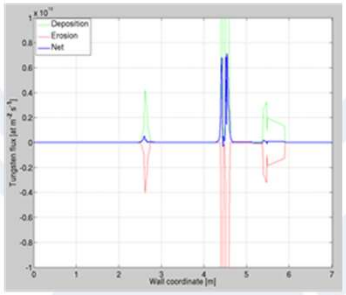
- ERO2.0, JINTRAC
- Sputtering and prompt redepostion
- Post-treatments

3

LINK WITH POST-MORTEM ANALYSIS AND TUNGSTEN MEASURMENTS

- ERO2.0 wall balance vs post-mortem analysis of the PFCs
- ERO2.0 vs measured tungsten sources (WII/WI)





[PHD A. Huart]

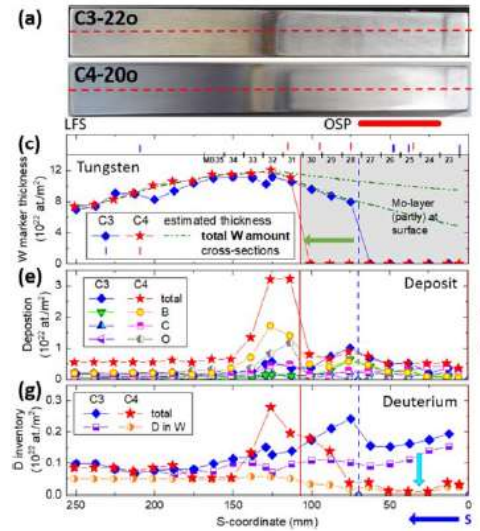
Needs in support of the Tokamak experiments: post-mortem ⇒ PWIE

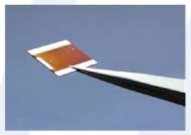
[previous talk A. Hakola]

RT06 task 3: M. Diez, E. Bernard

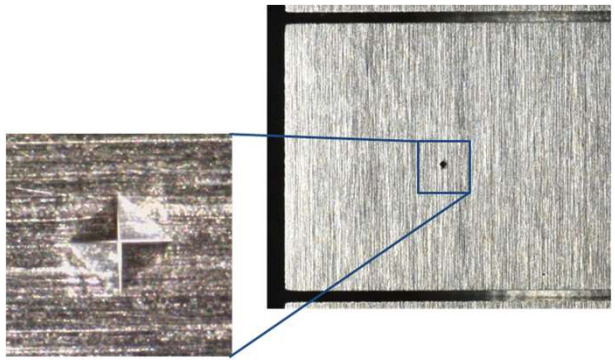
- JET DT3 – Helium campaign post-mortem analysis (2025) needed to confirm modification to tungsten surface
- Deposition/Erosion on samples (Co/Au/Pt/W markers)
- Deposition/Erosion on ITER-grade PFU (indentation + confocal microscopy during shutdown)

[M. Balden, Phys.Scr. 2021] **Erosion Marker WEST I**



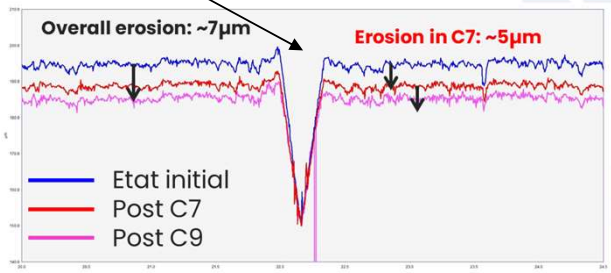


[A. Hakola NF 2021]



Max ISP

[M. Diez SOFT 2024]



