



WP PWIE SP B.2 & SP B.3, project meeting 2022 report on analyses of WEST PFCs and perspectives for 2023

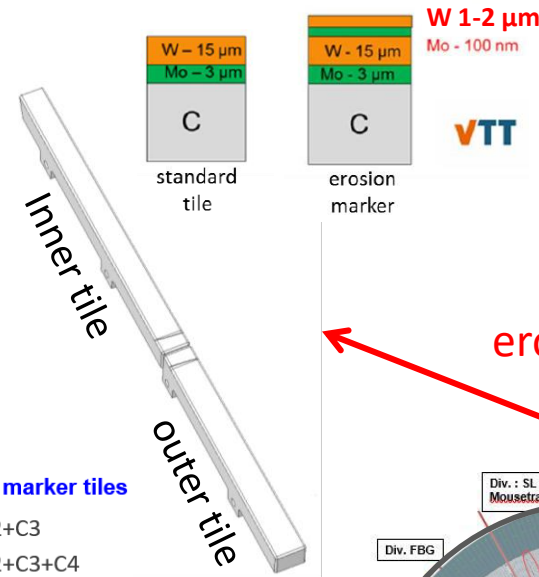
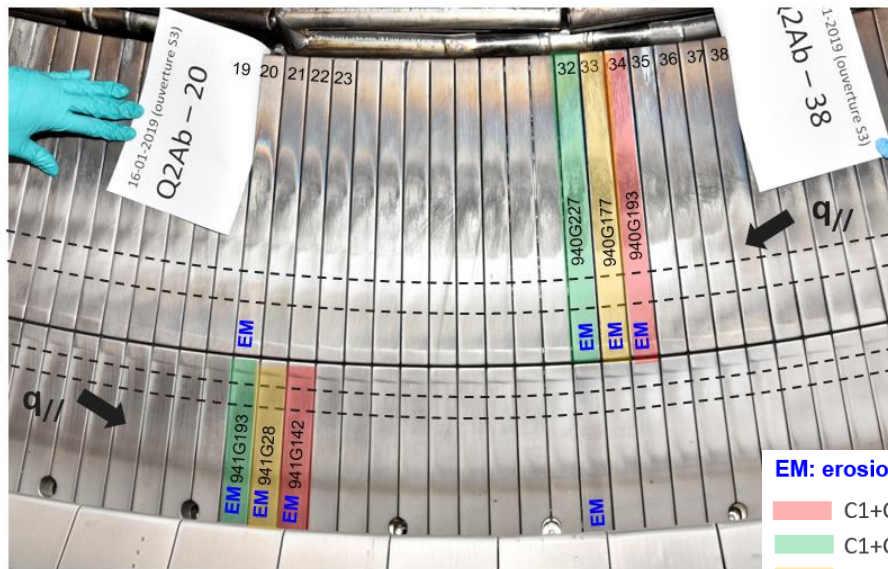
Mathilde DIEZ (CEA)

February 07, 2023

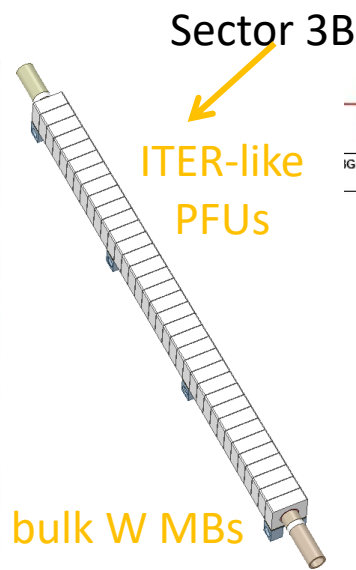
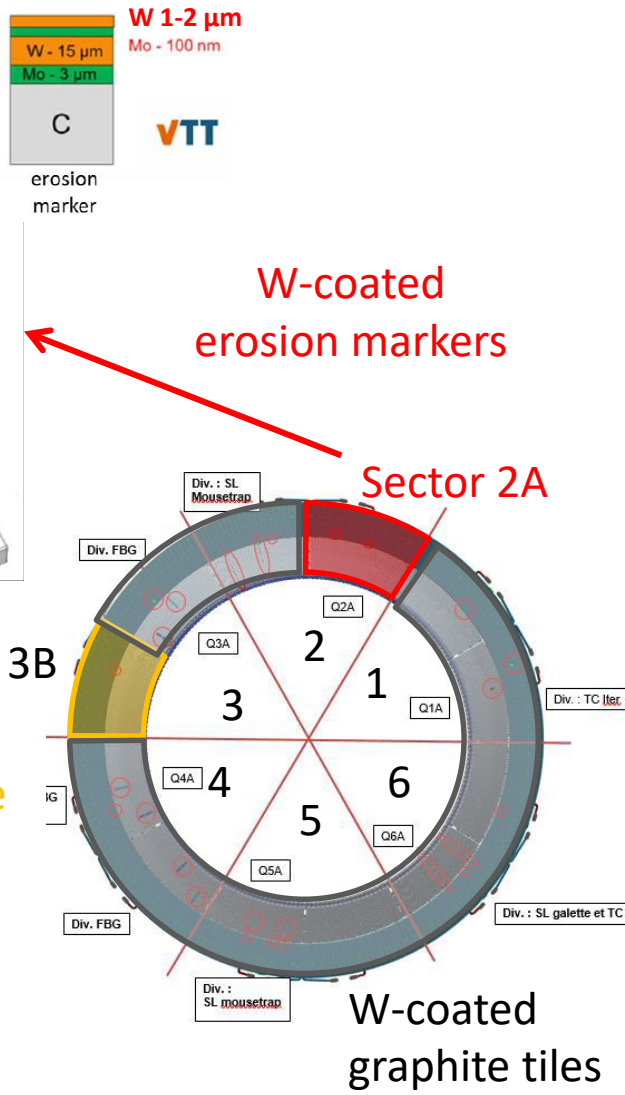


This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Reminder: divertor tiles installed in WEST during phase I



- EM: erosion marker tiles
- C1+C2+C3
 - C1+C2+C3+C4
 - C1+C2+C3+C4+C5

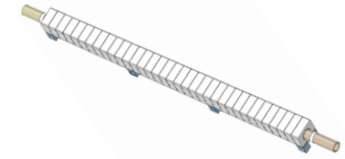


Current status of WEST PFCs analysis



1st step

Non-destructive analyses performed on the entire WEST tiles (no cutting) to better identify erosion/redeposition patterns and areas of interest



		top surface				gaps			top surface	gaps
		C3 marker (2021)	C4 marker (2021)	C4 only standard tile (2022)	C5 marker (2022)	C3 marker (2021)	C4 marker (2021)	C5 Marker (2022)	C4 ITER-like PFU (2022)	C4 ITER-like PFU (2022)
IPP MPG	SEM/FIB/EDS	done*	done*	done	done	done	done	Pending	done*	done
	Confocal microscopy	done*	done*	done	done	no	no	Pending	done*	no
	RBS/NRA	done*	done*	no	done	no	no	Pending	done*	done
CEA	Emissivity	-	-	-	-	-	-	-	done*	Done
	XRF	-	-	-	-	-	-	-	done*	-
	Confocal microscopy	-	-	-	-	-	-	-	done*	done

