GA-A--20120

DE91 004491

LIMITER BIAS EXPERIMENTS IN DIII-D

by

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This is a preprint of a paper to be presented at the 9th International Conference on Plasma Surface Interactions, May 21-25, 1990, Bournemouth, United Kingdom and to be printed in the *Proceedings*.

Work supported by
Department of Energy
Contract DE-AC03-89ER51114

GENERAL ATOMICS PROJECT 3466
NOVEMBER 1990

GENERAL ATOMICS

ABSTRACT

In DIII–D, H_α emission was reduced by a factor of 2-3 both at the limiter and at the inner wall by negative biasing ($V_{lim} \approx -300$ V). In these discharges, the line-average electron densities were approximately the same with and without limiter bias, which suggests that τ_p was improved by negative bias. Edge Bremsstrahlung emission signals were reduced by a factor of two. Repetitive bursts were observed in H_α signals and edge Bremsstrahlung signals. Impurity levels increased with limiter bias, which induced major disruptions. No improvement of τ_E was observed. These experimental data suggest that particle confinement characteristics of limiter biased discharges are similar to those with divertor H–mode.

1. INTRODUCTION

Understanding of transport and improvement of confinement are very important subjects in thermonuclear fusion research. Recent H–mode experiments in DIII–D [1] and JFT-2M [2] show that radial electric field just inside the separatrix becomes more negative after an L-H transition. In DIII low-recycling divertor, floating potential near the separatrix became more negative with improved confinements [3]. Limiter biasing experiments in MACROTOR [4], PBX [5], TEXT [6], and TEXTOR [7] demonstrated that by applying negative electric potential at the tokamak boundary, substantial improvement or change is obtained in particle confinement and recycling. Limiter biasing experiments in PBX with neutral beam heating show a modest improvement of energy confinement [5]. Recent CCT electron injection experiments [8] demonstrated formation of transport barrier by current injection. All these experiments indicate that edge radial electric field plays a very important role in confinement.

The objective of this paper is to discuss limiter bias experiments in DIII–D with ohmically heating and neutral beam heating to investigate effects of externally applied edge radial electric field in a large tokamak.

2. EXPERIMENT

The DIII–D device, its heating system, and its diagnostics are described elsewhere [1,9]. Electric potential was applied to a carbon limiter by using a circuit shown in Fig. 1. This limiter on the outer midplane was radially inserted by 10 cm from the normal position to separate the limiter-defined surface from the nonbiased material structure.

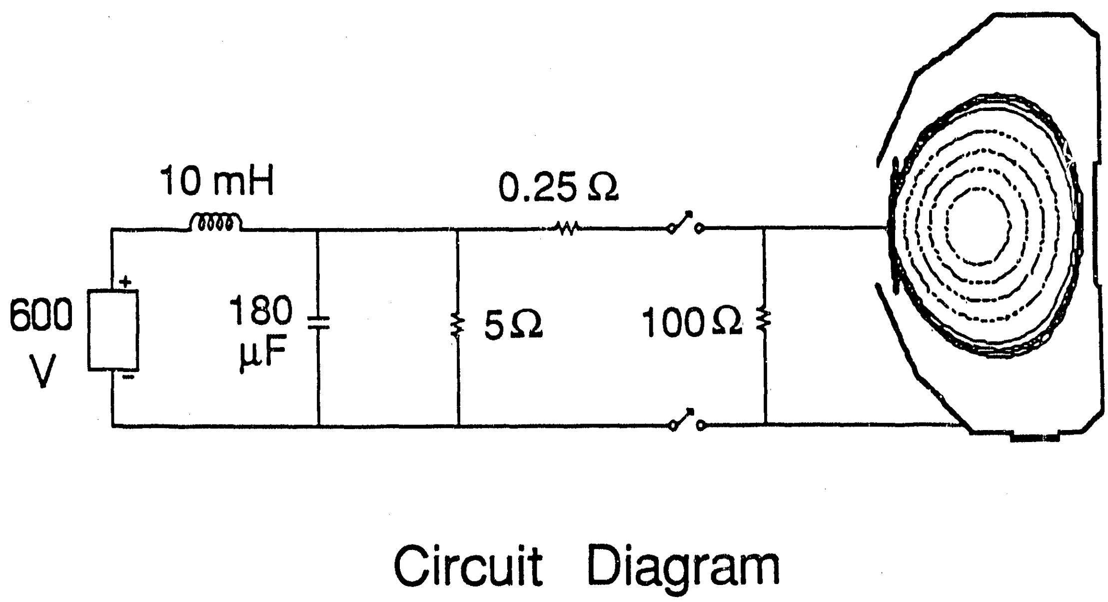

Fig. 1. Circuit diagram for the limiter bias experiments. Equilibrium shape and the limiter are also shown.

