Deuterium retention in Tore Supra long discharges

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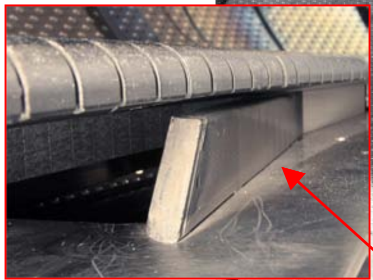
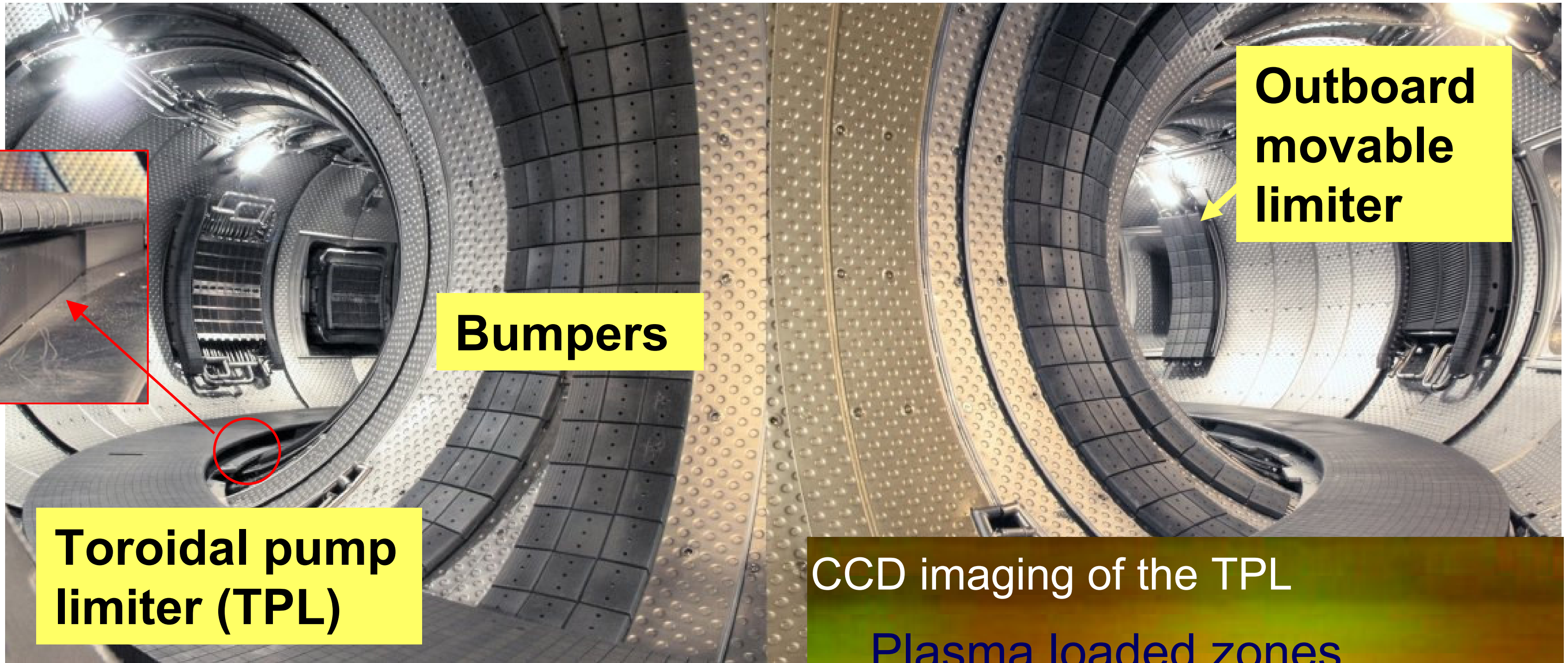
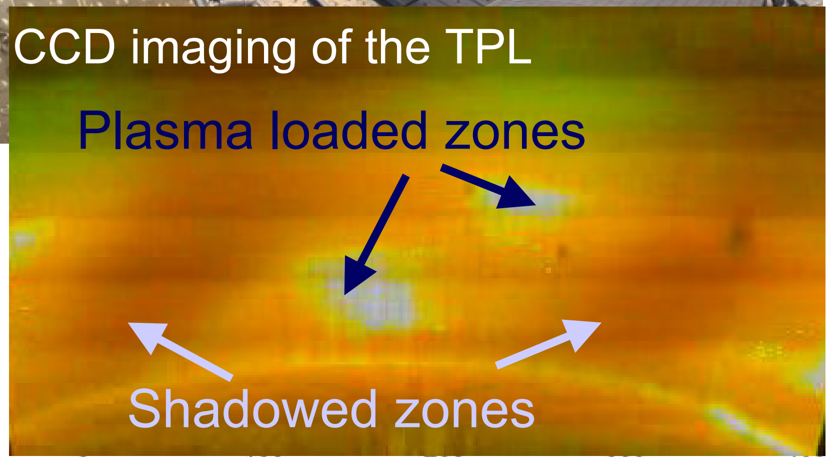
- Experimental results
    - Particle retention during long discharges
    - Particle recovery (after shot, glows, disruptions)
- Interpreting the particle balance

