Mixed-material studies in PISCES-B

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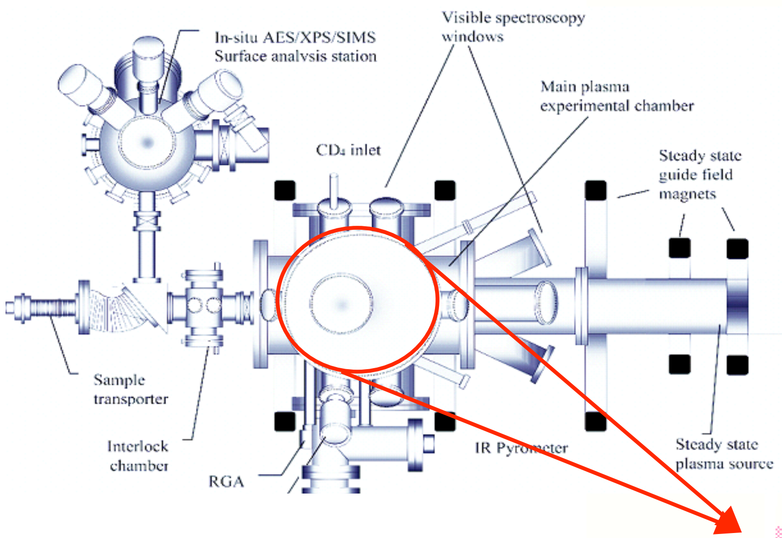
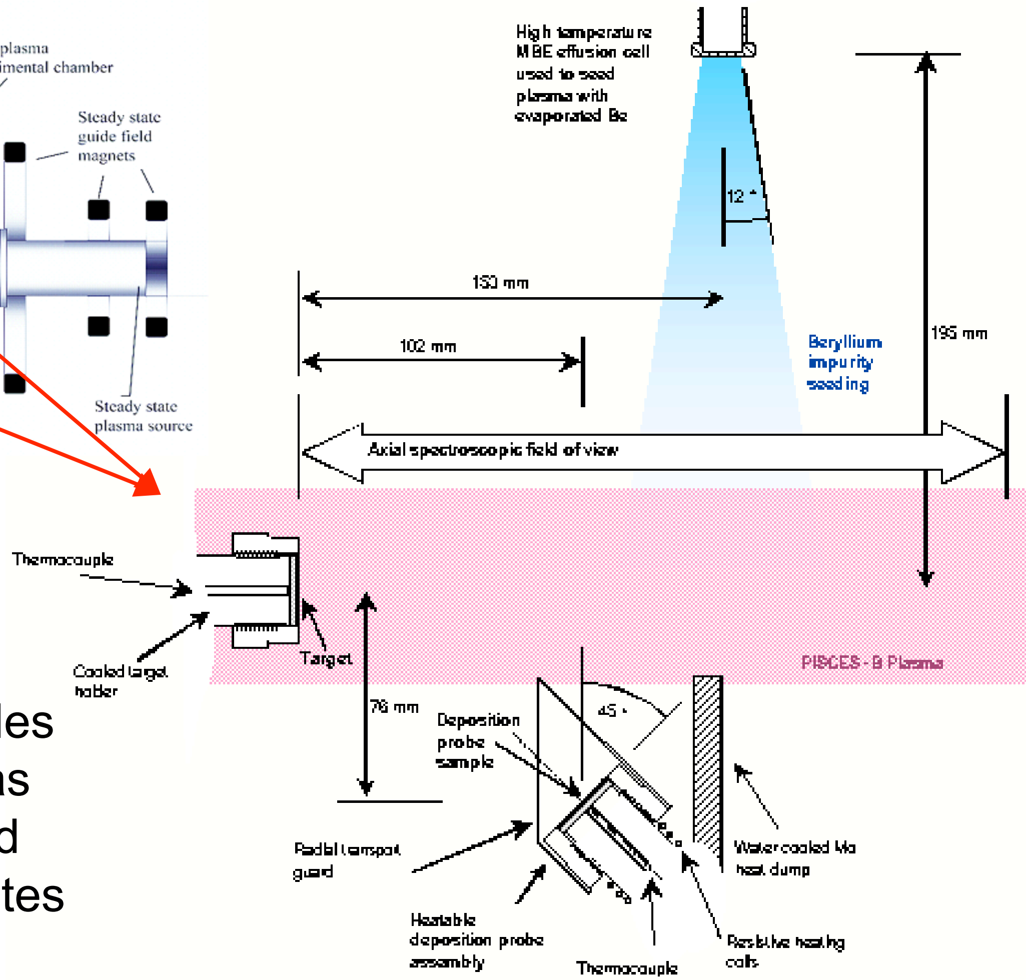
Part of the US-EU collaboration on Mixed-Material Effects on ITER

