MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK

Wendelstein 7-X

O4: Development of wall conditioning procedures

D12: Condition walls to enable plasmas with high density gradients necessary for high performance

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EUROfusion

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Overview

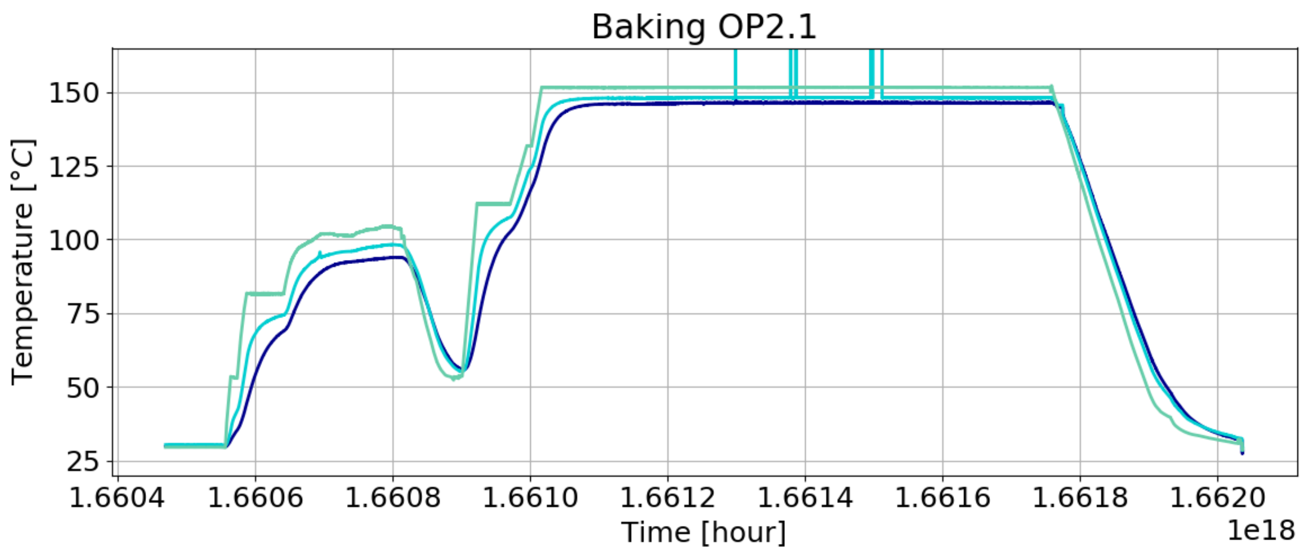
Wall conditioning enables

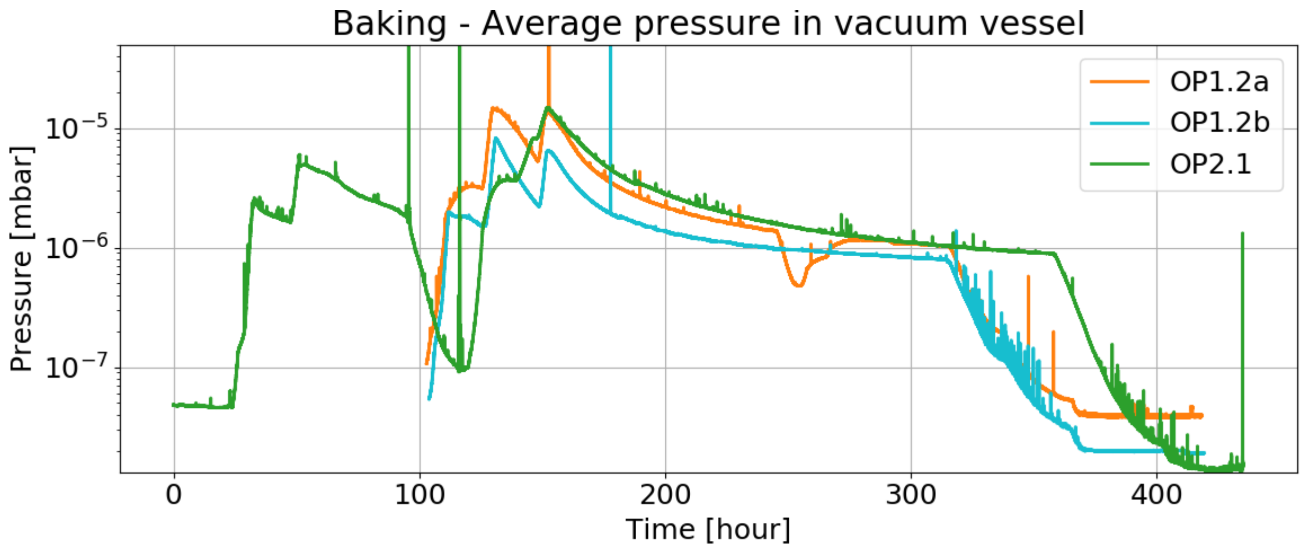
- longer $(> 500\ ms)$, high density $(> 10^{20}\ m^{-2})$ plasmas
- reduced impurity content and outgassing for improved density control and plasma performance

Outline

- Baking
- Glow Discharge conditioning
- Boronisation
- Electron Cyclotron Wall Conditioning (ECWC) with pulse trains
- ECWC with ultra short pulses
- Ion Cyclotron Wall Conditioning (ICWC)

