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

Since operation commenced with the ITER-like wall (ILW) in JET, which includes tungsten in the divertor structure, core impurity accumulation, has become an issue. The effect is particularly pronounced in hybrid scenario pulses where tailoring of the current profile is used to achieve higher normalised beta and confinement ($H_{98y} > 1$), than in the ELMy H-mode. A causal link is found between the occurrence of low-n MHD and impurity accumulation for many hybrid pulses with the ILW; in this paper these effects are examined and contrasted with results from the previous carbon wall (C-Wall).

1. SURVEY OF MHD IN HYBRID PULSES

Figure 1 shows the occurrence of MHD in all high power hybrid pulses with the ILW. Nearly all pulses have $n = 1$ activity, associated with the $q = 1$ surface. Some pulses have $n > 1$ activity associated with $q = 4/3$ (for $n = 3$) or 3/2 (for $n = 2$), and in many cases magnetic islands are observed by a π phase change in the ECE at the frequency and expected location of the mode. The $n = 3$ activity generally occurs simultaneously with strong coherent $n = 1$ activity. The $n = 2$ and 3 activity is generally associated with higher normalised β_N (Figure 2).

It is observed that the pulses with the highest β_N also have the highest H-factors, which means that in order to access typical hybrid performance expectations of H_{98y}~1.2, that pulses are likely to be in the domain where $n > 1$MHD is destabilised. The same relationship of β_N and confinement exists for hybrid pulses with the C-wall [2] and in fact $n = 2$ activity is slightly more common (32 out of 61 pulses for the data set described in Ref [2], though it should be noted the C-wall pulses generally have longer high performance phases in which the $n = 2$ activity can occur).

1. *n* > 1MHD ACTIVITY

As previously reported [3,4] $n > 1$ MHD activity, and most notably $n = 2$ activity, can lead to significant core impurity accumulation in the case of hybrid ILW pulses. This impurity accumulation then causes a substantial reduction in confinement (see Figure 3). The $n = 2$ activity has been identified as due to 3/2 neo-classical tearing modes (NTMs) in the cases examined and is normally triggered by a sawtooth. In contrast although the MHD activity is similar in C-wall pulses, the effect of the $n = 2$ NTMs is less significant due to the absence of the core impurity radiation effect (Figure 3). $n > 2$ NTMs have an equivalent but weaker effect with the ILW and generally no significant effect with the C-wall (see Figure 5).

The impurity penetration into the core starts with an initial low field side off-axis impurity localisation (Figure 4) which is predicted by neo-classical theory including centrifugal effects on the high-Z impurities. It is thought that 3/2 NTM islands observed to be of ~ 10cm width facilitate rapid transport of the off-axis accumulated impurities into the core. There are a few pulses where core impurity accumulation precedes the NTM onset and in these the NTM does not accelerate the accumulation process [4] – which is consistent with the island transport model.

2. n = 1MHD ACTIVITY

Core $n = 1$ activity is present in essentially all ILW and C-Wall hybrid pulses. With the C-wall the $n = 1$ activity is compatible with high performance ($H_{98y} > 1.2$); Figure 5 shows 2 of the best performing C-wall pulses.

Previous work has shown that many hybrid pulses with the C-wall are affected by a 3/2 NTM after several seconds of good performance [5]. In contrast with the ILW $H_{98y} \sim 1.2$ is not sustained and $n = 1$ activity accompanies a degradation of confinement. Figure 6 shows a selection of initially high performance hybrid ILW pulses in which only $n = 1$ activity occurs –the confinement degradation is accompanied by significant amplitude $n = 1$ activity.

With the ILW (but not C-wall), pulses are observed where the core $n = 1$ activity exhibits a π phase change in the vicinity of $q = 1$ indicating an m = 1 island [6]. In such cases SXR emission shows a helical core emission structure probably within the m = n = 1 island [6]. It is thought the localised island radiation might contribute to increasing the drive for the instability in the ILW case.

