A SEM, EDS and ^{3}He-NRA synergy in the micro analysis of AUG dust particles

Georgios Provatas

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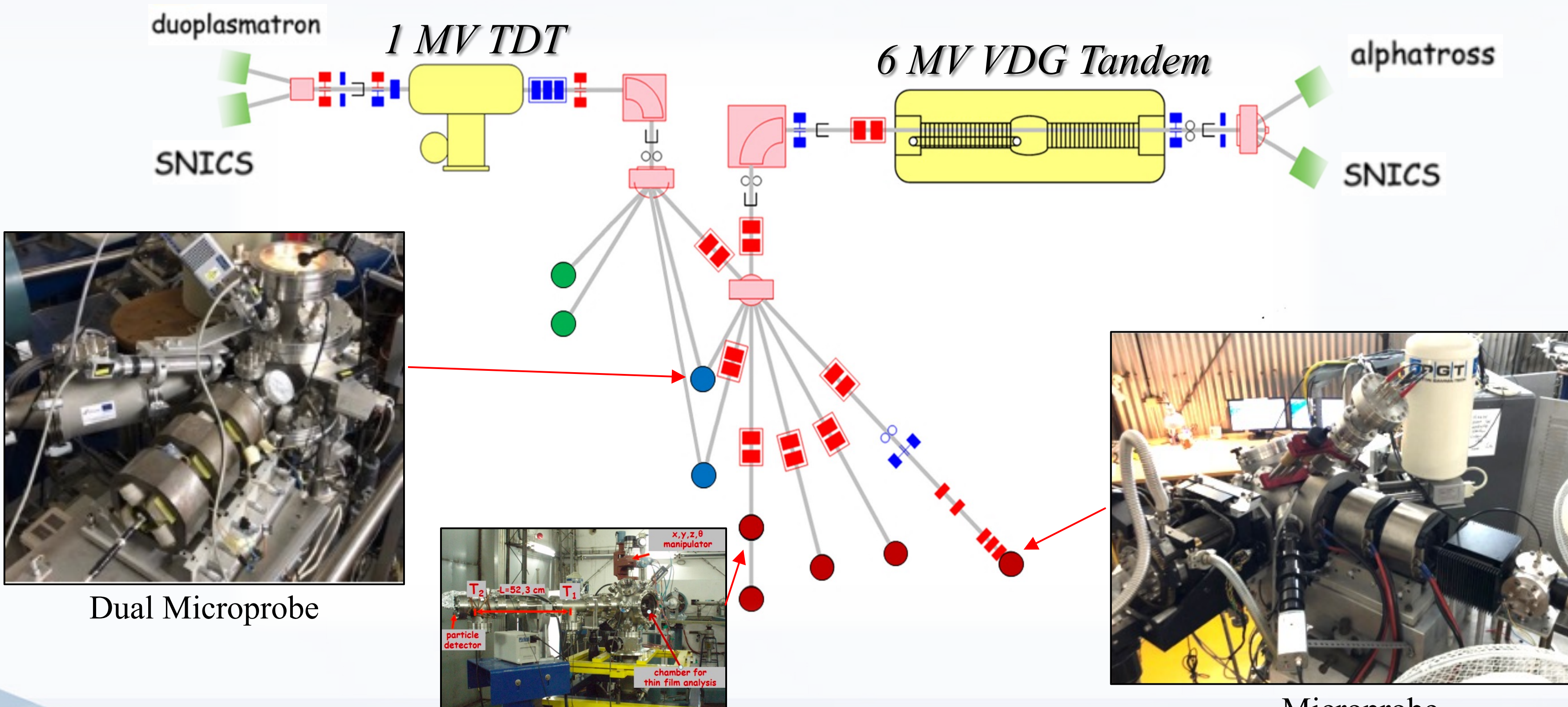
M. Balden, V. Rohde

The RBI accelerator facility infrastructure

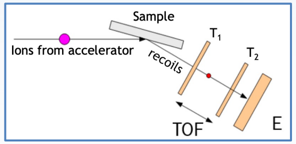


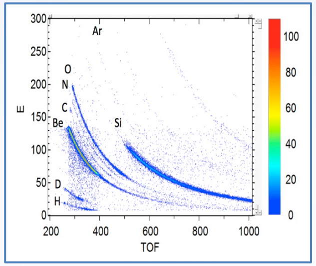
Dual Microprobe

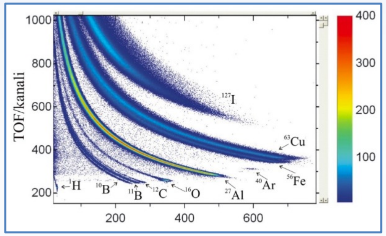
ToF ERDA

Microprobe

ToF-ERDA



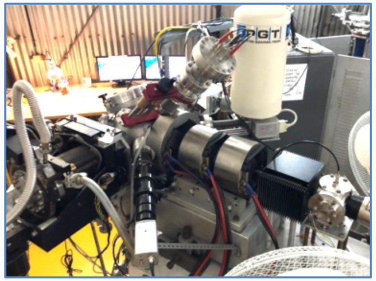


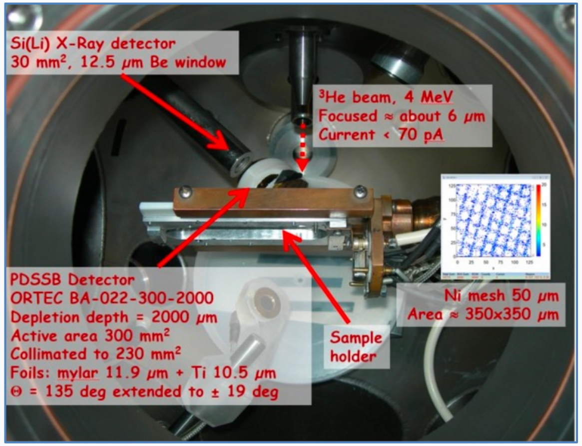


- Mass resolution is better than 1 for M < 40
- **Sensitivity 0.1 at%**
- **For films containing heavy elements (like W) TOF-ERDA can measure concentrations and depth profiles of light elements in first 100-200 nm**

→ Beam spot of few mm
Not appropriate for dust analyses

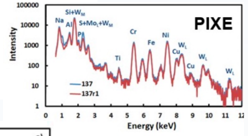
uNRA, uPIXE

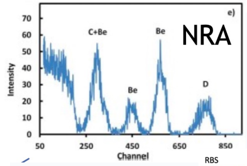


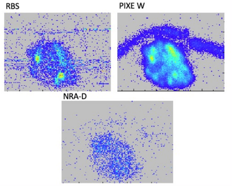


IBA analysis of dust particles:

- Focused ion beam: 2.7 - 4 MeV $^{3}He \approx 6$ μm
- Ion beam currents about 70 pA
- scanned areas: 350x350 μm
- NRA: light elements (D, B, Be, C, N)
- PIXE: Na and heavier elements
- EBS: C, O, N, etc.
- analysis to the depth of about 15 μm in Be rich samples

