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Gas Exhaust Study by RGA in JET After Disruptions and Impurity Seeding

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1. INTRODUCTION

ITER will start with a full tungsten divertor and will operate with type I ELMy H-mode. W erosion by impurities will determine the divertor target tiles lifetime. This erosion will be caused during semi-detached divertor operation, mainly by ELMs carrying both intrinsic impurities such as Be, O, and C; and seeded impurities applied to reduce divertor heat loads and induce inter-ELM detachment. Ar or Ne will also be injected during Massive Gas Injection (MGI) for disruption mitigation. JET with its ITER-Like-Wall (ILW) offers a unique insight into the gas impurity concentration in the ITER material mix: Be and W in the absence of C. The temporal evolution of the impurity concentration can be followed during a single discharge or a full day of operation, up to 35 discharges [1]. The experience from JET can be used to extrapolate the impact of impurities on ITER plasma operation.

Gas impurity concentration is studied utilizing the magnetically-shielded Residual Gas Analyzer (RGA) of JET sub-divertor. The temporal behavior of impurities released after MGI-mitigated and unmitigated disruptions during seeded and non-seeded discharges will be analyzed. MGI-induced disruptions will also be accessed as a method to control impurity levels [2]. This study will be focused on nitrogen, most probable seeding gas, which has the drawback to be retained in tungsten [3,4], produce tritiated ammonia, etc.

2. EXPERIMENTAL

Gas from the JET sub-divertor was analysed by means of the recently upgraded RGA system [5]. It consists out of a Hidden Analytical HAL 201 RC mass spectrometer inside a soft iron chamber installed to shield magnetically the quadrupole and allow measurement during a plasma discharge. The chamber is differentially pumped though a tunable flow restrictor reduces the pressure by only one order of magnitude to enhance sensitivity for minority species. Only stable molecules and atoms could be detected.

During a discharge discrete mass-to-charge (m/q) ratios are measured: 2-4, 12-21, 23, 28-32 and 40. The sampling rate is set to 1.4 s for a compromise to allow several points recording in the discharge flattop phase of more than 10s but with good signal-to-noise ratio. m/q signals have been, as shown in Table 1, assigned to their main and secondary species considering their cracking pattern. It is necessary to clarify that, unless specified, any mention to water and ammonia production will refer to both protonated and (partially) deuterated molecules. The exact isotope quantification is out of the scope of this work. It will be studied in [7], but in the case of water it seems to be most usually fully deuterated, and ammonia mostly protonated. As the RGA has not yet been calibrated, only qualitative trends could be given. For this purpose time integrals for each m/q are calculated from 2.5 s before a discharge until 70 s after end of a discharge. The background was taken as the average of the signal during the 40 s before plasma discharge.

3. RESULTS AND DISCUSSION

In a previous, more general work [6], a low impurity content was found in JET with the ILW. Main

contaminants are water and nitrogen, and evidences of ammonia production were found, which will be studied in a forthcoming paper [7]. A small legacy of N in a number of subsequent discharges (4-6) was found after N₂ seeding; Ar was detected only after many a number of MGI-induced disruptions with high Ar fraction in the injected Ar/D₂ mixture. Neon seeding has shown no legacy. In this work individual discharges are compared. In order to account for impurities decrease after a disruption, plasma parameters and configuration of both discharges have to be similar. Due to the inherent variability of a tokamak this is not frequently achieved, which limit the number of useful discharges.

3.1 NON-SEEDED DISCHARGES

As can be seen in Figure 1, when comparing two discharges (Pulse No's: 85394 and 85398), with two MGI-mitigated disruptions in between (Pulse No's: 85396-7), an evident decrease of the main impurities levels, 25-30% water and 40% N₂, can be observed. Oppositely, if disruptions are not mitigated only a slight decrease (5-10%) in the same absolute impurity levels are observed: Pulse No's: 85471 and 85474, also with two non-mitigated disruptions in between.

3.2 NITROGEN SEEDED DISCHARGES

In order to study impurities legacy caused by nitrogen seeded discharges in subsequent ones, non-seeded discharges done just after seeded ones are compared. These kind of discharges are routinely used as references during seeding experiments, so they usually have similar parameters. As can be seen in Figure 2, two non-seeded discharges are compared. If the previous heavily seeded discharge ended in a MGI-mitigated disruption (Pulse No: 85435) the impurity level is largely decreased: 30-40% ammonia, 10% water and N₂. This comparison is not completely reliable as Pulse No: 85435 had no NBI, and therefore less plasma power. However, as Pulse No: 85433 is a regular heavily seeded discharge, the impurity levels should be larger at Pulse No: 85435 due to the accumulation of nitrogen. This fact further highlight the possibility of using induced MGI-disruptions to control the nitrogen legacy in a device. As before, similar impurity levels are observed after non-mitigated disruptions. The comparison is done between a non-seeded discharge, Pulse No: 85174, after a regular seeded discharge (Pulse No: 85173 has around ten times less N₂ injection than Pulse No: 85431), with a non-seeded discharge after three non-mitigated disruptions, Pulse No: 85180.

