PWI-related works performed in IPPLM and WUT

Presented by Monika KUBKOWSKA

Association Euratom-IPPLM Council Meeting
March 15, 2013

Improve understanding of (enhanced) gross and net erosion

❖ **Material:** samples from a bulk tungsten tile exposed at the outer strike point during the 2010/2011 campaign in AUG

❖ **Aim of examinations**: evidence of crack formation and recrystallisation of the surface

❖ **Results:**

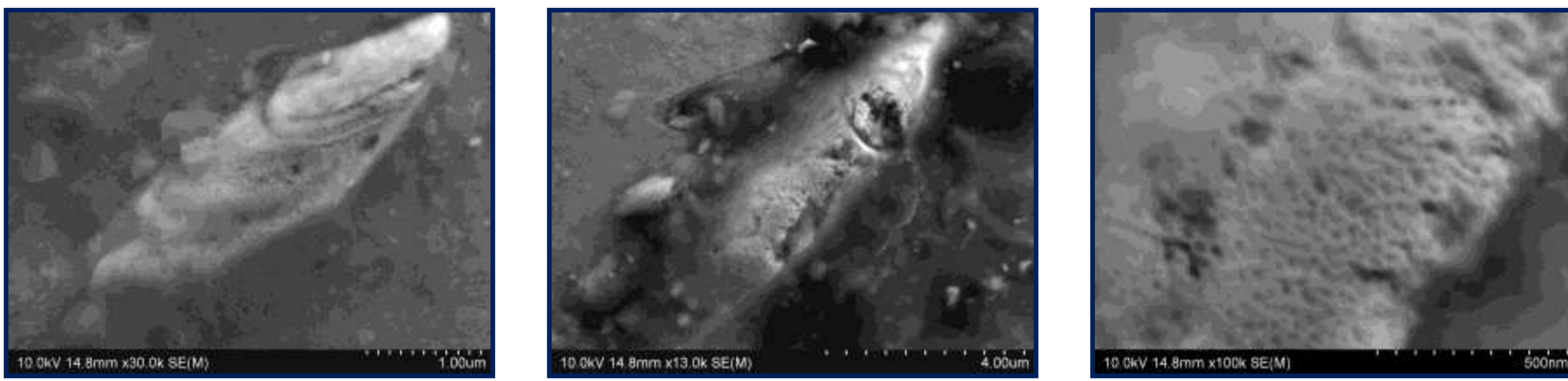
- The surface of the large sample is covered by a deposit of stratified character.

- Two large cracks were found at the surface. The long transverse crack (to the longer tile side) crosses almost entire sample thickness. The longitudinal is 15 mm long. Additionally, the transverse “scratch-like” cracks and cracks with the deposit built up were found. At the surface thin, “veins-like” cracks were also present.

- Artefacts in the form of small, elongated and aligned discs, up to 10 µm long were found. They are spread over entire surface of the large sample. These elements are strongly porous, sometimes with multilayered structure and a characteristic cup. They are a result of the presence of droplets or dust particles at the surface and the formation of a shadowed area behind them.

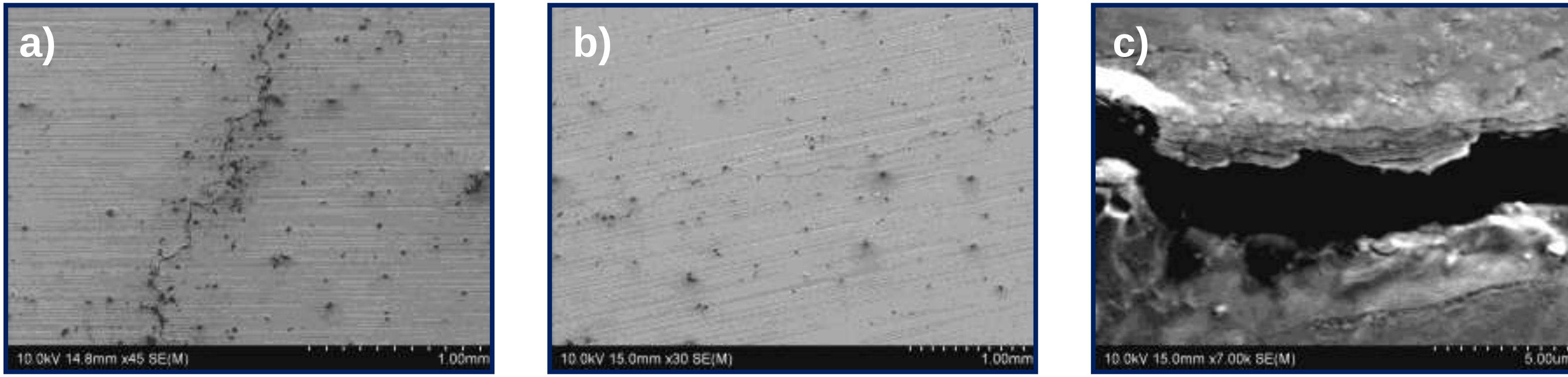
Improve understanding of (enhanced) gross and net erosion

SEM images of the tile surface

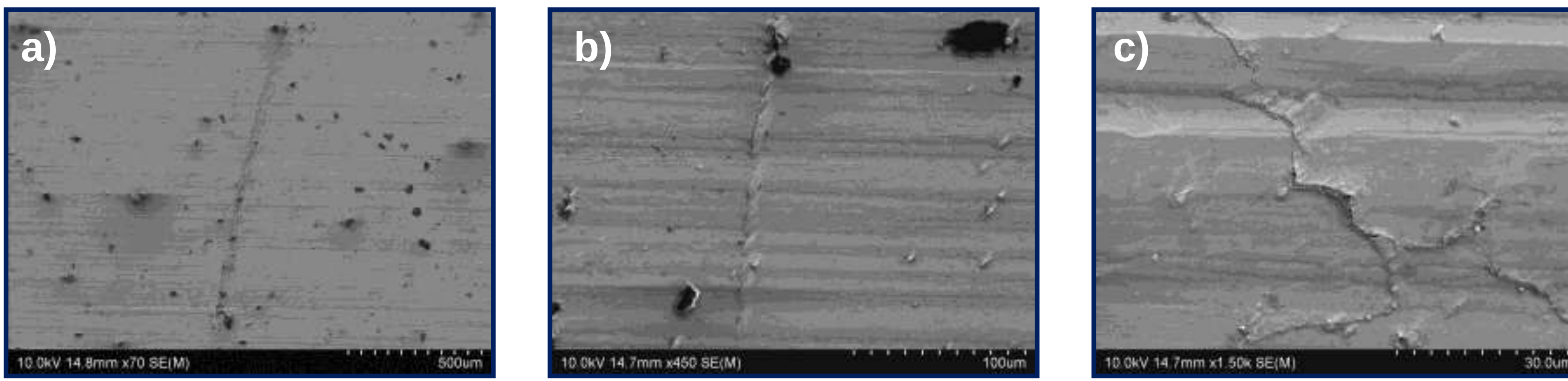


SEM images of the artefacts present at the large sample surface

Improve understanding of (enhanced) gross and net erosion

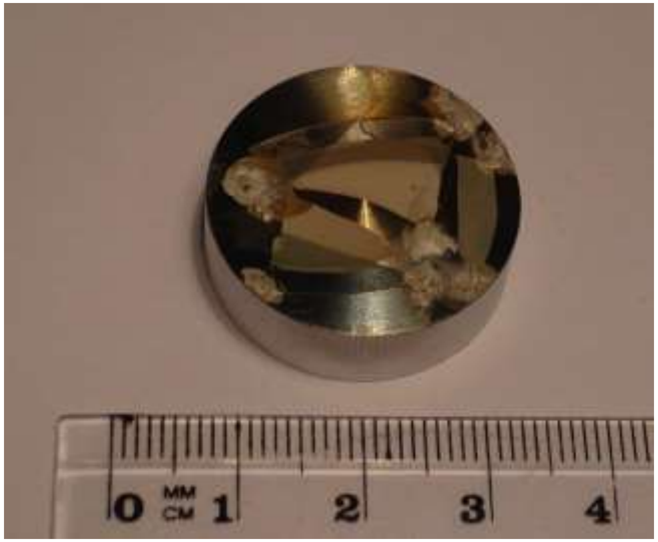


SEM images of: the transverse (a) and longitudinal crack (b-c)



SEM images of: a) the “scratch-like” crack, b) crack inside which the deposit built up, c) fine/”veins-like” crack

Provide input for dust sampled in present-day fusion device



The work presents results of the characterization of dust collected in ASDEX Upgrade, with the special emphasis on size, morphology, structure and composition of the dust particles.

Filter no 8, collected after 2009 campaign, from sector 11. The investigations concerned dust particles trapped in the PTFE disc filter rim. Additionally:

(i) TEM examinations of deposit present at the PTFE disc filter edge from Filter no 1 collected after 2009 AUG campaign

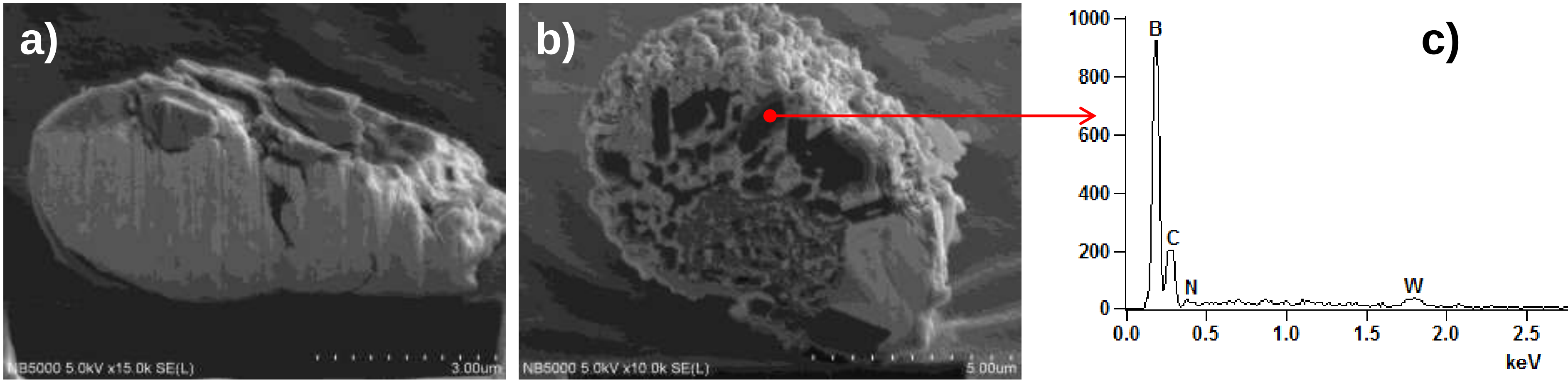
(ii) Examinations of particles present at the porous part of the PTFE disc filter from Filter no 1 collected after 2009 AUG campaign.