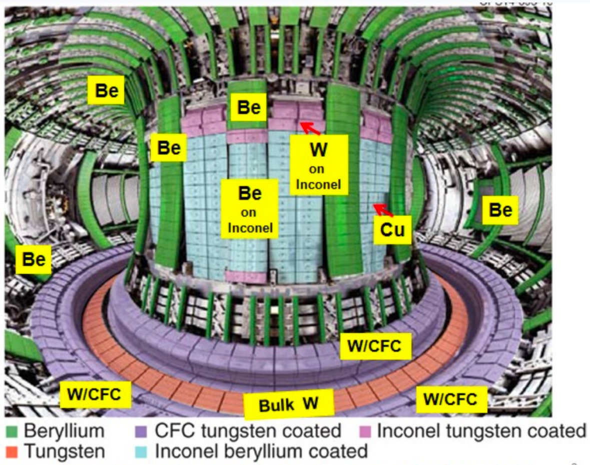






Previously on RBI

Dust particles from the JET-ILW studied at RBI



J.C. Flanagan et al., Plasma Phys. Control. Fusion 57 (2015) 014037

Ion Microbeam Analyses of Dust Particles and Codeposits from JET with the ITER-Like Wall

Stjepko Fazinić,[*,†] Tonči Tadić,[†] Marin Vukšić,[†] Marek Rubel,[‡] Per Petersson,[‡] Elżbieta Fortuna-Zaleśna,[§] and Anna Widdowson[‖]

2018

Micro-analyses of dust particles generated in the JET tokamak with the ITER-like wall

Stjepko Fazinić[1], Iva Božičević-Mihalić[1], Georgios Provatas[1], Tonči Tadić[1], Marek Rubel[2], Elżbieta Fortuna-Zaleśna[3], Anna Widdowson[4] and JET contributors[a]

2020

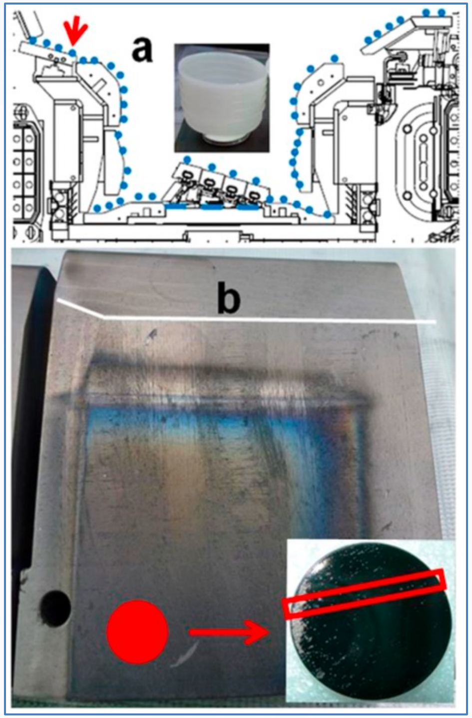
Article

Dust Monitors in JET with ITER-like Wall for Diagnosis of Mobilized Particles and Co-Deposited Layers

Stjepko Fazinić [1,*], Georgios Provatas [1,*], Iva Božičević Mihalić [1], Tonči Tadić [1], Marek Rubel [2], Justyna Grzonka [3], Per Petersson [2], Anna Widdowson [4], Sunwoo Moon [2] and Elzbieta Fortuna-Zaleśna [5]

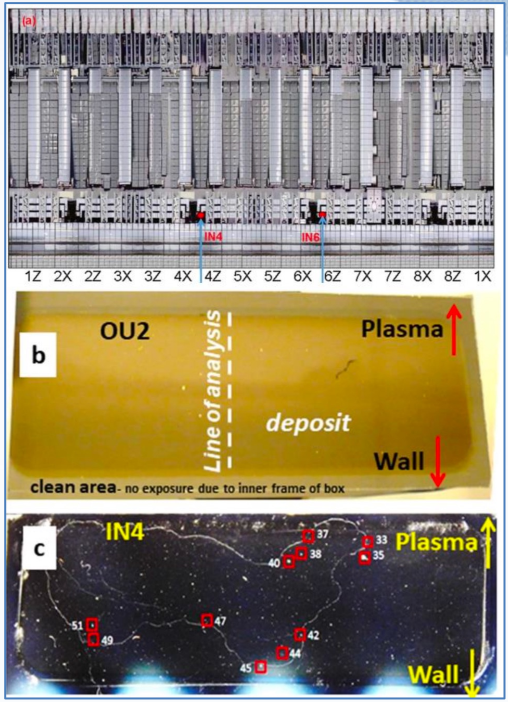
2022

Micro-analyses of JET-ILW particles @ RBI



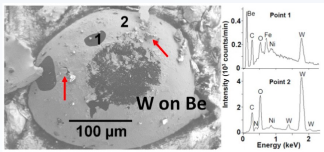
Dust sampled using stick carbon pad from the inner divertor tile after ILW-2 (2013-2014)

Samples collected from vacuum cleaner after the ILW-3 in 2015-2016

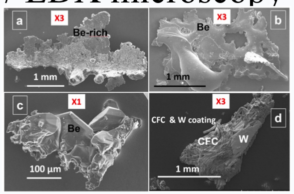


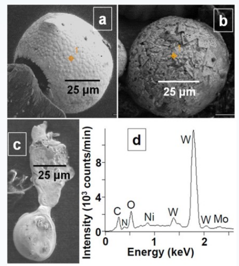
Dust particles collected ILW-2 and ILW-3 on Si plates-monitors, wall probes for erosion and deposition studies.

Micro-analyses of JET-ILW particles @ RBI



SEM / EDX microscopy



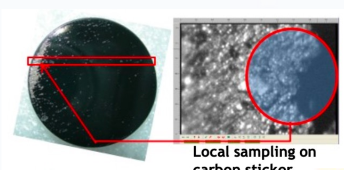


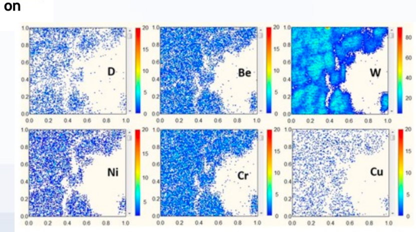
Initially, particles interesting for further analysis are characterized and selected by means of SEM/EDS microscopy.

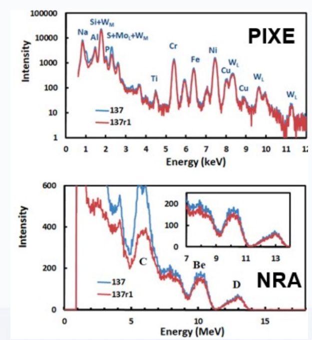
Warsaw University of Technology

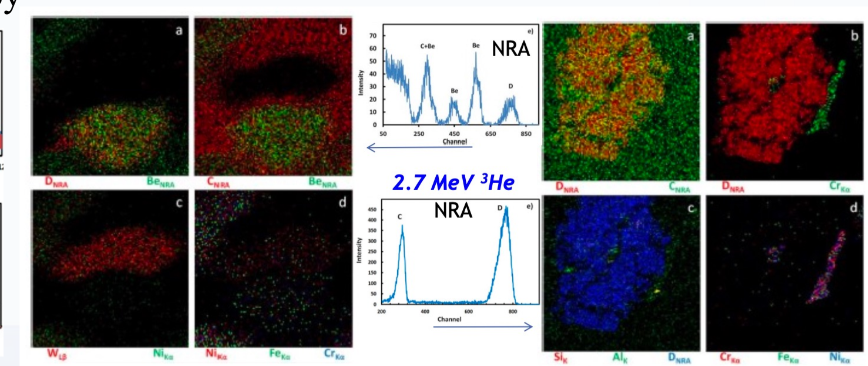
EDS not sensitive to D
Not accurate in light elements quantification

Selected particles were further studies by NRA, PIXE microscopy

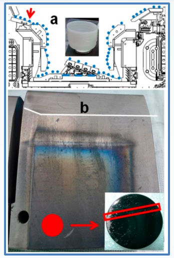








Findings from micro-analyses of JET-ILW particles @ RBI



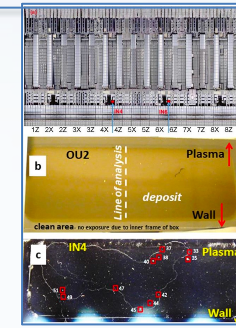
Two types of dust particles were found

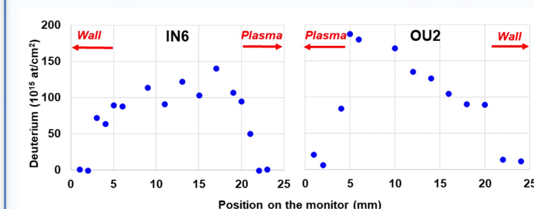
1) Larger Be-rich >90 at% with D up to 3.4 at% also Ni (1−3 at%), Cr (0.4−0.8 at%), W (0.2−0.9 at%), Fe (0.3−0.6 at%), and Cu and Ti.