Tore Supra : the CIEL configuration







- 15 m^2 of carbon plasma facing components
- Active cooling : stationary PFC temperature

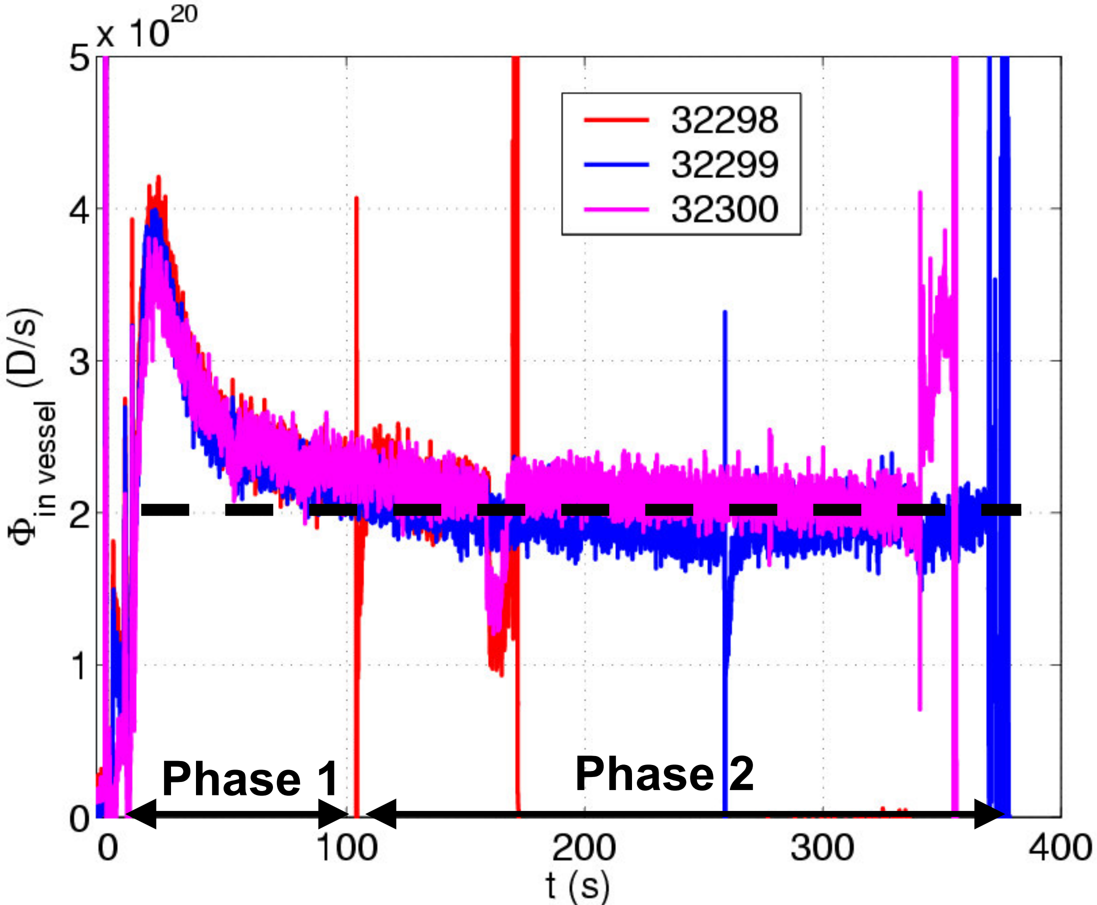
from 120°C (cooling loop) up to 250°C on the limiter for long pulses

- Active pumping : neutralisers below TPL
- Long pulse : LH driven discharge at V_{loop} ~ 0, low plasma current/density