Baking of the plasma vessel



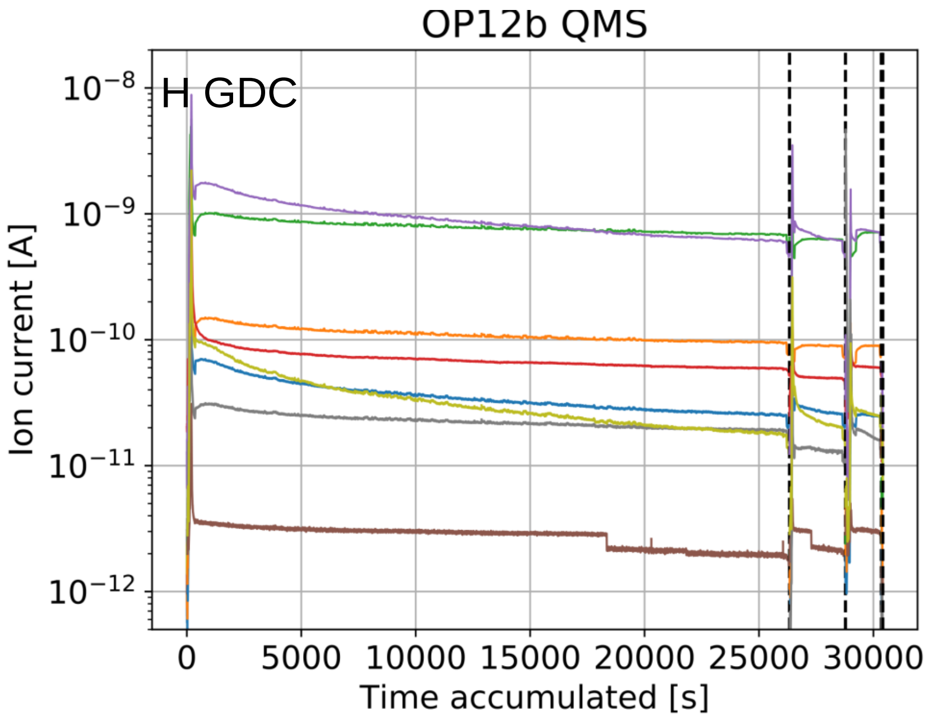


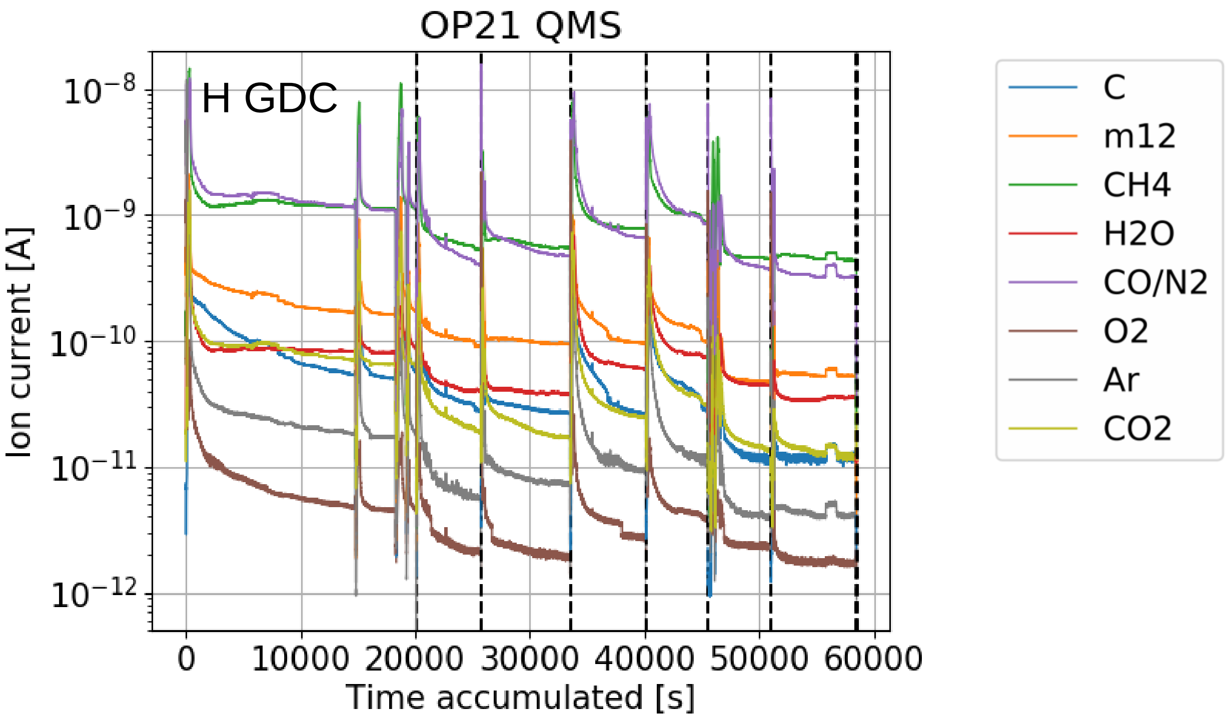
- Conducted as planned, some problems with heating up that have been overcome
- Pressure curve follows similar dependence as previous campaigns ($\approx t^{-0.7}$)
- Lower final pressure (with longer plateau time)

OP2.2/2.3

- Following the same working scheme

Glow Discharge conditioning





- Less accumulated H GDC before first plasma than in OP1.2b
- Plasma pulse length limited in the beginning of OP2.1 with too high impurity content in the walls. Subsequent H GDC-s improved this, as expected

OP2.2/2.3

- Similar scheme of long accumulated H GDC time, with He GDC afterwards, as well as in the morning of operation days when necessary
- Suggestion: longer H GDC before first commissioning plasma

Boronisation - Overview

- Boronisation conducted every $\approx 3000\ s$ of plasma operation
- Layer thickness estimation with $\rho_l = 2.4\ g\ cm^{-3}$
- Boronising scheme of OP1.2b resulted in sudden discharge termination
  → Parameters adjusted for stable discharge

- Stable discharge achieved with
  - $p < 8.5 * 10^{-3}\ mbar$
  - $I = 0.8\ A$
  - $H_2 - He$ cleaning discharge beforehand

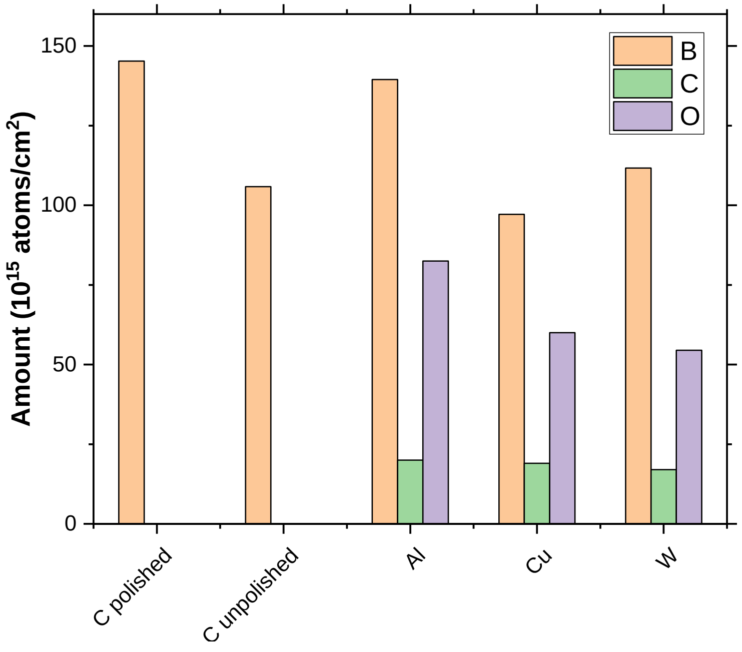
	OP2.1 5th	OP2.1 4th	OP2.1 3rd	OP2.1 2nd	OP2.1 1st
Accumulated active bor. phase	3:09 h	3:10 h	2:26 h	2:00 h	2:20 h
Total inj. gas during bor. phase	48 bar*l	38.08 bar*l	≈ 35.4 bar*l	≈ 6 bar*l	≈ 46 bar*l
Number of discharges	1	1	5	1	5
Estimated layer thickness	17.01 nm	13.56 nm	12.6 nm	2.14 nm	16.37 nm

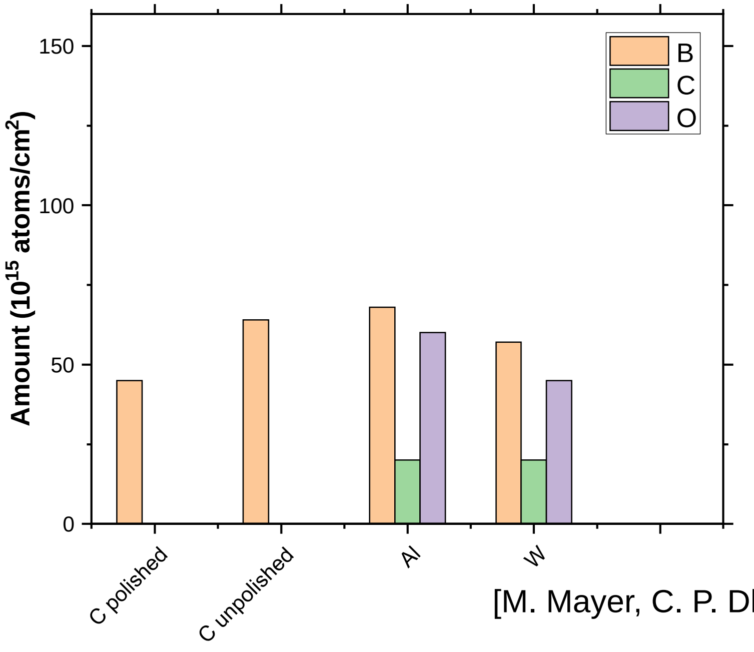
	OP1.2b 3rd	OP1.2b 2nd	OP1.2b 1st
Accumulated active bor. phase	5:00 h	5:30 h	3:30 h
Total inj. gas during bor. phase	51.25 bar*l	67.6 bar*l	29.4 bar*l
Estimated layer thickness	18.28 nm	24.12 nm	10.5 nm

Boronisation – Sample exposure

Conducted experiments

- Using the Multi-Purpose Manipulator (MPM) [C. Killer, D. Cipciar]
- During 3rd and 4th boronisation
- Samples: C (fine-grain graphite) polished and unpolished, Al, Cu, W
- Evaluation using Nuclear reaction analysis (NRA)