- Introduction
- Technical results
  - Temporal behavior of chemical erosion suppression
  - Response of Be/C to thermal transients
- Summary of possible mixed-material implications for ITER

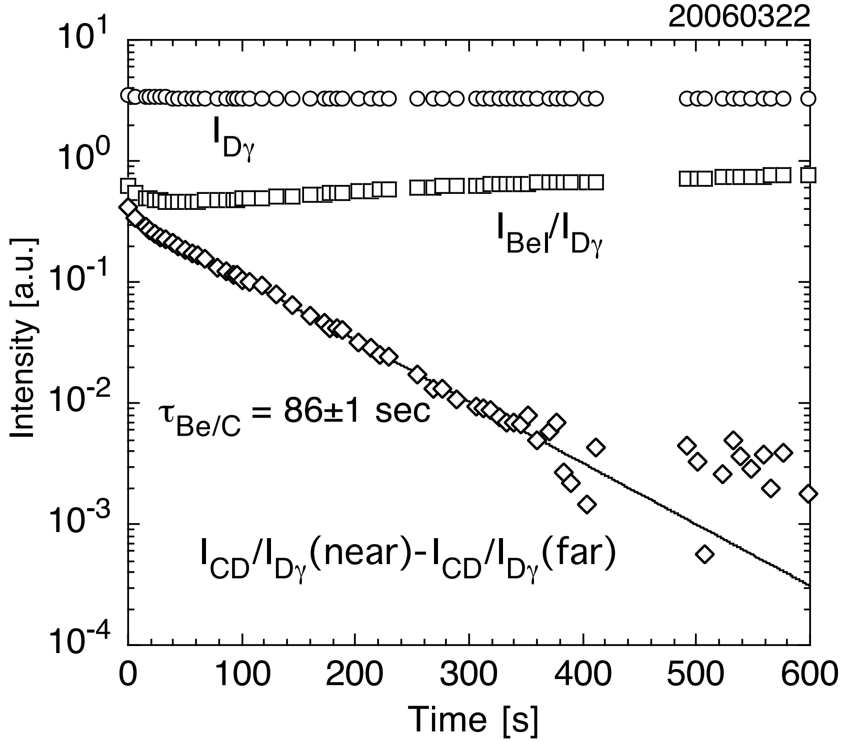
PISCES-B has been modified to allow exposure of samples to Be seeded plasma





P-B experiments simulate Be erosion from ITER wall, subsequent sol transport and interaction with W baffles or C dump plates, as well as investigation of codeposited materials using witness plates

Erosion suppression exhibits a temporal evolution ($\tau_{Be/C}$)

