WP PFC SP5: Post mortem analyses and material migration

Antti Hakola
VTT

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Introduction

- In 2020, besides the ongoing activity areas, finally WEST-related work started
  - ✓ SP5.1: Material migration in tokamaks
  - ✓ SP5.4: Development of mixed-material reference coatings
  - ✓ SP5.7: Dust production mechanisms in tokamaks
  - ✓ SP5.8: Post-exposure analyses of WEST plasma-facing units from deuterium and helium plasma operations
- Due to COVID-19, some tasks delayed or partly shifted into 2021
  - ✓ Especially, most of the SP5.8 activities only in 2021

Activity	Orig. PM in 2020	Analysis & HW (k€)	RUs involved
SP5.1	51.5	45.5	FZJ, IPPLM, JSI, MPG, RBI, VR, VTT
SP5.4	34.0	11.0	CEA, DIFFER, ENEA, FZJ, IAP, IPPLM, IST, JSI, RBI, VTT
SP5.7	24.0	3.0	ENEA, IAP, IPPLM, JSI, MPG, VR
SP5.8	25.0	9.0	CEA, FZJ, IAP, IPPLM, IST, MPG, RBI, VR, VTT

- Usage of facilities:
  - ✓ PSI-2: 4 days (sample exposure for WEST and test coatings)
  - ✓ MAGNUM: 1 days + 2 days from 2019 (exposing test coatings)

SP5 focus points in 2019/20

I: Understanding material migration pathways on AUG, W7-X, and WEST (SP5.1, SP5.8)

II: Clarifying the role of surface roughness and modifications on gross and net erosion of PFCs (SP5.1, SP5.4)

III: Developing Be-based coatings to simulate co-deposits observed on JET-ILW tiles and expected on ITER (SP5.4)

IV: Identifying dust sources on AUG and measuring and modelling the contribution of arcing to erosion and dust production (SP5.7)

V: Studying plasma-wall interaction processes in samples exposed to He plasmas (SP5.1, SP5.8)

SP5.1: what was promised?

- Surface analyses of AUG samples and wall tiles originating from plasma operations in 2019 and 2020
- Surface analyses of marker samples exposed on AUG in 2019 and 2020
- Erosion and deposition studies on W-coated samples with different roughness on AUG
- Post exposure analyses of W7-X marker tiles and other wall components including long-term samples after the OP1.2b campaign
- Analysis of plasma-exposed W7-X samples and tiles for their surface modifications and deposition of impurities and tracer elements
- Providing data of gross and net erosion patterns on AUG samples for modelling efforts under SP4.1 and SP4.2
- Surface analyses of W-isotope enriched coatings after exposure to tokamak plasmas

SP5.4: what was promised?

- Production and characterization of ITER and JET-ILW relevant Be-based coatings at different temperatures simulating plasma and baking cycles
- Production of ITER and DEMO relevant W-based coatings with different gas and impurity contents
- Preparation of reference coatings with different roughnesses for experiments under SP2 and SP5.1
- Production of samples for LIBS studies
- Loading selected samples with fuel (D, He) by plasma exposure in linear devices (MAGNUM, PSI-2)
- Surface analyses of the produced reference samples
- Development of Re/Ta reference coatings and isotope-enriched W samples

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SP5.7: what was promised?

- Determining arcing patterns on various AUG wall tiles
- Studying the dust production on AUG with the help of long-term samples
- Comparing the results obtained from AUG and other tokamaks (including FTU) for co-deposits with the lab samples produced by a dust-gun device
- Validate droplet ejection simulation results against experimental data of arcing obtained from AUG and JET
- Carry out laboratory experiments of W and Be dust generation during simulated air and water leaks

SP5.8: what was promised?

- Erosion, deposition, and fuel-retention studies of WEST PFUs after the C3 and C4 campaigns
- Characterizing ageing of PFUs including changes in their surface roughness and morphology, and crack formation
- Determining and analysing heat-load patterns on PFUs
- Investigating He retention, PFU erosion, formation of co-deposited layers on W surfaces, and the formation and destruction of W fuzz resulting from exposure of PFUs to He plasmas on WEST
- Developing in situ LIBS as a fuel-retention diagnostics on WEST

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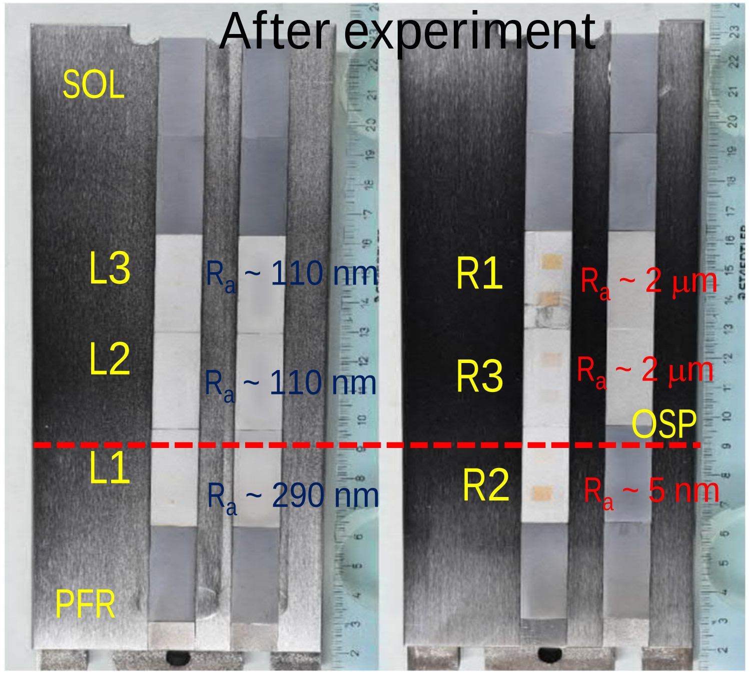
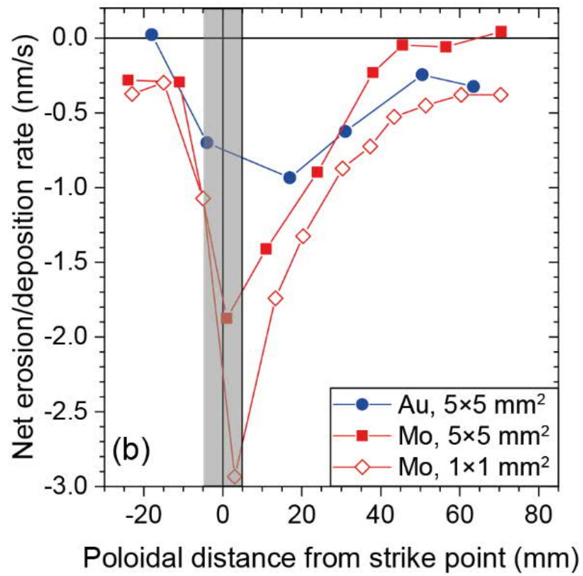
SP5.1: Material migration in tokamaks – main achievements

- with contributions also from SP5.4

AUG: exposing marker samples to L- and H-mode plasmas (VTT, MPG, RBI)

- Main goals:
  - ✓ Investigate gross and net erosion of W in different plasma conditions on ASDEX Upgrade (AUG) using Mo-coated (~200 nm) graphite samples with 1×1 mm^2 or 5×5 mm^2 Au marker spots (thickness ~20 nm)
  - ✓ Provide benchmarking data for ERO modelling
- <u>Experiment #1</u>: AUG L-mode experiment from 2019
  - ✓ $B_t = 2.5$ T, $I_p = 0.8$ MA, $n_{e,core} \sim 4\times10^{19}$ m^{-3}
  - ✓ $P_{ECRH} = 0.8$ MW, $T_{e,peak}$ ~20-25 eV, $\tau_{exposure} \sim 44$ s
- Achievements in 2020:
  - ✓ ERO and OSM simulations revisited (for PSI 2020, see SP4.2 talk)
  - ✓ Broad-beam RBS results for Au and Mo erosion consolidated, erosion profiles to be compared with microbeam data from samples L1, L2, R2, and R3 (estimated early 2021)





A. Hakola, J. Likonen, A. Lahtinen, K. Krieger, M. Balden, M. Brajković, M. Barac, S. Gouasmia, Z. Siketić, I. Bogdanović Radović

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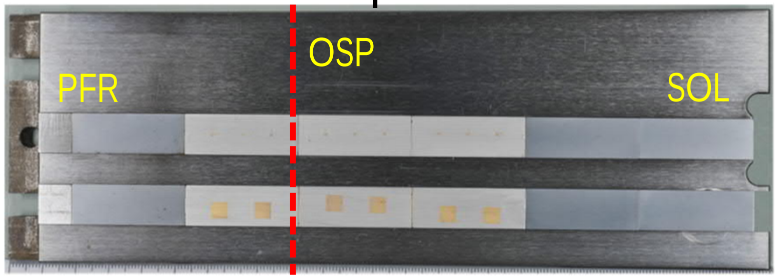
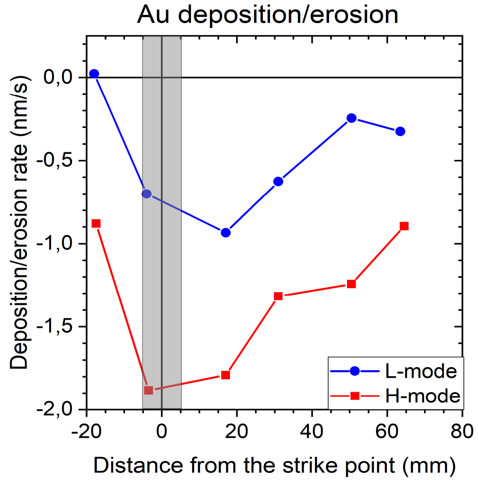
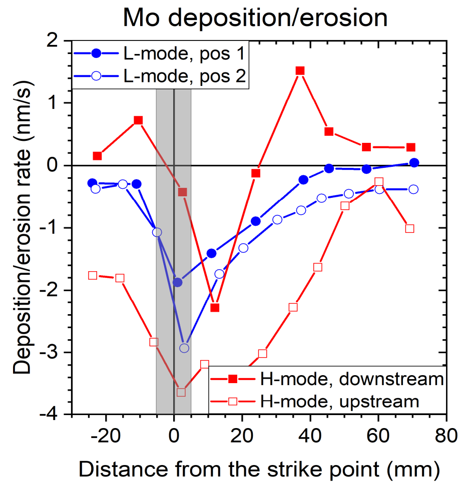
  - ✓ Provide benchmarking data for ERO modelling
- Experiment #2: AUG H-mode experiment from 2019 – “large ELMs”
  - ✓ $B_t = 2.4$ T, $I_p = 1.0$ MA, $n_{e,core} \sim 9\times10^{19}$ m^{-3}
  - ✓ $P_{ECRH} = 3.4$ MW, $T_{e,peak}$ ~20-25 eV, $\tau_{exposure} \sim 12$ s
- Achievements in 2020:
  - ✓ Broad-beam RBS measurements made and results available
  - ✓ Comparison between L- and H-mode results made (for IAEA FEC 2020)

After experiment







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AUG: exposing marker samples to L- and H-mode plasmas (VTT, MPG, RBI)

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  - ✓ Provide benchmarking data for ERO modelling
- <u>Experiment #3</u>: AUG H-mode experiment from 2020 with 2 different OSP positions – “small ELMs”
  - ✓ B_t = 2.5 T, I_p = 0.6 MA, $n_{e,core}$ ~ 8×10^{19} m^{-3}
  - ✓ P_{NBI}=5.0 MW, P_{ECRH} = 4.0 MW, $T_{e,peak}$ ~30 eV
  - ✓ Left tile: marker samples above OSP 2 and roughness samples between OSP1 and OSP2
  - ✓ Right tile: Re- and Mo-coatings and roughness samples between OSP 1 and OSP 2
- Achievements in 2020:
  - ✓ Experiment done in 07/2020
  - ✓ Post-exposure analyses pending

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After experiment

AUG: Microscale analyses of exposed marker samples (VTT, MPG, RBI)

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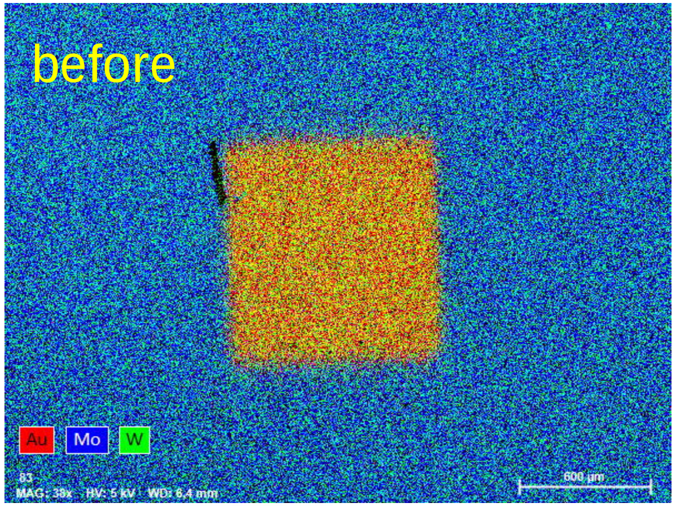
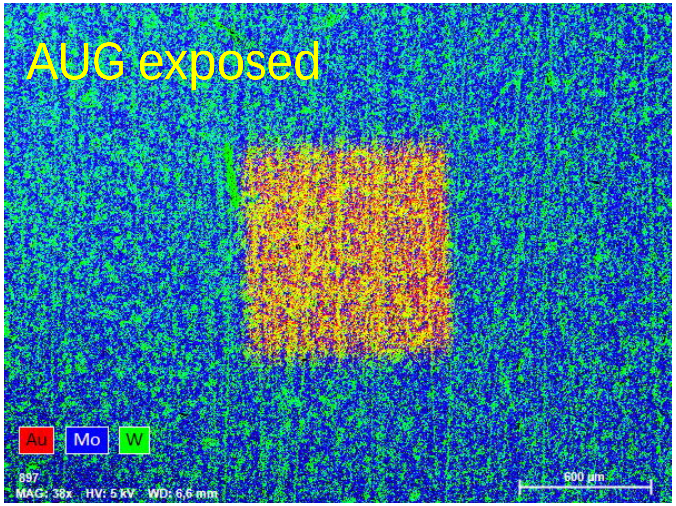
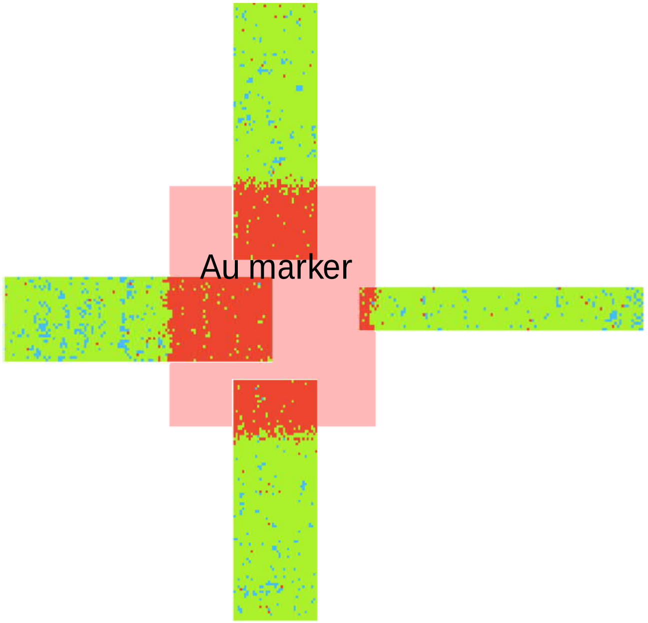
- Focus on samples from the AUG 2019 L-mode experiment
- SEM/EDX indicates the Au deposition outside markers being below sensitivity threshold (masked by Mo) – left and middle
  - ✓ To be verified by microbeam measurements at JSI
- First micro-PIXE and RBS measurements carried out for the L1 and L2 samples - right
  - ✓ Peaked erosion profile: L1 thickness ~10 nm, L2 thickness ~22 nm
  - ✓ Analyses complicated by overlapping W and Au peaks in PIXE
  - ✓ Au can be seen outside the marker spots (but results still to be confirmed)
  - ✓ Tiny spots rich in Fe, Cr, and Ni also observed (blue)