[M. Mayer, C. P. Dhard]

Results of analysis

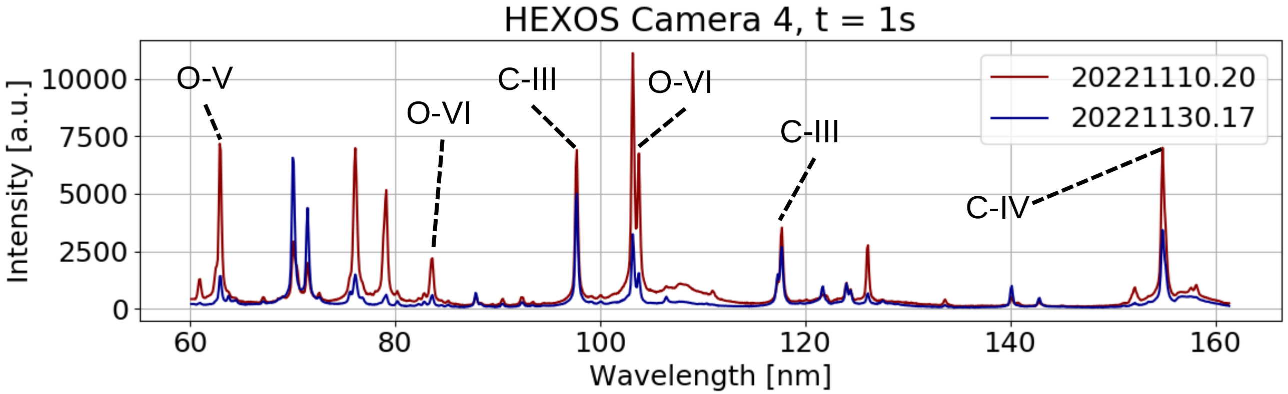
- Boron deposition:
  $10 - 15\ nm$ (3rd), $5 - 7\ nm$ (4th)
- No material dependence
- O and C on sample probably from air exposure
- Question: lifetime of boron layers?

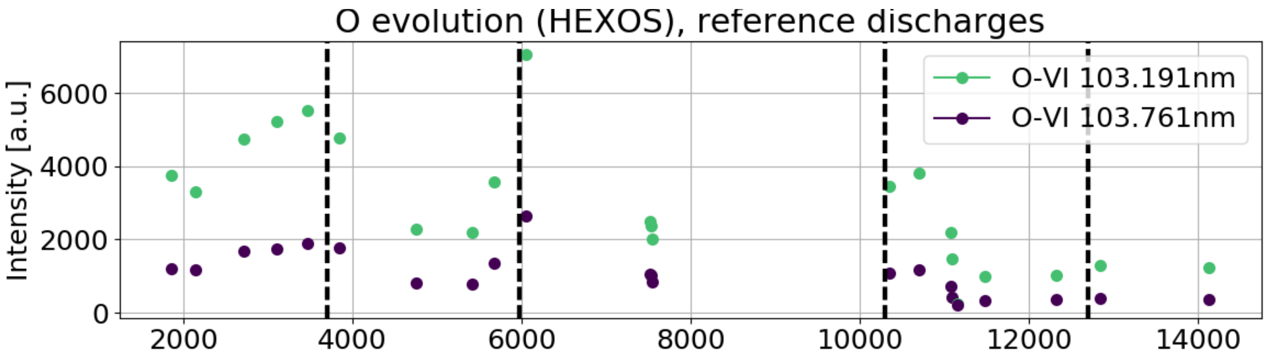
Further experiments in OP2.2/2.3

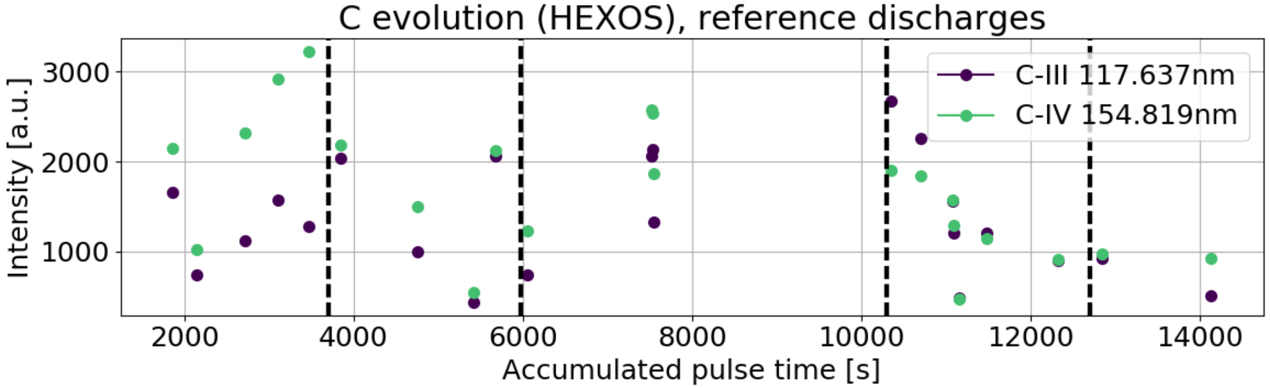
- Further sample exposure is desirable
- To provide individual measurement of added boron layer
- To extend the analysis
- Sample exposure during GDC

Boronisation – Effects on plasma

- After 1st boronisation:
  - Density limit increased due to the decreased impurity radiation at the edge, operation above $10^{20}\ m^{-2}$ possible
  - Reduced O and C levels
- Further boronisations needed to bind and coat the O and C redistributed from the strikelines.