* Published data

[M. Balden et al., Phys. Script 96, 2021]

[J. Gaspar et al., Nucl. Fusion, 2022]

[M. Diez et al., submitted to NME, 2023]

Current status of WEST PFCs analysis

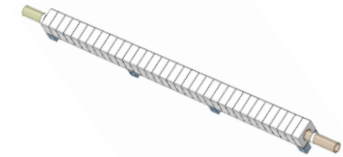


1st step

Non-destructive analyses performed on the entire WEST tiles (no cutting) to better identify erosion/redeposition patterns and areas of interest

2nd step

Cutting of WEST tiles



		C3 marker (2021)	C4 marker (2022)	C5 marker (2023)	ITER-like PFU (2023)
VTT	Core sampling	done	done	ongoing	
CEA	Diamond saw				ongoing

Current status of WEST PFCs analysis



1st step

Non-destructive analyses performed on the entire WEST tiles (no cutting) to better identify erosion/redeposition patterns and areas of interest

2nd step

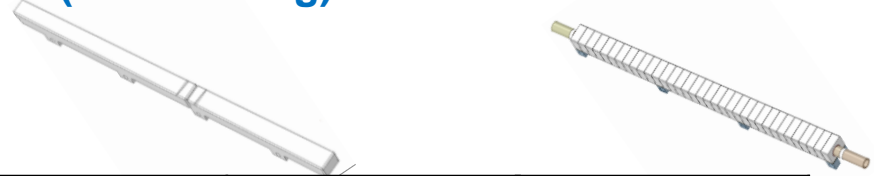
Cutting of WEST tiles

* Published data [I. Jogi et al., Journal of Nucl. Eng. 2023]

** gave rise to additional experiments on C4 standard tiles

3th step

Analyses performed on the WEST samples (after cutting)



	C3 marker tiles (2021)	C4 marker tiles (2022)	C5 marker tiles (2023)	ITER-like PFU (2023)
LIBS – UT	done*	Partially done	Pending	Pending
IBA – JSI	done	done	Pending	Pending
IBA – VR	done	?	Pending	Pending
SEM/EDS – IPPLM	done*	done	Pending	Pending
SIMS/IBA/SEM – NCSR	done	done	Pending	Pending
Tof-ERDA - RBI	done	done**	Pending	Pending
SIMS/IBA – IST	done	done	Pending	Pending
SIMS - VTT	done*	done	Pending	Pending
GDOES - IAP	done*	?	Pending	Pending
Raman/SEM/EDS – CEA/Uni	-	-	-	done



Main (selected) achievements in 2022

- *Microscopic observations related to erosion/ redeposition studies*
- *Helium content*
- *PWI into the gaps*
- *Compilation of depth profile data on C3 samples*
- *D inventory in C4 samples*



Main (selected) achievements in 2022

- *Microscopic observations related to erosion/redeposition studies*
- *Helium content*
- *PWI into the gaps*
- *Compilation of depth profile data on C3 samples*
- *D inventory in C4 samples*

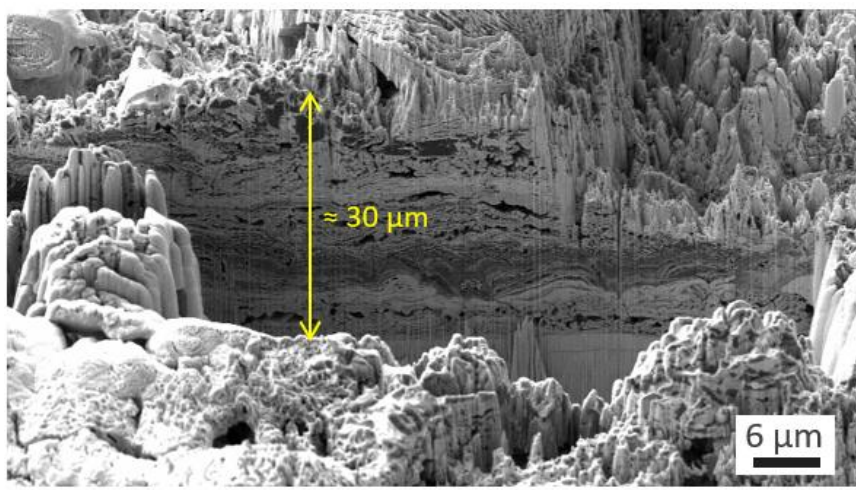
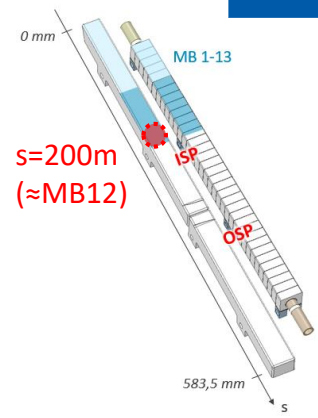
Thick deposited layers grow continuously ?

Goal: determine and compare thickness of the deposited layers after C3, C4, C5 (WP PWIE)

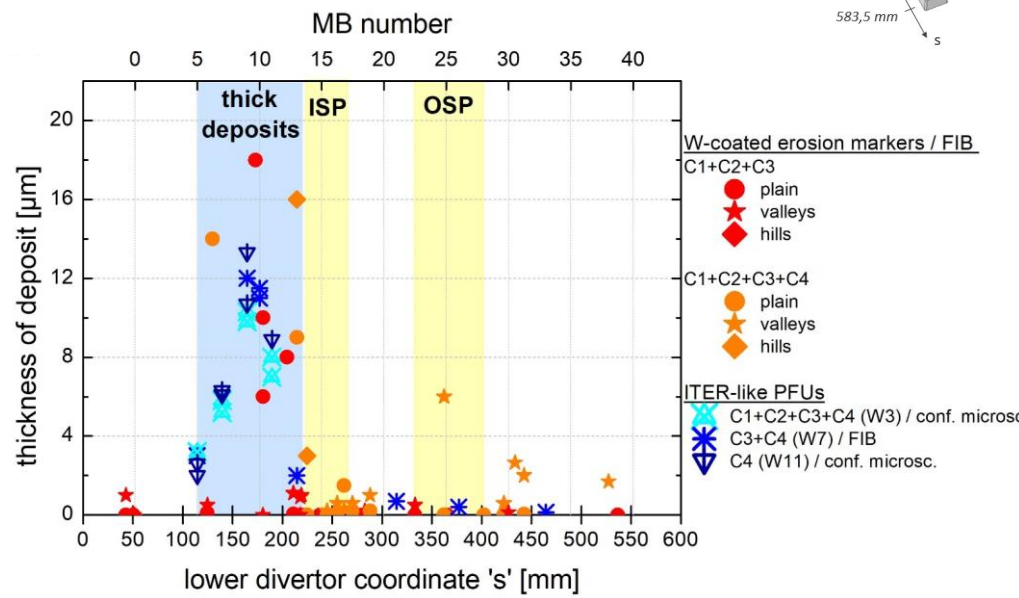
2022: SEM/EDS/FIB analysis of C5 erosion marker tiles

