# Arcing in DIII-D as a Source of PFC Erosion and Dust Production


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UCSD

# Motivation

- Evidence of arcing was found in magnetic confinement devices since the early days of fusion research
- Arcs cause erosion of PFCs and release of impurities into plasma
- G. Federici et al., Nucl. Fusion 41 (2001): "Arcing may be important [for erosion] in the divertor, but insufficient data from current tokamaks exist to reliably extrapolate to an ITER class device"
- Recent AUG work: In machines with metallic PFCs, arcing can be a significant and even locally dominant contributor to total erosion

  [A. Herrmann et al. J.Nucl.Mater. 390–391 (2009) 747]

  [V. Rohde et al. J.Nucl.Mater. in press]
- Arcs are known to produce micron-size particles, so they can be a source of dust production

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# Outline

1. Evidence of arcing in DIII-D
2. Characteristics of Type II arc traces
3. Relative importance of arcing for PFC erosion
4. Evidence of dust production by plasma-wall contact
5. Arcing in DiMES experiments
6. Future plans

# DIII-D tokamak

- Mid-size tokamak

  R = 1.67 m, a = 0.67 m

- 2 poloidal divertors

- Can run LSN, USN, DN and wall-limited configurations

- All-carbon PFCs (ATJ graphite and CFC)

- Inconel vacuum vessel

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# Two types of arc traces are observed

1. **Unmagnetized arcs – random walk traces – produced during glow discharges**

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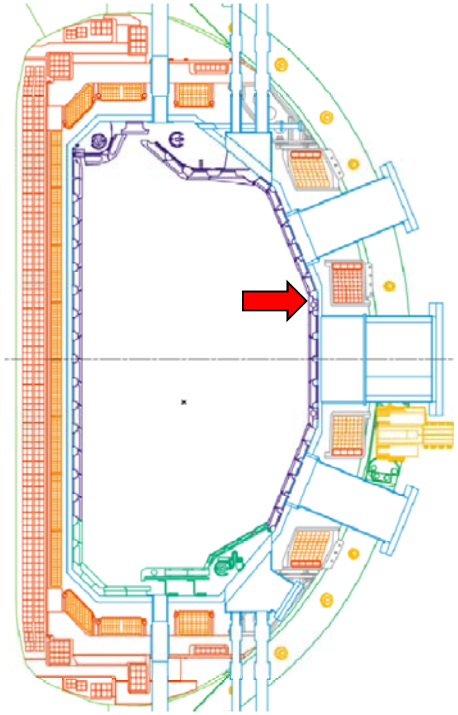

- On outboard wall tiles

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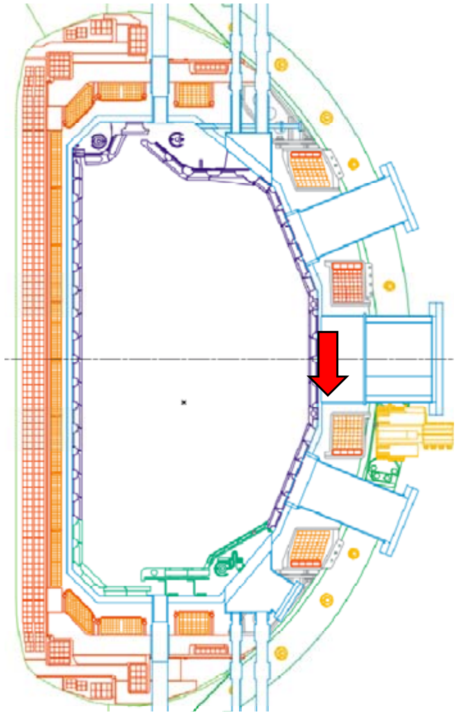

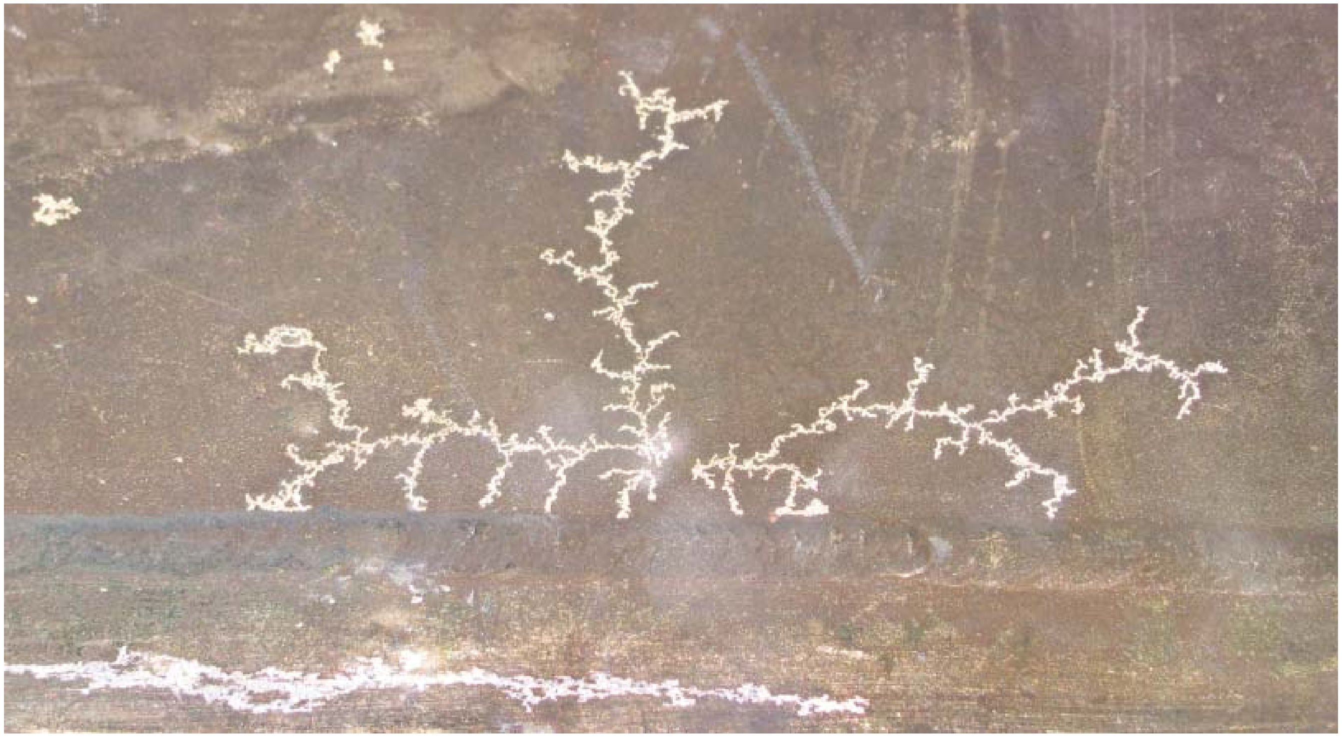

- Close to the edge of a mid-plane port

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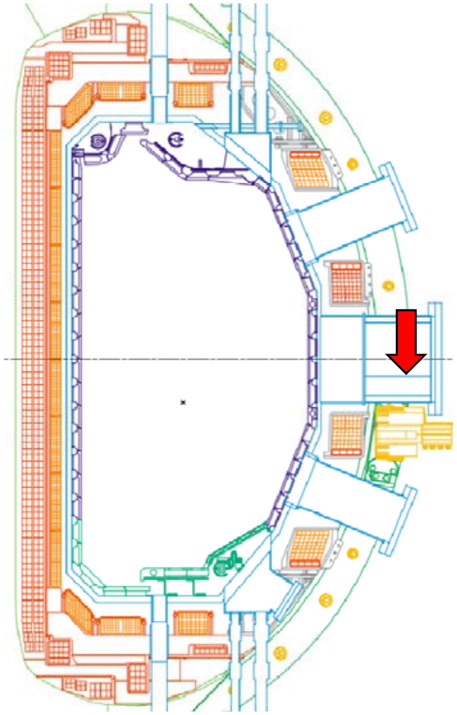