⇒ low density hot edge plasma (Te ~ 100 eV at the LCFS)

Particle retention in long discharges

Euratom cea



- Phase 1 (~ 100 s)

Decreasing retention rate

- Phase 2

Constant retention rate (= 50% of injected flux)
No saturation after 6 minutes

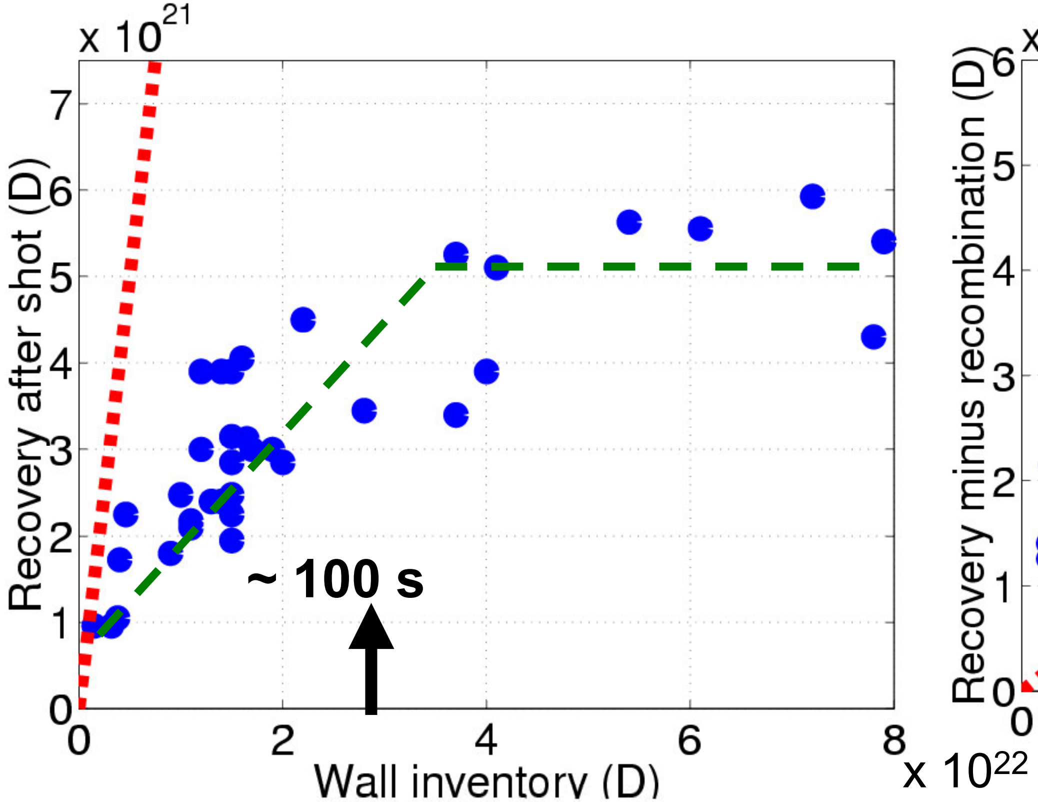
- In vessel inventory

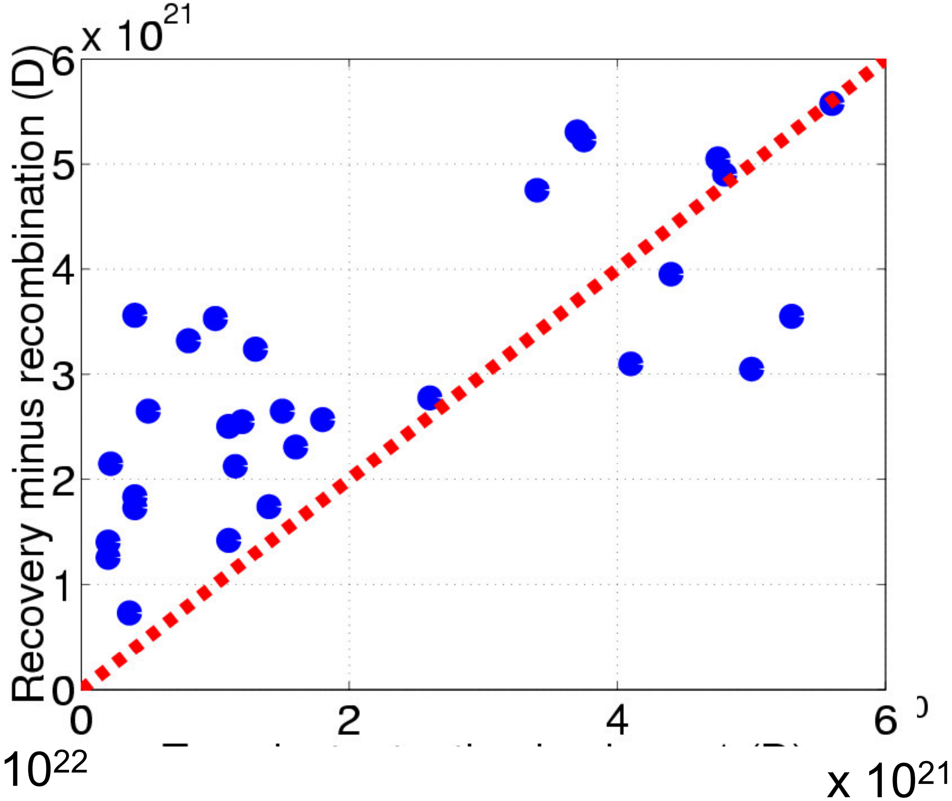
∝ shot duration in phase 2
(I_{max} = 8 10^{22} D for 6 minutes)

- Identical shot to shot behaviour

No saturation of in vessel retention after 15 minutes of cumulated plasma time

