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High Performance Plasma Operation on DIII-D During Extended Periods Without Boronization

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High performance plasmas, including both hybrid and advanced tokamak (AT) benchmark discharges, were shown to be highly repeatable in DIII-D over 6000 plasma-seconds of operation during the 2006 campaign with no intervening boron depositions or high temperature bakes [1,2]. Hybrid and AT discharges [3] with identical control targets were repeated after the initial boronization at the beginning of the 2006 campaign, and again just before and after a second boronization near the end of the 2006 campaign. After a long entry vent between the 2006 and 2007 campaigns, similar discharges were again repeated after the standard high temperature baking and plasma cleanup, but prior to a boronization. Performance metrics, such as β, confinement quality, and density control, were extremely well repeated. A low performance daily reference shot (DRS) was also established as a routine monitor of impurity influx. Over the 2006 campaign, the DRS database indicated little to no secular increase in impurity content. Oxygen content and Ni line emission were higher after the intervening vent, but were still minor contributors to plasma contamination. This indicates that erosion of boron films used for wall conditioning will not be a limitation to establishing long pulse high performance discharges in the new generation of superconducting tokamaks if graphite is used as the primary plasma facing material. These results contrast with recent work in devices using high-Z metallic plasma facing materials, where very frequent refreshing of boron films is required for high performance plasma operation [4-6].

1. Introduction

Boronization (BZN) was developed in the early 1990's as a means to coat plasma-facing surfaces in existing magnetic-confinement fusion research devices with a resilient, low-Z, hard coating [1,2]. The positive effects on impurity content and recycling properties of the short-pulse, low-duty-cycle experiments combined with the simplicity of implementation, led to wide use in the fusion research community. However, the benefit of BZN in the next generation of long-pulse, high-duty-cycle devices is questionable because the erosion lifetime of the film is shorter than the duration of a single discharge. Because graphite has very good thermo-mechanical properties, and is composed of low-Z carbon which is comparatively benign to core plasma performance compared to high-Z materials, there is strong motivation to demonstrate that high performance plasma operation is compatible with graphite plasma facing walls with infrequent or no BZNs.

Significant benefits were observed on DIII-D when BZN was first introduced in 1991 [1] including reduced plasma contamination and wall fueling. However BZN does come with some cost to the program, the biggest being a lost day of experimental time after each BZN due to the need to plasma condition fresh films. Because of growing interest in determining the repetition rate of BZN required for good wall conditioning, at the beginning of the 2006 campaign the decision was made to extend the period of operation between BZNs. A BZN was preformed before the start of physics experiments to help recover from a 1-year long entry vent. A daily reference shot was devised to help monitor secular changes to wall conditions. In addition benchmark high performance discharges, both hybrid and advanced tokamak [3], were run several times throughout the campaign. A second BZN was performed after 6800 plasma seconds of operation distributed across 3.5 months. During the period between BZNs, there were no vents or high temperature bakes. Plasma operation continued for three weeks following the second BZN, followed by a six-week entry vent. Operation began again early in 2007. After the usual post-vent wall conditioning, including high temperature baking, helium glow discharge cleaning, and plasma operation with neutral beam heating, a period of two weeks of physics experiments was then carried out prior to the application of a fresh BZN. In this paper, we will give a brief report on the secular changes observed from the daily reference shots. We will also report on the performance and impurity content of the high performance discharges over the course of the period from the initial BZN in 2006 through the post-vent operating period in early 2007.

2. Daily Reference Shots

A daily reference shot was established to monitor secular changes in the wall source of impurities and fuel particles. The shot is run as the first shot of the day on most operating days. It is a high triangularity, lower single null discharge, with a toroidal field of 2.0 T and a plasma current of 1.2 MA. The neutral beam heating is configured to provide three distinct phases: 1) A constant L-mode at an average beam power of 0.27 MW with feedback control of the electron density, 2) A power ramp to a beam power of 2.4 MW, an L-H transition occurs during this time, 3) An ELMing H-mode phase from 4.0 s to 5.5 s, with a beam power of 4.3 MW and no gas puffing. Impurity line intensities as a function of shot number measured using a tangentially viewing EUV spectrometer are shown in Fig. 1 during the L-mode phase and the high power ELMing H-mode phase, averaged over 100 ms. The data shown result from charge exchange recombination of fully stripped impurity ions with injected beam neutrals. Between the two BZN events (vertical dashed lines) there is a slow secular increase of the carbon emission during the L-mode phase, which appears to saturate after several hundred discharges. During the H-mode phase, the core impurity emission shows little or no secular trend. After the extended vent, shown by the red shaded area, oxygen contamination increases substantially, whereas carbon contamination is relatively unaffected. Edge lines from C III and O V show similar trends to the core lines shown here. The lack of a secular trend in the wall fueling source is indicated by the constancy in amount of gas required to reach the L-mode target density [Fig. 1(e)] and the rate of rise of the density immediately after the L-H transition [Fig. 1(f)].

