Surface Conditioning Techniques and Their Effect in NSTX

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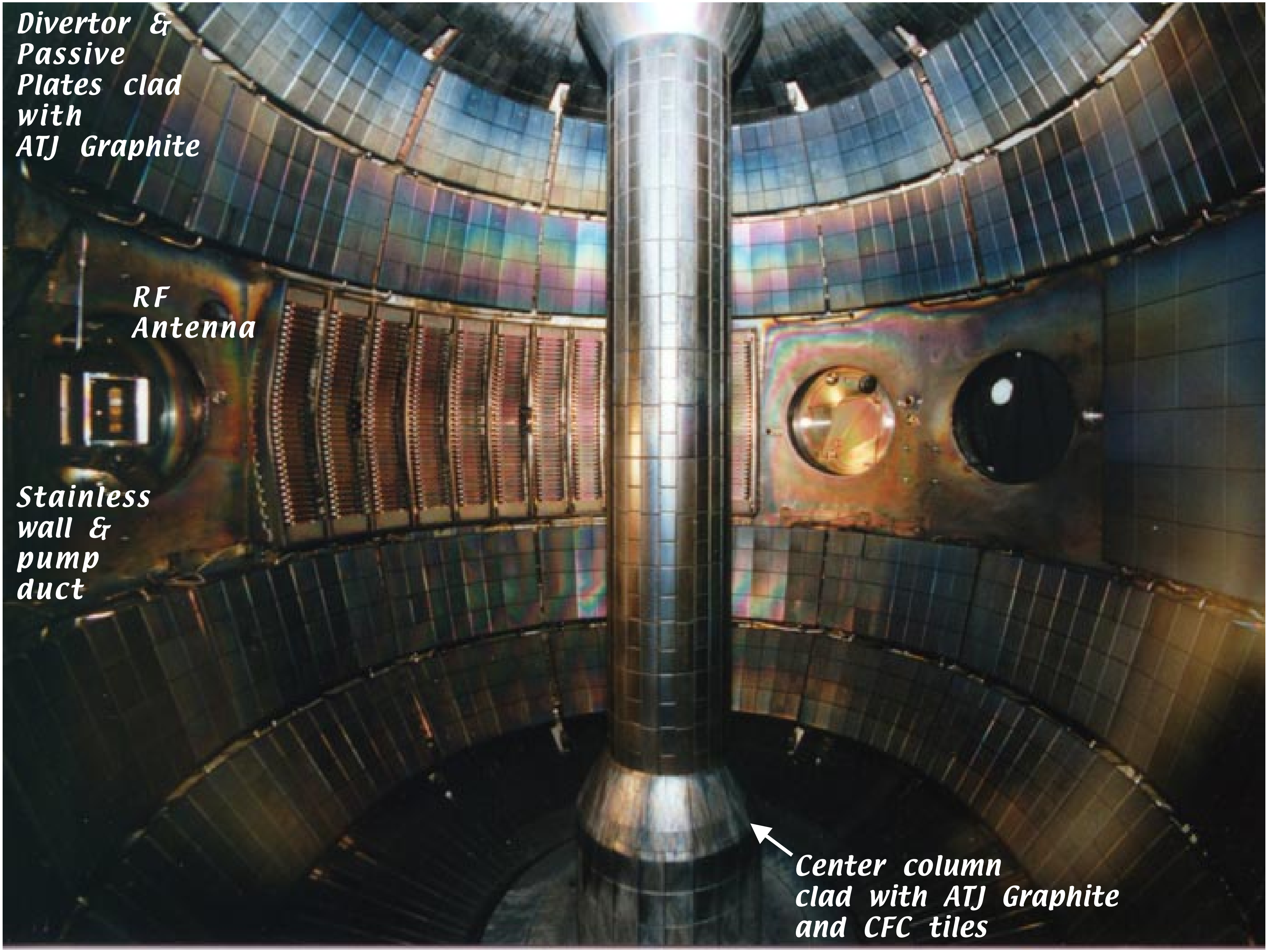
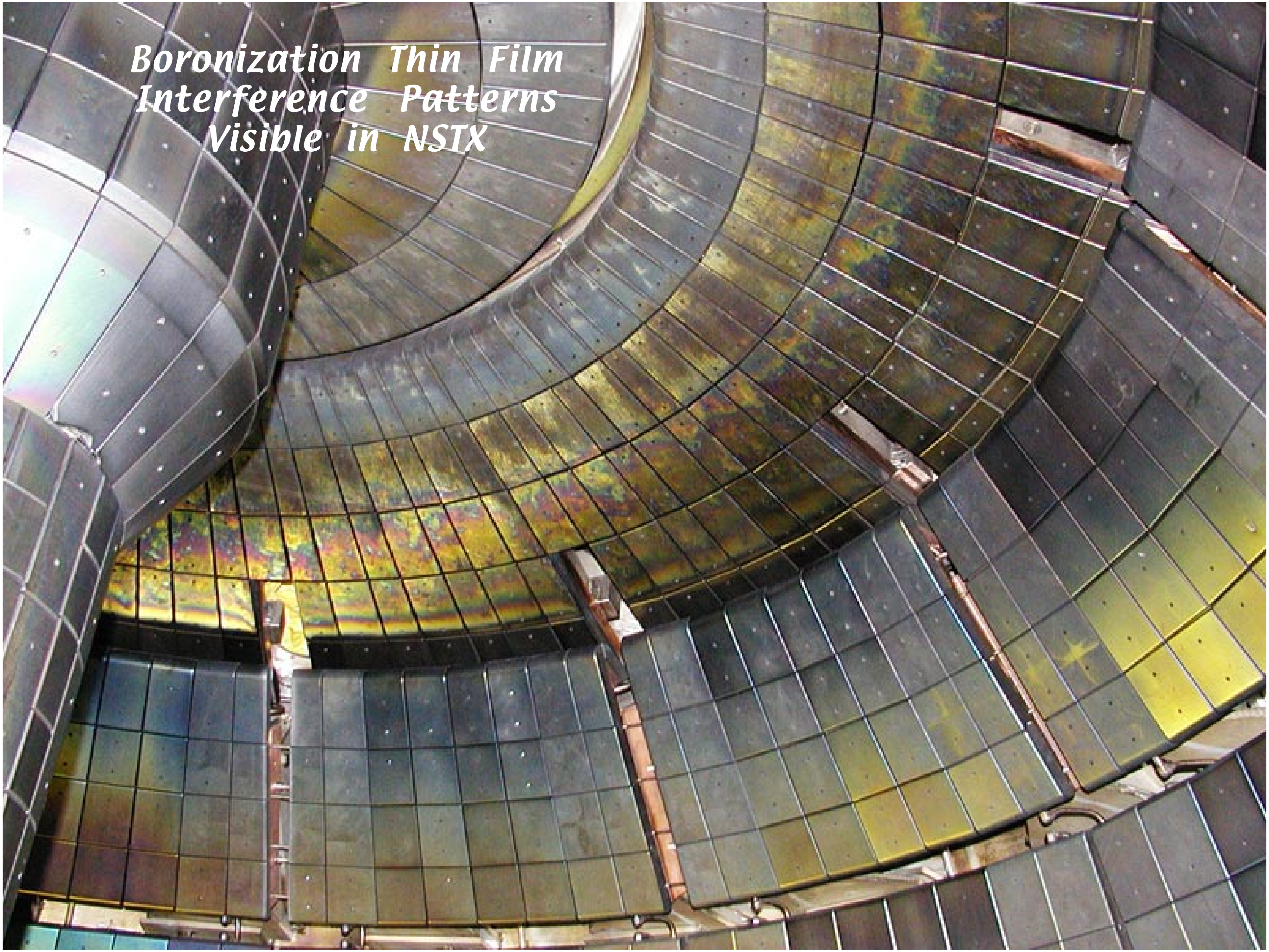