- ▶ After C5, up to 30 μm of deposited layers
- ▶ ($\approx 7\text{h}$ of plasma \rightarrow net deposition rate $\approx 1,2 \text{ nm/s}$)

- ▶ To be compared with (2021):
 $\approx 10 \mu\text{m}$ after C3
 $\approx 15\text{-}20 \mu\text{m}$ after C4



Erosion marker tile exposed to C1+C2+C3+C4+C5
 $s=200 \text{ mm}$

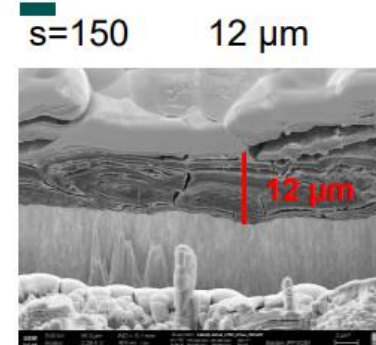
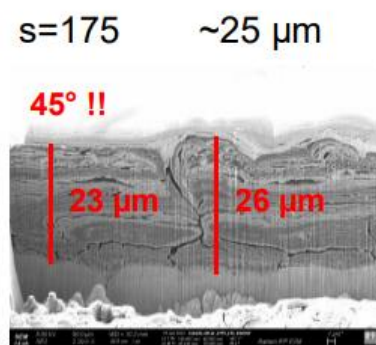
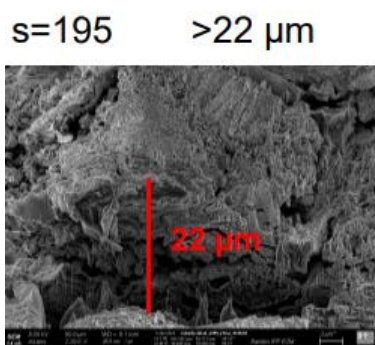
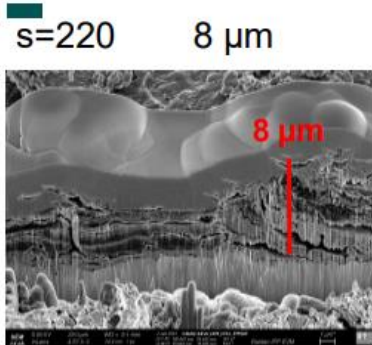
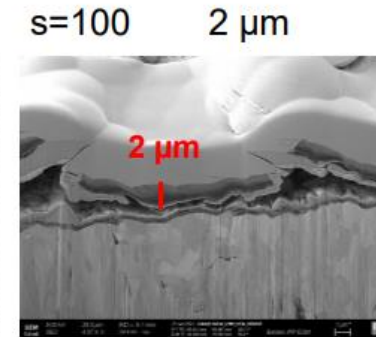
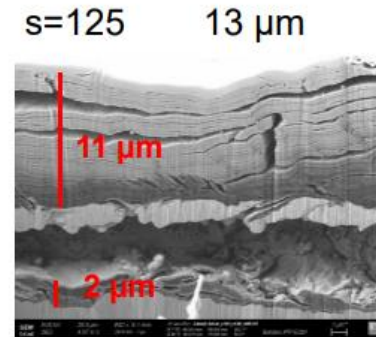
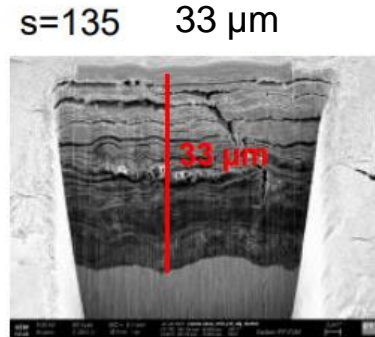
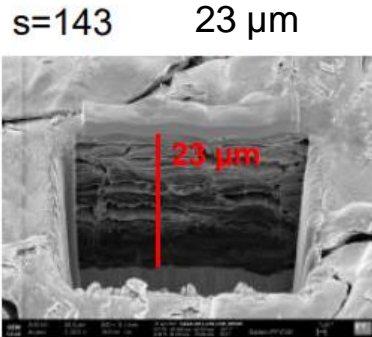
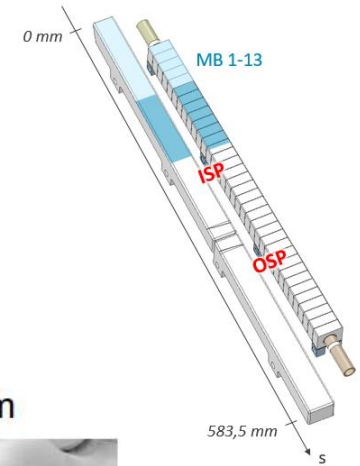


→ Results to be further analysed and to be confronted with the analysis of standard tiles exposed to C4 only (next slide)

Thick deposited layers grow continuously ?