AUG: Production of samples with varying surface roughness (JSI, VTT, MPG, ENEA)

E. Vassallo, D. Dellasega, M. Passoni

- Main goal:
  - ✓ Produce Mo-coated graphite samples with varying surface roughness for lab studies and AUG experiments
- In 2020, focus on additional batches for a new experiment on AUG (July 2020)
  - ✓ Substrates exposed to fluorine-based plasma etching → average roughness values R_a = 110 and 290 nm
  - ✓ Mo layer produced on treated substrates using Pulsed Laser Deposition
  - ✓ In addition, films produced on glass-blasted graphite (R > 1 μm)
- Produced films mimic the underlying substrate morphology

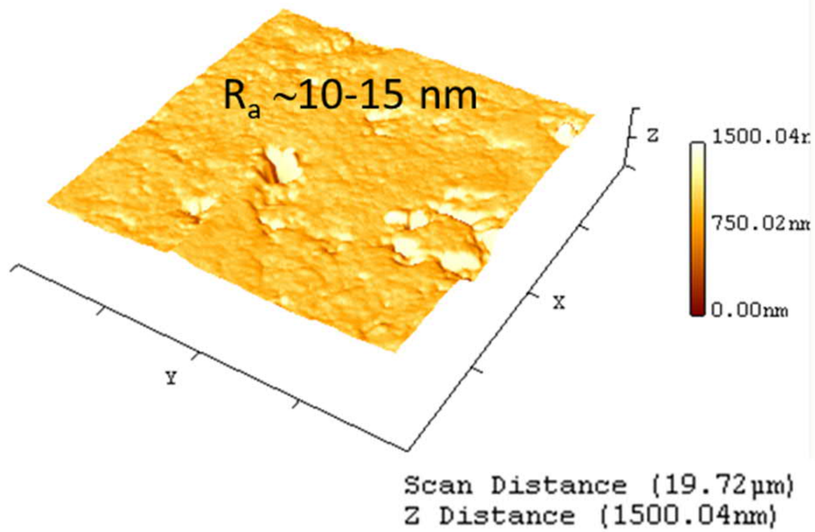


Fig. 1. As received polished SIGRAFINE® R6710 graphite -AFM analysis

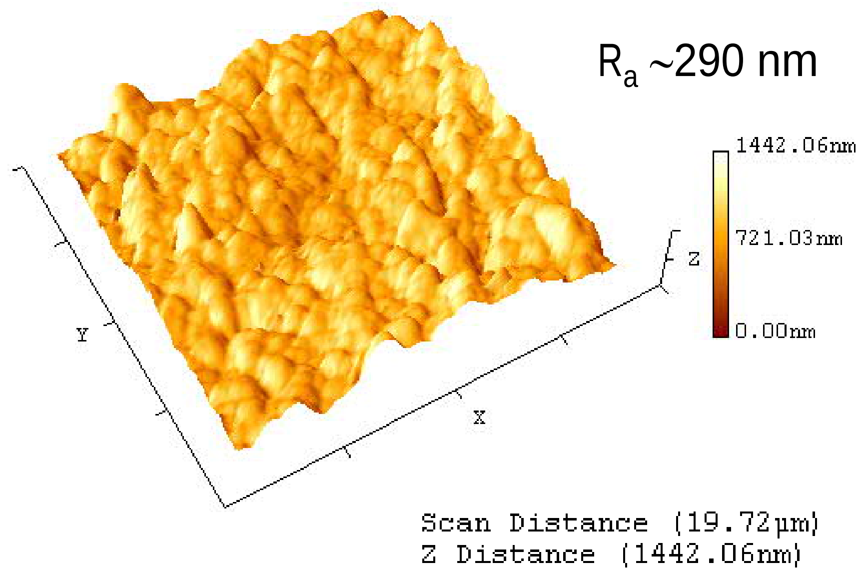
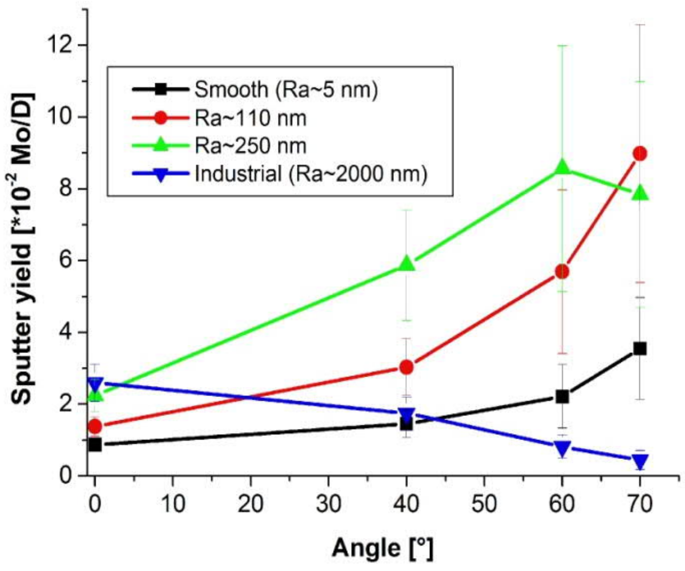


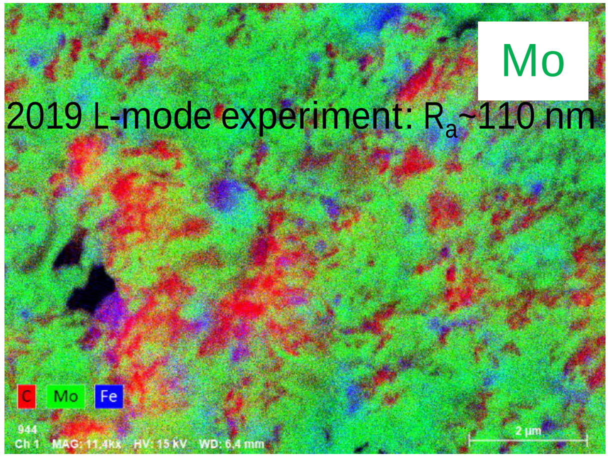
Fig. 2. Plasma treated graphite (etching for 90 min)

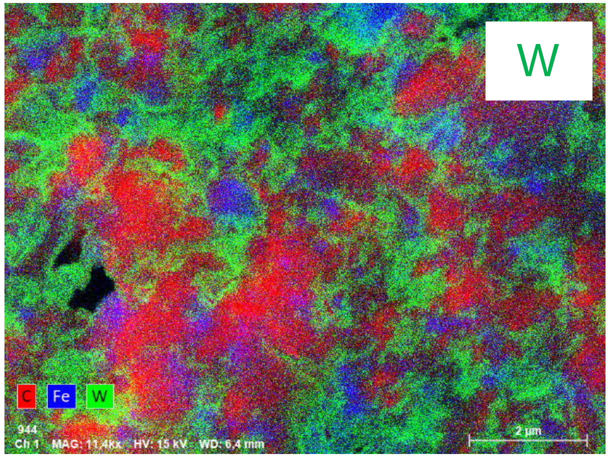
AUG: Exposure of roughness samples to L- and H-mode plasmas (JSI, VTT, MPG)

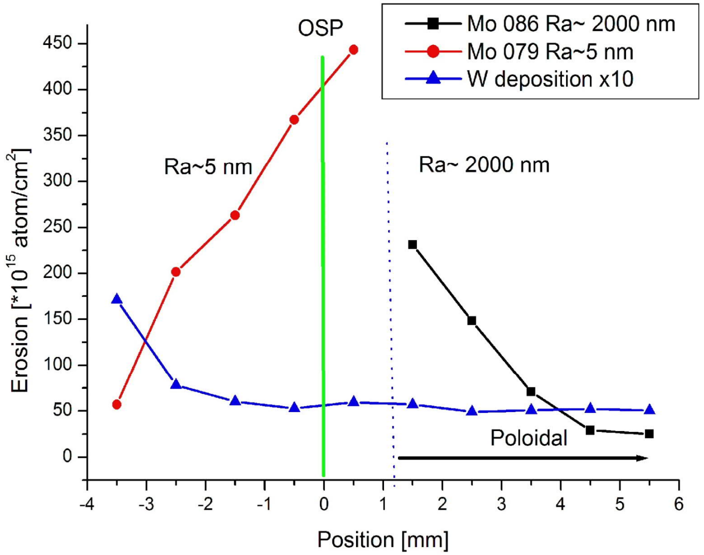
M. Kelemen, S. Markelj, M. Balden

- Key focus points in 2020
  - ✓ Finish analysis of data from laboratory samples → article sent for publication
  - ✓ Complete measurements of samples originating from 2019 experiment on AUG → article in preparation
  - ✓ Expose new sets of samples to AUG plasmas in 2020 → in connection with the marker samples
- AUG 2019 samples exhibit well-known deposition pattern (below): Erosion at elevations and deposition in depressions



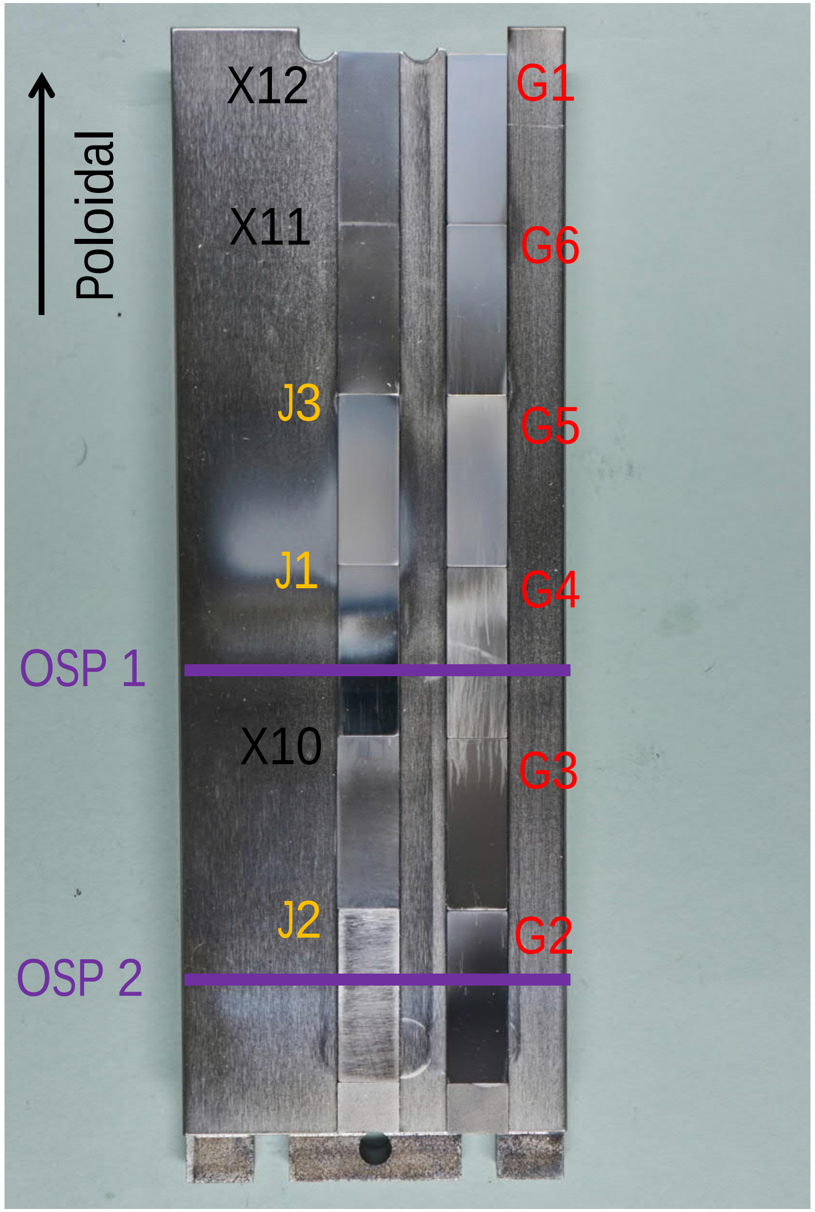






AUG: exposure of nanostructured W to He plasmas (FZJ, MPG, VTT, RBI)

- Samples resulting from a 2-phase plasma experiment on AUG
  - ✓ OSP 1: H-mode part for eroding fuzz
  - ✓ OSP 2: L-mode part for growing fuzz
- Sample types:
  - ✓ G1-6: Bulk W samples, pre-exposed in GLADIS (see right)
  - ✓ J1: W fuzz (from PSI-2); J2: W rough; J3: W polished
  - ✓ X10-12: Mo-coated graphite markers
- Main focus points in 2020
  - ✓ Determine deposition of impurities and He (X10-X12) on the samples
  - ✓ Complete microscopy analyses of G1-G6 and J1-J3