Provide input for dust sampled in present-day fusion device

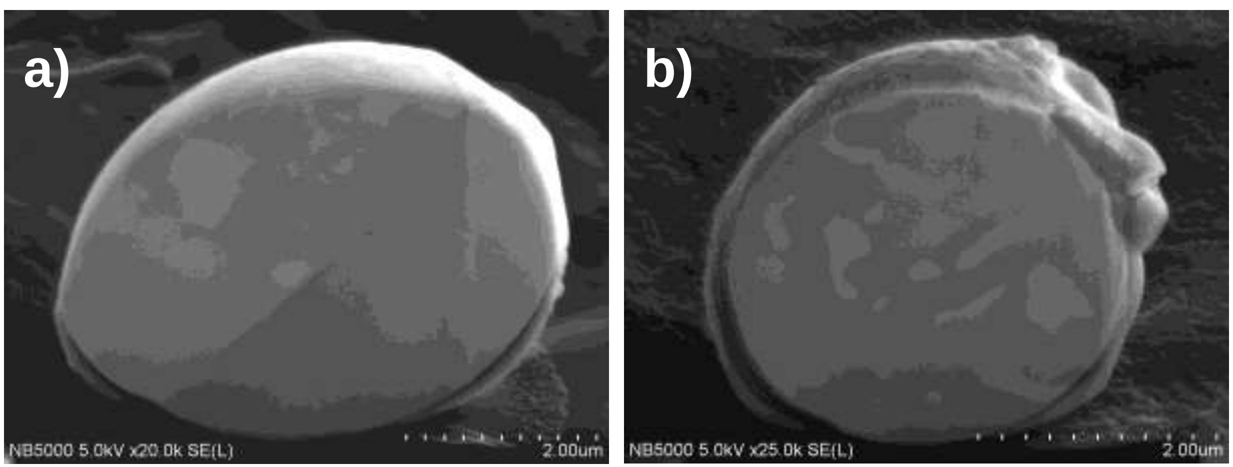
- The structure and composition of dust particles were examined by: high resolution scanning electron microscopy (HRSEM) combined with energy-dispersive X-ray spectroscopy (EDS), transmission electron microscopy (TEM), focused ion beam (FIB).

- **Results:**
  - Dominating tungsten particles, nearly 60 % of analysed population. Also carbon-based particles (composition: carbon based, co-deposits containing: C+O+Fe+Cr+Ni and C+O+Ca particles). Additionally the iron-based (mainly Fe-Cr-Ni) and particles rich in silicon.
  - The tungsten particles were of special interest. The following types of these particles were distinguished:
    a) spherical (typical size: 1.8 to 7 μm)
    b) irregular (1 to 20 μm)
    c) fine present at/inside the large ones
    d) flakes (up to 36 μm)

WP12-IPH-A03-2-09/PS+BS-01/IPPLM
Provide input for dust sampled in present-day fusion device



SEM images of irregular tungsten-based particles cross-sections. The structure with small grains (a) and (b) two phase particle, one phase is tungsten or tungsten rich, the other one contains boron together with corresponding EDS spectrum (c).

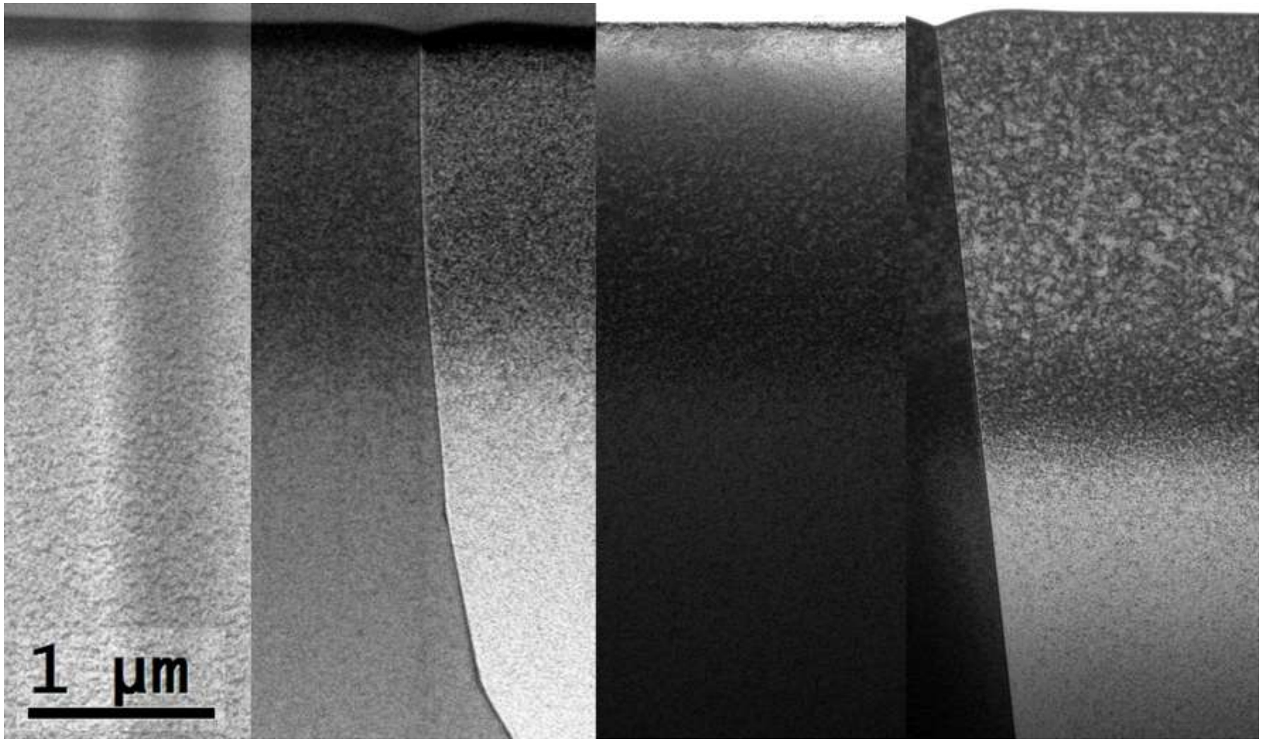


SEM images of spherical tungsten particles cross-sections: (a) grained structure and (b) the particle with two characteristic areas

Microscopic investigation of radiation damage in tungsten and its influence on deuterium retention WP12-IPH-A03-1-08/IPPLM

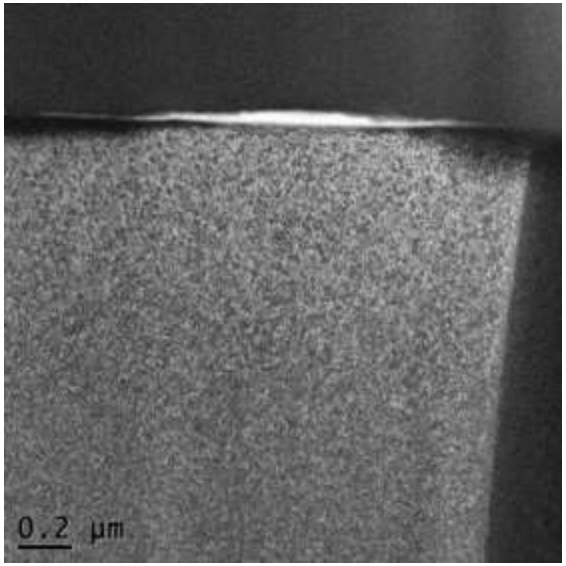
Polycrystalline tungsten was cut into 10 x 10 mm2 plates of the thickness of c.a. 0.5 mm and mechanically polished to mirror like finish. Prior to self-implantation the plates were recrystallized at 2200 ˚C for 1 hour. The radiation damage was made by implantation with 20 MeV W6+ ions up 0.01, 0.1 and 0.89 dpa. The implantation was carried out at IPP Garching in a chamber connected to the 3 MV tandem accelerator.

Comparison of the target cross sections for the un-implanted, 0.01dpa, 0.1dpa and 0.89dpa damaged samples respectively from the left.

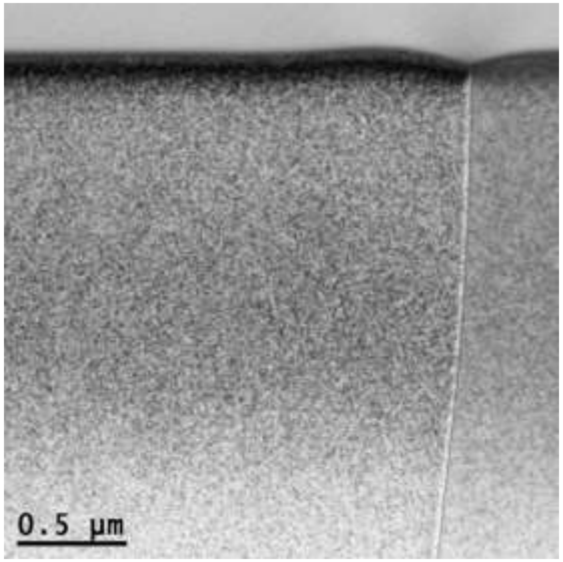


Microscopic investigation of radiation damage in tungsten and its influence on deuterium retention WP12-IPH-A03-1-08/IPPLM