1) small particles rich in Al and/or Si that were in some cases accompanied by other elements, such as Fe, Cu, or Ti or W and Mo.

1) Areas of ~120 × 120 μm rich in Be, W and steel or Inconel components and NRA spectrum with Be and D presence.
2) Carbon particles with high D-content

Clear evidence that fuel retention is predominantly associated with Carbon.



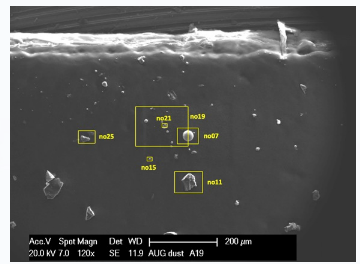


Different types of particles were found.
Deuterium content in co-deposits on the monitor did not exceed 2 x 10^{17}cm^{-2}.

Low fuel retention and a very small amount ITER-relevant dust generated in JET-ILW

Micro-analyses of particles from AUG @ RBI

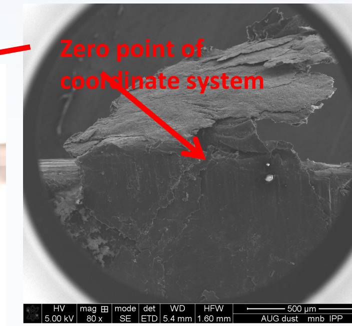
On 2020 M. Balden sent to RBI dust particles for AUG on two sticky carbon pads

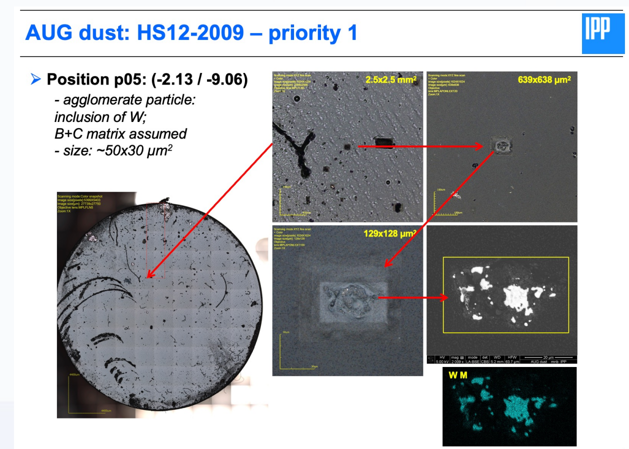


The ROIs were initially prioritized by means of EDS microscopy.

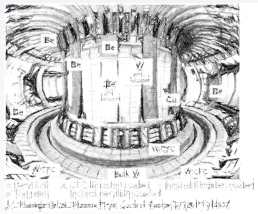
Detailed SEM images with coordinates of interesting particles highlighted for further u-IBA analysis.

Coordinates of 2nd particle at edge (-9.11 / 4.37)