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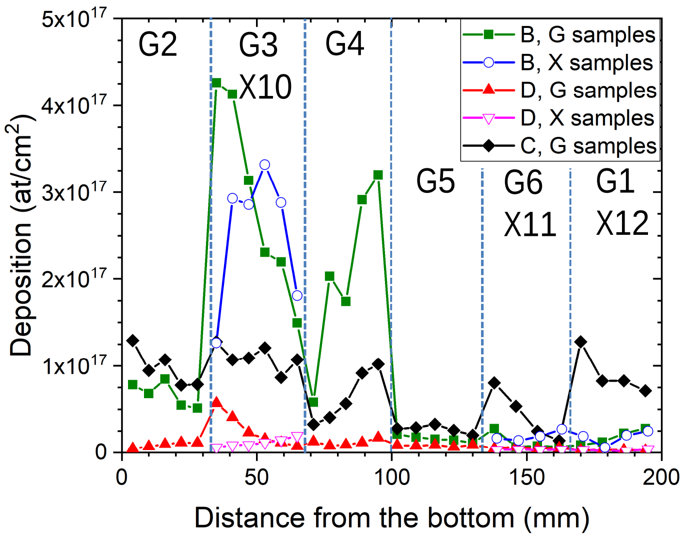
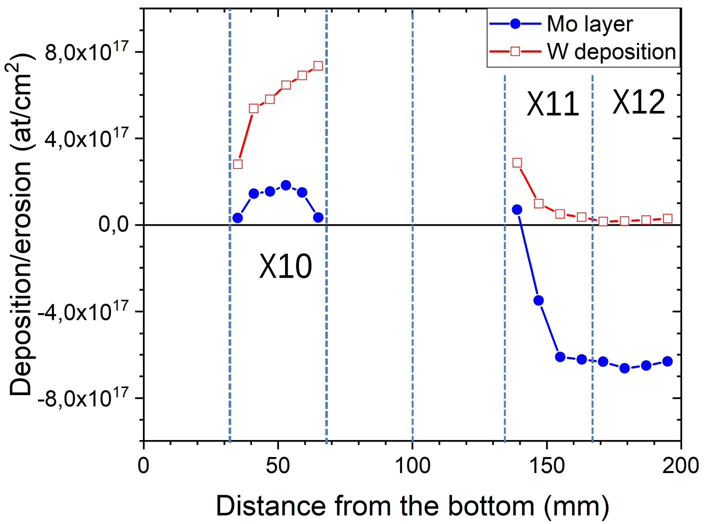
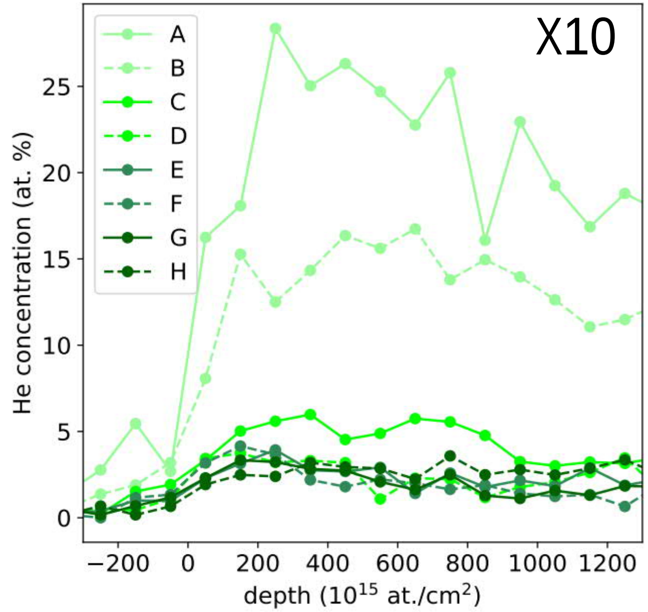
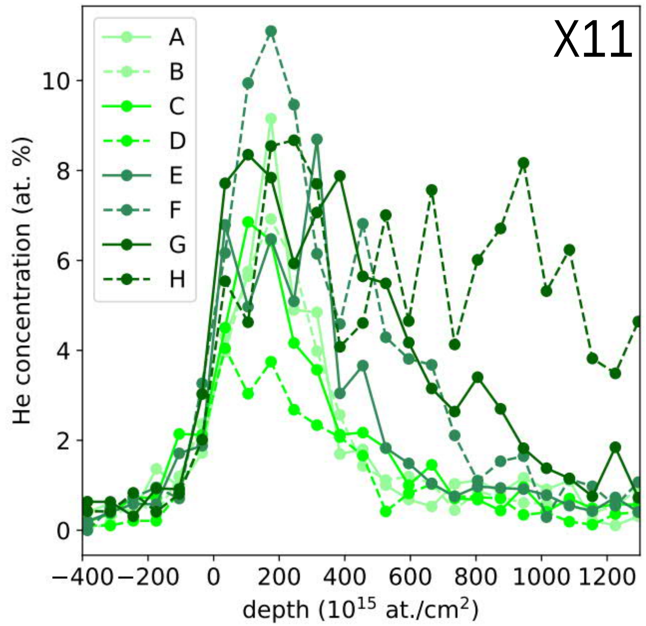
AUG: exposure of nanostructured W to He plasmas (FZJ, MPG, VTT, RBI)

- Observed elements D, He, B, C, N, O, Cr, Fe, Mo, and W
- Main results:
  - ✓ B shows strong deposition peaks below or around OSP 1, smaller peaks for D and C as well
  - ✓ He concentration up to 25 at.% on sample X10 (between OSP 1 and OSP 2), remains <10 at.% for X11 (in the SOL)
  - ✓ More metallic impurities on X10 than on X11
  - ✓ Net erosion up to 100 nm of Mo on X11 and X12, sample X10 shows net deposition of both W and Mo









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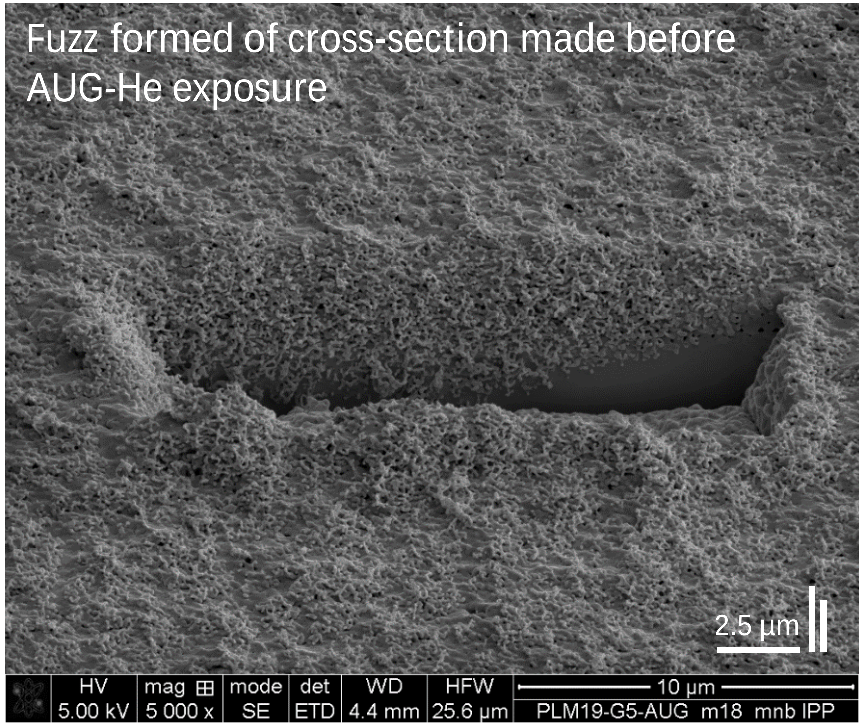
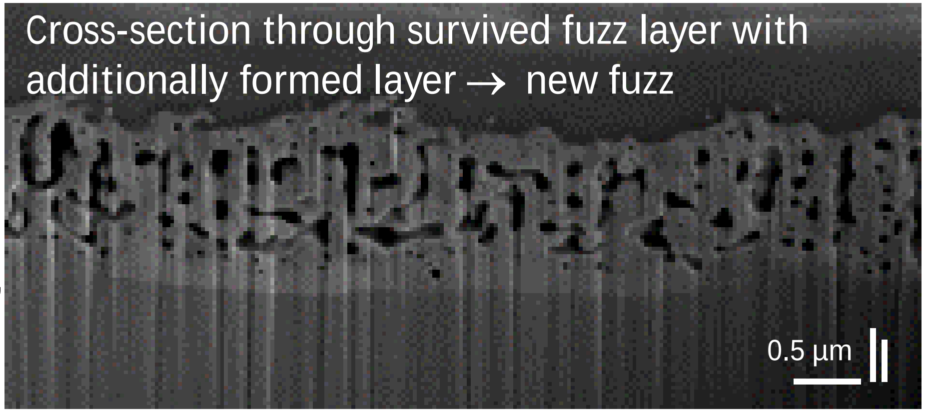
AUG: exposure of nanostructured W to He plasmas (FZJ, MPG, VTT, RBI)

- Microscopy analyses of the G samples completed and results made available for publications
- Main results:
  - ✓ Pre-formed fuzz survives and is covered by layer (unclear if erosion of fuzz nano-tendrils occurs)
  - ✓ New fuzz is formed on cross-section plane prepared before AUG exposure for fuzz thickness determination
  - ✓ Fuzz is formed on surrounding DIM-tile





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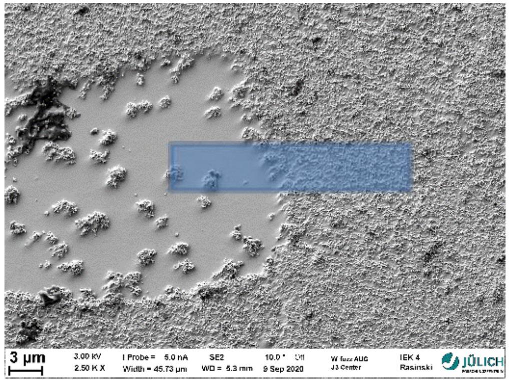
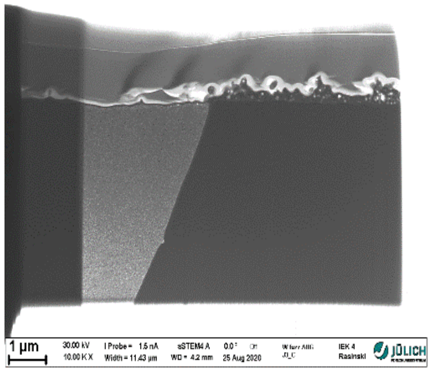
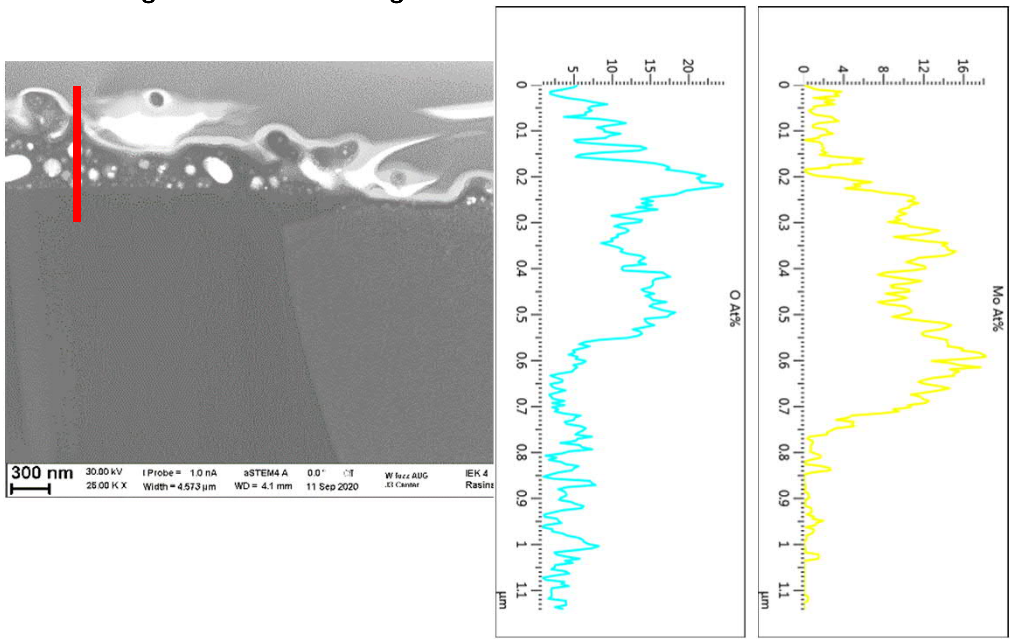
AUG: exposure of nanostructured W to He plasmas (FZJ, MPG, VTT, RBI)

- Also microscopy analyses of the J samples largely completed
- Main results:
  - ✓ Fuzz with thickness up to 400 nm found, consisting of tungsten with addition of Mo and O; Mo found throughout the layer, O in the top part
  - ✓ Distribution of fuzz not homogeneous along the surface.
  - ✓ Most of the samples covered with fuzz, but some grains are nearly free of it





SEM image of the J3 sample surface together with TEM lamella coming from marked region



STEM image of the J3 sample surface together with EDX line scan along red line. Enrichment in Mo and O is presented

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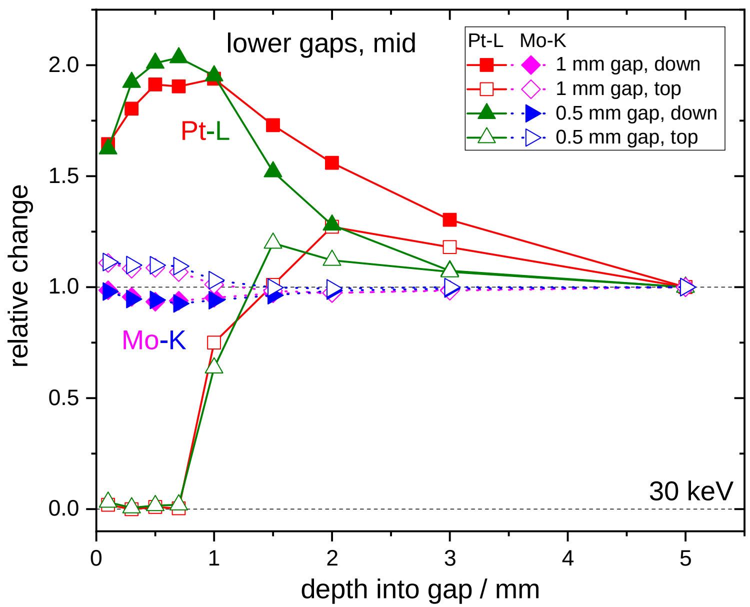
AUG: plasma loading in gaps of castellated divertor (MPG, RBI)

- Goal: Study ELM-induced toroidal power loads to gaps due to gyration of plasma species → experiment on AUG in reversed B_t/I_p with Pt-coated gap samples in early 2020
- Main results:
  - ✓ Erosion of Pt coatings confirmed, erosion varies along gaps
  - ✓ Re-deposition of Pt and Mo together with deposition of W, Ni, C, B and O from the plasma
  - ✓ Deep deposition into toroidal gaps



