Overview of recent DiMES experiments

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for the DiMES Team

Outline

1. **Erosion of ITER-relevant first wall materials**

   DiMES multi-sample probe #107

   exposed on June 20 2003

2. **Erosion in Helium Simple-as-possible plasmas**

   Helium SAPP DiMES

   exposed on September 18 2003

3. **Migration of micron size Carbon dust**

   Dust DiMES

   exposed on March 16 2004

Erosion of ITER-relevant first wall materials

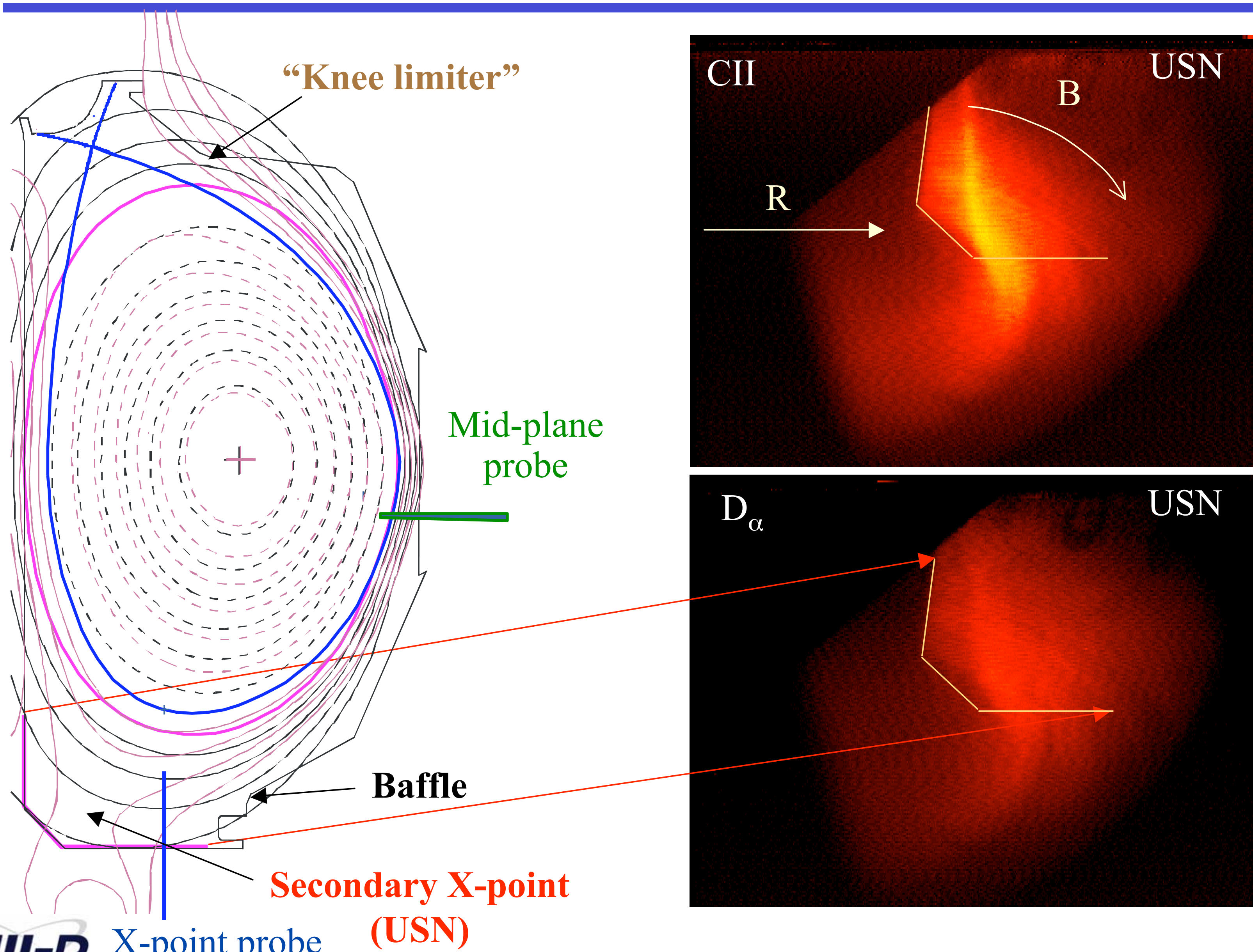
DiMES multi-sample probe #107

Motivation

- Plasma interaction with the first wall is of critical importance to ITER and future power reactors.
- Far Scrape-off Layer (SOL) density profiles are often relatively flat and extend all the way to the outer wall.
- Plasma-wall contact increases with discharge density.
- Cross-field fluxes in far SOL are dominated by large amplitude intermittent transport events that may propagate all the way to the outer wall and cause sputtering.
- Edge Localized Modes (ELMs) can result in transient increase of wall fluxes and cause extra damage.