It is necessary to mention that after N₂ seeded discharges part of the previously retained nitrogen is released as ammonia. This could be a combination of desorption of the previously developed ammonia, as it easily sticks at walls, decomposition and/or erosion of Be₃N₂ from the main wall [8], and chemical sputtering of the tungsten nitrides by the impinging deuterium [3].

3.3 MGI-INDUCED DISRUPTION

A session of MGI-induced disruptions for runaways generation was analyzed: from Pulse No's: 85445 to 85456. As the previous days a series of a N₂ seeding sessions were done some retained

N can be expected at walls or at tungsten tiles surfaces. In MGI-induced experiments no ammonia release were found. When the %Ar of the MGI mixture is increased from 10 to 40% a 20% more of N₂ release is detected. This suggests that larger Ar levels favors the release of nitrogen as its molecule, not as ammonia, due to the physical sputtering of tungsten and beryllium nitrides by Ar. In general, the larger the plasma energy, the larger impurity release, being thermal stored energy more important than magnetic one, as it defines the wall temperature achieved during thermal-quench. Also a large impurity level decrease is seen at the end of the session: 45% of water and 54% of N₂. However, protonated water level is recovered during the night, as it will come probably from leaks at the RGA chamber, although it is also detected during the overnight regeneration of the divertor He cryo-pumps. Anyway, this confirms the excellent impurity cleaning capabilities of induced MGI-disruptions at low %Ar, 10-30%, to avoid runaway electrons generation.

4. CONCLUSIONS

As expected, more impurities are released during MGI mitigated disruptions due to the much larger walls area heated when compared to a non-mitigated one, especially at larger plasma energies. Precisely these MGI disruptions could be induced to clean JET or ITER of most impurities at the end of a seeding session, or prior/alternated to specifically important discharges (for example, with tritium).

However, this has been a preliminary study, different parameters like plasma energy, plasma density, seeding rate of N₂, etc., have an effect on the efficiency of the removal and further investigations are required to disentangle them.

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species	4 m/q	16&17 m/q	18 m/q	20 m/q	28 m/q	32 m/q	40 m/q
Main	D ₂	NH ₃	H ₂ (D)O	D ₂ O + Ar	N ₂	O ₂	Ar
Minor		H ₂ (D)O + O ₂	NH _n (D) _m		CO		ND ₃

Table 1. Most and less probable species for each m/q ratio.

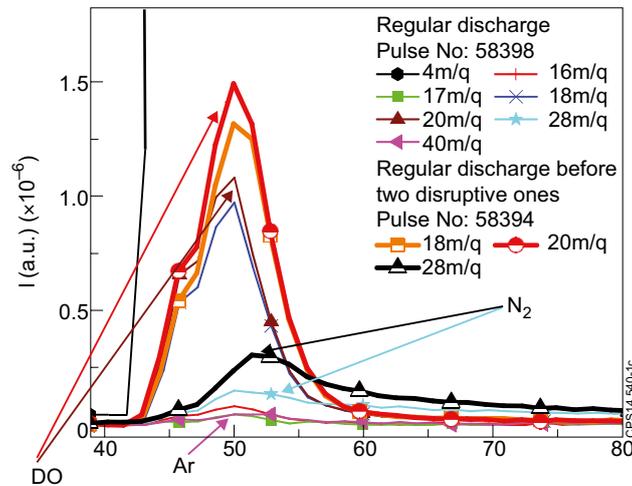


Figure 1: m/q impurities timetraces during non-seeded discharges after two MGI mitigated disruptions.

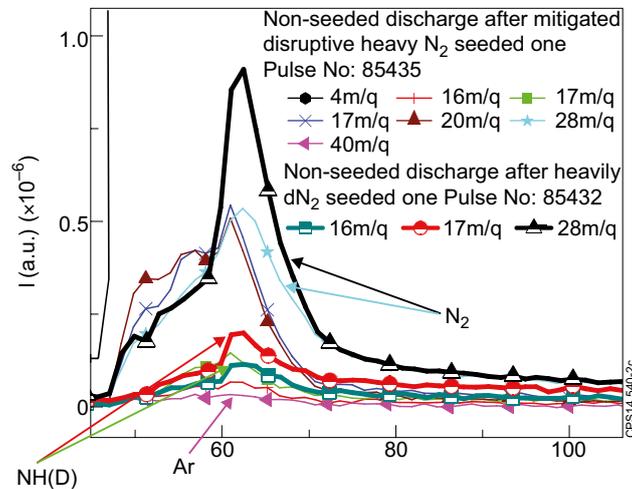


Figure 2. m/q impurities timetraces during N₂ seeded discharges after a MGI mitigated disruptions.