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1. INTRODUCTION

The idea of adopting Tungsten as the material for several Plasma Facing Components in ITER emphasizes the importance of understanding the transport that governs heavy impurities in low collisionality H-mode discharges and the ways to control their core concentrations. Various experiments worldwide have shown that electron heating by means of Radio Frequency power does flatten the impurity density [1]. In [1] the RF induced outward flow of Si traces was justified as due to Trapped Electron Modes (TEM) on the basis of gyro-kinetic calculations. In [2] the nonlinear gyro-kinetic simulation applied to ITER scenarios predict that the convection of impurities is usually directed inwards for ion heat fluxes which exceed or are equal to the electron heat flux, but can reverse direction in conditions in which the electron heat flux exceeds significantly the ion heat flux. In JET, various type of discharges at ITER relevant collisionality ($\nu_{eff} \sim 0.1$) had shown that both Ni (A = 28) and Mo (A = 42) feature flat or slightly hollow density profiles when ICRH is applied [3, 4].

2. EXPERIMENTAL RESULTS

A new RF power scan has been performed in JET in order to provide a more homogeneous subset of discharges and improve the statistics of the effect of ICRH on impurities. The heating scheme was that in H minority−which transfers power mainly to the electrons via collisions with RF generated fast protons−and the target plasma was in H mode with little or no sawteeth and featuring up to 12MW of Neutral Beam heating. The old and new discharges included in the dataset are summarized in the table below. Most of them are in H-mode, with the exception of Pulse No: 68383 which appears to be an L-mode. In order to work out the impurity transport parameters, time dependent spectroscopic and Soft X-Ray data following the transient injection of trace amounts of impurities via Laser Blow Off have been reconstructed by a 1D collisional-radiative impurity transport code [5].

The obtained database of −v/D (impurity convection to diffusion ratio, which at stationarity equals $\nabla n_Z/n_Z$) confirms that the technique of RF injection is indeed quite robust in flattening impurity profiles whenever ~3 MW of ICRH are exceeded. Data so far analyzed are shown in Fig.1 and can be fitted by a linear scaling, with the ICRH power P_{ICRH} ranging from 0 to 8 MW. Recent discharges are highlighted in full symbols. Positive values of −v/D mean inward convection and therefore tendency to accumulation. v/D values of Fig. 1 are estimates at $\rho = 0.2$ Values estimates at r =0.5 are instead shown in fig 2. In the latter radial position the effect of ICRH injection is to flatten the impurity profile in more or less the same manner (−v/D ~ 0) regardless of the injected power. An exception is represented by Pulse No: 74359, for which −v/D remains positive both at $\rho = 0.2$ and $\rho = 0.5$. Results of molybdenum injection with and without ICRH are shown in Fig.1 in blue. The expulsion effect of ICRH holds also for this heavier impurity. An attempt has been made to correlate the found v/D's with relevant discharge parameters such as T_i/T_e, q and its shear, plasma rotation and its shear. An apparent dependence on q has been found (see Fig.3), which however cannot be decoupled from the ICRH power, as the latter, for the same type of discharge, has an obvious effect on q. A weak dependence on T_i/ T_e, shown in Fig.4, seems also to be present. A more apparent dependence is instead that on $–R/LT_e$, shown in Fig.5, where a linear fit is also proposed. No clear dependence is found on density and ion temperature gradients.

GYROKINETIC SIMULATIONS

The linear version of the gyrokinetic code GS2 [6], including collisionality effects, has been used to identify the micro-instabilities present in the analyzed discharges and to study their impact on Ni transport. GS2 simulations predict quite small variations of v/D ratio as a function of q and T_e/T_i (see Fig's 6 and 7 respectively) though in the same direction as in the experiment. However, the main result is that the dominant turbulence is systematically of the Ion Temperature Gradient type with associated an inward flow. For TEM's to become dominant and produce an outward flow a much lower ion temperature gradient would be required, as seen in [1,3]. Interestingly the dependence of the predicted transport parameters on Z saturates with Z, so that approximately the same predictions hold for Ni, Mo and W.

NEOCLASSICAL TRANSPORT.

The contribution of neoclassical transport to the experimental Ni flow has been studied by running interpretive JETTO [7] simulations of Pulse No's: 74354 and 74360 (with and without ICRH respectively) in which the predictive impurity transport code UTC/SANCO [8] assumes neoclassical transport only (from NCLASS [9]). Besides a strong screening effect at the H-mode edge barrier, the result in both types of discharges is that neoclassical transport produces a continuous accumulation in the core due to an inward flow (see Fig 8). Neoclassical v and D are very small compared to the values experimentally found. Inclusion of Bohm /gyro-Bohm transport produces larger transport parameters but still directed inwards.