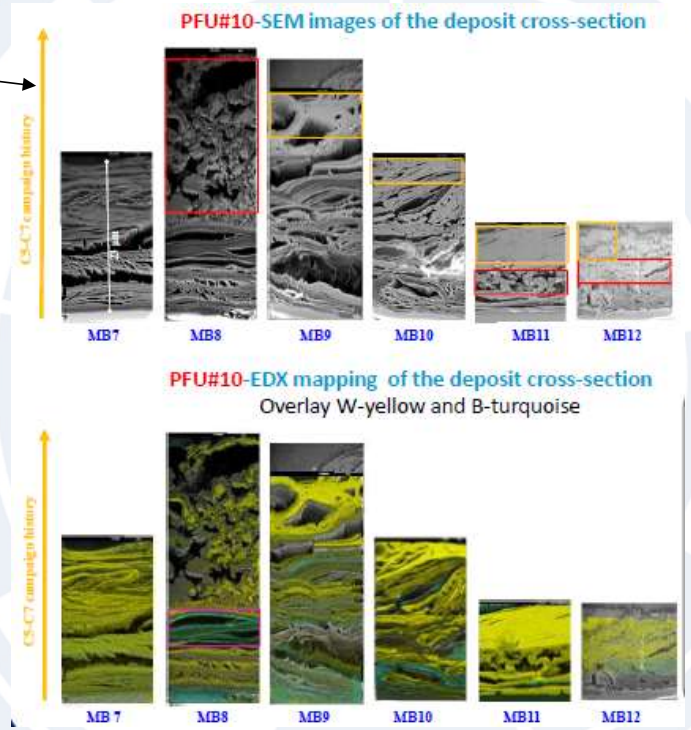
Needs in support of the Tokamak experiments: post-mortem ⇒ PWIE

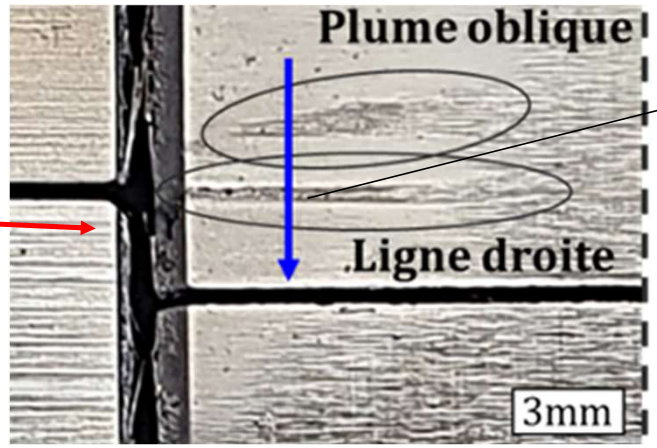
[previous talk A. Hakola]

RT06 task 3: M. Diez, E. Bernard

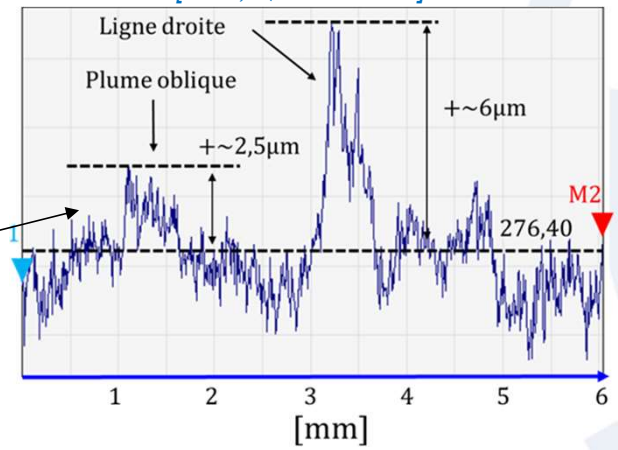
- Analyses of the surface layers in WEST (thickness, structure, composition): SEM, EDX…
- Erosion in the toroidal gaps

[C. Martin, PSI 2024]





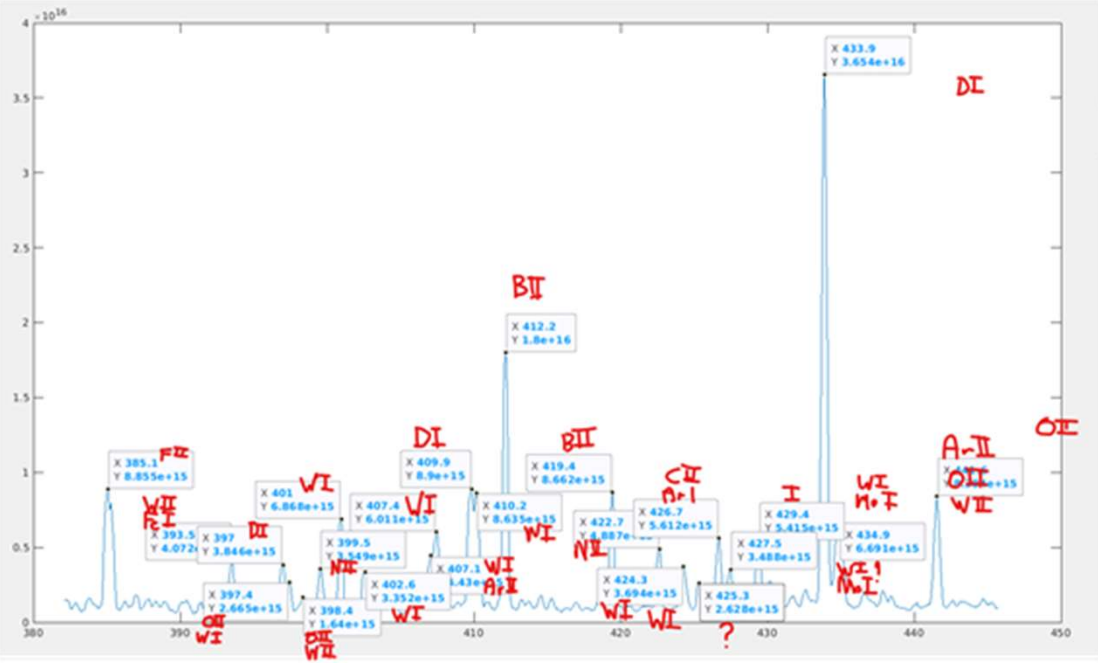
[PHD, Q. Tichit 2024]



