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*Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA.
†Sandia National Laboratory, Albuquerque, New Mexico, USA.
‡Lawrence Livermore National Laboratory, Livermore, California, USA.
#University of California San Diego, La Jolla, California, USA.
¶University of Toronto, Toronto, Canada.

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Effect of Changes in Separatrix Magnetic Geometry on Divertor Behavior in DIII-D EX-D

T.W. Petrie[1], J. Canik[2], A.W. Leonard[1], M.A. Mahdavi[1], J.G. Watkins[3], R.J. Buttery[1], M.E. Fenstermacher[4], J.R. Ferron[1], R.J. Groebner[1], D.N. Hill[4], A.W. Hyatt[1], C.T. Holcomb[4], C.J. Lasnier[4], T.C. Luce[1], R.A. Moyer[5], and P.C. Stangeby[6]
e-mail: petrie@fusion.gat.com

[1]General Atomics, P.O. Box 85608, San Diego, CA 92186-5608, USA
[2]Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831, USA
[3]Sandia National Laboratories, P.O. Box 5800, Albuquerque, NM 87185, USA
[4]Lawrence Livermore National Laboratory, Livermore, CA 94550, USA
[5]University of California San Diego, La Jolla, CA 92093-0417, USA
[6]University of Toronto Institute of Aerospace Studies, Toronto M3H 5T6, Canada

We report results and interpretation of recent experiments on DIII-D designed to evaluate divertor geometries favorable for radiative heat dispersal. Two approaches studied involved lengthening the parallel connection in the scrape-off layer (SOL), $L_{||}$, and increasing the radius of outer divertor target, R_{TAR}, with the goal of reducing target temperature, T_{TAR}, and increasing n_{TAR}. Based on 1-D two-point modeling [1]: $n_{TAR} \propto [R_{TAR}]^2\ [L_{||}]^{6/7}\ [n_{SEP}]^3$ and $T_{TAR} \propto [R_{TAR}]^{-2}\ [L_{||}]^{-4/7}\ [n_{SEP}]^{-2}$, where n_{SEP} is the midplane separatrix density. These scalings suggest that conditions conducive to a radiative divertor solution can be achieved at low n_{SEP} by increasing either R_{TAR} or $L_{||}$. While our data are consistent with the above $L_{||}$ scalings, the observed scalings on R_{TAR} displayed a more complex behavior, under certain conditions deviating from the above scalings. Our analysis indicates that deviations from the R_{TAR} scaling were due to the presence of convected heat flux, driven by escaping neutrals, in the more open configurations of the larger R_{TAR} cases.

We examined the configurations in Fig. 1, among others, in H-mode and L-mode confinement regimes. The collisionalities in the SOL for these plasmas straddle the conduction and sheath-limited regimes [1]. The plasmas were characterized by n_e/n_G = 0.4-0.8, P_{IN} = 4-6 MW, H_{89p} = 1.2-2.0, and q_{95} = 4-5 in H-mode; n_e/n_G = 0.2, P_{IN} = 1.5 MW, and q_{95} = 3.8-4.0 in L-mode. The ion $\boldsymbol{B}x\boldsymbol{\nabla}\boldsymbol{B}$ drift direction was toward the X-point with no active particle exhaust.

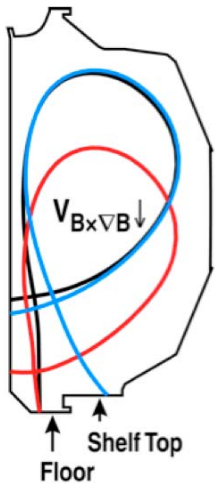

Fig. 1. The 3 principal plasma cross-sections: 1. R_{TAR} = 1.20 m, I_p = 40 m (black), 2. R_{TAR} = 1.20 m, I_p = 32 m (red), and 3. R_{TAR} = 1.66 m, I_p = 35 m (blue).

The variation of n_{TAR} and T_{TAR} at the outer strike point (OSP), as determined from Langmuir probe data, in L-mode, are in qualitative agreement with the two-point model when "Floor" and "Shelf Top" regions are considered separately, i.e., n_{TAR} increases and T_{TAR} decreases as R_{TAR} is increased [Fig. 2(a)]. However, the data show a clear discontinuity when the outer strike point was swept over the shelf top. The R_{TAR}-exponents for n_{TAR} and T_{TAR} on the shelf top are ≈2-3, as expected from two-point modeling, while on the floor the R_{TAR}-exponents are much higher. In H-mode cases, similar to L-mode, n_{TAR} increased and T_{TAR} decreased as R_{TAR} was swept radially outward on the floor [Fig. 2(b)]. While there is only one H-mode shot on the shelf top with upstream parameters matching with the floor data, a discontinuity of n_{TAR} and T_{TAR} across the floor-shelf top boundary is still evident.

