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Role of ELMs in the production and concentration of Tungsten in JET discharges

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Abstract

We report the analysis of a series of 230 shots taken randomly in the JET ITER-Like Wall (ILW) database. The goal of the analysis is to study the effects of the Edge-Localized-Mode (ELM) crash on the Tungsten source eroded in the outer divertor. The main findings are that the mean Tungsten source per ELM is proportional to the mean density drop of the pedestal during the crash. During Nitrogen seeding, the tungsten source per ELM is increased further. The frequency of the ELMs is found to be driven by the Power crossing the separatrix but is also fond to depend inversely on the density drop of the pedestal. The scaling for the frequency applies for seeded discharges as well. The role of the temperature pedestal in the process has not been tested and is still unclear. The ratio of Tungsten in the bulk over tungsten source during ELMs is a decreasing function of the ELMs frequency.

Database and signal processing

The only criteria applied for the shots selection is that the chosen time window should be long enough to include several ELMs, with no obvious change in ELM regime. The main plasma parameters should be stationary during the time window. The database includes all kinds of

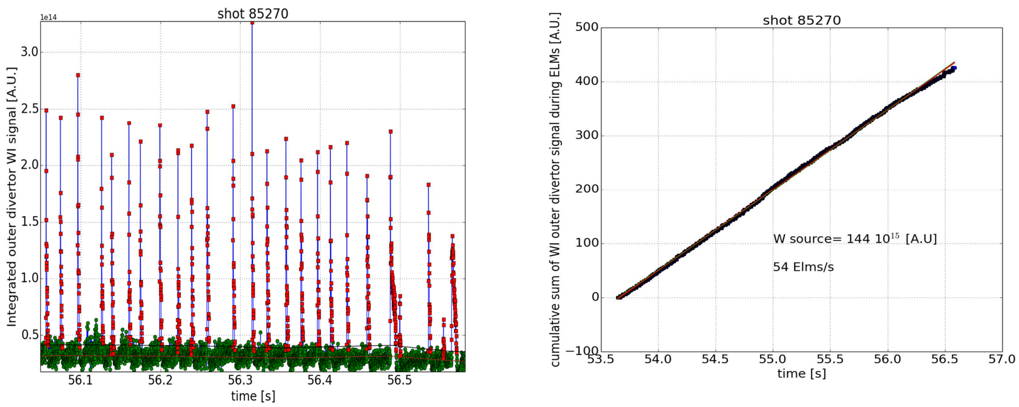

Figure 1

Left : example of ELM filtering on WI outer divertor Signal.

Right : Cumulative sum of filtered ELMs as a function of time.

plasmas during ILW operation, including Nitrogen and Neon seeding shots. The total power applied to the plasma ranges from 6 to 26 MW, Toroidal field from 1.3 to 2.87 T, Plasma current from 1.3 to 3MA, NL and $N_{pedestal}$ are measured using lines of sight of the Interferometry diagnostic, NL ranges from 0.9 to 2.4 10^{20} m^{-2}. The gas fuelling was also varied and the data include shots with kicks. The ELM filtering program is applied on the

*See the Appendix of F. Romanelli et al., Proceedings of the 25th IAEA Fusion Energy Conference 2014, Saint Petersburg, Russia integrated outer divertor signal measuring the neutral source of Tungsten WI. This signal is composed by summing up 10 spectroscopic lines of sight monitoring the outer divertor. No calibration is applied to this signal. An example of filtering is shown in Figure 1 left. The mean number of ELMs per second is measured (ELMs of all sizes are included in the count). The cumulative sum of the WI signal during ELMs is computed as a function of time and displayed in Figure 1 Right. The slope of this curve gives a value proportional to the number of Tungsten atoms emitted per second. The mean number of Tungsten atoms per ELM (uncalibrated) is also calculated.