Particle recovery after shot





- **Small fraction recovered after shot**
- **Recovery > plasma content : the wall releases particles**

- **Recovery correlated to retention in phase 1 : transient retention mechanism**

Particle recovery after glow discharge and disruptions

Recovery after He glow discharge (6 hours) : 1.5 - 2 10^{22} D < I_{max}

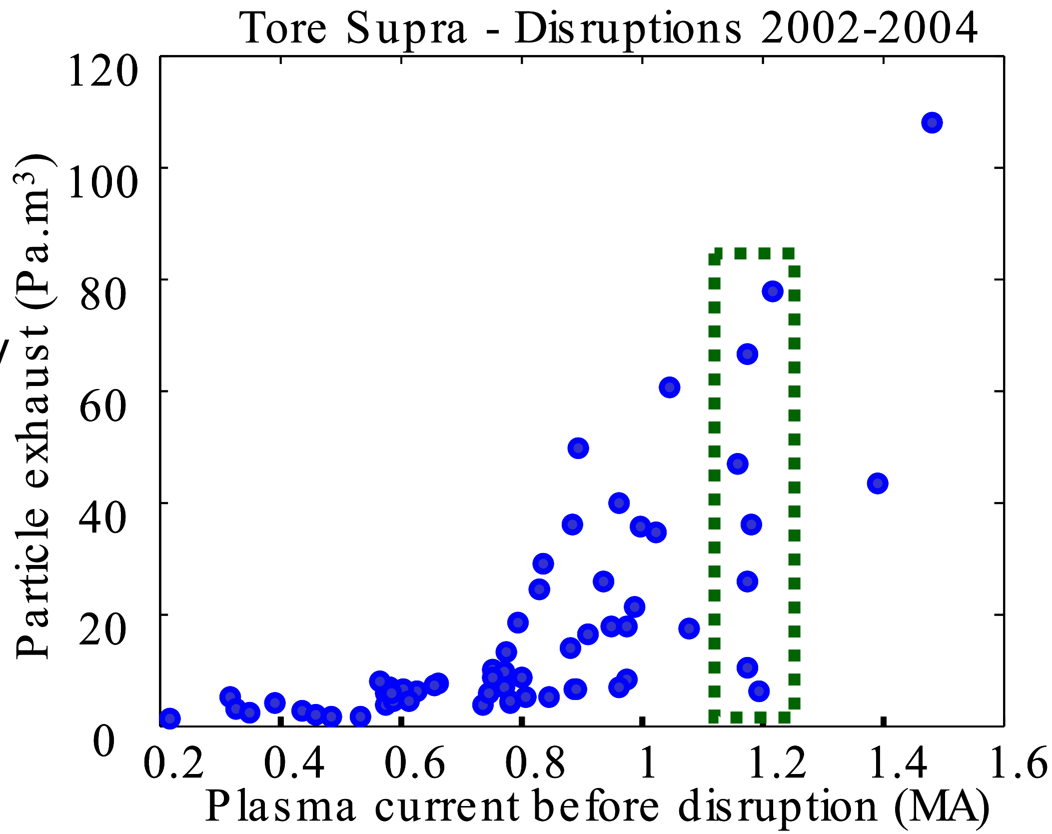
• Independent of the quantity trapped during the day of experiment