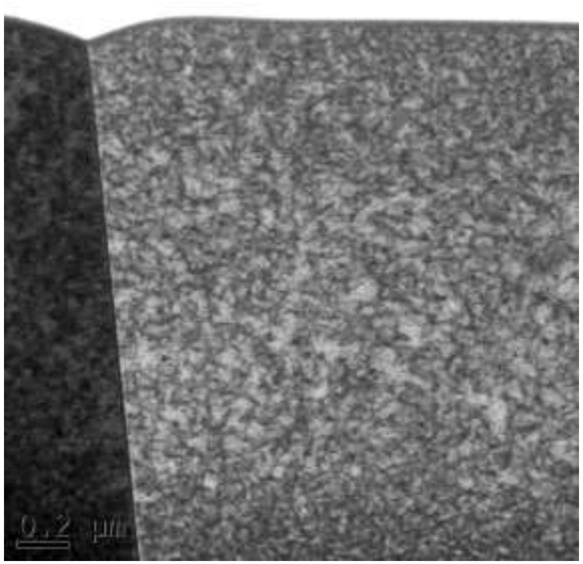
Micrographs of the undamaged samples

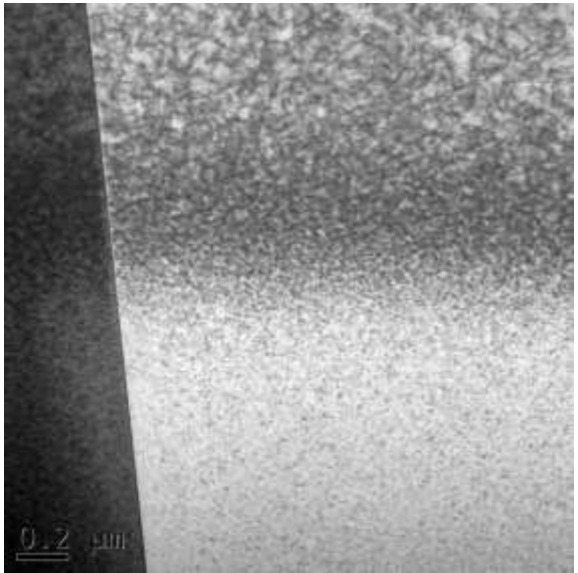


Micrographs of the 0.01dpa damaged samples



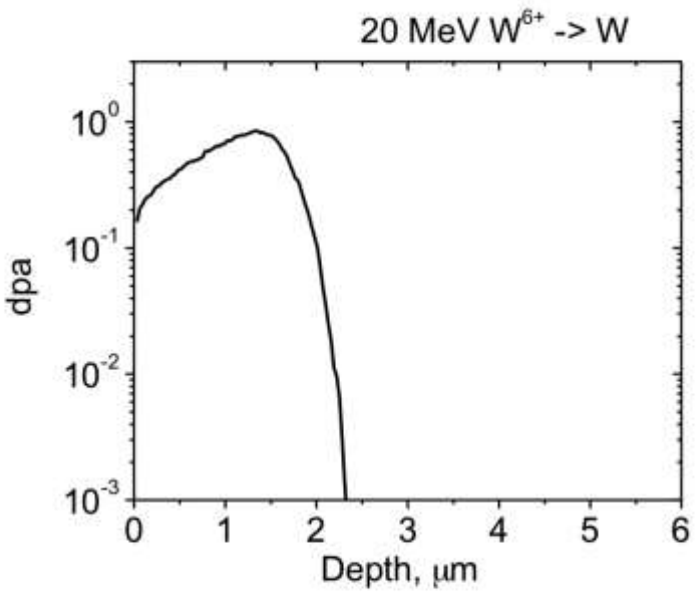
Micrographs of the 0.89dpa damaged samples

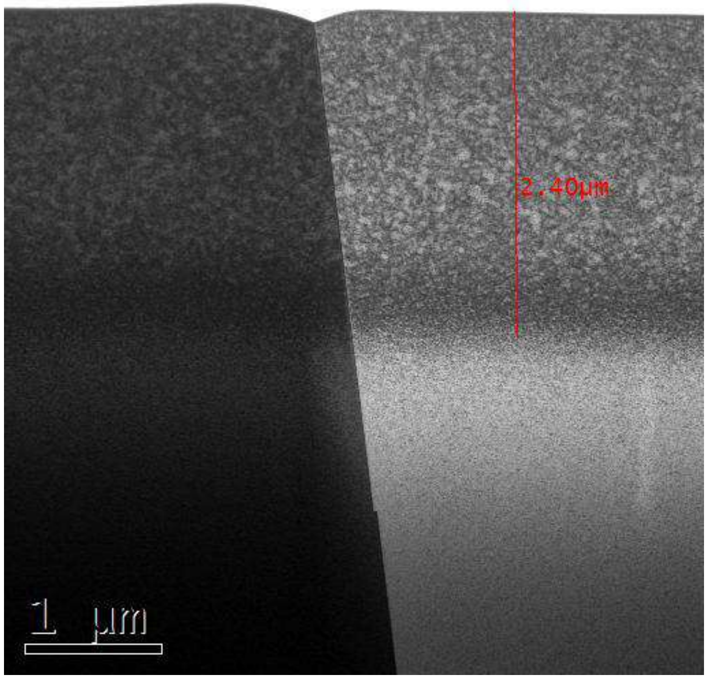




Microscopic investigation of radiation damage in tungsten and its influence on deuterium retention WP12-IPH-A03-1-08/IPPLM

Comparison of the depth of implantation calculated by the SRIM software and the damaged zone "thickness" measured at the TEM lamella



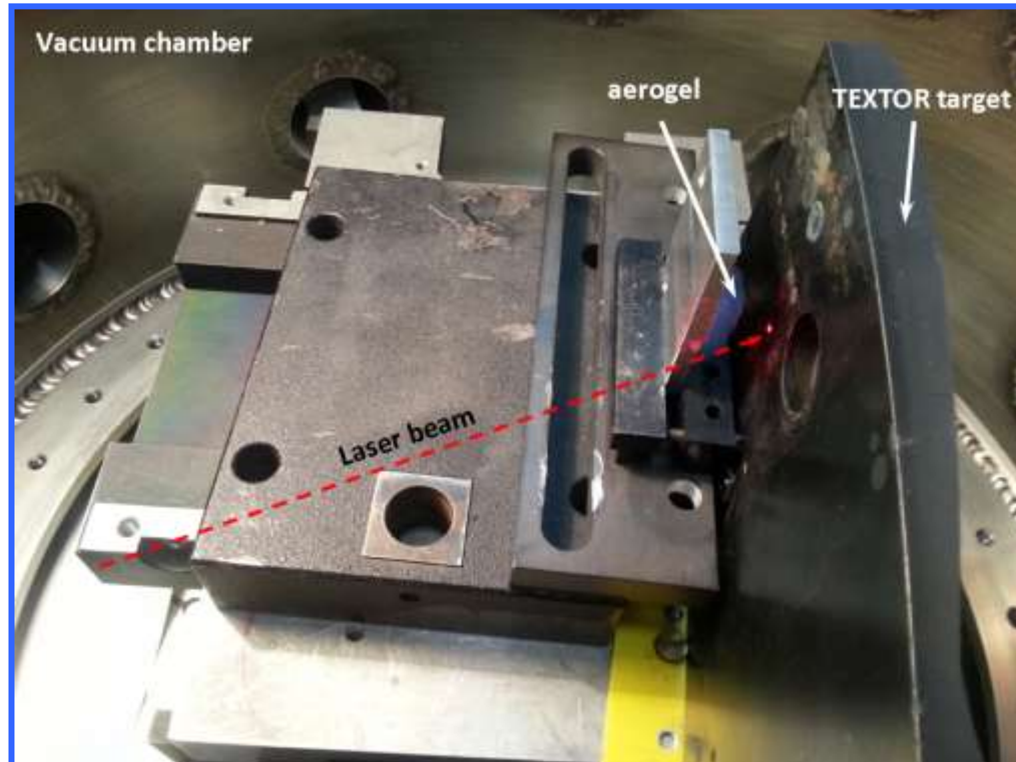


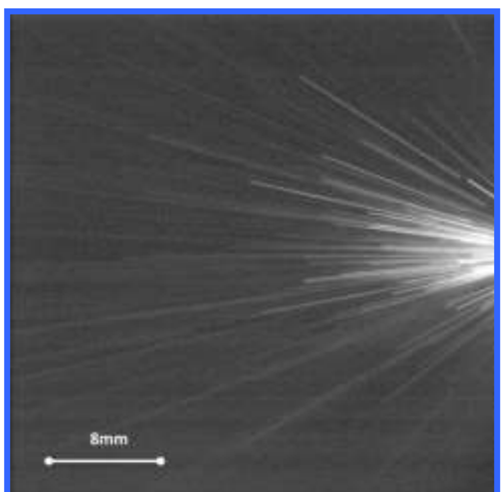
The results of the task were presented at 19th International Workshop on Inelastic Ion-Surface Collisions (IISC-19) 16 – 21 September 2012, Frauenchiemsee, Germany Ł.Ciupiński, O.V.Ogorodnikova, T.Płociński, M.Andrzejczuk, M.Rasiński, M.Mayer, K.J.Kurzydłowski, TEM OBSERVATIONS OF RADIATION DAMAGE IN SELF-IRRADIATED TUNGSTEN

Characterization of laser ablated dust, including measurements of velocity and fuel content of single dust particles WP12-IPH-A03-2-08

- **TEXTOR sample deposited with deuterium-containing layers was irradiated by nanosecond Nd:YAG laser pulses (3.5 ns, 0.5J@1063nm). Dust which was released in this process was observed by the means of CCD camera and was collected in aerogel collectors provided by VR, Sweden.**

Experimental set-up (average power density 13 GW/cm^2)





A CCD camera image of the expanding dust in abscence of aerogel in the chamber taken 24us after laser pulse, exposure time was 100 us. Estimated velocity 100 m/s

Characterization of laser ablated dust, including measurements of velocity and fuel content of single dust particles WP12-IPH-A03-2-08

