GA–A26651

SCALING OF DIVERTOR HEAT FLUX PROFILE WIDTHS IN DIII-D

by
C.J. LASNIER, M.A. MAKOWSKI, J.A. BOEDO,
N.H. BROOKS, A.W. LEONARD and J.G. WATKINS

APRIL 2010

GENERAL ATOMICS

DISCLAIMER

GA–A26651

SCALING OF DIVERTOR HEAT FLUX PROFILE WIDTHS IN DIII-D

by
C.J. LASNIER[1], M.A. MAKOWSKI[1], J.A. BOEDO[2],
N.H. BROOKS, A.W. LEONARD and J.G. WATKINS[3]

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]University of California-San Diego, La Jolla, California
[3]General Atomics, PO Box 85608, San Diego, California

Work supported in part by
the U.S. Department of Energy
under DE-AC52-07NA27344
and DE-FC-04ER56498

GENERAL ATOMICS ATOMICS PROJECT 30200
APRIL 2010

GENERAL ATOMICS

Peak steady-state divertor heat flux, $\hat{q}_{\mathrm{div}}$, in high confinement burning plasmas remains an open design issue for next generation high power tokamaks such as ITER, largely because of uncertainties in the heat flux profile width, λ_q. Recent experiments in DIII-D featuring divertor heat flux measurements with improved temporal and spatial resolution show that the heat flux profile width in ELMing H-mode discharges, $\lambda_{q,div}$, varies as $1/I_p$ and is nearly independent of power, in agreement with earlier data [1]. The variations in midplane scrape-off layer (SOL) electron temperature scale lengths (λ_{Te}) are much weaker.

Present divertor designs for future high power tokamaks such as ITER call for radiative dissipation of a significant fraction of the heat conducted along SOL field lines to the divertor ($q_\parallel$) to achieve adequate lifetime component lifetime. Both $q_\parallel$ and λ_q are sensitive to perpendicular transport in the SOL, so there is strong motivation to determine how these quantities vary with plasma conditions. Previous studies over the last decade examining the dependence of the divertor heat flux profile width on tokamak operating parameters produced diverse results for the parameter dependence of λ_q in different devices [2].

Improved heat flux measurements, coupled with improved alignment of the divertor tiles and a better picture of SOL turbulence, motivate new experiments in DIII-D to determine the variation in $\lambda_{q,div}$ with fundamental tokamak and SOL parameters (I_p, B_T, P_{SOL}, ρ^*, and ν^*) for lower single null ELMing H-mode plasmas. The divertor heat flux was calculated from infrared camera measurements using a new high-resolution fast-framing IR camera (107 μs frame time and 2.5 mm spatial resolution). The frame rate was sufficiently fast to resolve the quiescent heat flux from that due to ELMs. The widths shown here are as measured at the divertor plate and λ_q is defined as the full width of the heat flux profile at half its maximum.

We find that $\lambda_{q,div}$ at the outer divertor separatrix intercept decreases as $1/I_p$, Fig. 1, consistent with previous measurements and with NSTX data [3], but stronger than expected from changes in connection length alone ($\lambda_q \propto L_\parallel^{2/7}$, $L_\parallel \propto 1/I_p$ with B_t=const, so $\lambda_q \propto I_p^{2/7}$). The stronger dependence is attributed to changes in radial transport. We note that the inner divertor is often partially detached with higher divertor radiation as compared to the outer divertor; no ISP heat flux peak was seen at the lowest plasma current. The SOL magnetic flux expansion for these discharges is about 7, implying that λ_q at the outer midplane varied from 0.3 to 1.0 cm.