Recovery after disruption :
up to 5 10^{22} D < I_{max}

• Threshold in Ip :

- Ip < 0.8 MA : ~ after shot recovery
- Ip > 0.8 MA : increase with Ip ⇒ dissipated energy high enough to heat D rich deposited layers
[D. Whyte, PSI 2004]

• Large scatter at given Ip :
machine history dependent ?
(highest exhaust in start up phase)

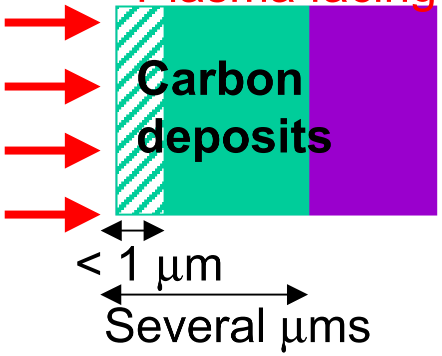


Sample analysis : D content

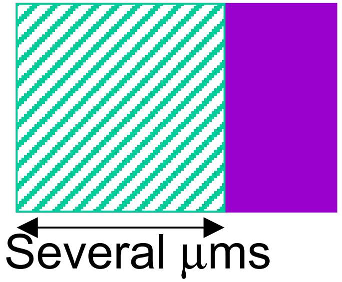
Euratom cea

Net deposition zone

Plasma facing



Shadowed

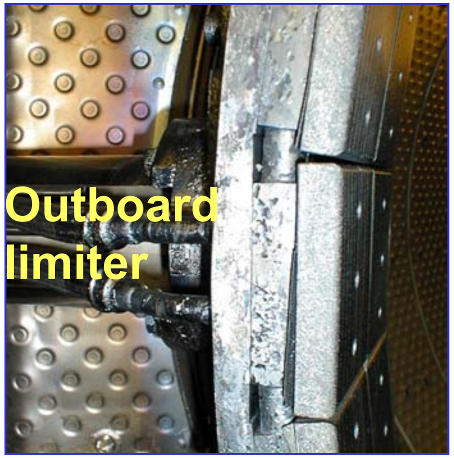


<u>Hot deposits (> 500°C)</u>

D/C ~ 1 %

$N_D \sim 10^{21}$ at/m^2 * S

[C. Brosset, PSI 2004]



<u>Cold deposits (~ 120 °C)</u>

D/C ~ 10 %

$N_D \sim 10^{22}$ at /m^2 / µm * S * d

Net erosion zone
(main plasma interaction area)