❖ **Sample images:**

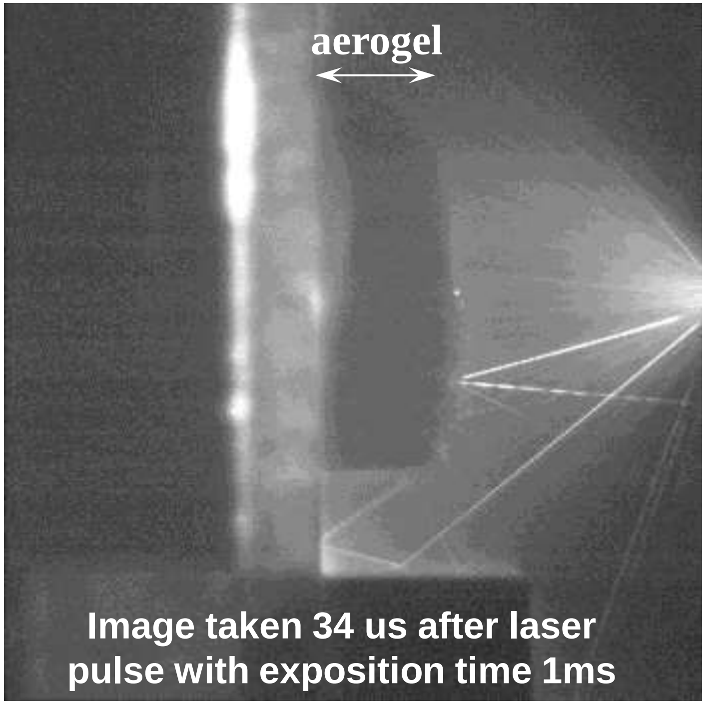


Image taken 34 us after laser pulse with exposition time 1ms

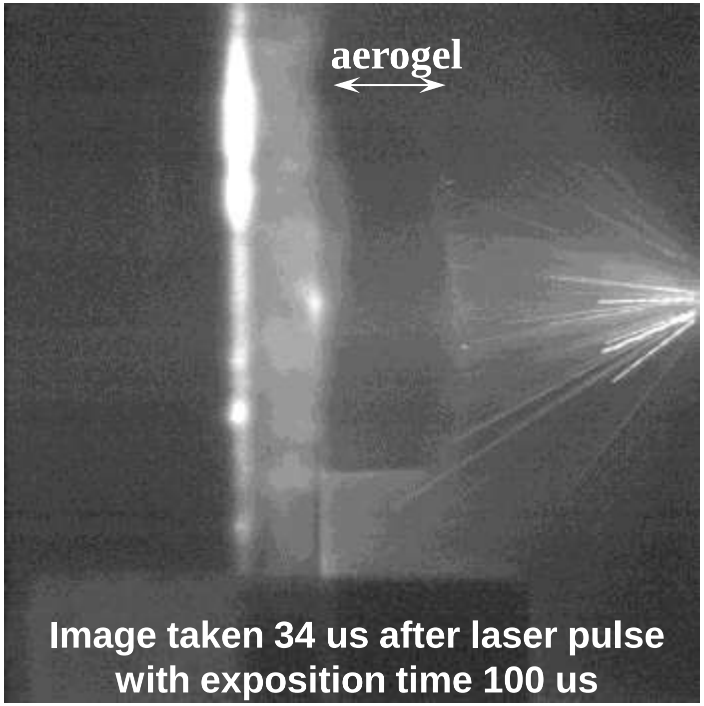


Image taken 34 us after laser pulse with exposition time 100 us

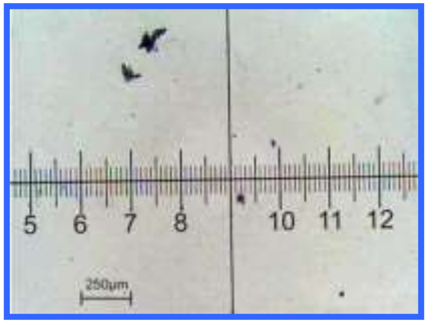


Image taken from optical microscope with visible micro particles in aerogel

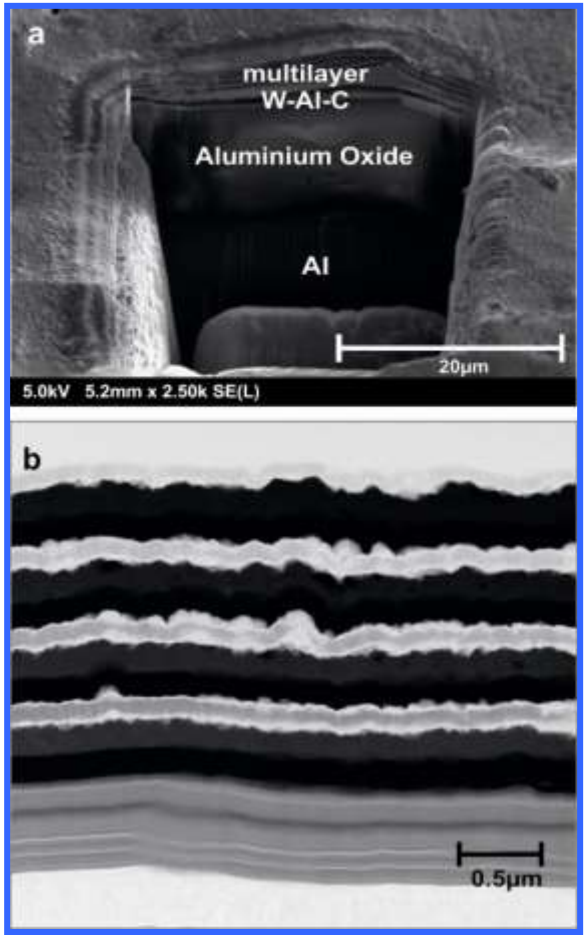
- ❖ 8 aerogels were investigated (one was destroyed). Aerogels were located in different distances from the target varied from 0.2 to 1.5 cm. Usually 10 laser pulses were used to „implant" the dust into the aerogels
- ❖ The caught dust is(was) analysed by the VR Sweden

➢In the future it is planed to use the aerogels in real thermonuclear machines to investigate the dust created during the discharge.

Investigation of surface effects and dust production in fiber-laser fuel removal treatment WP12-IPH-A03-2-04

- Experiments with the use of Nd:YAG (3.5 ns, 0.5J@1063nm) and Yb:fiber (100ns, 1mJ, up to 100kHz) lasers were done to investigate a sample with mixed material layer (W:Al:C in atomic ratio 1:1.6:2.4)

- Analysis of this kind of sample can give an information about the efficiency of laser removal (treatment) of co-deposits from tokamak walls. In this case the aluminum substrate simulates a beryllium wall while the mixed material layer simulates materials deposited during the discharges.

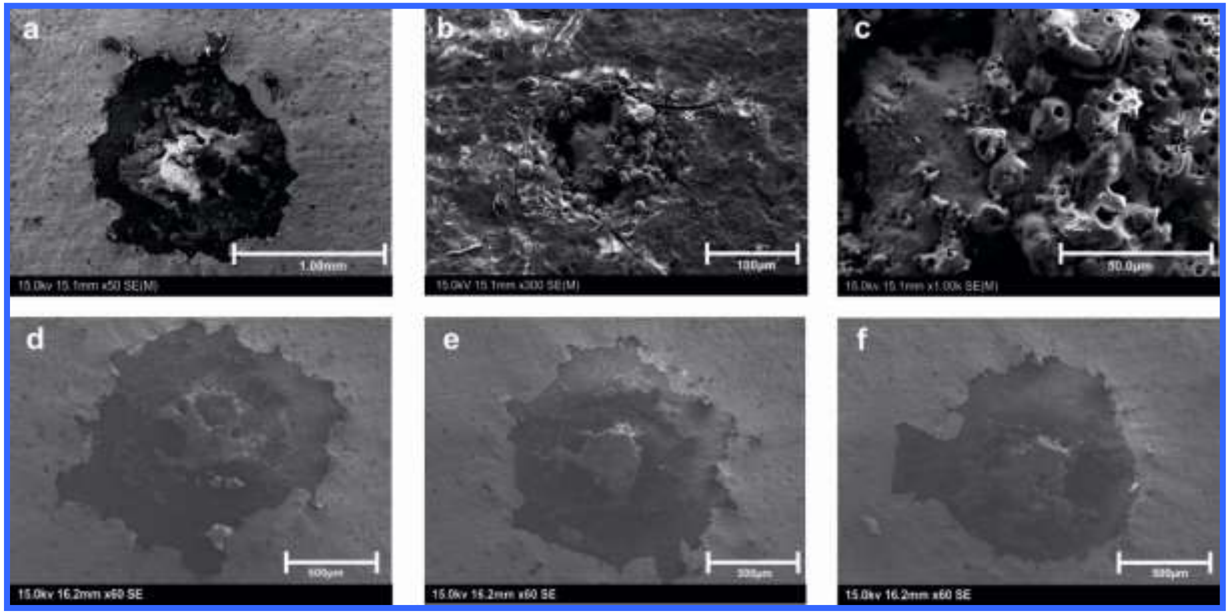


- Experiments with the Nd:YAG laser showed that for the power density of 2.5×10^{10} W/cm^2 both the W:Al:C mixed material layer and ceramic aluminum oxide layer were removed. Application of lower power density (~10^8 W/cm^2) still makes damages to the ceramic layer with visible cracks where aluminum droplets can be observed (which could originate from the substrate).

Investigation of surface effects and dust production in fiber-laser fuel removal treatment WP12-IPH-A03-2-04

- In experiments with Yb:fibre laser 4 power densities were applied: 1.3×10^{6}, 9.6×10^{5}, 7.6×10^{5} and 6.4×10^{5} W/cm^{2}. SEM images of craters obtained for these power densities by 10 s with 100kHz are presented (a, d-f) together with the close-ups of the crater after irradiation of 1.3×10^{6} W/cm^{2} (b,c).
- Only for the highest power density the aluminum substrate has been uncovered while for the lower power densities, below 10^{6} W/cm^{2}, the ceramic layer has not been damaged and only the mixed material layer has been removed (d-f).

- It means that the threshold for removal of aluminum oxide layer is at level 10^{6} W/cm^{2}.
- In the performed experiment the material removed by the fibre laser pulses did not create a macroscopic dust as it was observed in the case of Nd:YAG laser

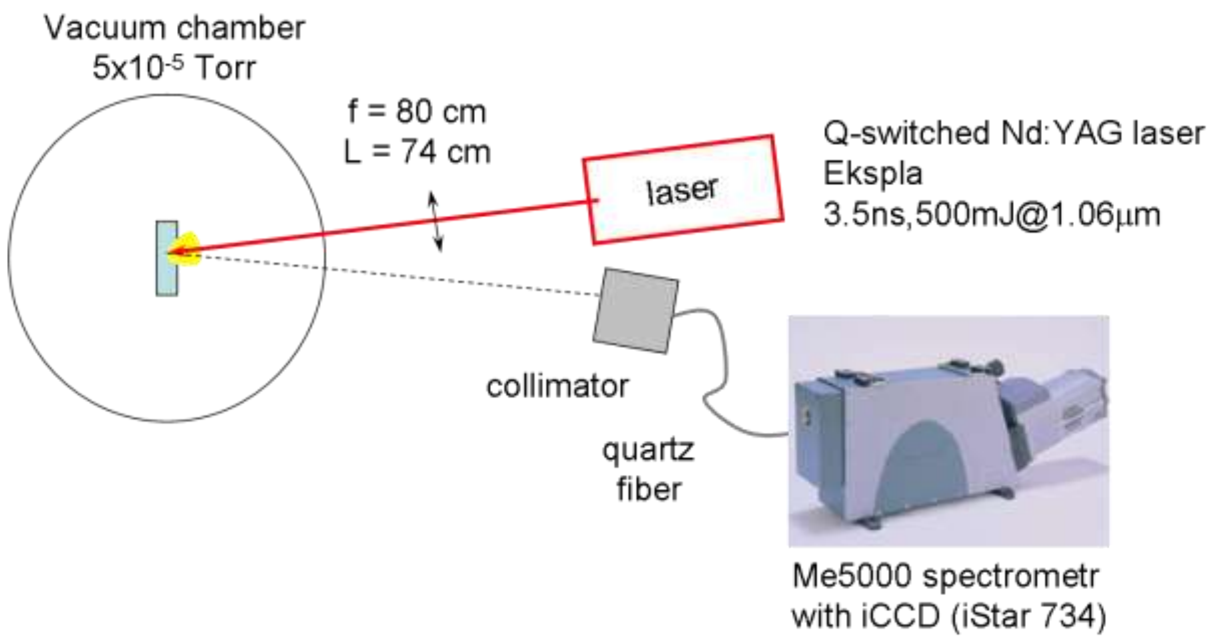


Results of presented work have been presented in 2012 at PSI conference and the paper entitle „Investigation of the Irradiation Effects on Laser-Removal and Surface Morphology of Mixed Material Sample” will be published in Journal of Nuclear Materials