Divertor & Passive Plates clad with ATJ Graphite
RF Antenna
Stainless wall & pump duct
Center column clad with ATJ Graphite and CFC tiles

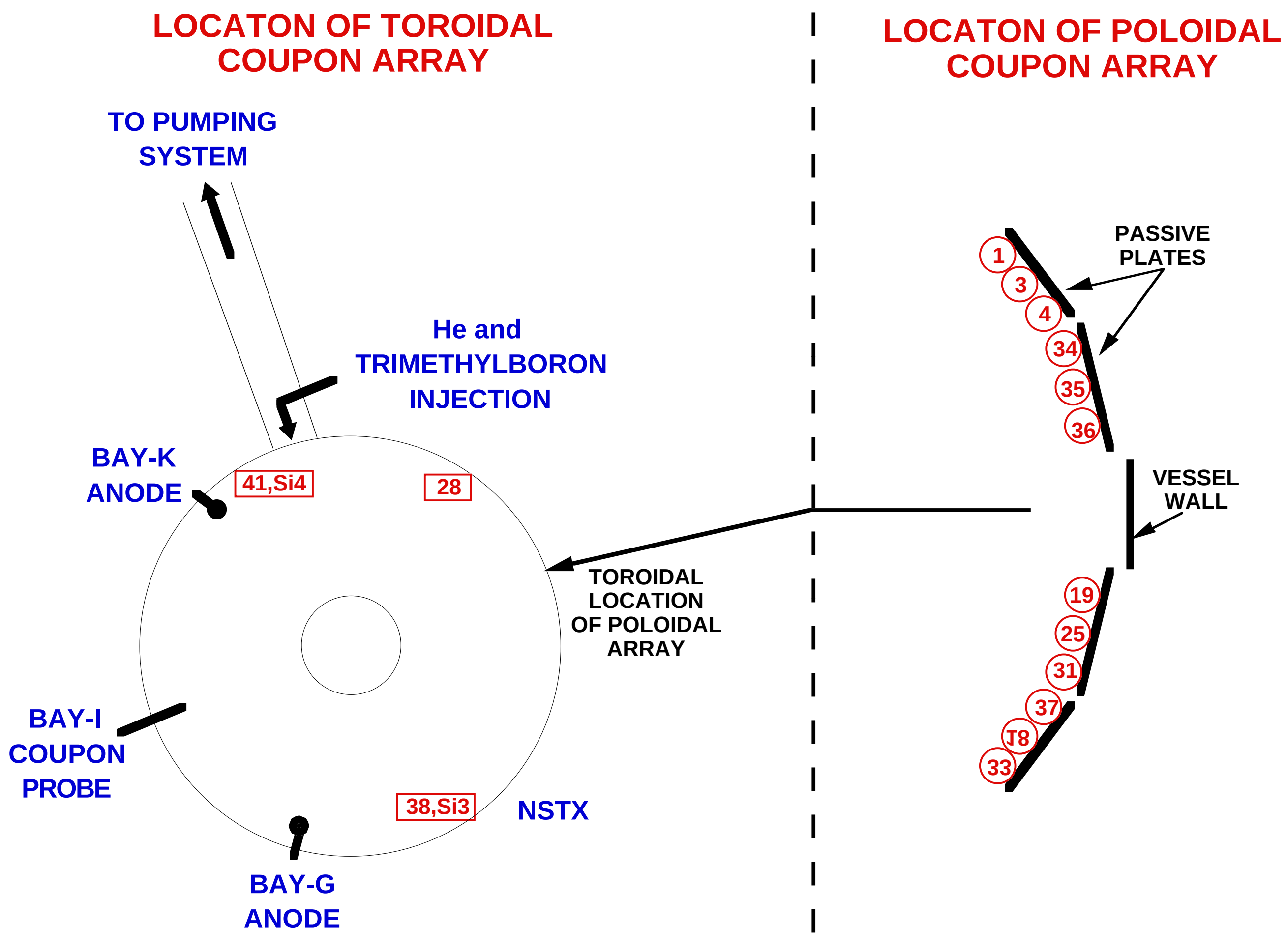
Overview

- **Wall conditioning has proved to be the key to achieving high performance in fusion devices.**
  - Reservoir of particles in the wall surface exceeds that in the plasma by several orders of magnitude
  - Hydrogenic and impurity influx needs to be controlled to permit density control and to minimize radiative losses. Wall conditioning techniques such as baking and helium discharge cleaning (HeGDC) deplete the surface of trapped hydrogen
  - Wall coatings modify the properties of plasma facing surfaces and trap impurities.

- **On NSTX we use:**
  - daily and inter-discharge HeGDC
  - after pumpdown, 350°C PFC bake-out aided by D_2GDC and HeGDC
  - periodic boronization using deuterated trimethylboron in HeGDC
  - plasma boronization: fueling deuterium discharges with He-trimethylboron mixture and pure trimethylboron.


Boronization Thin Film
Interference Patterns
Visible in NSTX

Boron deposition monitored by witness coupons



Ion beam analysis of coupons removed after 9 boronizations and the associated discharges:

Boron areal density was measured via the $^{11}B(^{1}H,\ ^{4}He)^{8}Be$ nuclear reaction with a 650 eV proton beam,

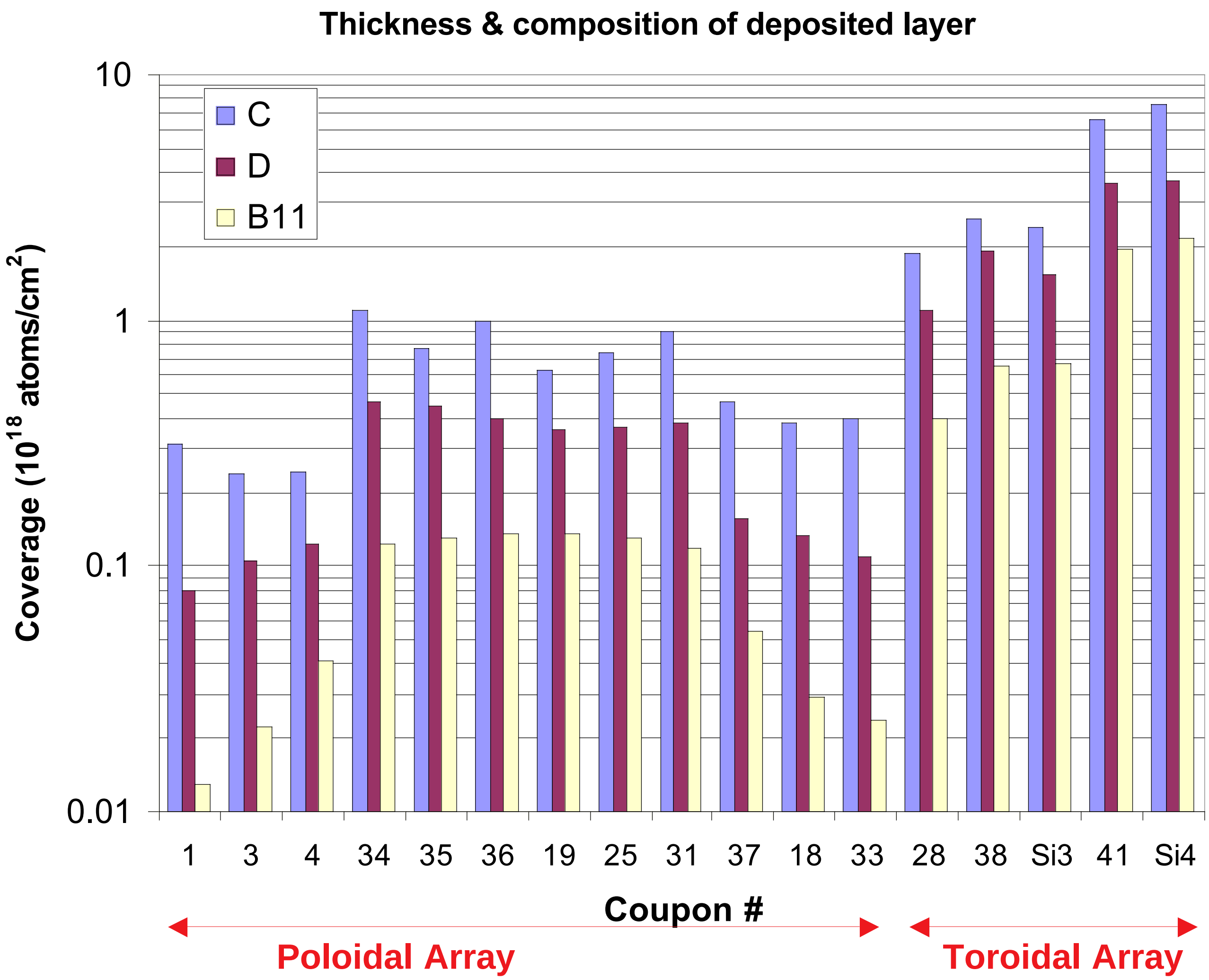
Deuterium by the $^{2}D(^{3}He,p)^{4}He$ reaction with a 700 keV ^{3}He beam