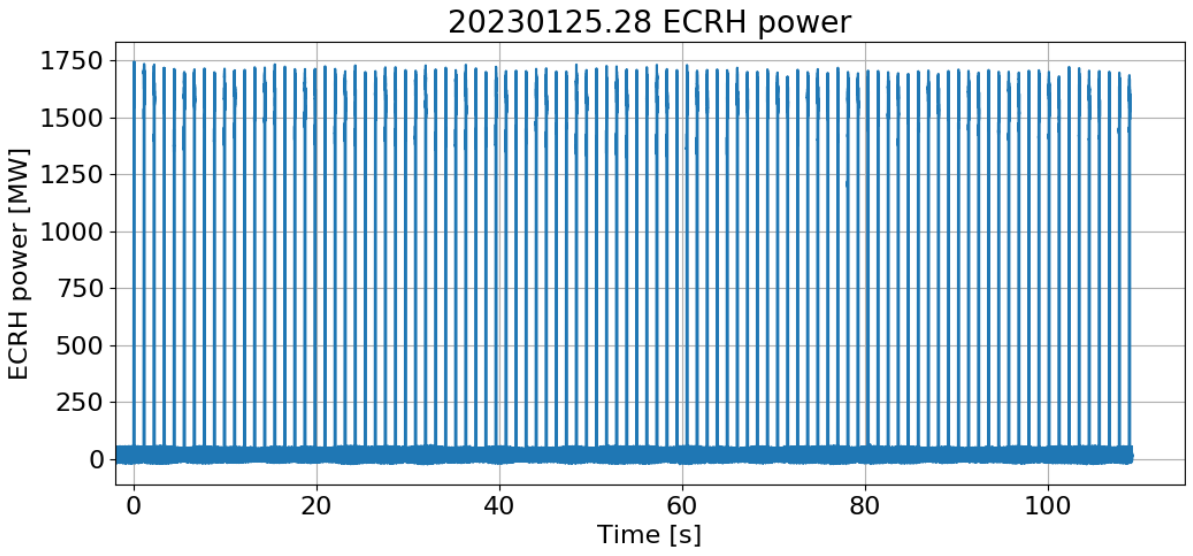


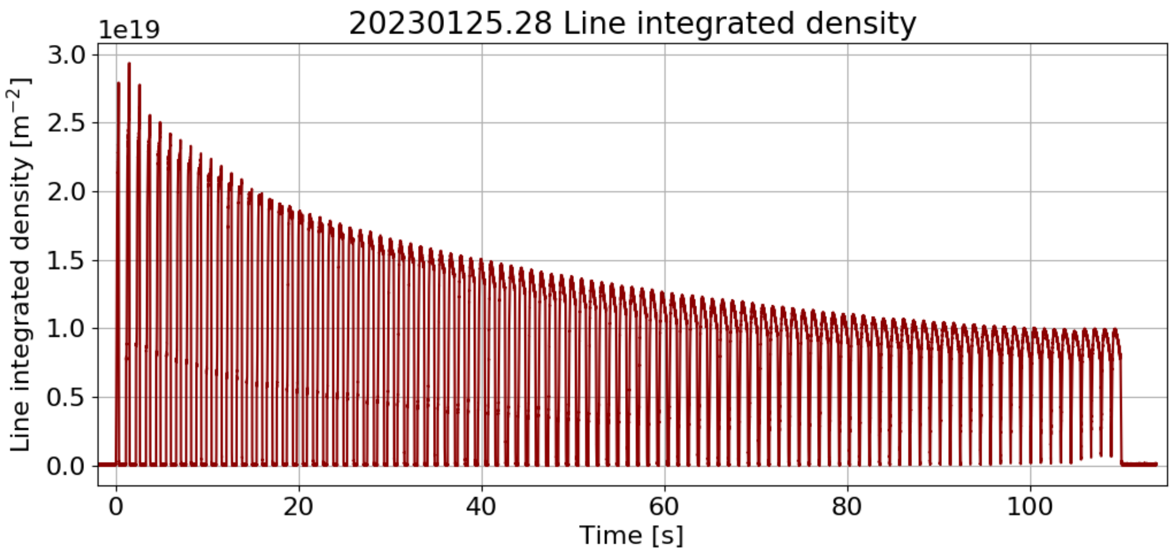
For OP2.2/2.3

- Continue with same parameter range for boronising discharge
- Frequency and gas input of boronisations to be revised?
- No drop in plasma performance after a weak boronisation
  - Desired gas input: $35 - 48\ bar * l$
  - Gas input during 2nd: $6\ bar * l$

ECWC with pulse trains

- Used when the wall is saturated with fuelling gas and density control is lost
- H or He pulse trains depending on fuelling gas to minimize dilution
- Succesful pulse train when line integrated density reached $< 1 - 1.5 \ * 10^{19} \ m^{-2}$ [O. Grulke]
- Pulse train optimisation to make the train as short as possible with maximum efficiency to save time for the main physics program [A. Goriaev]
    - Systematic study on pulse length, pulse interval, input power, gas prefill, nr of pulses

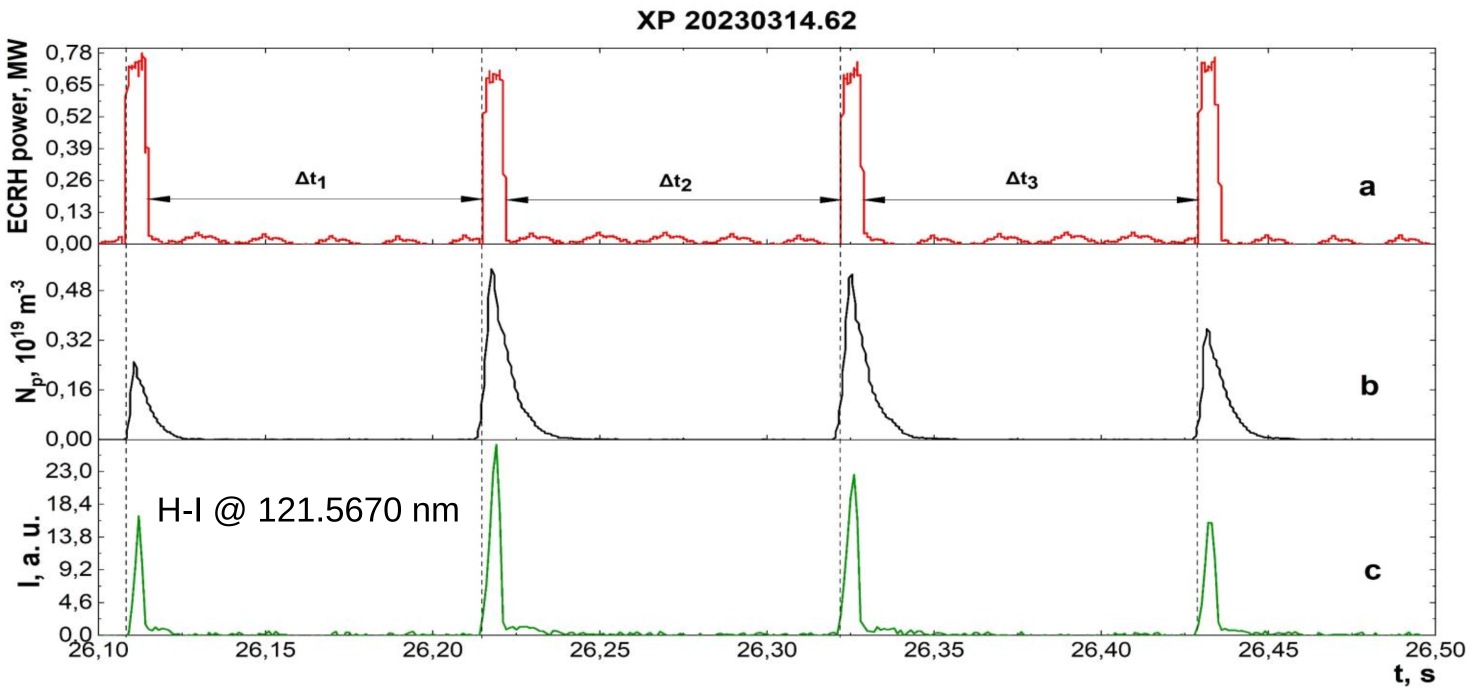




OP2.2/2.3

- Follow similar working scheme
- Taking into account results of available systematic optimisation study

ECWC with ultra short pulses



H_2 $P_0 = 1.1\times10^{-3}$ Pa, $\Delta t_1 \approx \Delta t_2 \approx \Delta t_3 \approx 100$ ms

[V. E. Moiseenko, Y. V. Kovtun]

Conducted experiments

- High energy H neutrals (avoid full gas ionization)
- Provide plasma neutralization through recombination

Results

- Ultra-short pulses produce partially ionized plasma, hot electrons are in minority
- Pulses are stable in series
- Plasma decay time is shorter than the particle confinement time

Further experiments in OP2.2/2.3

- To do pulse length – gas pressure optimization
- To see impact on wall conditions (removing particles from surface) with the developed optimum scenario