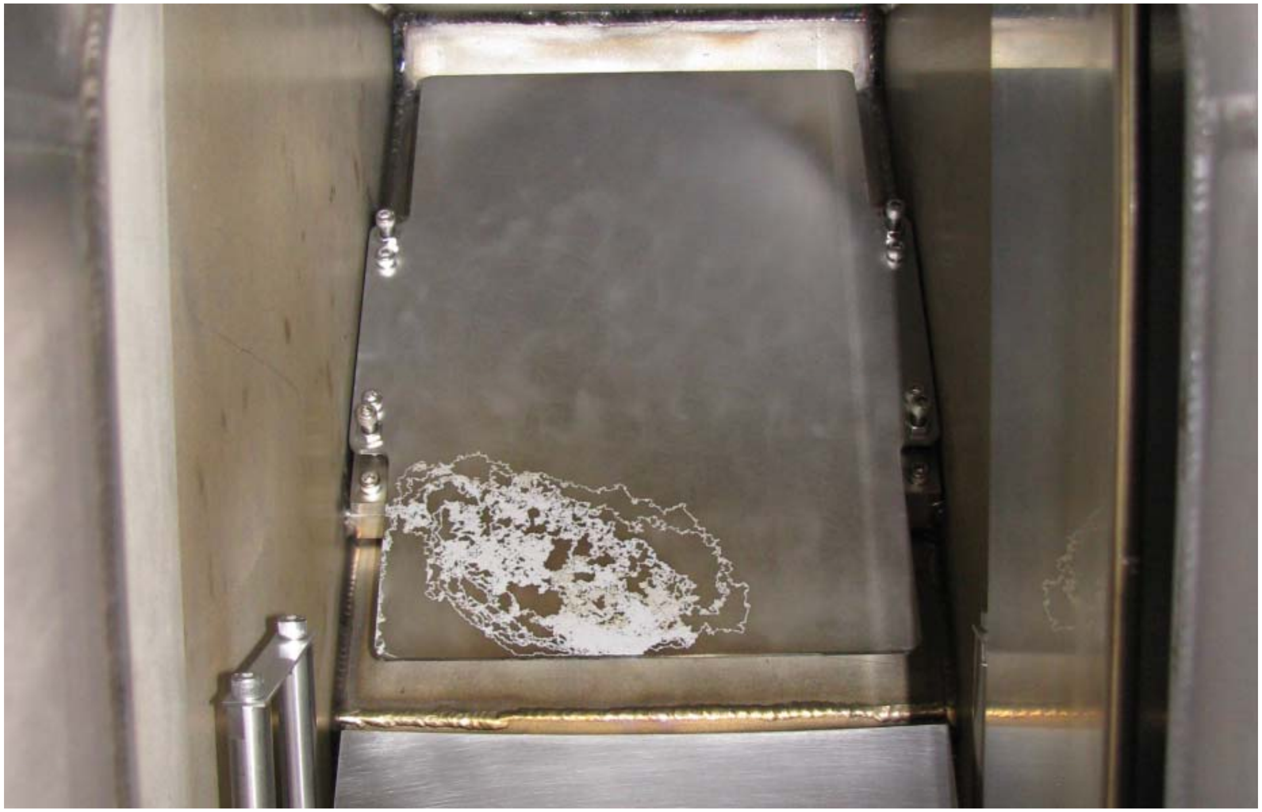

❖ **On a microwave diagnostic mirror inside mid-plane port**

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# Two types of arc traces are observed

1. **Unmagnetized arcs - random walk traces**
   - **Relatively rare isolated events**
   - **Not a concern for net erosion and dust production**
   - **May be a problem for diagnostic mirrors**

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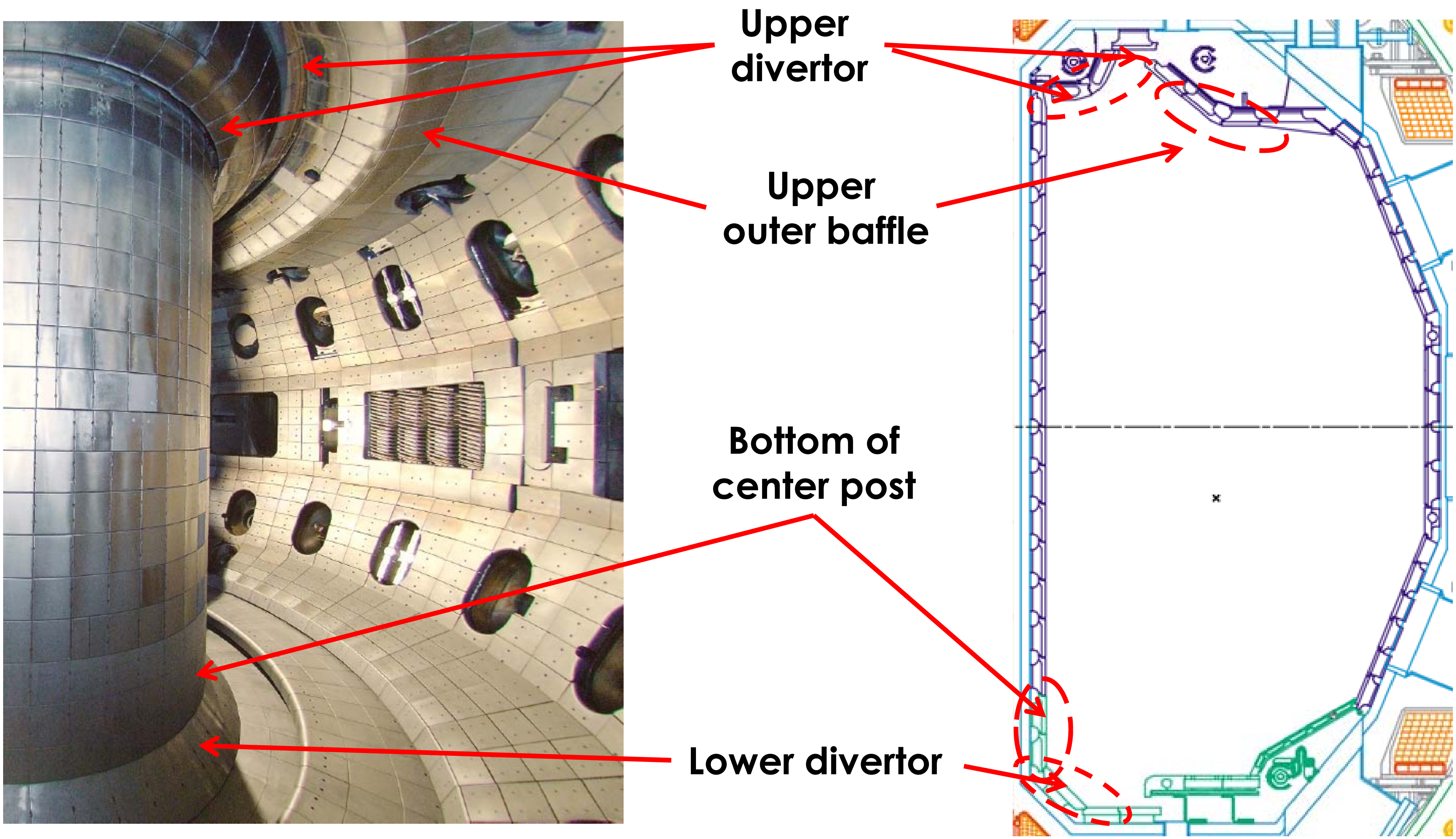
# Two types of arc traces are observed

1. Unmagnetized arcs - random walk traces
   - Relatively rare isolated events
   - Not a concern for net erosion and dust production
   - May be a problem for diagnostic mirrors

2. Magnetized arcs – scratch-like (type II) traces roughly perpendicular to the local magnetic field
   - Subject of the remainder of this talk

Note: Type I arc pits may be also present but hard to identify because of surface roughness

# Locations of strongest arcing in DIII-D




- Highest density of arc traces is observed in the areas where strike points are placed and conditions favor arcing

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# Arc traces in upper divertor