We postulate that this discontinuity is due to less effective neutral trapping when the outer strike point is on the shelf top. We further postulate that re-ionization of escaping neutrals upstream can drive a convected heat flux towards the target and that this heat flux tends to increase divertor temperature and reduce the divertor density. To examine the validity of this postulate we have conducted SOLPS-Eirene code [2] modeling of actual

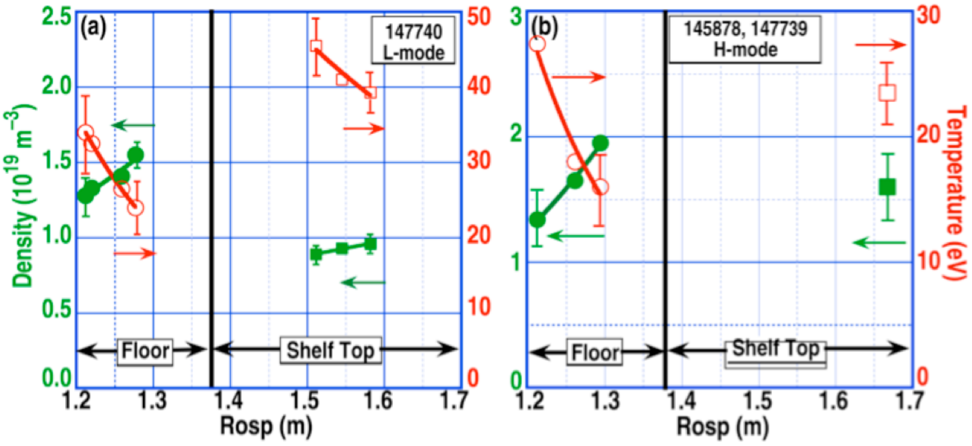

Fig. 2. The variation of electron density n_{TAR} and temperature T_{TAR} at the outer divertor target as a function of radial outer strike point location R_{TAR}. (a) *L-mode* case: I_p = 0.78 MA, B_T = 1.95 T, P_{IN} = 1.6 MW, q_{95} = 3.8, constant pedestal density (feedback control). (b) *H-mode* case: I_p = 0.79 MA, B_T = 1.95 T, P_{IN} = 4.8 MW, $q_{95} \approx 4$, n_{SEP} = 0.8–0.9x10^{19} m^{-3}, T_{SEP} = 75–90 eV.

discharges with the existing vessel wall boundaries and a number of cases with modified wall boundaries.

Preliminary modeling indicates that neutrals play a significant role in the qualitative picture presented above. SOLPS modeling of n_{TAR} and T_{TAR} are shown in Fig. 3 for two H-mode discharges with different R_{TAR}. Electron diffusivity χ_e, ion diffusivity χ_i, and particle diffusivity D are determined by fitting to the upstream n_e, T_e, and T_i profiles from the Thomson scattering and charge exchange recombination diagnostics, respectively. Qualitatively, n_{TAR} and T_{TAR} show the same behavior with R_{TAR} as observed in the experiment, with T_{TAR} from SOLPS, in fact, approximating the experimental T_{TAR}. SOLPS indicates lower n_{TAR} and higher T_{TAR} when the OSP was on the shelf top. SOLPS modeling of the "floor" plasmas in Fig. 2(b) also showed the importance of neutrals trapping with strong increases in n_{TAR} and decreases in T_{TAR}, as the OSP approached the baffle structure.

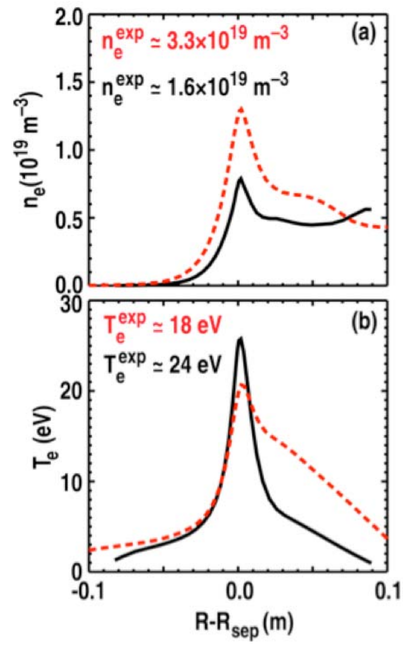

Fig. 3. (a) n_{TAR} and (b) T_{TAR} profiles from SOLPS analysis of H-mode shots 145878 (R_{TAR} = 1.66 m, solid black) and 146010 (R_{TAR} = 1.20 m, dashed red). Their respective peak experimental values are included in each box. I_p = 0.79 MA, B_T = 1.95 T, P_{IN} = 4.8 MW, $q_{95} \approx 4$, $n_{SEP} \approx 0.9$x10^{19} m^{-3}, $T_{SEP} \approx 75$ eV.

Changes in $L_{||}$ on n_{TAR} and T_{TAR} were consistent with the simple two-point model prediction, i.e., assuming n_{TAR} and T_{TAR} for a given $L_{||}$ yields n_{TAR} and T_{TAR} for a second value of $L_{||}$ case to ≈10%. The cross-section of the main plasma and R_{TAR} were held fixed (Fig. 1, black & red curves), while $L_{||}$ was varied between 32 m and 40 m. Small differences in upstream density at the separatrix n_{SEP} (<10%) were taken into account. Due largely to differences in poloidal flux expansion, the *between ELM* peak heat flux at the outer divertor target, based on infrared camera measurements, was greater in the high X-point case ($L_{||}$=40 m) than in the low X-point case ($L_{||}$=32 m), i.e., ≈1.1 MW/m^2 vs ≈0.9 MW/m^2. These heat flux results based on infrared camera measurements fell within ≈20% of heat flux determined by Langmuir probes assuming γ_T=7.

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