Confocal microscopy

Call WPTE 2025 deadline 11th of October

Thank you for your attention


×10^16
X 433.9
Y 3.654e+16
DI
BII
X 412.2
Y 1.8e+16
DI
X 409.9
Y 8.9e+15
BII
X 419.4
Y 8.662e+15
X 385.1
Y 8.855e+15
X 401
Y 6.868e+15
X 407.4
Y 6.011e+15
X 410.2
Y 8.635e+15
X 422.7
X 426.7
Y 5.612e+15
X 429.4
Y 5.415e+15
X 427.5
Y 3.488e+15
X 434.9
Y 6.691e+15
X 397
Y 3.846e+15
X 399.5
X 397.4
Y 2.665e+15
X 402.6
Y 3.352e+15
X 398.4
X 424.3
Y 3.694e+15
X 425.3
Y 2.628e+15
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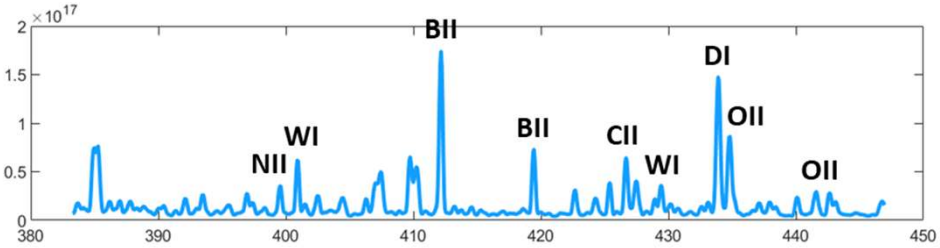
1
1.5
2
2.5
3
3.5
4
380
390
410
420
430
440
450

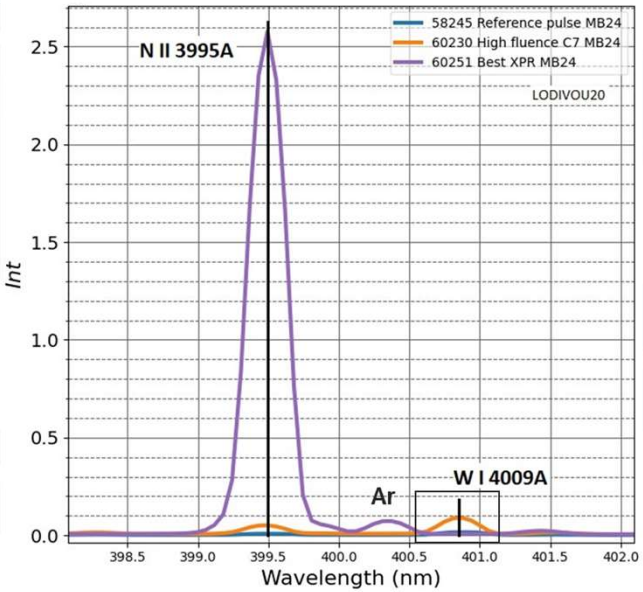
Needs in support of the Tokamak experiments: Atomic / molecular data

⇒ PWIE

[see previous talk C. Guillemaut]

