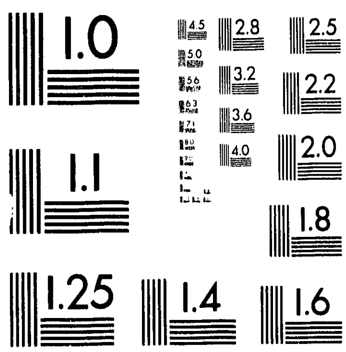
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Conf-931070--4

UCRL-JC-114695
PREPRINT

Benchmarking UEDGE with DIII-D Data*

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This paper was prepared for submittal to the
4th International Workshop on
Plasma Edge Theory in Fusion Devices
Varenna, Italy
October 4-6, 1993

September 1993

Lawrence Livermore National Laboratory

DISCLAIMER

Benchmarking UEDGE with DIII-D Data*

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Abstract

Comparisons between a 2-D fluid simulation of the SOL plasma of a diverted tokamak and experimental data from the DIII-D are shown. It is concluded that a simple diffusive model for perpendicular transport is consistent with the data. Discrepancies in the simulation suggest that impurity radiation may be playing a significant role in the experiment, and that further work is required to understand hydrogen recycling at the divertor.

1. Introduction

The UEDGE code is a 2-D fluid code used to simulate the Scrape-off-layer (SOL) plasmas which exist at the edge of a tokamak[1] This code utilizes classical physical processes for transport of plasma particles and energy parallel to the magnetic field in the SOL, and anomalous diffusion for perpendicular transport. Kinetic effects are approximated by limiting the electron and ion parallel thermal fluxes to a fraction of the thermal heat flux, nTc_s, where c_s is the plasma sound speed. We report here comparisons between 2-D fluid simulations and experimental data taken on the DIII-D tokamak.

In section 2 of this paper we describe the diagnostic set used to determine the parameters of the plasma in the SOL. A key question which arises in describing the SOL plasma is that of determining the location of the last closed flux surface, the separatrix. We describe the technique used for that determination in section 3. Section 4 contains a detailed comparison between calculated and measured SOL plasma parameters for a particular DIII-D shot. Finally, we finish with discussion.

* Work performed under the auspices of the USDOE contracts W-7405-ENG-48 by LLNL, and DE-AC093-89ER51114 by General Atomics

2. Description of the diagnostic set used for benchmarking

The SOL of the DIII-D tokamak is instrumented to determine the relevant plasma parameters at several poloidal locations. A typical single null plasma configuration is shown in Figure 1. The electron density and temperature are measured by three instruments: a Thomson scattering system along the line R=1.94 m, with spatial resolution on the order of 1 cm near the edge of the plasma; a retractable Langmuir probe array which is inserted 15 cm below the midplane from the outside of the torus; and a Langmuir probe array which spans the lower divertor. The ion temperature is determined by a Charge Exchange Recombination (CER) instrument which determines the temperature at Z≈0. The power deposited on the divertor floor is measured with an Infrared camera system (IRTV) which views the floor from a port at the top of the torus. Additional IRTV systems view the center post and upper divertor. Hydrogen recycling is measured by an array of photodiodes with optical filters selected to measure emission of the H_α line.

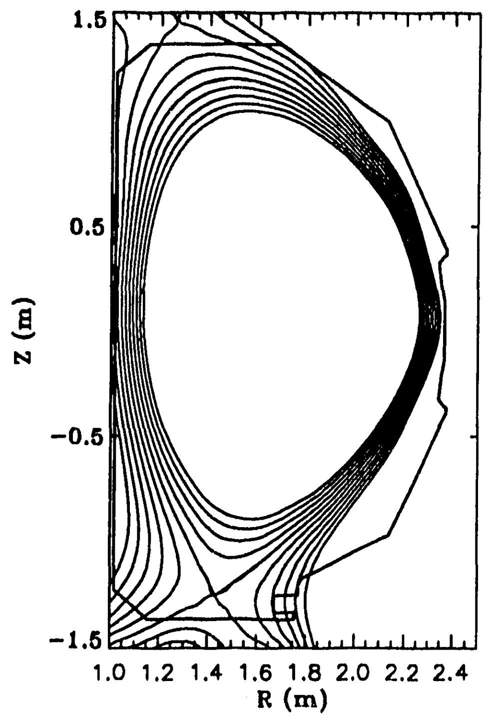

Figure 1: Typical magnetic equilibrium for a single null DIII-D plasma.