- Increased arcing next to a leading edge of misaligned tile

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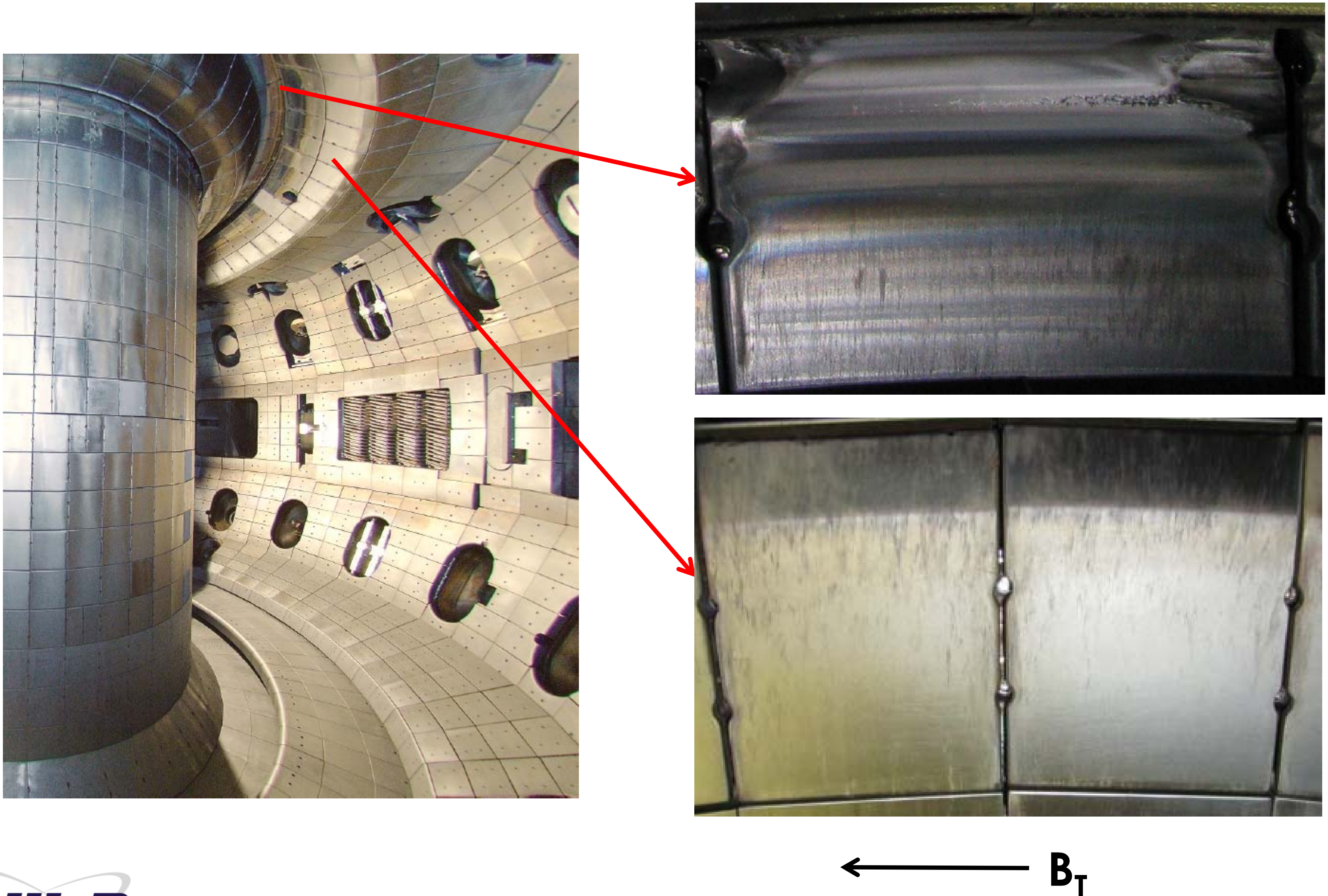
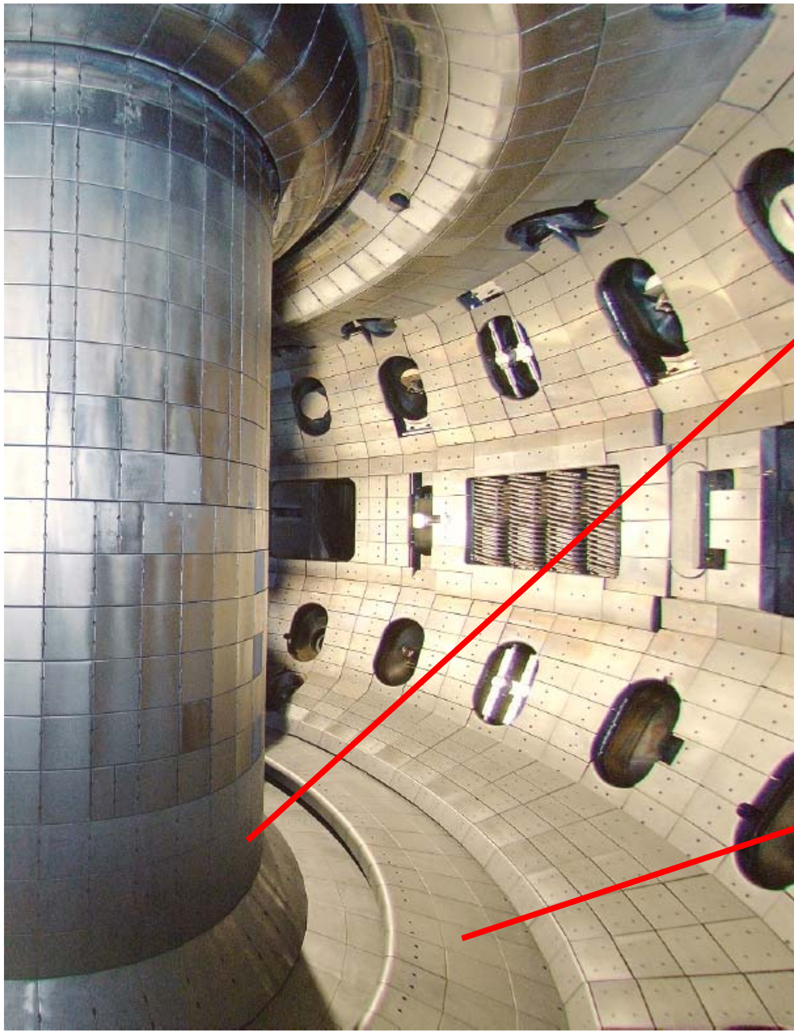
# Arc traces in upper divertor



# Arc traces in lower divertor

- Strongest arcing at the bottom tiles of the center post

# Arc traces in lower divertor



← $B_T$

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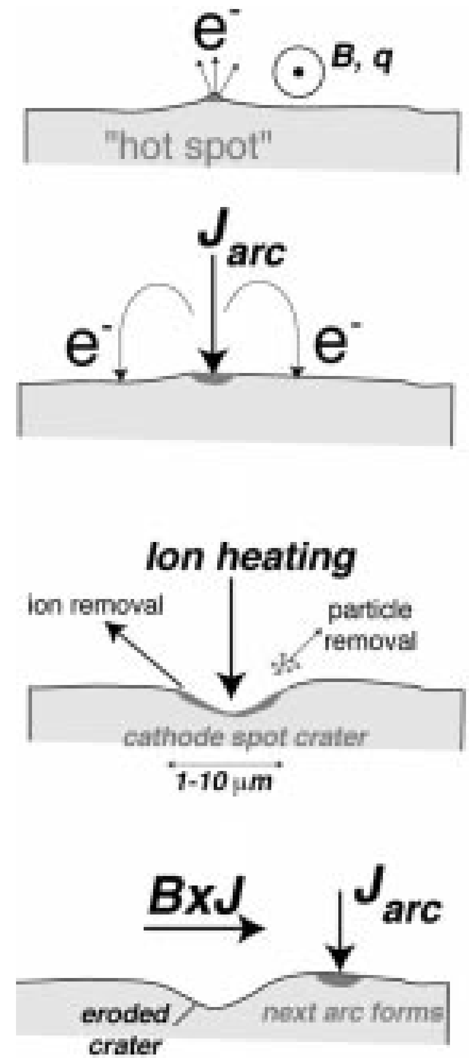
# Arcing in magnetized SOL

- An arc begins due to increased electron emission from a “hot spot”
- Current is closed by energetic plasma electrons returning to area adjacent to and much larger than the cathode spot
- The current channel of the arc contracts by its self-magnetic field, resulting in a small cathode spot and large current densities
- Heating of the surface is by plasma ions
- Ions and particles are removed from the crater
- New arc forms on the “retrograde” side of the crater, where arc magnetic field aligns with external B, causing BxJ motion of the arc
- This results in scratch-like traces perpendicular to B




[Fig. 22, G. Federici et al., Nucl. Fusion 41 (2001) 1967]