Detection of the chemical components of ITER relevant (co)deposits by the LIBS- investigation of calibrated samples in various irradiation conditions.
WP11-ETS-DTM-01-05-02/IPPLM

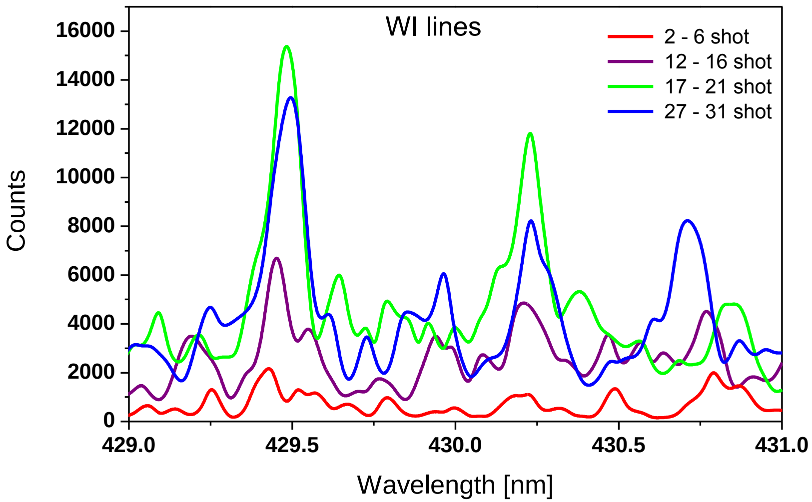
Laser experiments were performed with the use of ITER-like samples – with DLC and mixed of W:Al:C layer with Deuterium content. As a substrate, tungsten was used.

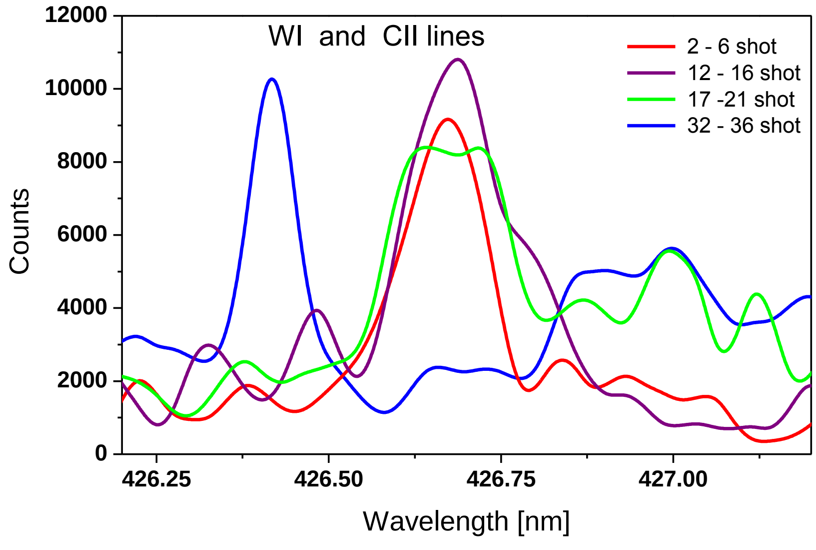
The experiments were conducted for three values of the fluence 2.5 J/cm^2 , 0.6 GW/cm2; 14.5 J/cm^2 , 3.6 GW/cm2; 25.8 J/cm^2 , 6.5 GW/cm2.

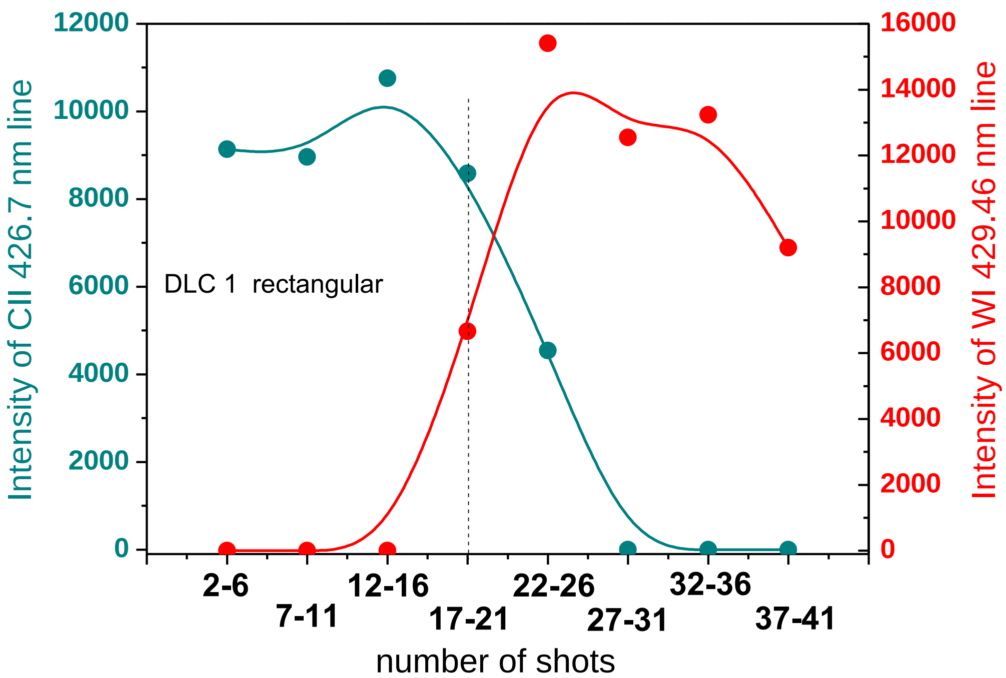


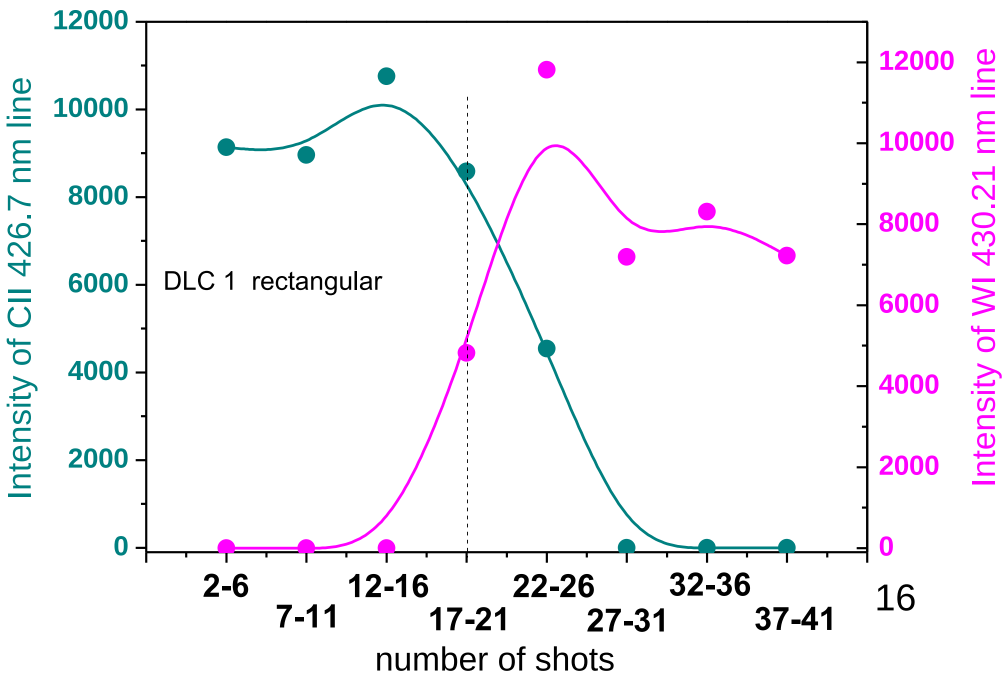
Several laser techniques, like LIBS (Laser Induced Breakdown Spectroscopy), LIDS (Laser Induced Desorption Spectroscopy) or LIAS (Laser Induced Ablation Spectroscopy) are considered as a candidates for tritium measurements
as well as erosion and deposition of reactor wall materials.