Net deposition zones

<u>TPL deposits analysis still in progress</u>

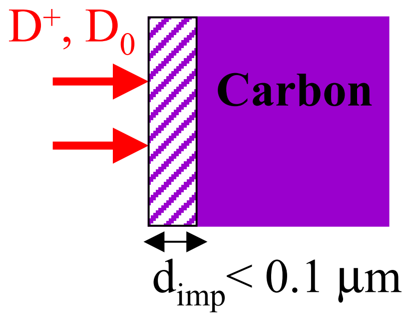
Cold deposits in shadowed areas

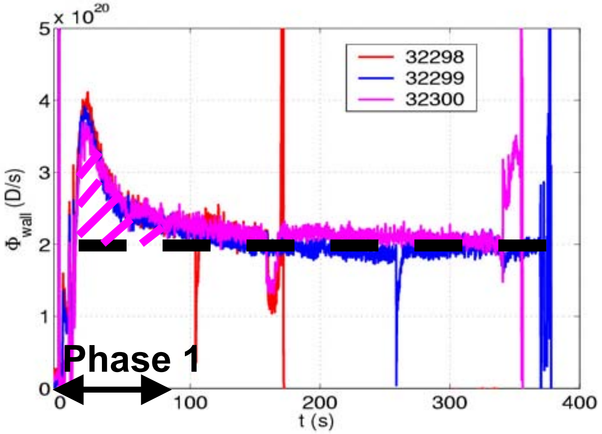
→ D reservoir

Interpreting the particle balance

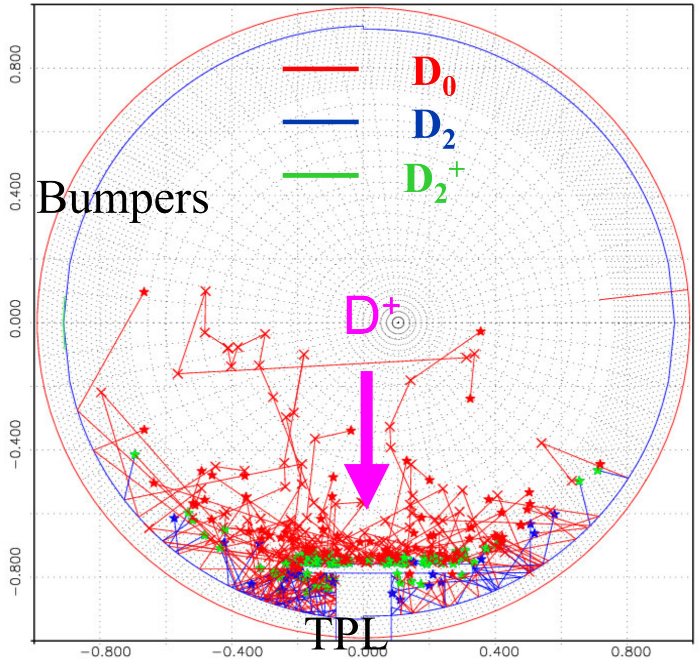
- **Implantation D → C**

Progressive saturation of bombarded surfaces (D^+, D_0) until C_{Dmax} reached





Saturation time :
from ~ 1s (TPL)
to ~ 100 s (bumpers)

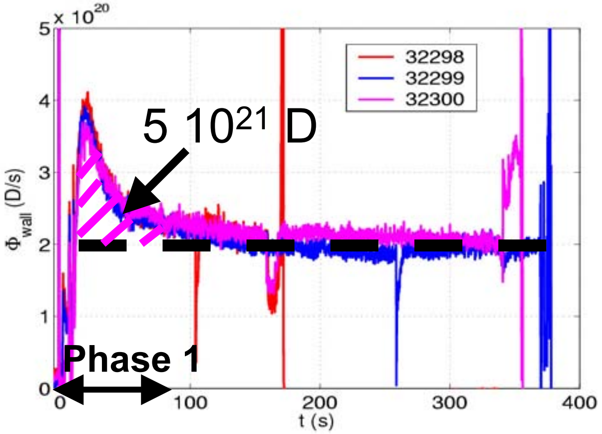


[E. Tsitrone, PSI 2004]

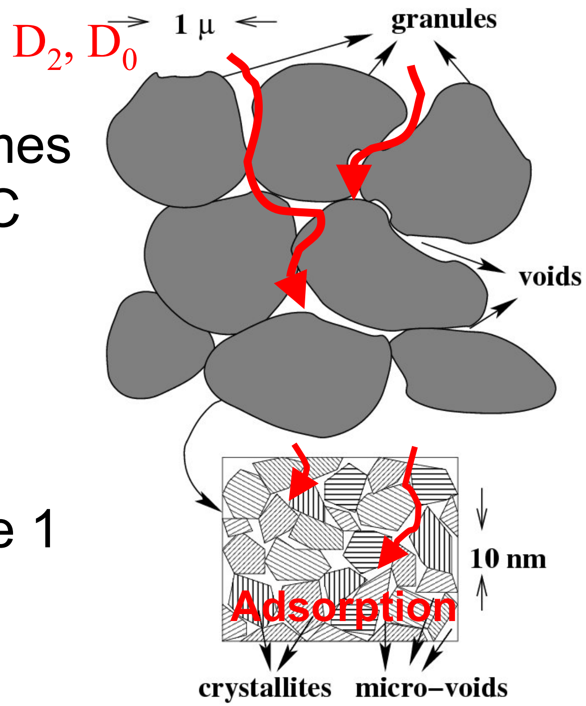
BUT : does not explain shot to shot behaviour unless very strong diffusion takes place

Interpreting the particle balance

• Filling the CFC porosity



• TS deposited layers : 100 times more porous than original CFC
[P. Roubin, PSI 2004]