ICWC

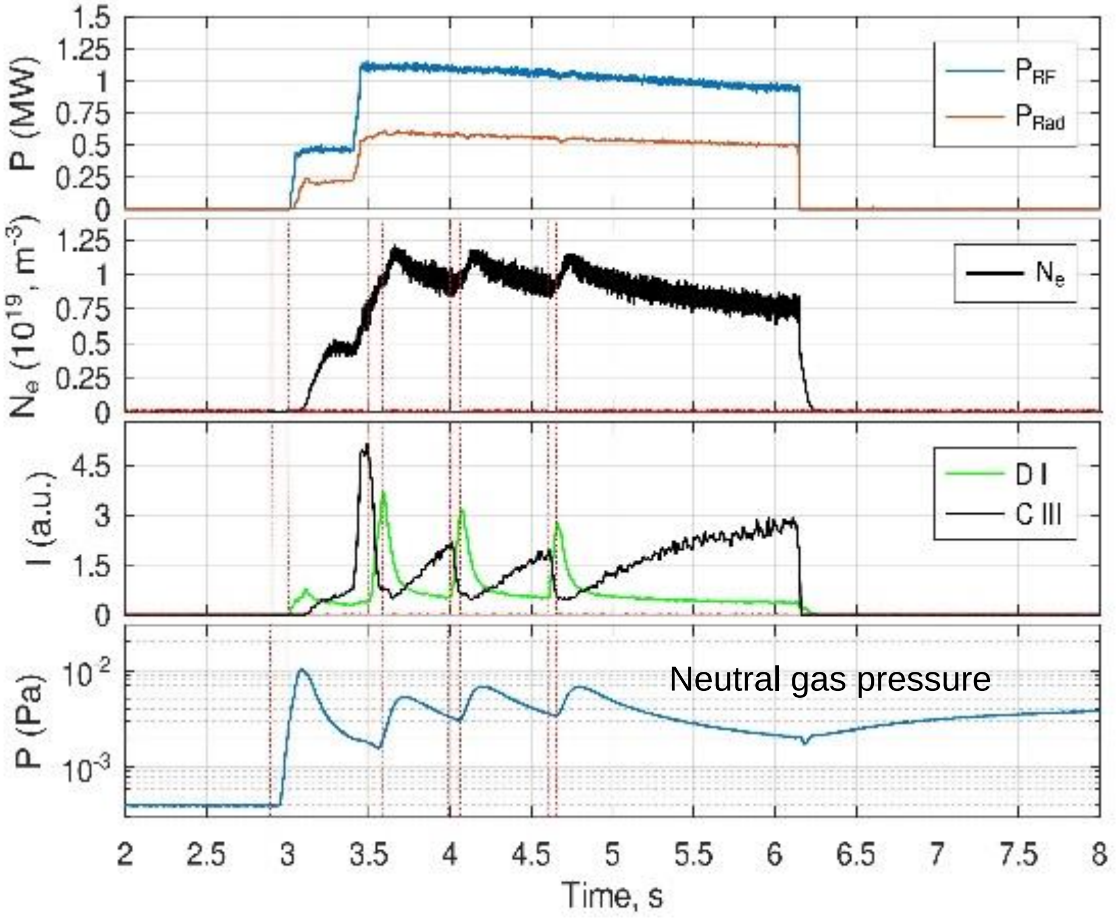
Experiments

- Low magnetic field ($0.1 - 0.5\ T$), high density ($10^{18}\ m^{-3}$), low temperature ICRH discharges
- Suitable for wall conditioning (removing particles from surface)
- LHD experiment demonstrates availability of these type of discharges (reliable gas breakdown)
- At W7-X, the first attempt to produce a similar discharge ($\omega > \omega_{ci}$ regime, but still low density) demonstrated the principal possibility

Further experiments in OP2.2/2.3

- To further explore this regime and its wall conditioning properties

#184846 (LHD)



Dashed dotted lines: switch -on and -off gas puff. B_0 = 0.5 T.

[V. E. Moiseenko, Y. V. Kovtun]

Summary

Base wall conditioning: conducted as planned, to be repeated in OP2.2/2.3

- **Baking**
- **Glow discharge**
- **Boronisation** - frequency and gas input of boronisations to be discussed

Wall conditioning during plasma operation with magnetic field:

- **ECRH pulse trains** worked reliably, systematic study to be done, to be repeated in OP2.2/2.3
- **Ultra short ECRH pulses** demonstrated, to be tested for wall conditioning in OP2.2/2.3
- **Low magnetic field ICRH pulses** demonstrated, to be tested for wall conditioning in OP2.2/2.3

D12: Condition walls to enable plasmas with high density gradients necessary for high performance

- Limited NBI operation limited the availability of these high performance plasmas
- Aim to maximize the pumping capacity of the wall (instead of acting like an uncontrolled source)
- ECRH pulse trains are a good start for this aim
- The efficiency of other desaturation methods (e.g. ultra short ECRH blips, ICWC) need to be systematically explored in combination with pulse trains

Backup - Estimation of thickness of boron layer

$$l = f_{cr} F_{prec} n_{mol} \frac{M_B Q_{inj}}{V_m \rho_l S}$$

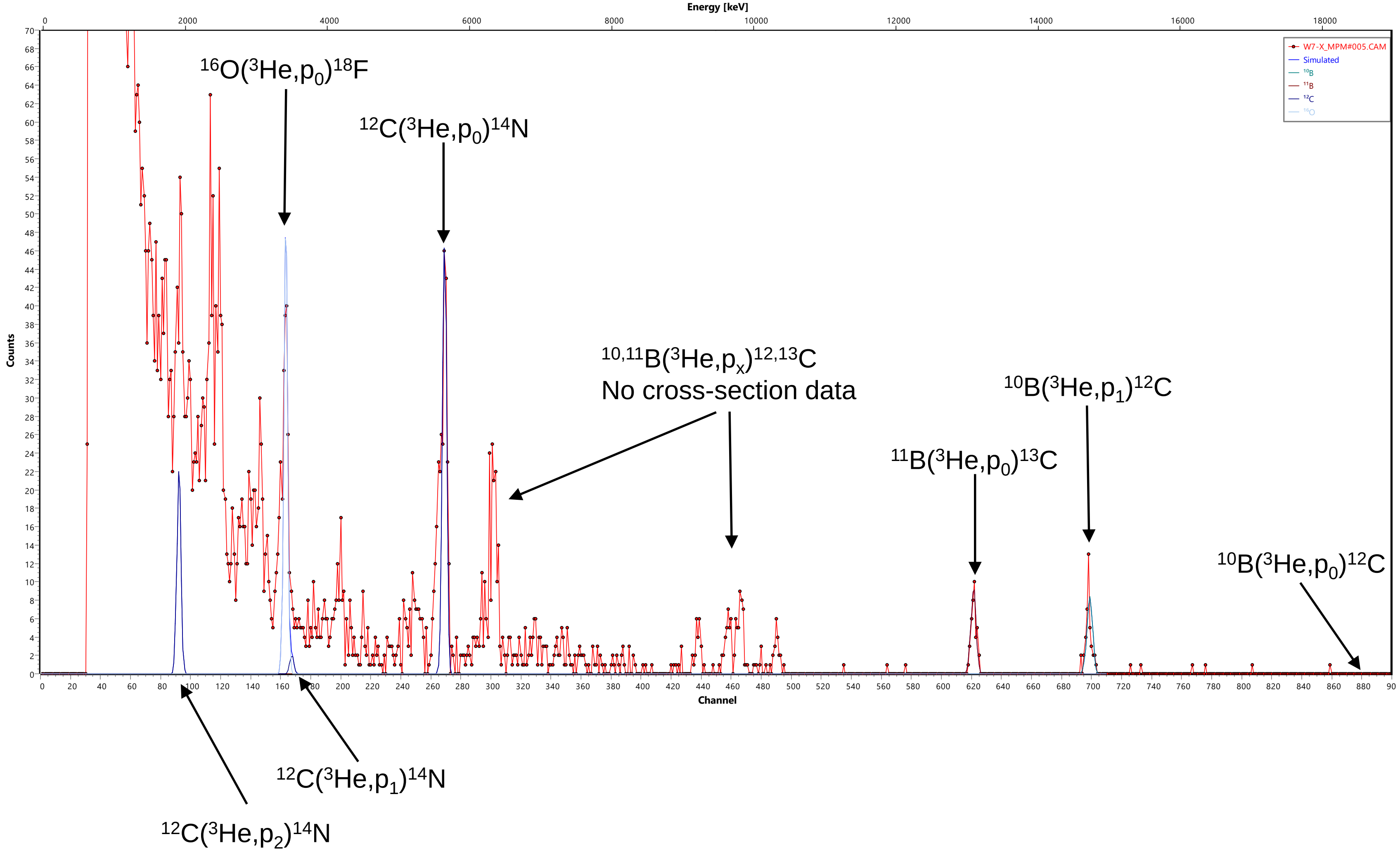
- Assuming all injected boron gets deposited
- Not taking into account lower decompising rate in the beginning of boronising phase