Carbon by Rutherford backscattering with a 1500 keV proton beam.

- Factor of 5 variation in deposition toroidally
- Factor of 6 to 9 variation in deposition poloidally

B/C ratio 1/3

D/(B+C) ratio 2/3

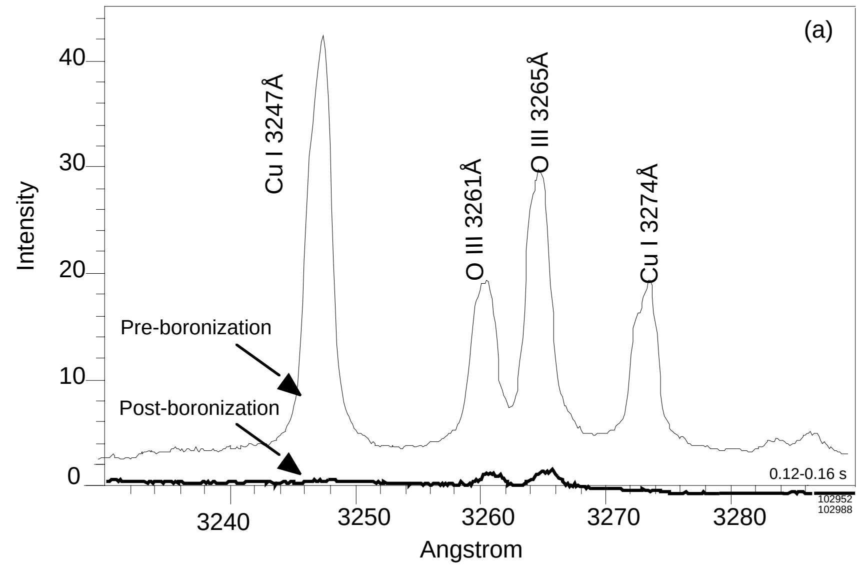


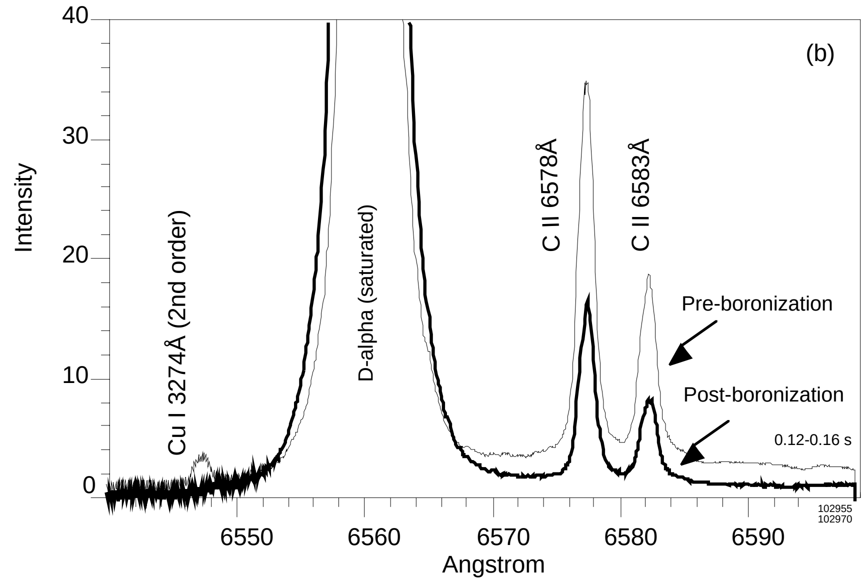
He GDC boronization of NSTX using deuterated trimethylboron (TMB) has significantly improved plasma performance

TMB has been applied 14 times using HeGDC (90%He,10%TMB), about every 2-3 operating weeks (~300-400 discharges).

Reference D_2 discharges following HeGDC/TMB showed:

1. *Factor of 15x reduction in O luminosity*
2. *Factor of 2 decrease in C luminosity*
3. *....*



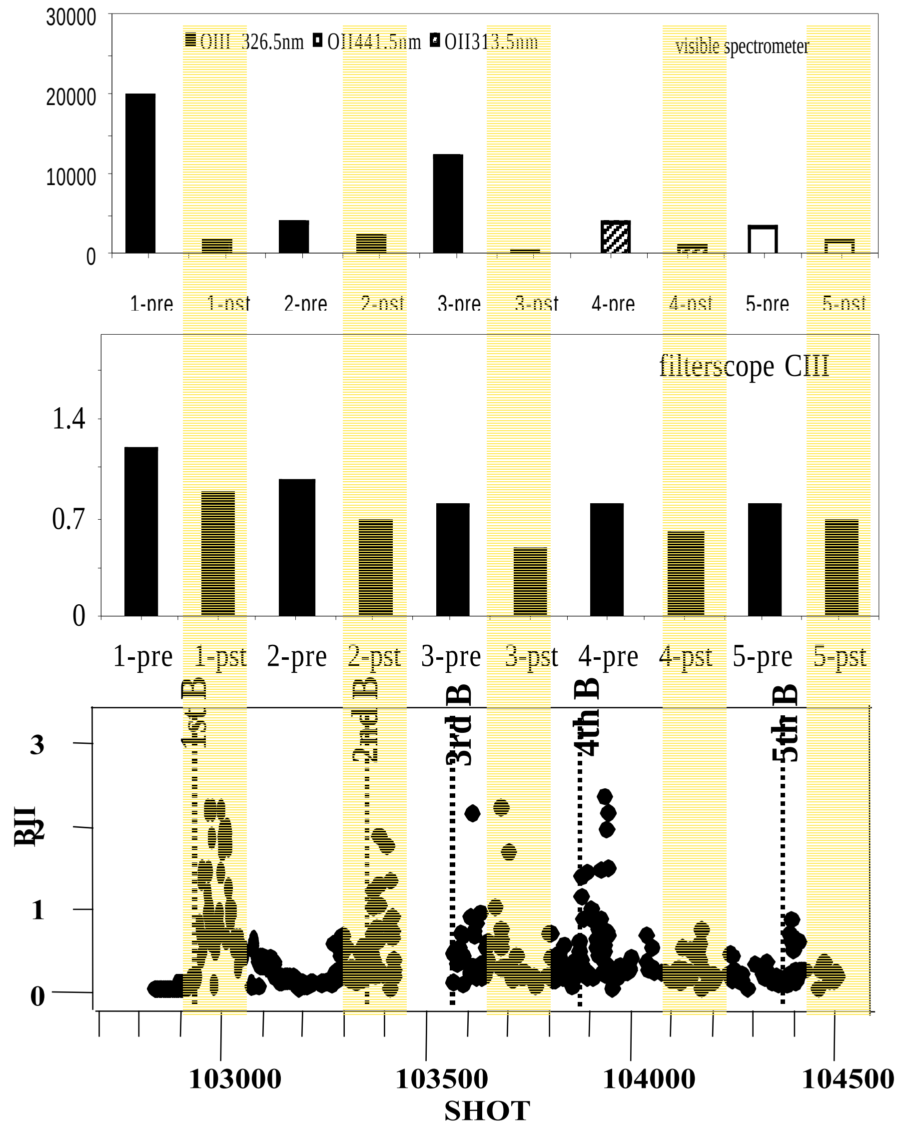


Glow Discharge Boronization Consistently Reduced Oxygen and Carbon

- *O III pre- & post-boronization. (difficult to compare due to changing fiducials)*

- *C III Pre- & Post-boronization. (difficult to compare due to changing fiducials)*

- *B II vs shot number.*



H. Na

He GDC Boronization of NSTX....

