

CONF-9606226--3

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G.D. Porter, S. Allen, M. Fenstermacher, D. Hill, M. Brown, R.A. Jong, T. Rognlien, M. Rensink,
G. Smith, R. Stambaugh, M.A. Mahdavi, A. Leonard, P. West, T. Evans,
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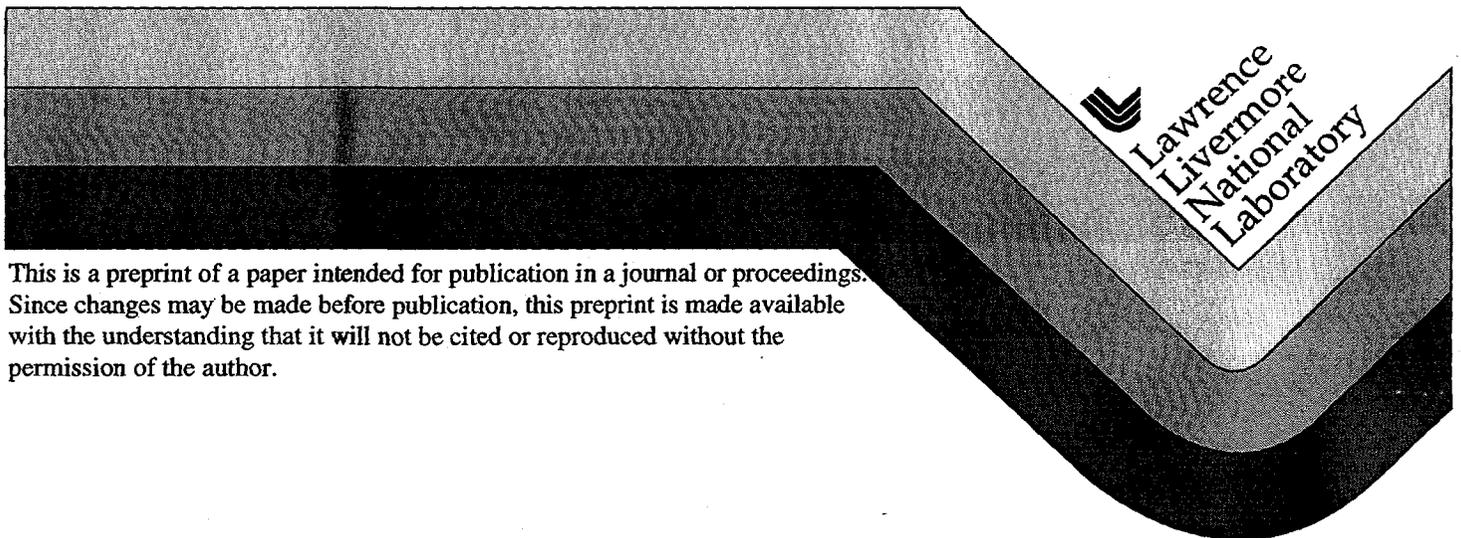
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This paper was prepared for submittal to
23rd European Physical Society (EPS) Conference on Controlled Fusion and Plasma Physics
Bogolyubov Institute for Theoretical Physics
Kiev, Ukraine, June 24-28, 1996

June 18, 1996



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Divertor Characterization Experiments*

G.D. Porter, S. Allen, M. Fenstermacher, D. Hill, M. Brown, R.A. Jong, T. Rognlien, M. Rensink, G. Smith

Lawrence Livermore National Laboratory

P.O. Box 808, Livermore, CA 94550

R. Stambaugh, M.A. Mahdavi, A. Leonard, P. West, T. Evans,
and the DIII-D team

General Atomics

P.O. Box 85608, San Diego, CA 92186-9784

1. Abstract

Recent DIII-D experiments with enhanced Scrape-off Layer (SOL) diagnostics permit detailed characterization of the SOL and divertor plasma under a variety of operating conditions. We observe two distinct plasma modes; attached and detached divertor plasmas. Detached plasmas are characterized by plate temperatures of only 1 to 2 eV. Simulation of detached plasmas using the UEDGE code indicate that volume recombination and charge exchange play an important role in achieving detachment. When the power delivered to the plate is reduced by enhanced radiation to the point that recycled neutrals can no longer be efficiently ionized, the plate temperature drops from around 10 eV to 1 to 2 eV. The low temperature region extends further off the plate as the power continues to be reduced, and charge exchange processes remove momentum, reducing the plasma flow. Volume recombination becomes important when the plasma flow is reduced sufficiently to permit recombination to compete with flow to the plate.