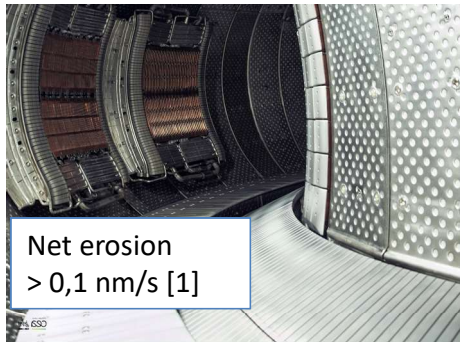


- S/XB WI 400.9nm
- S/XB NII (399.5 nm), D2; H2, isotopic ratio
- WII 435 nm /WI 400.9nm line ratio (prompt redeposition)
- PZD W, B, N2, O
- CAPS for W: WD and WH lines? (AUG data published, JET one is recorded)

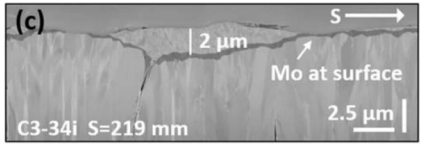


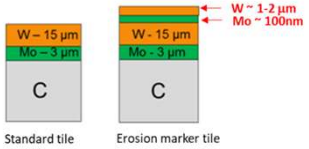
Fiducials on W MBs to measure the net erosion

WEST phase I
W coated graphite divertor



Net erosion
> 0,1 nm/s [1]





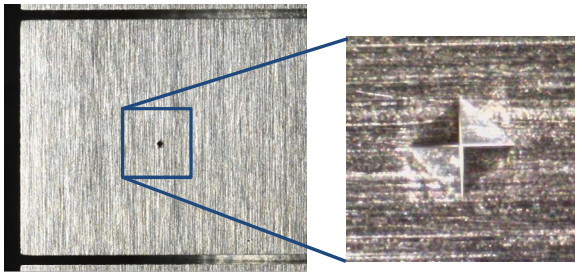
marker layers

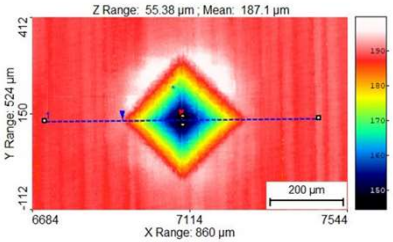
WEST phase 2
ITER grade bulk W divertor

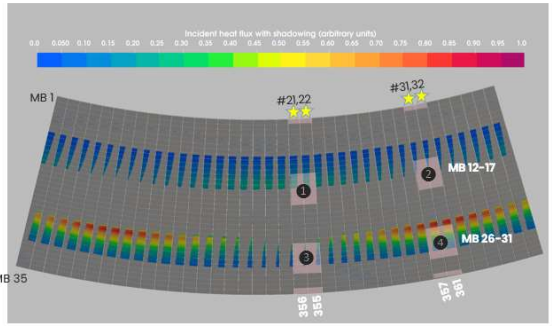
No tools /diagnostic to evaluate the erosion

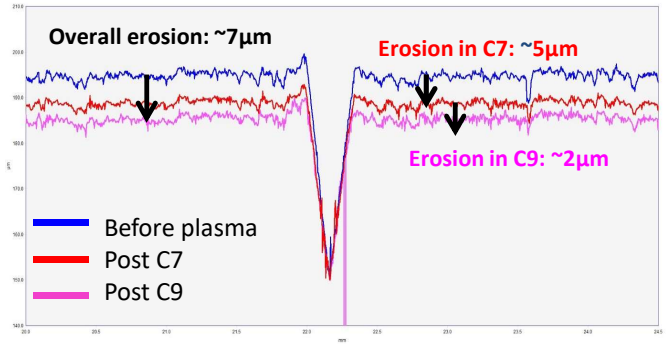
- **Objective**
- Develop a method to evaluate the net erosion of actively-cooled W PFUs in a real tokamak environment with long plasma discharges over an integrated period of time

Evolution of fiducials topography (depth) to evaluate the erosion of W monoblocks









Needs in support of the Tokamak experiments: Linear devices

⇒ PWIE

Investigation on the structure, and D-retention in W redeposits created by sputtering at various growth rates

- Mimic the thick W layers observed in WEST (“attached” plasma condition RT06), growth rate, chemistry f(ne, Te) on cold surface (70°C)
- Predict the ITER layer build-up (wall from Be to W gives additional W sources during current ramp up RT04)