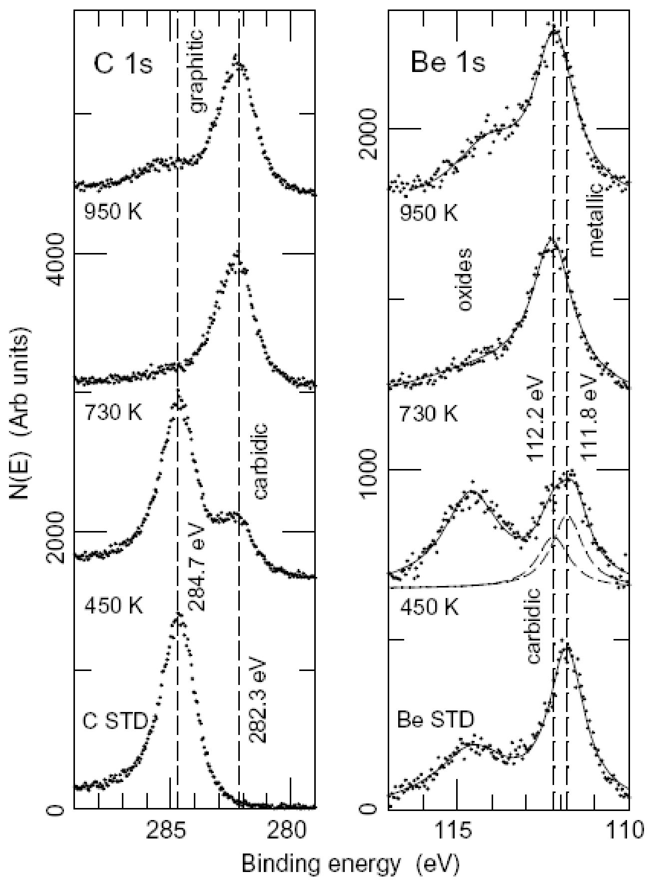


- Understanding the temporal behavior is critical to determining the fundamental mechanisms responsible for erosion mitigation

- PMI modeling codes should be able to reproduce temporal behavior to provide confidence

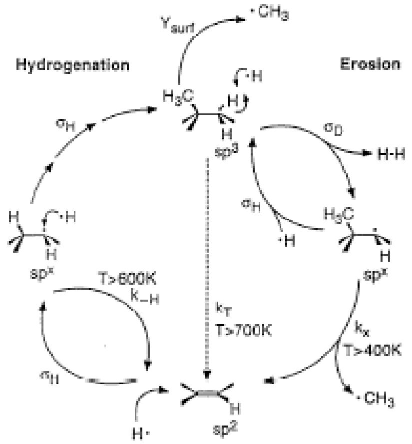
XPS data shows Be_2C formation in resultant mixed-material surface

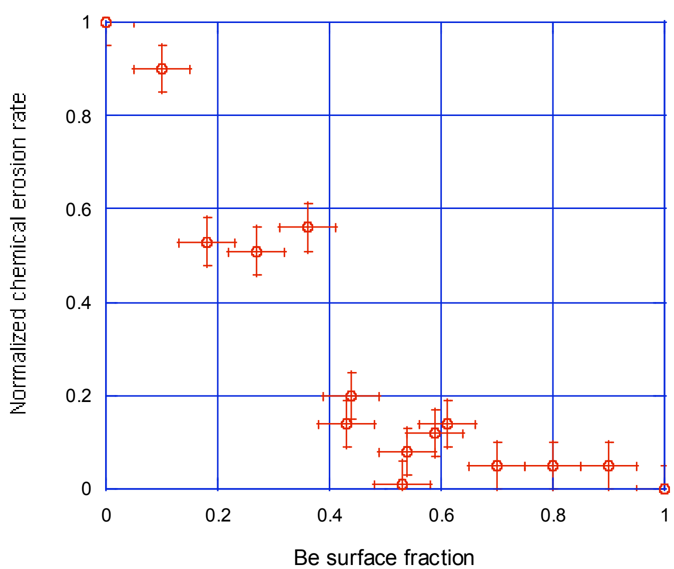
XPS analysis of Be on C sample surface
[M. Baldwin et al., in press JNM]



- Virtually all C remaining at the surface is bound as carbide ($t > \tau_{Be/C}$)
- Presence of carbide inhibits chemical erosion of C
- Carbide layer reduces sputtering yield of bound Be
- Subsequently deposited Be can be more easily eroded
- Codeposits are primarily Be once carbide layer forms