2. Introduction

The design of a viable means of removing the plasma particle and energy exhaust continues to be one of the most challenging efforts in the design of the ITER device. Detailed plasma models which have been validated against extensive experimental data are an important component in that design effort. Diagnosis of the Scrape-off Layer (SOL) and divertor plasmas in the DIII-D tokamak has recently been enhanced with new measurements of the plasma density and temperature in the divertor region¹, and an extension of the measurements of impurity behavior. An recent extensive experimental campaign has fully characterized the behavior of the SOL and divertor plasmas under a variety of operating conditions, including operation with additional Deuterium and/or impurity gas injection to induce divertor plasma detachment. The meaning of

* Work supported by U.S.DoE under LLNL contract W-7405-ENG-48 and GA contract DE-AC03-89ER51114

the data obtained from this experimental campaign is the subject of this report. We briefly describe the overall experimental results in Section 3, focusing on the qualitative behavior we have observed. We describe the application of our 2-D plasma model to the experimental data, focusing on simulation of detached plasma operation, in Section 4.

3. Experimental Results

Initial experimental results from recent DIII-D experiments using the enhanced set of SOL diagnostics have been described previously² Additional results are described in papers presented at this conference. We do not attempt to describe the totality of these results, but simply offer a broad overview of the observed behavior to provide background for understanding the detailed modeling results discussed in the next section. The experiments were done over a broad range of plasma operating conditions. We obtained two distinctly different states of the divertor plasma for all operating conditions—an attached and detached plasma. The attached plasma state is characterized by high ion currents to the plate, and plate electron temperatures above 10 eV. The detached state, described in detail earlier³, is characterized by low plate ion currents, and low electron temperatures. One of the principal observations made with the new divertor Thomson system in DIII-D is that the electron temperature of the detached state is only 1 to 2 eV. Such low temperatures raise the possibility that volume recombination processes may play a role in determining the physics of the divertor plasma, and hence the power and particle load on the divertor. Since the physics of the detached plasma is of particular interest in the divertor design of future devices, we describe our modeling of the detached state in the next section.

4. Results of modeling detached plasmas

We attempt to better understand the physical processes which lead to the detached plasma state by simulating experimental results with the UEDGE code⁴, a 2-D fluid plasma code with classical parallel physics and anomalous perpendicular transport. We consider a DIII-D discharge which obtained detachment with deuterium injection and use a simple fixed fraction model to simulate the effect of impurity radiation. The simulation begins by determining the anomalous perpendicular transport coefficients consistent with the measured upstream radial profiles of density and temperature. We obtain the best match for the discharge discussed here (87506) with $D_{\perp} = 0.2 \text{ m}^2 / \text{s}$, $\chi_e = 0.28 \text{ m}^2 / \text{s}$. In general, we find the electron thermal diffusivity increases with heating power.

Having used the experimental measurements of the upstream density and temperature to

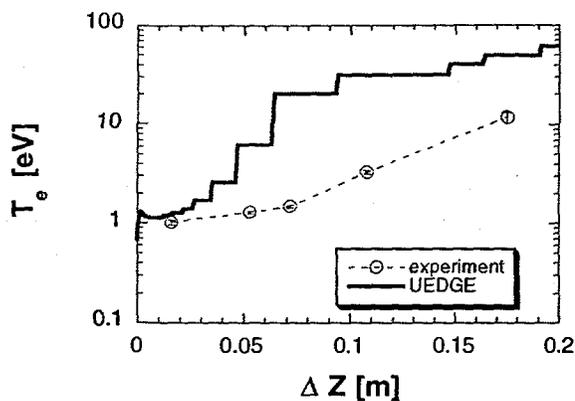


Figure 1 Variation in the electron temperature along a vertical line at $R=1.94$ m.