CONCLUSIONS

Applying ICRH power in JET H mode discharges has a flattening effect of both Ni and Mo elements by the generation of an outward flow. Such results represent good auspices for the use of W in JET as few MW of ICRH power should be enough to avoid significant W accumulation in the core. The experimental outward flow remains however unexplained. Unlike the ASDEX Upgrade case [1], in which the effect of central ECRH on Si was explained on the basis of TEM modes, in the analyzed JET discharges the main microinstabilities are ITG, which produce an inward flow. AUG discharges featured larger T_e gradients and lower T_i gradients than those of the analyzed JET Pulse No's, where ion heating is always prevailing due to the presence of large amount of NBI power. Neoclassical transport appears to produce in these JET discharges an inward flow and cannot therefore explain the experimental results either. The question remains whether other physical mechanisms linked to the presence of ICRH injection, such as for example the presence of fast ion tails may be the cause of the impurity expulsion from the core.

ACKNOWLEDGEMENTS

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REFERENCES

[1]. C. Angioni et al; Plasma Phys. Control. Fusion **49** (2007) 2027

[2]. C. Angioni et al; Nucl. Fusion **49** (2009) 055013

[3]. M.E. Puiatti et al; Phys. Plasmas **13** 042501 (2006)

[4]. L. Carraro et al; 34th EPS Conference on Plasma Phys. Warsaw ECA Vol **31** FO-4.028 (2007)

[5]. M. Mattioli et al; J.Phys.B **34**,127 (2001)]

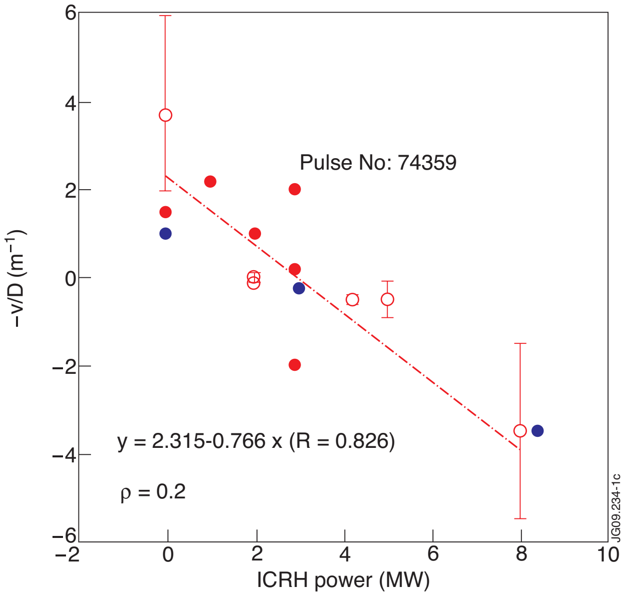
[6]. M. Kotschenreuther et al; Comput Phys Commun **88** (1995) 128

[7]. G. Cenacchi and A Taroni 1988 JETTO: A free-boundaryplasma transport code (basic version) Report JET-IR (88) 03

[8]. A.D. Whiteford et al; Proc of the 31st European Conf. (ECA), London, 2004, p. 1.159.

[9]. 33W. A. Houlberg et al; Phys. Plasmas **4**, (1997) 3230

Pulse No:	I_p (MA)	B_t (T)	NBI (MW)	ICRH (MW)	H/He^3
58143	1.8	3.27	13.6	4.7	He^3
58149	1.8	3.27	14.6	5.1	He^3
66432	1.8	3.35	20	2	He^3
66434	1.8	3.35	20	2	He^3
68383	2.3	3.2	8.3	8	H
69808	1.8	3.2	11	0	H
74354	1.5	3	12	0	H
74355	1.5	3	12	1	H
74359	1.5	3	12	3	H
74360	1.5	3	10.7	2.9	H
74363	1.5	3	10.5	2.9	H