More details on this in the following presentation

Far SOL plasmas extend in the lower divertor in USN and IWL



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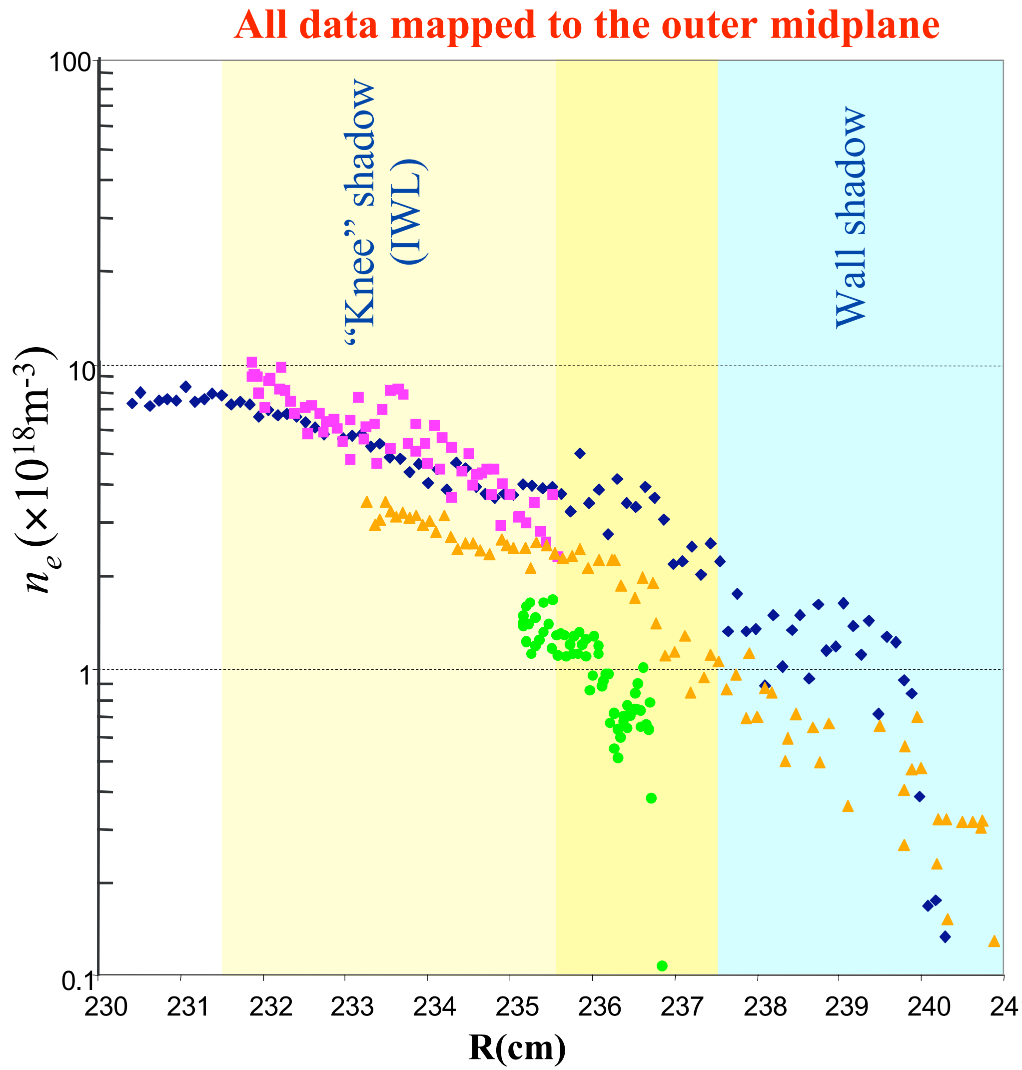
Lower divertor plasma conditions in IWL and USN are comparable to those near the outer wall



Shot 107577
IWL configuration L-mode
B = 2 T, I_p = 1 MA
P_{NBI} ~ 6.5 MW
$\langle n_e \rangle \approx 2.5\times10^{19}$ m^{-3}, f_{Gw} ~ 0.32

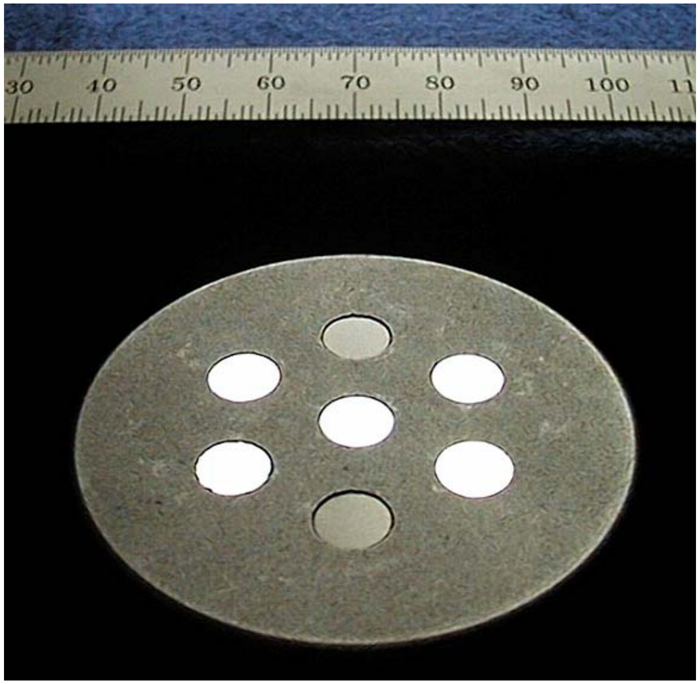
- **Mid-plane probe**
- **X-point probe**

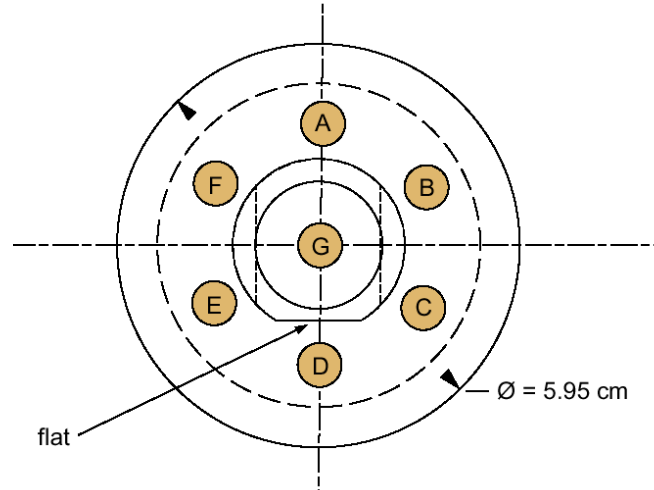
Shot 114849
USN configuration L-mode
B = 2 T, I_p = 1 MA
P_{NBI} ~ 4 MW, P_{ECH} ~ 2 MW
$\langle n_e \rangle \approx 1.6\times10^{19}$ m^{-3}, f_{Gw} ~ 0.18