M. Warrier et al., Contrib. Plasma Phys. 44, No. 1-3, (2004)

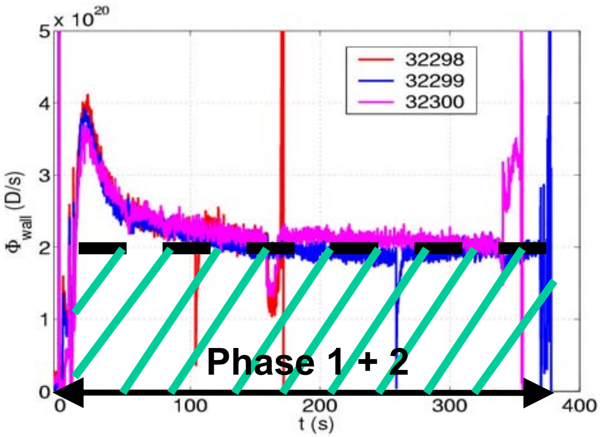
• Extrapolation from lab exp (77 K) :
10^{22} D/g deposits ⇒ 0.5 g enough to account for phase 1

• Adsorption : weak bond (≠ chemical bond)
⇒ ok for transient mechanism

• Outgassing after shot ~ phase 1 duration (~ 100s) :
ok with filling / emptying the porosity reservoir

Good candidate for phase 1 BUT : extrapolation from lab to tokamak environment (temperature)

Interpreting the particle balance



• **Codeposition :**

physical sputtering

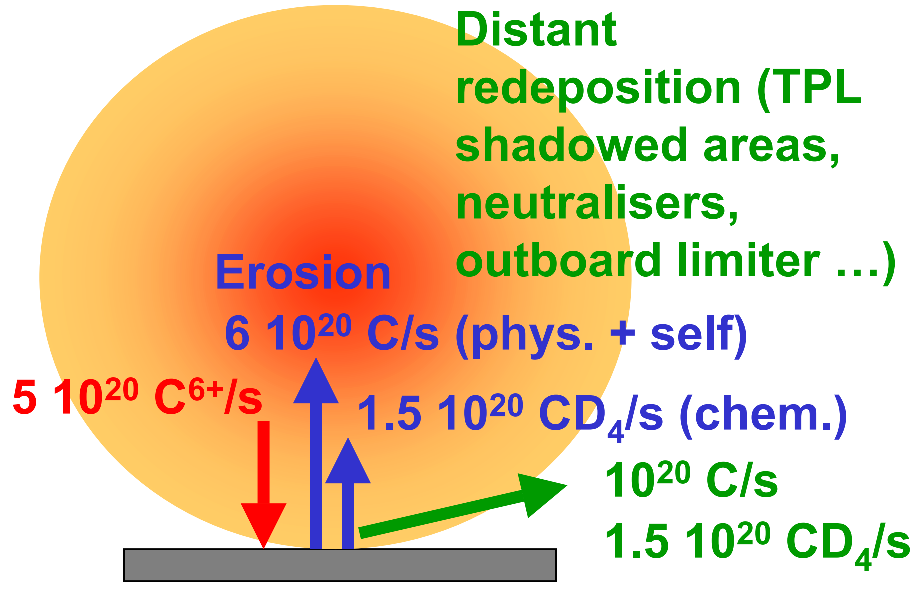
chemical sputtering

Preliminary estimates of carbon erosion sources

• physical + chemical sputtering by D^+ and D_0

• self sputtering by C^{n+} (assumed 5% C in D^+ flux)

• ok with Zeff, ok with low net erosion on TPL (high local redeposition), ok with layers growing rate