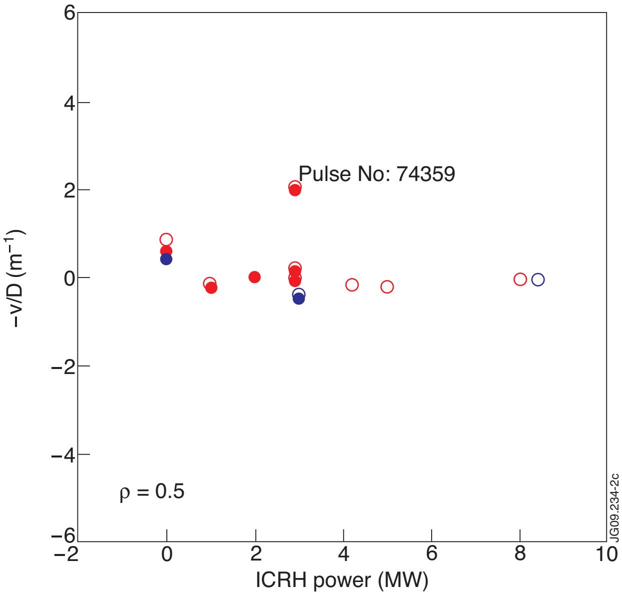
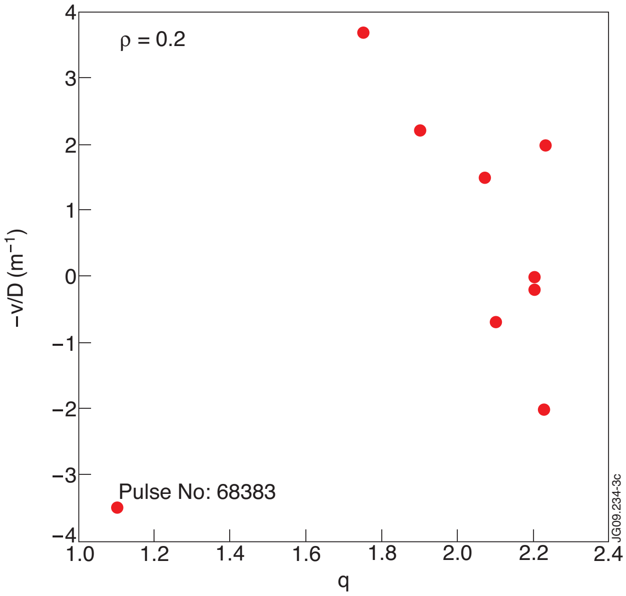


Figure 1: v/D versus P_{ICRH} @$\rho = 0.2$ In red Ni, in Blue Mo. Full red and blue = new data The fit is over all Ni data.

Figure 2: v/D versus P_{ICRH} at $\rho = 0.5$. Color code as for Fig.1. Note the change of scale.



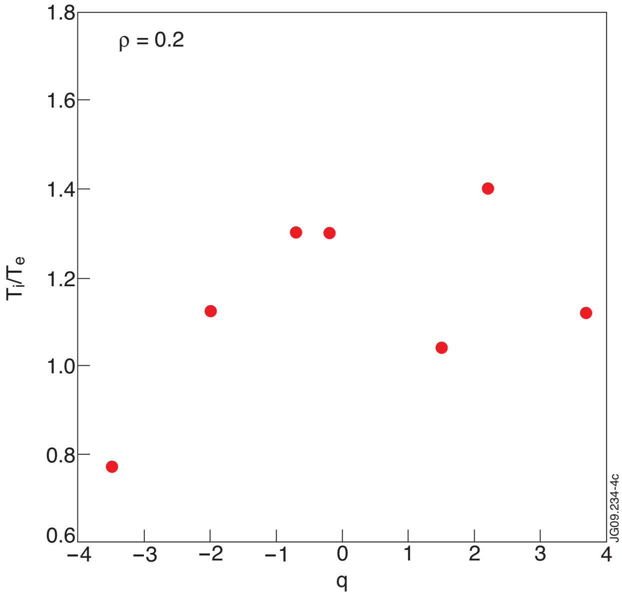


Figure 3: Dependence of $-v/D$ on q for Ni data at $\rho = 0.2$. The isolated shot at the bottom left is Pulse No: 68383.

Figure 4: Dependence of $-v/D$ on T_i/T_e for Ni data at $\rho = 0.2$.

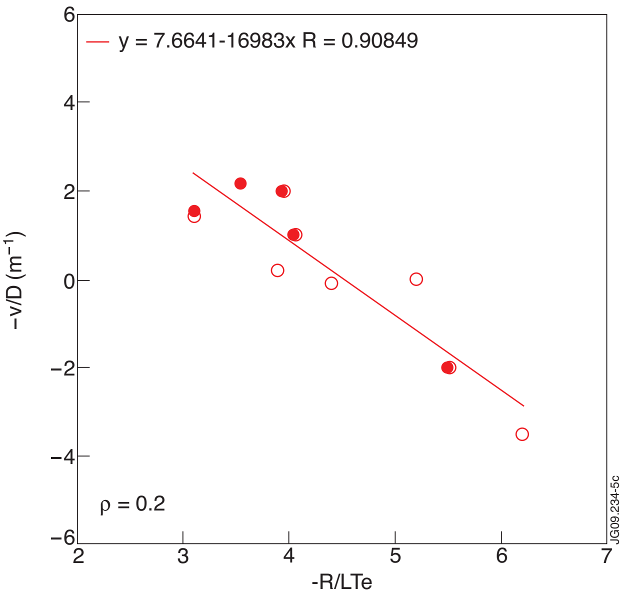


Figure 5: Dependence of $-v/D$ on $-R/LT_e$ for $\rho = 0.2$.

