GA–A26654

PARTICLE CONTROL AND TRANSPORT EXPERIMENTS IN THE DIII-D TOKAMAK WITH GRAPHITE WALLS

by
S.L. ALLEN, E.A. UNTERBERG, A.G. McLEAN, N.H. BROOKS,
A.W. LEONARD, M.A. MAHDAVI, W.P. WEST, J.W. DAVIS,
A.A. HAASZ, B. FITZPATRICK, P.C. STANGEBY
and D.G. WHYTE

MAY 2010

GENERAL ATOMICS

DISCLAIMER

GA–A26654

PARTICLE CONTROL AND TRANSPORT EXPERIMENTS IN THE DIII-D TOKAMAK WITH GRAPHITE WALLS

by
S.L. ALLEN[1], E.A. UNTERBERG[2], A.G. McLEAN[2], N.H. BROOKS,
A.W. LEONARD, M.A. MAHDAVI, W.P. WEST, J.W. DAVIS[3],
A.A. HAASZ[3], B. FITZPATRICK[3], P.C. STANGEBY[3]
and D.G. WHYTE[4]

This is a preprint of a paper to be presented at the 23rd IAEA Fusion Energy Conference, October 11–16, 2010 in Daejon, Republic of Korea and to be published in Proceedings.

[1]Lawrence Livermore National Laboratory, Livermore, California
[2]Oak Ridge National Laboratory, Oak Ridge, Tennessee
[3]University of Toronto Institute for Aerospace Studies, Toronto, Ontario, Canada
[4]Massachusetts Institute of Technology, Cambridge, Massachusetts

Work supported in part by
the U.S. Department of Energy
under DE-AC52-07NA27344, DE-AC05-00OR22725
and DE-FC02-04ER54698

GENERAL ATOMICS ATOMICS PROJECT 30200
MAY 2010

GENERAL ATOMICS

Retention of hydrogenic isotopes in the first wall of future burning plasma experiments such as ITER can lead to an unacceptable in-vessel tritium inventory. Dynamic particle balance measurements on DIII-D indicate that the total uptake of deuterium during a plasma discharge is dominated by the wall uptake during the initial (ohmic or L-mode) part of the discharge with very little uptake observed during the H-mode phase. In some cases, these measurements infer net depletion of deuterium from wall during the H-mode phase. The total wall uptake inferred by these dynamic measurements is consistent with that inferred from "static" measurements of total pressure rise after the discharge. Since the relative duration of H-mode to L-mode is much longer in ITER than present-day devices, these measurements suggest that scalings based on data from present-day devices may overestimate the tritium retention expectations in ITER.

$$\overbrace{\overset{\text{Gas Input}}{\Gamma_{\text{Gas}}} + \overset{\text{(NBI Input)}}{(\Gamma_{\text{NBI}})} + \overset{\text{Neutrals}}{\Gamma_{\text{Neutrals}}}}^{\text{Sources}} \; - \; \overbrace{\overset{\text{Pump Exhaust}}{\Gamma_{\text{pump}}} - \overset{\text{Plasma Density Rise}}{\frac{\partial(n_eV)}{\partial t}} = \overset{\text{Wall Rate}}{\Gamma_{\text{wall}}}}^{\text{Sinks}}$$

DIII-D provides a unique test bed for assessing the retention of hydrogenic isotopes in graphite surfaces as nearly all of the plasma-facing components are graphite, the wall can be baked to ~350°C before plasma operations, three divertor cryopumps provide significant particle exhaust (20 m^3/s), a variety of plasma shapes can be studied, and recovery from off-normal events is achieved by glow conditioning between shots. Previous DIII-D experiments [1] used a "dynamic" particle balance calculation based on sources and sinks of a single reservoir, as shown in Eq. (1). This measurement technique has now been compared with "static" particle balance measurements that use the total measured pressure rise after the discharge to estimate the total wall uptake [2]. Measurements in ELMing H-mode, L-mode, and ohmic plasmas with cryopumping indicate that the two techniques agree to within ~10%, providing additional confidence in the dynamic technique. After the initial plasma ramp up, Fig. 1, the dynamic measurements show that the wall retention rate is very small and constant. ELMing H-mode results were obtained with electron cyclotron heating (ECH) (no particle input) and with neutral beam injection (NBI) (beamlines open during the discharge), and both show very low wall retention [Fig. 1(g)]. In some cases with NBI heating, the observed wall retention rate is negative, indicating that particles are being removed from the wall. These results demonstrate the importance of the dynamic measurements, as the static (shot-averaged) measurements are dominated by the wall flux during the initial (ohmic or L-mode) part of the discharge.