SUMMARY

With the C-wall sustained high performance (with $H_{98y} > 1.2$ for > 5s) has been achieved in the hybrid regime and is compatible with core $n = 1$ activity. With the ILW sustained high performance is not achieved and confinement degradation is coincident with core $n = 1$ MHD (but causality between the MHD and confinement degradation has yet to be established). Due to their effects in causing tungsten impurity accumulation $n = 2$ and 3 NTMs have a much more significant effect with the ILW than with the C-Wall.

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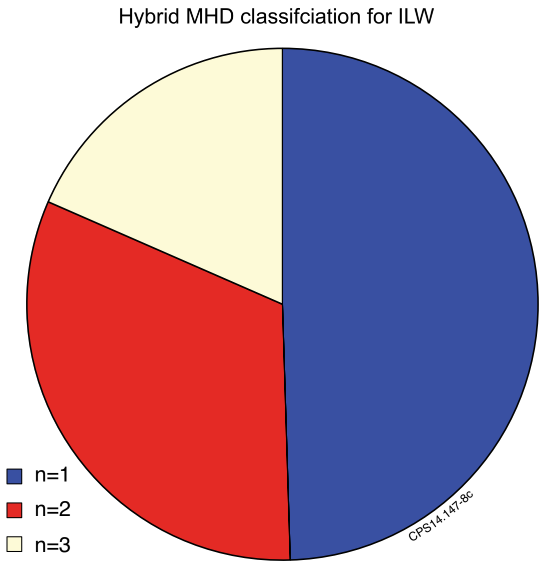

Figure 1: Occurrence of n = 1 to 3MHD instabilities in hybrid ILW pulses. If n = 2 activity occurs then that is recorded as the observed activity, n = 3 activity is recorded next and finally if n = 1 is the only activity that is recorded.

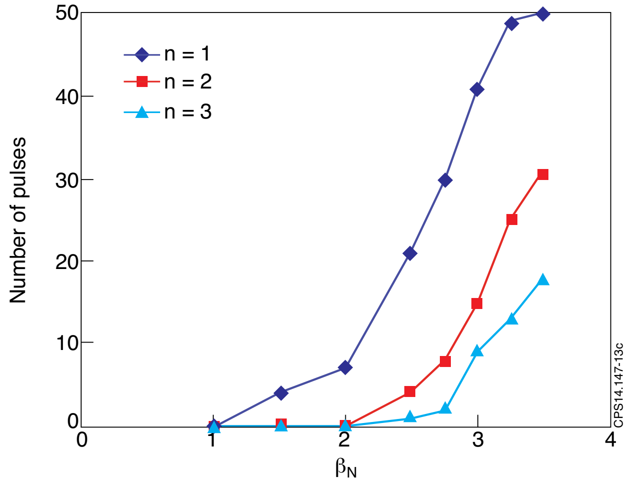

Figure 2: Cumulative number of pulses exhibiting n = 1, 2 or 3MHD. The occurrence of n = 2 activity at lower β_N < 2.75 corresponds, in all but one case, to pulses where the mode is triggered by a long period sawtooth (>0.5s); which is known to trigger 3/2NTMs at low β_N [1].

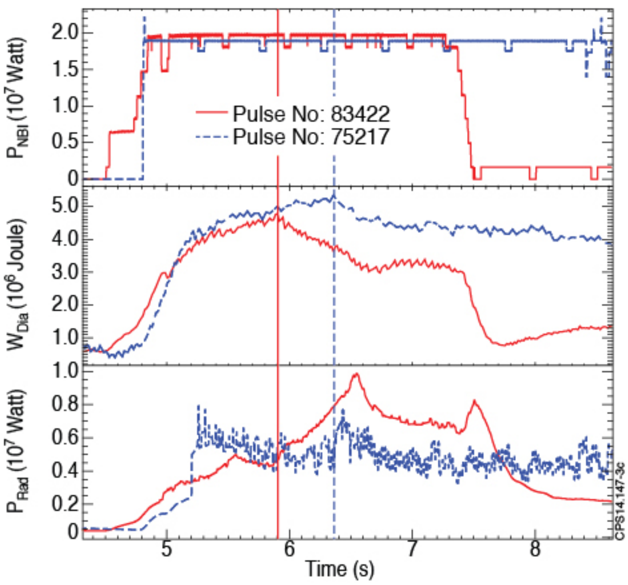

Figure 3: Comparison of 2 pulses with ILW (red) and C-Wall (blue). The vertical broken lines show the 3/2 NTM timing.