2022: SEM/EDS/FIB analyses of standard tiles exposed to C4 only

- ▶ After 1 campaign only, deposited layers up to $\approx 30\mu\text{m}$



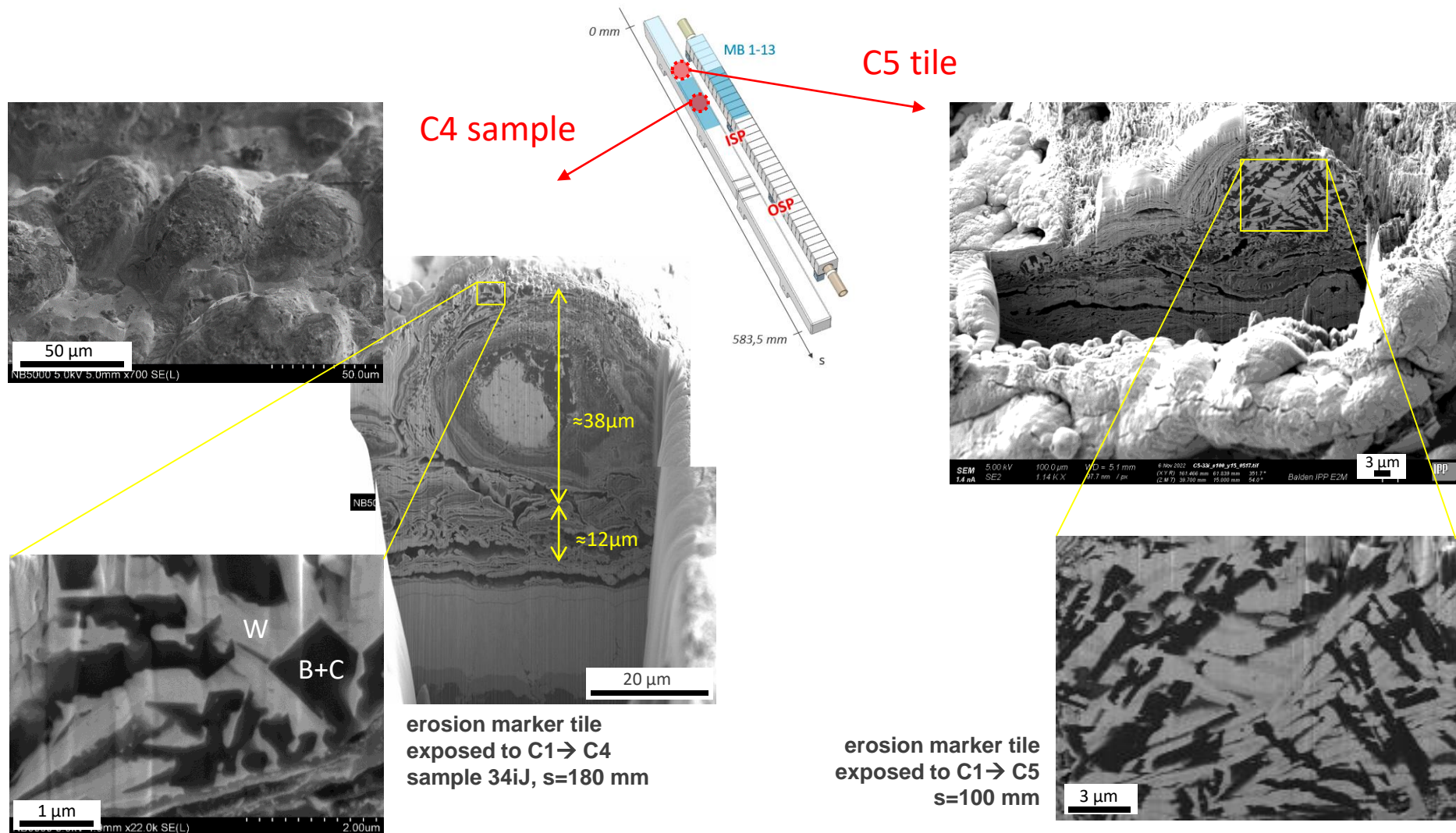
Complex deposits structure observed after C4 and C5



Warsaw University
of Technology



- Presence of inhomogeneously-distributed deposits with boron-rich particles after C4 and C5 (boron carbides?)





Main achievements in 2022

- *Microscopic observations related to erosion/redeposition studies*
- ***Helium content***
- *PWI into the gaps*
- *Compilation of depth profile data on C3 sample*
- *D inventory in C4 samples*

Helium detected in the OSP of C4 marker tiles!



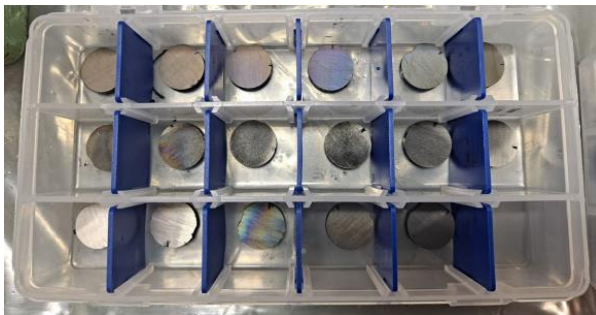
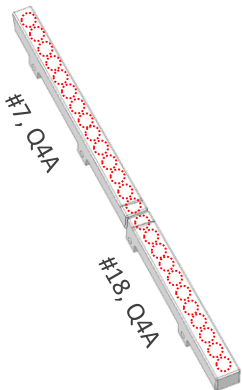
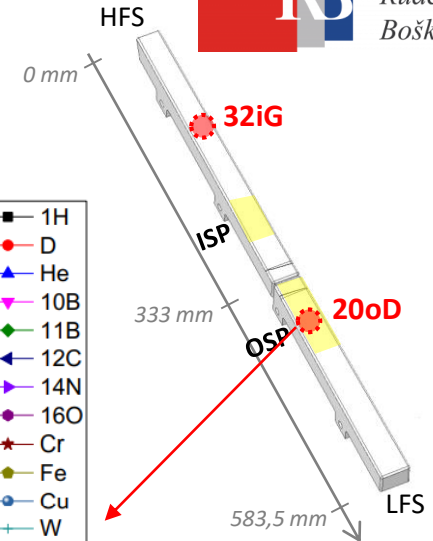
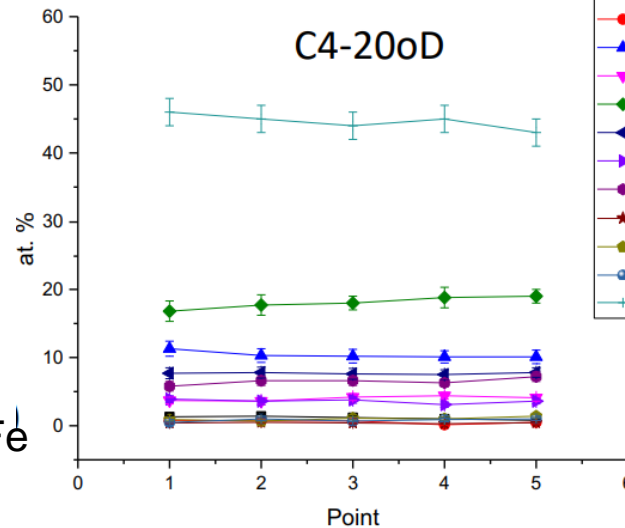
Institut
Ruđer
Bošković

Results obtained in 2022 on C4 erosion markers

Goal: obtain elemental concentration on the sample surface

IBA (Tof-ERDA) performed at RBI on:

