IMPURITY ACCUMULATION IN JET ELMY H-MODE DISCHARGES

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Abstract

Evidence of impurity accumulation in JET ELMy H-mode discharges is presented, ~10% of recent pulses included in the ELMy H-mode database being affected. ELMs lead to a peaking of the n_e profile and a consequent rise in the central impurity levels. A difference in impurity behaviour is noted between pulses run with the successive divertor geometries used in JET, accumulation mainly being seen during the Mk II campaigns. This difference is understood in terms of the n_e profile development and increased impurity levels. High confinement and low ELM frequency are also contributory factors to the accumulation. First transport simulations give results consistent with a neoclassical mechanism.

1. Introduction

The ELMy H-mode regime is of particular importance because of its relevance to ITER. Investigations of the impurity behaviour in JET are therefore crucial for the design of the next step device. Evidence is presented of the accumulation of impurities in the centre of JET ELMy H-mode discharges. In this context, 'accumulation' is used to indicate a peaking in the impurity concentration profile, rather than simply high levels of impurities. Changes are seen both for the metallic contaminants – Ni, Cr, Fe, Cu and Mn – and to a lesser extent for low atomic number (Z) impurities, chiefly C.

2. Example of central impurity accumulation

A 2.5T, 2.5MA discharge with D fuel, pulse 38294, is used to illustrate the phenomenon. Its bulk plasma parameters are shown in figure 1. Increasing radiation from the centre of this discharge is observed with the bolometers (figure 2) and the soft X-ray cameras. VUV spectroscopy (KT2) provides evidence of intense Ni and Cu features, which dominate the spectrum. Figure 2 compares the time development of 4 line intensities, the lower 3 ionization stages observed by KT2 and the NiXXVII line by the soft X-ray crystal spectrometer (KX1). The higher temperature lines rise more steeply than those from lower temperature plasma regions, suggesting a redistribution of the Ni ions towards the plasma centre. Also shown is the Ni concentration derived from the NiXXVII line intensity assuming coronal equilibrium in the plasma centre. The C concentration profiles measured by the charge exchange diagnostic (figure 3) are initially hollow, then flatten and, unusually, even peak as the Neutral Beam Injection (NBI) is stepped down from 24 to 25s. The changes for C are less severe than for Ni, suggesting a Z dependence and a possible neoclassical mechanism.

First transport simulations for pulse 38294 using the SANCO diffusive convective transport code [1] require a central diffusion, $\sim 0.05 m^2.s^{-1}$, and an inward convective term, $\sim 2 m.s^{-1}$, of a similar magnitude to the results from the neoclassical FORCEBAL code [2]. As yet unresolved differences in the convective velocity profiles are being investigated.

The electron density, n_e, profile is 'eroded' at the plasma edge by the ELMs and subsequently peaks. This contrasts with ELM-free hot-ion H-mode n_e profiles, which flatten and even become hollow, emphasizing the role of ELMs in the peaking process. The erosion begins early in the ELMy H-mode phase, before the Ni levels are significant. The accumulation is therefore a result of the n_e profile change, small increases in the central Ni concentration sometimes being seen immediately the peaking first happens. However, for accumulation to occur, the peaking must reach the plasma centre. In this region, the diffusion is low and neoclassical effects can dominate the particle transport.

The amplitude of sawteeth oscillations was generally found to decrease during the recent (Mk II) ELMy H-mode discharges. However, in pulses where accumulation is observed the sawteeth disappear entirely (figure 1). The T_e profile flattens, the reduction in T_e leading to an increase in resistivity, a modification of the current profile and a higher axial safety factor. This explanation is consistent with EFIT calculations. It suggests that the accumulated impurities are affecting the bulk plasma parameters.

3. Survey of the JET ELMy H-mode database

A significant number, ~10%, of recent (Mk II) pulses show some evidence of accumulation. In addition, the frequency of occurrence increases with the successive JET divertor geometries, only 2 out of 176 pulses included in the earlier Mk I divertor database showing characteristics of accumulation.

A simple and relevant means of diagnosing the importance of the peaking of the n_e profile is to determine the increase in the Ni concentration measured by KX1, the number of pulses showing a x5 increase for a period of at least 2s being counted. This period should exclude any bias due to discrete metallic influxes, whose effects are generally short-lived.