If Be acts like B doping, then Be should inhibit C atoms from chemically eroding

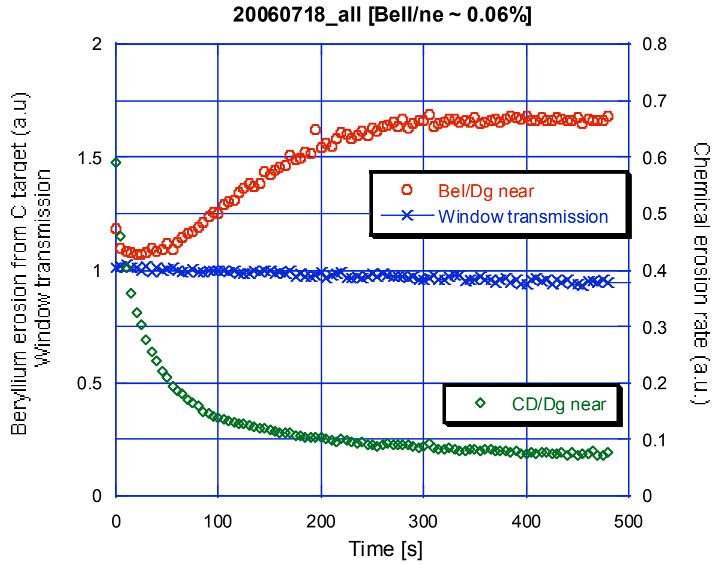


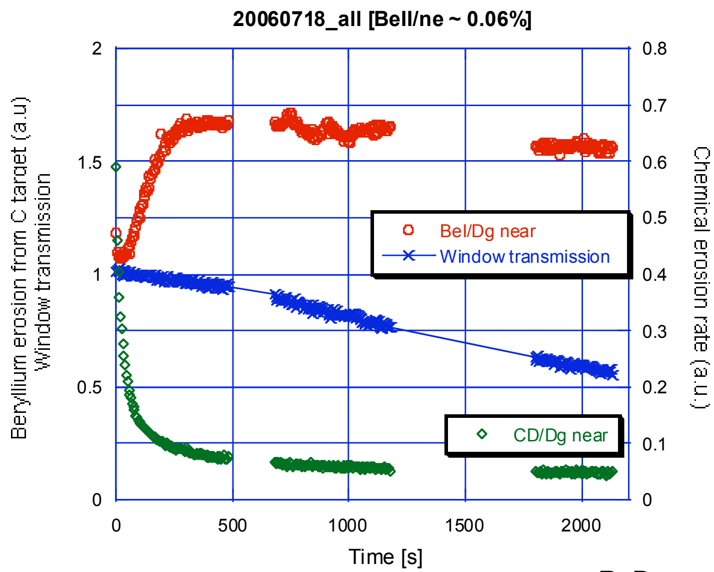


- Chemical erosion model [Schenk et al. JNM 220-222(1995)767] predicts boron reduces sp^2 component in favor of sp^3 hybridization.

- In-situ Be seeding data shows similar behavior of chemical erosion mitigation

Be first shuts down C chemical erosion, then subsequent Be re-erodes from surface