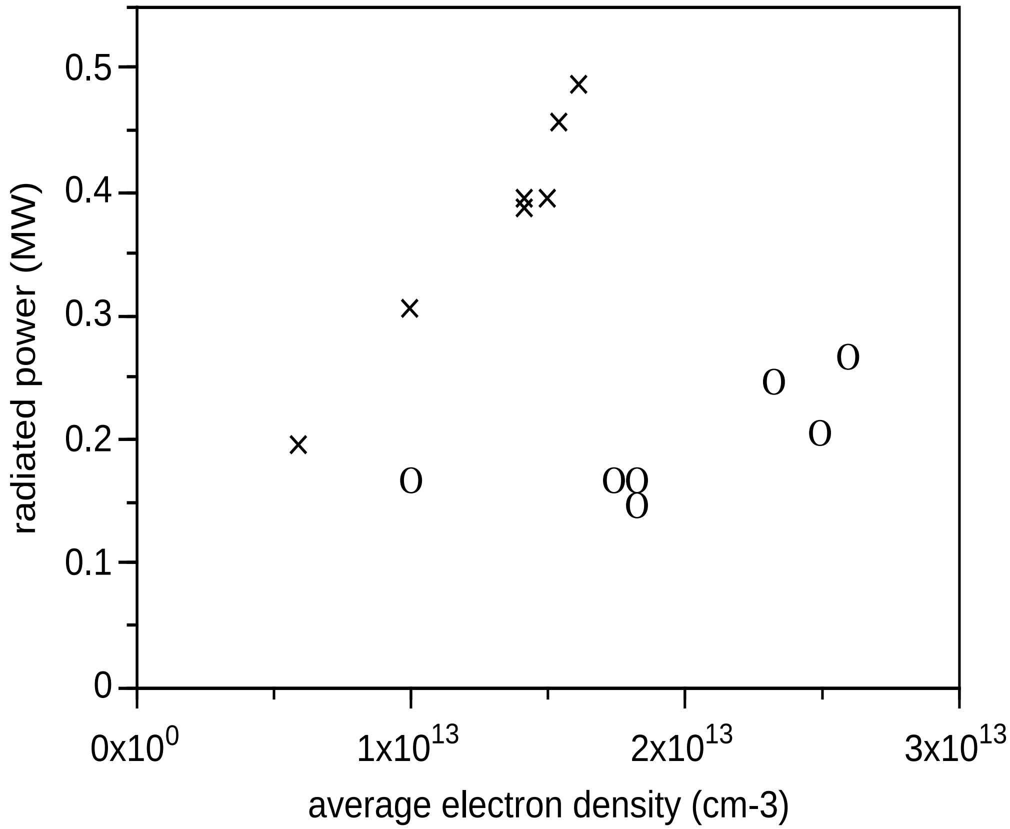
3. Radiated power reduced by a factor-of-two.

4. Z effective decreased by a factor-of-three.

5. typical core impurity content after fresh boronization
   1-1.5% carbon,
   0.25-0.5% boron,
   0.1-0.3% oxygen
   with negligible metal content.
   (D Stutman)

6. ...