Campaign	No. of pulses in database	% showing x5 increase in Ni conc.
Mk I - C Phase	110	22%
Mk I - Be Phase	66	19%
Mk IIA (By-pass leaks unplugged)	142	36%
Mk IIAP (By-pass leaks plugged)	176	46%

Although not an indication of accumulation in the present discharges, these data suggest that in near steady-state operation a significant number of discharges may be affected. The larger number of pulses with accumulation in the Mk II than Mk I campaigns is due to clear differences in the development of the n_e profiles throughout a discharge; in the Mk II campaign the peaking is greater. This is represented by the increase in the peaking of the n_e profile during a discharge, the peaking being defined as the ratio of a central n_e (at a major radius of R=3.0m for Mk I and 3.1m for Mk II) to that nearer to the plasma edge (at R=3.5m for Mk I and 3.6m for Mk II). The increase is found to be typically 0.20, 0.37 and 0.35 for the Mk I, Mk IIA and Mk IIAP campaigns, respectively. However, there is no indication as yet that the peaking alone explains the differences within the Mk II campaign.

Checking on other factors affecting the accumulation, the Ni impurity levels, confinement measured relative to the ITER89-P L-mode scaling (H89), ELM frequency and triangularity of the configuration have been compared for pulses showing a x5 increase in Ni concentration and those with no significant increase for each of the campaigns. Pulses with higher Ni concentrations (figure 4), high confinement and low ELM frequency tend to have the greater increase in concentration. Triangularity does not appear to be a contributory factor except through its influence on ELM frequency. The concentrations, confinement and ELM frequency are interrelated making it difficult to find a causal link between these parameters.

The range and distribution of confinement and ELM frequency for pulses in the Mk IIA and Mk IIAP campaigns is similar. The Ni levels increase progressively in going from the Mk I through the Mk IIA to the Mk IIAP campaigns. The higher percentage of pulses showing a x5 increase in Ni concentration may be due to the higher Ni levels in the Mk IIAP campaign or more likely may result from factors leading to the increased impurity levels. The frequently observed dependence of the central impurity concentration on D_α or main chamber neutral pressure, a high D_α or pressure restricting the central impurity concentration to low values, shows the importance of screening within the Scrape-Off-Layer (SOL) as a factor determining the bulk plasma impurities. This behaviour is thought due to high neutral pressures favouring a wide SOL [3].

All pulses in the database had NBI additional heating and some, ~13%, also had Ion Cyclotron Resonance Heating (ICRH). No clear dependence on the use of ICRH was found, typically 25-33% of pulses with ICRH showing greater than a x5 increase in Ni concentration.

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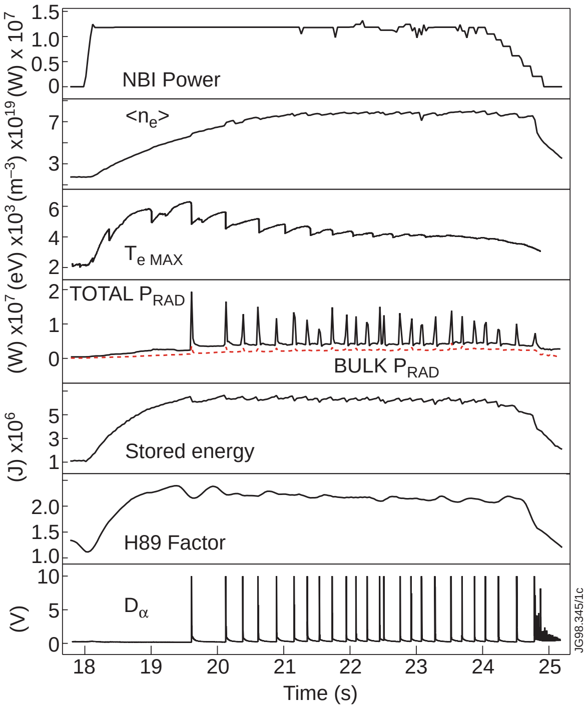

Figure 1. Plasma parameters for the 2.5T, 2.5MA, D fuelled pulse 38294, showing time histories of NBI Power, volumed averaged n_e, maximum T_e, total and bulk plasma radiated power, stored energy, H89 confinement factor and D_α.