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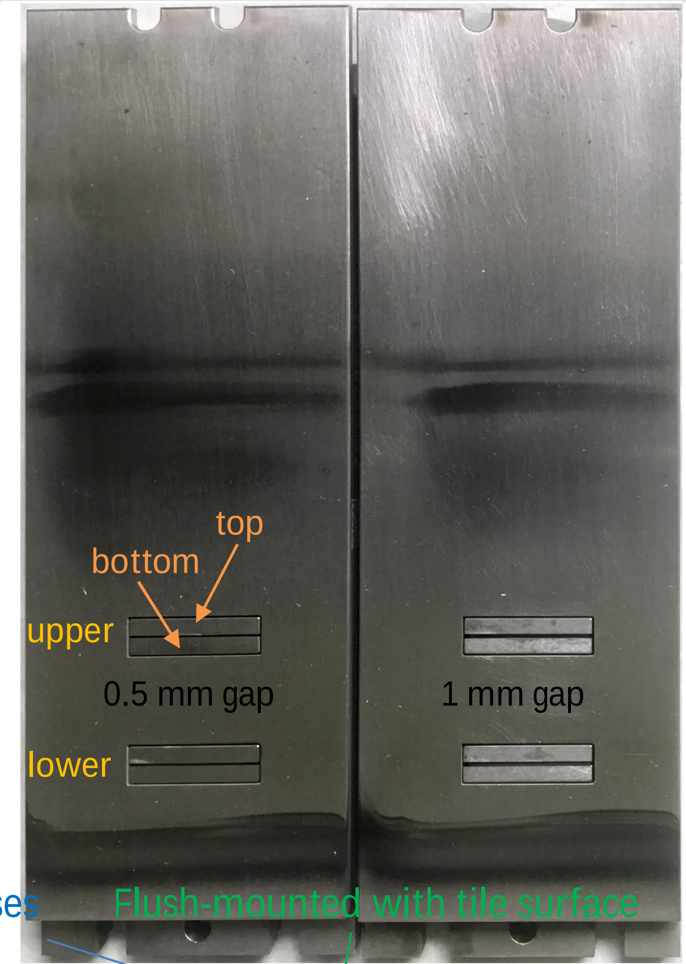
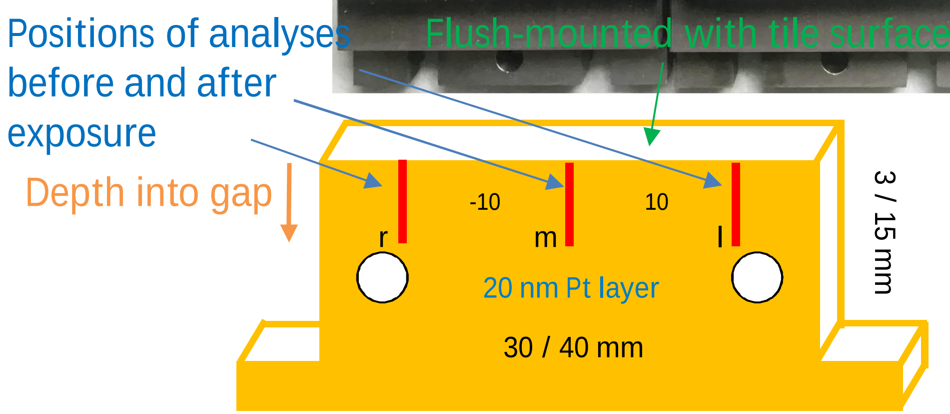
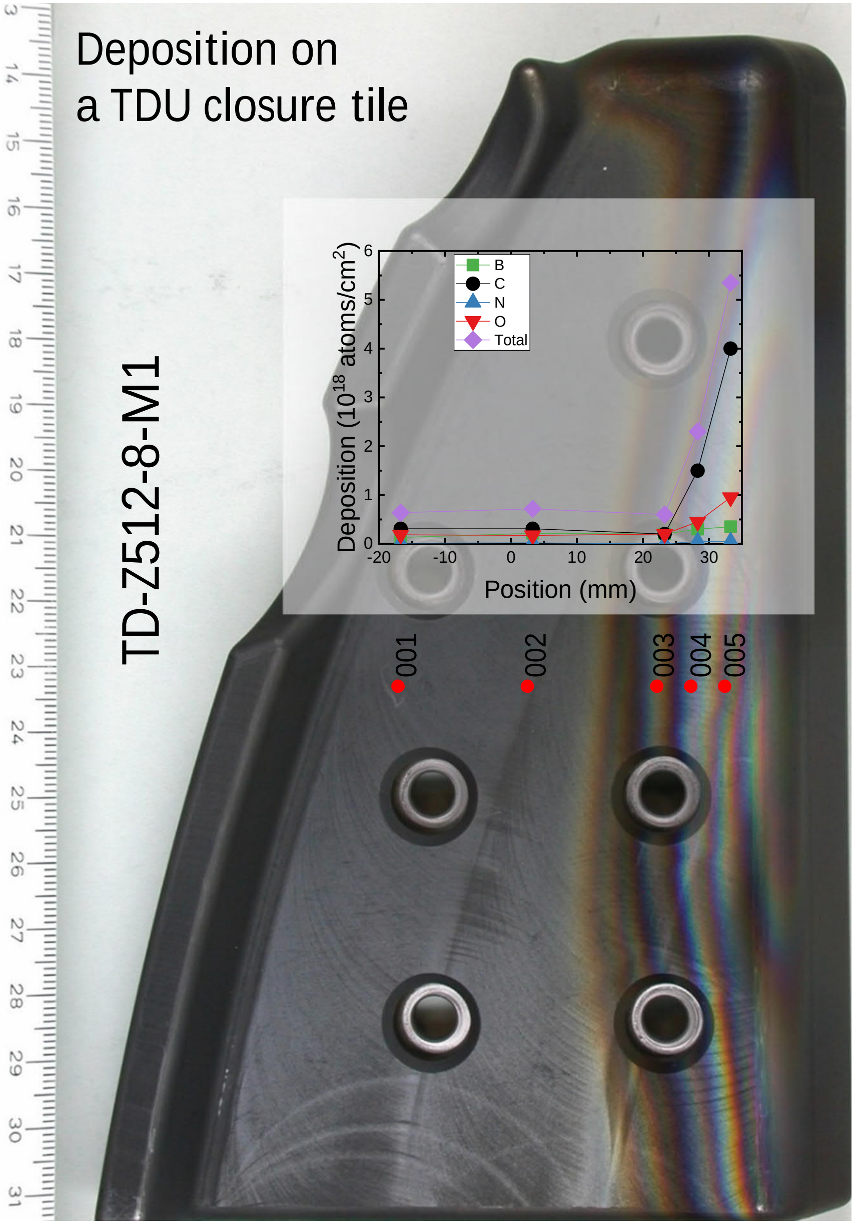




W7-X: erosion/deposition patterns on wall components (MPG, FZJ, IPPLM)

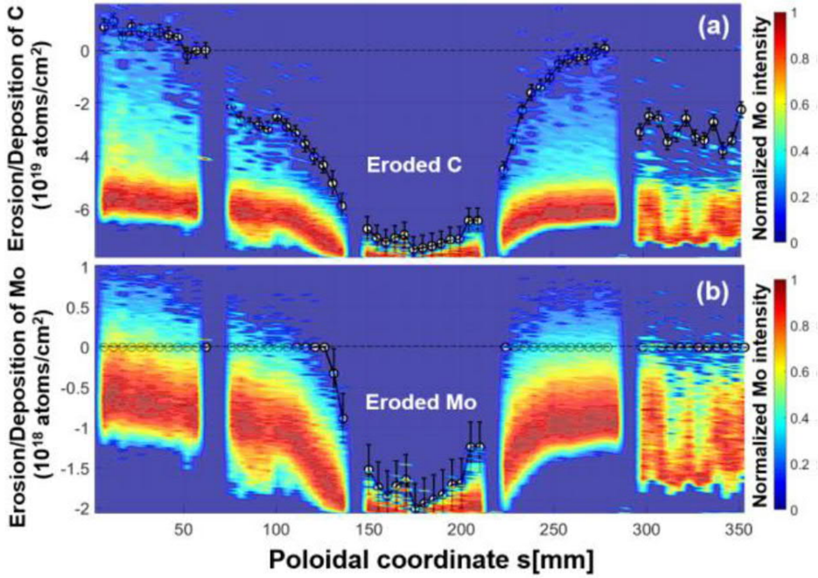
- Main goals in 2020: complete analysis of ion-beam data to determine erosion/deposition profiles on various W7-X samples after OP1.2b
- Main results of the analyses:
  - ✓ W-coated Inner Heat Shield tiles
    - o W erosion small, tiles coated with B and C
  - ✓ Regular carbon tiles from Inner Heat Shield and Baffles
    - o Sometimes deposits > 1 µm, mainly C and B
  - ✓ Various other parts (GDC electrode, reflectometry mirrors, pumping gap closure tiles,...) measured and evaluated
- Novel methods developed for data evaluation:
  - ✓ "Before" measurements analysed using automated fits and artificial neural networks
  - ✓ "After" measurements analysed using artificial neural networks



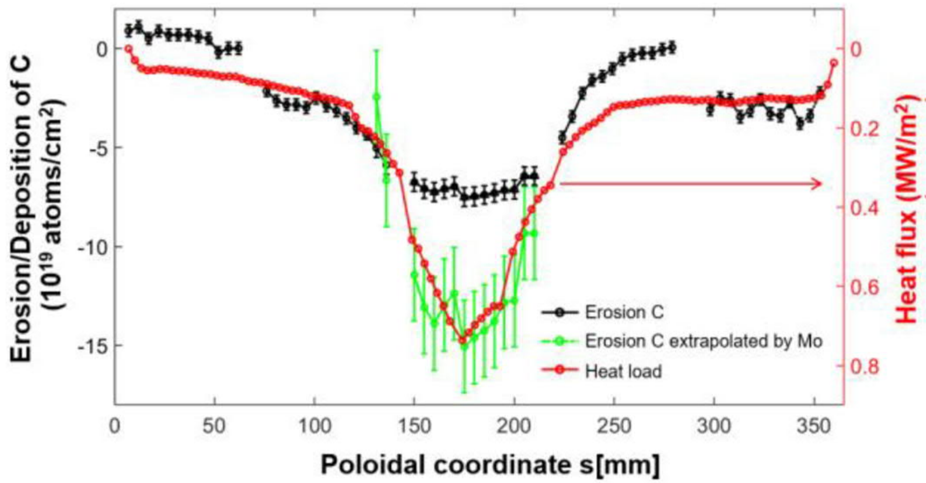
M. Mayer, S. Brezinsek, M. Rasinski, D. Zhao, E. Fortuna-Zalesna

W7-X: erosion/deposition patterns on wall components (MPG, FZJ, IPPLM)

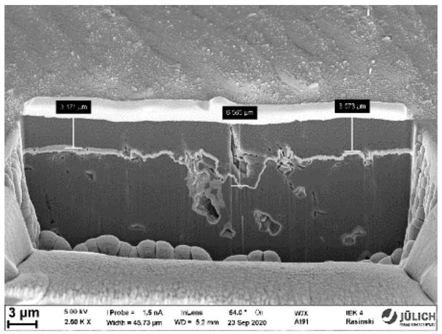
- Main goals in 2020:
  - ✓ Apply picosecond-LIBS for determining erosion/deposition patterns on OP1.2a wall components
  - ✓ Carry out microscopy analyses for OP1.2b wall components
- Status of the work:
  - ✓ Clear erosion/deposition patterns observed for C and Mo after the OP1.2a campaign
  - ✓ Analysis of the OP1.2b tiles ongoing – first erosion data of C with Mo interlayer available
  - ✓ Set of OP1.2b samples delivered to Warsaw for detailed microscopy studies → work started



Erosion of C (a) and Mo (b) of the target element TM2v2 by ps-LIBS (OP1.2a campaign).



Erosion/deposition of C during OP1.2a based on ps-LIBS.



SEM image of the A191 tile with visible Mo marker interlayer and erosion of deposited C

M. Mayer, S. Brezinsek, M. Rasinski, D. Zhao, E. Fortuna-Zalesna

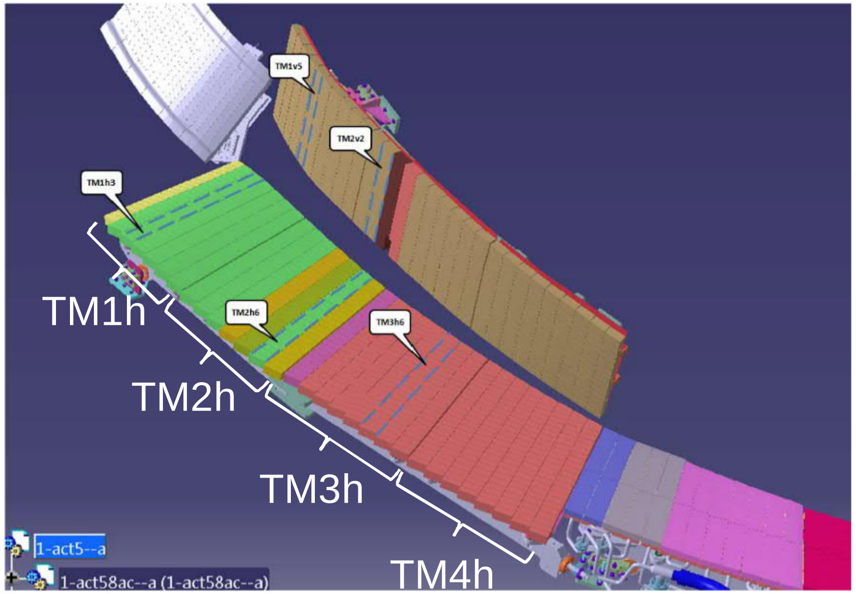
W7-X: deposition patterns of ^{13}C on wall components (FZJ, MPG, VTT, VR)

