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** See annex of F. Romanelli et al, "Overview of JET Results",*
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ABSTRACT.

During high power commissioning of the JET LH launcher, the radiation and impurity release has been analyzed from various diagnostics: VUV and visible spectroscopy, bolometry. These two last diagnostics have lines-of-sight viewing the launcher and can provide information about the electron and/or impurity source localisation. Using a database of 800 plasmas, it is concluded that the iron contamination (FeXV and FeXXIII) is very low for 94% of the pulses and increases linearly with LH power. During arcs, a strong and fast increase of the radiation along the line-of-sight viewing the launcher is observed. This diagnostic could provide a tool for arc detection complementary to the RF measurements aiming at reducing the metal contamination in the plasma.

1. INTRODUCTION

During the 2008-09 JET campaigns the Lower Hybrid Current Drive (LHCD) system has been commissioned up to 5.5MW for 1s. Although most of the experiments were performed in L-mode discharges (742), some of them (63) discharges were performed in H-mode at lower power (≤3MW). Most of the discharges were performed with the following plasma parameters: $B_t \approx 2.3$T (resp. 2.7T), $I_p \approx 1.8$ (resp. 1.95MA),$n_l \approx 2\times10^{19}m^{-3}$ (resp. $4\times10^{19}m^{-3}$) in L-mode (resp. H-mode). The iron contamination of the plasma was estimated from the intensity of the FeXXIII and FeXV lines of the VUV spectrometer [1] located in a vertical port at an angular distance of 135° from the LH launcher. The FeXV line has a maximum intensity for T_e~400eV. This temperature occurs at a radius R~3.75-3.80m, ~10cm inside the separatrix and the line intensity is closely related to the impurity source. The vertical bolometry camera [2] at the same toroidal location than the launcher provides lines-of-sight viewing the top (‘BOLO1’), the middle (‘BOLO2’) and the bottom (‘BOLO3’) of the launcher whereas a fourth line-of sight (‘BOLO4’) viewing the wall bellow the launcher is used as a reference. These signals were weighted with respect of BOLO2, assuming that before LHCD, the plasma radiation is uniform. In addition, a new visible spectrometry diagnostic located in a horizontal port views the upper part of the launcher along 6 chords and allows measuring the D_α emission. All signals are normalized to the plasma line-averaged density.

2. GLOBAL ANALYSIS OF THE 2008-09 DATABASE

The FeXV line intensity has been used to qualify the iron source into the plasma. This line is found to be in most cases more intense than the FeXXIII line except for the H-mode pulses. Figure 1 shows the maximum of these signals as a function of the LHCD power for the two types of discharges. 94% of the discharges have a low Fe contamination ($I_{Fe} < 2\times10^6$counts/s). It should be noted that the points are scattered regardless of the LHCD power and reflect the antenna conditioning and coupling conditions. From the 804-pulse data base, 22 disruptions are attributed to LHCD arcs and subsequent metal release ($I_{Fe} > 2\times10^6$counts/s for 19 of them). Impurity release is correlated to an increase of the bolometry signals viewing the LHCD launcher (figure 2). In most cases the maximum of radiation is measured on BOLO1 (45%) or BOLO2 (48%). For arc-free discharges, this could indicate a higher density in the upper part of the launcher resulting from the mismatch of the poloidal shape of the antenna with respect of the magnetic surfaces [3]. The database shows clearly a regular increase of the radiation with the LH power (with a power exponent between 1 and 2).. This is also measured by the visible spectroscopy camera viewing the top of the antenna and suggests an increase of density in front of the launcher due to enhanced ionization provided by interaction of the LHCD wave with the plasma edge [3]. For strong radiation cases, the maximum occurs on BOLO2, near the mid-plane, in 60% of the pulses.

In most cases a low (resp. high) radiation leads to low (resp. high) impurity radiation. For only two discharges, the maximum radiation is low ($<1\times10^5$ W/m^2) but the iron contamination is rather high ($2\times10^6 < I_{Fe} < 4\times10^6$ counts/s).