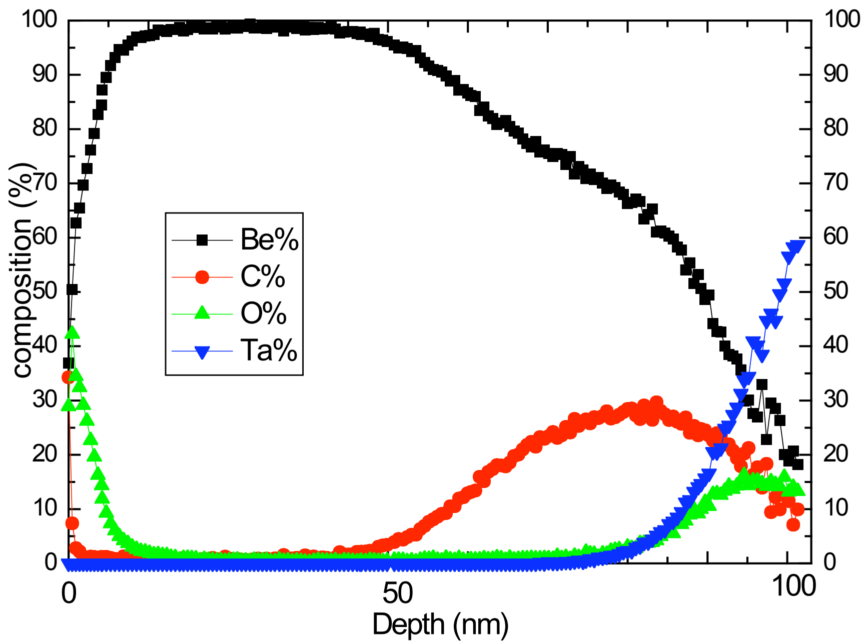




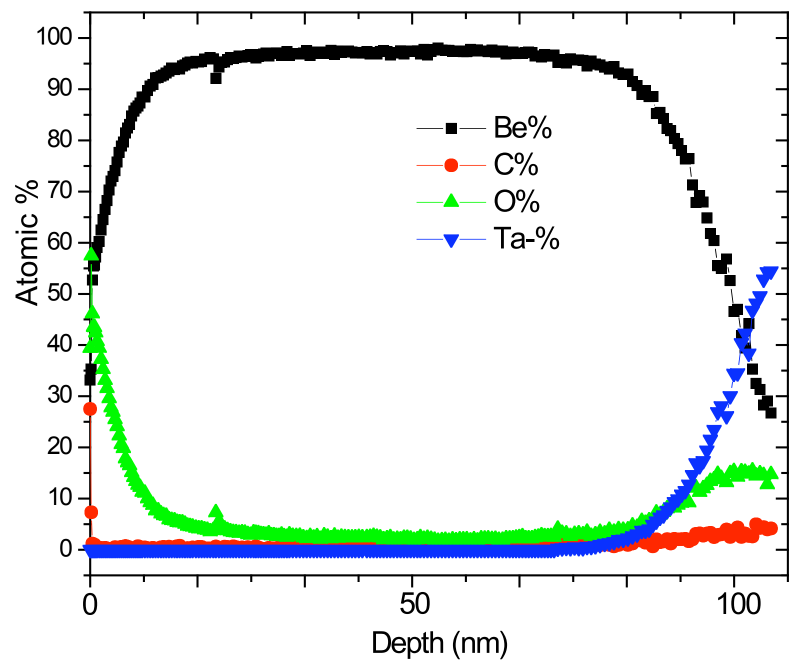
- Evolution of a mixed Be/C surface
  - Be oven opens at t = 0 sec.
  - Be ions arriving at t < 50s shut down chemical erosion by forming Be_2C surface layer [Baldwin JNM 2006 available on-line]
  - Once Be_2C is formed, subsequent Be arriving (T > 50 s) is more easily eroded and begins coating windows
  - Be_2C surface thickness saturates after carbide forms 50s in this exposure [Baldwin JNM 2006]
  - Resultant codeposited material is primarily Be [Baldwin JNM 337-339(2005)590]

WPM samples show collection of beryllium-rich codeposits during Be seeding runs

Carbon target : 300ºC target exposure

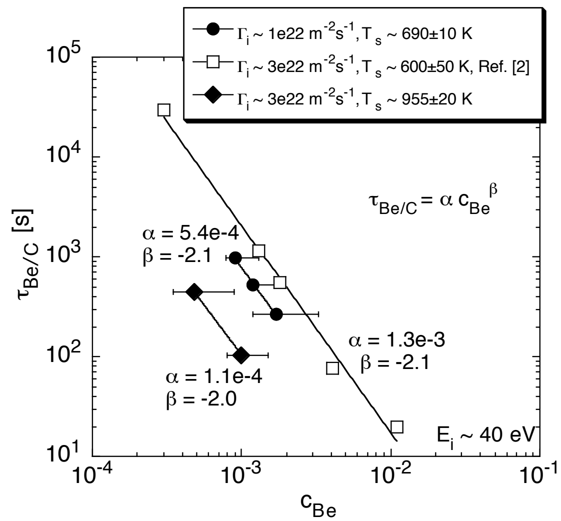


Carbon target : 700ºC target exposure



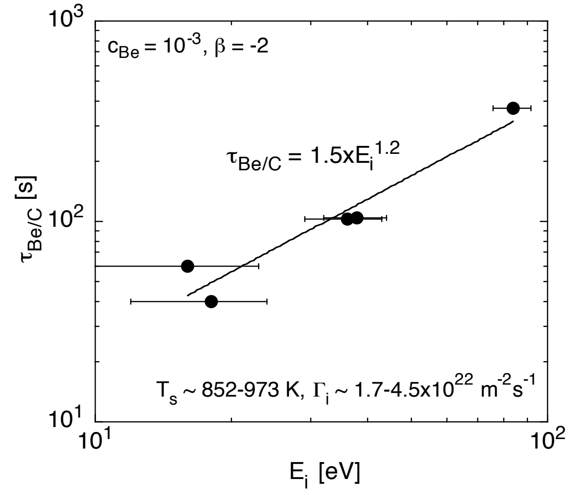
More C is detected in codeposits during lower C target temperature exposure (possibly due to a combination of lower chemical erosion yield and/or quicker beryllium carbide layer formation)

