Max-Planck-Institut für Plasmaphysik, EURATOM Association

# Characteristics of different dust sampling techniques in view of the classification of particles from full-tungsten ASDEX Upgrade

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## Motivation

In next-step fusion devices (D-T, ITER-like wall), <u>dust</u> is considered a <u>safety hazard</u> due to its:

- Chemical reactivity with steam and air (volatile compound formation, explosion)
- Radioactivity (tritium and activation products)
- Toxicity (beryllium)

⇨ <u>Properties of dust</u> particles necessary input for safety risk assessment (e.g. size, density, chemical composition, active surface area, mobilization property)

<u>Operational issues</u> are also associated with dust:

- Radiation energy losses in core and SOL
- Risk of dust-triggered disruptions

⇨ Link between discharge conditions, dust generation, mobilization, transport and deposition pattern

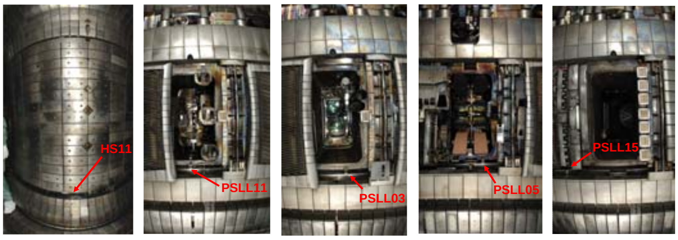
Identification and linking of dust sources and particle morphology

⇨ <u>Aim</u>: Reconstruction of average dust life-cycle of each class (access via inner morphology studies of individual particles)

## Experimental

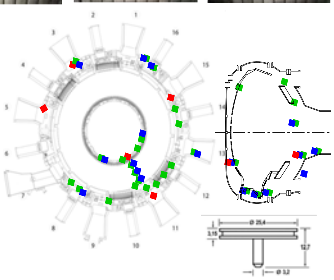
**<u>Photographical in-vessel inspection</u> after opening:**

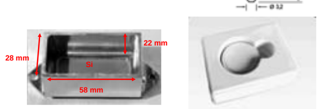
- Campaign-wise documentation of PFC status
- Documentation of diagnostics positions
- Identification of areas of intense plasma wall interaction (possible dust sources)




**<u>In-vessel dust sampling</u>:**

- **Si wafer collectors** – *during campaign*
  - \+ highest collection efficiency (grav.+ el. force)
  - \+ lowest sample contamination
  - \- limited number & predefined sampling sites
  - \- coated during boronisation
- **Filtered vacuum cleaning** – *after campaign, standard method used since 2000*
  - \+ best optical & elemental contrast conditions
  - \+ sampling also in V.V. pockets
  - \- low air flow & only mobilizable dust
  - \- formation of conglomerates
- **Adhesive tape sampling** – *after campaign*
  - \+ fast sampling on large number of positions
  - \+ no dust particle dislocation due to charge up
  - \- glue degeneration in air with time
  - \- only low electron fluxes for SEM analysis






*Top: Positions of dust collection sites of 2008 & 2009 campaign: Si wafer (♦), filters (♦) & tapes (♦). Bottom: Si wafer collector holder, tap holder and filters.*

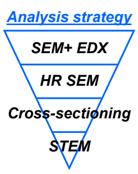
**<u>Dust sampling campaigns:</u>**

- **2009**: Jan-Dec 09, 3 x Boron, 1101 shots, 5275 sec plasma: 5(4) Si wafers, 10 filters, 41 taps
- **2008b**: Sep-Nov 08, 2 x Boron, 354 shots, 1822 sec plasma: 5(4) Si wafers
- **2008a**: Jan-Jul 08, 3 x Boron, 755 shots, 3553 sec plasma : 3(2) Si wafers
- **2007**: Mar-Oct 07, 0 x Boron, 383 shots, 1847 sec plasma: 3(3) Si wafers

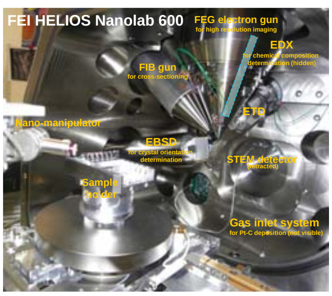
## Post-mortem dust analysis

- <u>Automated particle</u> detection and <u>element analysis</u> Thresholding of grey-scale SEM images + EDX spectra
- Typically >10000 particles per specimen
- Elemental composition for each particle (except Si for wafers, C for tabs, Al for filters)

***<u>Analysis strategy</u>***



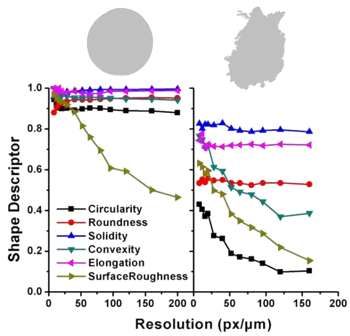

- Representative particle of each class imaged via **H**igh **R**esolution SEM
- Inner morphology via cross-sectioning of individual particles
- Crystalline structure