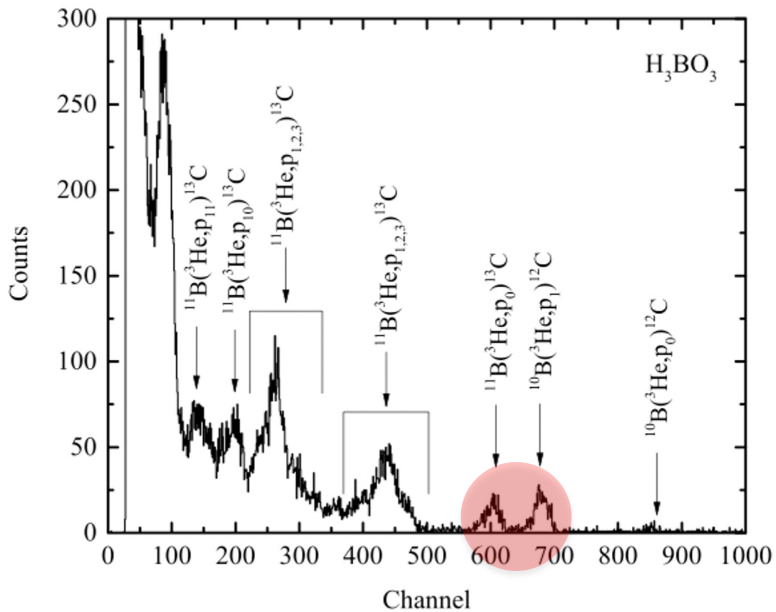


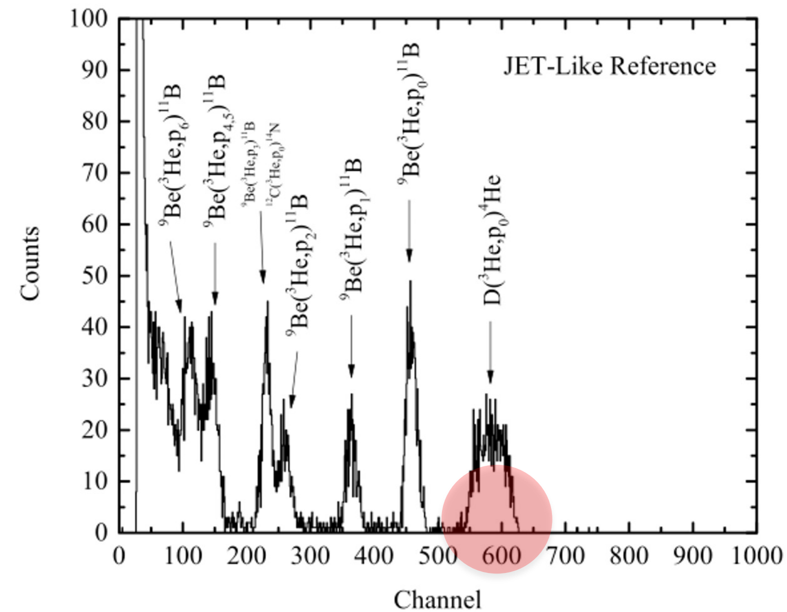


Micro-analyses of particles from AUG @ RBI



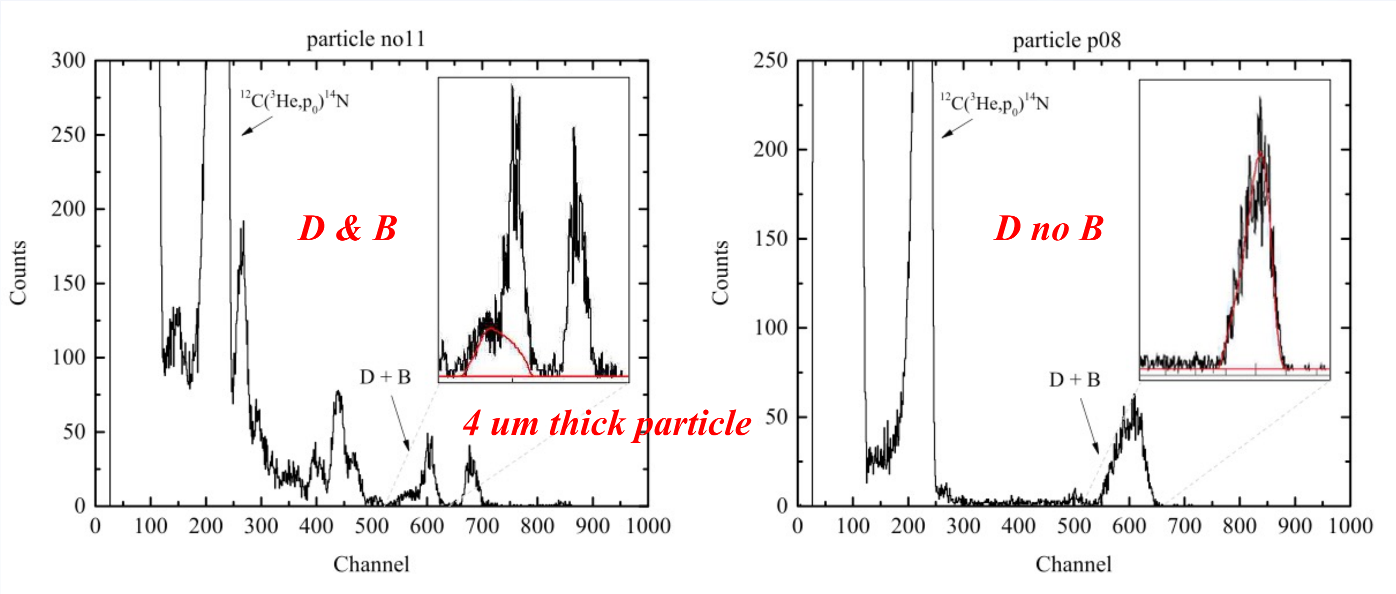
In AUG first wall is Be-free, however, Boron could be present due to boronization, that creates a thin B film on the walls to reduce the levels of impurity contamination in plasma



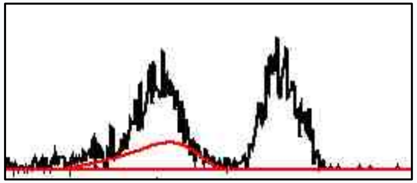


NRA analysis for D quantification can be challenging due to signal overlap.

Micro-analyses of particles from AUG @ RBI



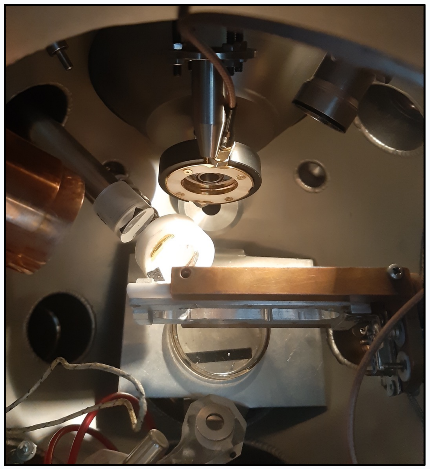
8 um thick particle

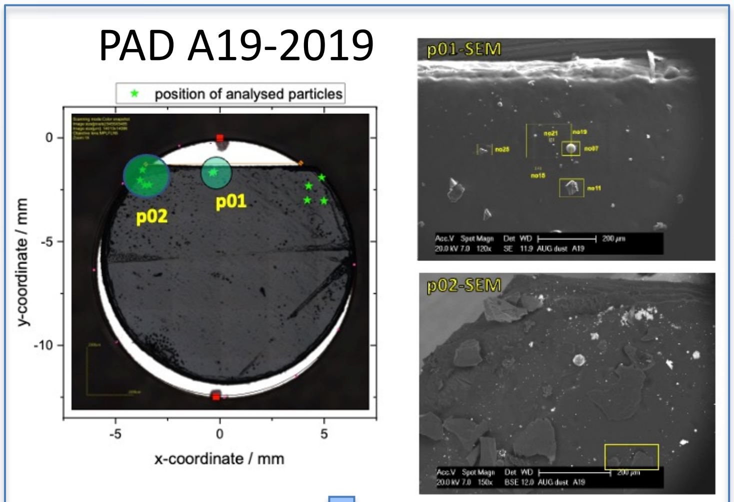


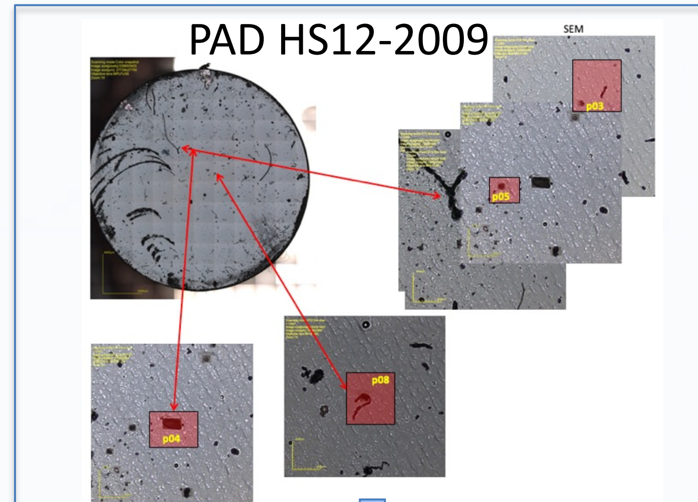
NRA analysis for D content carried out using SIMNRA, taking into account the angular spread of the detector.

Micro-analyses of particles from AUG @ RBI

The two pads were inserted in the microprobe and with the use of a microscope ROIs were identified







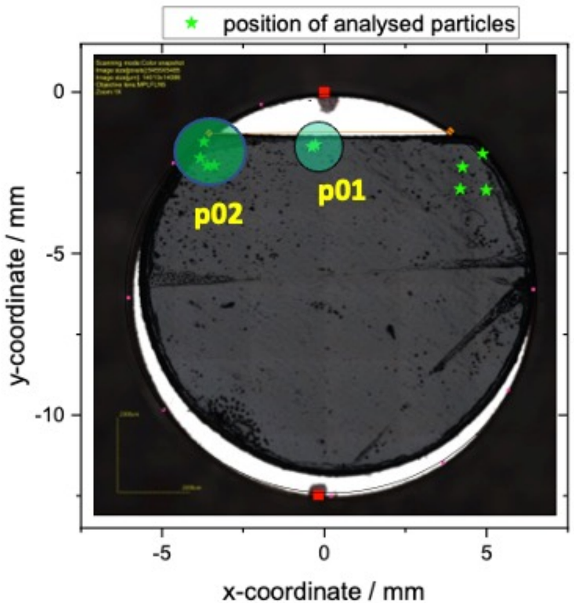
Deuterium with Boron

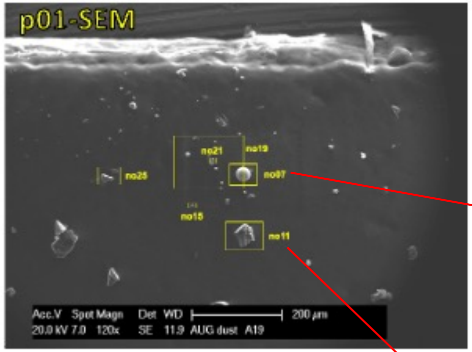
Boron free = Clear isolated D peak for analysis