determine the perpendicular transport coefficients, we compare the simulated electron temperature near the divertor with that measured on the divertor Thomson system in Figure 1. The experimental measurement is obtained at a major radius of 1.94 m, and extends from about 1.5 cm above the divertor plate to about 20 cm off the floor. The measurement is entirely within the SOL for this particular discharge, i.e. no data are taken in the private flux region. As can be seen in Figure 1, the temperature measured near the floor is only 1 eV, consistent with the simulation. The

measured temperature remains between 1 and 2 eV until approximately 8 cm off the floor. The X-point is only 15 cm off the floor, so the low temperature region is measured to extend over a large portion of the plasma below the X-point. Although the simulation obtains similar temperatures at the floor, the spatial extent of the low temperature region is somewhat smaller than measured. This discrepancy probably arises from the simple treatment of impurity radiation which is used for the simulation. The simulation obtains temperatures between 1 and 2 eV over a much larger spatial extent on the inner divertor leg because of the higher density and larger radiation occurring on that region. Despite the discrepancy on the spatial extent of the low temperature region, it is interesting to examine the simulation in detail to determine the physical processes which are important in this detached plasma.

The dominant processes can be deduced from the data shown in Figure 2. The upper portion of this figure shows the poloidal variation of the volume recombination and ionization rates along the separatrix on the inner leg. The lower portion of the figure shows the poloidal variation of the Mach number of the plasma flow, and the ratio of the time scale for recombination ($1/\nu_{\text{recomb}}$) to the time constant for flow to the plate. The ionization rate peaks about 10 cm off the plate, corresponding to the location of the region where the electron temperature drops below that needed for efficient ionization (about 5 eV). Since the electron temperature is in the range of 1 to 2 eV below this ionization front, charge-exchange reactions dominate over ionization. Hence collisions between plasma and neutrals are an effective way of transferring momentum from the plasma to the neutrals, and thus to the walls. This momentum removal then results in a decrease in the parallel flow velocity, as seen in the lower curve of Figure 2. When the flow velocity slows sufficiently to permit volume recombination to compete with flow to the plate, the recombination rate increases, and the plasma ions are converted very effectively to neutrals, reducing the ion flow to the plate. As shown in Figure 1, the simulated temperature at the outer strike point has also

dropped to only 1 eV, sufficiently low to permit volume recombination. However, the ionization front is only about 4 cm off the plate, rather than 10 cm for the inner divertor, and there is little momentum loss from charge exchange. Hence the ion current to the outer plate remains high, as seen experimentally. The simulated divertor heat load is also much higher at the outer plate than the inner, consistent with experiment.