Radiated power before (×), and after (O) boronization

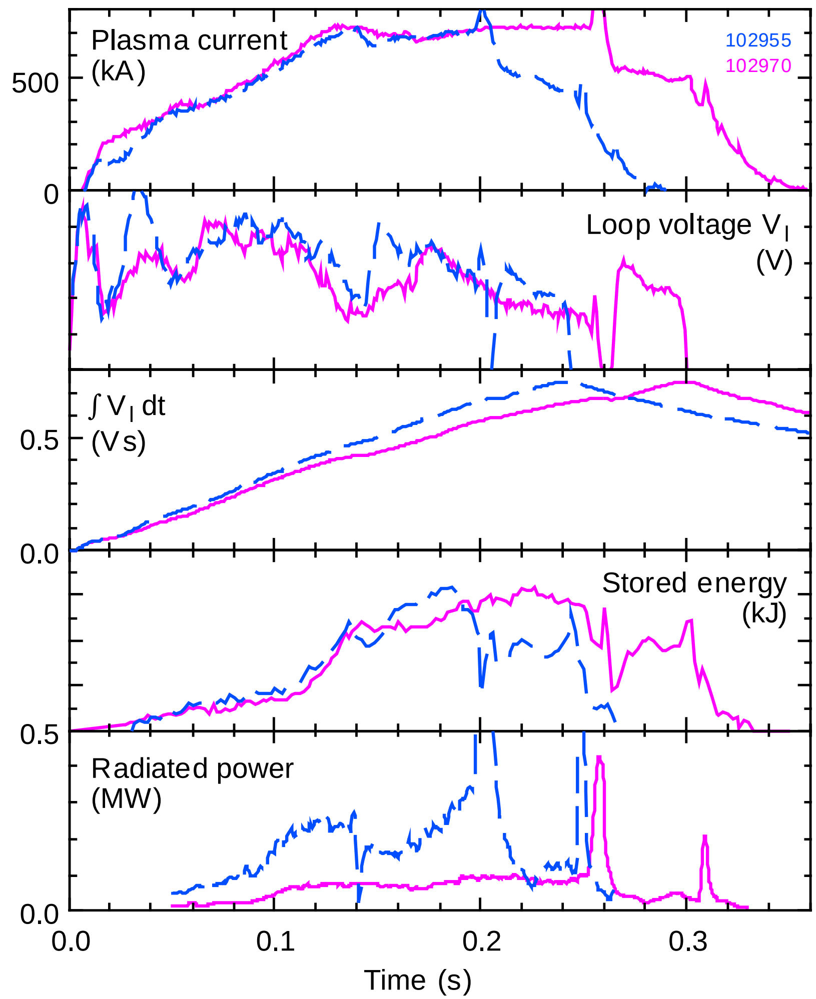


S.Paul, B.LeBlanc, R.Maingi

Plasma Performance After Boronization Improved Significantly

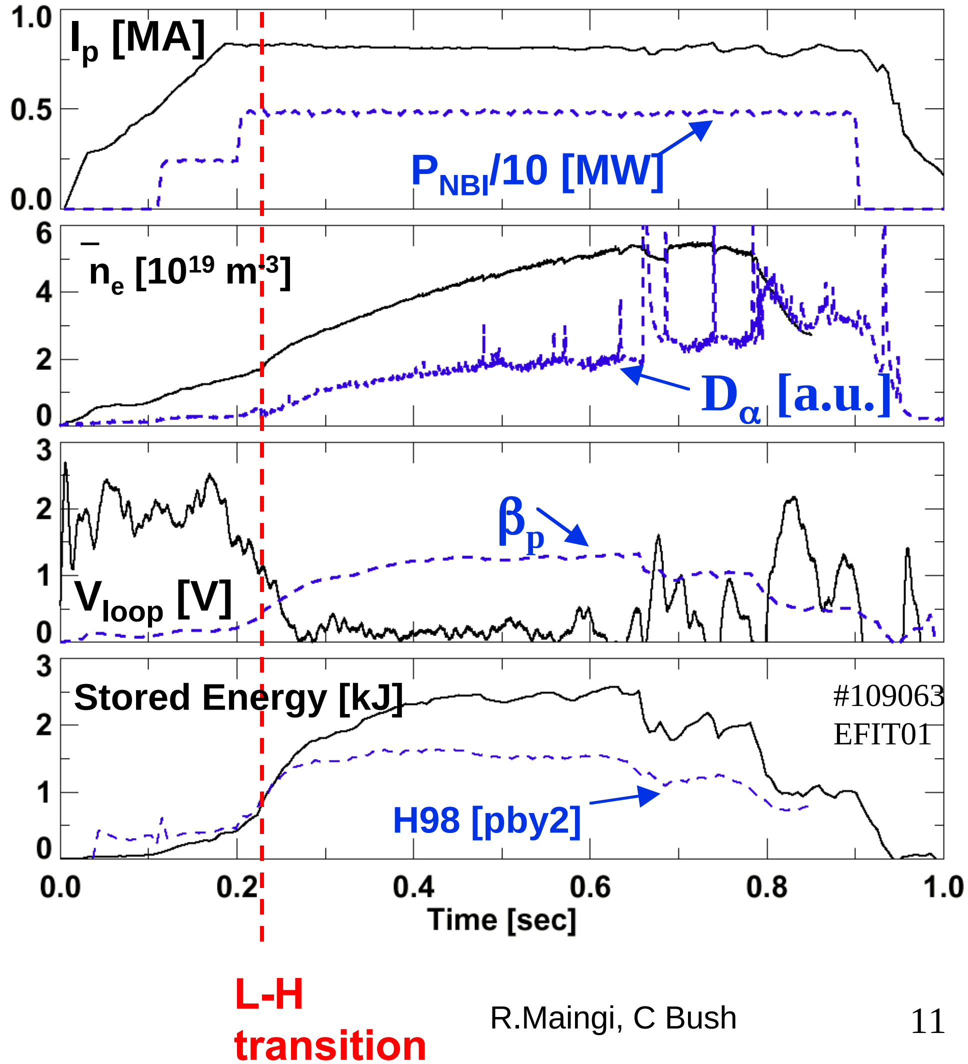
6. Plasma current flat-top increased by 70%.
7. Loop voltage at time of highest stored energy reduced by 30%
8. Volt-second consumption lower after boronization.
9. Confinement time 30% higher in post boronization discharge.

Discharges BEFORE and AFTER Boronization



Plasma Performance After Boronization Improved Significantly

5. *The D_2 density limit increased from about 60% of the Greenwald limit density to about 75%-80% after boronization*
6. *He density limit increased from 75% to 100% of the Greenwald limit*
7. *Access to H-mode plasmas occurred following the 3rd Boronization, and the 4th Boronization*
8. *Low loop voltage enabled 1 sec. duration discharges*

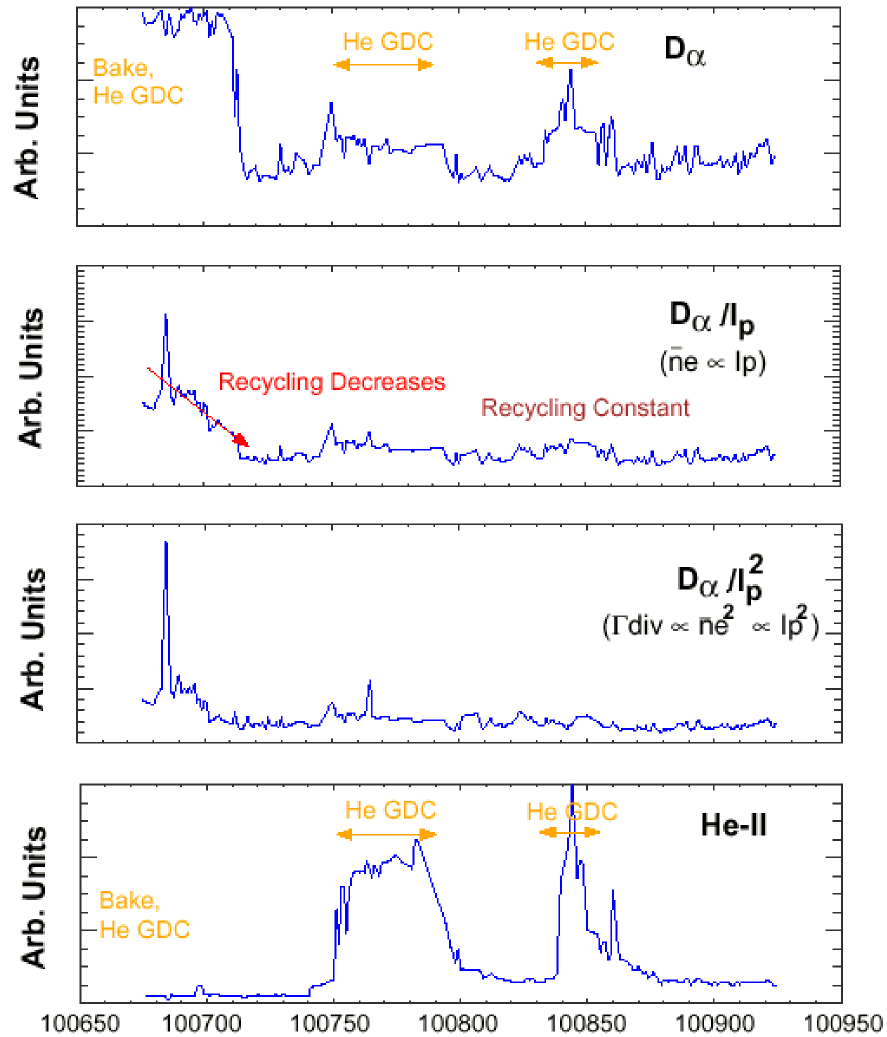


R.Maingi, C Bush

HeGDC applied between discharges enhanced impurity and density control during NBI and Ohmic Plasmas