- **Mid-plane probe**
- **X-point probe**

Lower density in USN is probably due to the secondary X-point

DiMES #107 multi-sample probe



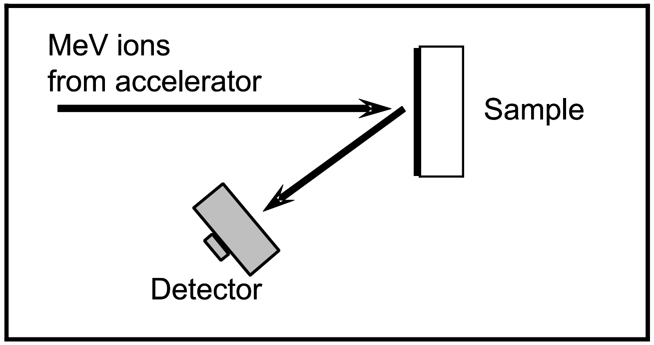


A	53a C Si marker
B	R5C4 Be on Si
C	Witness 74 Be on Si
D	53b C Si marker
E	V on Si
F	W on Si
G	C1 C on Ti/Si

- DIMES #107 has been exposed to a series of 22 plasma discharges
- 20 of the discharges were USN, 2 IWL
- Most of the discharges were L-mode (there were a few spontaneous transitions to ELMing H-mode)
- All discharges had comparatively low density

Ion Beam Analysis (IBA) by Bill Wampler (SNL)

- Individual samples have been by analyzer by IBA including Rutherford Backscattering spectroscopy (RBS) and Nuclear Reaction Analysis (NRA):



RBS 2 MeV 4He
RBS 1.5 MeV H
NRA 0.35 MeV H 9Be(p,α)6Li and 9Be(p,d)8Be
NRA 0.65 MeV H 11B(p,α)8Be
NRA 0.7 MeV 3He d(3He,p)α

- Changes in film thickness were determined by comparing yields of scattered particles or nuclear reaction products, or energy loss of scattered particles, before and after the plasma exposure.
- Reference samples were analyzed together with the samples to minimize errors due to variations in methods of measurement.

Summary of IBA analysis results

CARBON

- **Samples a & d**, graphite with implanted Si depth marker

  Change in depth of Si marker measured by 2 MeV 4He RBS gives net carbon deposition of 10±10 nm, i.e. no carbon erosion within accuracy of measurement (±10 nm).

- **Sample g**, carbon film on titanium film on silicon

  2 MeV 4He RBS and 1.5 MeV H RBS: No change in C film thickness within accuracy of measurement (±10 nm).

BERYLLIUM

- **Sample b,** Be on silicon substrate sample R5C4
- **Sample c,** Be on silicon substrate witness 74

✓1.5 MeV H RBS: Change in beryllium thickness < 10% of film thickness, calculated from yield of H scattered from Be. Poor sensitivity due to high background from H scattered by silicon substrate

✓Nuclear reaction analysis, 0.35 MeV H 9Be(p,α)6Li and 9Be(p,d)8Be:

Change in Beryllium thickness is less than 1 nm

Summary of IBA analysis results (continued)

TUNGSTEN

- **Sample f**: Tungsten film on silicon substrate

✓2 MeV 4He RBS: Tungsten thickness after exposure 3.1% or 3.4 nm less than before exposure.

✓1.5 MeV H RBS: Tungsten thickness after exposure 2.8% or 3.1 nm less than before exposure

VANADIUM

- **Sample e**: vanadium film on silicon substrate

✓2 MeV 4He RBS: Vanadium thickness after exposure 4.4% or 4.4 nm less than before exposure.

✓1.5 MeV H RBS: Vanadium thickness after exposure 3.3% or 3.3 nm less than before exposure

CONCLUSION:

- The levels of erosion were very small on all the samples, close to or below the limit of detection by the experimental methods used.
- Higher densities or longer exposures are required in the future

