

Influence of Divertor Geometry on Neutral Compression, Impurity Enrichment and Particle Exhaust on JET

H.Y. Guo, I. Coffey, G. Corrigan, M. Groth¹, P.J. Harbour, M. von Hellermann, D.L. Hillis², J. Hogan², L.D. Horton, C.F. Maggi, G.F. Matthews, G.M. McCracken, P.D. Morgan, M.F. Stamp, A. Taroni

JET Joint Undertaking, Abingdon, Oxon., OX14 3EA, UK
¹*and University of Manchester(UMIST), Manchester. M60 1QD, UK*
²*Oak Ridge National Laboratory, Oak Ridge, TN 37831-8072, USA*

1. Introduction

JET has investigated three pumped divertor configurations which have progressively increased geometric closure to the escape of recycling neutrals from the divertors: Mark I (1994-95), Mark II (1996-97) and Mark IIGB (1998-99), as shown in Fig. 1. A pumped divertor is beneficial for improving plasma purity through divertor screening and direct pumping. In addition, it is essential for helium ash removal from a fusion reactor [1]. Adequate exhaust of He ash for ITER requires [2]:

- $\tau^* \alpha / \tau_E \leq 10$

where $\tau^* \alpha$ is the global alpha particle confinement time and τ_E is the energy confinement time;

- $\eta_{He} = \left(p_{He} / 2p_{D2} \right)_{div} / \left(n_{He} / n_e \right)_{cor} \geq 0.2$

where η_{He} is the helium enrichment factor, the ratio of the helium concentration in the divertor to the helium concentration in the core.

to reduce plasma dilution and to minimise the required pumping speed, thus reducing tritium recirculation.

In this article we first report the effects of increased geometrical closure on the impurity exhaust observed in JET Mark I, Mark II and Mark IIGB pumped divertors, followed by the comparison of He enrichment in Mark II and Mark IIGB. A comparison of the enrichment factors for He/Ne/Ar is also made, together with detailed modelling using the EDGE2D/NIMBUS code. In addition, the effect of the divertor closure on the intrinsic carbon impurity behaviour is assessed.

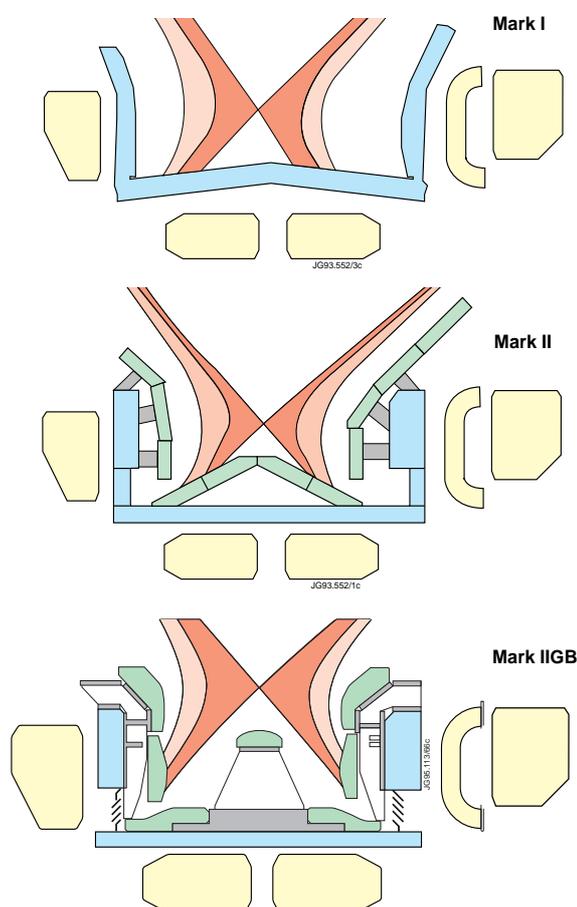


Fig. 1: Poloidal cross sections of the JET Mark I, Mark II and Mark IIGB pumped divertors.

2. Impurity exhaust

Increasing the divertor closure in JET has led to a significant increase in the neutral pressure in the subdivertor, thus improving the deuterium exhaust [3]. Impurity exhaust has also been improved with increased divertor closure. Fig. 2 shows the evolution of Ne VII line intensity following a short Ne puff (trace level) and the subdivertor pressure for the comparable L-mode discharges in Mark I, Mark II and Mark IIGB divertors, respectively. The discharges have similar heating power (~ 2 MW) and plasma densities. The Ne decay time shows a tendency to decrease with the improved divertor closure from Mark I \rightarrow Mark II \rightarrow Mark IIGB, and correlates with the progressive increase in subdivertor pressures.

Figure 3 shows the Ne decay time against the subdivertor pressure for the L-mode discharges with different divertor configurations. It appears that there is a rather good correlation between Ne decay time and subdivertor pressure. Note that experiments using simultaneous deuterium gas injection at the top or midplane and divertor pumping show small or no effect of induced SOL flow on the impurity exhaust, in contrast with results reported from such experiments carried out in DIII-D [4]. (This may be due to the large intrinsic flows that are present in the SOL in JET [5]).