- Cracking factor: $f_{cr} = 1$
- Fraction of the precursor gas in the mixture: $F_{prec} = 0.1$
- Number of B atoms in a precursor gas molecule: $n_{mol} = 2$
- Molar mass of B: M_B
- Amount of injected gas during boronising phase: Q_{inj}
- Molar volume of ideal gas: V_m
- Average density of an amorphous B layer: ρ_l
- Total area of coated PFCc: S

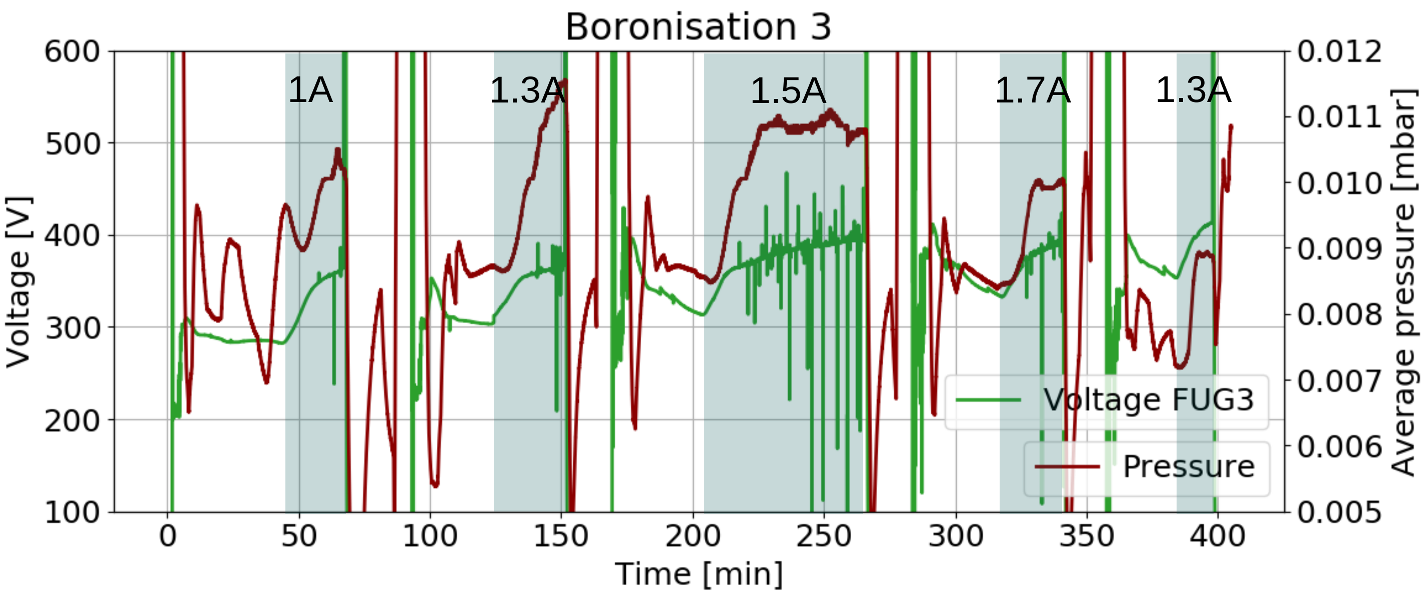
Backup - Impurity levels during the boronising discharge

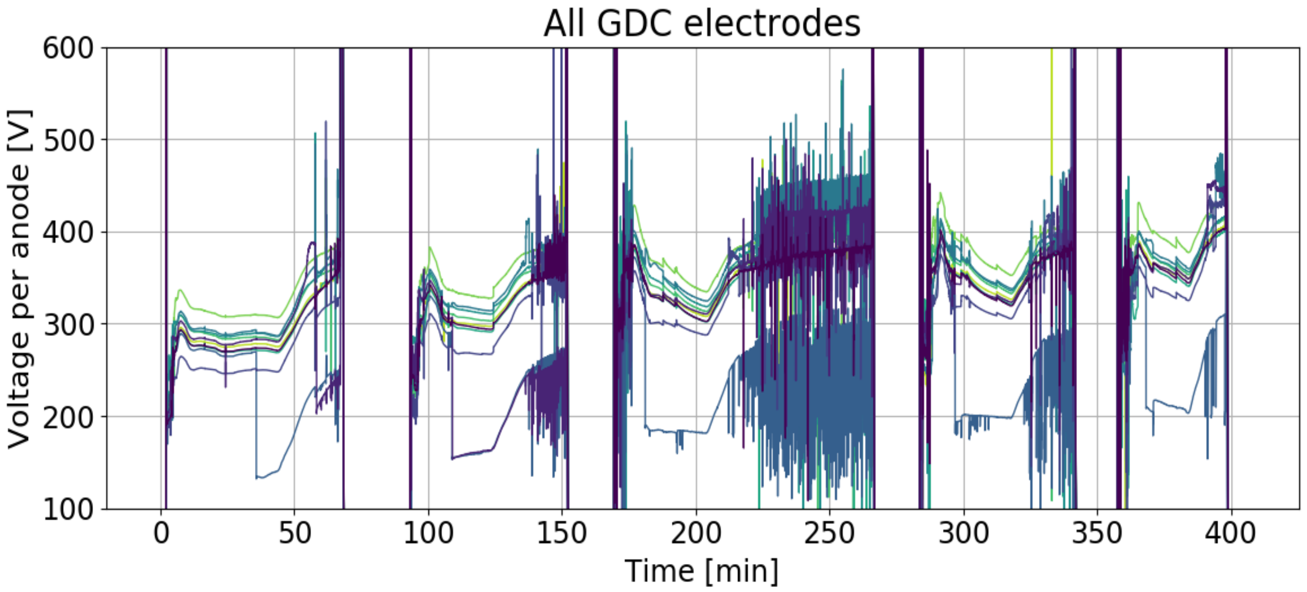
Nuclear reaction analysis (NRA)

- 3 MeV $^{3}He^{+}$
- Reactions:
  $^{10,11}B(^{3}He,p_{x})^{12,13}C$
  $^{12}C(^{3}He,p_{0,1,2})^{14}N$
  $^{16}O(^{3}He,p_{0})^{18}F$
- 2 detectors at 135°
  - 30 msr, good resolution
  - 80 msr, medium resolution



Backup - Optimising the boronising discharge





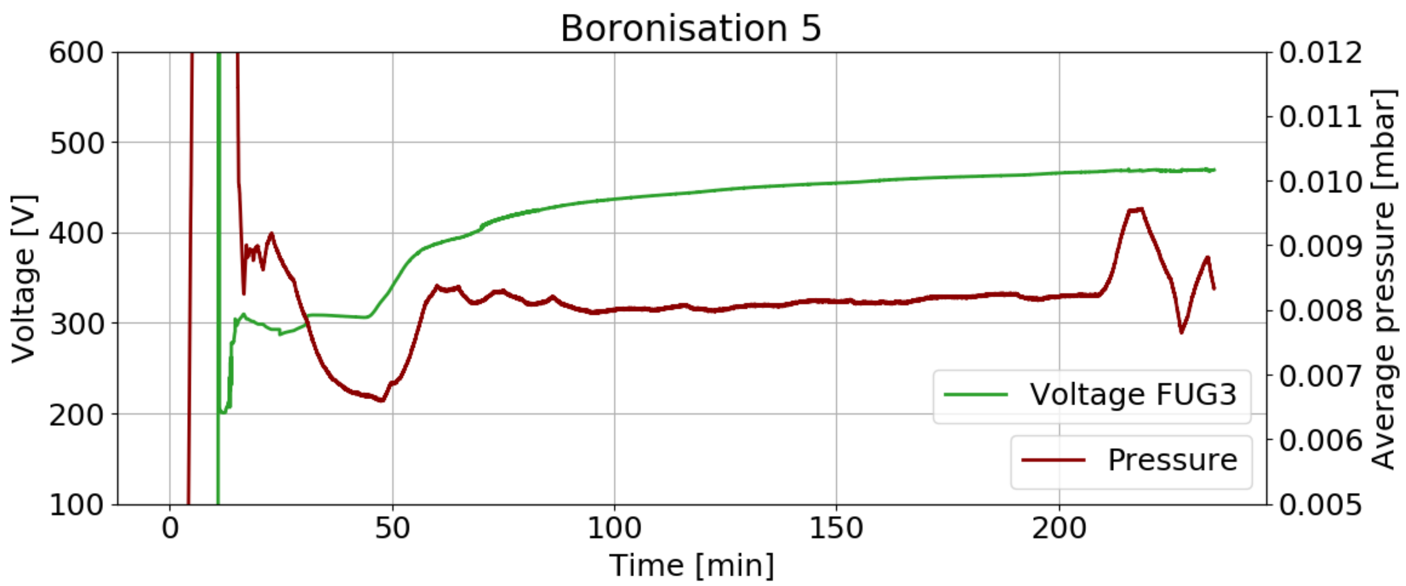
- Fluctuations in electrode voltage, downspikes in floating voltage