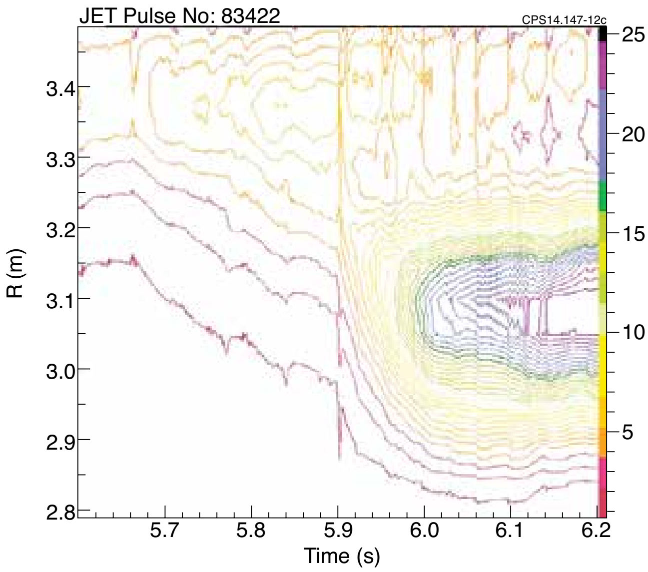

Figure 4: Vertical SXR camera – the radii (R(m)) are the intersection radii of the SXR chord with the midplane. The NTM at 5.9s causes the off-axis impurity localisation to rapidly peak on-axis.