S. Brezinsek, T. Dittmar, M. Mayer, A. Hakola, T. Vuoriheimo

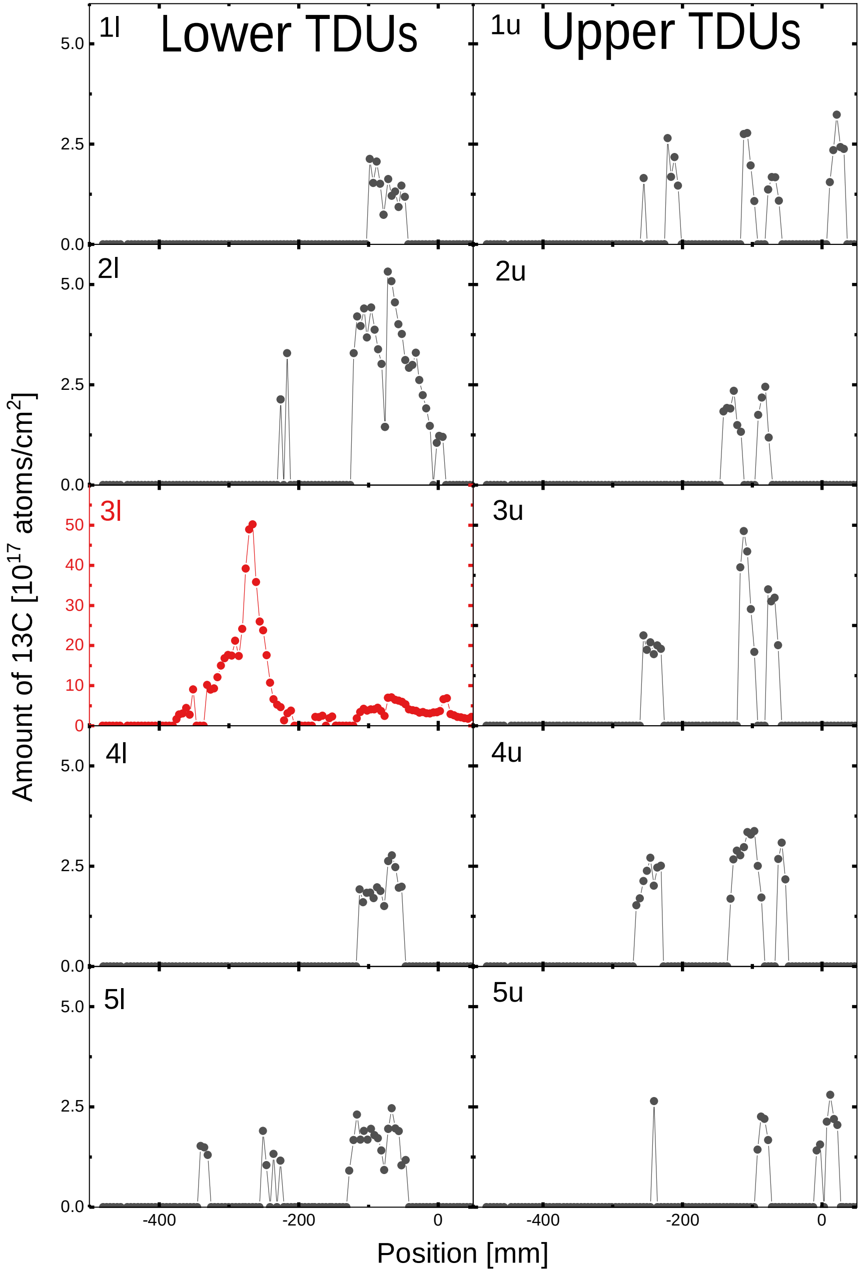
- Main goal in 2020: determine deposition profiles of tracer elements (including ^{13}C) on plasma-exposed W7-X samples
- $^{13}CH_4$ puffed during the last discharges of OP1.2b through TDU 3l

Results of ion-beam analyses:

- ^{13}C deposition relatively uniform throughout the analysed tiles but the pattern has a striped nature (exception: vicinity of the injection hole)



^{13}C deposition profiles on TM2h6 of all TDUs



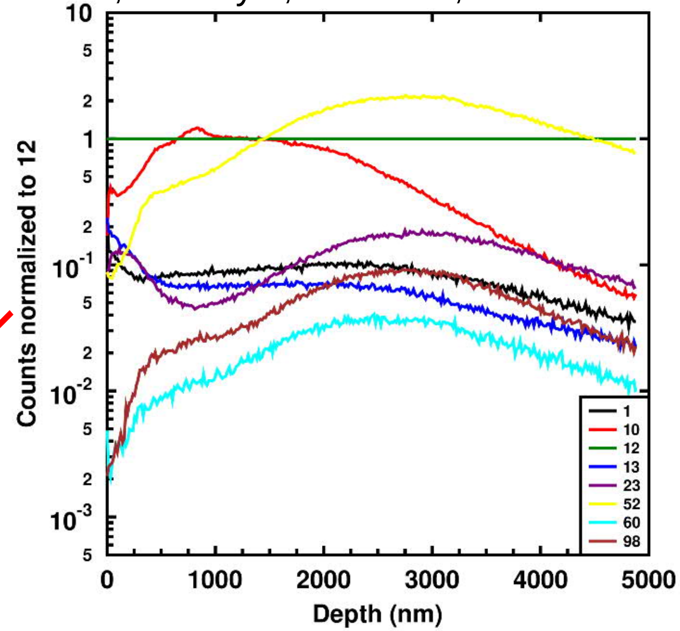
W7-X: deposition patterns of ^{13}C on wall components (FZJ, MPG, VTT, VR)

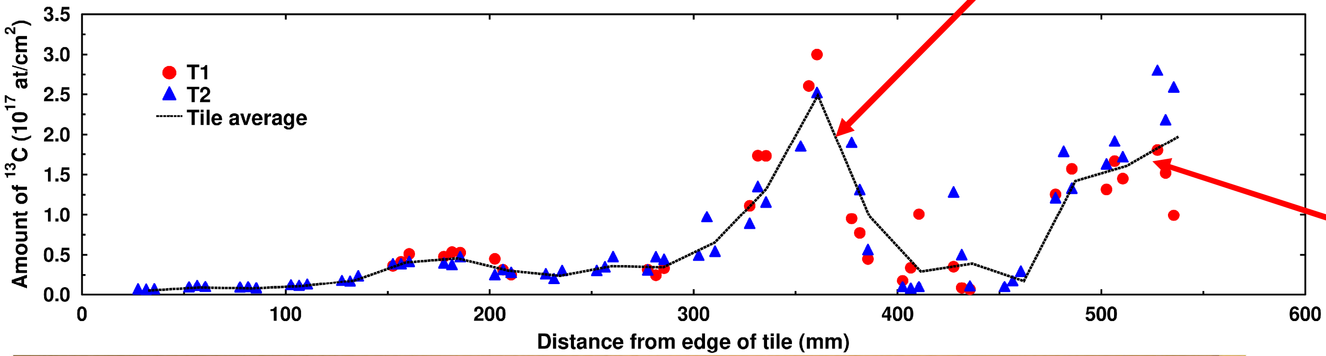
S. Brezinsek, T. Dittmar, M. Mayer, A. Hakola, T. Vuoriheimo

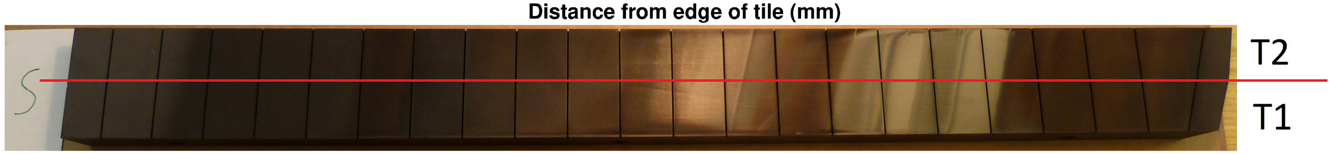
- Main goal in 2020: determine deposition profiles of tracer elements (including ^{13}C) on plasma-exposed W7-X samples
- $^{13}CH_4$ puffed during the last discharges of OP1.2b through TDU 3l

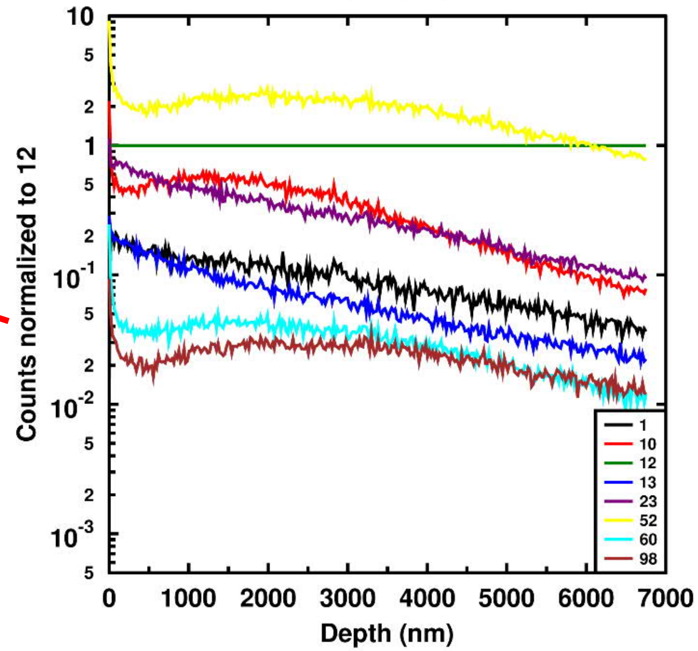
Results of SIMS analyses:

- ^{13}C deposition results agree with ion-beam data. NB! different wall tiles analysed
- Areas with ^{13}C peaks show also complex deposits with B, C, and metals (Cr, Fe, Ni, Mo)







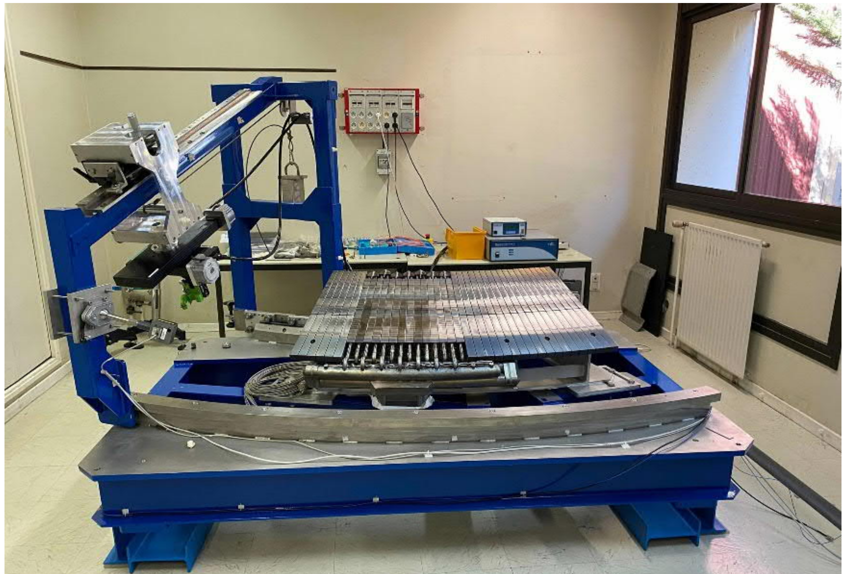


SP5.8: Post-exposure analyses of WEST plasma-facing units from deuterium and helium plasma operations

WEST: status of post-exposure analyses of plasma-facing units (CEA)

Analysis of test divertor sector exposed in C4 performed in CEA:

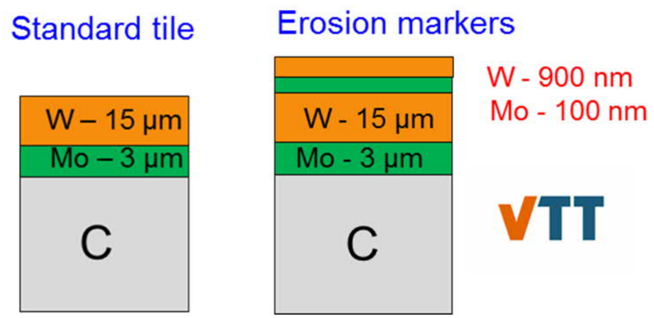
- Metrology: no large evolution of PFU misalignment
- Confocal microscopy: preliminary results indicate no major propagation of top surface cracks between C3 and C4 (tbc)
- PFU emissivity: confirms strong spatial variations consistent with complex erosion/re-deposition pattern
- X fluorescence analysis (for heavy impurities) and optical microscopy ongoing



Test divertor sector Q3B on the confocal test bed

Analysis of erosion markers exposed in C3 and C4:

- Step #1: full-tile analysis at MPG (Garching) using broad-beam RBS and NRA as well as SEM/EDX for two tiles exposed in C3 (next slides)
- Step #2: tiles to be sent to VTT for sample cutting (cutting scheme under discussion) and SIMS
- Step #3: samples to be sent to other EU labs involved (IAP, RBI, VR, JSI, IPPLM, IST, UT…)
- Step #4: Repeat for tiles exposed in C4 (He campaign)



E. Tsitrone, E. Bernard et al.

WEST: first results from two C3 plasma-facing units (CEA, MPG)

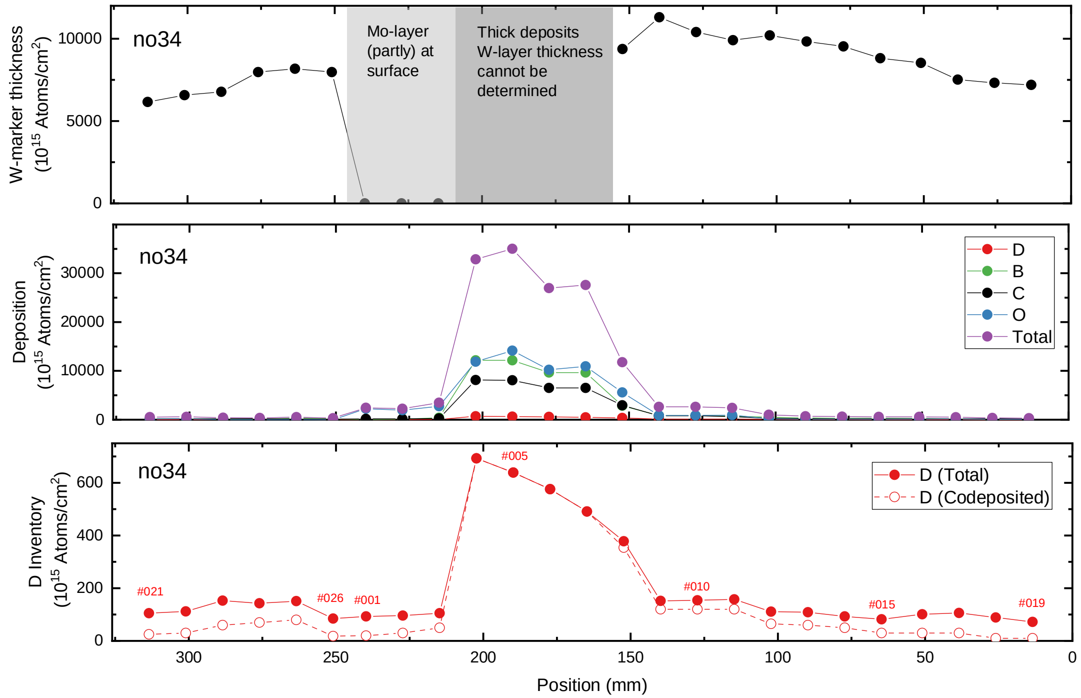
Two marker tiles, removed from WEST after the C3 campaign, became available for analyses in 2020