3. Determination of location of separatrix

A typical H-mode profile of electron density and temperature in the SOL, as determined from the Thomson scattering system, is shown in Figure 2. The key feature of these profiles is the steep gradient near the plasma edge in both the density and temperature. The steep gradient region of the density typically lies 1-2 cm outside that of the temperature. Since the density and temperature at the separatrix is important for our fluid model, we must know the position of the separatrix accurately. The details of the technique we use to determine this position lie beyond the scope of this paper. Basically, we determine the equilibrium shape consistent with the magnetic data using the magnetic equilibrium code, EFIT[2]. The details of the shape of the separatrix are sensitive to input assumptions made in this code, in particular, the behavior of the plasma current at the separatrix. The proper choice of these input variables is determined by requiring the peak power measured at the inner and outer strike points on the divertor floor to lie near, but slightly outside, the strike points determined by EFIT. In H-mode operation this typically requires permitting finite current at the separatrix. Examination of several hundred H-mode shots indicate the peak power at the outer divertor lies within 1-2 cm of the EFIT-determined strike point, while that at the inner divertor lies within 3-5 cm. The consistency of these data lend confidence in our ability to accurately locate the separatrix.

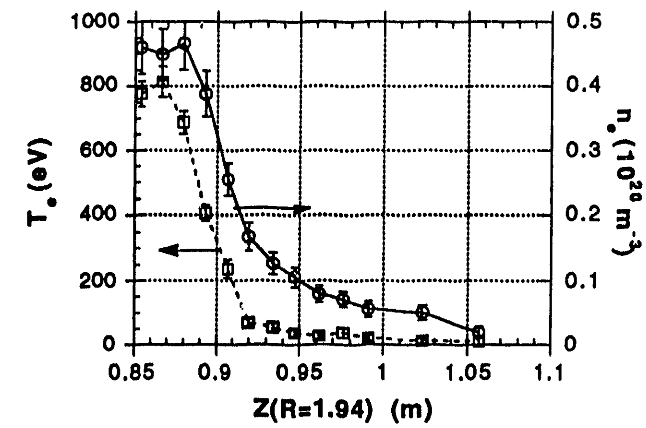

Figure 2: Typical profile of electron density (open circle) and temperature (open squares) near the plasma separatrix.

It is also important to know the separatrix position along the line on which the Thomson scattering system determines the plasma density and temperature. The equilibrium determined to be consistent with the divertor power profile typically places the separatrix near the outside edge of the steep gradient region of the electron temperature, e.g. at Z=0.91 in the data shown in Figure 2. This is consistent with simple phenomenological arguments for its location. The plasma thermal energy flows only normal on closed flux surfaces, while it can flow both normal and along magnetic field lines on the open surfaces in the SOL. If the perpendicular thermal energy flow is diffusive, $q \propto \partial T/\partial r$, we expect the radial temperature gradient to be reduced (for constant thermal diffusivity) on the open field lines. However, the parallel energy flow can not appear discontinuously as one goes from closed to open lines. Rather, the tendency of the temperature to be constant on a flux surface on closed lines requires that $dT/ds \approx 0$, and hence $q_{||} \approx 0$ at the separatrix. Hence the reduction in the radial temperature gradient will occur slightly outside the separatrix, as obtained by our EFIT solutions. The final check on the accuracy of the location of the separatrix will be the calculated power across the separatrix. If we have correctly modeled the density and temperature profiles, with purely diffusive models for perpendicular thermal energy flow, the calculated power across the separatrix will be consistent with that inferred experimentally. If, however, we have inaccurately located the separatrix, the density and temperature at the separatrix will be wrong, and hence the calculated power will be inconsistent with the experiment.

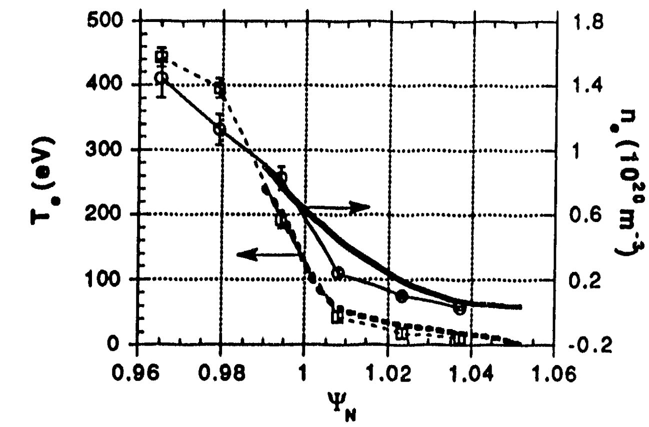

Figure 3: Comparison of measured (open circles) and calculated (solid line) electron density, and measured (open squares) and calculated (dashed line) electron temperature.

4. Comparison of calculated and measured plasma parameters

We use a boundary condition of fixed density and temperature (both electron and ion) at the 99% flux surface to simulate a specific DIII-D experiment with the UEDGE code. This forces the particle and energy fluxes to vary poloidally, depending on the radial gradients. We vary the perpendicular diffusion coefficients for particles, $D_\perp$, ion thermal flux, χ_i, and electron thermal flux, χ_e, until the radial profile of the plasma density and temperature are consistent with those determined experimentally. The measured and calculated profiles of electron density and temperature for shot 78037, at 2800 ms is shown in Figure 3. We plot the plasma parameters versus the normalized flux rather than Z as in Figure 2, with the separatrix located at Ψ_N=1.0. This simulation was obtained with $D_\perp$=0.04 m^2/s, and χ_e=χ_i=0.12 m^2/s. Typically, the ion temperature is significantly higher than the electron; on the order of a factor of two. In addition, the ion temperature gradient is smaller than the electron.