Resuts for DLC1 rectangular
Delay = 50 ns
Width = 2000 ns
Fluence = 28 J/cm^2
P = 8 GW/cm^2

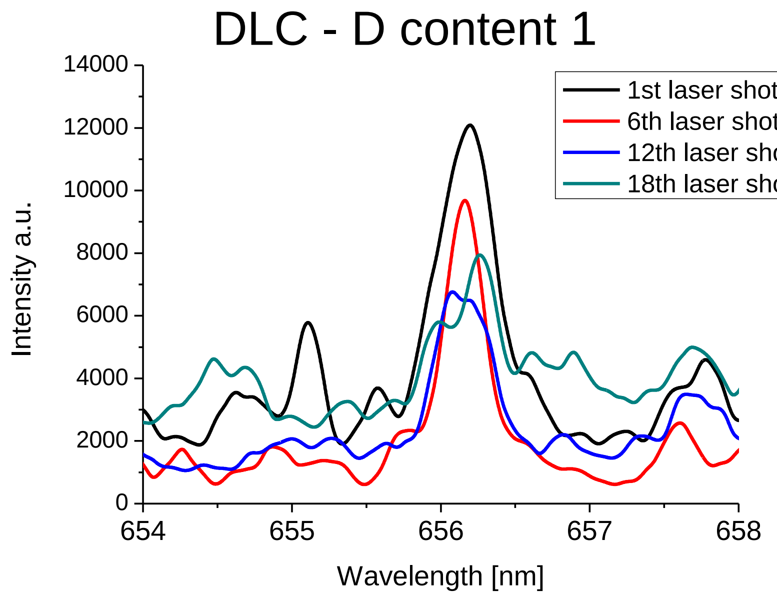


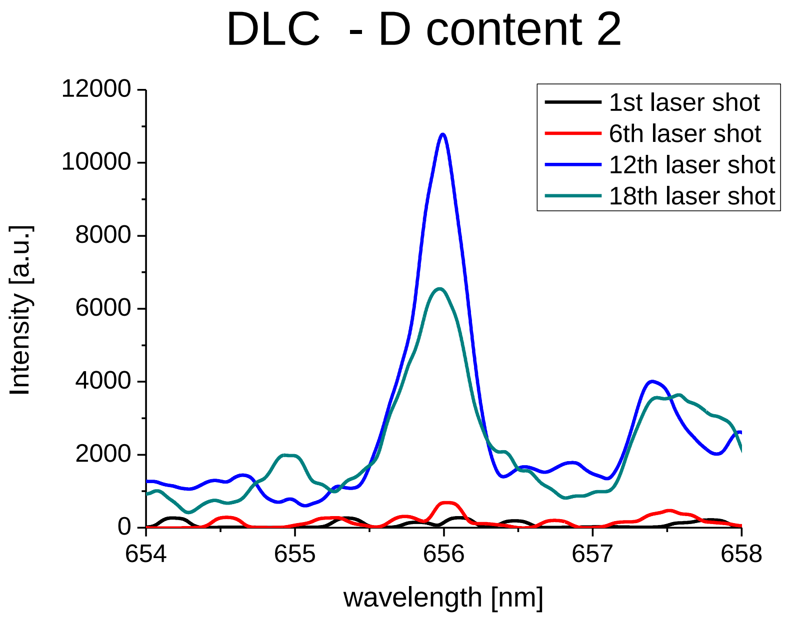


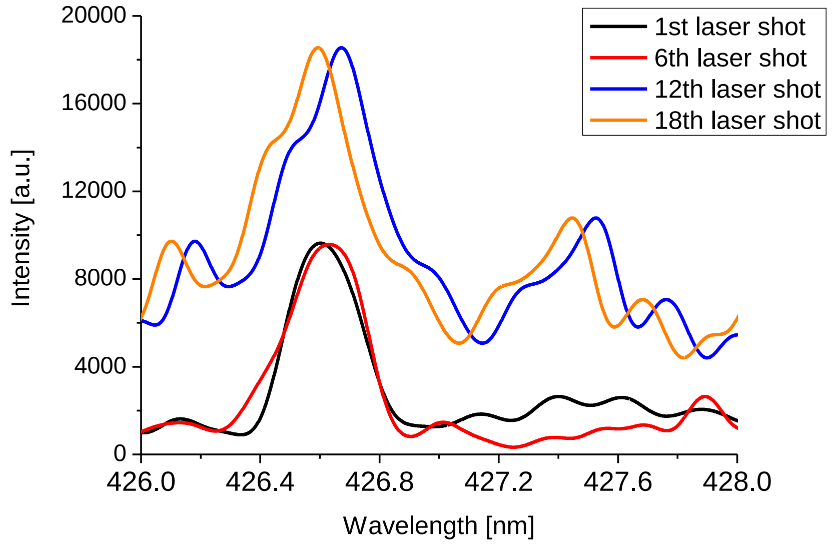


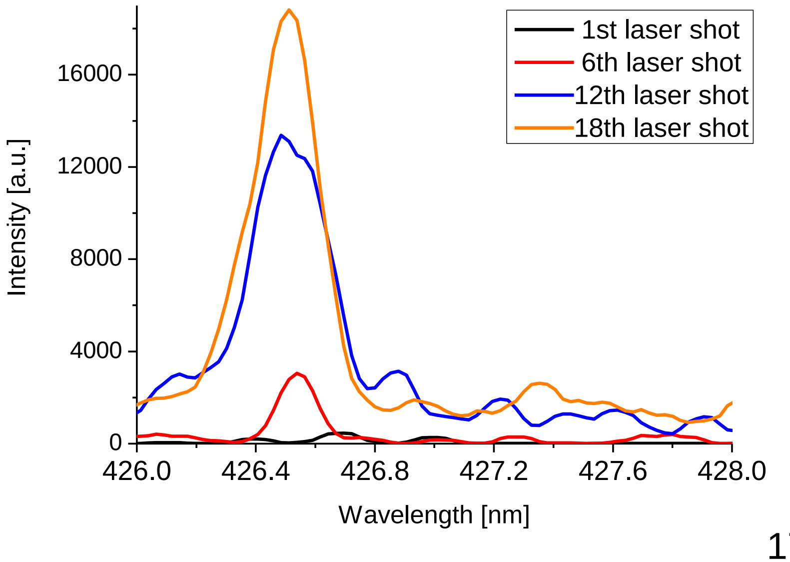


DLC samples with content of deuterium

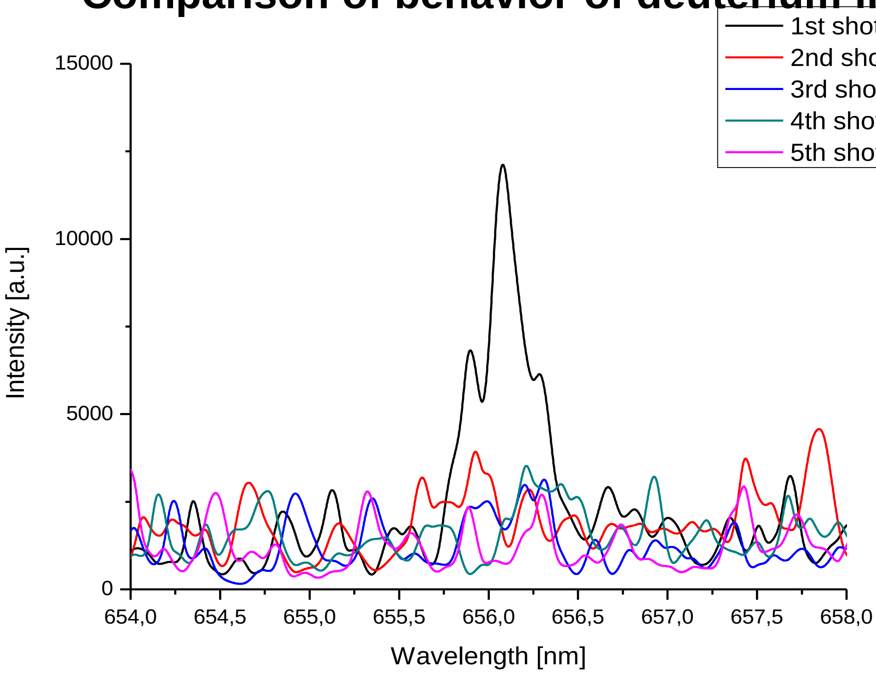


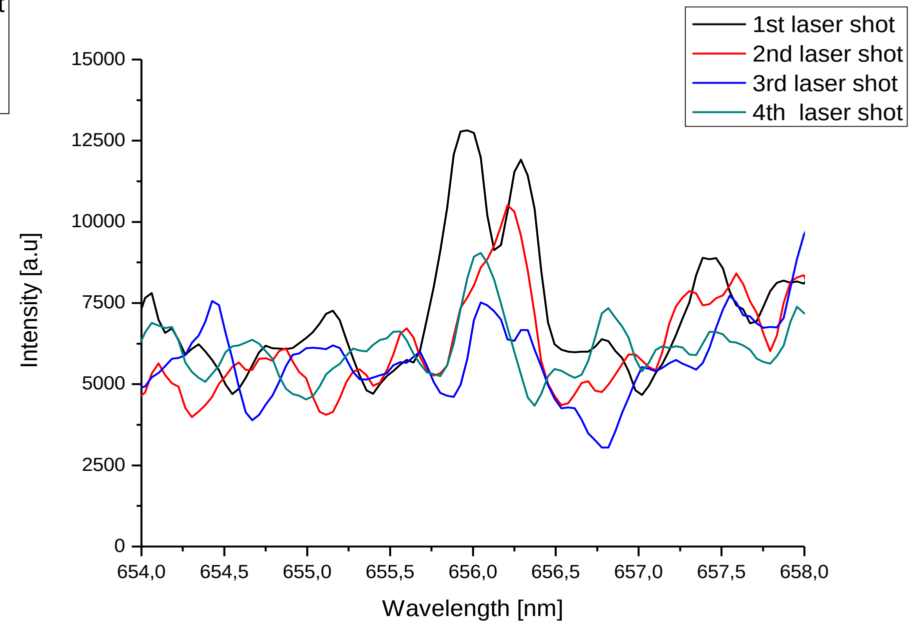




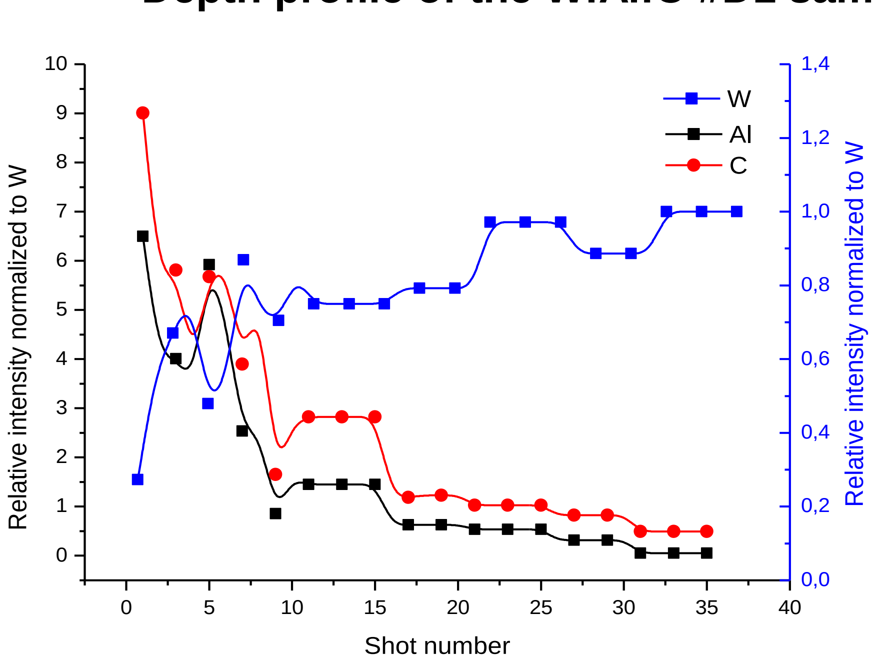


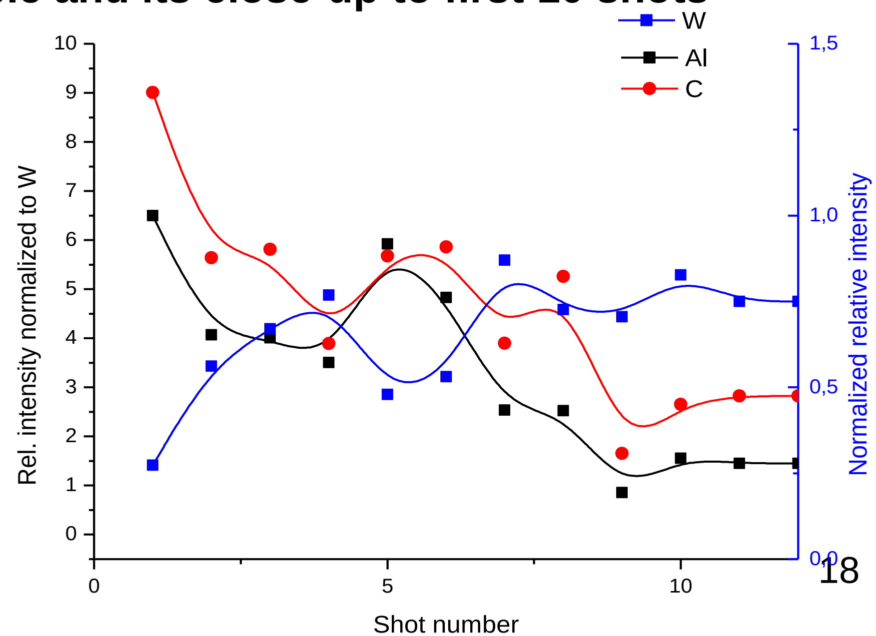
Comparison of behavior of deuterium line in W:Al:C #1 and W:Al:C# 3 sample.



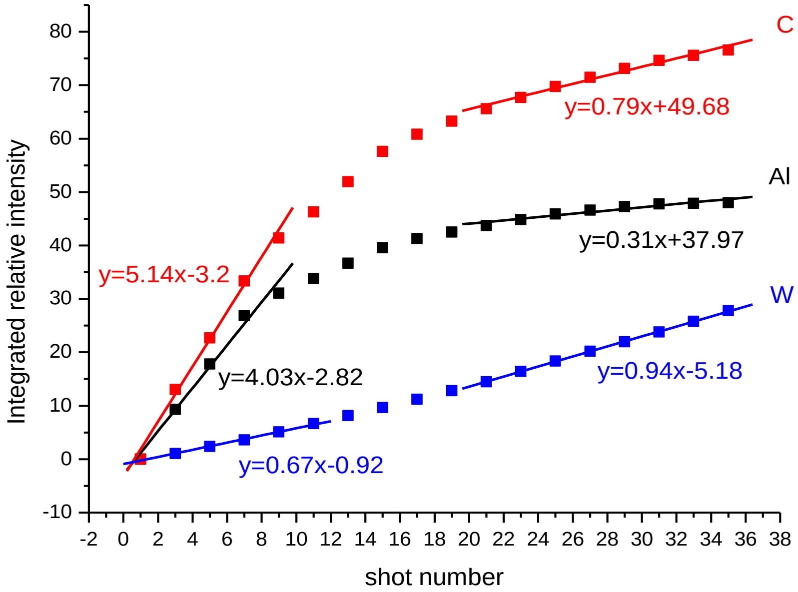


Depth profile of the W:Al:C #D1 sample and its close-up to first 10 shots





Integrated intensity of W, Al and C lines and their linear fits – slop method



Based on results the chemical contents of the sample was assessed as: 52% C, 41 % Al, 7% W.

Deuterium was present only in the first shot for the W:Al:C#D1 sample and small deuterium peaks were observed for first 3-4 shots at the W:Al:C#D3 sample. The measurements suggested that deuterium content was significantly lower than 10 % with rather poor accuracy.

Results were presented:

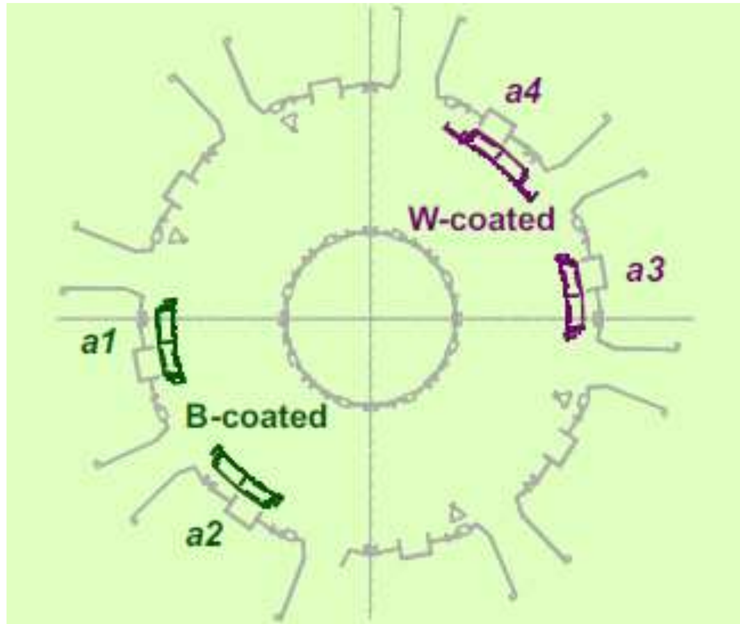