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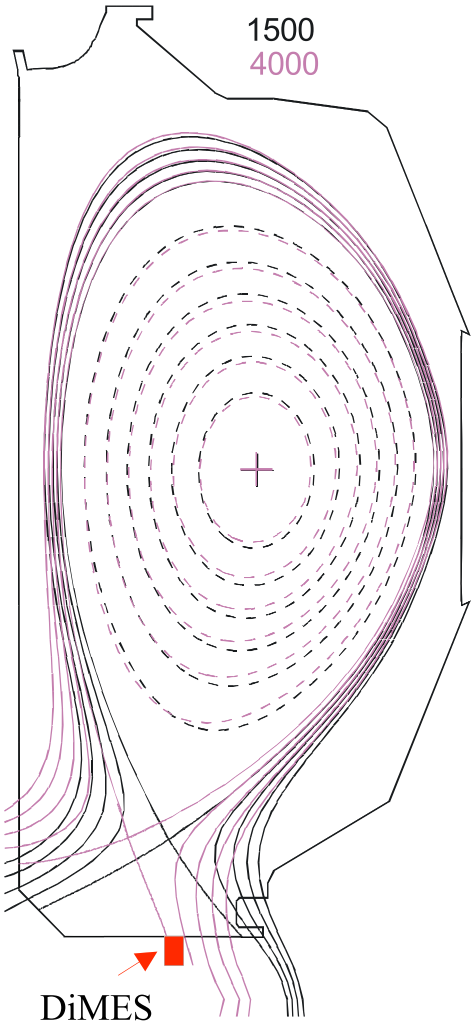
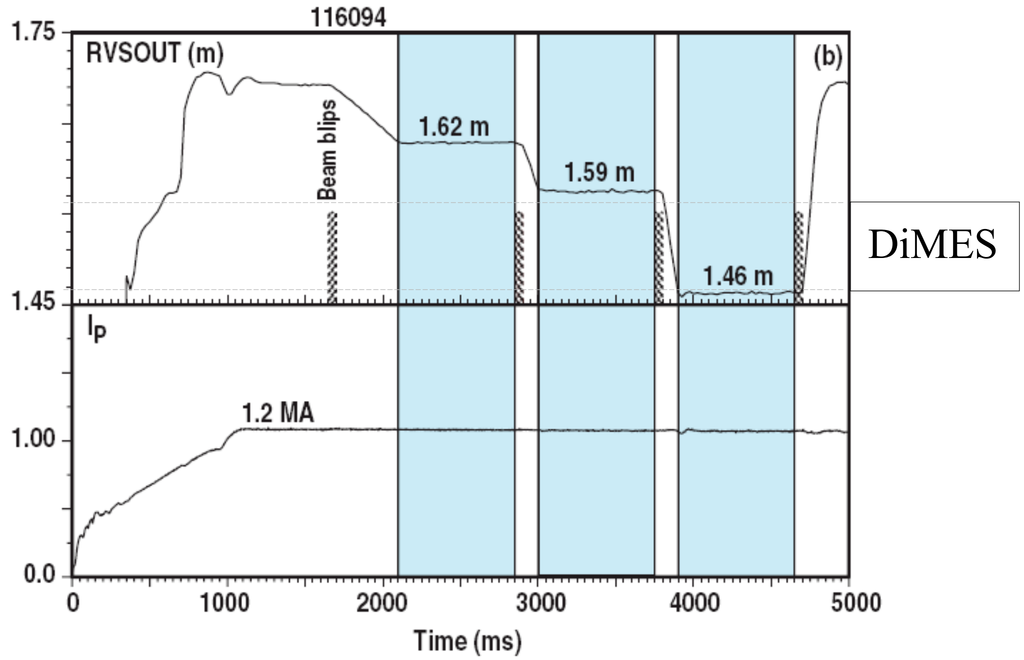
Erosion in Helium Simple-as-possible plasmas
Helium SAPP DiMES

Motivation and background

- He SAPP experiment led by Neil Brooks was performed to study physical sputtering of carbon by helium (no chemical sputtering in He)
- The primary analysis was relying on MDS spectrometer data (testing theoretical predictions on C I line shape)
- DiMES exposure was not in the original shot plan
- We decided that exposing a depth-marked DiMES sample in order to measure the carbon erosion will provide a useful addition to this experiment
- The experiment was conducted in a single day with a changeover from D to He performed using electron cyclotron heating (ECH)-only, H-mode discharges in helium (about 15 shots)
- The changeover went well, with resulting plasmas being about 85% He.

He SAPP experiment





- The line-averaged core density was changed, shot to shot, to give the five values 1.4, 2.4, 3.5, 4.5, and 6.8_10^{13} cm^{-3}
- Within each shot, the OSP was moved in stepwise fashion to dwell positions at successively smaller major radius
- The innermost OSP dwell position was at the inboard edge of the DiMES sample
- The sample was exposed to 13 discharges with the total exposure time of about 10 s