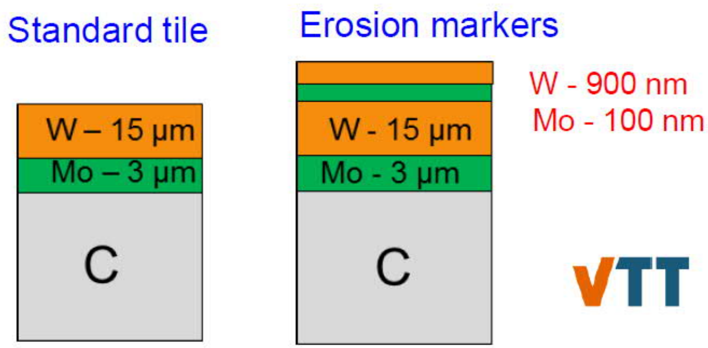
- Analyzed using RBS, NRA, SEM and EDX
- Cutting of the tiles into smaller pieces for other analyses under discussion (by VTT)
- Tiles from the C4 campaign most likely available in 2021

- Results of RBS and NRA analyses:
  - ✓ Initial W layer thickness varies across tile (unfortunately no pre-measurements)
  - ✓ Mo interlayer partly at the surface (light grey), then areas with very rough and thick deposits (dark grey)
  - ✓ D depth profile: surface peak (in deposit) and tail (in W: 0.2-0.5%) extends also beyond ~3 µm

M. Balden, M. Mayer

Inner divertor graphite marker tile “no34”



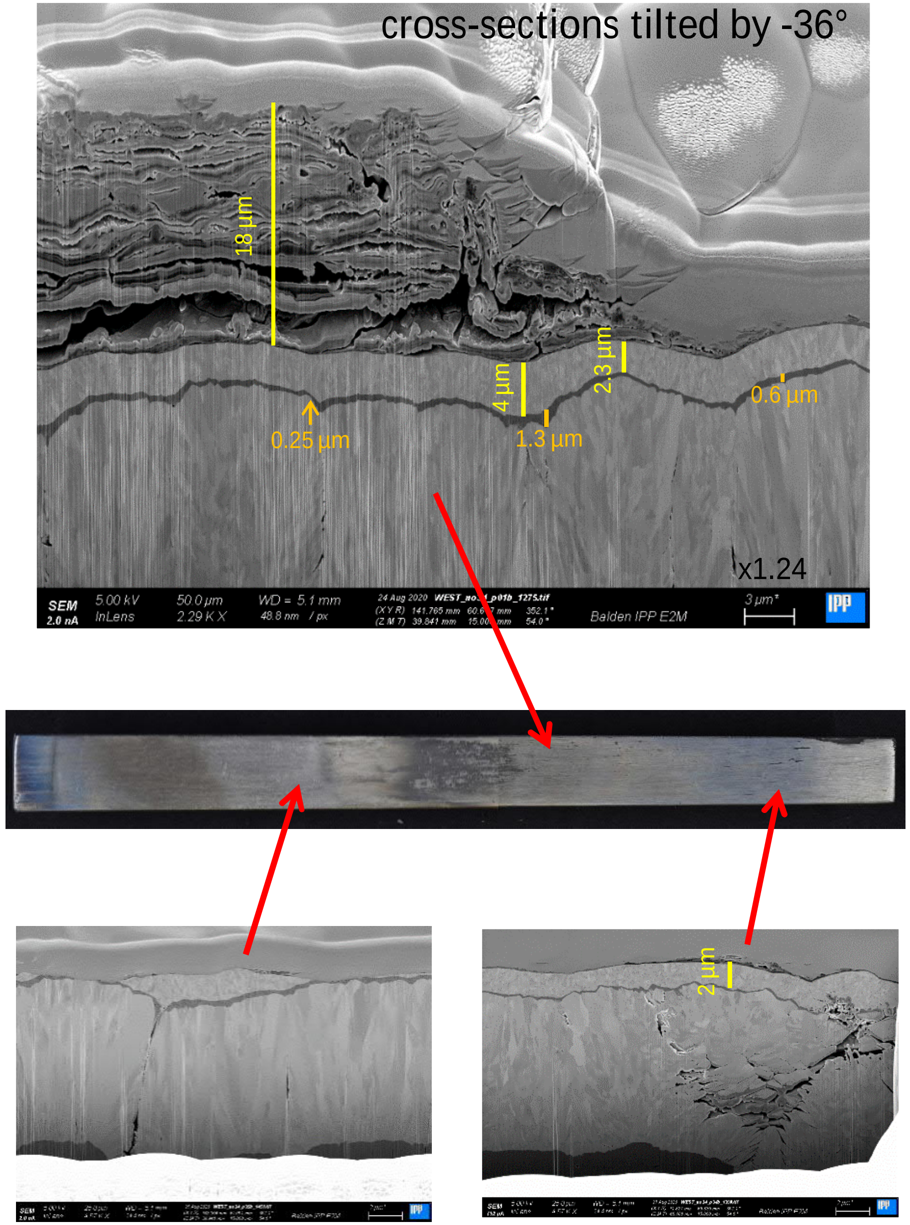


WEST: first results from two C3 plasma-facing units (CEA, MPG)

Two marker tiles, removed from WEST after the C3 campaign, became available for analyses in 2020

- Analyzed using RBS, NRA, SEM and EDX
- Cutting of the tiles into smaller pieces for other analyses under discussion (by VTT)
- Tiles from the C4 campaign most likely available in 2021

- Results of SEM, EDX and FIB analyses:
  - ✓ Cross-sections confirm Mo interlayer on the surface → erosion several µm
  - ✓ Deposits: >10 µm with typical “multilayer” structure; B-rich layer of boronization present
  - ✓ Traces of soft (no detectable erosion) and strong arcing (trace depth >20 µm) observed



M. Balden, M. Mayer

SP5.4: Development of mixed-material reference coatings

Be films: production of reference samples (IAP, VTT, RBI, IST, JSI, CEA)

- Focus points in 2020 – all samples at varying temperatures (from RT to 400°C)
  - ✓ Be-D samples with different thicknesses (up to 30 μm) and surface roughness (R_a=50-2000 nm)
  - ✓ Be-D-He and Be-D-Ne layers

Be-D coatings

Coating property	D (at%)	Substrate temperature (°C)	Thickness (μm)
Rough surface	10	R.T.	5
		100	
		400	
		JET Like Pulses	
Neat	5	R.T.	10
		200	
		JET Like pulses	
Neat	5	R.T.	20
		200	
		JET Like pulses	
Neat	5	R.T.	30
		200	
		JET Like pulses	
Rough (Ra = 100 nm)	5	R.T.	5
		100	
		400	
Rough (Ra = 500 nm)	5	R.T.	5
		100	
		400	
Rough (Ra = 2000 nm)	5	R.T.	5
		100	
		400	

Be+D=X coatings

X	D (at%)	Substrate temperature (°C)	Thickness (μm)
Ne – 2.5%	5	R.T.	5
		100	
		400	
Ne – 5%	5	R.T.	5
		100	
		400	
Ne - 2.5%	10	R.T.	5
Ne - 5%			
He – 2.5%	10	R.T.	5
He – 5%			

C. Porosnicu, P. Dinca, B. Butoi, C. P. Lungu, O. G. Pompilian, C. Staicu, V. Nemanic, M. Žumer

Be films: analyses of reference samples (IAP, VTT, RBI, IST, JSI, CEA)

- Analyses of mainly 2019 samples and partly a subset of the 2020 samples
  - ✓ Be-D samples with different thicknesses (up to 30 μm) and surface roughness (R_a=50-2000 nm)
  - ✓ Be-D-H, Be-D-He, Be-D-N, and Be-D-Ne as well as Be-O-C-D layers
- Main observations (as of 11/2020)
  - ✓ D content generally decreases with deposition temperature
  - ✓ Higher levels of impurities (N) increases retention (but more analyses needed)

M. Brajković, Z. Siketić, I. Bogdanović Radović, R. Mateus, E. Alves

Example 1: TOF-ERDA results of D and Ne contents of different Be-Ne-D layers

Sample	D (at. %)	Ne (at. %)
Be+D(5)+Ne(2.5), RT	11.1	1.1
Be+D(5)+Ne(2.5), T=100°C	10.0	0.59
Be+D(5)+Ne(2.5), T=400°C	< 0.01	< 0.01
Be+D(5)+Ne(5), RT	11.9	2.0
Be+D(5)+Ne(5), T=100°C	5.2	< 0.10
Be+D(5)+Ne(5), T=400°C	12.7	2.7

Example 2: EBS and NRA results of D and N contents of different Be-D-N layers

Sample	D (at. %)	N (at. %)
Be+D(5)+N(2.5), RT	0.98	~0.5
Be+D(5)+N(2.5), T=100°C	0.19	~0.5
Be+D(5)+N(2.5), T=400°C	0.09	~1.0
Be+D(5)+N(5), RT	2.1	~1.0
Be+D(5)+N(5), T=100°C	2.1	~1.0
Be+D(5)+N(5), T=400°C	0.18	~2.0

VTT

Be films: analyses of reference samples (IAP, VTT, RBI, IST, JSI, CEA)

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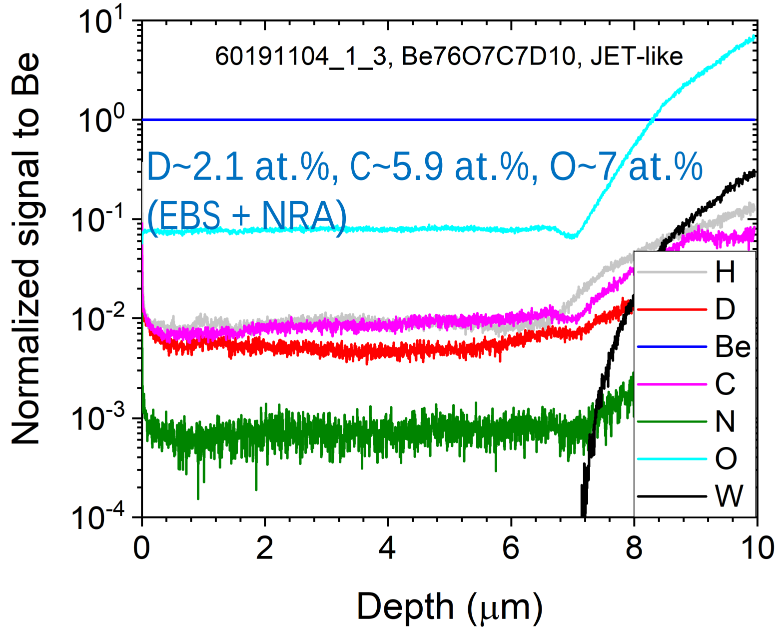
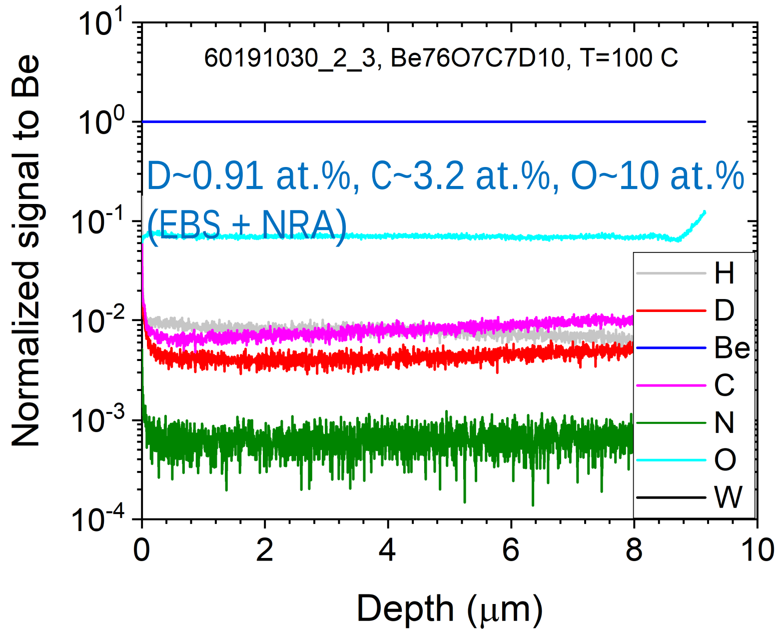
  - ✓ Deposition using "JET-like" heat pulses indicates increased retention compared to constant temperature (especially at the surface)



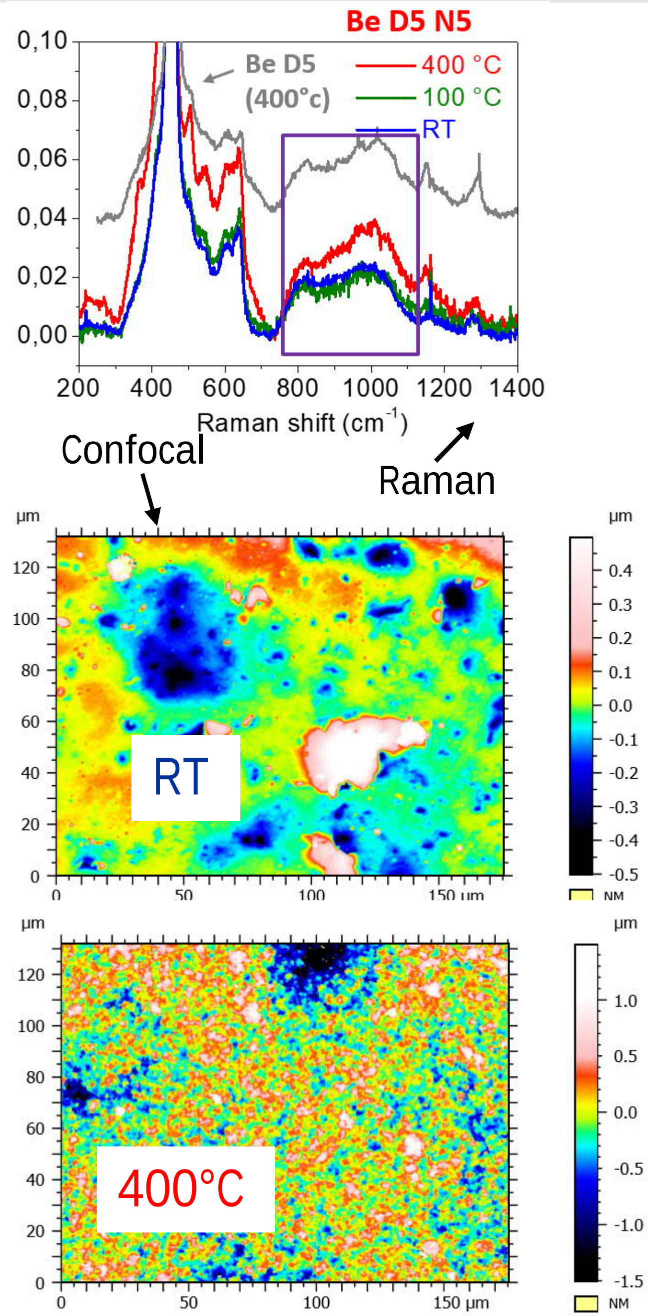


A. Hakola, J. Likonen

Be films: analyses of reference samples (IAP, VTT, RBI, IST, JSI, CEA)