NSTX

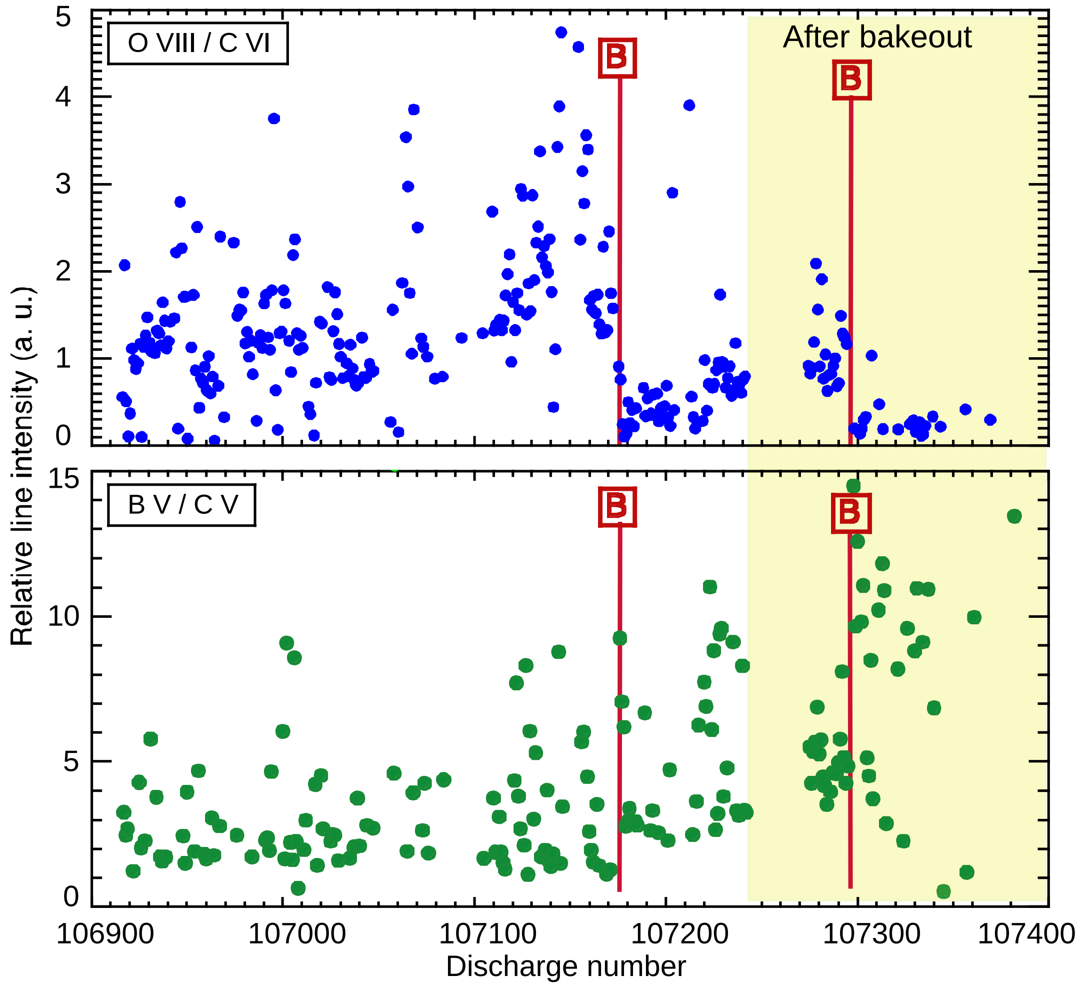
- *Edge Luminosity Behavior of Dα and He II Decreases After HeGDC Sequences*
- *~40 Ohmic Discharges Required to Achieve Low Reproducible Dα Edge Light*
- *HeGDC Useful for Improving Startup*
- *Special Cases: Following CHI, 30 mins of HeGDC & 5-10 Single Null Discharges Needed to Reduce Visible Light Emission Back to pre-CHI Levels*



350°C PFC bake-out aided by D_2GDC and HeGDC

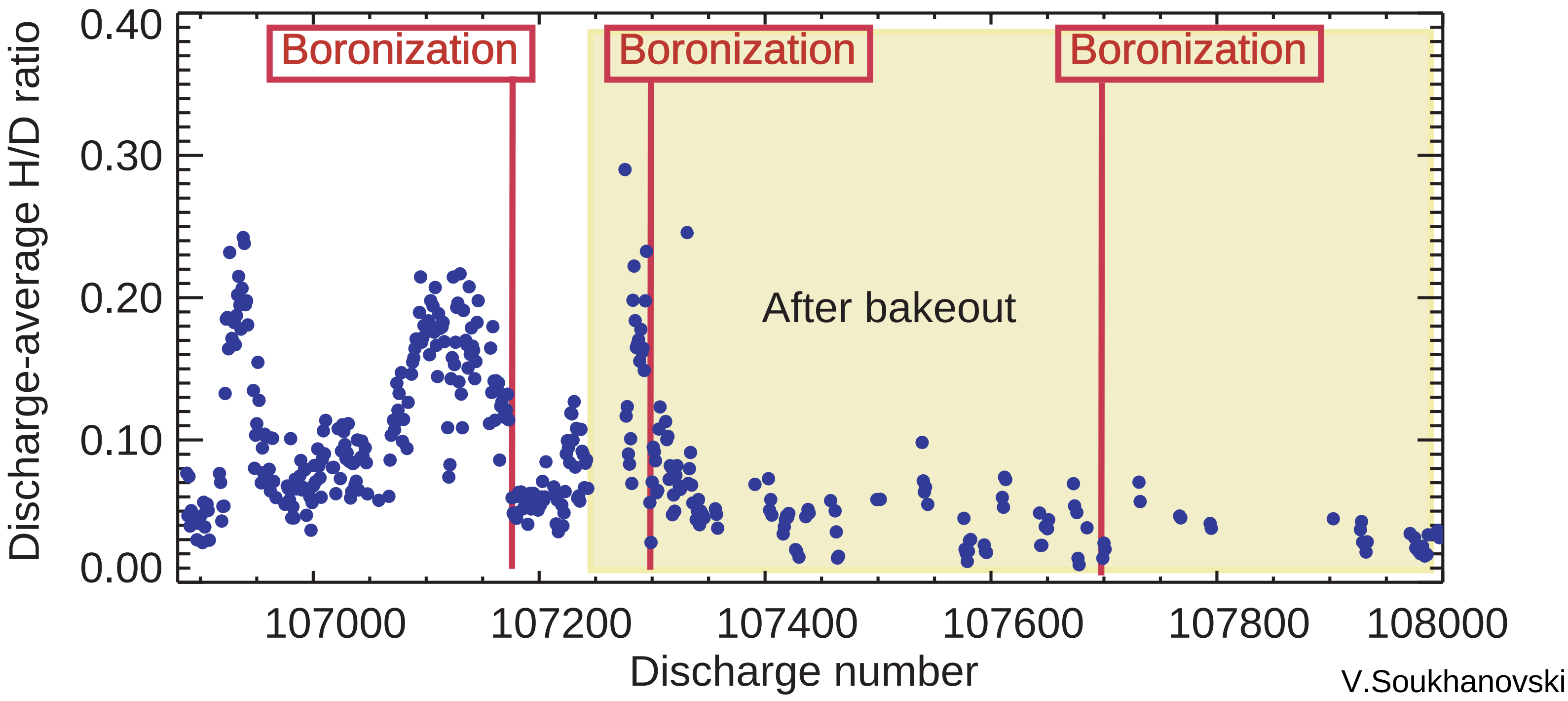
Oxygen and Carbon luminosities after bake-out and the following boronization were significantly lower

Bake-out only is insufficient to improve performance, boronization also required



V.Soukhanovskii

Discharged-average H/D ratio after bake-out followed by boronization decreased significantly



Fueling Deuterium Discharges With 90% He + 10% TMB

• Trimethylboron (TMB) injected into plasma edge reboronizes plasma-wetted surfaces

HeGDC is used to deposit boron film over the vessel interior (100 nm)

• Subsequent erosion of this deposited film occurs preferentially on plasma wetted surfaces, e.g., center column and divertor strike points.

• On TEXTOR (Esser et al.) and TdeV (Boucher, et al.) tested plasma fueling with boron gases, and obtained interesting results and improved performance.

• On PISCES, the injection ofcarborane into the plasma resulted in very high boron film deposition rates (~1000 nm/min) on the target samples. This was attributed to good transport of the injected carborane to the plasma wetted surface. (O. Buzhinskij, PSI-15)

• NSTX has performed preliminary tests of plasma boronization.

Initial test of direct injection of TMB [$B(CD_3)_3$] yields x2 decrease in central radiation & H-mode

- TMB fueling to 15.8 Torr-liters reached operational limits: 800 KA discharge only reached 500 kA due to high radiative power losses and He recycling.

