Assessment of Fuel Reabsorption by Thermally Pre-heated Co-deposited Layers

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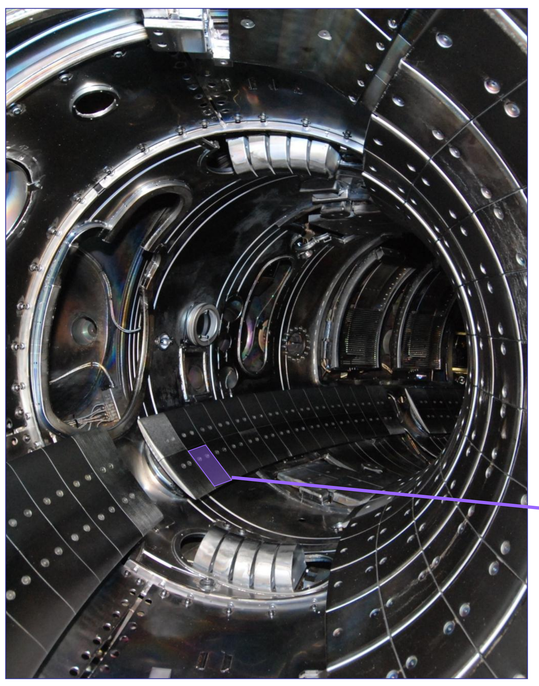
Background and Motivation

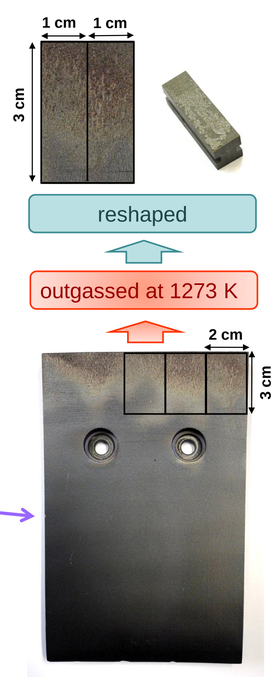
- Reduction of in-vessel fuel inventory in fusion devices is essential when operation with tritium is considered. Especially in presence of a carbon wall.
- Two basic schemes for fuel removal are currently considered: (i) desorption of hydrogen-containing species, (ii) removal of the entire fuel-rich co-deposit. In all cases, the outgassed deposited layers remain in the vessel and they would be repeatedly exposed to plasma.
- **How do the outgased layers respond to plasma during the repeated exposure?**

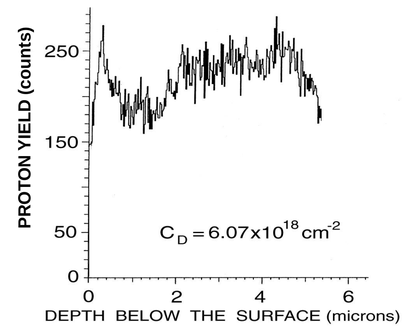
Analysis Methods

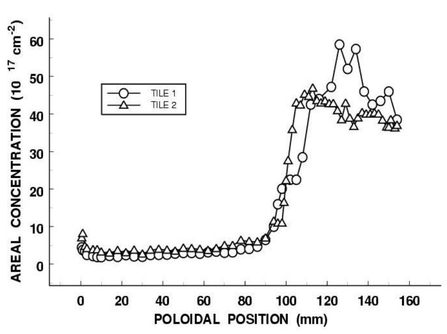
- Scanning Electron Microscopy (SEM) with Energy Dispersive X-ray Spectroscopy (EDX)
- Thermal Desorption Spectrometry (TDS)
- Nuclear Reaction Analysis (NRA)
- Rutherford Backscattering Spectrometry (RBS)