Figure 2 shows an ohmically heated deuterium discharge with positive bias. The toroidal field was 1.8 T, plasma current was 800 kA. The limiter potential was ramped up slowly to observe the discharge behavior with small voltages. Edge Bremsstrahlung signals ($r/a \approx 0.8$) and radiation loss power shows very interesting characteristics. These signals decrease as the limiter voltage is ramped up, showing minimum at $\approx$100 V. Above 100 V, they start to increase up to the limiter voltage of $\approx$200 V. No significant change was observed in electron density, central Bremsstrahlung emission, H_α emission at the limiter and the wall with positive bias.

Figure 3 shows an ohmically heated discharge with negative bias. For small limiter voltages, limiter H_α increases from prebias values, whereas wall H_α, edge Bremsstrahlung, and radiation power decreases. As the limiter voltage becomes more strongly negative, H_α signals at the limiter start to decrease, and H_α signals both at the limiter and at the inner wall were reduced by a factor of 2-3 at $V_{\rm lim} \approx -300$ V. The radiation loss increases very rapidly up to 100% of input power, which made the discharge very unstable. In these discharges, the line-average electron densities were approximately the same with and without limiter bias, which suggests that $\tau_{\rm p}$ was improved by negative bias. Edge Bremsstrahlung emission signals were reduced by a factor of two, suggesting that edge electron density was reduced with limiter bias. Steeper density gradient and smaller particle flux again suggests that particle confinement is improved with negative bias. Repetitive bursts were observed in H_α signals and edge Bremsstrahlung signals. No improvement of $\tau_{\rm E}$ was observed, which may be due to excessive radiation loss. These experimental data suggest that particle confinement characteristics and edge plasma properties of limiter biased discharges are similar to those with divertor H–mode.

Similar experiments were carried out to investigate effects of limiter biasing with neutral beam heating. Figure 4 shows a discharge with neutral beam heating power of 1.6 MW and peak limiter voltage of -250 V. The working gas was deuterium and beam species was hydrogen. The toroidal field was 1.8 T and plasma current was 800 kA.