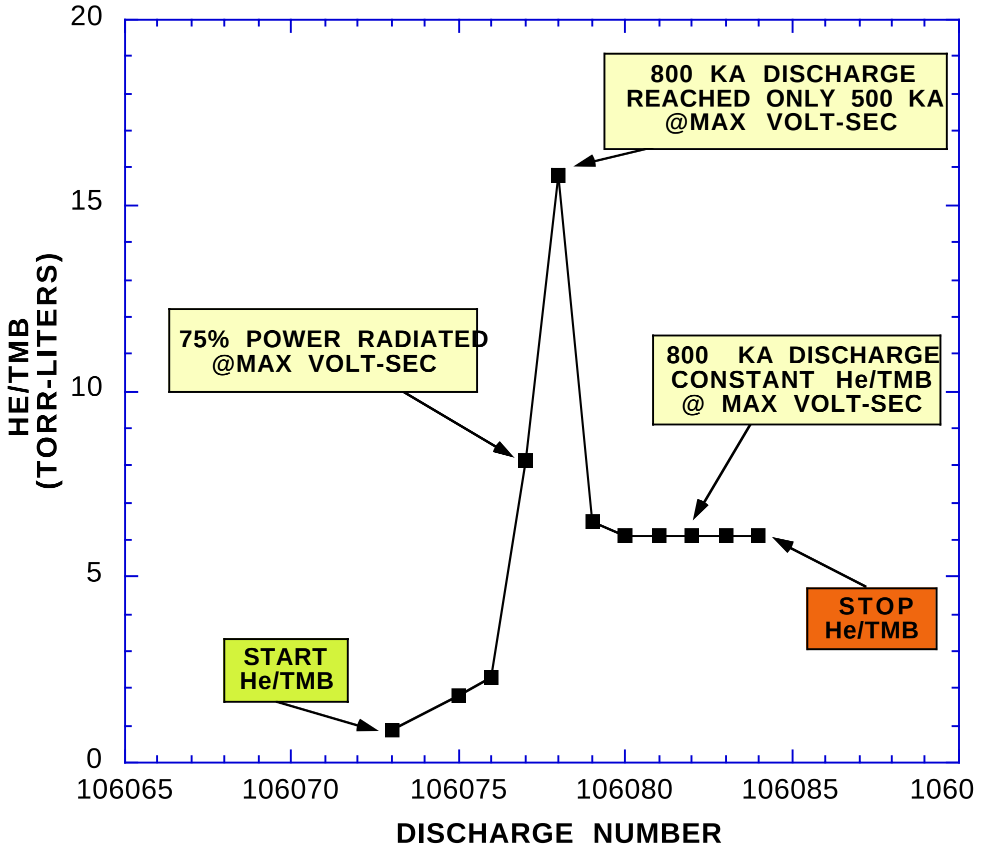
- TMB fueling was then reduced to 6Torr-liters for next 6 TMB fueled discharges (12 discharges total) : showed 50% decrease in central radiation after TMB.

- The subsequent post-TMB, LSN, 900 kA, 1.5 MW, NBI fiducial discharge exhibited a transition into the H-mode.

- The edge O and C luminosities were comparable within the limited statistics due to initially clean conditions. Edge fueling with TMB did not increase B V and C VI.

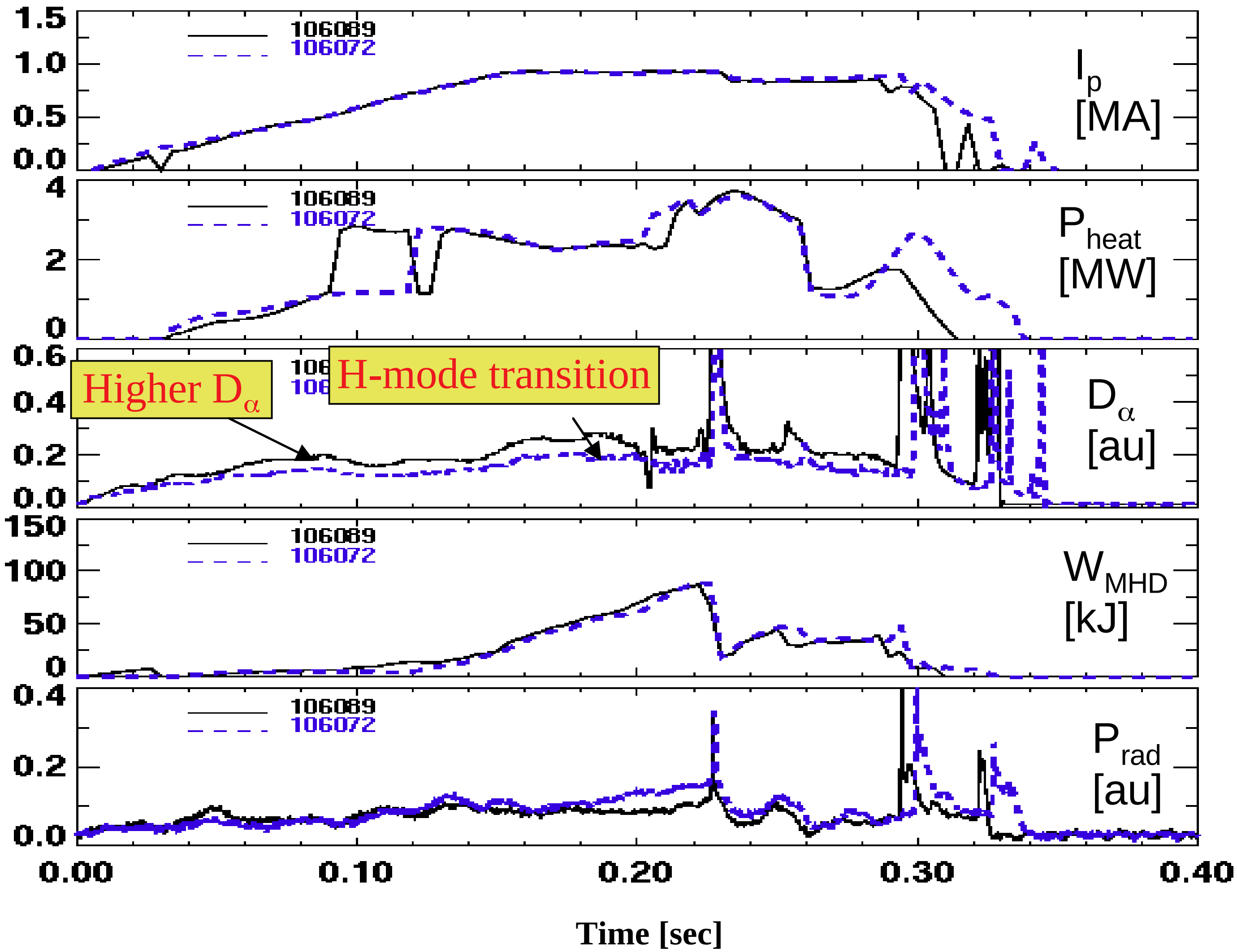
- Density profile for the post-TMB CSL discharge exhibited an outboard shoulder.

- Future experiments with pure TMB fueling being planned.