3. Impurity enrichment

Helium enrichment studies have been performed under both L- and ELMy H-mode conditions in the Mark II and Mark IIGB divertors. The enrichment is derived from the ratio of the partial pressure in the subdivertor volume, measured by Penning gauge spectroscopy, to the core plasma concentration, determined by the Charge Exchange Recombination Spectroscopy (CXRS). For the L-mode discharges the helium enrichment decreases with the subdivertor pressure and also depends upon the strike point position. Preferential enrichment is obtained as the strike point is moved towards the pumping entrance slot [6]. In the case of ELMy H-modes, the enrichment is less sensitive to the strike point position. In going from Mark II to Mark IIGB, the helium compression is increased, but the enrichment changes little due to the simultaneous increase in subdivertor neutral pressure. To illustrate this, Fig. 4 shows the evolution of He compression ($n_{\text{He}}^{\text{div}}/n_{\text{He}}^{\text{cor}}$), He enrichment and subdivertor pressure for two comparable H-

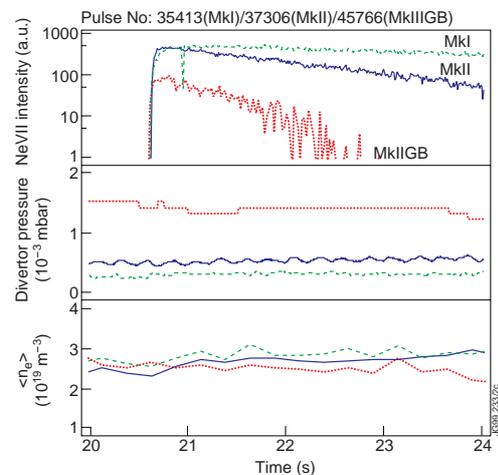


Fig. 2: Time traces of comparable L-mode discharges in Mark I, Mark II and Mark IIGB divertors, illustrating the changes in Ne decay time following a short trace-Ne puff.

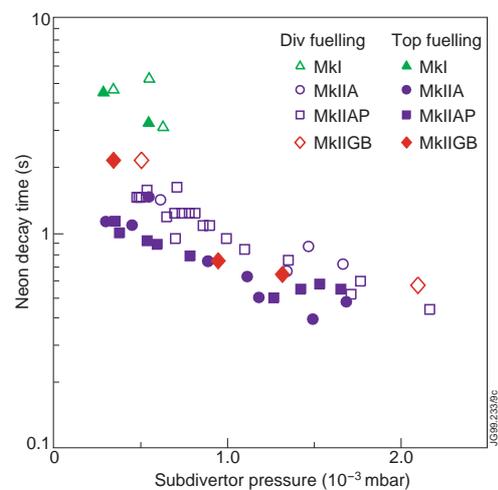


Fig. 3: Neon decay time versus subdivertor pressure for different divertor configurations, with D_2 fuelling from top and divertor, respectively.

mode discharges performed in Mark II and Mark IIGB, respectively. The two discharges have the same neutral beam heating power, similar plasma density and confinement.

Figure 5 shows the divertor enrichment relative to the core (a) and edge concentration (b) for He/Ne/Ar impurities as a function of the subdivertor pressure for both L- and H-modes. It appears that He/Ne/Ar have similar enrichment factors at low subdivertor pressure/plasma density. However, Ne enrichment factors are improved as the subdivertor pressure increases. The impurity enrichment is dependent on both plasma conditions and atomic physics. We have employed the 2-D fluid EDGE2D/NIMBUS codes to simulate the enrichment for He and Ne in L-mode plasmas with the following input parameters: $P_{\text{sol}} = 2\text{MW}$, $n_{\text{sep}} = 0.3\text{-}1.5 \times 10^{19} \text{ m}^{-3}$, $D_{\perp} = 0.2 \text{ m}^2/\text{s}$ and $\chi_{\perp}^{i,e} = 0.5 \text{ m}^2/\text{s}$ (in flux space). As in the experiments, He and Ne impurities are introduced by a short puff (at trace level). The intrinsic carbon content is controlled by both physical and chemical sputtering. For chemical sputtering, data from [7] are used with a yield reduction factor of 0.5 to match the measured divertor carbon emission. The calculated results are shown in Fig. 5(c). The code reproduces quantitatively the edge enrichment factors for both He and Ne. In particular, the calculated results show that Ne enrichment increases with separatrix density and rolls over at sufficiently high densities, in contrast to He enrichment, consistent with experimental observations. In addition, the simulation of He enrichment during ELMs has been carried out using the B2-Eirene code. The preliminary results for a typical Mark I case with an ELM frequency of 60 Hz show that He enrichment varies by a factor of ~ 3 during an ELM, suggesting that details of ELM behaviour must be understood to be able to extrapolate ELM-averaged enrichment values to future machines such as ITER.