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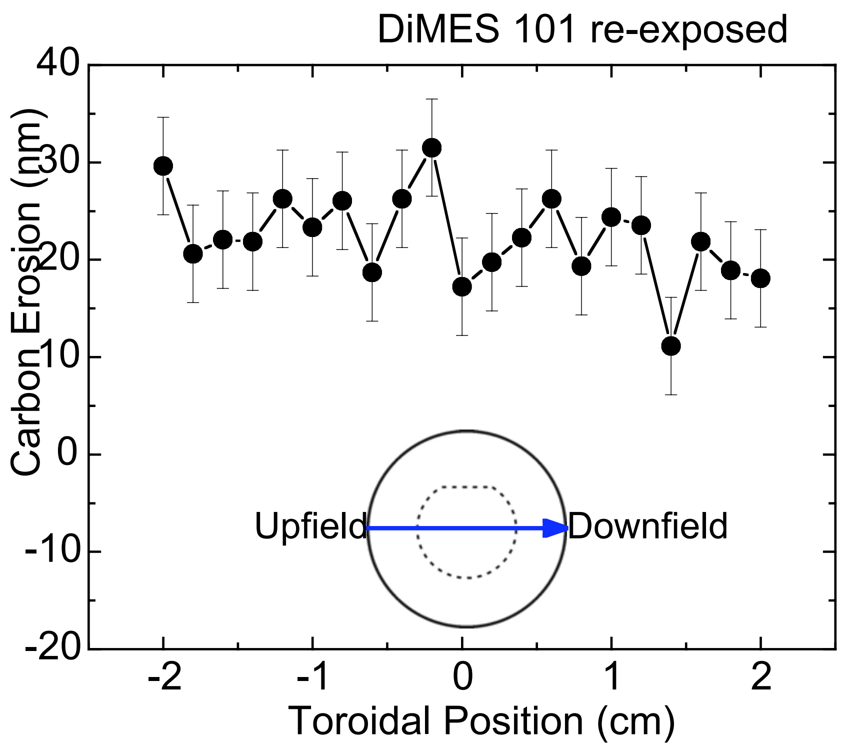
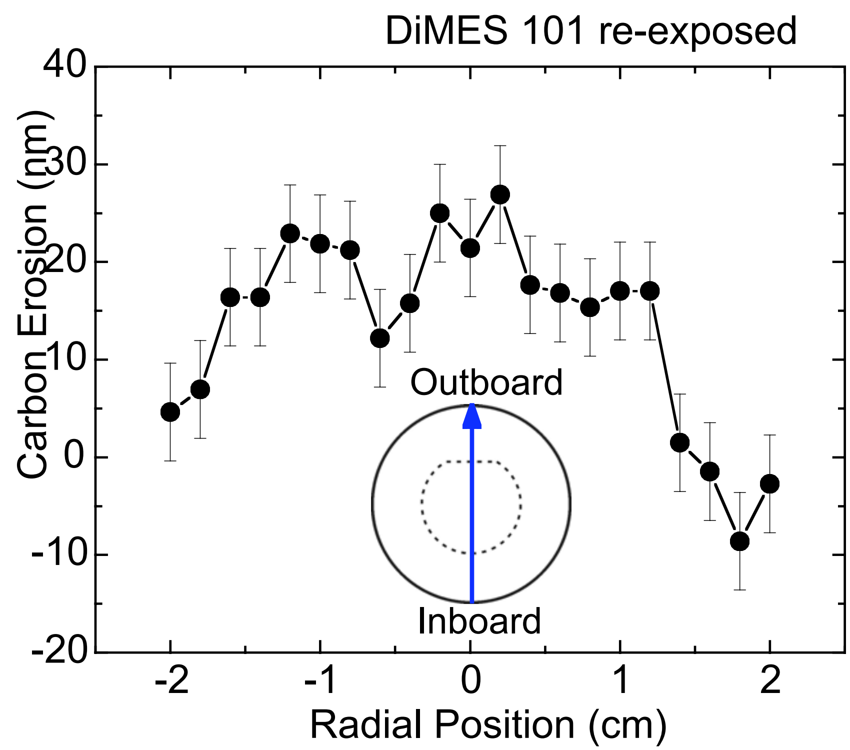
Analysis results from Bill Wampler





The total net measured erosion is about 25 nm, making an average rate of 2.5 nm/s

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Discussion of results and future plans

- Net erosion in low density SAPP discharges in deuterium was not previously measured
- The closest to this condition was the measurement of net erosion in low power (single neutral beam source) ELM-free H-modes, where the net erosion rate of carbon near the OSP was ~ 3 nm/s
- The strike point plasma conditions in the He SAPP experiment were poorly characterized since the target probes were not taking data (had data acquisition problems)
- The experiment may be repeated, hopefully with the probes running
- We will try to get erosion measurements in deuterium SAPP discharges for direct comparison
- Can this experiment be modeled? If so, what data do we need supply?

Migration of micron size Carbon dust
Dust DiMES

Motivation

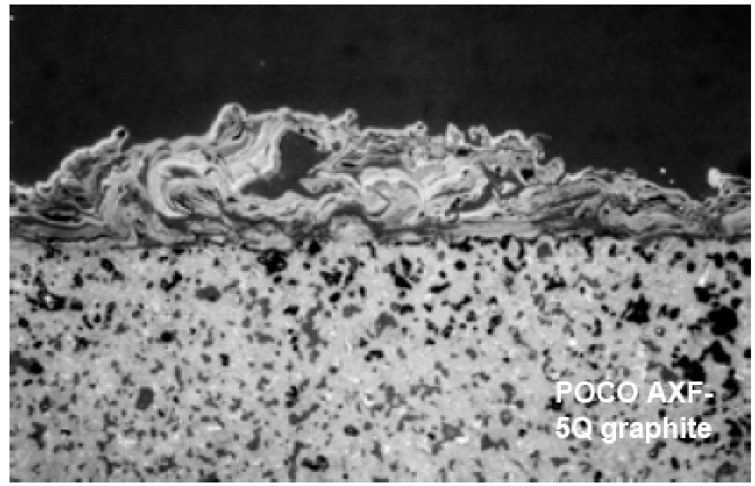
- Micron size dust is commonly found in tokamaks

Examples from Charles Skinner's HTPD invited talk on deposition diagnostics

Tore Supra Neutralizer:

Thick deposited layer - 150 µm after 2h20m of plasma; (= 1day of ITER ops.), High growth rate (20 nms^{-1})   P. Ghendril

Cross section of TFTR co-deposit.



collaboration with M Paffett, R Reiswig, S Willms, LANL

- Dust can be a serious problem for ITER for a number of reasons:
  - Tritium retention and co-deposition with Carbon dust
  - Accumulation of toxic and radioactive materials
  - Be dust in the divertor may cause hydrogen explosion hazard
  - Dust can cause core contamination and degrade performance