Scaling of the tungsten source produced by the ELMs

Figure 2 left: The mean tungsten source per ELM (outer divertor) is found to be proportional to the mean density drop of the pedestal during ELM crash. Dependence with pedestal

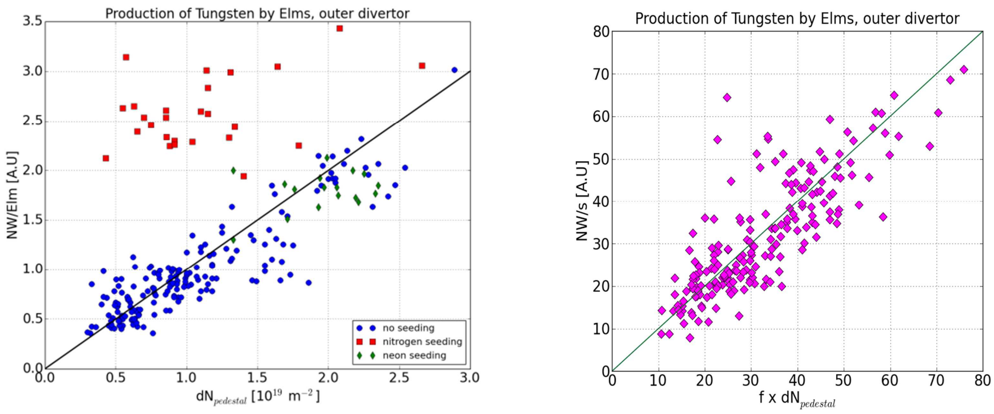

Figure 2

Left : Mean number of tungsten atoms per ELM as a function of mean pedestal density drop during ELM crash. Right : Dependence of mean number of tungsten atoms per second with mean pedestal density drop during ELM crash and ELM frequency (No seeding).

temperature has not been checked so far and will be investigated in the near future. However the data is already rather well aligned (standard deviation 0.25). We have not observed any effect of the position of the outer strike point though its position was scanned from the center horizontal target over the corner to the vertical target. The result presented here is not incompatible with the idea that physical erosion by ELMs occurs in a range of particles energies where the cross section for erosion is constant [1-4]. As far as the nature of particles responsible for the tungsten erosion during ELM crash is concerned, it is necessary to estimate the concentration of the different impurities to give an answer. This concentration is not calculated for these shots though concentrations of about 1% of Beryllium have been estimated in ILW plasmas [5]. With such a concentration Deuterium should dominate the physical erosion. We notice however that the case with nitrogen seeding stands out and shows an increase of the tungsten source by about a factor of 2 relative to the scaling. Surprisingly no increase of the tungsten source with neon seeding is found. Figure 2 right is simply the consequence of the previous finding. The source rate during ELMs $N_{tungsten}/s$ in the case where no nitrogen seeding is applied is simply proportional to the mean drop of the pedestal density multiplied by the ELMs frequency.

Scaling of the ELMs frequency

The frequency for type 1 ELMs has been found to be an increasing function of the power crossing the_separatrix [6]. Here we reexamine this dependency, keeping in mind that the ELMs encountered so far in our database with the ILW regardless of their size have the characteristics of type 1 ELMs. The result is shown in Figure 3. The frequency of the ELMs is found to be increasing with the power crossing the separatrix and decreasing with the density drop of the pedestal during ELM crash. The standard deviation of the data around the fitting curve is 8.5 Hz. This scaling is in agreement with the usual observation that the ELM size

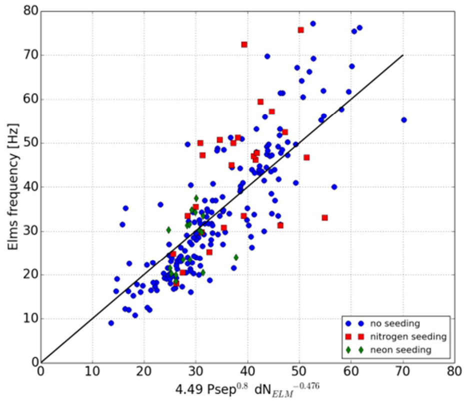

Figure 3
Scaling of ELMs frequency with Power through separatrix and mean density drop during ELMs