Chemical erosion suppression time ($\tau_{Be/C}$) depends on several quantities that can be varied almost independently

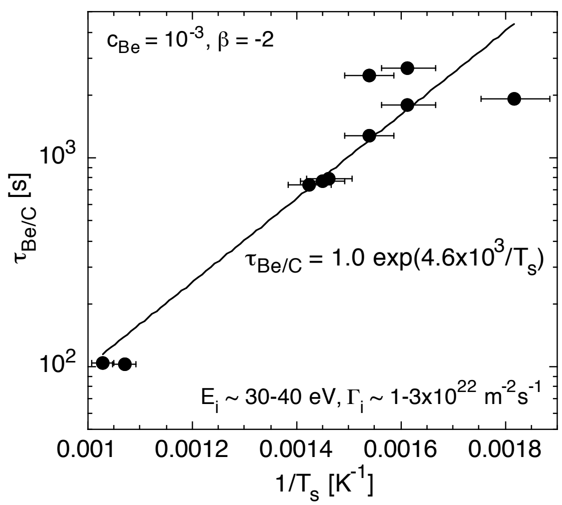


Be concentration in plasma

Incident ion energy



Surface temperature of target

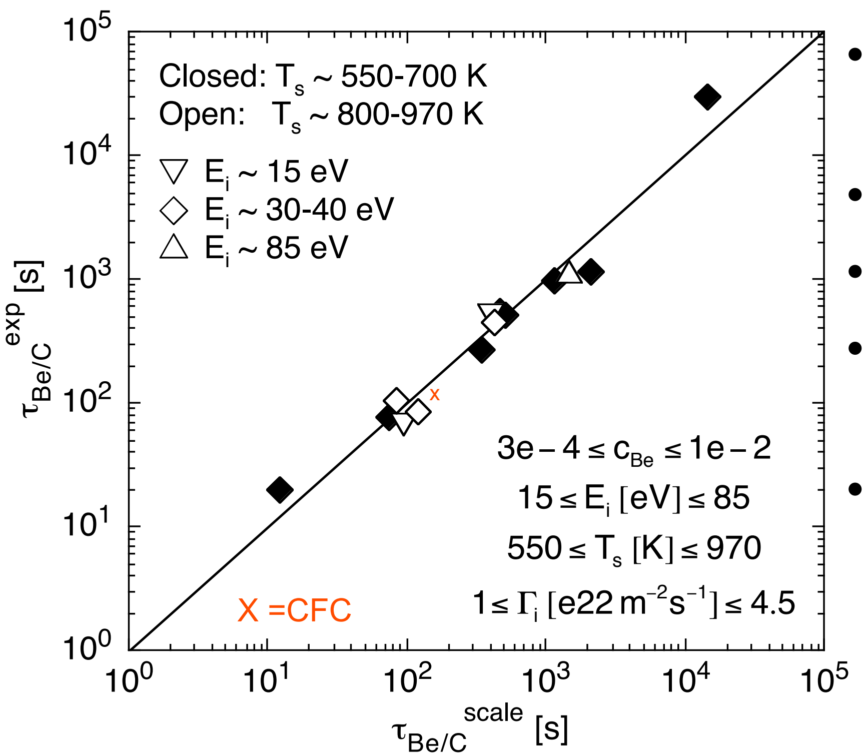


From D. Nishijima et al., PSI17.

PISCES chemical erosion mitigation time scaling predicts suppression between ELMs in ITER

$$\tau_{Be/C}^{scale}\ [s] = 1.0\text{x}10^{-7}\ c_{Be}^{-1.9\pm0.1}\ E_i^{0.9\pm0.3}\ \Gamma_i^{-0.6\pm0.3}\ \exp((4.8\pm0.5)\text{x}10^3/T_s)$$

From D. Nishijima et al., PSI17.