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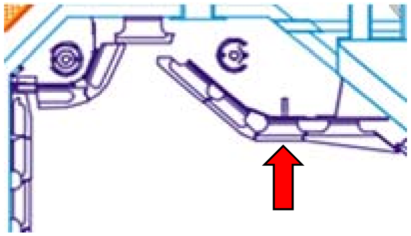
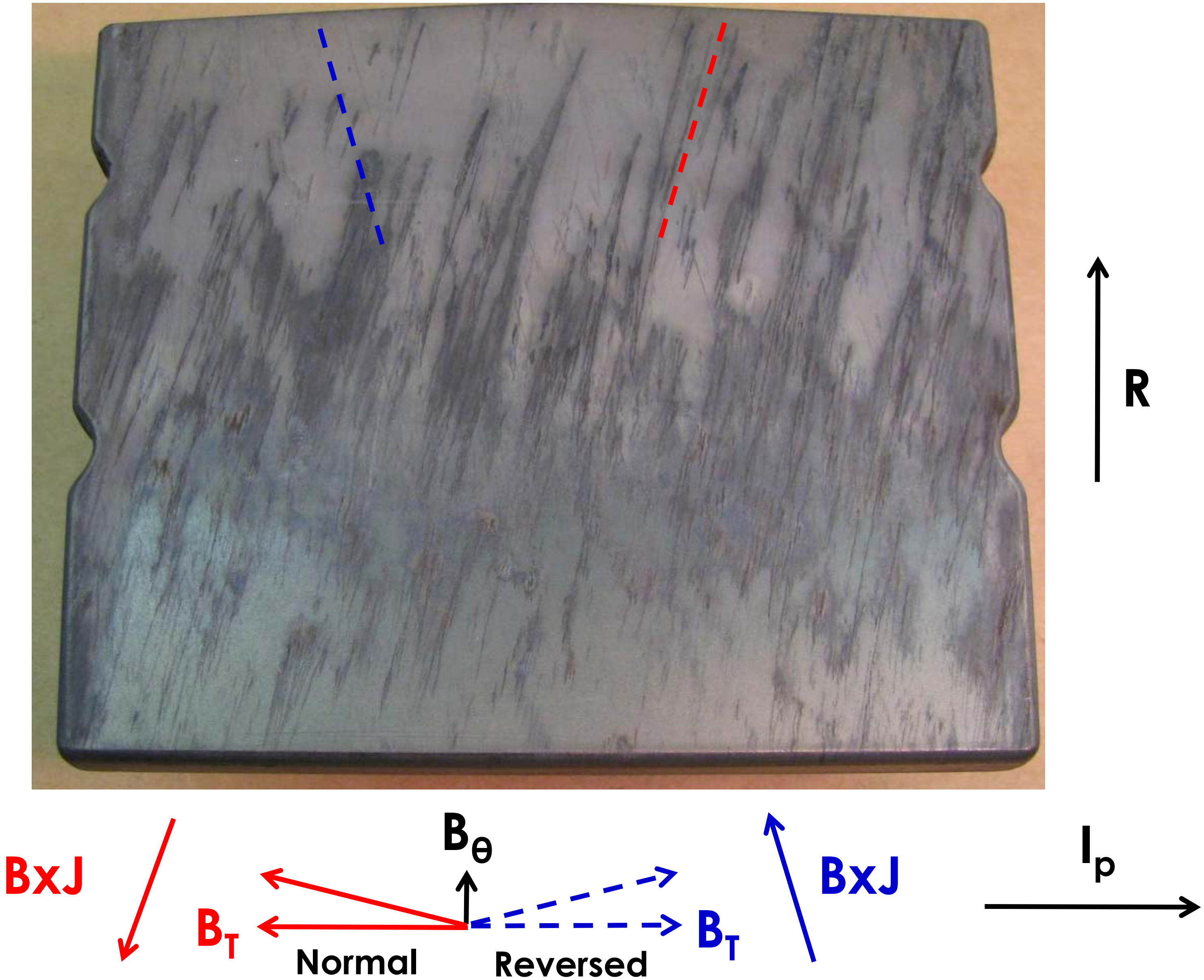
# Arc traces are perpendicular to local B



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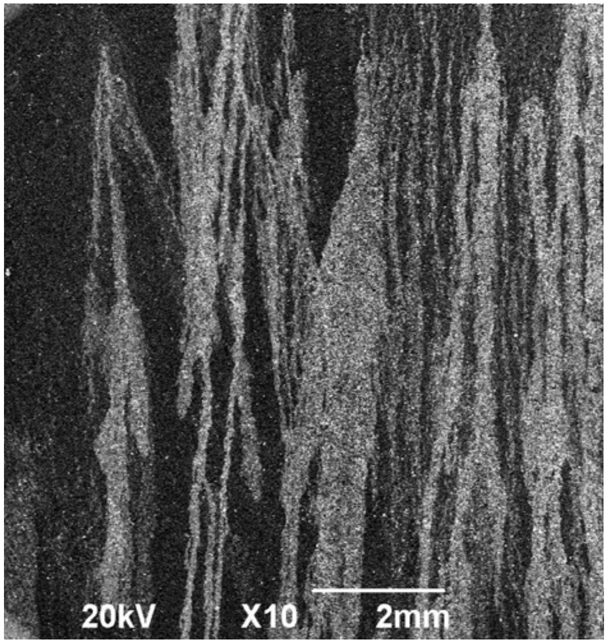
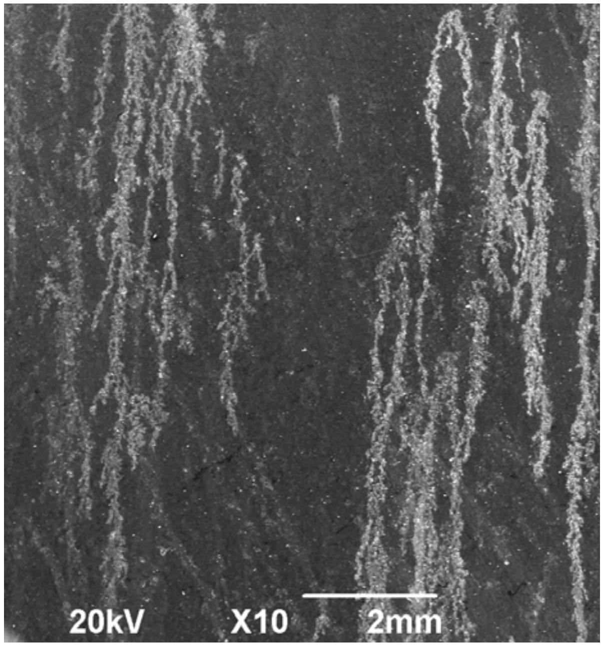
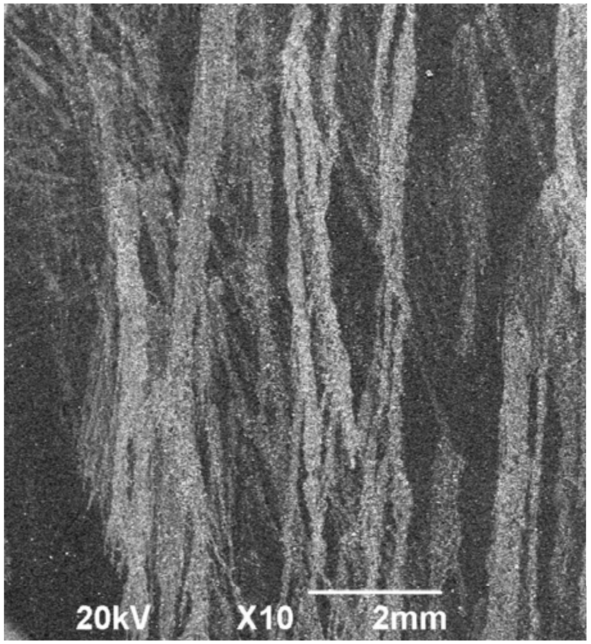
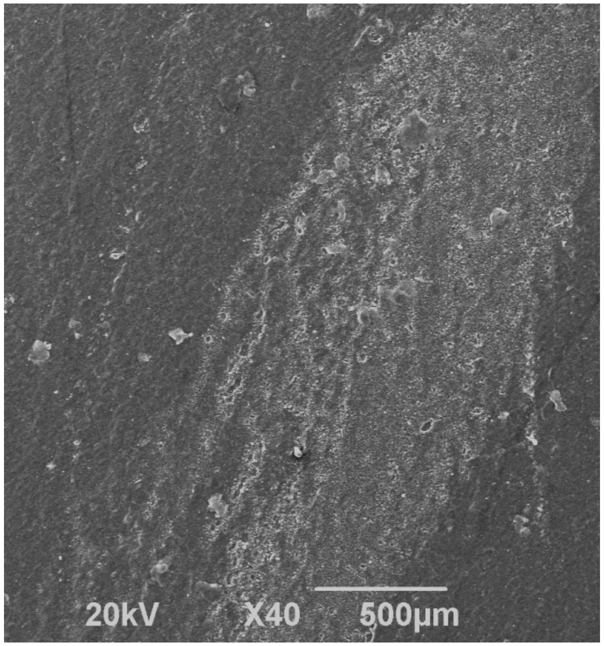
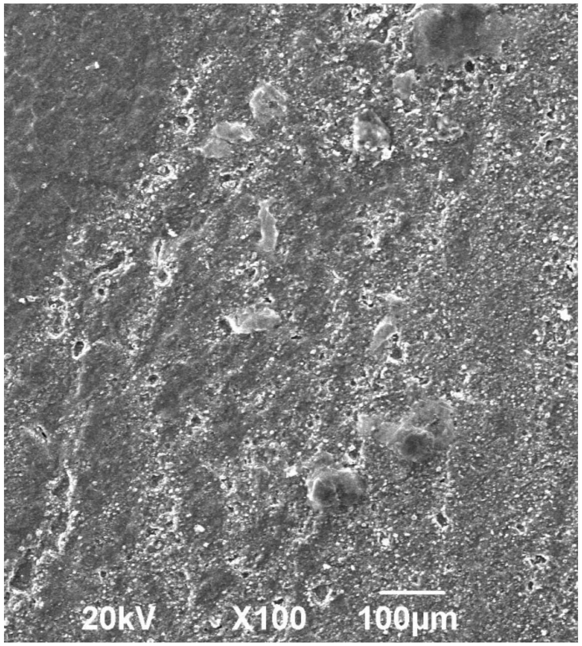
# Arc traces have complicated structure