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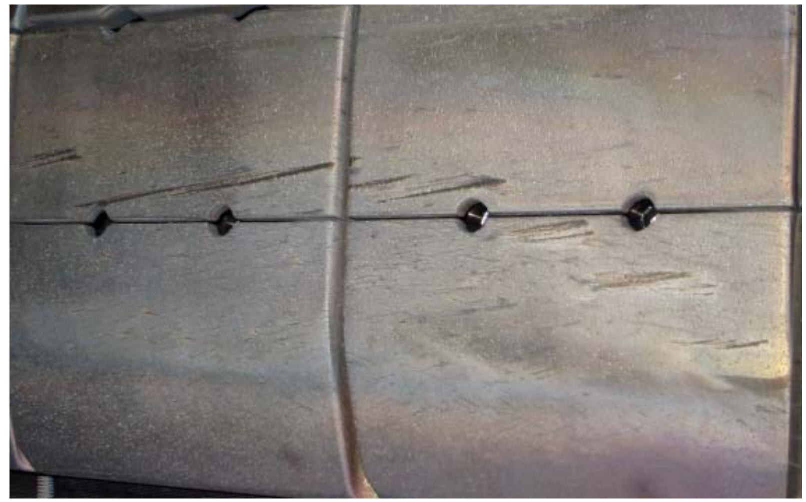
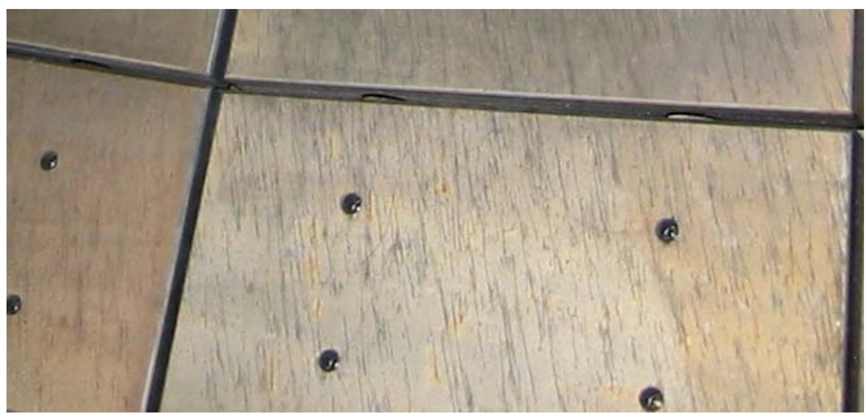
Motivation (continued)

- In DIII-D dust is commonly found during vents in ports, between tiles etc.
- Many of DIII-D tiles feature scratch-like marks, supposedly due to arcs





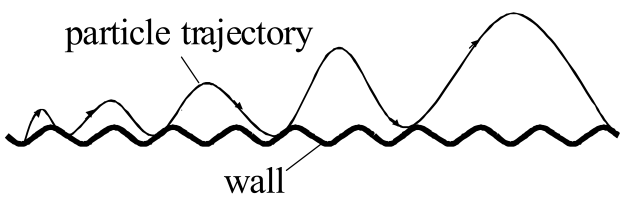
Potential source of dust?

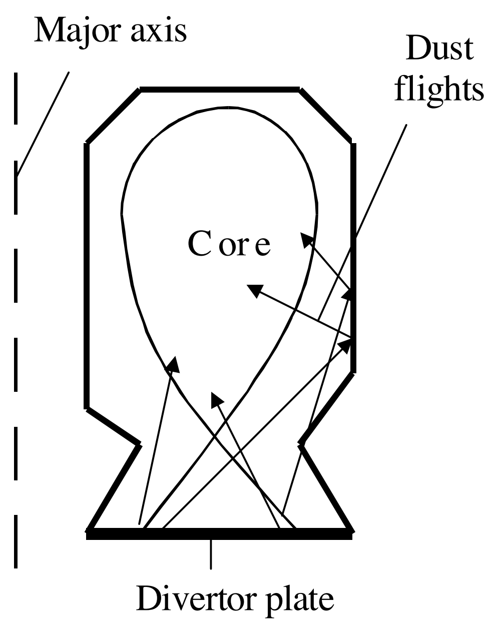
Motivation (continued)

- A recent paper by Sergei Krasheninnikov et al (submitted to Phys. Plasmas) shows that in a tokamak edge plasma dust particles can move with high speed and traverse distances comparable to tokamak radii

- Dust particles acquire negative charge due to balancing of the electron and ion fluxes
- Due to acceleration by plasma flows in the vicinity of material surface, dust particles can acquire very high speeds (~ 10 m/s and higher)
- Interactions of dust particles with surface inhomogeneities (micro-roughness, steps, corners, etc.) can cause escapes of dust particles from near wall region and flights toward the tokamak core

Figures from
S. Krasheninnikov et al





CONCLUSIONS:

- As a result, the dust deposition areas on the wall structures can be far away from the origin of the dust.
- It is also very likely that transport of dust particles can be an important mechanism of core plasma contamination by impurities

Dust DiMES sample: modified sample #91

A small dip (~ 0.7 mm deep and about size of a dime) was machined in the middle of the sample surface and then polished by fine sanding paper

A small amount of graphite dust scraped off the side of an old DiMES plug was placed in the dip