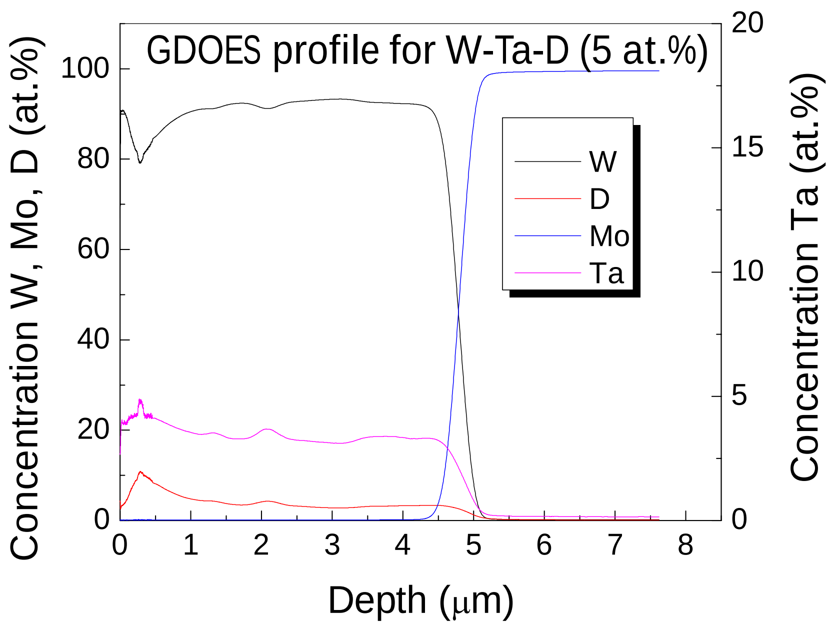
- Analyses of mainly 2019 samples and partly a subset of the 2020 samples
  - ✓ Be-D samples with different thicknesses (up to 30 μm) and surface roughness (R_a=50-2000 nm)
  - ✓ Be-D-H, Be-D-He, Be-D-N, and Be-D-Ne as well as Be-O-C-D layers
- Main observations (as of 11/2020)
  - ✓ D content generally decreases with deposition temperature
  - ✓ Higher levels of impurities (N) increases retention (but more analyses needed)
  - ✓ Deposition using "JET-like" heat pulses indicates increased retention compared to constant temperature (especially at the surface)
  - ✓ Samples produced at the highest temperatures show rough surfaces with lots of defects
  - ✓ No systematic dependence on retention as a function of roughness observed (so far)

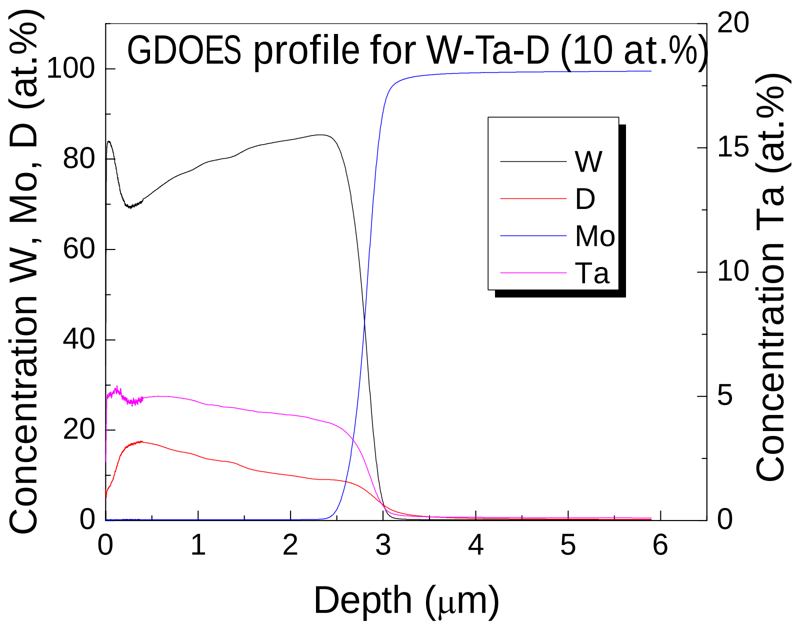
C. Pardanaud, M. Kumar, G. Giacometti, C. Martin, P. Roubin

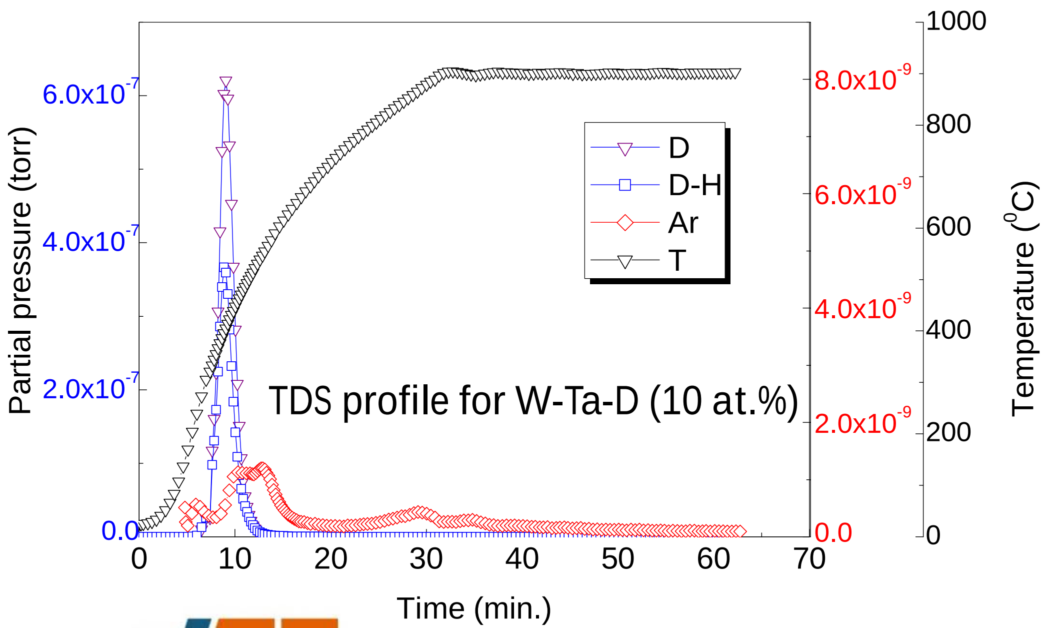


VTT

W films: production of samples for LIBS and MAGNUM (IAP, DIFFER, VTT, IPPLM)





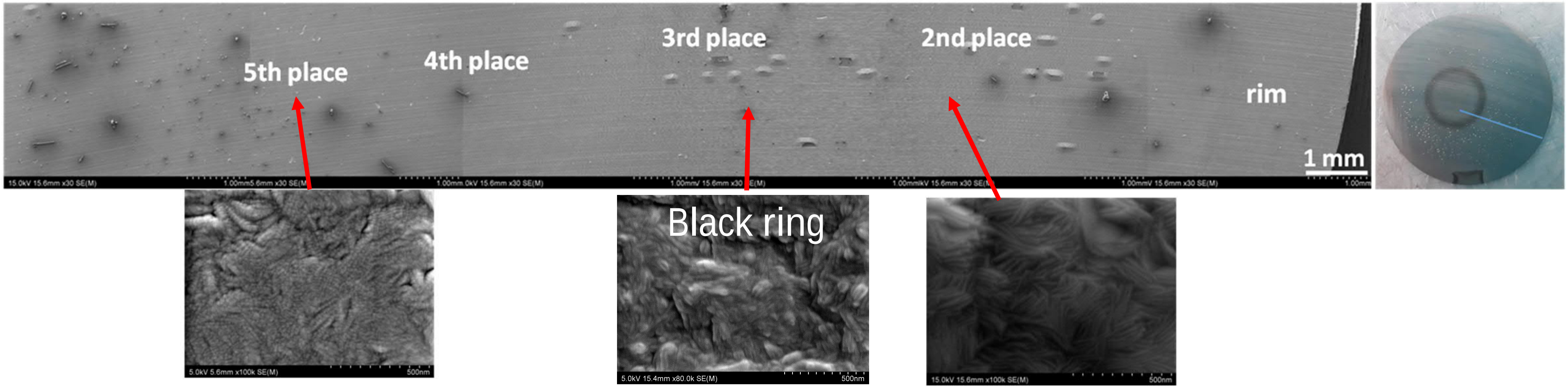


- Goals in 2020:
  - ✓ W-Ta and W-Ta-D coatings for LIBS and MAGNUM and PSI-2 plasmas
  - ✓ W-N-D coatings for LIBS studies (pending)
- Properties of the W-Ta-D layers
  - ✓ Ta content ~3.8-5 at.%, D content 4.6-4.8 at.% or 9-15 at.% → all close to the desired targets
  - ✓ Layers exhibit uniform depth profiles

E. Grigore, M. Gherendi, F. Baiasu

W films: production of samples for LIBS and MAGNUM (IAP, DIFFER, VTT, IPPLM)

- Sample exposure in MAGNUM in early 2020 → investigate fuel retention and coating behaviour in D or D+N plasmas with varying plasma temperatures
  - ✓ W-Ta and W coatings from 2019 and 2020 (IAP)
  - ✓ W coatings with different morphologies (ENEA)
- Samples sent for analyses: SIMS (VTT), LIBS (UT), and microscopy (IPPLM)
- Microscopy analyses:
  - ✓ Lots of blisters on the samples and surface morphology changes towards the sample edge
  - ✓ Thick re-deposits especially at the center of the beam spot

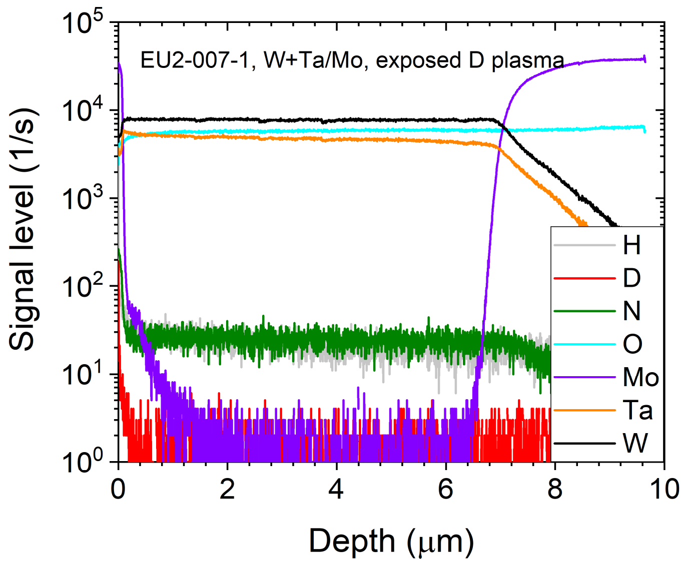


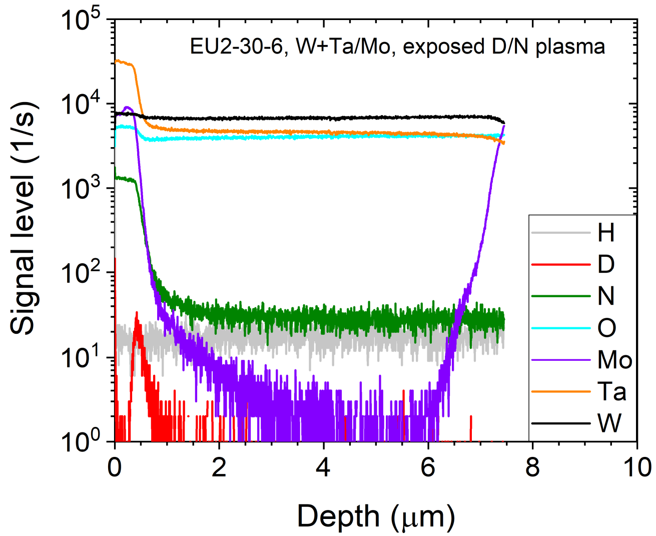
Examples of SEM images from a W-Ta sample resulting from exposure to D plasma

H. van der Meiden, E. Fortuna-Zalesna, W. Zielinski, S. Szpilewicz

W films: production of samples for LIBS and MAGNUM (IAP, DIFFER, VTT, IPPLM)

- Sample exposure in MAGNUM in early 2020 → investigate fuel retention and coating behaviour in D or D+N plasmas with varying plasma temperatures
  - ✓ W-Ta and W coatings from 2019 and 2020 (IAP)
  - ✓ W coatings with different morphologies (ENEA)
- Samples sent for analyses: SIMS (VTT), LIBS (UT), and microscopy (IPPLM)
- SIMS analyses:
  - ✓ Re-deposited layers at the center of the beam spot, consist mainly of Mo and Ta
  - ✓ D retained typically in the deposit, can also show an implantation-like profile





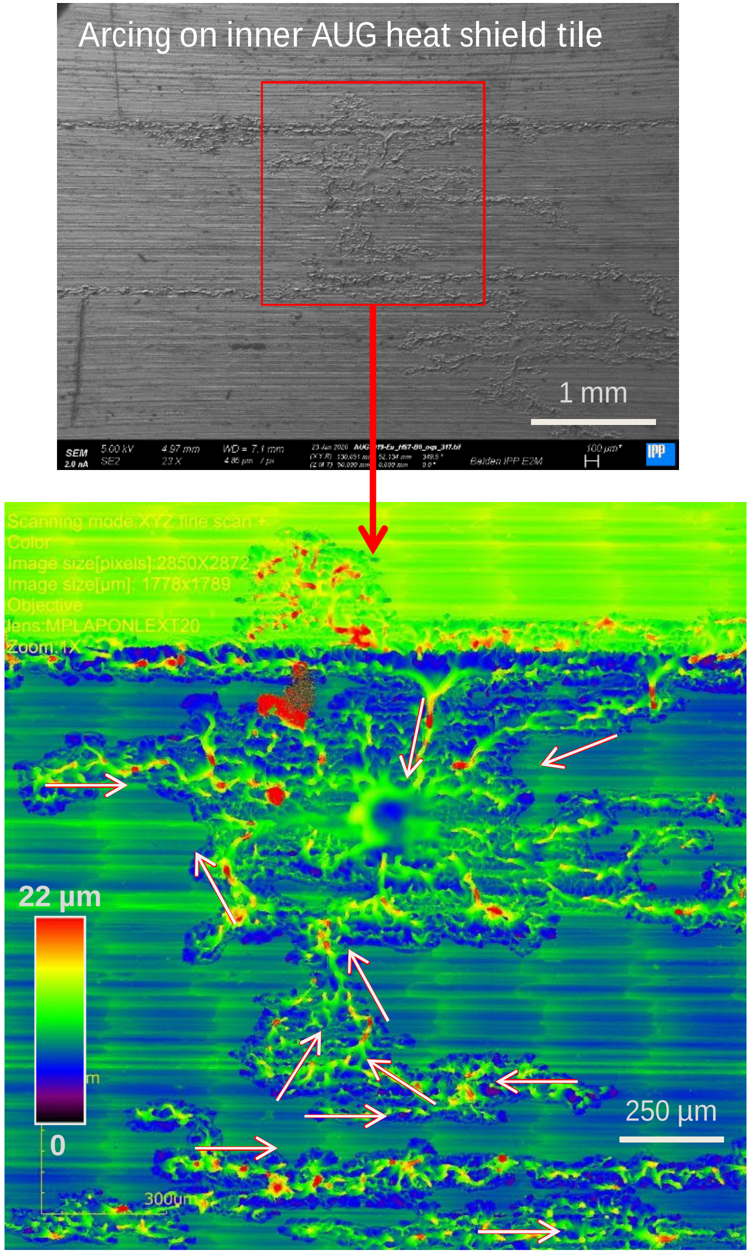
Examples of SIMS depth profiles from W-Ta sample resulting from exposure to D and D+N plasmas