Sequence for direct injection of 90% helium and 10% TMB [$B(CD_3)_3$] into 800 kA, D_2 discharge

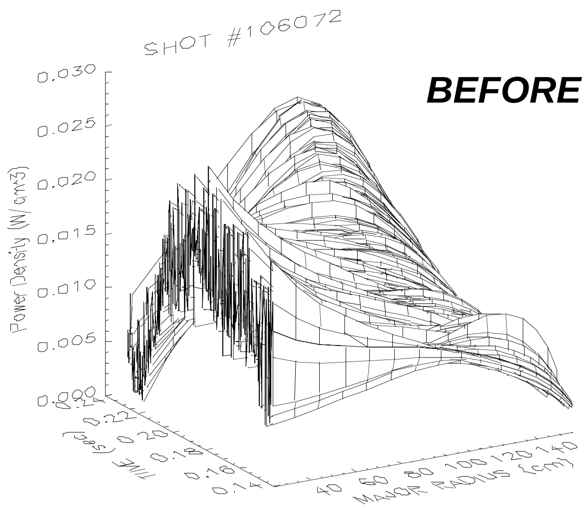
Plasma Boronization (black) NBI Lower Single Null Diverted Discharge Lead to Lower Radiated Power and H-mode Transition

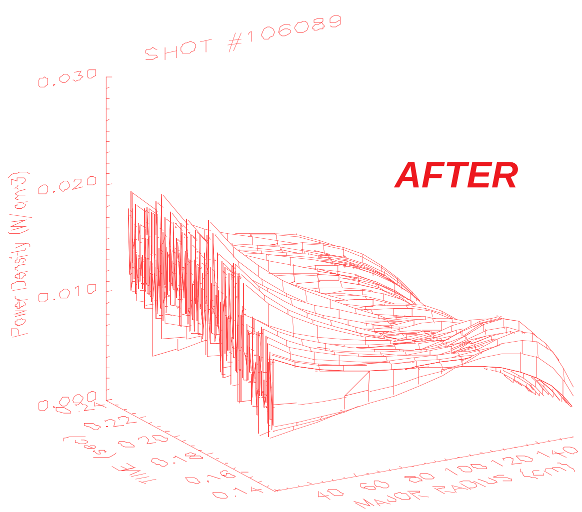


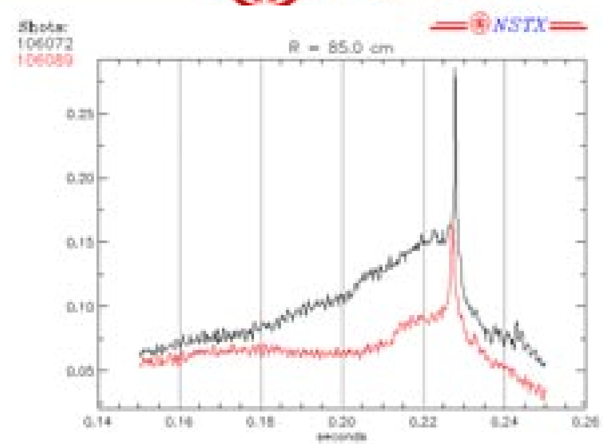
R.Maingi

NSTX He/TMB plasma boronization lead to lower radiated power and better NBI performance

- *A comparison of LSN, 1 MA, 1.5 MW, NBI fiducial discharges before and after He/TMB fueling, showed ~x2 decrease in central rad after He/TMB.*

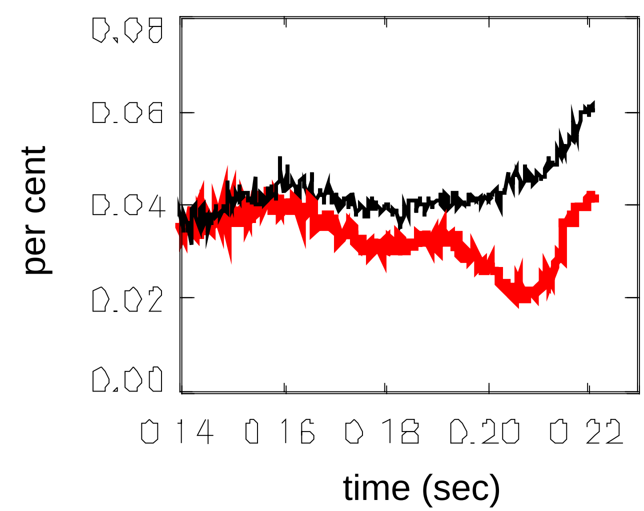






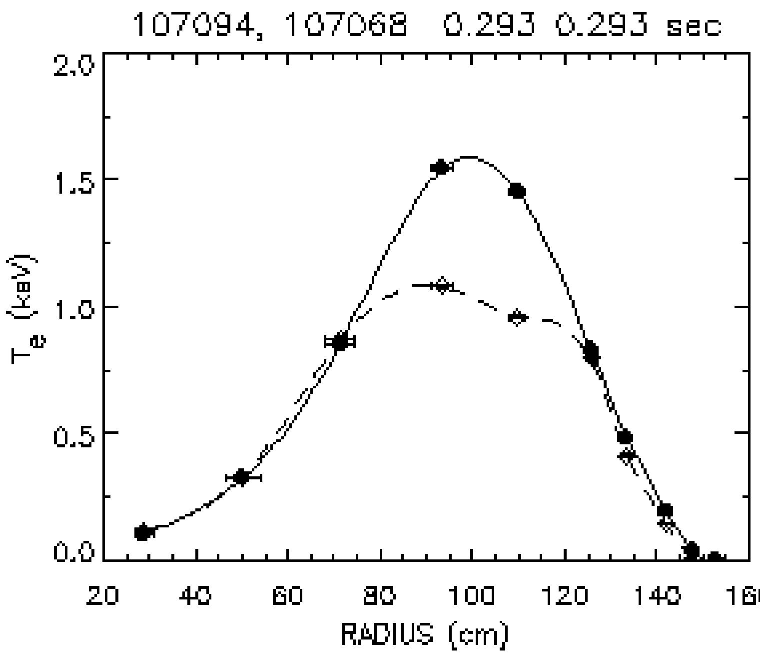
Central Radiation (a.u.)

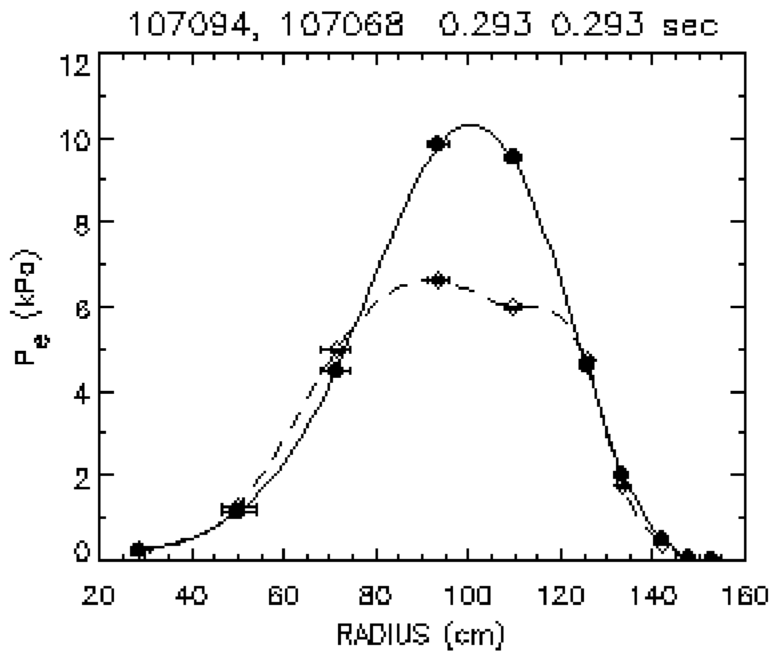
Equivalent Iron Concentration



S.Paul

High T_e in NBI discharge following TMB fueling





LeBlanc

- ***Comparison of electron temperature, and pressure profiles for one of the highest T_e (1.6 keV) achieved in NBI heated discharges observed in a fiducial discharge following a TMB fueling sequence (solid), and a fiducial discharge before TMB fueling started (dashed) . Same density.***

Conclusions

- High Temperature bake-out (350°C) is clearly needed to expedite the removal of H_2O and CO from NSTX graphite PFC's.
- Boronization using HeGDC with 90% He and 10% deuterated trimethylboron (TMB, i.e, $B(CD_3)_3$) enables significant improvement in plasma performance.
- Daily HeGDC and inter-discharge HeGDC (5-10 min) are required for impurity and density control during high power operations.
- TMB fueling experiments are showing promise for real-time maintenance of boron films and the effects of cladding the plasma in a low-Z mantle.