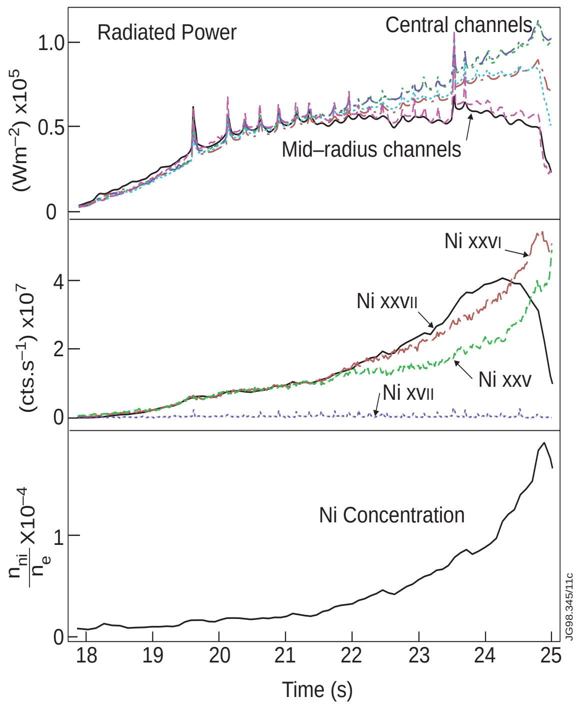

Figure 2. Time development of the bolometric measurement of radiated power, the KX1 measurement of Ni concentration and of NiXXVII, NiXXVI, NiXXV and NiXVII line intensities, the intensities suggesting a redistribution of the Ni ion density profile.

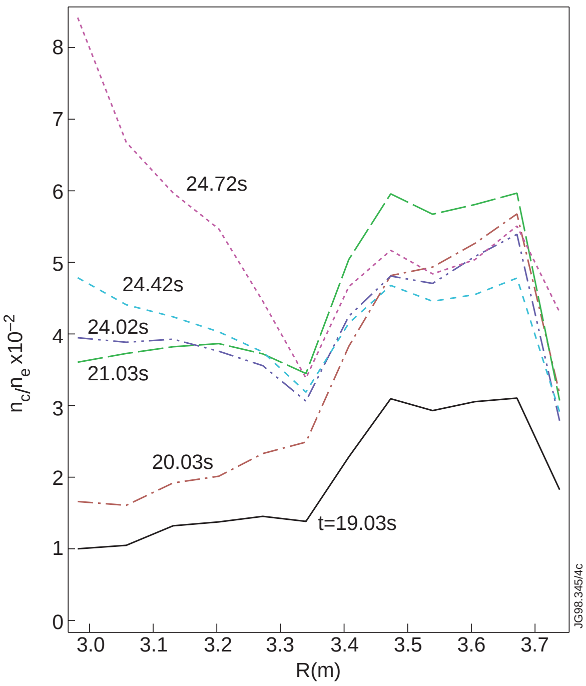

Figure 3. Radial profiles of the C concentration measured by the charge exchange diagnostic, showing a flattening and eventual peaking of the profile.

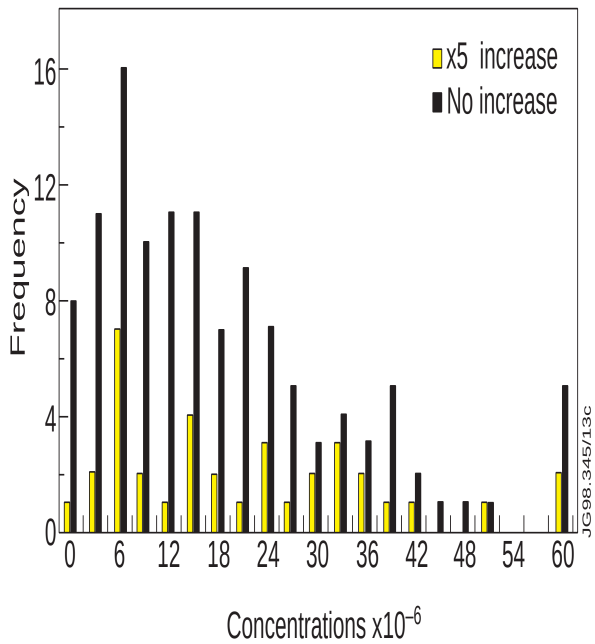

Figure 4. Comparison of the Ni concentration measured 1s after the start of the NBI for Mk I pulses that show a greater than x5 increase in concentration with those having no significant increase.