IMPURITY RADIATION IN ELMY H-MODE

In case of large ELMs, the bolometry signals are strongly modulated and arc detection is less sensitive. From the 63 pulses performed in H-modes, only two discharges have a large Fe release ($I_{Fe} > 1\times10^6$counts/s). One of this discharge is shown on figure 3. Two filtering frequencies have been applied to the bolometry signals. The low frequency ($f_c = 80$Hz) allows to detect the occurrence of an arc in the upper part of the launcher (magenta trace) at t = 5.9s. It should be noticed that in the early phase of the LH pulse (t < 5.9s), the radiation from this upper part is anomalously high (~0.5×10^5 W/m^2) for a rather moderate power (2.5MW) and small arcs are probably occurring as also suggested by the small decrease of the coupled power, due to the RF protection system which is only acting on some generators: at the time the radiation from the upper part is strongly increasing (t = 5.9s), only 3 klystrons over 8 are turned off whereas power reflection coefficients increase transiently or decrease elsewhere.

ANALYSIS OF THE DISRUPTIONS

The 22 pulses, all in L-mode discharges, which terminate by a disruption are characterized by an increase of the radiation before the LHCD system is switched off either at the preset time or when an arc is detected by the protection system. On figure 4 we show the delay between the time when one of the 3 bolometry signals exceed a threshold (1×10^5 W/m^2) and the time the LHCD system is switched off. This time is varies between ~20ms and 1s. For very short delay, lower than 50ms (4 discharges), the disruption could probably not be avoided, but for the others we expect that the metal release could have been sufficiently reduced for preventing from radiation collapse. It should be noted that the threshold level is rather accurately determined to 1×10^5W/m^2 since in many cases the maximum radiation flux is in the 1-2×10^5W/m^2 range which is one order of magnitude higher than that of the arc-free discharges.

CONCLUSION

The RF protection system based on reflected power measurements at the antenna input may not be sufficient for arc detection. When the number of secondary waveguides of the multijunction increases, required for very large antennas, the system is expected to be even more insensitive to the change of impedance due to an arc located near the opening of a secondary waveguide [4]. On JET, the vertical bolometry camera viewing the antenna is an efficient tool to detect arcs with fast response (~5ms) and some spatial resolution (~30cm) allowing not switching off the whole generator when an arc is detected. For L-mode discharges, we found that a threshold on the radiation flux from the launcher can be used as part of the protection system aiming at reducing the metal contamination and the disruption occurrence. More precisely, a threshold $1\times10^5 W/m^2$ is likely to be the optimum, in particular for preventing the plasma from disruptions. In ELMy plasmas, the analysis of the few shots for which a large impurity influx was measured indicate that, provided the signal is adequately low-pass filtered and the threshold optimized between 1 and $2\times10^5 W/m^2$, arc detection can be efficient. Further analysis on a larger database would be necessary to precise the optimal strategy depending probably on the recycling conditions, ELM frequency and amplitude. The geometrical configuration of the diagnostic is not optimal as the line-of-sight viewing the top of the antenna is very tangential to the magnetic surfaces and antenna front face. On ITER, using the spatial resolution with more favourable lines-of-sight, the reduction of power could be of the order of 10% only when an arc is detected from enhanced radiation from the launcher.

The alternative use of the visible spectroscopy camera, just viewing the top of the antenna on JET, will be investigated in future work.

ACKNOWLEDGEMENTS.

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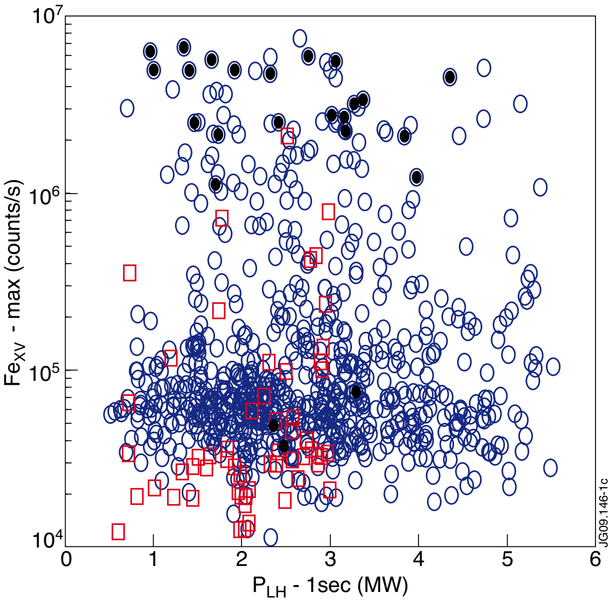

Figure 1: Intensity of the maximum of FeXV line for L-mode (circles) and H-mode (squares) discharges as a function of the LHCD power (highest value for 1s). The 22 L-mode disruptions are indicated with full circles.