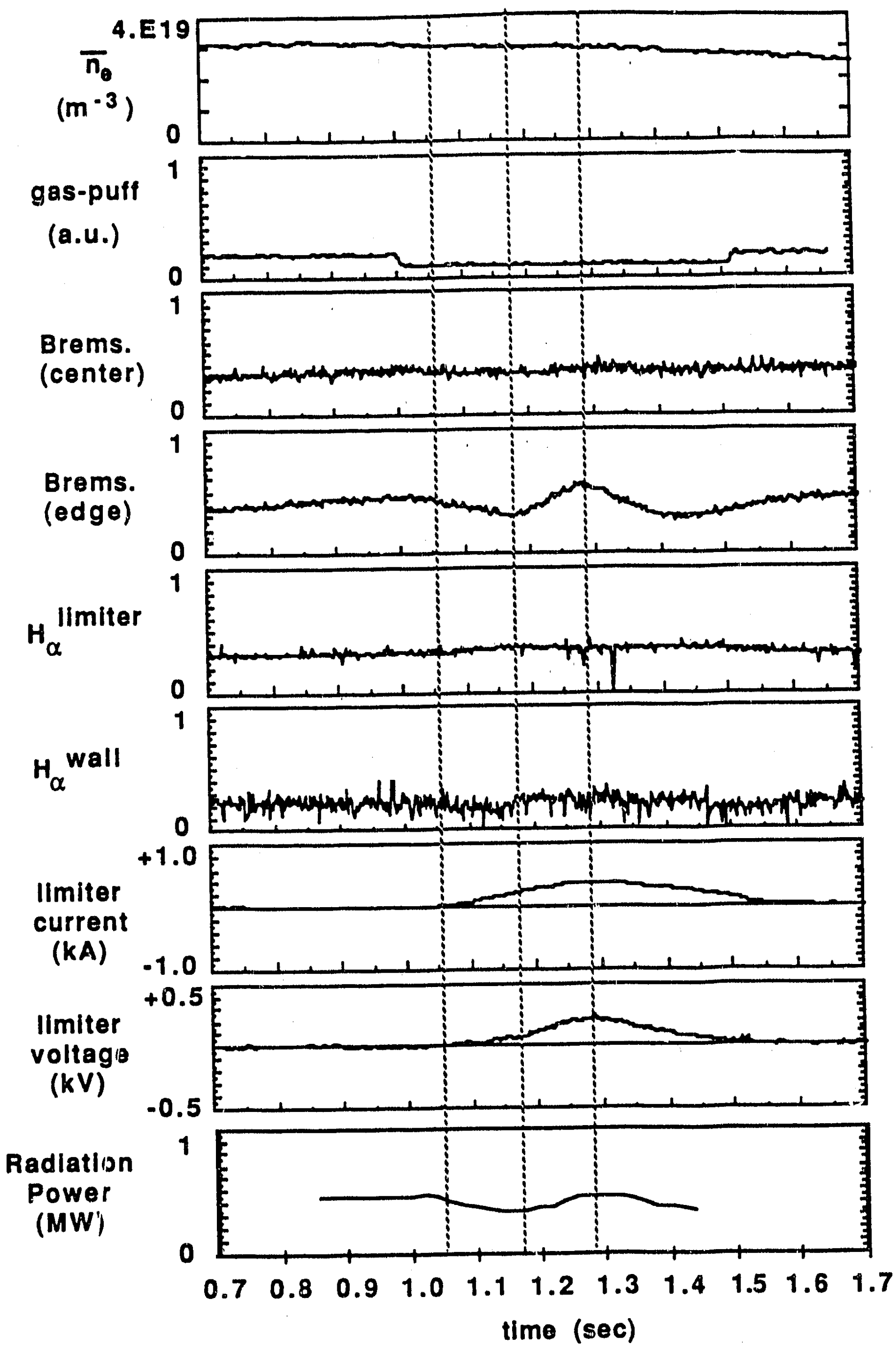

Fig. 2. Positive divertor bias with ohmic heating.