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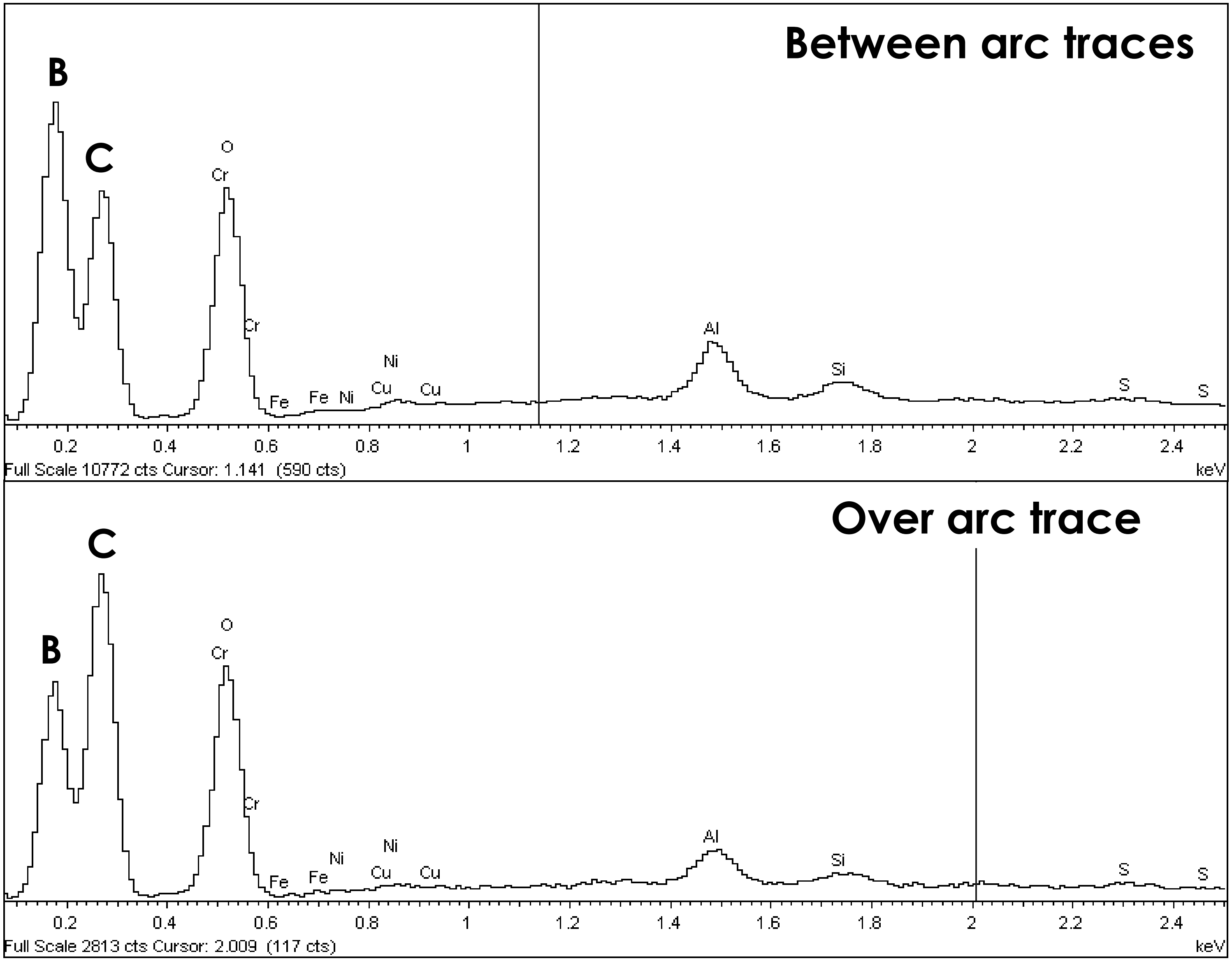
# B/C ratio is reduced in arc areas

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# Are boronizations increasing arcing rate?

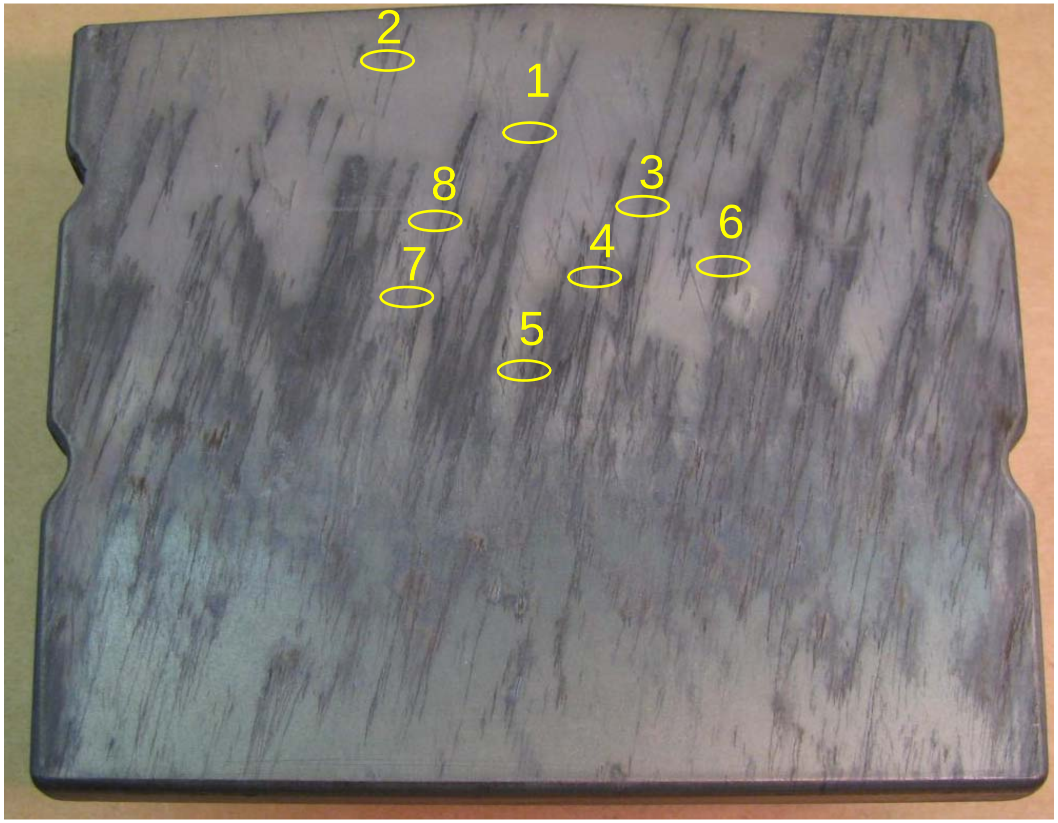
Old floor tile

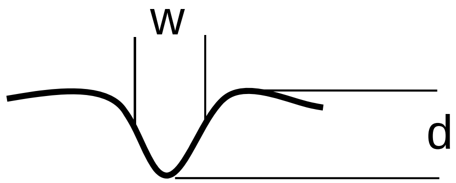
New floor tiles

- New lower divertor tiles installed in 2006 have much fewer arc traces than the old tiles
- Thin isolated coatings have been shown to increase arcing
- Before 2006 boronization was done every 3-4 weeks of operations and after 2006 only about once per campaign
- Is this the reason for less arcing?

# Arc trace characteristics

- A tile from the upper outer baffle analyzed by profilometry




| # | d (μm) | w (μm) |
|---|---|---|
| 1 | 10 | 200 |
| 2 | 5 | 80 |
| 3 | 5 | 80 |
| 4 | 4 | 80 |
| 5 | 4 | 60 |
| 6 | 5 | 150 |
| 7 | 5 | 100 |
| 8 | 5 | 80 |