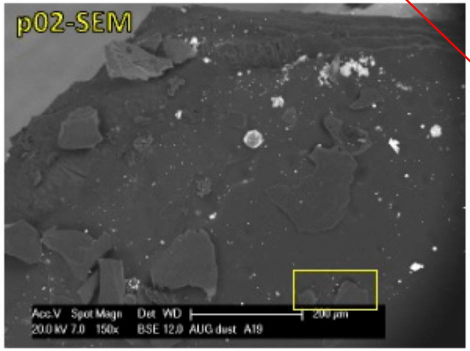
Micro-analyses of particles from AUG @ RBI

PAD A19-2019

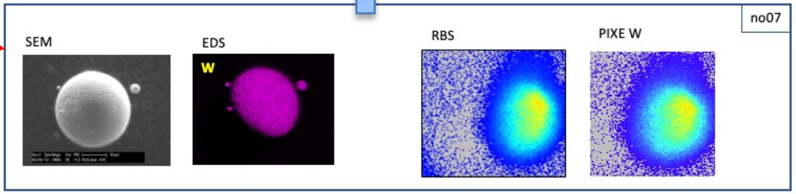
Most of the collected particles in the first pad are located near the top edge

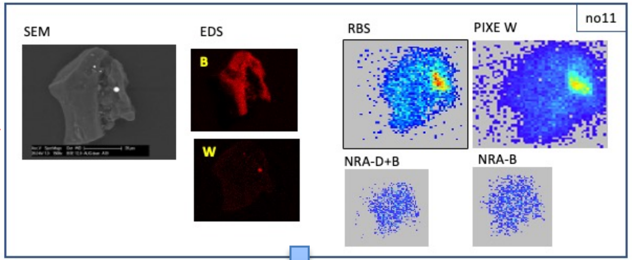






W sphere ⌀ 40 um, includes Al, K, Na





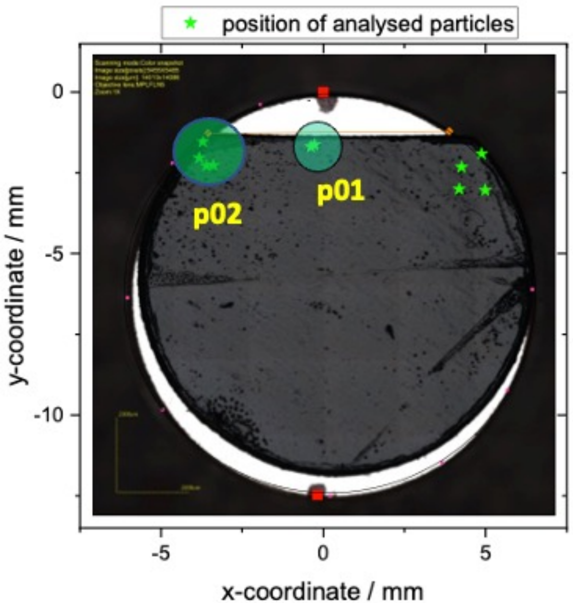
50x60 um, and 8um thick particle

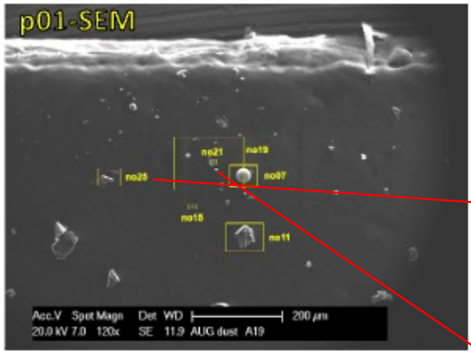
Deuterium: 43 (7) x10^{15} at/cm^2

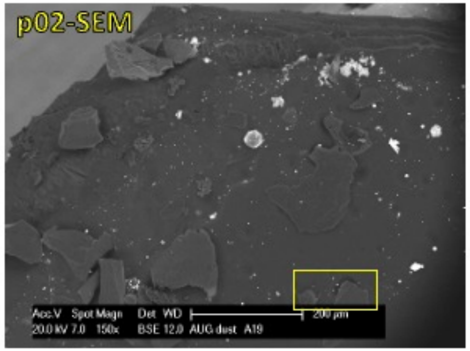
B, W, Al, Cr, Fe

Micro-analyses of particles from AUG @ RBI

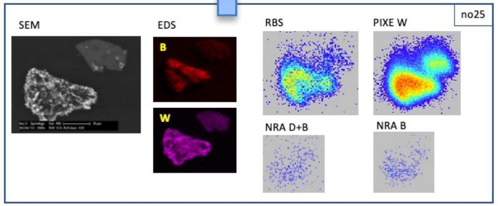
PAD A19-2019

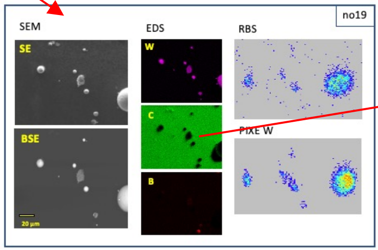


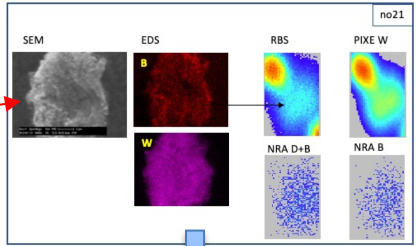




2 particles
20x20, 30x40 um and 8 um thick
Deuterium: 18 (3) x10^{15} at/cm^2
B, W, Al, Cr, Fe



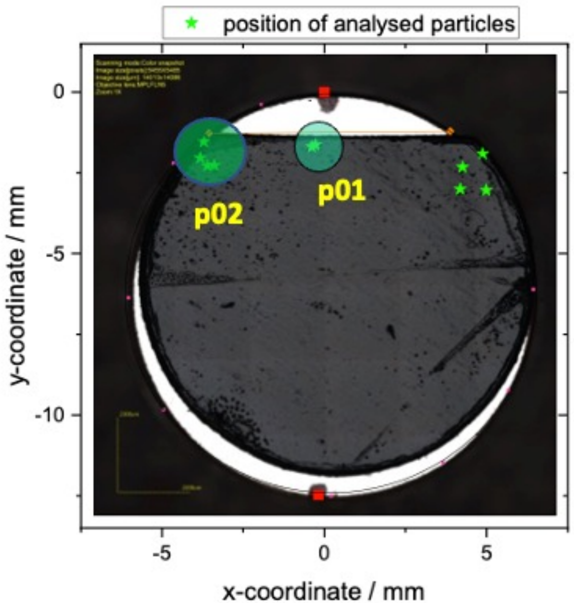


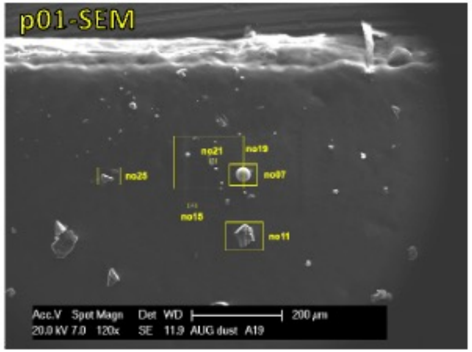


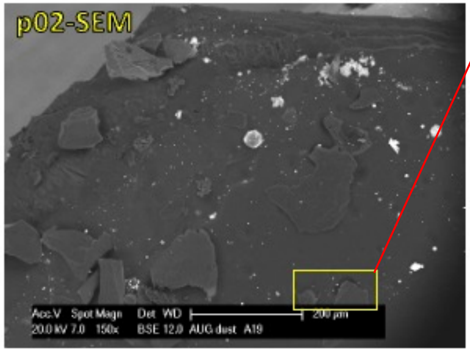
Middle particle of 3 particles in map
15x20 um and 4 um thick particle
Deuterium: 12 (2) x10^{15} at/cm^2
B, W, Al, Cr, Fe