H. van der Meiden, A. Hakola, J. Likonen

SP5.7: Dust production mechanisms in tokamaks

AUG: characterization of arcing patterns on different wall tiles (MPG, JSI)

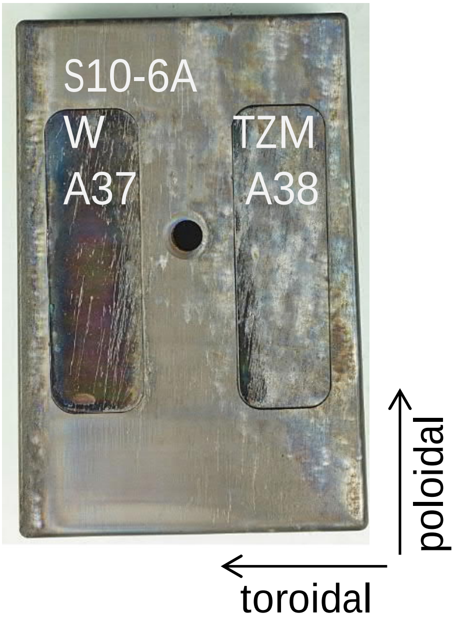
- Arcing patterns completely characterized on the removed WN and central-column tiles of AUG
- Example 1: Tracking evolution of strong arcing patterns on the central column of AUG
  - ✓ Dot-like arc traces (not moving) → during glow discharges (without magnetic field)
  - ✓ Erratic running arcs: direction diverging from typical one during flat top phase → due to start-up phases or disruptions?
  - ✓ New traces since 2018: old traces partially buried under thick deposits
- Example 2: Arcing patterns on a polished W-divertor tile, half-coated with WN
  - ✓ "Obvious arcing" visible by eye but activity not confirmed by microscopy
  - ✓ Thick deposits formed, even in nominally erosion-dominated region and surface became rougher
  - ✓ WN layer partially delaminated possibly by arcing

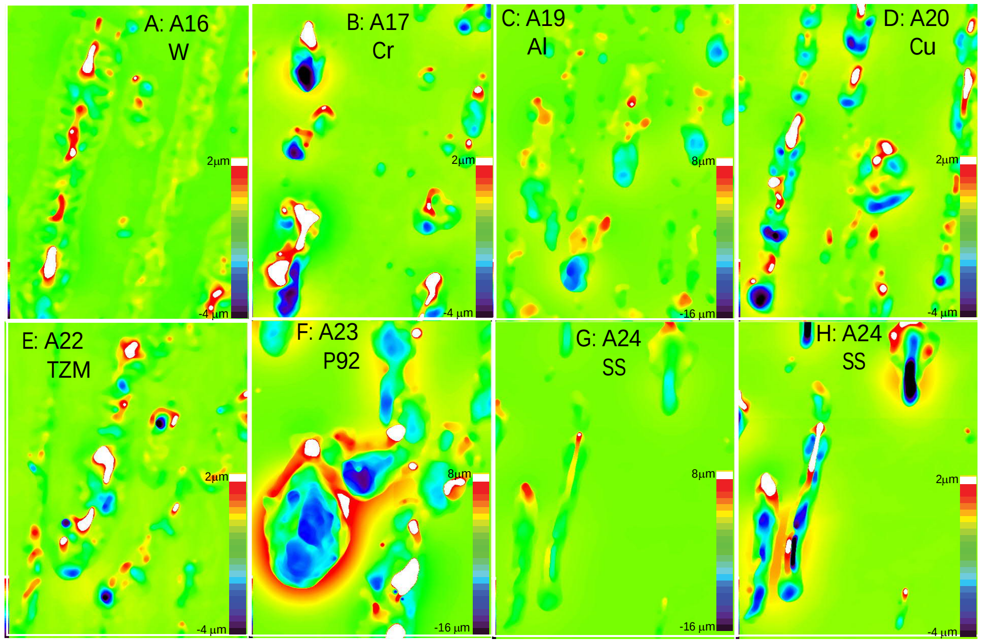


M. Balden

AUG: characterization of arcing patterns on different wall tiles (MPG, JSI)

- Arcing patterns completely characterized on the removed WN and central-column tiles of AUG
- Example 3: Polished inserts on inner baffle to study the effect of material properties on arcing
  - ✓ Magnetic steel (e.g. Eurofer, P92) exhibits much higher erosion by arcing than non-magnetic stainless steel
  - ✓ Depth of arc traces depends mostly on the melting temperature of the material
- Example 4: Arcing patterns on bare and WN-coated W tiles after one year plasma exposure
  - ✓ On bare W tile, arcing causes W melting and formation of ridges in the center of arc traces
  - ✓ On WN-coated areas, arcing mainly causes delamination of the coating



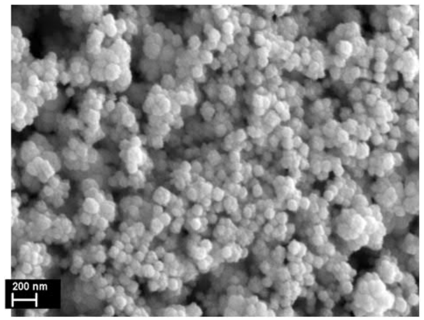


M. Balden, M. Panjan, M. Čekada

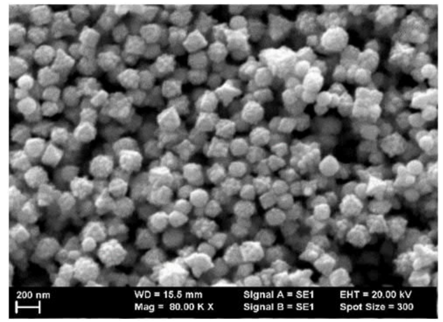
W and Be dust generation in the presence of air and water leaks (IAP)

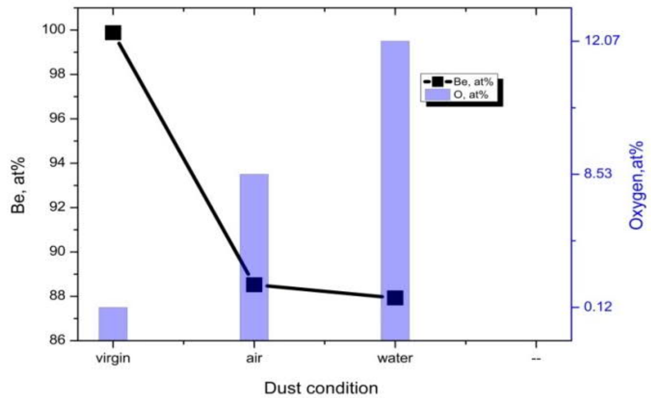
- Main results on the W front:
  - ✓ Functional systems for W dust preparation available - Magnetron Sputtering Gas Aggregation (50-200 nm) and Microarc Discharge (0.1-10 μm)
  - ✓ W dust production rates and particle morphology influenced by gaseous impurities and usage of different gases (Ar vs. He) and humidity levels
- Main results on the Be front:
  - ✓ Agate ball mill applied to create various types of dust from Be pebbles
    - o Air: dust size mainly >160 μm
    - o Water: dust size more evenly distributed in 36-160 μm and >160 μm particles
  - ✓ O content increases in water (from 9 to 12 at%)
  - ✓ Be, Cr, Cu, Fe, Mo, Ni and W found in the particles
    - o Less Be, Cu and Fe in water
  - ✓ Formation of insoluble oxides on the particles?

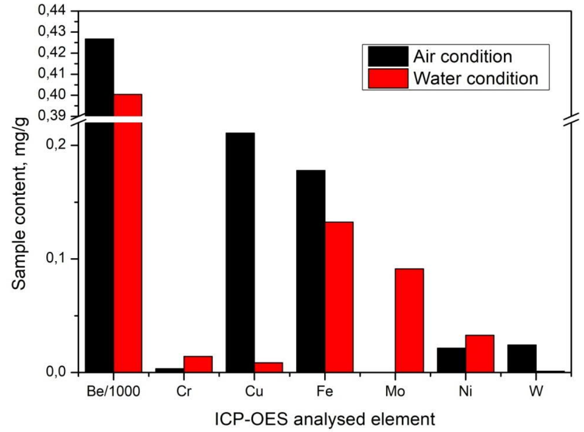
Dry Ar



Ar + H_2O 0.5%





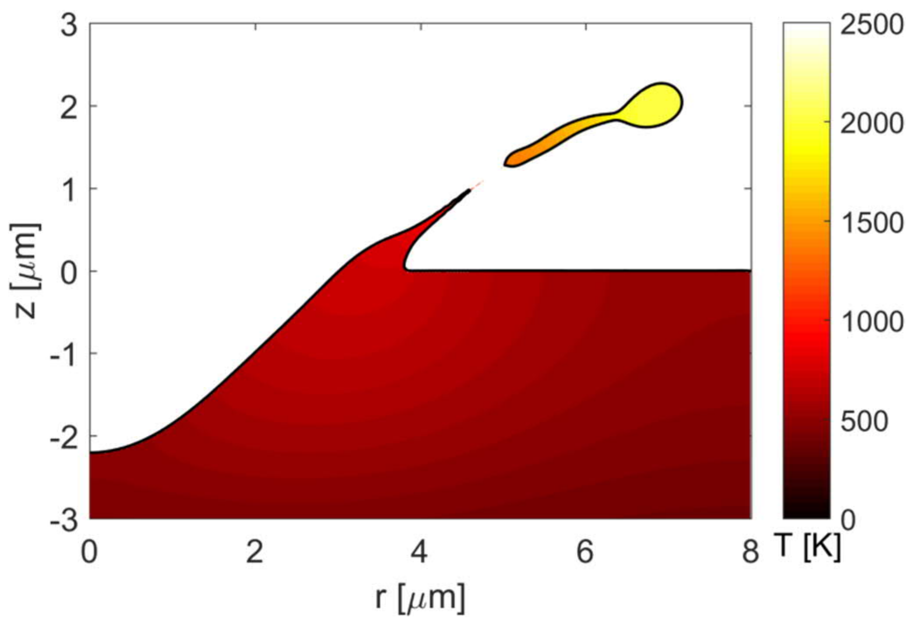


G. Dinescu, C. Lungu

Modelling dynamics of liquid metal pools and droplet ejection (VR)

Numerical benchmark

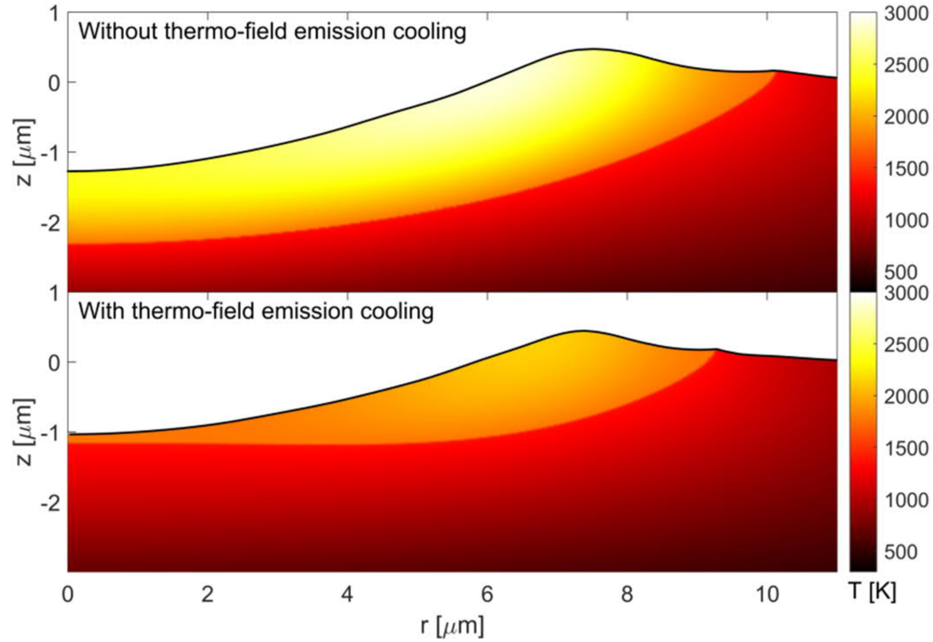
- Hydrodynamic ANSYS model with prescribed plasma pressure and heat flux profiles established for Cu cathode
  - ✓ Successful benchmark to experiments
  - ✓ Prediction of droplet detachment consistent with experiments despite missing near-cathode physics



L. Vignitchouk, S. Ratynskaia, L. Brandt, M. Crialesi Esposito

Effect of near-cathode processes

- Extra heat and pressure from ionized vapor and thermo-field emission
- Thermo-field emission dominates vapor cooling and is essential to recover the proper cathode temperature response



Newly established collaboration with the fluid dynamics group at KTH for alternative numerical implementation of the full model

Summary

- SP5.1:
  - AUG: dedicated experiments carried out (under MST1) and post exposure analyses ongoing
  - W7-X: erosion/deposition patterns on wall tiles clarified and determination of ^{13}C concentrations on various samples underway
- SP5.4:
  - Be films: optimization of deposition recipes to reproduce JET-ILW results for D retention and simulate exposure and baking conditions in ITER ongoing
  - W films: films routinely produced for experiments on MAGNUM-PSI and for LIBS
- SP5.7:
  - New approach to model arcing being introduced and numerically benchmarked
  - AUG and W7-X tiles extensively analysed to better understand formation of arcing patterns
- SP5.8:
  - Task finally started by surface analyses of 2 marker tiles originating from the C3 campaign