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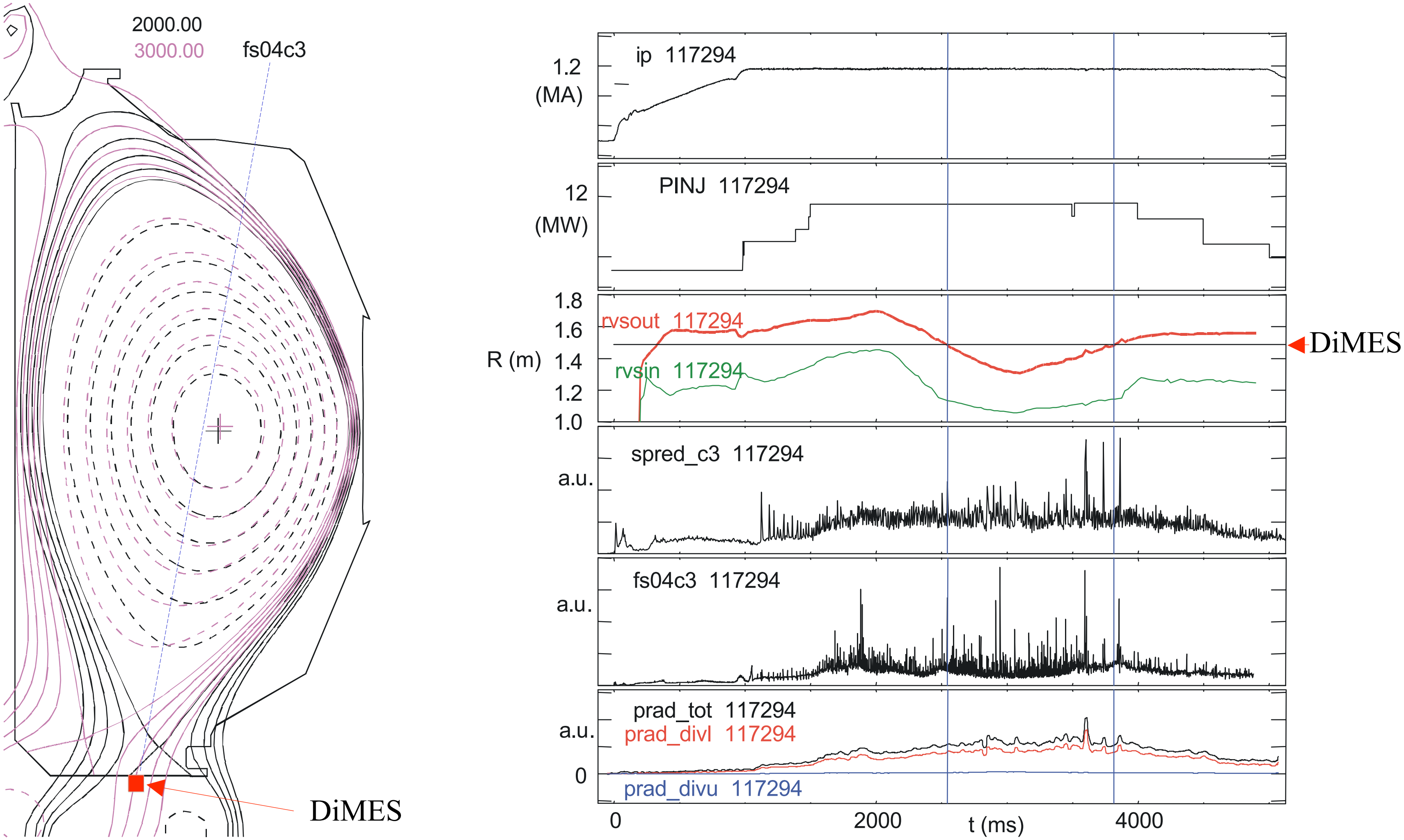
No measurements of the dip profile or amount of the dust were made

Sample exposed to two high-power LSN shots wit OSP sweep



- OSP was swept across the sample twice, around 2.6 and 3.8 s
- ISP dwells near the sample for about 200 ms around 2.0 s
- No visible increase in carbon light from either core or divertor

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The dust was there but did not get to the core

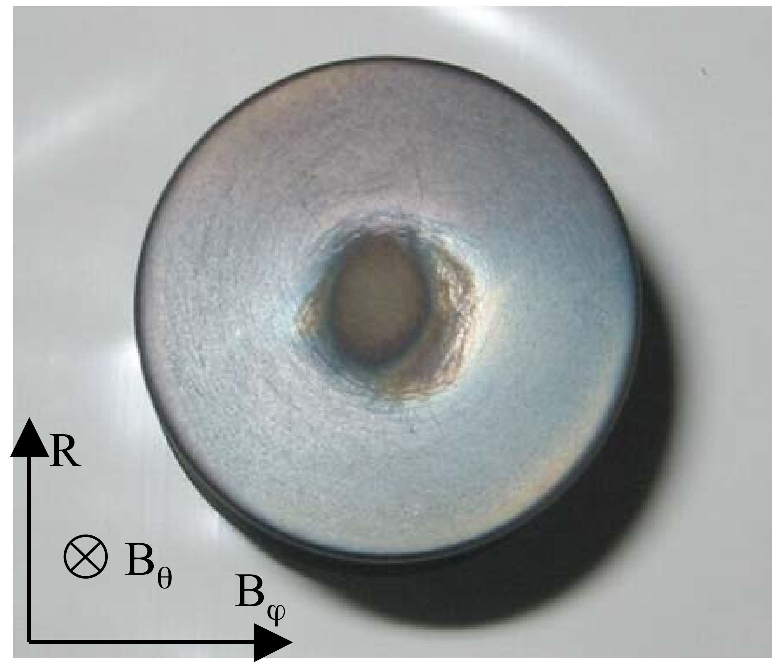
- The diagnostics turned on for the exposure included DiMES TV, two tangential divertor cameras with carbon filters, MDS spectrometer, IRTV, and DISRAD. Bolometers, filterscopes and SPRED were also on.
- No obvious increase in the core carbon content or the radiated power was noticed.
- The most notable evidence of the dust presence comes from the MDS spectrometer chord directly viewing the sample. After the first pass of the OSP over the sample the background radiation increased significantly (by about 120 counts). C I line intensity also increased in a step-like manner.
- These two facts (increase in visible continuum and in C I line radiation), taken together, suggest dust as the origin of the rise in the C I signal.
- During the second pass of the OSP the background radiation increase was also observed, but it was smaller (about 30 counts).
- All cameras saw some bright spots but it was not obvious that any of those were due to the dust. The camera data are yet to be analyzed.

So, where did the dust go?