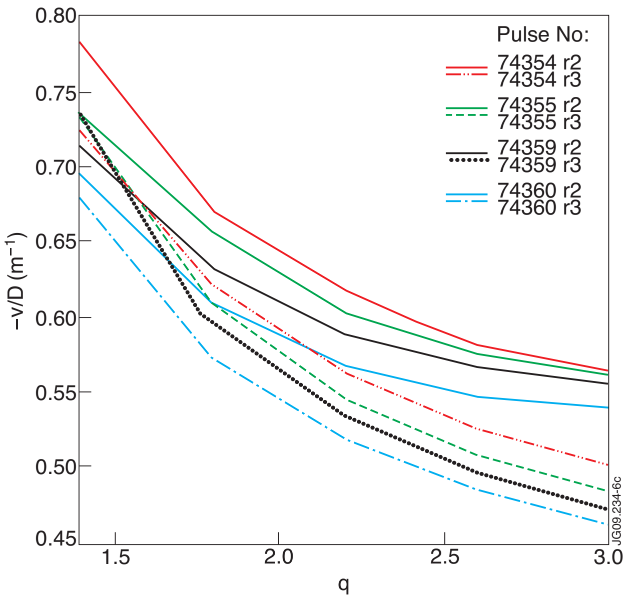


Figure 6: Rv/D resulting form a GS2 scan on q for Ni.

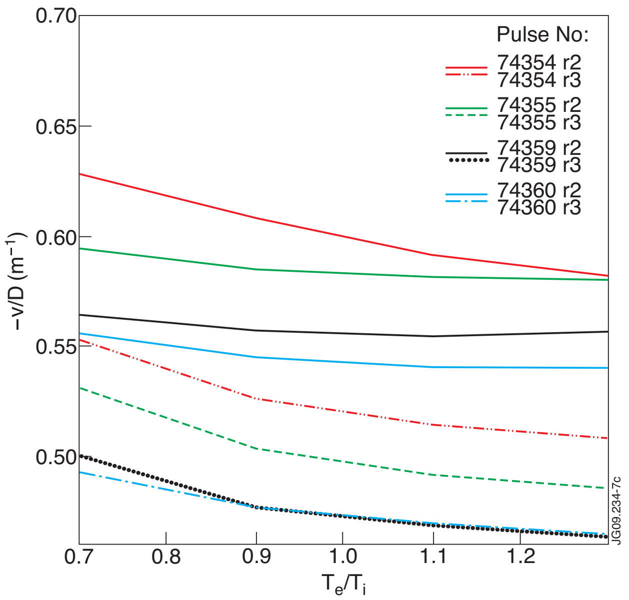


Figure 7: v/D resulting form a GS2 scan on T_i/T_e for Ni.

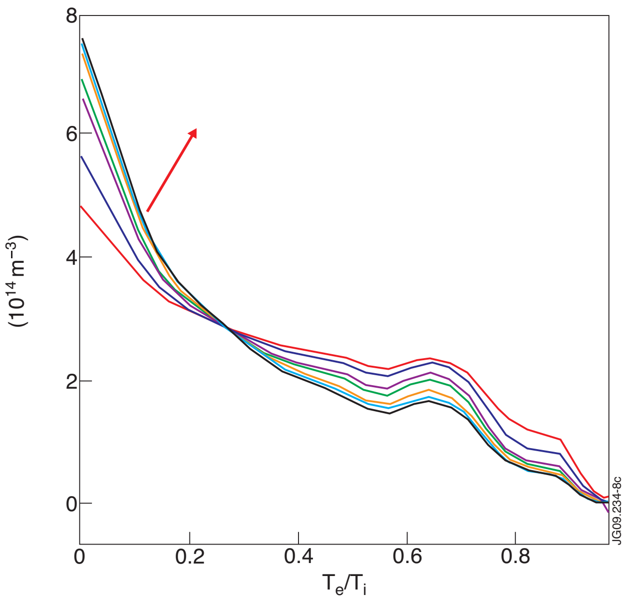


Figure 8: Simulated evolution of the Ni total-density profile assuming neoclassical transport. The profile keeps increasing in the core.