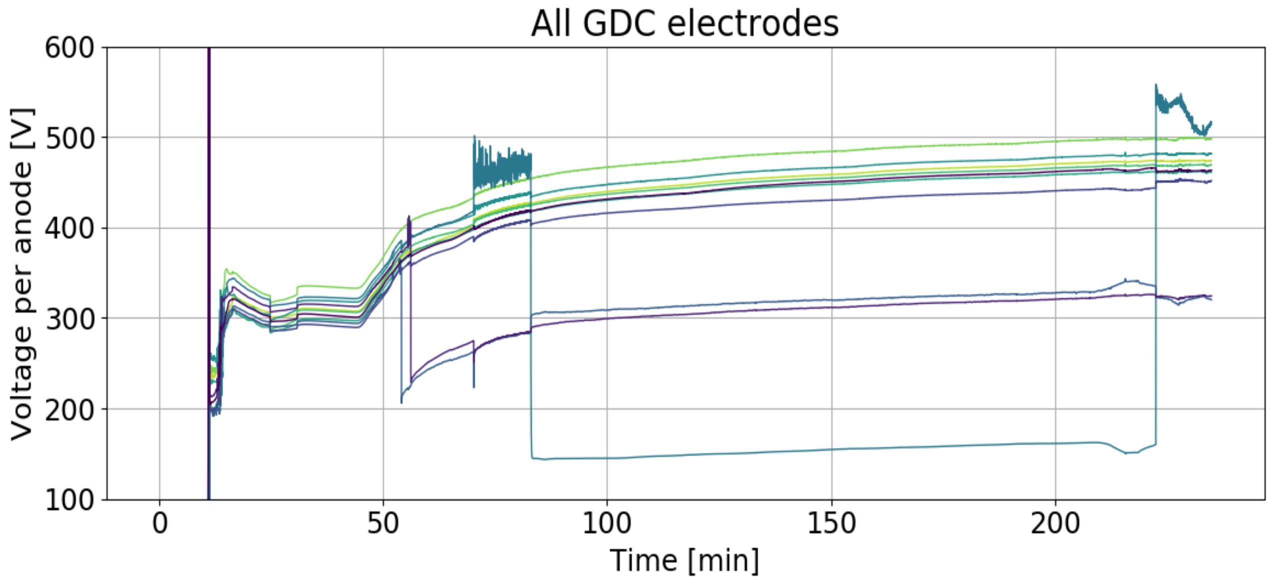
  → Indicates impurity presence [AUG]

- Increased fluctuations at $p > 10^{-2}\ mbar$

- $U - I - p$ characteristic done with $H_2 - He$ mixture glow discharge to simulate boronising discharge

Backup - Optimising the boronising discharge



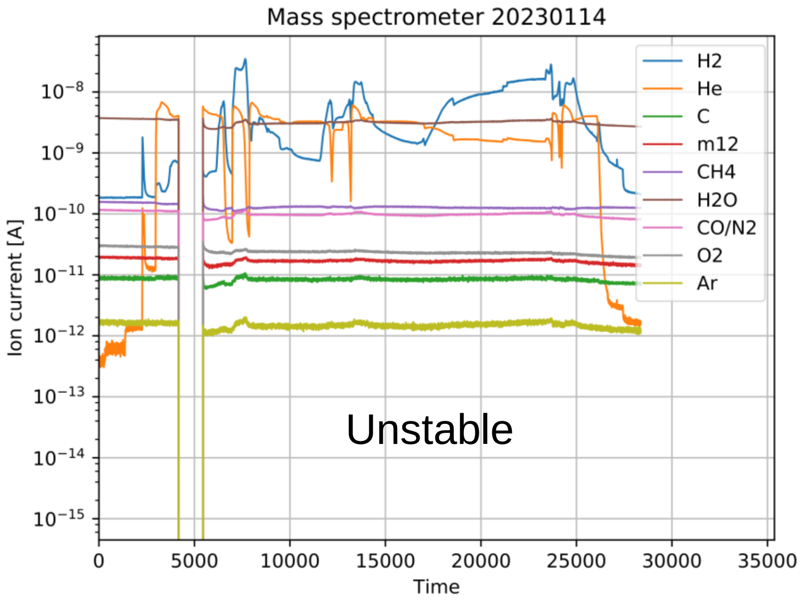


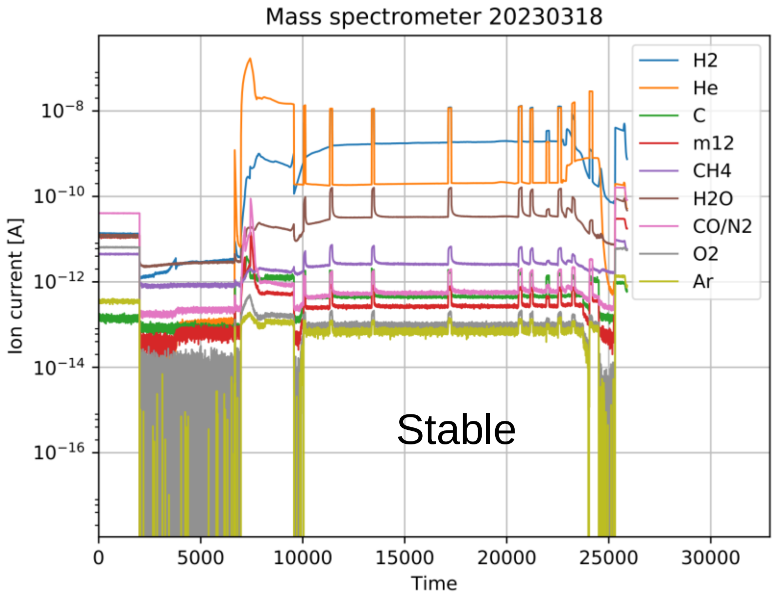
- Adjusted parameter range:
  - $p < 8.5 * 10^{-3}\ mbar$
  - $I = 0.8\ A$
- Cleaning effects of $H_2 - He$ glow discharge possibly contributed

  → Repeated for last boronisation

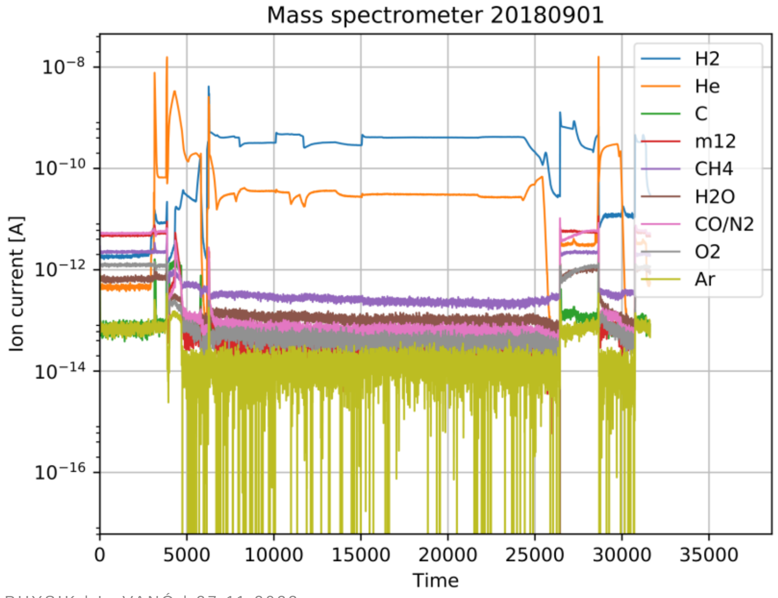
Backup - Impurity levels during the boronising discharge