Materials for study: ALT-II deposits

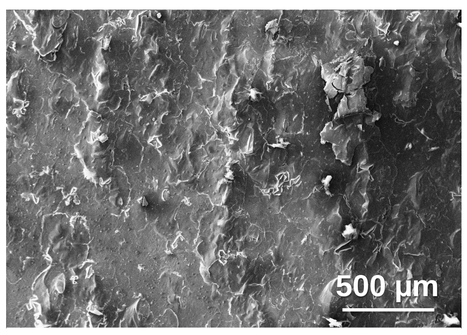


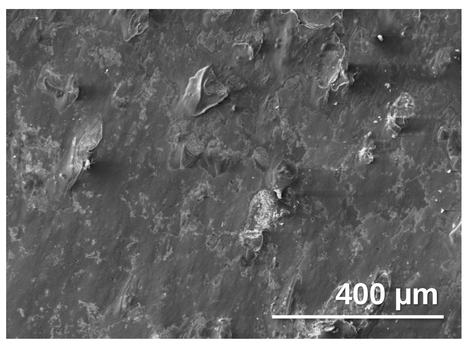




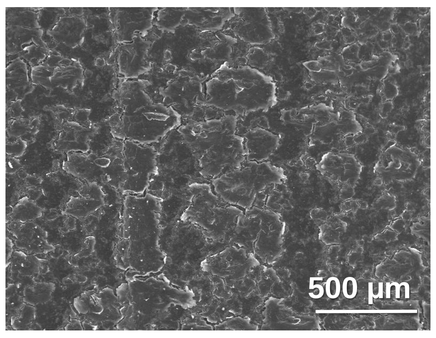


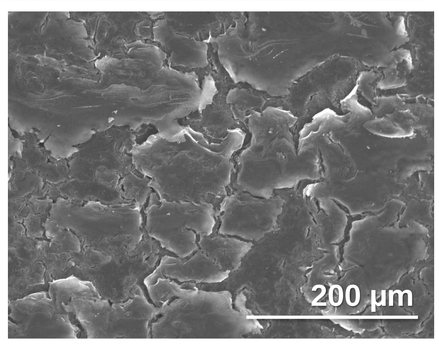
Original deposits:





Deposits after outgassing:

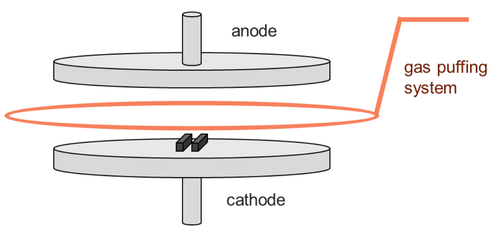




Experimental set-up

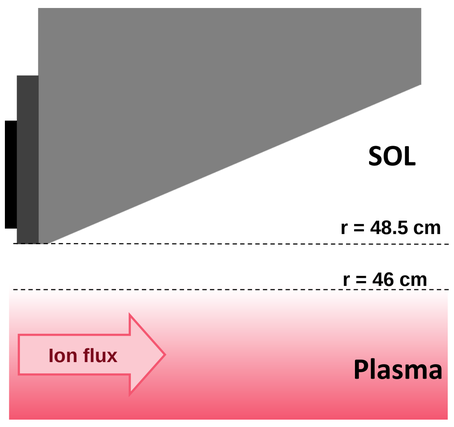
PADOS:
Laboratory system for layer deposition

- deuterium plasma, **glow discharge**
- $U_{cathode}$ = 350 V, $I_{cathode}$ = 49 mA, $T_{cathode}$ = 450 K
- Exposure time: 3 hours
- $\Gamma \sim 1 \times 10^{15}$ $cm^2 s^{-1}$

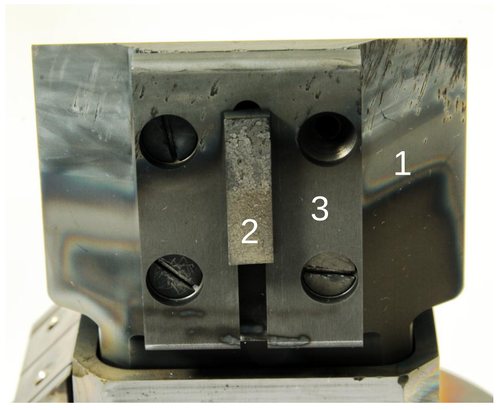


TEXTOR

- **SOL plasma**, > 3 cm behind the main limiter
- Plasma parameters: B_t = 2.2 – 2.6 T, $n_e = 2.5 – 3 \times 10^{19}$ m^{-3}, I_p = 350 – 400 kA
- 2 exposures: 40 and 25 plasma seconds
- $\Gamma \sim 5 \times 10^{19}$ $cm^2 s^{-1}$



positioning of the test limiter in relation to plasma



Test limiter after exposure in TEXTOR (1) with a specimen of ALT-II tile (2) and a pure graphite holder serving also as reference material (3).

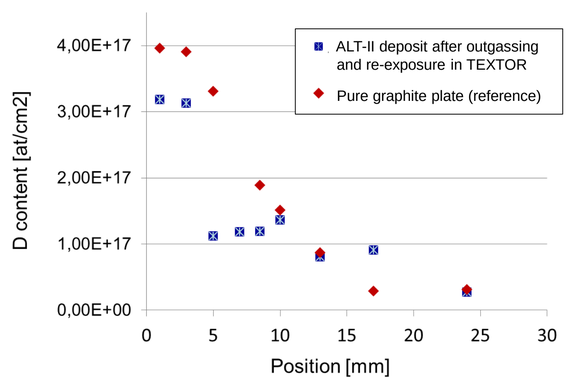
Results: Nuclear Reaction Analysis

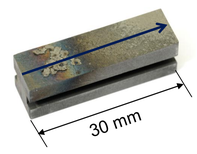
2 MeV ^{3}He beam; D(^{3}He,p)^{4}He

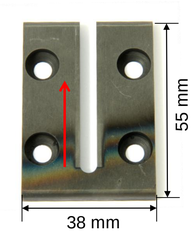
PADOS:

	D retention (at·cm^{-2})	remarks
Re-exposed deposit	4.7×10^{18}	broad depth distribution (> 7 μm)
Pure graphite	1.33×10^{17}	70% of fuel in the surface layer (1.5 μm)