-20th International Conference on Plasma Surface Interactions (Development of ITER Relevant Laser Techniques for Deposited Layer characterization and Tritium Inventory, A. Malaquias, V. Philipps, A. Huber, A. Hakola, J. Likonen, J. Kolehmainen, S. Tervakangas, M. Aints, P. Paris, M. Laan, A. Lissovski, S. Almaviva, L.Caneve, F.Colao, G. Maddaluno, M. Kubkowska, P. Gasior, H.J. van der Meiden, A.R. Lof, P.A. Zeijlmans van Emmichoven, P. Petersson and M. Rubel)

-24th IAEA Fusion Energy Conference (Development of Laser Based Techniques for In Situ Characterization of the First Wall in ITER and Future Fusion Devices, V. Philipps, A. Malaquias, A. Hakola, G. Maddaluno, P. Gasior, M. Laan, H.J. van der Meiden, M. Rubel, A. Huber, M.Zlobinski, B.Schweer, N. Gierse, Q. Xiao, S. Almaviva, L.Caneve, Colao, A.Czarnecka, M. Kubkowska, E.Fortuna, P. Petersson).

High Power ICRH operation with metallic PFC
WP12-IPH-A11-3-03/PS-01/IPPLM

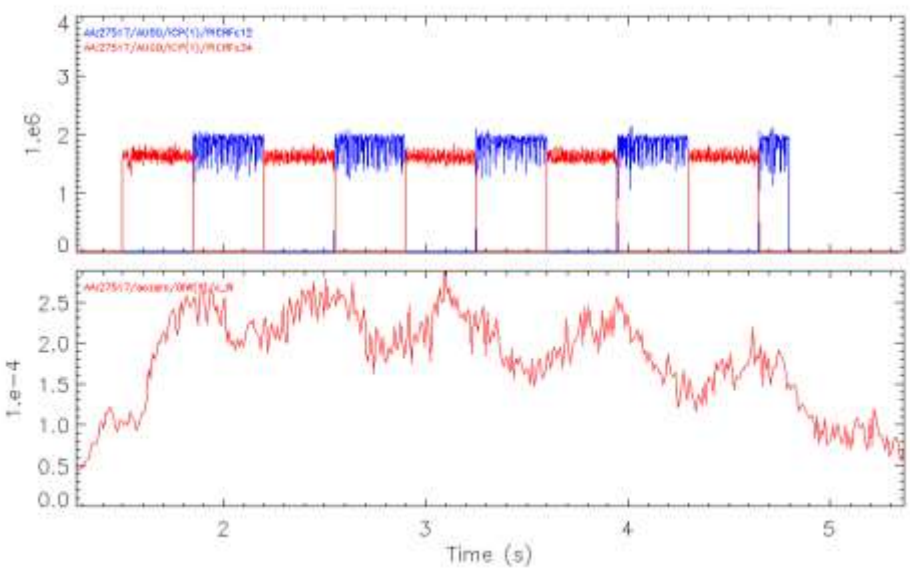
ICRH system at ASDEX Upgrade (AUG)

AUG - divertor tokamak with a full-tungsten first wall
R_{maj} < 1.65 m,
R_{min} < 0.5 m,
B_T < 3.1T,
I_p < 1.6 MA
pulse duration < 10 s



ICRH AUG system: antenna a1, a2, a3, and a4.

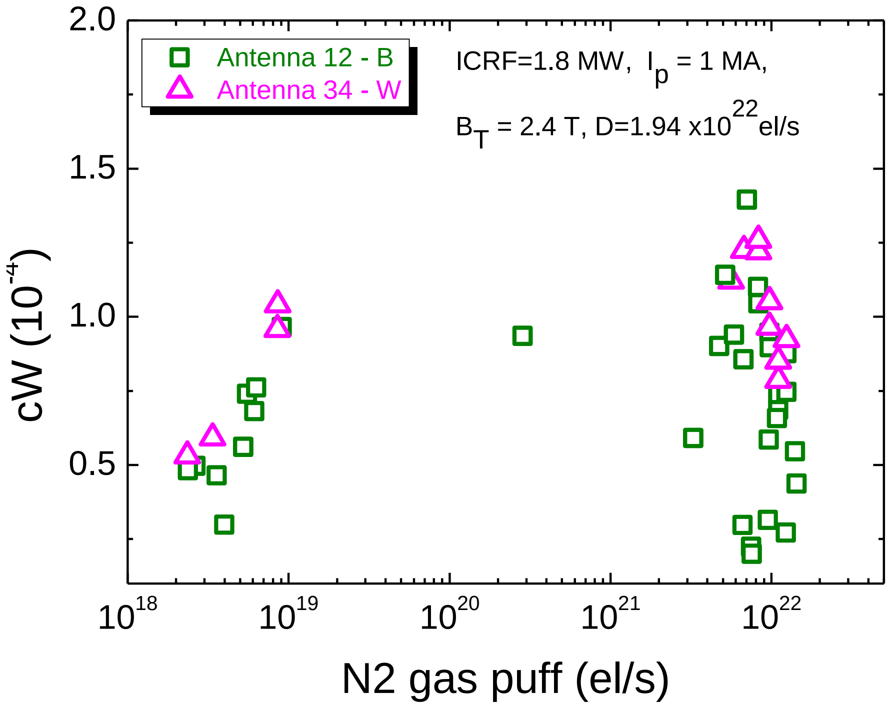
During 2012 experimental campaign the side limiters of the a1 and a2 antenna were coated by a 50 mm thick boron layer