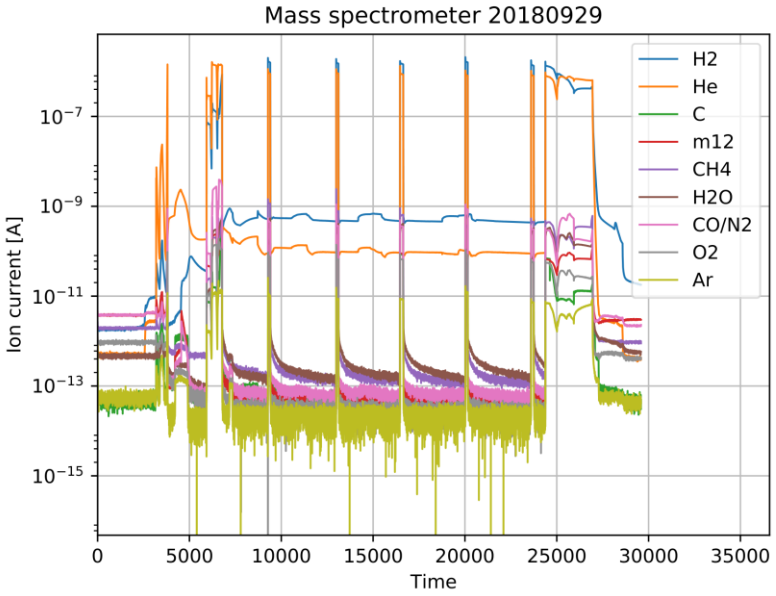
OP2.1





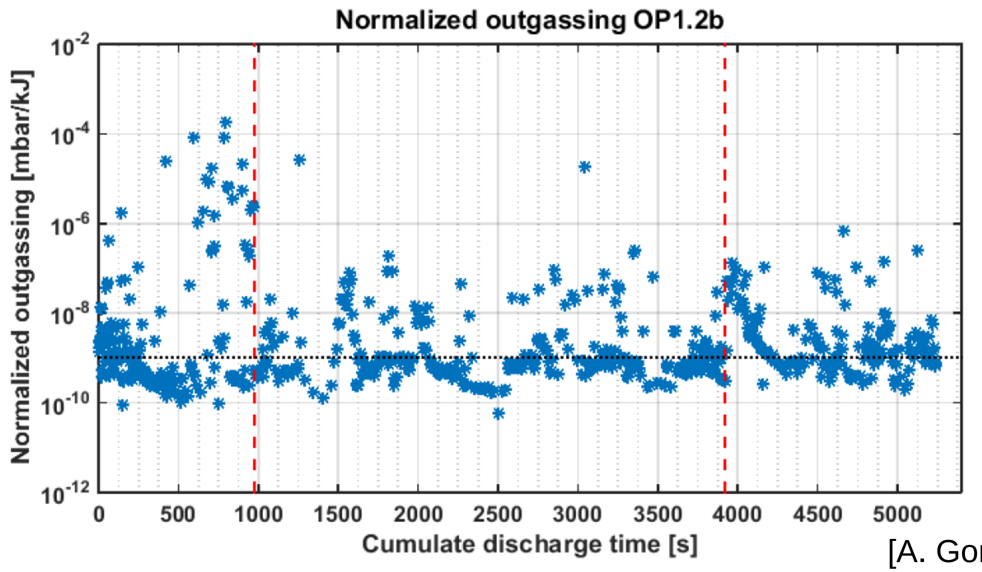
OP1.2b



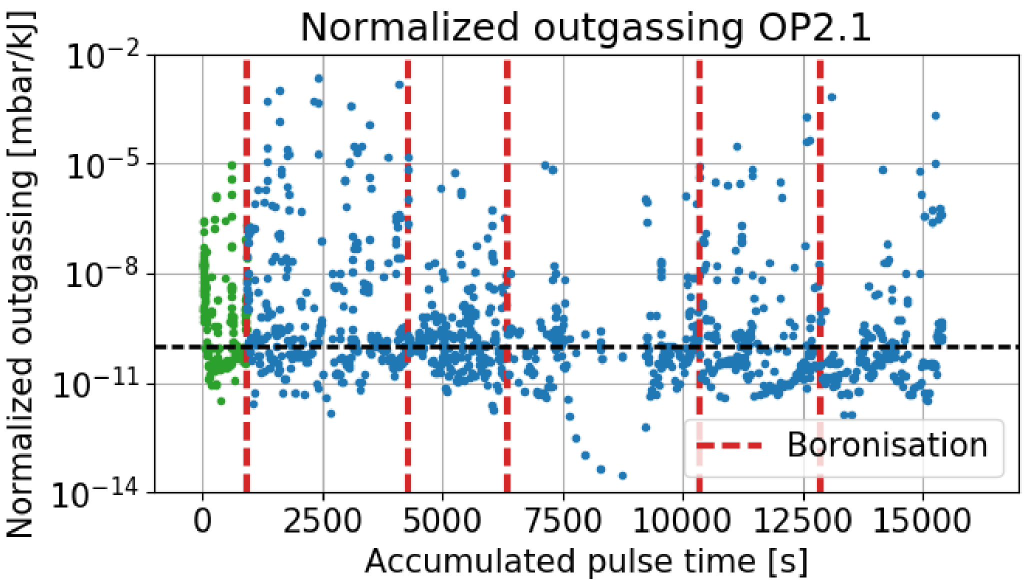


Backup - Outgassing trend

- No significant effect on outgassing trend from boronisations, high scattering remains
- Baseline lower than in OP1.2b due to actively cooled divertor and possibly to change in divertor material
- Not trend observable in impurity outgassing level from ref. discharges



[A. Goriaev]



Backup - Proposals

Base wall conditioning:

- Agor_006: Evaluation of wall conditioning evolution throughout experimental campaign via reference discharges
- Agor_004: Initial wall conditioning for OP2.1 and OP2.2 (baking and glow discharge)
- Dhard_026: Boronization of W7-X plasma-facing components during OP2.1 and OP2.2d
- Erwa_007: Comparison of wall condition before and after boronization
- Mam_002: Boron deposition during boronizations (sample exp.)
- Dhard_014: Exposure of W/W-alloy and other material samples during WC using mid-plane manipulator (sample exp.)
- Mam_003: Carbon erosion during glow discharge cleaning (sample exp.)
- Suma_006: Effects of wall conditioning discharges on plasma facing materials in W7-X (sample exp. From Japan)

Backup - Proposals

ECWC and ICWC:

- Agor_005: Electron Cyclotron Wall Conditioning development (pulse trains)
- Din_018: Electron Cyclotron Wall Conditioning (ECWC) development (pulse trains)
- Dhard_016: Tests and optimization of Ion Cyclotron wall conditioning (ICWC)
- Din_019: Scenarios of pulsed ECRH and ICRH wall conditioning in hydrogen (ultra short ECRH blips, low B ICRH pulses)
- Moiseenk_002: Scenarios of pulsed ECRH and ICRH wall conditioning in hydrogen
- Dhard_025: Optimization of synergy between Ion Cyclotron and Electron Cyclotron wall conditioning in W7-X (piggyback)

- Roblu_001: Classification of conditioning effectiveness utilizing particulate injections
- Roblu_002: Boron particulate injection into alternate magnetic configurations for material integration assessment