TEXTOR:





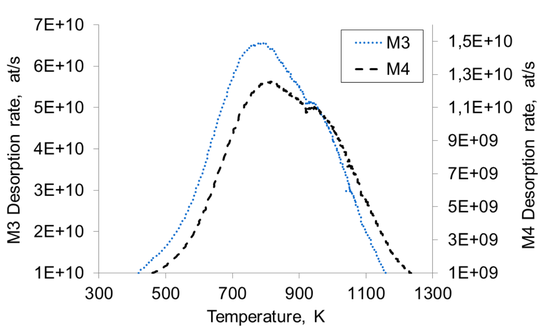


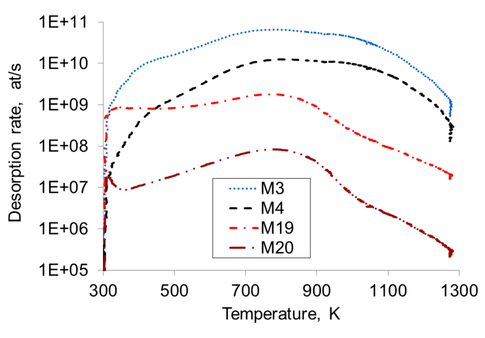
Deuterium retention is low due to poor contact between a deposited layer and the substrate

Results: Thermal Desorption Spectrometry

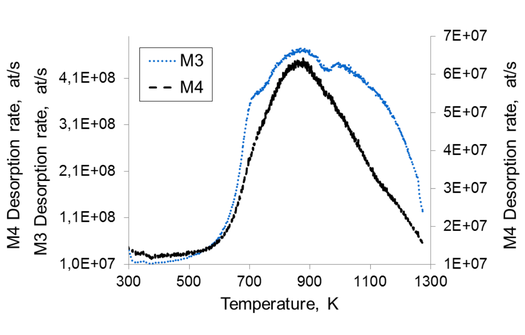
- Monitoring masses: M2 (H_2), M3 (HD), M4 (D_2), M19 ($HDO+CHD_3$), M20 (D_2O+CD_4)
- Heating rate 0.055 $K \cdot s^{-1}$

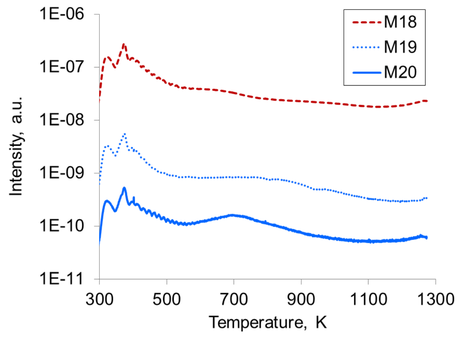
Original ALT-II deposit:



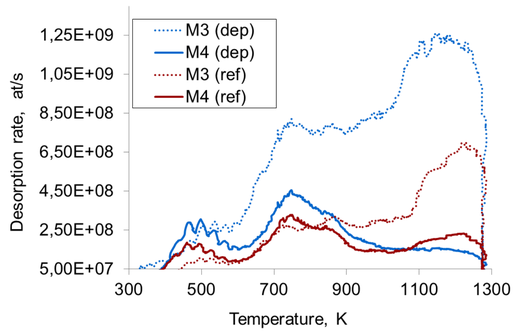


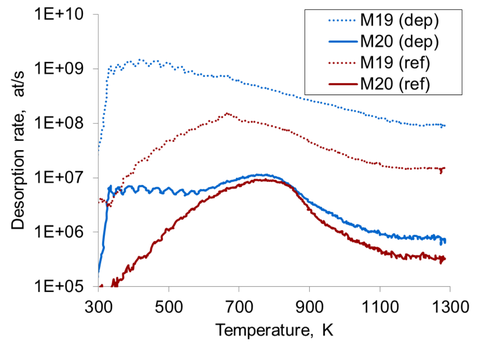
Re-exposure in TEXTOR:





Re-exposure in PADOS:





- Water vapour is easily adsorbed by deposits and isotope exchange leads to HDO and D_2O
- Temperature above 600 K are needed in order to remove hydrocarbons (CHD_3 and CD_4) efficiently

Summary

- Annealing at high temperatures (up to 1273 K) enhances layer brittleness leading eventually to detachment of co-deposits.
- Deuterium depth distribution measured with NRA in re-exposed deposits is broad (6 μm) in comparison to the distribution in fresh graphite (< 1.5 μm) used as reference material.
- The measured values of the fuel retention in the re-exposed deposits are 30 to 40 times lower than in the pure graphite, showing that the fuel re-absorption does not lead to an immediate re-saturation of deposits. This may be partly explained by the detachment of the original deposits during the outgassing procedure.
- Desorption characteristics (M3, M4) for the original co-deposit and after repeated exposure in TEXTOR are the same, whereas exposure in PADOS results in several binding states..
- All re-exposed deposits adsorb large amount of water vapor. One observes the presence of HDO and D_2O probably attributed to isotope exchange.