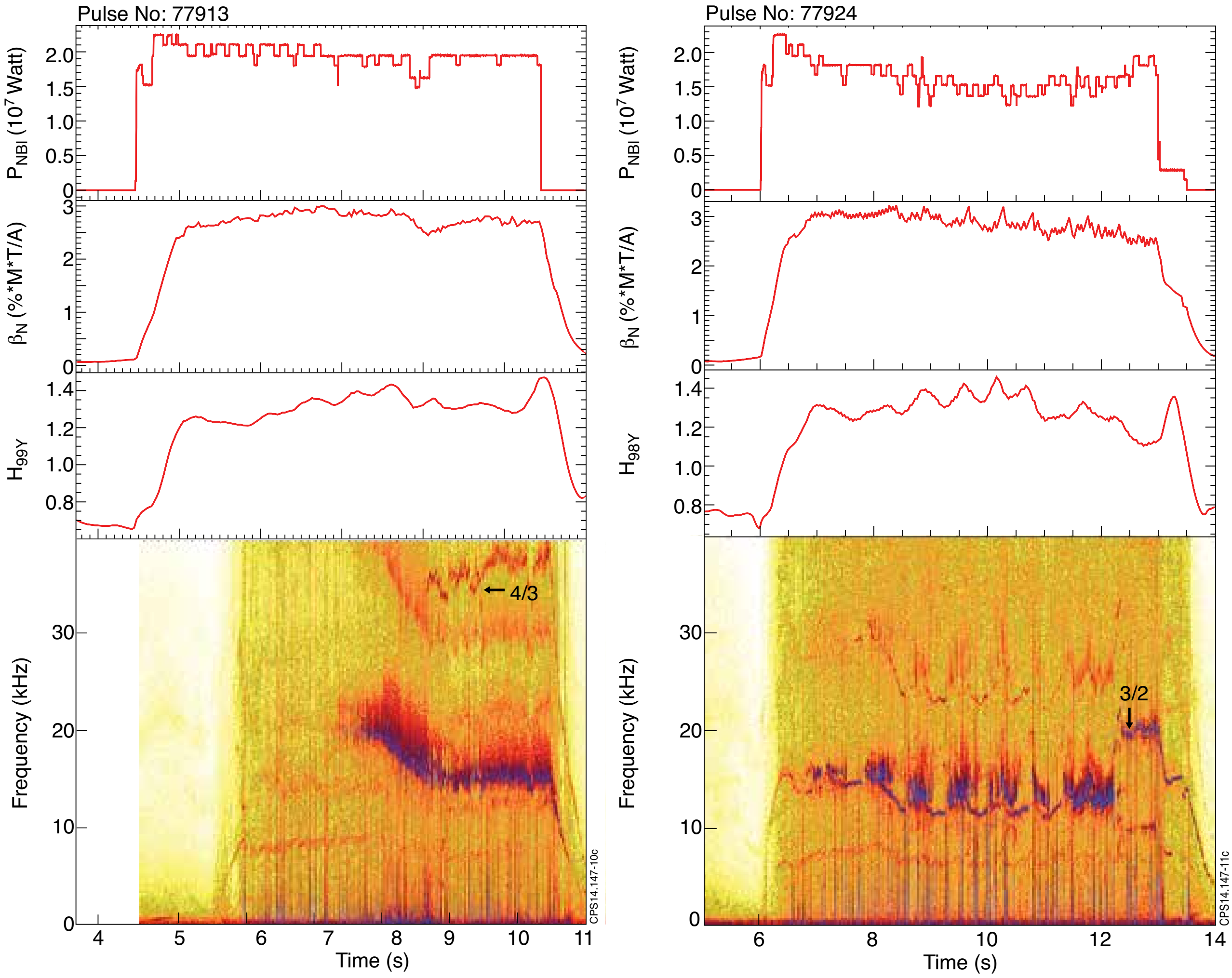

Figure 5: High performance hybrid C-wall pulses. The n = 1 activity at ~ 15kHz has no significant effect on confinement. Later in both pulses a n > 1 mode develops and the 3/2 mode does affect performance.

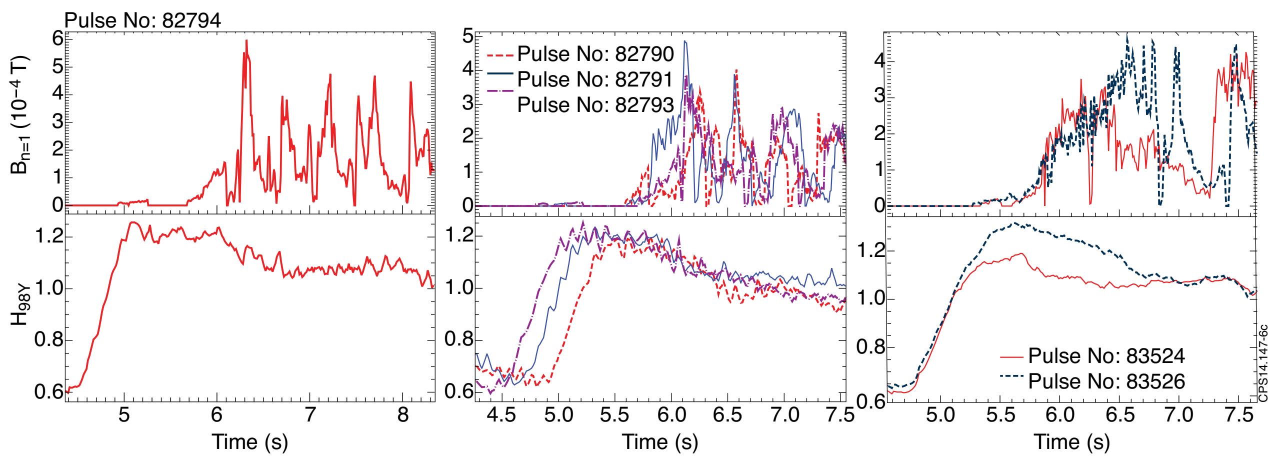

Figure 6: High performance hybrid ILW pulses in which only core n = 1 activity occurs. In all cases n = 1 activity degrades confinement. A range of pulses are shown to highlight that the degradation is a common event.