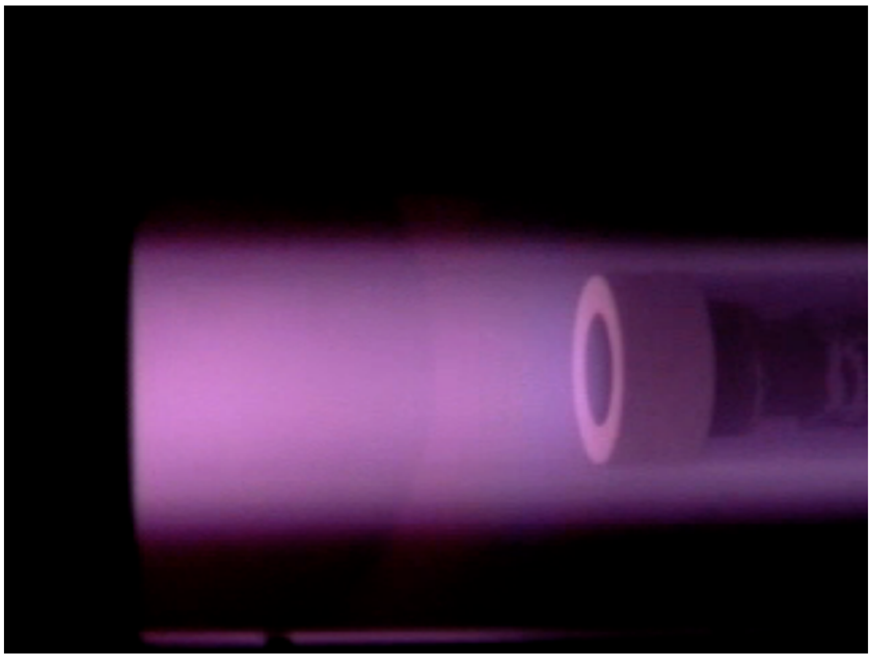
- Surface temperature effects reaction rate
- Be plasma concentration effects arrival rate at surface
- Ion energy effects erosion rate
- Ion flux impacts through redeposition
- Type of graphite does not seem to play a significant role (ATJ vs. CFC)
- Scaling law using these variables has been developed to allow extrapolation to ITER conditions ($\tau_{Be/C}^{ITER} \sim$ 6 msec)

[c_{Be} = 0.05, E_i = 20 eV, T_s = 1200 K and $\Gamma_i = 10^{23}$ $m^{-2}s^{-1}$]

Thermal transient experiments: Motivation for positive pulse biasing

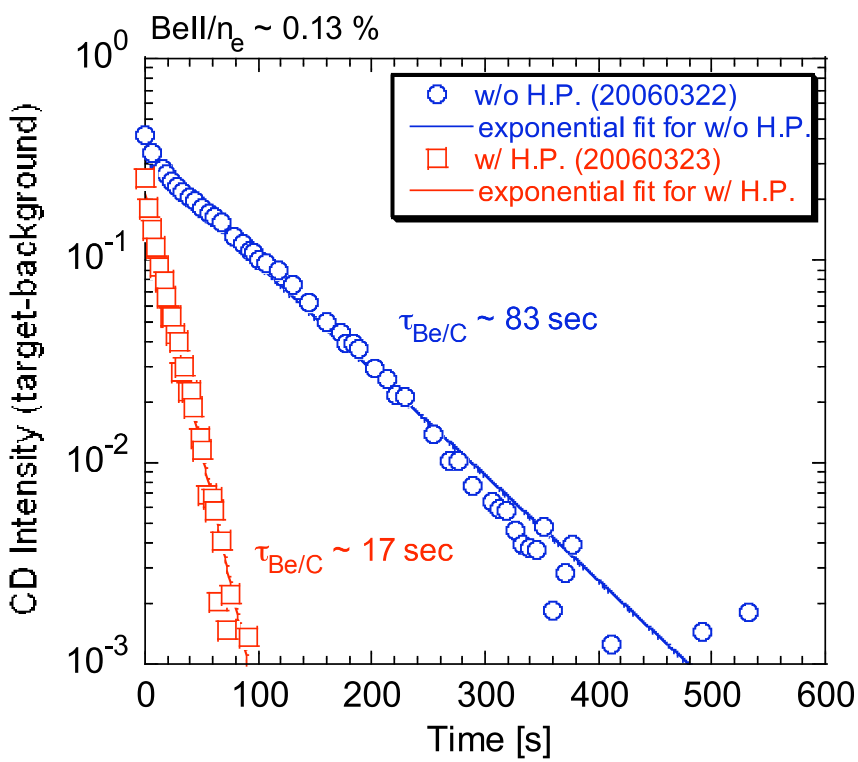
- PISCES has shown that Be plasma impurities suppress carbon target erosion at temperatures up to 1000°C
- ITER will experience large temperature excursions (up to 3800°C) at the carbon dump plates during periodic ELMs
- Will the thin, surface Be, Be/C layers survive such dramatic temperature excursions?
- How will Be-W react during temperature excursions?
- It is possible to simulate the large temperature excursions associated with ITER ELMs in PISCES-B using positive sample biasing during plasma discharges.