- The accuracy was poor because of surface roughness of 1-2 μm

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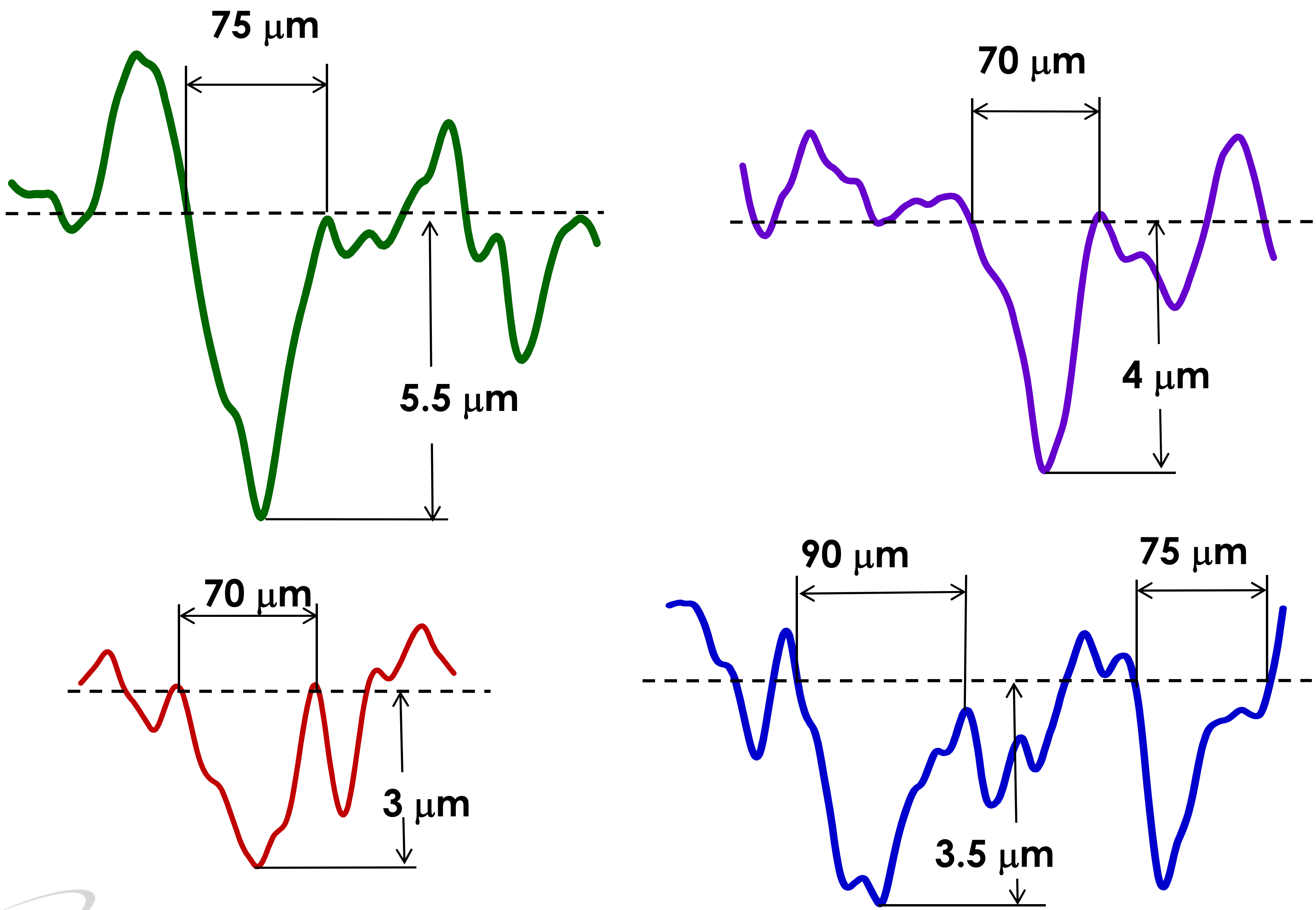
# Arc trace depth profiles

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# How large is total erosion by arcing?

- We don’t have any time-resolved arc measurement capabilities, so we can only estimate integral erosion over the time of exposure of a PFC surface
- A proper estimate would require analyzing a large number of tiles exposed for a known period of time
- In DIII-D most tiles in the locations of intense arcing have been exposed for 5 – 15 years
- Arc traces are eventually covered by re-deposited material, new traces form on top
- We can attempt only an order-of-magnitude estimate
- We take average depth ~5 μm, width ~80 μm, length ~1 cm
- Eroded carbon ~ $3.5 \times 10^{-6}$ g/arc

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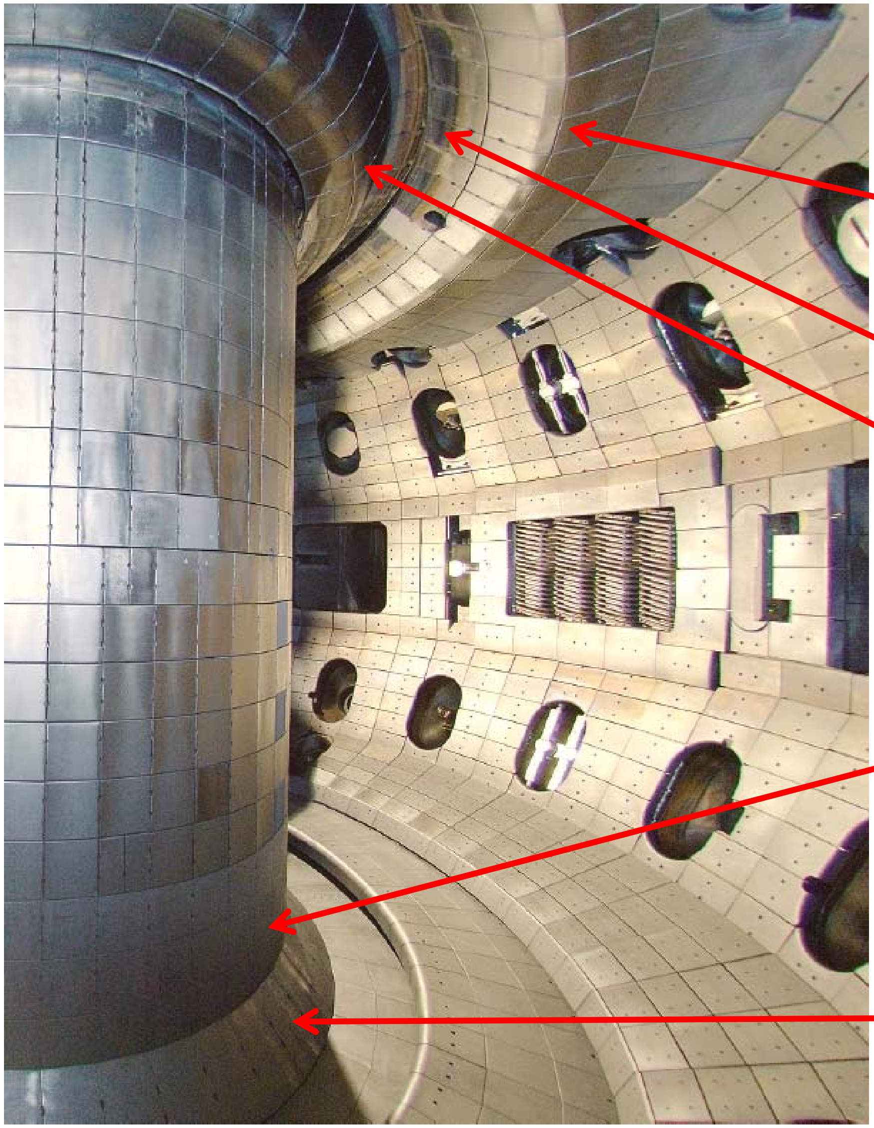
# Arc density and areas affected



N = number of arc traces per $cm^2$

A = total area affected ($cm^2$)

N = 5
A = 20000

N = 15
A = 3500

N = 3
A = 3000

N = 30
A = 17000

N = 20
A = 15000

**A total of ~ $10^6$ arc traces => total C erosion ~ 4 g**

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# Contribution of arcs overall carbon erosion is small

- Arc traces on the PFCs are accumulated over a few years, so net erosion by arcs is < 1 g/year

- Net erosion of carbon in the lower divertor per campaign is ~ 5 g [Wong C.P.C. et al J. Nucl. Mater. 196–198 (1992) 871]

  larger than arc erosion for the whole vessel

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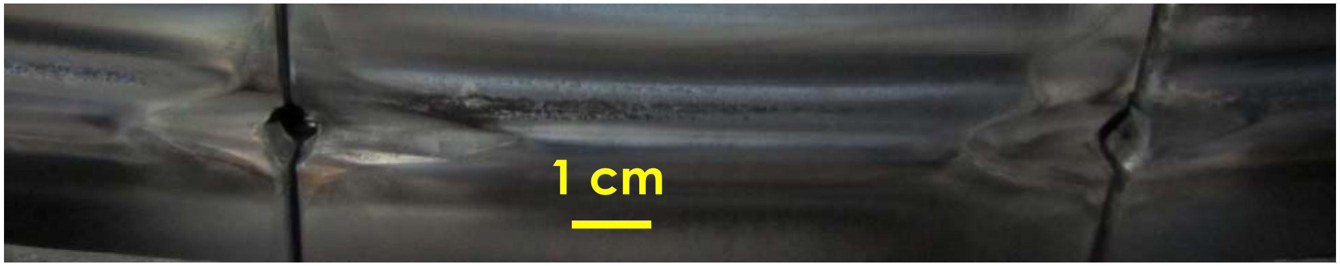
# Contribution of arcs overall carbon erosion is small

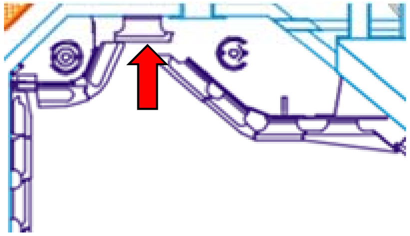
- Arc traces on the PFCs are accumulated over a few years, so net erosion by arcs is < 1 g/year, probably ~ 0.1 g per campaign

- Net erosion of carbon in the lower divertor per campaign is ~ 5 g [Wong C.P.C. et al J. Nucl. Mater. 196–198 (1992) 871]

  larger than arc erosion for the whole vessel

- Another major source of carbon erosion is erosion of tile leading edges and bolt holes



- Just for one row of bolt holes in the upper outer divertor, total amount of eroded carbon is ~ 50 g

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# Is arcing important for dust production?