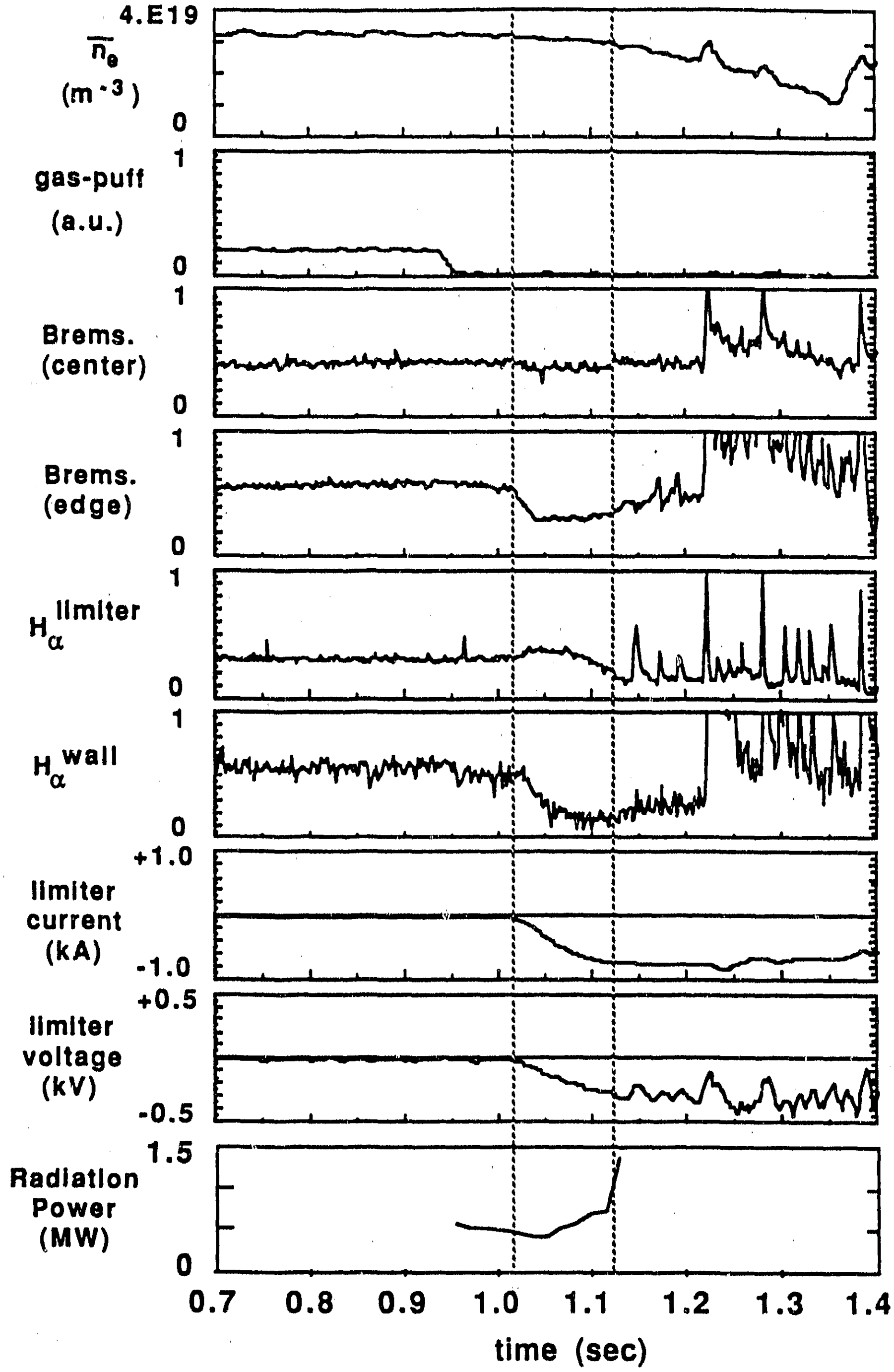

Fig. 3. Negative divertor bias with ohmic heating.