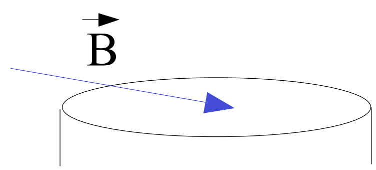
Dust DiMES sample before and after exposure

Before

After

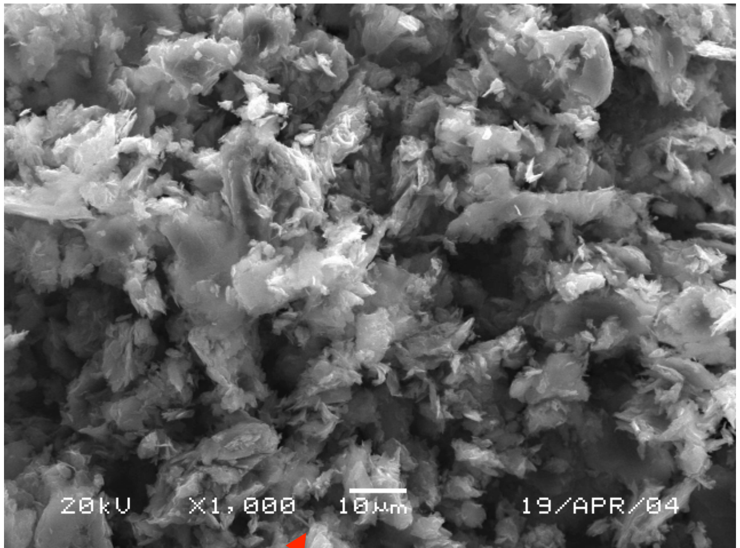


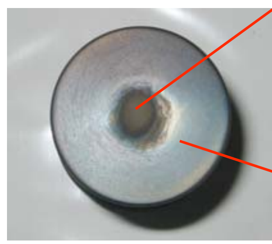
- There was no loose dust on the sample surface upon removal
- An oval gray area appeared on the left side of the dip
- This area was shaded from the direct plasma contact along the field lines during the exposure to OSP



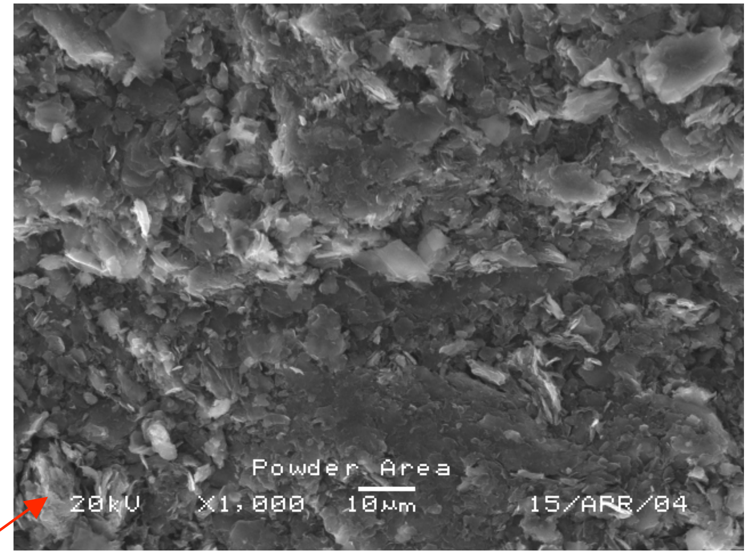
Microphotographs of the sample and dust

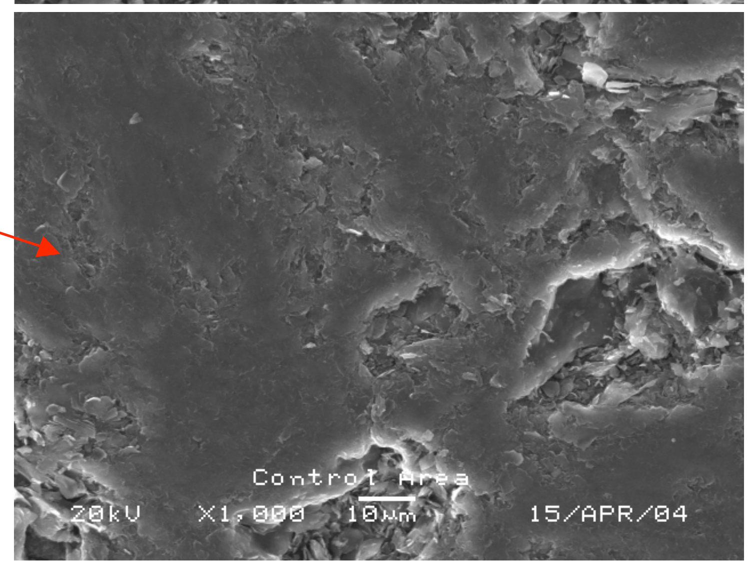
Dust used to load the sample





Inside the gray area





Outside of the gray area

It looks like at least some of the dust got re-deposited in the shaded part of the dip

Conclusion on the dust DiMES

- It seems that during our first exposure dust did not get very far
- Some of the dust got re-deposited locally
- Does this mean that dust can not migrate far? Certainly not!
- There is plenty of data from the exposure yet to be analyzed
- We will continue experimenting with the dust
- Next time we will use better characterized dust (we got some from Japan) and will also try to quantify the amounts of dust lost to the plasma versus that re-deposited locally

End note

- **The three experiments described here are still far from complete**
- **Further analysis of the existing data will be performed**
- **More exposures are likely to follow in all three areas**
- **We will appreciate input from the PFC community on the future measurements, possible improvements, etc.**
- **In particular, we hope there will be interest in modeling some of those experiments**

Let's revisit this during the discussion!