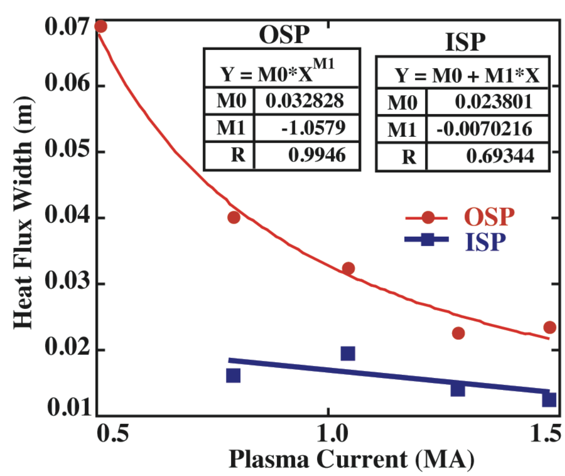

Fig. 1. Profile widths plotted against plasma current.

Scans of plasma current and magnetic field $|B_T|$ were also obtained at constant edge safety factor, q_{95}, to avoid changing the SOL connection length. Unlike previous data obtained from a B_T scan at constant I_p (yielding $\lambda_q \propto \sqrt{|B_T|}$, very nearly proportional to $L_{\|}^{2/7}$), the new data at constant $L_{\|}$ (q_{95}) show λ_q decreasing linearly with toroidal field, Fig. 2, presumably as a the result of changes in transport with I_p as above. In other scans, we found only very weak dependence of $\lambda_{q,div}$ on input power, in agreement with data from NSTX [3], JET [4] and ASDEX-Upgrade-DIVII [5]. There is also little variation in $\lambda_{q,div}$ with line-average plasma density for $n_e \leq 0.7 n_{GW}$, above which the width sharply increases.

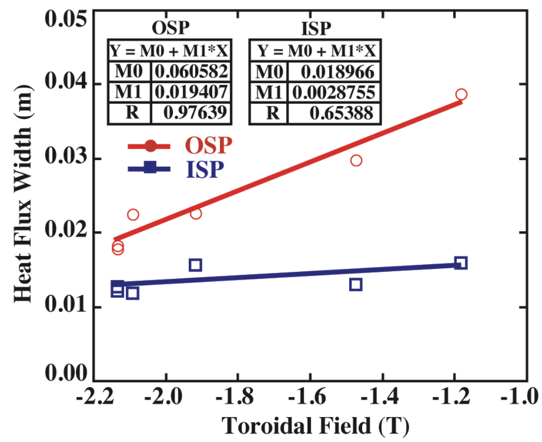

Fig. 2. Profile widths versus toroidal field at constant q_{95}.

The relation between the divertor heat flux profile width and the midplane SOL plasma parameters is needed for SOL model validation activities and to heat flux scaling studies for tokamak design. We use midplane electron temperature profiles from Thomson scattering measurements as a proxy for λ_q at the midplane because it is routinely measured and because we expect a strong correlation between them due to high electron thermal conduction; SOL models predict $\lambda_{Te} = (7/2)\ \lambda_q$. However, our data show $\lambda_{Te} \approx$ const even as $\lambda_{q,div}$ varies by nearly a factor of two. We have also measured density and potential fluctuations in the SOL in low-power H-mode discharges using fast-plunging Langmuir probes at two poloidal locations, seeking to correlate changes in $\lambda_{q,div}$ with changes in edge turbulence.

Our results are also being compared to simulations from the UEDGE 2D fluid code, which accurately includes the SOL magnetic geometry, divertor geometry and neutral recycling, and radiative losses. In these simulations we are focusing on testing the physics by matching the observed trends rather than detailed profiles since the number of free parameters controlling the divertor/SOL conditions greatly exceeds the number of measurements.

This work was supported in part by the US Department of Energy under DE-AC52-07NA27344 and DE-FC-04ER56498.

[1] C.J. Lasnier, *et al.,* Nucl. Fusion **38**, 1225 (1998)
[2] A. Loarte, *et al.,* J. Nucl. Mater. **266-269**, 587 (1999)
[3] R. Maingi, *et al.,* J. Nucl. Mater **363-365**, 196 (2007)
[4] T. Eich, *et al.,* J. Nucl. Mater. **333-339**, 669 (2005)
[5] A. Herrmann, Plasma Phys. Control. Fusion **44**, 883 (2002)