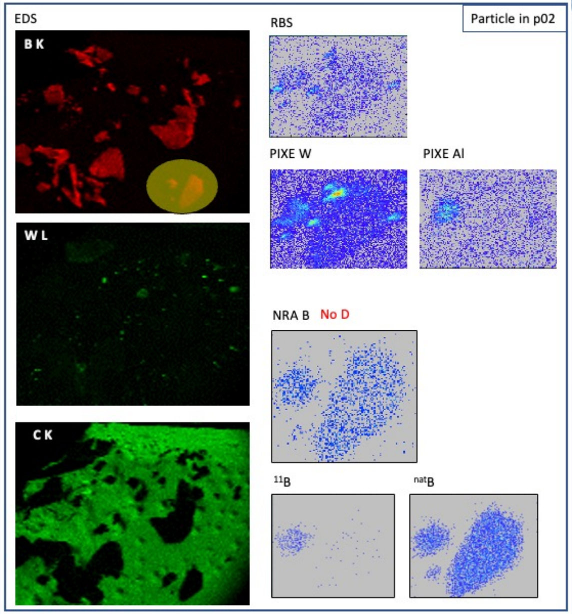
Micro-analyses of particles from AUG @ RBI

PAD A19-2019









Strange? area of two Boron particles 50x60 um and 20x20 um

No Deuterium

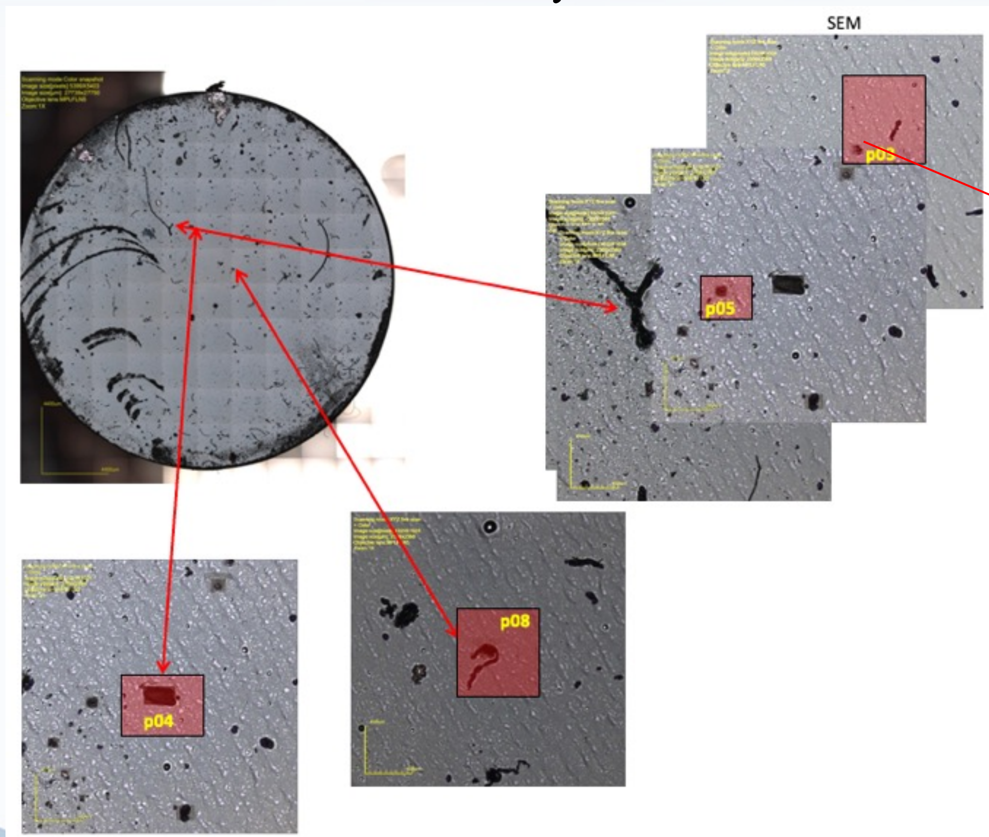
One particle enriched in ^{11}B the other ^{nat}B,

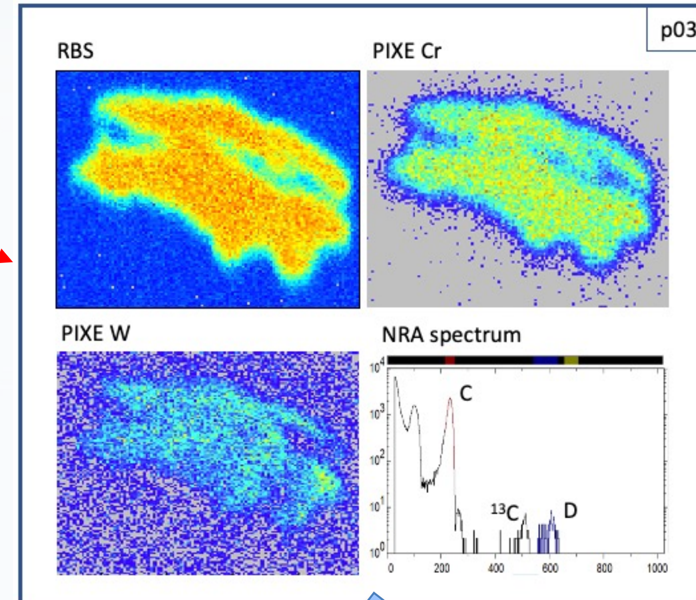
Includes W, Al.