- ▶ sample “32iG” (deposition area)
 - H, D, B, C, N, O, Cr, Fe, Cu, W
- ▶ sample “20oD” (OSP)
 - 45% W
 - 15-20% B
 - 10% He
 - rest : <10% C, O, H, D, N, F, Cr, Fe



Produced samples after core drilling
C4 standard tiles

... lead to further characterization in 2023

- ▶ He content profile along the radial direction of two C4 standard tiles installed in max OSP heat flux area (Q4A)
- ▶ scheduled for 6-8th February at RBI, Croatia



Main achievements in 2022

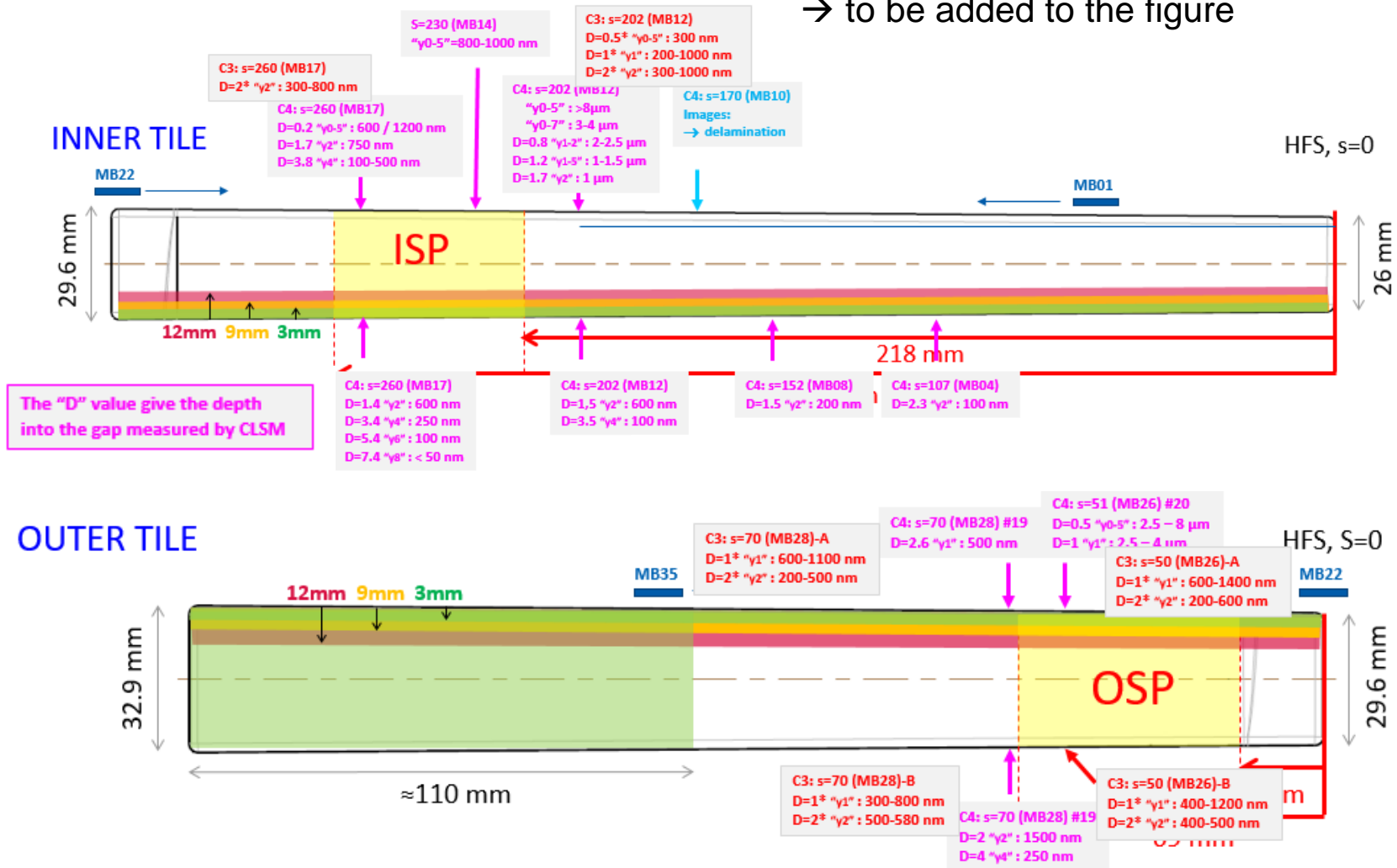
- *Microscopic observations related to erosion/redeposition studies*
- *Helium content*
- ***PWI into the gaps***
- *Compilation of depth profile data on C3 samples*
- *D inventory in C4 samples*

Deposited layers found deep into the gaps...



Goal: determine and compare thickness of deposited layers into the gaps on C3, C4, C5 marker tiles