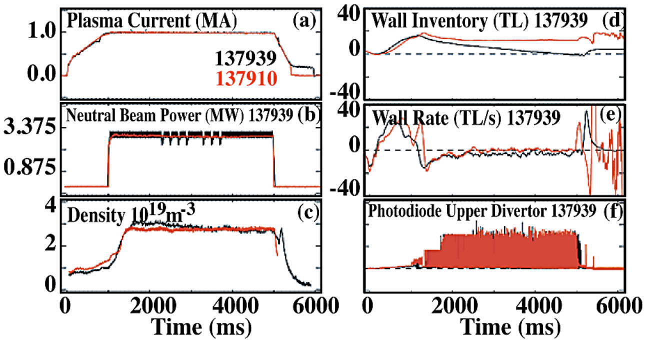

Fig. 1. ECH-heated (red) H-mode plasma is compared with a NBI (black) discharge. The plasma current, neutral beam or ECH power, electron density; wall inventory and wall rate from the dynamic particle balance; along with the photodiode signal are compared with a neutral beam heated H-mode. DIIID shot. Note that in both cases, the wall flux (g) is quite large in the L-mode ramp-up period, but during the ELMing H-mode, the wall flux is very close to zero.

Dynamic particle balance measurements during resonant magnetic perturbation (RMP) ELM suppression show that the wall retention rate and inventory is dependent on pedestal density and divertor conditions [3]. The dominant term in the particle balance equation during RMP discharges was the cyropump exhaust rate. In a closed divertor configuration, the pump exhaust is significant throughout the ELM suppression phase. In contrast, in a more open divertor configuration, the exhaust decreased to nearly zero as the divertor transitions to a low-recycling state. It is found that the 3D magnetic field structure imposed by the RMP helps to define the magnetic geometry of the divertor, and hence the particle exhaust.

To complement these experiments, DIII-D has a broad research program of carbon transport studies, including toroidally-symmetric injection of ^{13}C into a series of (typically ~15) discharges at the end of a run campaign, followed by removal of tiles during a vent and subsequent analysis to determine the regions of high deposition [4]. Injection into the "crown" of a single-null divertor plasma in L-mode (2004) showed that the highest concentration of ^{13}C was at the inner strike point. For ELMing H-mode plasmas (2006), the deposition extended into the private flux region. Recently, (2008) the injection into the crown of an unbalanced double-null plasma (drsep~2) has shown more ^{13}C deposition near the injection point (i.e. opposite the main divertor). Utilizing a unique porous graphite plate [5] to inject CH_4 into the divertor at rates comparable to the intrinsic erosion rate of C, direct measurements have been made of the contribution of carbon produced by chemical erosion relative to total C sources in the divertor. Under cold plasma conditions, this ratio declined dramatically from ~50% to <15%. At 75°C, the measured CE yield near the outer strike point was ~2.6% in attachment dropping to only ~0.5% in cold plasma. Under full detachment, near total extinction of the CD band occurred, consistent with suppression of net C erosion.

DIII-D is also studying the feasibility of thermo-oxidation techniques to remove carbon deposited layers along with the co-deposited hydrogenic species. These techniques have been well characterized in test chambers [6], and the technique has had some limited application in magnetic confinement devices. In preparation for an experiment on DIII-D, oxygen bake tests of internal components were carried out at U. Toronto and DIII-D to identify systems that could be damaged. These tests included the cryopump components, ECH antennas, diagnostic mirrors, and other internal components. The largest effect was found on copper surfaces, which could receive an oxide coating. We are planning a DIII-D oxygen bake experiment for the end of the 2010 run campaign, which will address both the removal of co-deposited ^{13}C layers and recovery of high-performance plasma operations. We are planning a 2 hour bake at 350°C in a 20% oxygen atmosphere at 1.3 kPa, which is estimated to remove 1-2 microns of co-deposits.

This work was supported by the US Department of Energy under DE-AC52-07NA27344, DE-AC05-00OR22725, and DE-FC02-04ER54698 and the work performed at the U. Toronto was funded by the Natural Sciences and Engineering Research Council of Canada.

[1] R. Maingi, et al., Nucl. Fusion **36** (1996) 245
[2] D. Whyte, et al., to be published
[3] E.A. Unterberg, et al., Nucl. Fusion **49** (2009) 092001
[4] S.L. Allen, et al., 21st IAEA, 2006, see also W.R Wampler, et al., J. Nucl. Mater. **363-365** (2007) 72.
[5] A.G. McLean, PhD thesis, U. Toronto, 2009, see also A.G. McLean, et al., Phys. Plasmas, to be published, 2010.
[6] J.W. Davis, A.A. Haasz, J. Nucl. Mater. **390-391** (2009) 532.