Large power loads can be drawn to P-B sample during positive biasing



- During 1.5 MW/m^2 power pulse graphite surface temperature rises to ~2000°C (by pyrometers)
- Bulk graphite temperature rise at back of sample ~20°C during 0.1 s. pulse (thermocouple)
- Surface temperature rise is limited by power supplies (IPP has supplied a new power supply as part of US-EU collaboration)

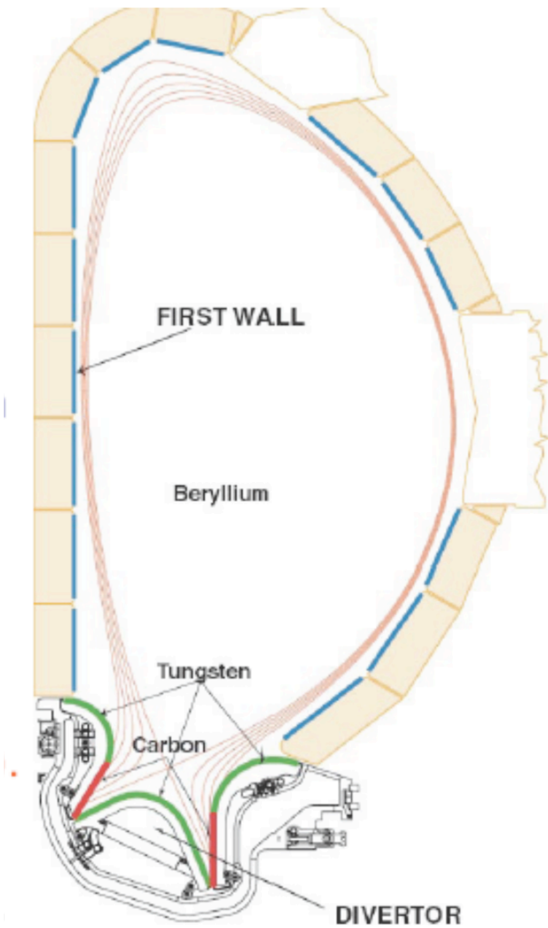
Transient surface heating promotes Be_2C formation leading to shorter mitigation times



Surface temperature during heat pulse ~ 1200°C
[from R. Pungo et al., PSI17]

- Pulsing surface temperature to the 1200°C range results in faster chemical erosion suppression
  - Be_2C disassociates at ~2200°C at 1 atm
  - Beryllium boiling point = 2471°C at 1 atm
- D retention during transient surface heating also increases by ~50% both with and without Be plasma seeding

How might mixed materials impact ITER?



- Due to elevated temperature of C dump plates, carbides will likely form and limit C erosion
- If a full C divertor were employed, carbide formation on regions of the baffles, where the temperature is lower, would take longer, resulting in more C erosion and thereby more hard-to-remove tritium
- Be deposition on W baffles will likely not result in significant beryllide formation ($T_W \sim 400°C$)
- If a full W divertor were used, beryllide formation near the strike points would be a concern (perhaps an issue for the JET ITER-like wall experiments)
- Beryllide formation in ITER only appears to be a concern on the W cassette liner 'louvers' (that are designed to be hot surfaces)