5. References

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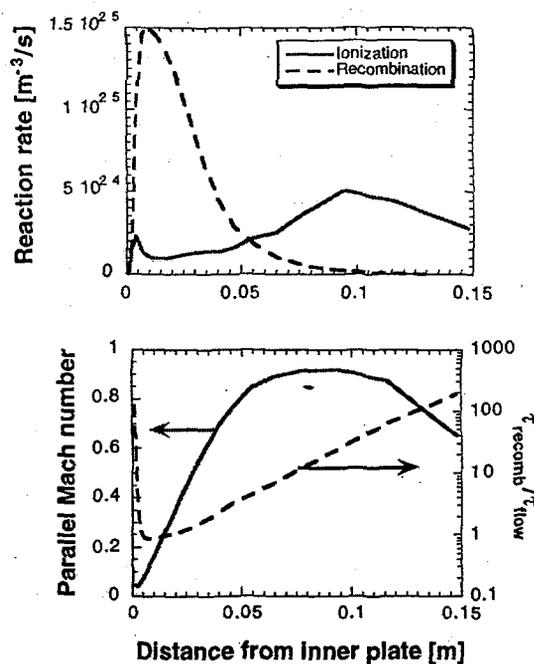
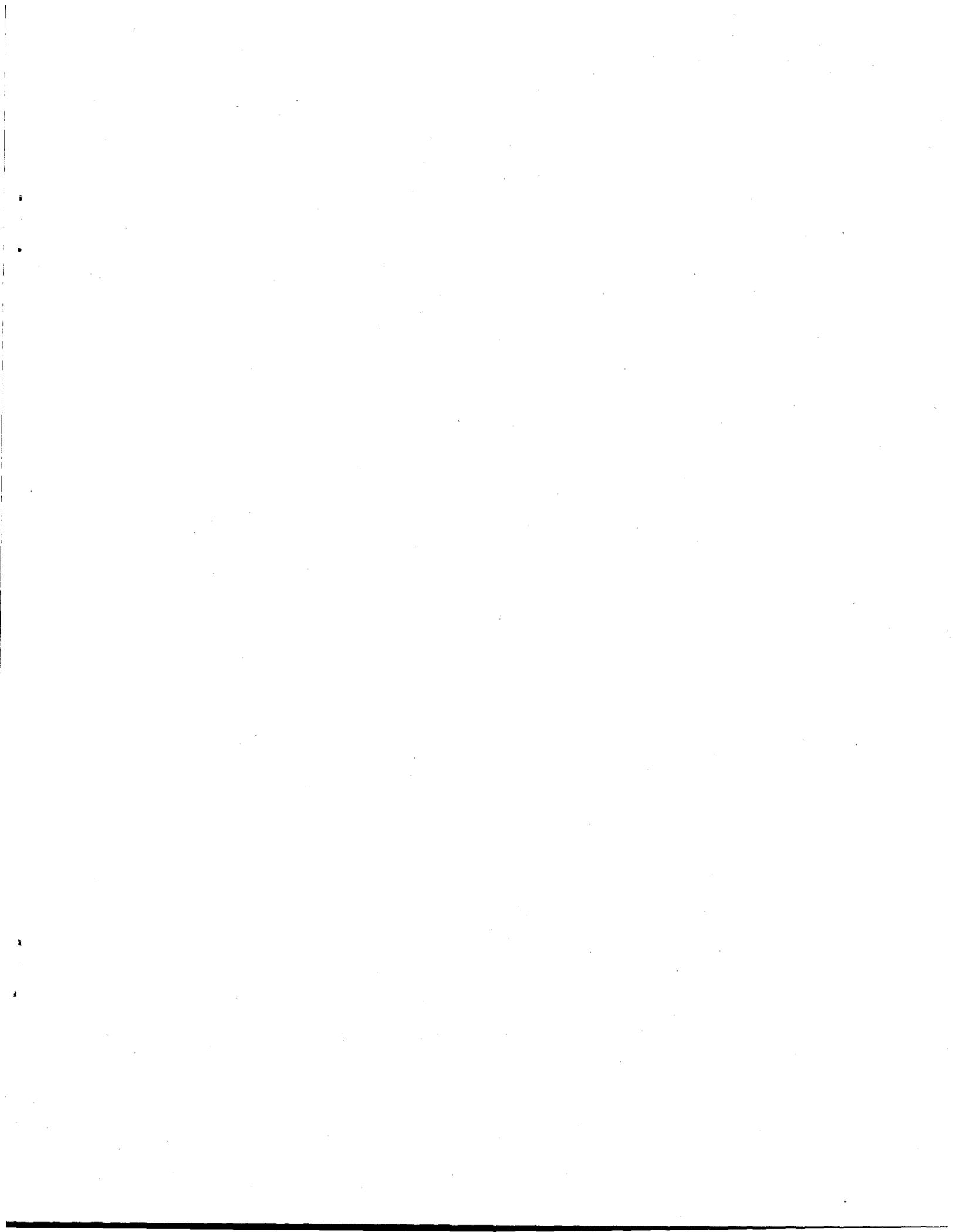


Figure 2 Poloidal variation of plasma parameters near the separatrix on the inner leg.



**Technical Information Department • Lawrence Livermore National Laboratory
University of California • Livermore, California 94551**