Micro-analyses of particles from AUG @ RBI

PAD HS12-2009

Absence of Boron. Areas of analysis near the middle of the pad

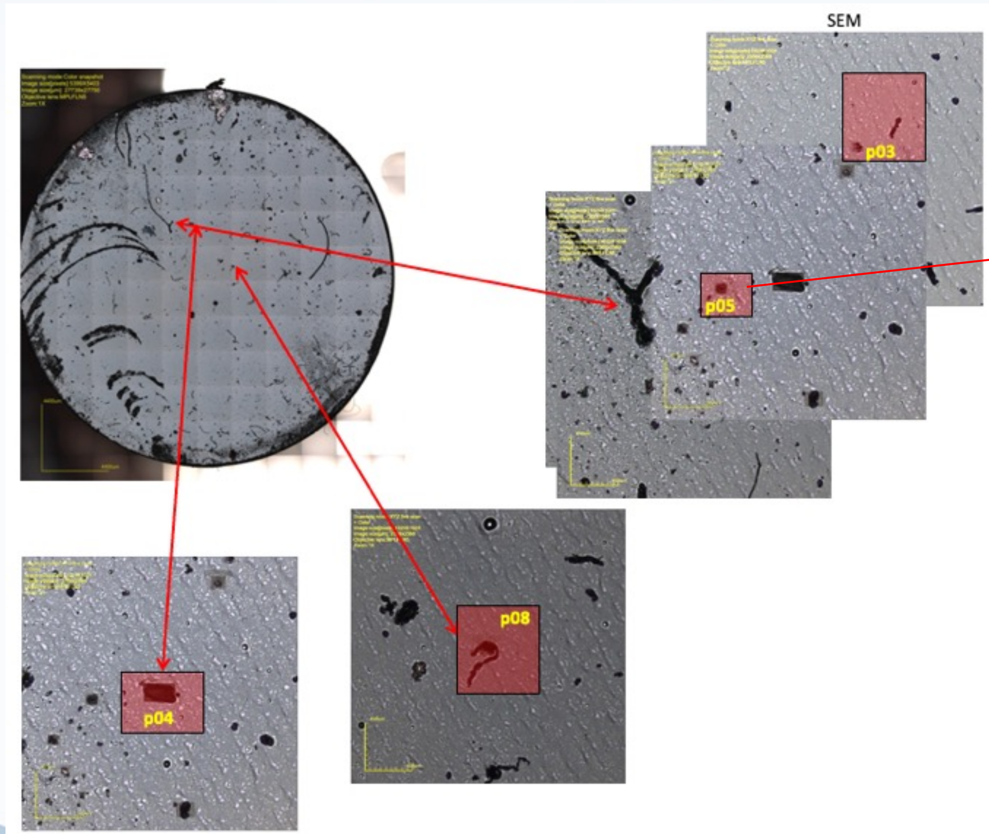


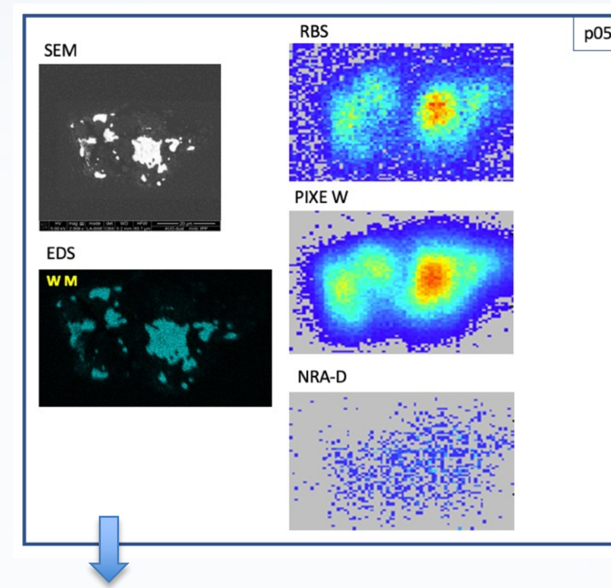


Big particle, 100x50 um and 10 um thick
Deuterium: 5 (1) 10^{15} at/cm^2
Cr, W, Fe present

Micro-analyses of particles from AUG @ RBI

PAD HS12-2009





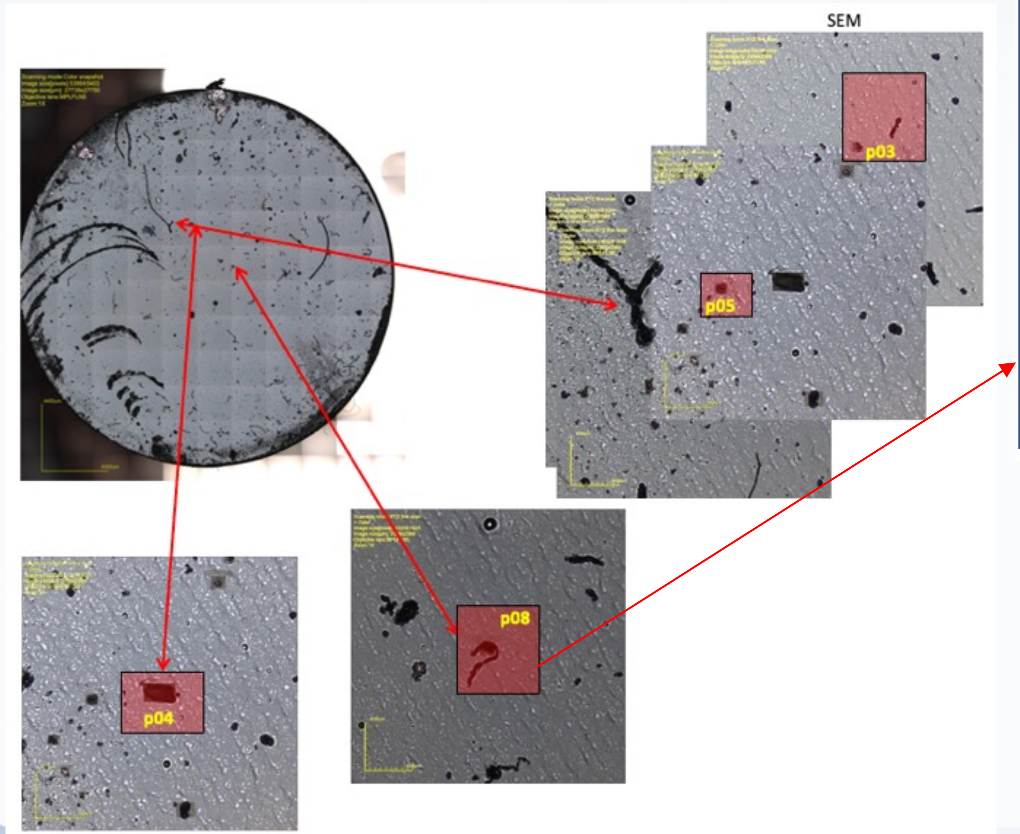
70x50 um area with a cluster of particles. Average 3 um thick.

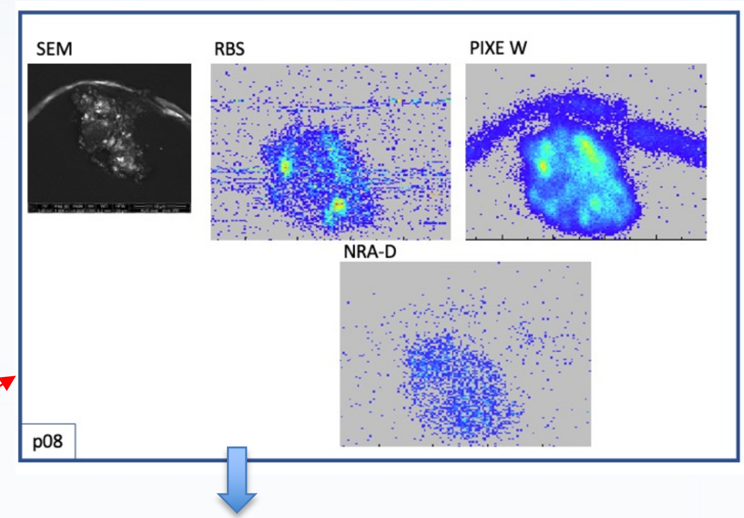
Deuterium: 105 (16) 10^{15} at/cm^2

W, Al, K.