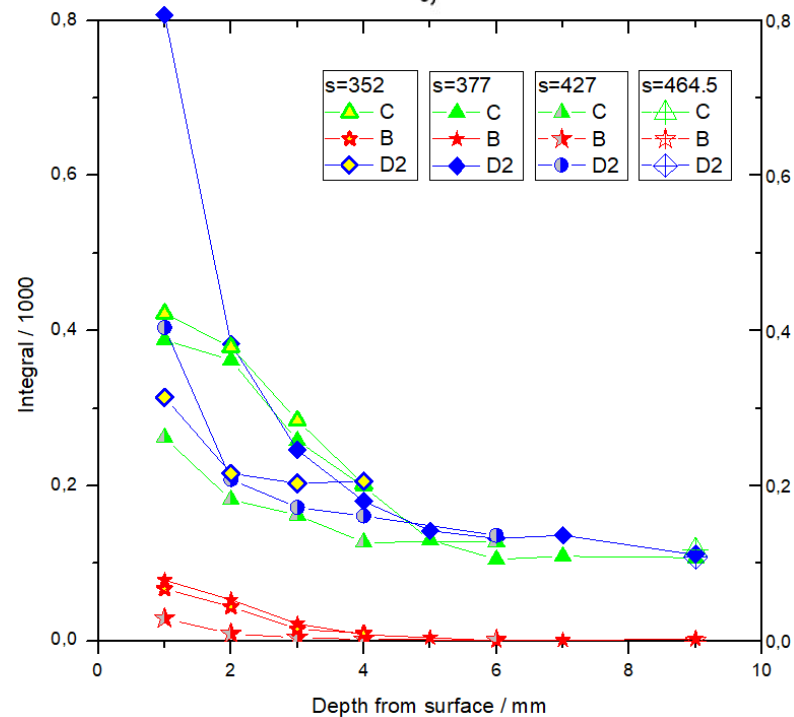
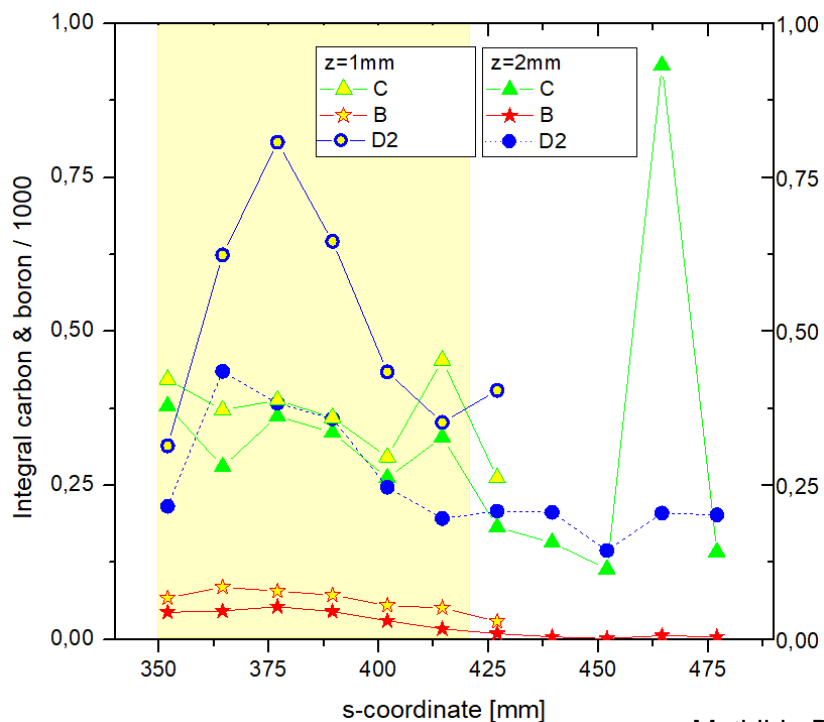
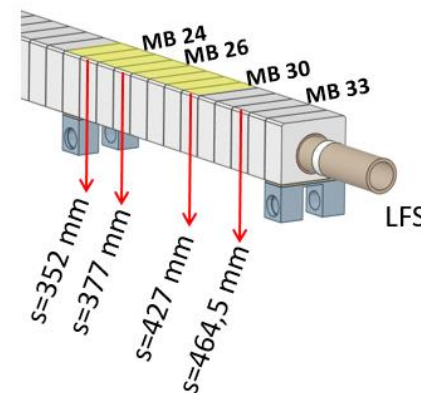
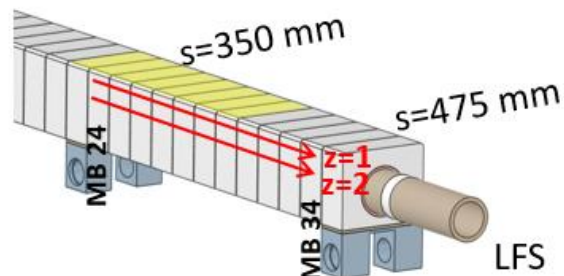
2022: data measured on C5 marker tiles
→ to be added to the figure



... with C, B, D light impurities content



Goal: determine content of deposited layers into the gaps on ITER-like PFU





Main achievements in 2022

- *Microscopic observations related to erosion/redeposition studies*
- *Helium content*
- *PWI into the gaps*
- ***Compilation of depth profile data on C3 samples***
- *D inventory in C4 samples*

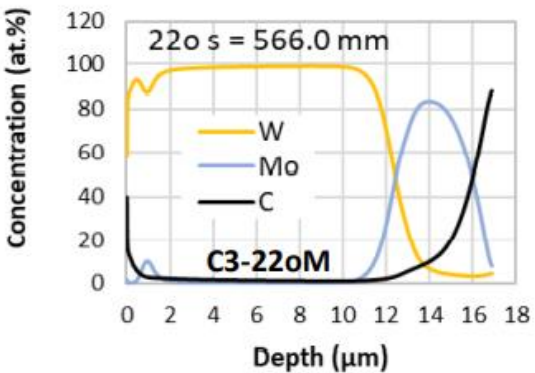
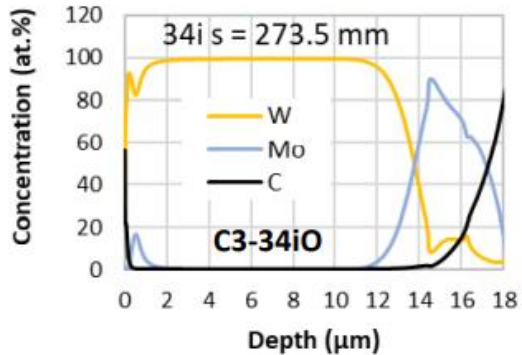
LIBS/GDOES/SIMS cross-analysis successfully conducted on C3 samples !



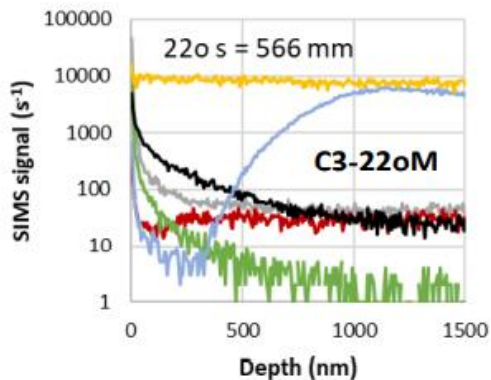
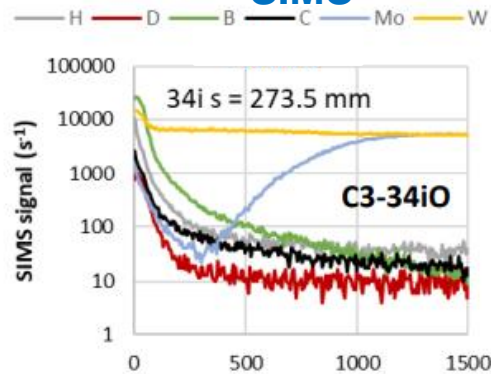
Goal: investigate the feasibility of the LIBS method for the analysis of composition and fuel retention in samples

- ▶ Comparison made between GDOES, SIMS and LIBS
- ▶ Detailed depth-profile characterization of the deposits