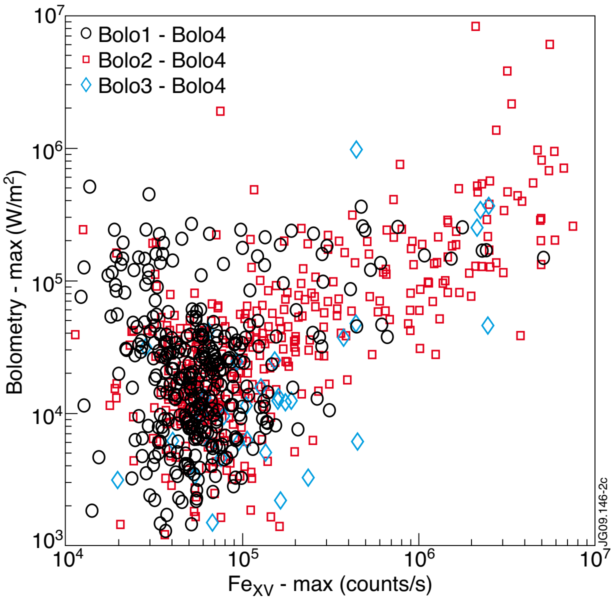

Figure 2: Normalized and low-pass filtered (250Hz) bolometry signals as a function of the FeXV maximum For each discharge the maximum of the 3 bolometry channels viewing the launcher is plotted

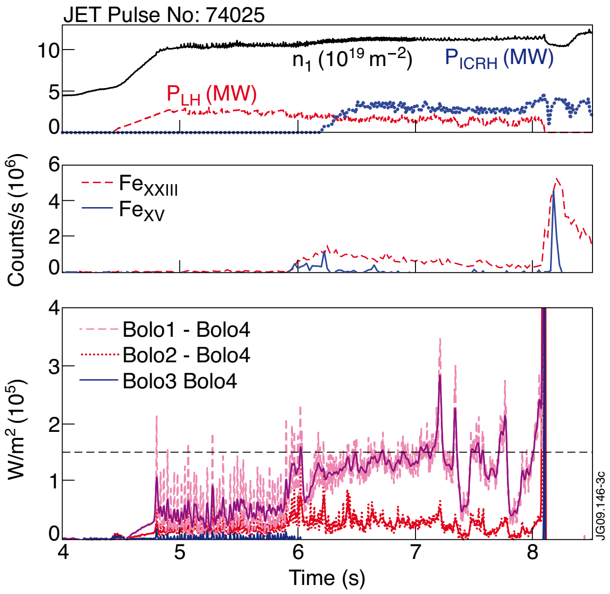

Figure 3: ELMy H-mode pulse with arcs producing metal release. Processed bolometry signals are filtered fc = 80Hz (thick lines) and fc = 250Hz (dotted line).

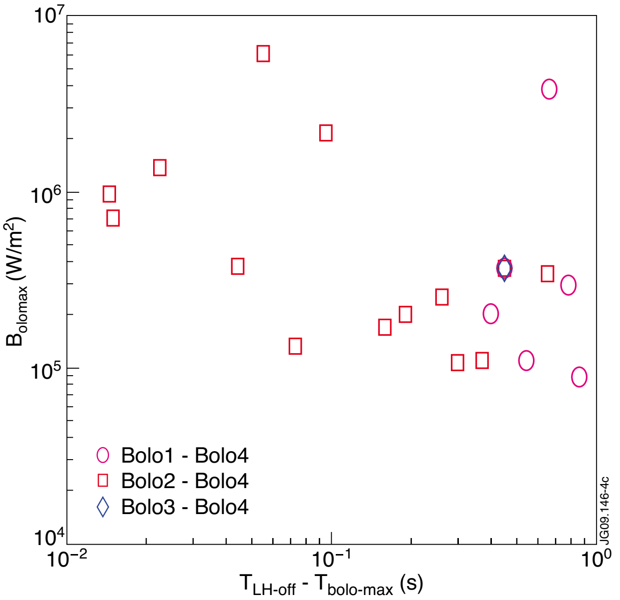

Figure 4: Maximum of the bolometry signals versus delay between the time when the bolometry signals exceed the threshold and the time the LHCD system is switched off.