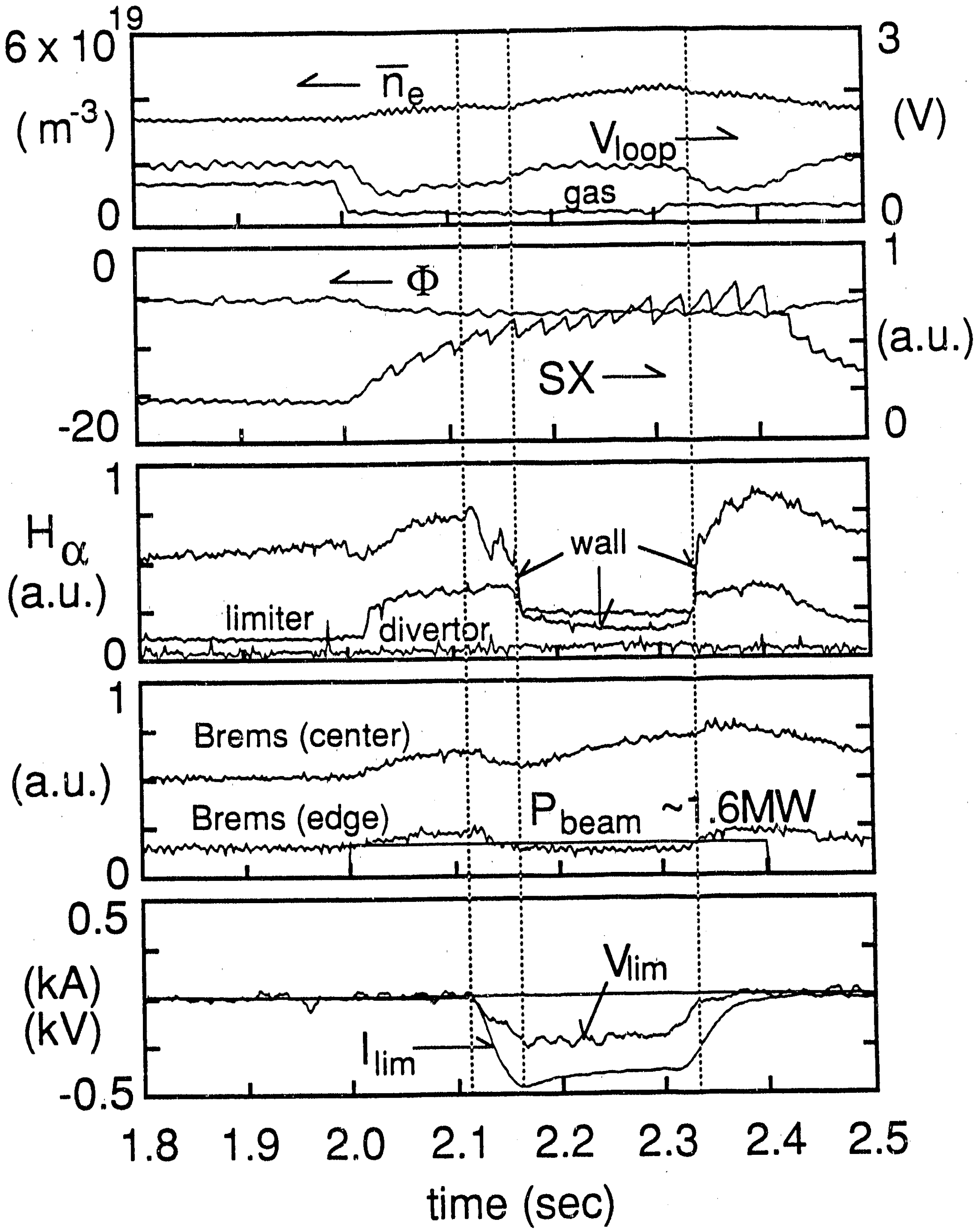

Fig. 4. Negative divertor bias with 1.6 MW neutral beam heating.

With small limiter voltages ($0 > V_{lim} > -200$ V), the H_α emission from the wall decreased from the prebias levels. However, the H_α emission from the limiter showed a slight increase. With stronger limiter voltages ($V_{lim} < -200$ V), both the limiter H_α and wall H_α emissions went down precipitously. The electron density increased at this moment, which shows that particle confinement is improved. Line intensities of carbon, oxygen, and nickel increased. Improvement in energy confinement was not observed.

Neutral beam power was increased to investigate discharge characteristics with higher heating power. In this experiment, it was difficult to reproduce transition-like characteristics observed in Fig. 4 even with heating power similar to Fig. 4. The reason for the change in discharge behavior is not clear. In a few discharges, however, transition-like behavior is observed. Figure 5 shows a discharge with higher neutral beam injection power (5 MW). At 0.45 sec after the limiter bias turn-on, transition-like behavior similar to Fig. 4 is observed. After the transition, H_α emission was reduced both at the limiter and at the wall. Impurity levels and radiation power increased significantly, which made the discharge unstable.

