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Helium Enrichment Studies in JET Discharges

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INTRODUCTION

One requirement for steady state operation in future fusion reactors based on the D(T,n)α reaction is an adequate exhaust of the reaction product helium (He). The figures of merit generally quoted for He exhaust capabilities are: 1) the ratio of the global residence time of α-particles within the plasma, τ^*_{He}, to the plasma energy-confinement time τ_E [1], 2) the ratio of partial pressure of He (p_{He}) in the divertor to that of deuterium (p_{D2}), divided by the ratio of the He and deuterium density in the core (n_{He} and n_D , respectively) . The latter defines the enrichment factor η (equation 1).

$$\eta = \frac{p_{He}}{2p_{D_2}}\Big|_{Div} \Big/ \frac{n_{He}}{n_D}\Big|_{Core} , \tag{1}$$

Helium enrichment factors are usually well below unity, illustrating the general difficulty of helium removal from the core plasma of tokamaks [2,3]. The current ITER design requires He enrichment factors of 0.2 [4].

JET EXPERIMENTAL STUDIES

Helium enrichment in low and high energy confinement (L/H) modes has been studied in JET. The MkIIAP divertor allows magnetic configurations where the plasma strike zones are on either the horizontal (H), or the vertical (V) target plates, or on an intermediate corner slot position (C), as shown in figure 1.

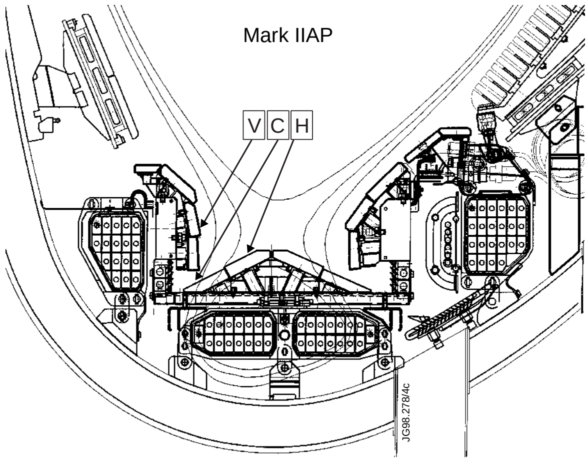

Figure 1 MkIIAP Divertor - magnetic configurations

Core He measurements are provided by means of active Charge Exchange Recombination Spectroscopy (CXRS). The CXRS system comprises spatial and temporal measurements of ion density and temperature throughout the core plasma. The spatial reference for the core He concentration presented (HeII, 4686 Angstrom) is at r/a ~ 0.3. Partial pressure measurements of deuterium and helium in the subdivertor volume close to the cryopump panels are made by applying a new spectroscopic technique to a commercial Penning gauge [5,6]. The simultaneous observation of the Penning discharge on the HeI (5875 Å) and D_α (6561 Å) wavelength assesses the partial pressures of divertor gas constituents of the JET tokamak, by comparison to a calibrated standard concentration.

A limiting factor of the enrichment studies was preferential pumping of deuterium by the JET divertor cryo pump. Helium was fuelled via the plasma edge and recycles completely. No evidence of He pumping has been found.

EXPERIMENTAL PROGRAMME AND RESULTS

In L-mode with input power of 2 MW Neutral Beam Injection (NBI), a configuration scan has been performed where within one plasma discharge the plasma strike zones have been moved from the horizontal to vertical divertor target plate, including the corner position. A total of 2-3*10^{20} He atoms was puffed into the vessel at the midplane within 40ms, at the time the strike points were first established on the horizontal target plate. Each configuration lasted for approximately two seconds giving sufficient time for steady state. A typical discharge evolution is shown in figure 2. Further investigations on He enrichment have been made by systematically varying the shot-to-shot deuterium gas fuelling.

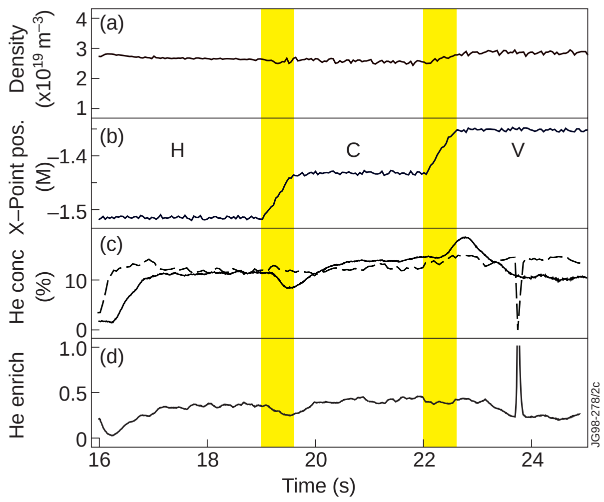

Figure 2 Temporal evolution of a) density, b) vertical x-point position, c) core He concentration (dotted line) and subdivertor He concentration (solid line) , and d) He enrichment of discharge #43709 (2 MW L-Mode); He gas puff at 16s

As shown in figure 3, the He enrichment in L-mode varies between 0.20±0.05 and 0.6 ±0.16. The highest values of the He enrichment are obtained when the strike points are in the corner position; and the lowest are found when the plasma strike zones are on the vertical plate. The He enrichment gradually decreases with increasing plasma density.