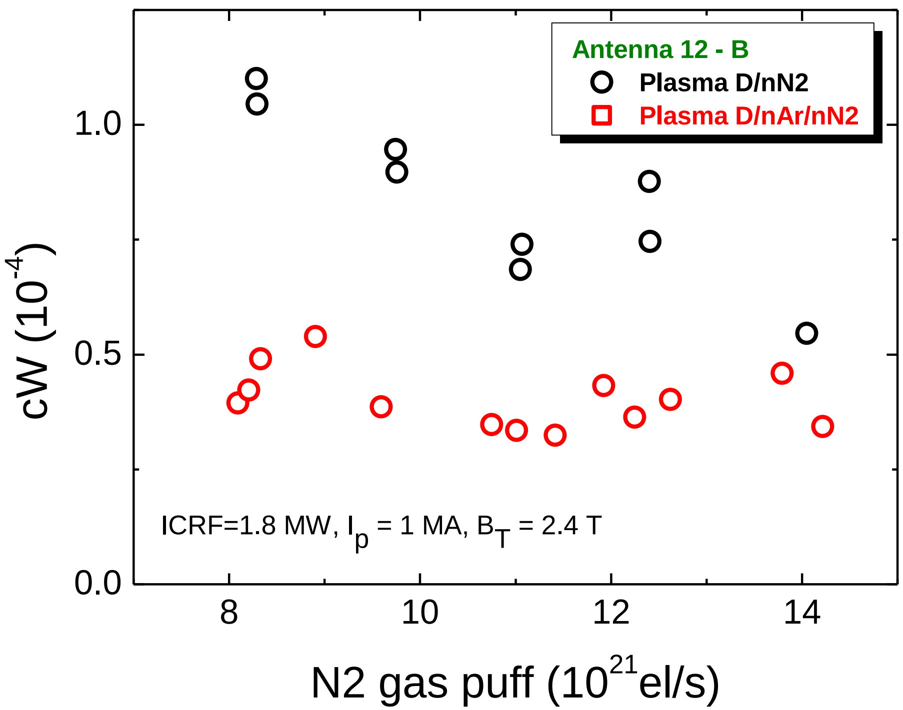


For the same ICRH power less W impurities during Antenna 12 (B-coated) operation in comparison with Antenna 34 (W-coated)

High Power ICRH operation with metallic PFC
WP12-IPH-A11-3-03/PS-01/IPPLM

Influence of N_2 and Ar gas puff on W concentration during ICRH



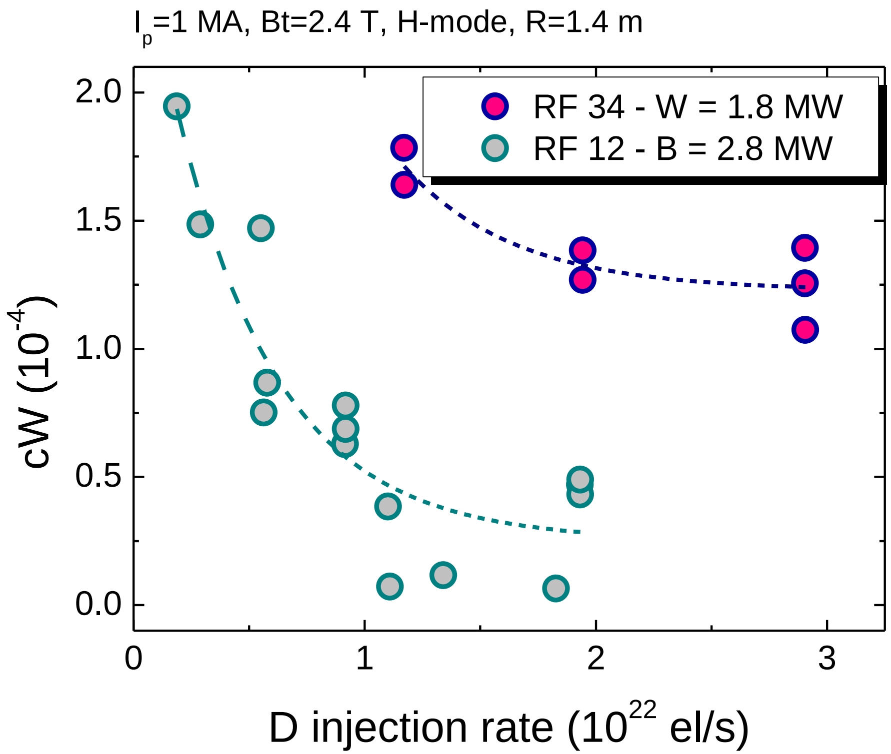


- **The W content is reduced by the injection N_2 gas puff in the range 10^{21}-10^{22} el/s**
- **For low N_2 injection rate 10^{18}-10^{19} el/s W concentration incerased in the plasma**
- **In both cases the same highest W concentration was observed during antenna 34 (W-coated) operation**

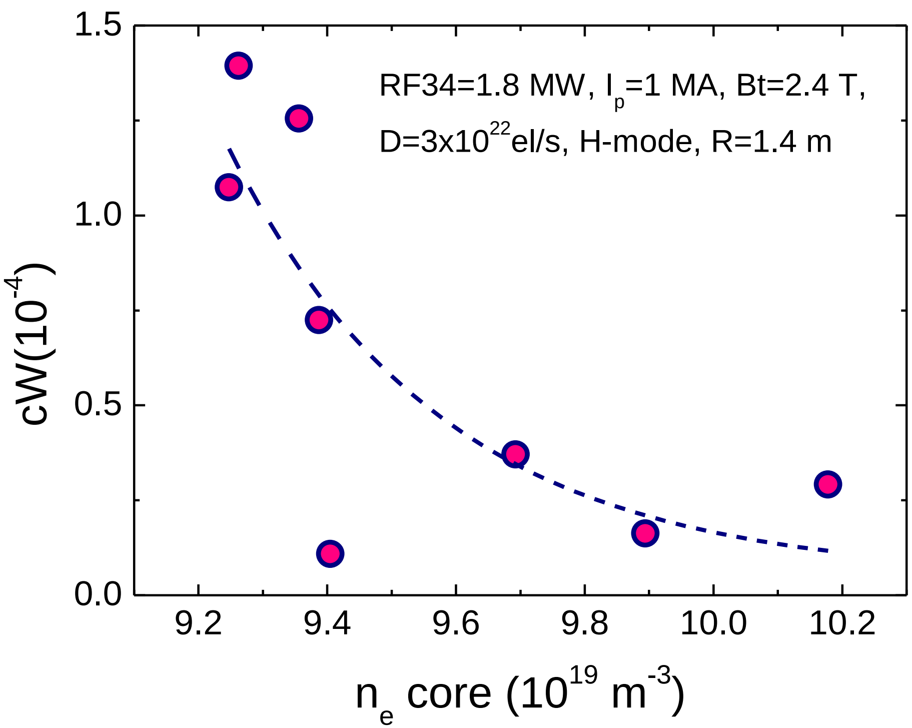
- W concentration is increasing with ICRH power
- For the same ICRH power the W concentration is reduced with N_2 gas puff
- 2 x better result is obtained with additional Ar gas puff

High Power ICRH operation with metallic PFC
WP12-IPH-A11-3-03/PS-01/IPPLM

Influence of deuterium gas puff on W concentration during ICRH



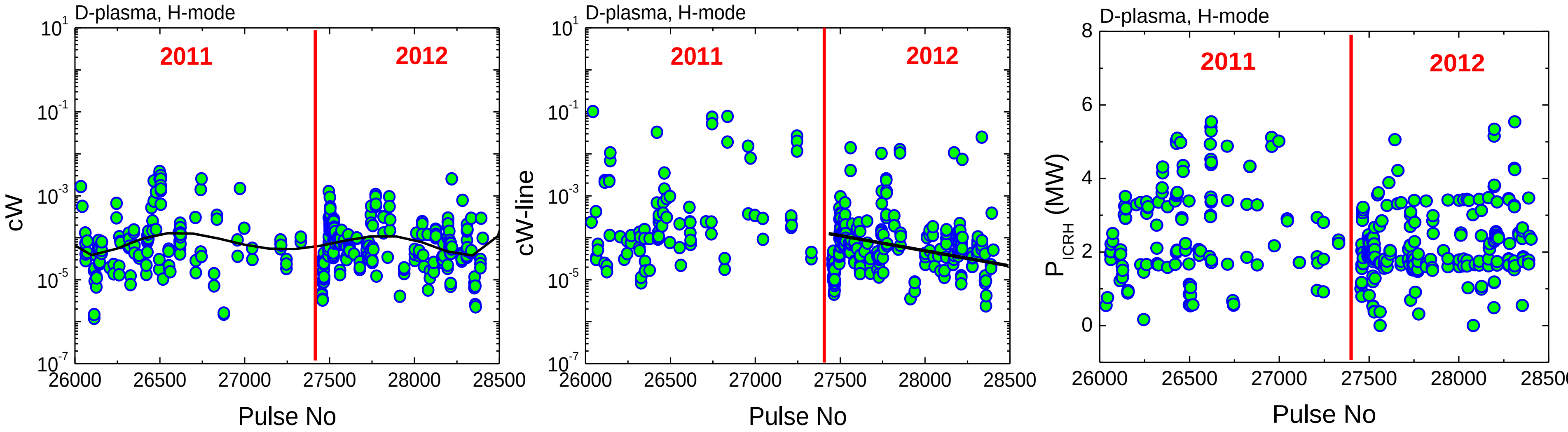
- W concentration decreasing with D injection rate for diffrent antennas
- It was observed lower W content during antenna 12 (B-coated) operation in comparison to antenna 34 (W–coated)



- For the constant D injection rate, heating power the W concentration decreased with the core electron density

High Power ICRH operation with metallic PFC
WP12-IPH-A11-3-03/PS-01/IPPLM

Statistical analysis of W during ICRH



• Averages of W concentration (continuum and line radiation) were calculated for all pulses during 2011 and 2012 in time ranges with ICRH in use for H-mode D-plasma.

• Most of the pulses were with 2 or 4 MW of ICRH power.

• Decreasing of W content in the plasma with the pulse number for each campaign was observed.

Thank you for your attention!