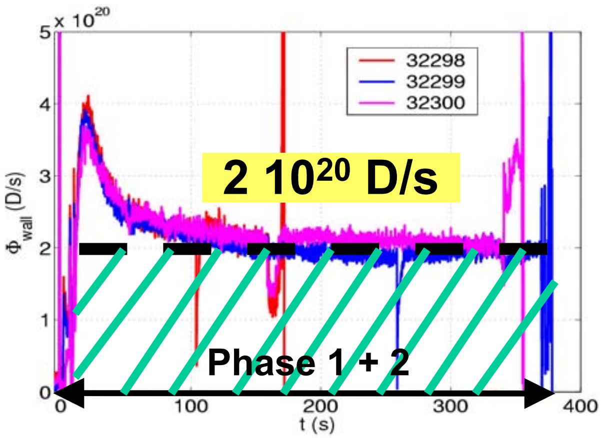


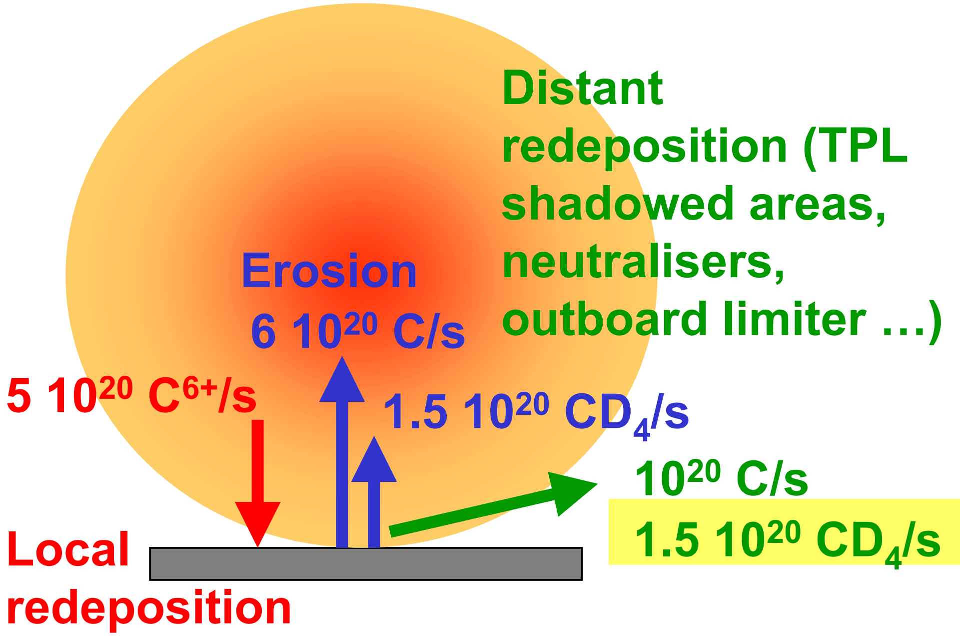
Local redeposition

$\Rightarrow$ **carbon balance roughly coherent**

Interpreting the particle balance

• **Codeposition : D balance**





• 1/3 of produced CD_4 trapped :
but high D/C ratio film : **not observed**

• If D/C = 0.1 : need **2 10^{21}** C/s of net redeposition : high erosion/redeposition on TPL (> 100 µm on 4 m^2): **not observed**

⇒No coherence between **D retention rate** / **D/C ratio** / **C erosion/redeposition**

D rich film created during the discharge subsequently depleted in D (glows, disruptions) ?

Hard to explain the retention rate in phase 2 with codeposition alone

Summary

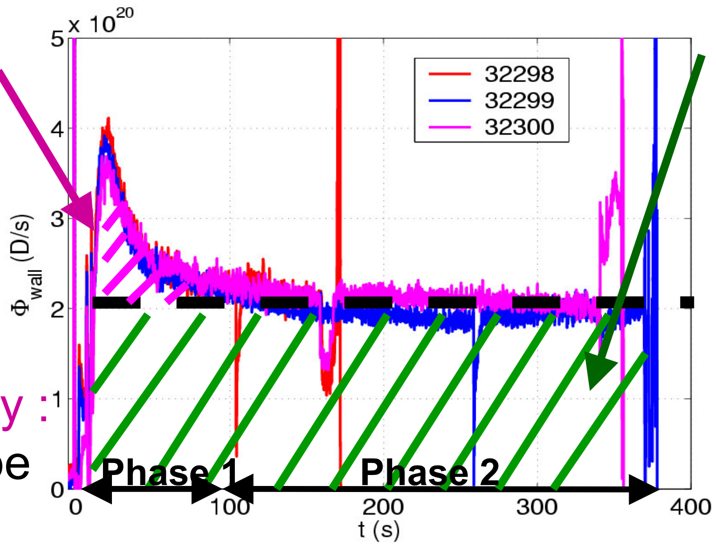
• **D retention** : no wall saturation after 15 minutes in high T_e / low n_e edge plasma

• **D recovery** (He glow discharge, disruptions) < in vessel inventory accumulated in a single long discharge

Transient retention : recovered after shot

• D implantation in C : progressive saturation but not transient

• D adsorption in porosity : good candidate, but to be assessed in tokamak environment



Permanent retention : NOT recovered after shot

• Codeposition of D and C : Can hardly explain the retention rate in phase 2

• D content sample analysis : D mainly in cold deposits in shadowed areas (120 °C)

Missing D not found yet but still a lot to investigate (TPL deposits, pumping ducts …)