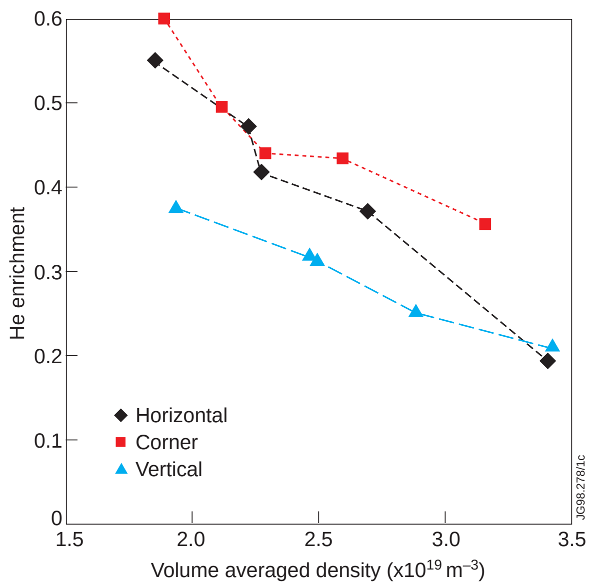

Figure 3 He enrichment in 2 MW L-mode discharges, strike zones on horizontal and vertical target, and in corner position (error of order 25%)

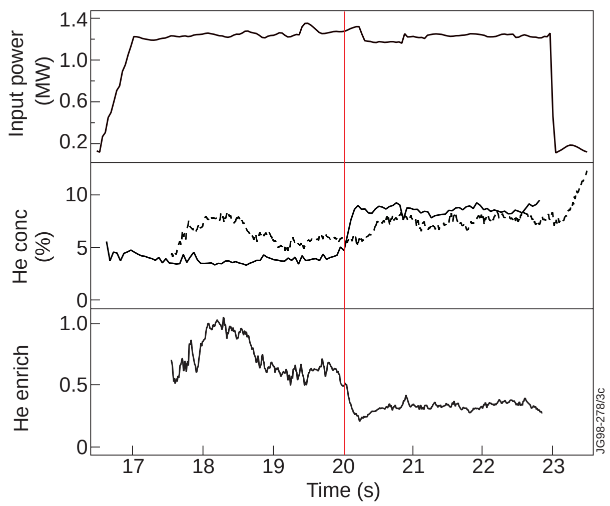

Figure 4 Time evolution of a) Input Power, b) He concentration in core (solid line) and subdivertor (dotted line), and c) He enrichment in a 12W ELMy H-Mode discharge # 44333 , corner position, He gas puff at 20sec

Helium enrichment has been studied in ELMy H-mode (7 MW and 12 MW of NBI) in horizontal, vertical and corner divertor configuration. The enrichment factors are given in table 1 and vary between 0.20±0.06 to 0.8±0.24, and 0.2±0.06 to 1.3±0.45 in 7 MW and 12 MW discharges, respectively. Generally it was found that when He (2-3*10^{20} atoms) was injected into the discharge (figure 4), the He enrichment decreases by about a factor 2 to 3. High power ELMy H-modes have commonly a larger enrichment than low power discharges, and only a weak dependence on plasma density was observed.

Table 1 He enrichment factors in ELMy H-Mode Discharges (errors of order 30%)

	7 MW ELMy H-Mode		12 MW ELMy H- Mode	
Divertor Configuration	before He puff	after He puff	before He puff	after He puff
core He concentration	4%	10 - 12%	4 - 6%	9 - 12%
horizontal target	0.3 - 0.8	0.2 - 0.3	0.9 - 1.3	0.2 - 0.3
corner position	-	-	1.2	0.4
vertical target	0.3 - 0.5	0.2 - 0.3	0.6 - 1.1	0.3 - 0.5

DISCUSSION AND SUMMARY

In view of the requirements of adequate He exhaust in future fusion devices, recent He enrichment studies at JET have shown an enrichment well below unity in L-Mode and in low power ELMy H-Modes discharges. In ELMy H-Modes, heated with 12 MW of NBI, the He enrichment factors can reach and exceed unity. All He enrichment factors obtained are well above the value of 0.2 required by the present ITER design [4].

A divertor configuration scan in L-Mode has shown that the He enrichment is at its maximum with the strike zones in the corner slots of the divertor. In ELMy H-Mode discharges, the enrichment factors were not strongly affected by the all divertor configuration. Characteristically, a sudden decrease of the He enrichment was found, when He was injected into the discharge, indicating a preferential accumulation of He in the core.

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