(dN_{ELM}) decreases with the frequency but by inverting the scaling it can be seen that dN_{ELM} is also an increasing function of the power through the separatrix. The result here suggests that the time to refill the pedestal density may be a factor driving the frequency of the ELMs. We notice also that the data for nitrogen and neon seeding follows the same scaling. The same process probably drives the ELM frequency in seeded discharges. We plan to extend the analysis to type 1 ELMS in Carbon discharges and check type 2 ELMS in JET Carbon and ILW discharges against the scaling presented here.

Dependences of the amount of tungsten in the discharge

The amount of tungsten in the bulk of the discharge is roughly estimated with the help of the bulk radiated power and mean density of the plasma. This supposes that the radiation from the bulk comes only from tungsten. In this case the relative invariance of the radiative function of tungsten with electron temperature [7] allows writing the amount of tungsten in the discharge as:

$$\iiint Nw\, dV = Prad_{bulk}/(<Ne>\, L_w^{eff})$$

The ratio of Number of tungsten atoms estimated in this way over tungsten source during ELMs is plotted in Figure 4 as a function of ELMs frequency. This ratio is found to be a decreasing function of the ELMs frequency indicating that the flushing effect of the ELMs is real. At frequencies below 40 Hz many shots have a high ratio of bulk tungsten over source during ELMs. Individual observation of the two terms forming the ratio indicates that the amount of tungsten in the discharge is high while the source of tungsten by ELMs is low for these shots. In fact the amount of tungsten eroded by the ELMs continues obeying the scaling displayed in figure 2 left but the level of radiated power is unusually high. We will investigate if the increase in radiated power correlates with the tungsten bundle line measured in the bulk or if some other type of impurity must be invoked to explain the high level of radiated power measured for these shots. In the latter the ratio displayed in Figure 4 for these shots would be wrong. Another possibility is a change of the tungsten influx produced by changes in gas flow and SOL properties.

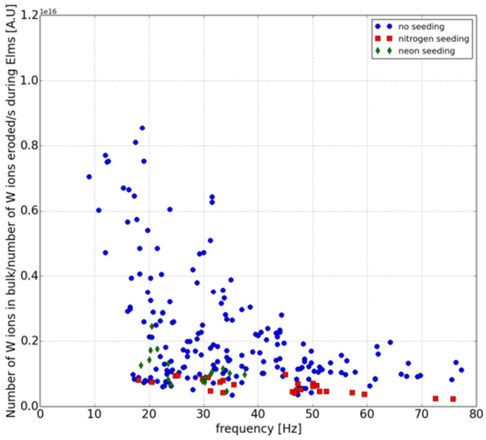

Figure 4

Ratio of number of tungsten ions in the bulk of discharge over number of tungsten atoms eroded by the ELMs /s. The ratio is shown as a function of ELMs frequency.

Conclusions

A database of 230 shots in ILW has allowed drawing some conclusions on the effect of tungsten erosion by ELMs. One of the strongest results is that the mean tungsten source per ELM is directly proportional to the mean pedestal density drop during the ELMs. Some results are also presented showing that the ELMs frequency is a function of both the power through separatrix but also of mean pedestal density drop during ELM crash. The number of shots seems to be sufficient to draw firm conclusions about these two items. However, the situation is less clear about the flushing effect of the ELMs on tungsten where the observed dependencies are rather fragile. In particular the estimate of the amount of tungsten in the discharge using the bulk radiated power has not been correlated with observations of spectroscopic lines of tungsten. To really confirm the flushing effect of the ELMs on tungsten, it is necessary to increase considerably the number of shots in the database. It is also necessary to investigate how the temperature of the pedestal modifies (or not) these results.

Acknowledgment:

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