The power across the separatrix calculated from the simulated density and temperature profile shown in Figure 3 is 4.0 MW, compared with 3.0 MW inferred from the experiment. Although somewhat high, the calculated power is near the experimental uncertainty associated with determining the power radiated inside the last closed flux surface. Typically the power calculated in UEDGE when the density and temperature profiles are matched to the experiment varies from slightly higher, as in this case, to a factor of two lower than the experimentally inferred power. A detailed comparison of the measured and calculated exhaust power profile, however, is somewhat poorer. The profile of the measured and calculated divertor parallel power density at the outer strike point for the shot shown in Figure 3 is shown in Figure 4.

The very sharp peak in the simulated power near the separatrix is consistent with the data. However, the broad shoulder in the simulation, created by flow in the ion channel, does not exist in the experiment, hence the simulated profile is significantly broader than measured. The most obvious difference, however, is the scale of the two curves in Figure 4. The peak simulated power is almost a factor of 4 higher than measured. This difference arises from at least three sources. First, the power radiated in the SOL is significantly higher in the experiment than we calculate assuming only hydrogen (1.4 MW versus 0.2 MW). Secondly, the experiment only accounts for 2.4 MW of the 3.0 MW crossing the separatrix leading to a 0.6 MW uncertainty in the divertor power. Finally, the simulation has 1.0 MW more power across the separatrix than the experiment. Reducing the discrepancy between the experiment and simulation will require a combination of more consistent total power flow, and increasing the SOL radiation in the simulation, presumably by including radiation from impurities.

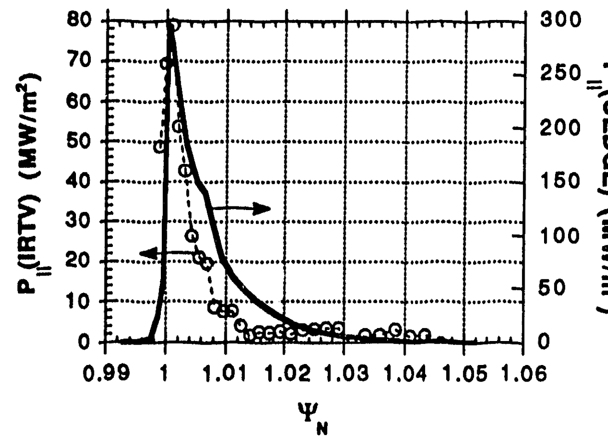

Figure 4: Comparison of measured (open circles) and calculated (solid line) parallel power profile at the divertor floor.

Further comparison between simulation and experiment can be made by examining the plasma conditions at the divertor floor. This is done by comparing the density and temperature with that determined from the Langmuir probe array, and comparing the calculated H_α emission with that measured. Space constraints of this paper do not permit showing detailed comparisons. Suffice it to say the density calculated at the outer strike point is significantly higher than measured, although the peak temperature is within a factor of two of the 45 eV measured near the separatrix. The simulated density and temperature are approximately a factor of two higher than measured at the inner strike point. These differences are consistent with the H_α emission where the simulated emission is within a factor of two of the measured at the inner strike point, and almost a factor of 10 higher at the outer.

5. Discussion

While we are not yet able to reproduce all SOL plasma parameters with a 2-D fluid model, we have shown that some aspects of the model are consistent with the experiment. The agreement between measured and calculated midplane density and temperature profiles, together with the correctly simulated *shape* of the divertor power profile, suggests that a simple diffusive model for perpendicular transport is consistent with experiment. Furthermore, the reproduction of the details of the midplane electron temperature profile, together with the consistency of the power across the separatrix suggest an accurate experimental determination of the position of the separatrix. The values of the anomalous diffusion coefficients required to obtain this consistency is considerably smaller than previously used for modeling future devices, with $D_\perp \leq 0.1$, and $\chi \leq 0.5$ m^2/s.

On the other hand, details of the plasma parameters at the divertor were not accurately modeled. In particular, the magnitude of the divertor power was grossly overestimated. This discrepancy, together with the underestimation of the measured power radiated in the SOL, suggests impurity radiation may be playing a major role in the experiment, and must be included in our simulations. The divertor density and temperature, together with the resulting H_α emission, were not accurately modeled with the code. These discrepancies suggest further work must be done on the model for recycling at the divertor floor.

References

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[2] L. L. Lao, et.al., Nucl. Fus., **30**, 1035, (1990)

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