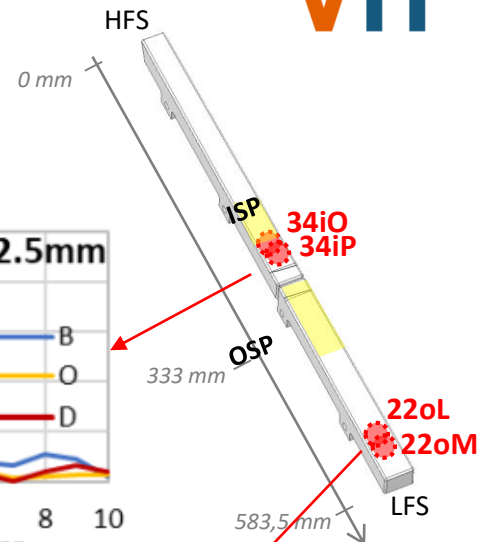
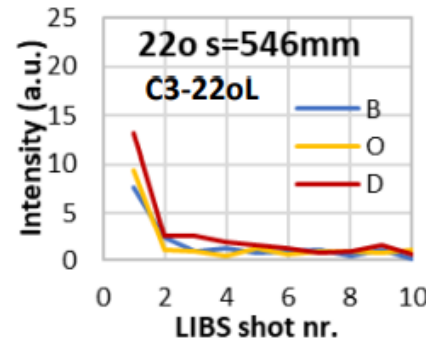
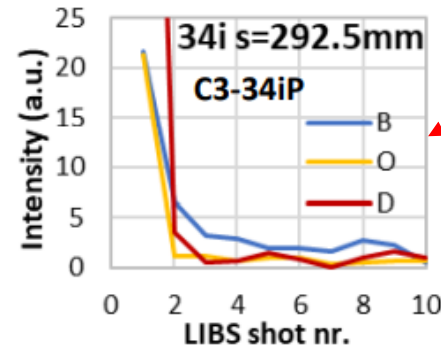
GDOES



SIMS



LIBS





Main achievements in 2022

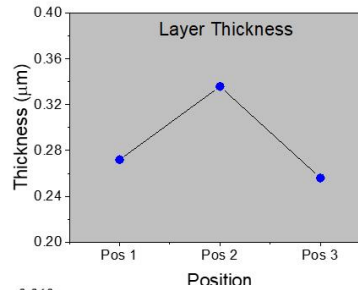
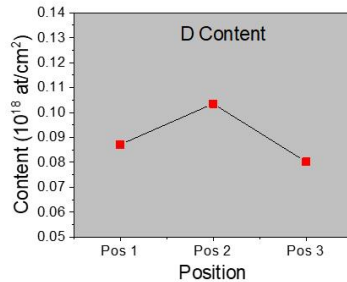
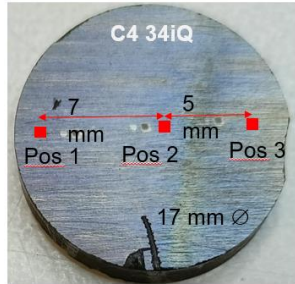
- *Microscopic observations related to erosion/redeposition studies*
- *Helium content*
- *PWI into the gaps*
- *Compilation of depth profile data on C3 sample*
- ***D inventory in C4 samples***

D inventory in C4 marker samples

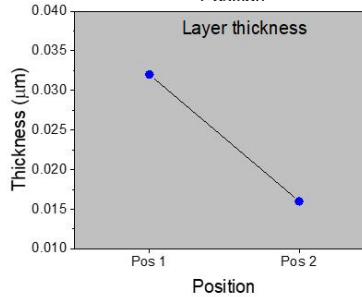
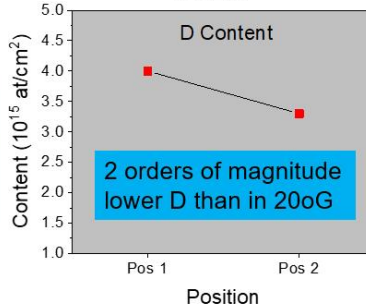
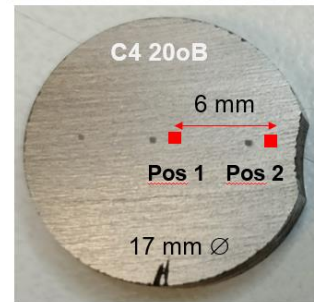
Goal: investigation of surface erosion (RBS/NRA)

120 μm Mylar between target and detector
 $^2\text{H}(^3\text{He}, p_0)^4\text{He}$: V. Kh. Alimov et al C. S. data

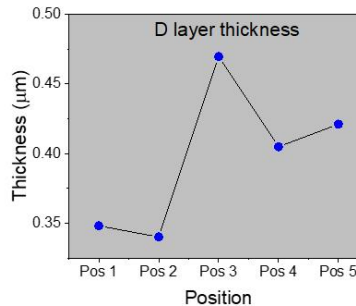
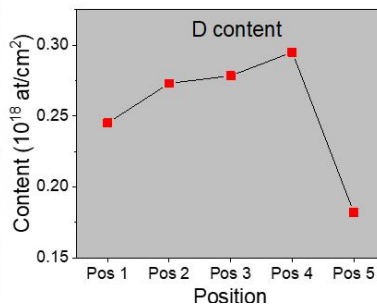
Beam: ^3He
 Energy: 2 MeV
 Detection Angle: 135°



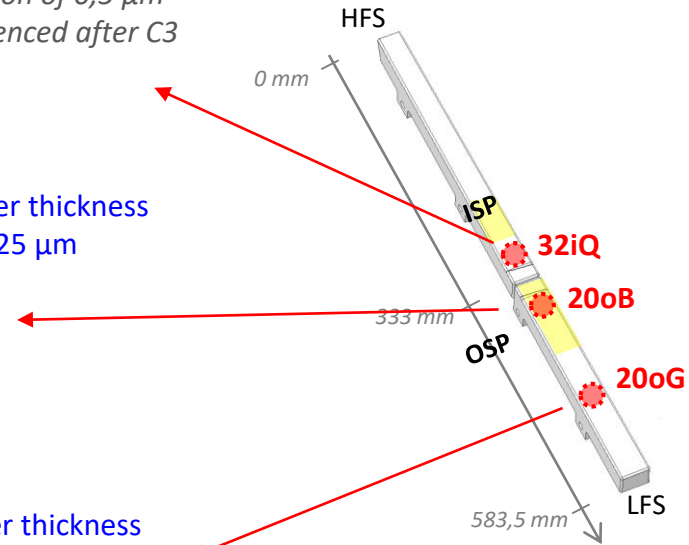
D layer thickness
 $\approx 0,3 \mu\text{m}$
 Erosion of $0,5 \mu\text{m}$
 evidenced after C3



D layer thickness
 $\approx 0,025 \mu\text{m}$



D layer thickness
 $\approx 0,4 \mu\text{m}$
 No erosion evidenced after C3



- D less present in OSP erosion dominated area
- max D content $\approx 0,3 \cdot 10^{18}$ at/cm² in shadowed region