Micro-analyses of particles from AUG @ RBI

PAD HS12-2009

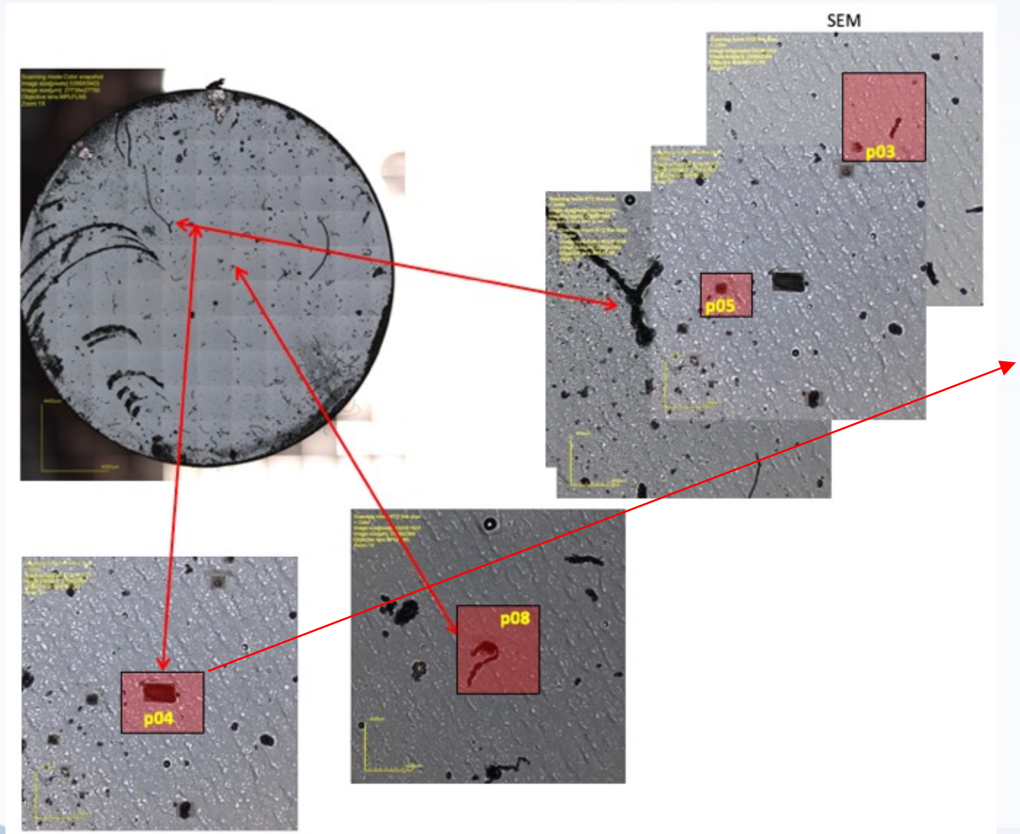


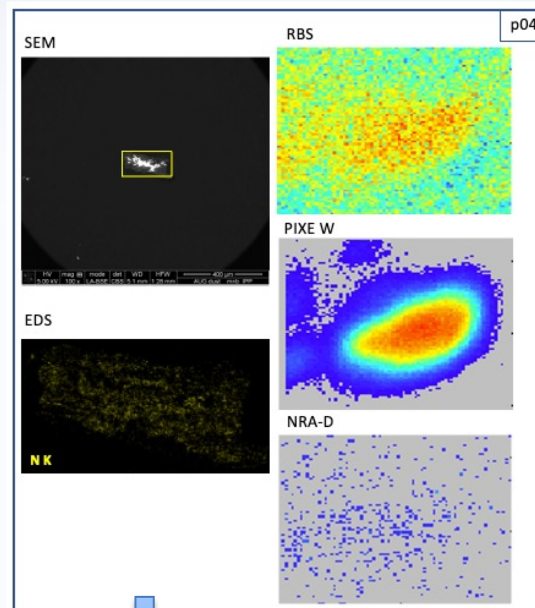


70x40 um area with 2 particles, 10 um. On of them contains D 10 um thick
Deuterium: 487 (40) 10^{15} at/cm^2
W, Al, Cr, Fe, K, Na.

Micro-analyses of particles from AUG @ RBI

PAD HS12-2009





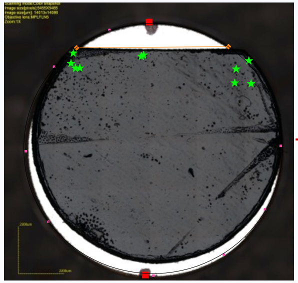
A big, 200x200 um area with few big structures. In average 10 um thick

Deuterium: 13 (2) 10^{15} at/cm^2

W, Al, Cr, Fe.

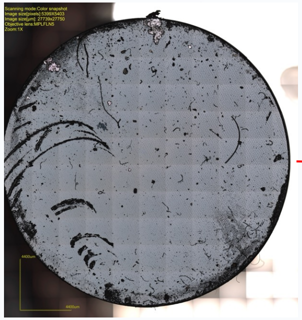
Micro-analyses of particles from AUG @ RBI

PAD A19-2019



Particles or groups of particles with sizes up to 50x60 um
Particles with Deuterium up to 43 x10^{15} at/cm^2
Containing B, W, Al, Cr, Fe

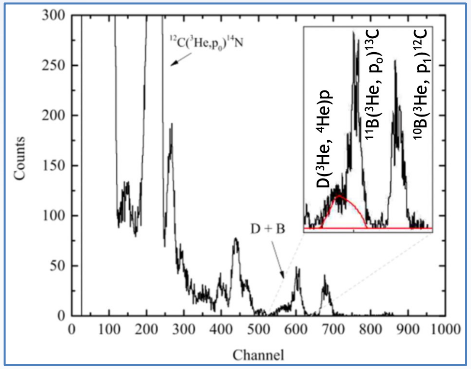
PAD HS12-2009

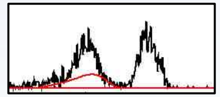


No Boron

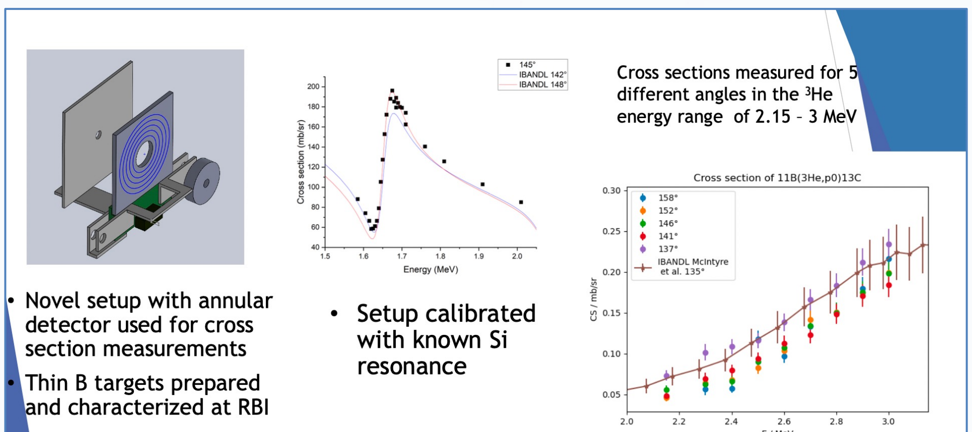
Larger particles or groups of particles with sizes up to 200x200 um
Two types of particles with Deuterium:
Areal density up to 13 x10^{15} at/cm^2
Areal density up to 487 x10^{15} at/cm^2
Containing W, Al, Cr, Fe,

On the road to accurate NRA analyses





Need for reliable $^{11}B(^3He,p_0)^{13}C$ and $^{10}B(^3He,p_1)^{12}C$ reactions cross sections



Within the IAEA CRP F11023, contract no. 24308
We collaborate with RUBION Bochum accelerator laboratory in the study of:

- $^9Be(^3He,p_i)^{11}B$ up to 6 MeV
- $^{12}C(^3He,p_i)^{14}N$ up to 6 MeV
- $^{11}B(^3He,p_i)^{13}C$ up to 6 MeV
- $^{10}B(^3He,p_i)^{12}C$ up to 6 MeV

Thank you!