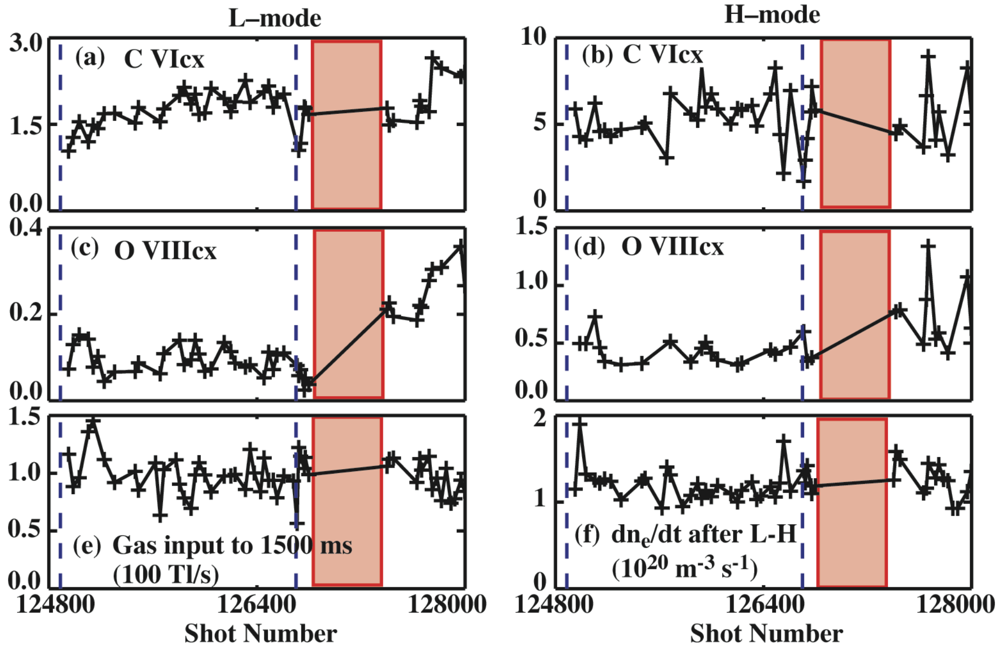

Fig. 1. (a-d) Impurity emission (10^{14} photons/cm^2/str/s) from the core region of the plasma plotted as a function of shot number from the daily reference shots. The C VI and O VIII EUV lines are from charge exchange recombination from a modulated heating beam that crosses the viewing chord of the spectrometer near the magnetic axis of the plasma. (e) The D_2 gas input during rampup phase. (f) Rate of density rise just after L-H transition. A total of 6800 s of plasma duration was conducted between the BZNs (vertical dashed lines).

3. High Performance Discharges

Over the course of the 2006 and early 2007 campaigns high performance discharges, both hybrid and advanced tokamak [3] types, were occasionally repeated. Figure 2 shows time traces from a set of four hybrid discharges taken over this period. In these discharges, the injected beam power is feedback controlled to keep β_N constant [Fig. 2(a)]. The consistent fusion performance figure of merit ($G=\beta_N H_{89}/q_{95}^2$) indicates that confinement is consistent in these hybrid shots throughout this extended period [Fig. 2(b)]. The contribution of oxygen and carbon impurity to Z_{eff} in the core plasma, as measured by charge exchange recombination emission, is shown in Fig. 2(c,d). Oxygen contribution is small throughout the campaign. Relatively high oxygen contamination is typical after a long entry vent and is brought down by a BZN. The primary contributor to Z_{eff} is usually carbon. As seen in Fig. 2(d), the carbon content is reasonably constant in these hybrid discharges across the entire 2006 campaign and into the initial operations of 2007. The radiated power [Fig. 2(e)] is low, about 20% of the injected beam power. It is slightly higher after an entry vent, but reconstructions of data from the 42-chord bolometer array indicate the increased radiation is dominantly in the divertor. Also of note is the consistency of hybrid operation over seven sequential shots, 126479 to 126485, with no between shot helium glow-discharge cleaning.