→ Results in good agreement with those obtained on the full C4 marker tile [M. Balden et al., 2021]



Perspectives for 2023



Goal: complete the work (at least measurements) on the C3/C4/C5 marker tiles

C4 marker tiles

- ▶ Finish receiving all sample results
- ▶ Data treatment

C5 marker tiles

- ▶ RBS/NRA, SEM/FIB data treatment on the entire tiles
- ▶ Complete core sampling
- ▶ Perform samples analysis
 - *ICFRM: E. Bernard et al. on C3/C4 marker tiles analysis*
 - *Any papers / conferences contribution on WEST PFCs welcome !*

Standard tiles exposed to C4 only

- ▶ SEM/FIB/EDX Data treatment

C4 standard tiles

- ▶ Complete the measurements of helium content by Tof-ERDA
- ▶ Data treatment

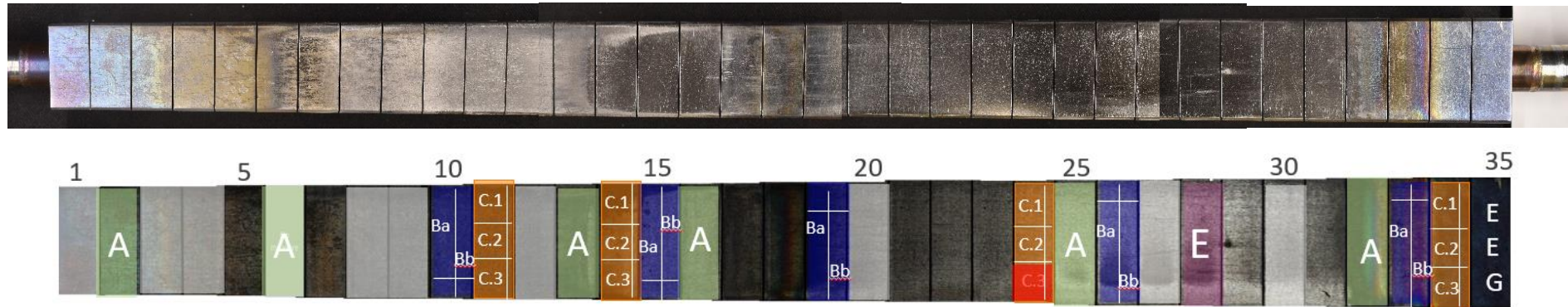
Others

- ▶ Thoughts about the analysis of poloidal/toroidal gaps

Perspectives for the analysis of ITER-like PFUs



Distribution matrix of C3+C4 ITER-like PFU#13



The W monoblock sample analysis in 2023 is organized as follow:

- ▶ **Batch A:** composition variation on the plasma exposed surface
- ▶ **Batch B:** He and microstructure
- ▶ **Batch C:** fuel retention
- ▶ **Batch D:** optical hot spots
- ▶ **Batch E:** surface modification along the toroidal direction

batch C – Retention

MB 11-14-24-34

1. Microscopy PIIM (EDS, Raman, FIB, TEM deposits)
2. μ NRA: JSI
3. ERDA (Helium): IPP MPG (to be confirmed)
4. TPD /TDS: PIIM, France (sample: 10x10mm²)
5. Metallography at Mines (14.3 and 24.3)

batch A – « composition variation on the plasma exposed surface »

MB 2-6-13-16-25-32

SIMS: VTT, Finland (requires cutting)

LIBS: UT, Estonia

NIFS+ANU, Japan (comparison first wall samples)

Batch Ba&Bb – « He and microstructure »

MB 10-15-19-26-33 cut in two

- | | |
|---|--|
| <ol style="list-style-type: none"> 1. Microscopy: WUT ? 2. IBA: VR 3. PAS: CEMHTI (M15) 4. Metallography: Mines de St Etienne | <ol style="list-style-type: none"> 1. Microscopy: PIIM 2. IBA: RBI 3. GDOES: INFLPR |
|---|--|

batch E – surface modification on toroidal direction

Whole MB28, requires cutting

DEMOKRITOS, Greece

Fuel retention, deposition/erosion + 'humps' on leading edge, microstructure/grain size : → SEM, EDX, FIB, IBA, ...

(+ emissivity variation at IUSTI, France ?)

Will be discussed during a dedicated meeting → Doodle poll coming soon...

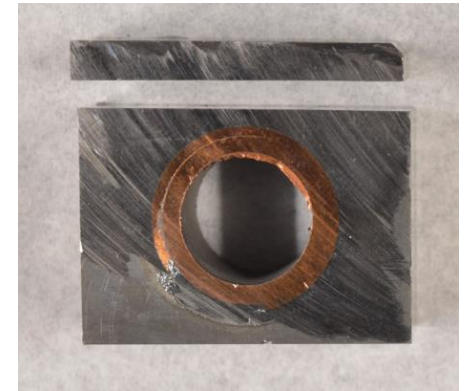
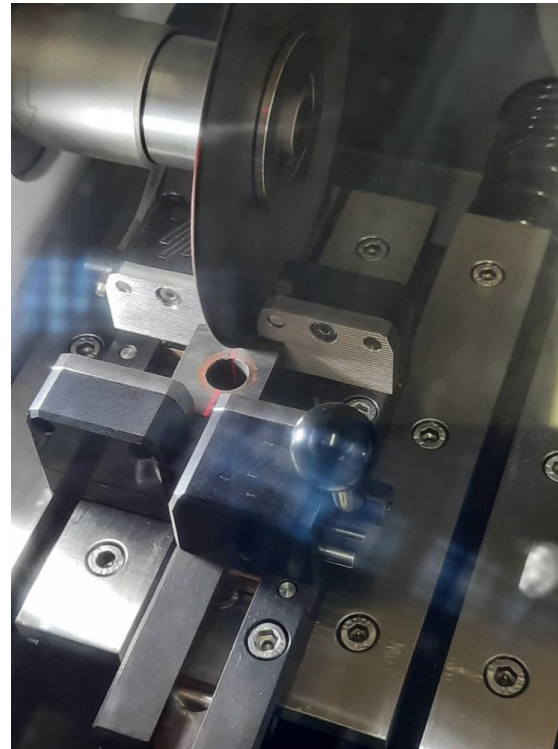
batch D « Optical Hot Spot » - M24.3

Microstructure/optical hot spot at Mines de St Etienne, France



W monoblock samples cutting is now starting !

- ▶ precision cutting
- ▶ diamond saw (able to cut hard materials such as W)
- ▶ water free (no surface contamination)



Samples analysis scheduled to start mid-2023



EUROfusion



This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.