4. Intrinsic impurity behaviour

Figure 6 compares the Z_{eff} , from the bremsstrahlung measurements, between Mark II and Mark IIGB divertors for L-mode discharges. As can be seen, Z_{eff} is reduced from Mark II to Mark IIGB. Note that these measurements are subject to large uncertainties (up to 30%). However, the data from the CXRS show similar trends. It appears therefore that the divertor/SOL screening for impurities may be improved with improved divertor closure,

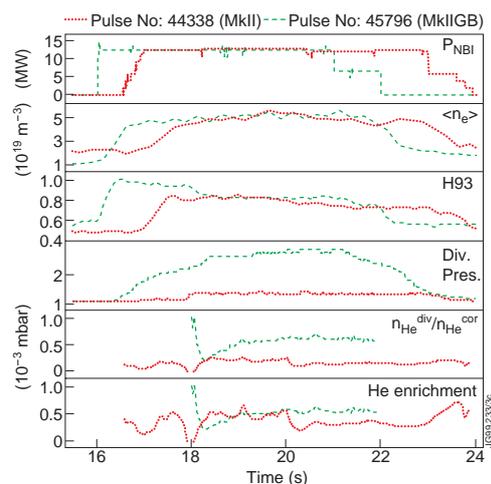


Fig. 4: He enrichment, He compression ($n_{\text{He}}^{\text{div}}/n_{\text{He}}^{\text{cor}}$) and subdivertor pressures in two comparable H-mode discharges in Mark II and Mark IIGB.

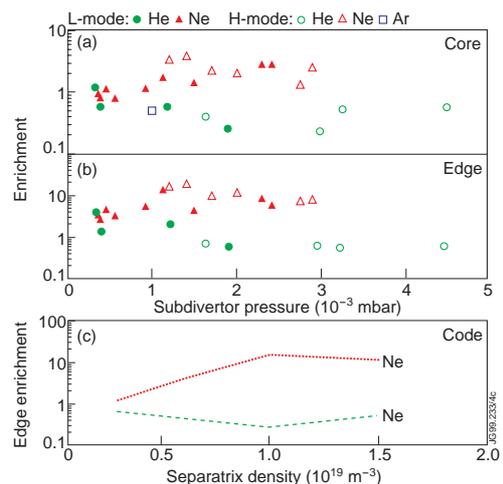


Fig. 5: Measured core (a) and edge (b) enrichment factors for He/Ne/Ar in MkII GB, together with the EDGE2D results (c).

which has been predicted by the EDGE2D code. In addition, the L-mode density limit is improved in Mark IIGB (by ~15%), compared to the MkII case. It is to be mentioned that no obvious changes in Z_{eff} have been observed in the ELMy H-modes [3] (presumably due to the presence of ELMs). However, preliminary results from the CD₄ injection experiments have shown stronger divertor/SOL screening for impurities in Mark IIGB divertor than in Mark II for H-modes as well. In going from Mark I to Mark II, impurity sources were increased by a factor of ~2, attributed to the enhancement of chemical sputtering at the Mark II divertor target due to the higher base temperature of the target plate [8], thus offsetting the effect of the divertor closure.

5. Summary and conclusions

The subdivertor pressure has increased significantly from Mark I→Mark II→Mark IIGB, hence improving deuterium pumping. The exhaust for recycling impurities has also been improved with increased divertor closure. In particular, Ne exhaust rates are dependent on the plasma conditions and show a strong correlation with the subdivertor pressure. Experiments using simultaneous deuterium gas injection into the upstream SOL and divertor pumping show little or no effect of induced SOL flow on the impurity exhaust, which may be due to the large intrinsic SOL flows that are present in JET. He compression increases in Mark IIGB, compared to Mark II, similar to D₂ compression. Hence, He enrichment shows little changes. Ne, as well as Ar, has enrichment factors similar to He at low subdivertor pressure. At high divertor neutral pressure, the neon enrichment is enhanced compared with helium, which is related to the respective ionisation mean-free paths. The edge enrichment factors for both He and Ne are quantitatively reproduced by the EDGE2D/NIMBUS codes under L-mode conditions. In addition, the divertor closure manifests itself as a decrease in Z_{eff} in L-mode discharges, leading to an improvement in the density limit (by ~15%).

References

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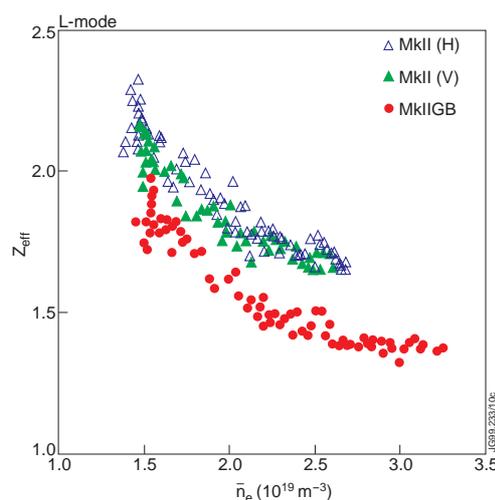


Fig. 6: Z_{eff} against plasma line average density for L-mode discharges in Mark II and Mark IIGB with ~ 2MW NB heating .