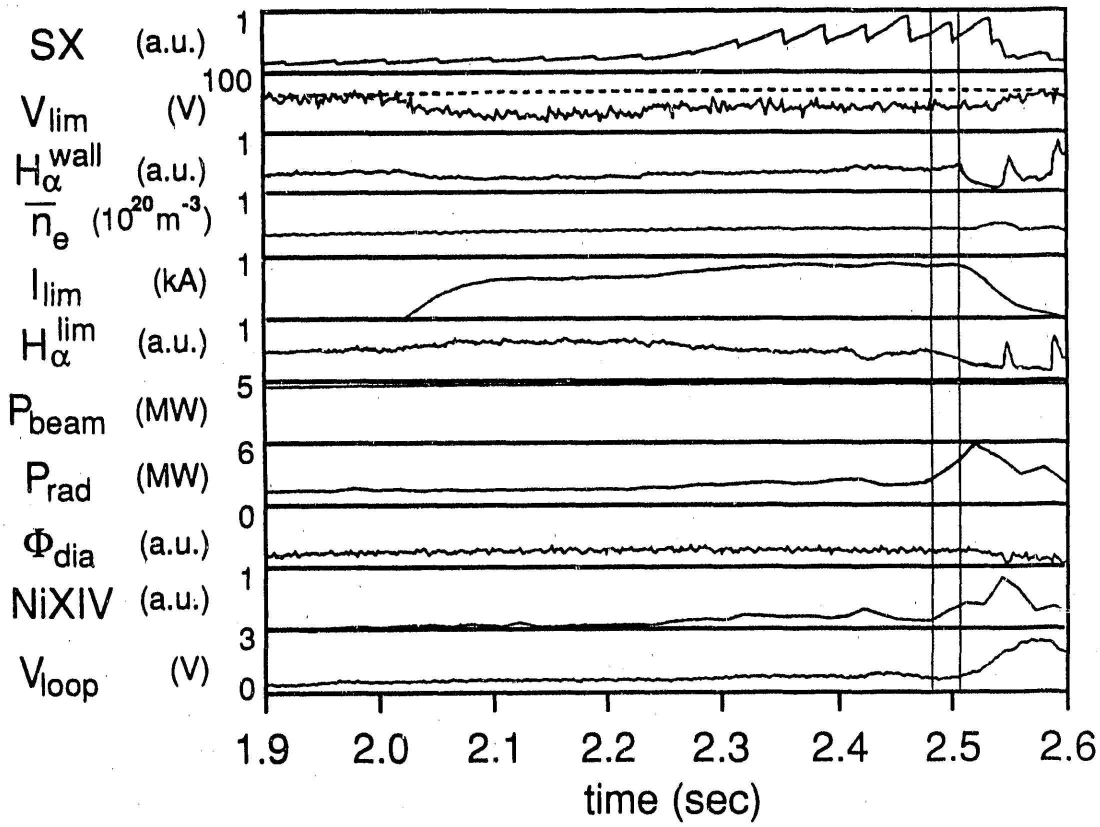

Fig. 5. Negative divertor bias with 5 MW neutral beam heating.

3. DISCUSSION

The particle recycling characteristics exhibited with small, negative limiter voltages were similar to the ones observed in MACROTOR, PBX, and TEXTOR. As limiter voltage was negative with respect to the wall, the ions tend to flow toward the limiter and the electrons flow toward the wall. This can be understood as transport process in the scrape-off layer. However, the change in edge Bremsstrahlung emission ($r/a \approx 0.8$) with both bias polarities, and reduction in particle recycling both at the limiter and the wall cannot be understood as the process just in the scrape-off layer. These phenomena can be only understood as a change in transport process *inside* the limiter-defined surface. As the potential is applied at the limiter, radial electric field near the limiter-defined surface becomes negative, edge plasma starts to rotate, and the radial electric field penetrates inside the limiter defined surface via momentum transfer by radial viscosity or charge-exchange process. The reason for the bifurcation-like behavior is not clear yet. The increase in impurity levels can be due to either improvement in confinement, or increase in impurity influx, or both. As the particle confinement is improved, it may be natural to suppose that impurity confinement is improved as well. If the improvement in particle confinement is due to negative electric field at the edge, impurities should be confined better than the particles, since impurities feel stronger electric force due to their multiple charges.

In this investigation, the effects of edge radial electric field on energy confinement is not clear due to increase in radiation loss power. In DIII–D and JFT-2M, two rows of divertor plates will be biased with respect to the wall and with respect to each other to investigate edge potential and edge current in particle and energy confinement, stability, current drive, and impurity control [10,11]. In these experiments, impurity control by divertor would allow us to do a conclusive investigation on the role of edge electric field in energy confinement.

4. SUMMARY

Experiments in DIII–D demonstrated following characteristics with an electrically biased limiter.

1. H_α signals both at the limiter and at the inner wall were reduced by a factor of 2-3 by strong negative biasing ($V_{lim} \approx -300$ V). In these discharges, the line-average electron densities were approximately the same with and without limiter bias, which suggests that τ_p was improved by negative bias.

2. Edge Bremsstrahlung emission signals were reduced by a factor of two. The central chord Bremsstrahlung signal did not change with bias, suggesting that the electron density profile has a steep gradient at the plasma edge.

3. Repetitive bursts were observed in H_α signals and edge Bremsstrahlung signals.

4. Impurity levels increased with limiter bias, which induced major disruptions.

5. No improvements of τ_E was observed.

These experimental data suggest that particle confinement characteristics of limiter biased discharges (1-4) are similar to those with divertor H–mode. We have not observed improvement of τ_E, which might simply imply that the convection loss is not an important energy transport mechanism with the plasma parameter range investigated. Increased level of impurities and radiation loss power could also have prevented the improvement of energy confinement. In high density discharges and neutral beam heated discharges, the global energy confinement could be dominated by edge convection loss. In those discharges the global energy confinement might be improved by the limiter bias. In addition, the impurity level would be suppressed in high density discharges.

ACKNOWLEDGMENTS

The authors would like to appreciate fruitful discussions and continuous encouragement by Drs. R.D. Stambaugh, J. Luxon, D. Overskei, T. Ohkawa, and T. Simonen. One of the authors (M.S.) would like to express sincere thanks to Drs. S. Konoshima, S. Tamura, and M. Yoshikawa for continuous support.

This work was supported by the U.S. Department of Energy under Contract No. DE-AC03-89ER51114.

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