- Arcs are known to produce micron-size particles
- The dust inventory on the lower divertor surfaces in DIII-D is estimated at ~1 g (from dust collection results)
- Upper bound estimate of the dust production by disruptions during a run year also gives ~1 g (from fast camera data)
- Arcing can not be ruled out as a contributor to dust production
- We lack suitable diagnostics to correlate arcing rate with dust observation rate

# Dust is released from chamber wall by plasma contact

Shot number 137965

Full light, 3000 f/s

- Could arcing play a role? Possibly, with existing camera setup we can not tell

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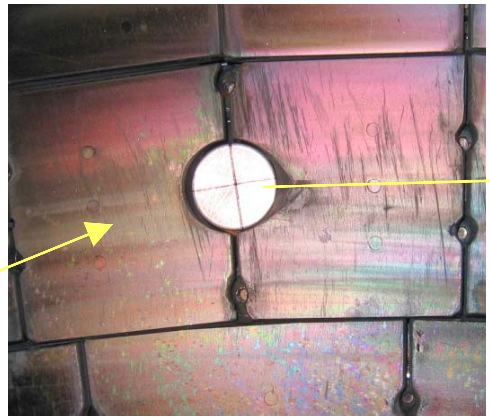
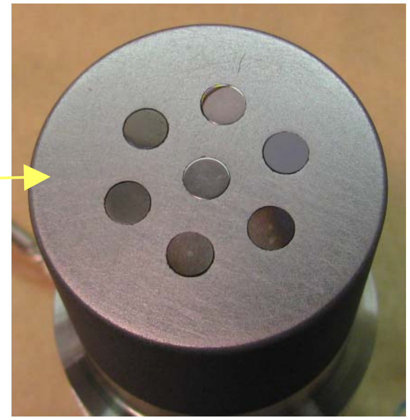
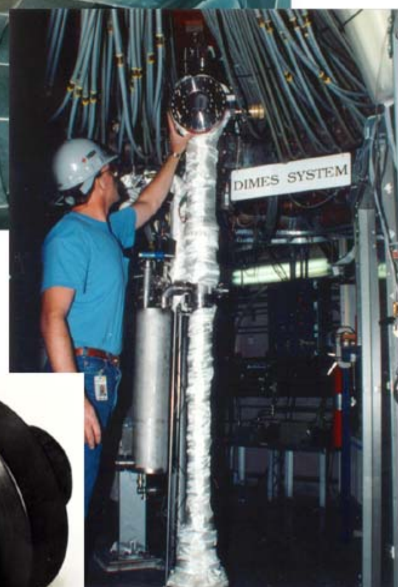
# Divertor Material Evaluation System - DiMES





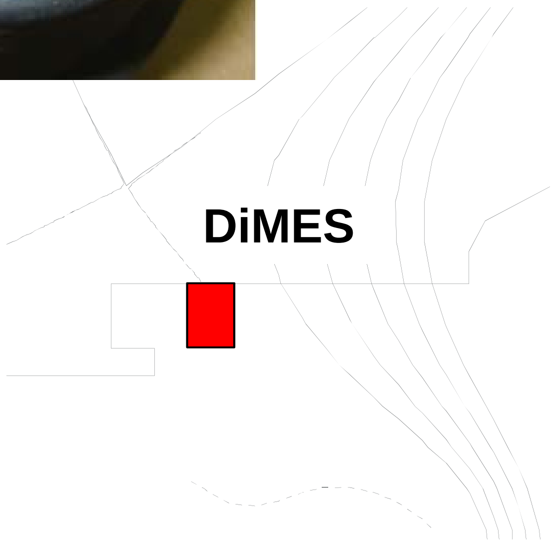


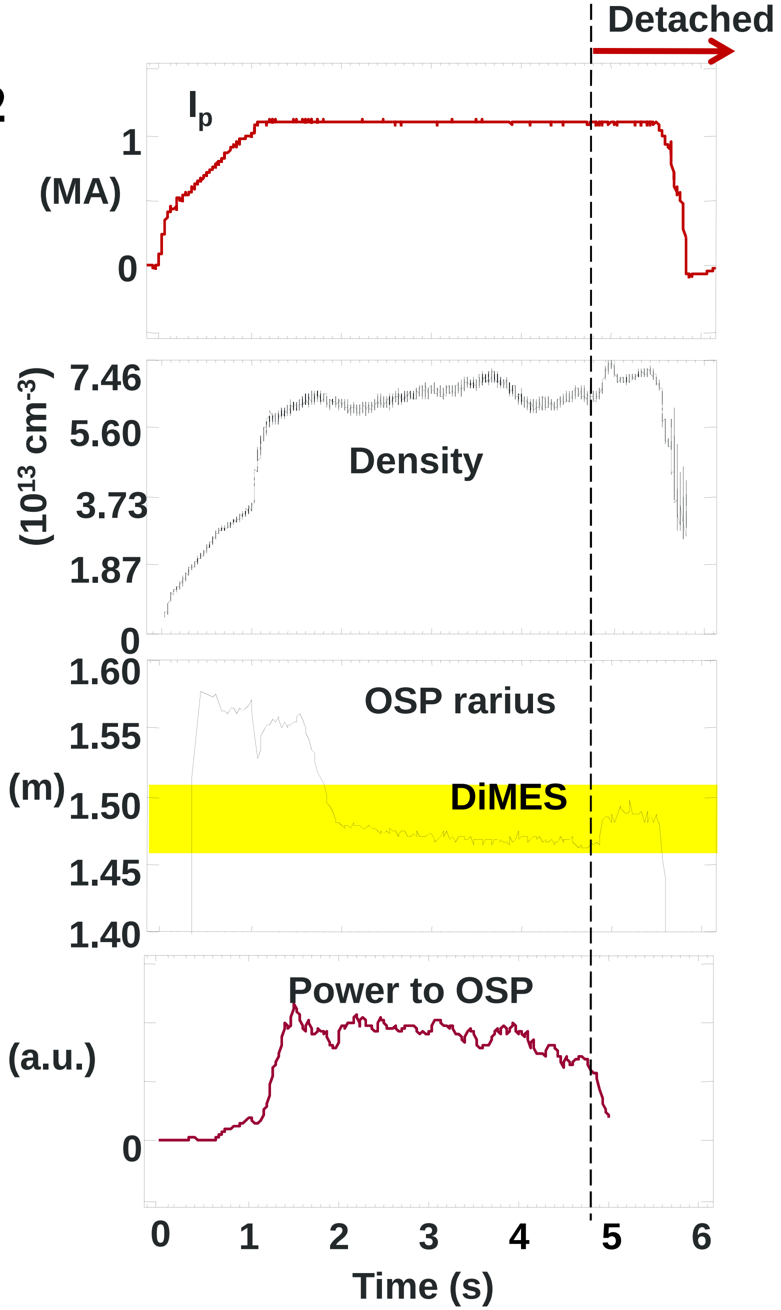

- DiMES system is used to insert material samples in the lower divertor of DIII-D
- A minimum exposure is for 1 plasma discharge

# Sample exposed near semi-detached OSP

- Depth-marked graphite sample with deposited W and V stripes was exposed in 2 ELMing H-mode discharges with Ar puff to induce detachment