## Conclusion

- Less re-deposited layers and dust observed since completion of full W first wall in AUG
- Classification scheme based on outer morphology & elemental composition of $10^5$ particles (7 classes)
- More than one third part of all particles dominated by tungsten (flakes and spheroids)
- More than 90% of all W-dominated spheroids are W-droplets (arcing as origin)
- Part of all flakes are conglomerate of W-droplets embedded in C-B matrix (originated by flaking off of deposited films from areas with strong arcing activity)

## Dust particle classification




*Shape descriptors vs. image resolution: the perimeter dependent parameters Convexity, Surface Roughness and Circularity show a strong dependency. From the 3 remaining descriptors Roundness was identified as a robust criterion at low image resolutions (sandard.: 16 px/µm).*

Separation of:

- *<u>Dust</u>*: direct plasma wall interaction products
- *<u>Debris:</u>* produced by maintenance works or during plasma operation without direct plasma contact

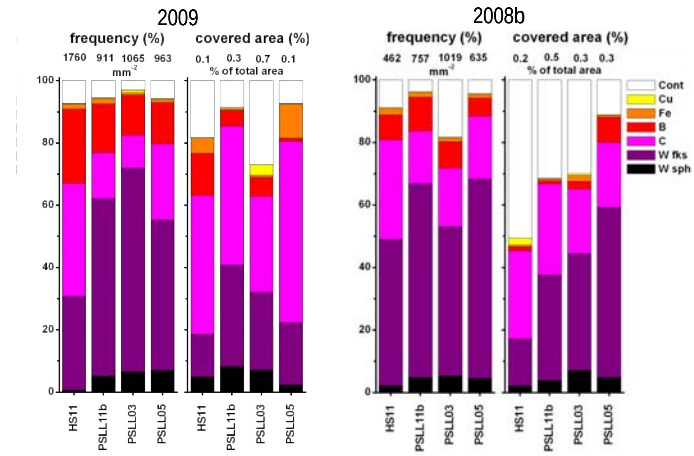
⇨ <u>7 classes:</u> chemical composition and shape criteria

| Parameters | W sph | W fks | C | B | Fe | Cu |
|---|---|---|---|---|---|---|
| *Roundness* | ≥ 0.85 | < 0.85 | ns | ns | ns | ns |
| *B* | ns | ns | ns | 1(0) | ns | ns |
| *C* | ns | ns | 1 | 0 | ns | ns |
| *O* | ns | ns | ns | ns(1) | ns | ns |
| *Fe* | ns | ns | 0 | 0 | 1 | 0 |
| *Cu* | ns | ns | 0 | 0 | 0 | 1 |
| *W* | 1 | 1 | 0 | 0 | 0 | 0 |
| *Na,S,Ka,Ca,Ni* | ns | ns | 0 | 0 | ns | ns |
| *Mg,Al,Ti,Zn,Mo, Ag,Au* | 0 | 0 | 0 | 0 | 0 | 0 |

*Classification scheme: ns means "not specified", „1" stands for "element detected" and brackets represent bool "or" operation. Only if a particle fraction of > 5 % in one sample show similar characteristics a new class is introduced.*

## Dust composition

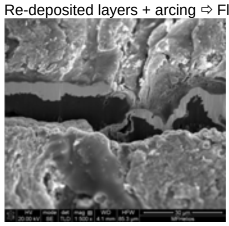
- Toroidal symmetry seen for lower PSL in 2009
- Local sources of dust to be considered (arcing and local melting sites)
- Off-normal events e.g. divertor delamination large impact
- Low particle coverage of 1k/mm² due to full W




*The fraction of total number of particles and fraction of covered area per class: the numbers above the columns give the particle density per mm² and the fraction of area covered by particles.*

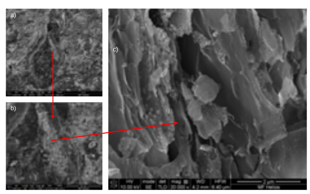
## Dust sources

- Arcing ⇨ droplets (W)
- Re-deposited layers + arcing ⇨ Flakes (W, C, B)



*Cross-section through an arc track and partly detached layered re-deposited material (W coating on graphite)*

- W droplets embedded in C-B matrix + ablation ⇨ Conglomerates
- Local melting of in V.V. structures & PSL ⇨ Fe, Cu



*SEM images of AUG divertor tile suffering strong arcing. a) Overview with large arc track, b) edge of arc track in medium magnification, and c) detail view of partly flaked co-deposited layer beside arc track.*

- Other local sources e.g. i) "contamination" below diagnostics dominated by $SiO_2$ particles from glass fibre isolation or ii) particles originating from damaged diagnostics (Al-coated $MgF_2$ mirror)

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