Performance and impurity parameters of Advanced Tokamak plasmas are shown in Table 1. A key difference between these AT discharges and the hybrid discharge is operation at higher q_{95} to achieve higher β_N and a higher fraction of bootstrap current. As the table shows, good performance is maintained across the entire period. Oxygen edge emission and nickel core emission are reduced by the BZN between shots 126472 and 126763, but neither provide significant contamination. Carbon, the dominant impurity, is reduced for about 20 shots (~160 plasma-seconds) following a BZN, but then returns to the typical levels shown.

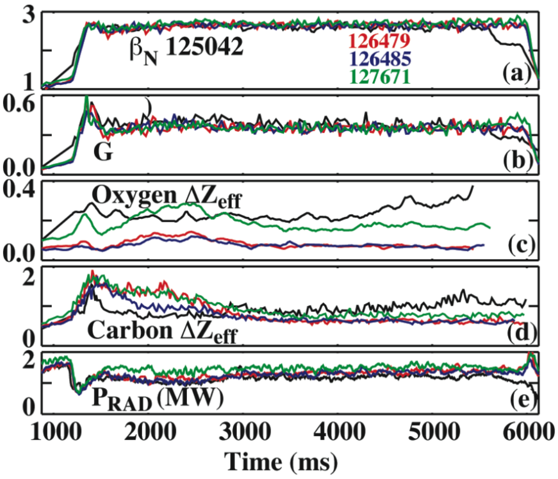

Fig. 2. Performance and impurity parameters from benchmark hybrid discharges: Black: 125042 taken 557 s of plasma time after previous BZN. Red: 126479, 5820 s; Blue: 126485, 5859 s; Green: 127671, 900 plasma-s after the end of a 6 week entry vent and 2010 s after previous BZN. From shot 126479 to 126485 the usual between shot helium glow discharge cleaning was turned off.

Table 1. Performance and impurity parameters for Advanced Tokamak high performance plasmas relative to total time of plasma operation since the previous BZN and entry vent. The neutron production rate measurement system was not functioning properly on shot 127672.

Shot	126472	126763	127672
Time from BZN (s)	5775	320	2017
Time from vent (s)	6665	8010	907
β_N	3.75	3.70	3.80
G ($\beta_N H_{89}/q_{95}^2$)	0.38	0.37	0.39
H_{89}	2.65	2.65	2.65
Neutrons (10^{15} s^{-1})	1.7	1.7	–
OV 730 Å (au)	4.6	2.3	8.8
Ni XXVI	0.41	0.14	0.33
ΔZ_{eff} carbon	1.0	0.9	1.0

4. Conclusions

Routine repetition of benchmark high performance discharges over a period of ~6000 plasmas seconds of operation with no intervening boronizations or high temperature bakes was recently demonstrated on DIII-D, which has >95% graphite plasma facing surfaces and is usually operated with strong divertor pumping. Wall fueling and impurity sources were not observed to increase significantly over this period in high performance operation and in daily reference shots. These results are in contrast to recent results from two tokamaks with high-Z metallic plasma-facing surfaces, Alcator C-Mod [4] and ASDEX-Upgrade [5,6], where frequent boronizations were observed to be necessary to reliably reproduce high performance. These results are encouraging for the use of graphite in the new generation of long-pulse superconducting divertor tokamaks, where plasma pulse lengths will greatly exceed the erosion lifetime of BZN films.

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References

[1] G.L. Jackson, J. Vac. Sci. Tech. **10**, 1244 (1992); G.L. Jackson, *et al.,* Phys. Rev. Lett. **67** (1991) 3098.
[2] J. Winter, J. Nucl. Mater. **176-177** (1990) 14.
[3] M.R. Wade, *et al.*, Nucl. Fusion **45** (2005) 401.
[4] B. Lipschultz, *et al.,* Phys. Plasmas 13 (2006) 056117.
[5] R. Neu, *et al.,* Plasma Phys. Control. Fusion **44** (2002) 811.
[6] A. Kallenbach, *et al.,* Plasma Phys. Control. Fusion **47** (2005) B207.