Sample before exposure

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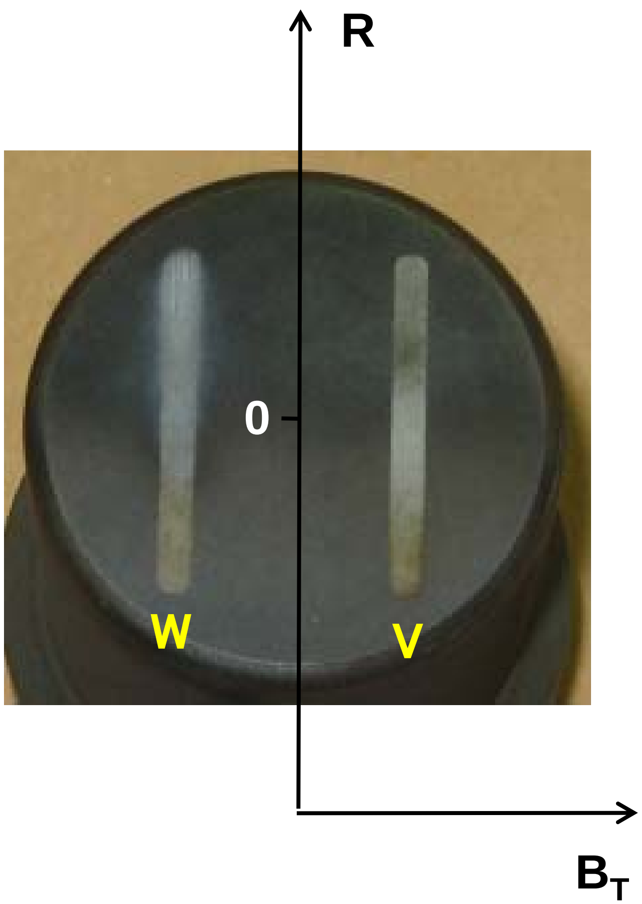
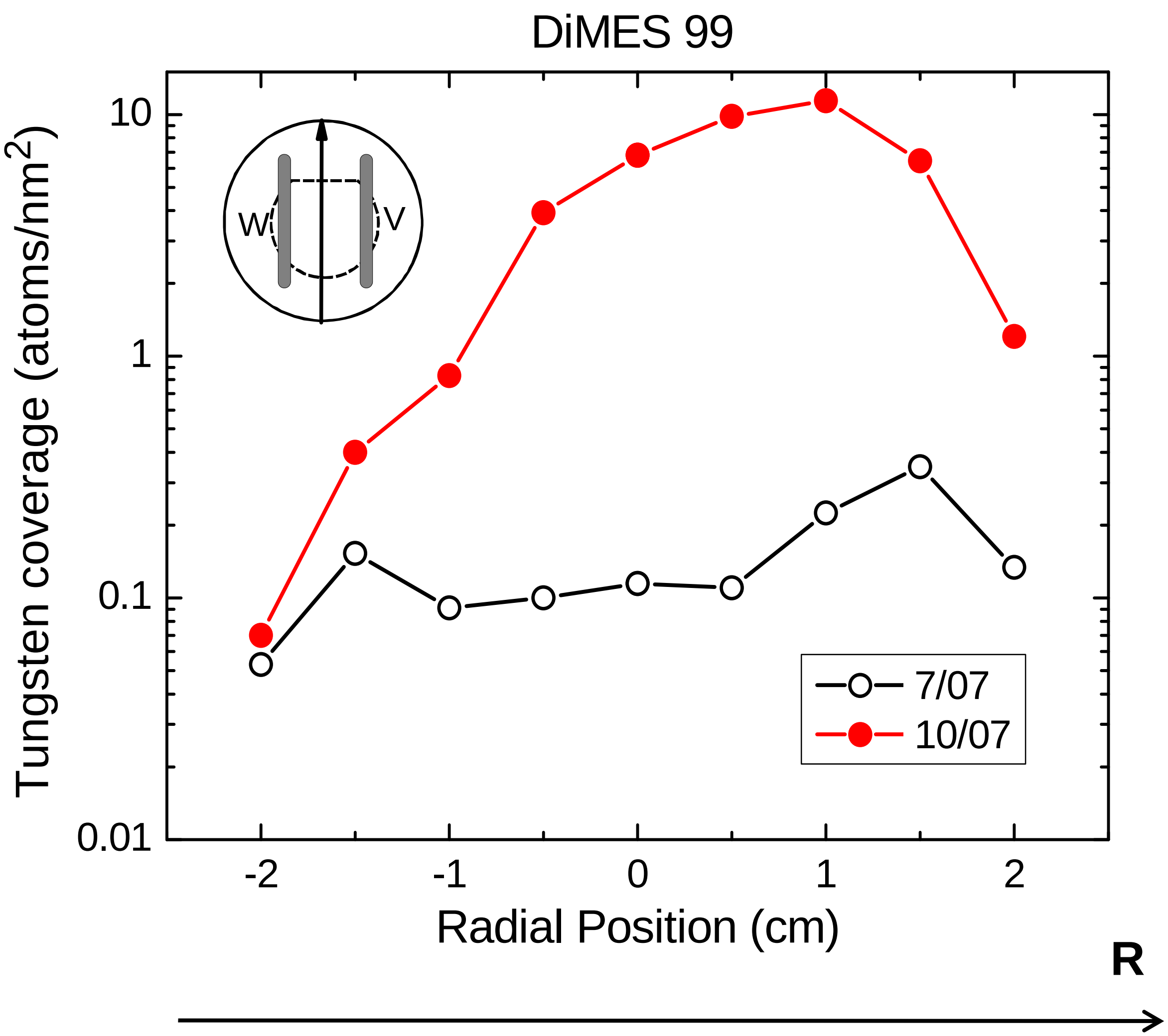
# Tungsten stripe showed erosion on the outboard side

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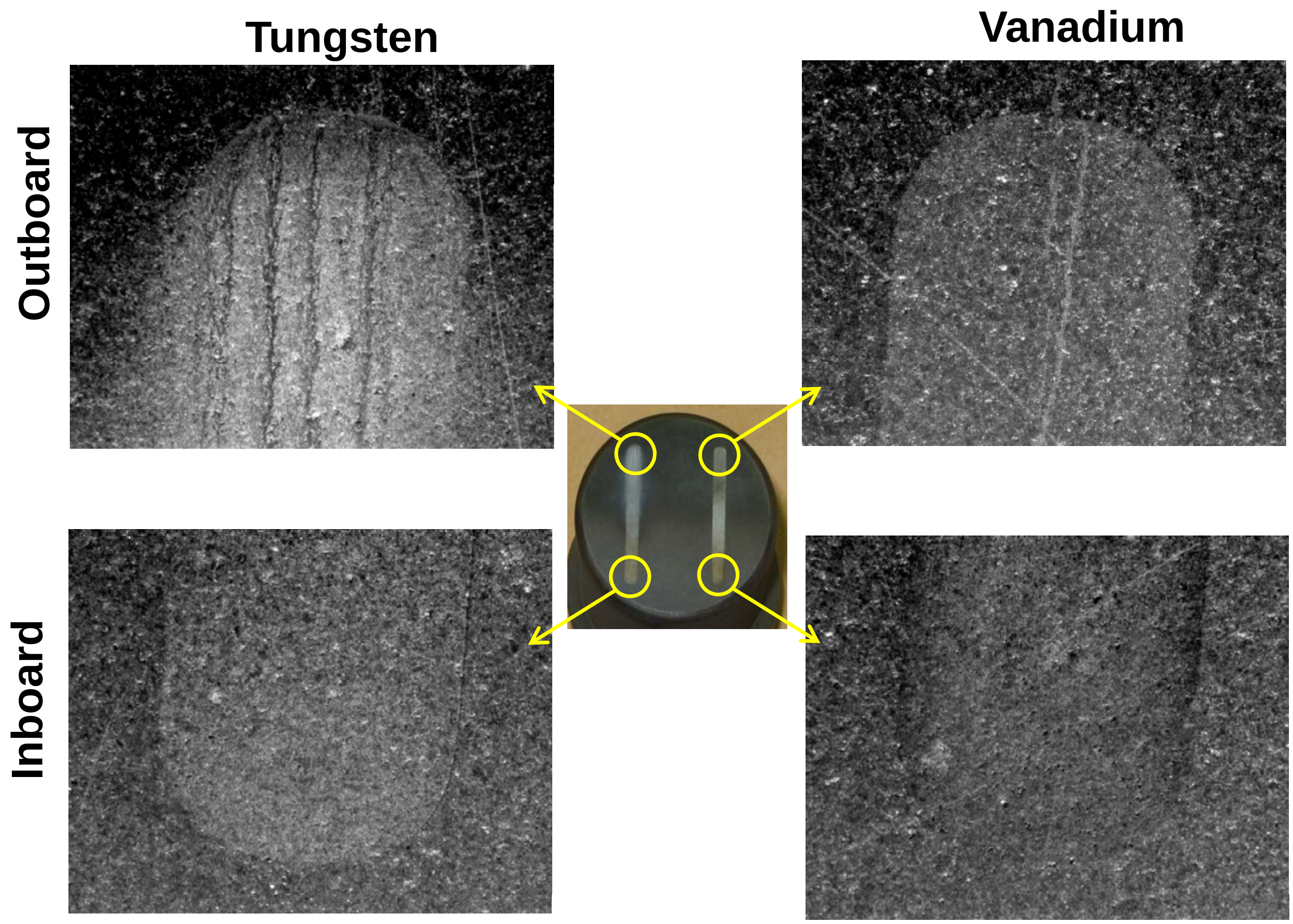
# Tungsten erosion was by arcing




- Little or no arcing on vanadium
- Consistent with older DiMES results showing arcing on W and no arcing on Be [D.G. Whyte et al, JNM 1997]

# Future plans

- A radial set of pre-characterized tiles has been installed in the lower divertor for 2011 campaign to measure net erosion and arcing

- High magnification fast camera view of DiMES is planned for optical detection of arcs
- DiMES samples with isolated surface can be used to measure arc currents
- Studies of arcing on tungsten are planned in collaboration with IPP Garching (V. Rohde)
- More analysis of dismounted old tiles will be performed

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# Summary

- Based on the  evidence available, arcing is a relatively small contributor to overall carbon erosion in DIII-D
- Arcing can not be ruled out as a notable contributor to dust production
- Dust release by plasma-wall contact is observed, but the role of arcing is yet to be quantified
- Tungsten is affected by arcing more than carbon, vanadium and beryllium