29th EPS Conference on Plasma Phys. and Contr. Fusion Montreux, 17-21 June 2002 ECA Vol. ***26B****, P-2.051 (2002)*

Mitigation of disruptions with fast impurity puff on ASDEX Upgrade.

G. Pautasso, A. Savtchkov *, *S. Egorov, R. Dux, K.H Finken* *, *O. Gruber, G. Haas, G. Mank* *, *M. Maraschek, V. Rohde, U. Seidl and the ASDEX Upgrade Team;*
Max-Planck-Institut für Plasmaphysik, EURATOM Association, 85748 Garching, Germany;

(*) Institut für Plasmaphysik, Forschungszentrum Jülich, Association KFA-EURATOM, Member of the Trilateral Euregio Cluster (TEC), 52425 Jülich, Germany

Introduction. The injection of impurity gas into a plasma, which is irreversibly going to disrupt, is one of the the mitigation strategies (besides killer pellets) which has been tested on ASDEX Upgrade. This method of partially cooling down the plasma through ionization of neutral gas and radiation, before its thermal energy is naturally conducted through the SOL onto the plasma facing component, has been gaining attention because of its simplicity and effectiveness. In addition, the injection of high-Z impurities has the effect of accelerating the decay of the plasma current, of reducing the amount of induced current in the structures and therefore of reducing the mechanical forces on the machine.

Fast valve. A fast valve system, developed by the authors of the Forschungszentrum in Jülich [1], has been used on ASDEX Upgrade for the series of experiments presented in this paper. The fast valve can inject up to a few 100s mbarl of impurity gas within 1 ms. Experiments were carried out with up to 180 mbarl (3 bar * 60 cm^3 = 4.5 10^{21} particles) of Helium (He), Neon (Ne) and Argon (Ar) in limiter and divertor plasmas. The valve was located at a major radius of 4.55 m and 3.43 m in the discharges of the 14000 and 15000 series, respectively, while the plasma edge was at about 2.12 m.

Purpose of the experiment. The purpose of the present experiment was to look for an impurity gas puff regime which can routinely be used on ASDEX Upgrade for disruptions mitigation (in conjunction with a disruption prediction system). We compared the performance of He, Ne and Ar in reducing the mechanical forces and thermal loads on the machine after disruptions and choose optimal gas quantity and pressure taking into account that: 1) the quantity of gas puffed in the torus should not give rise to a pressure higher than 10^{-3} mbarl, to avoid activating security measures, foreseen in case of a leak (the ports of the NI sources close and the sources are reconditioned); 2) above 10^{-2} mbar there is the risk of damaging diagnostics and turbo-pumps.

The tokamak is not equipped with ports able to close within a few ms (is it possible at all?) in order to protect diagnostic and auxiliary equipment; the gas pressure and quantity is therefore smaller than the ones used in DIII-D [2] (70 bar reservoir and 3 10^{22} particles).

Most of the experiments were carried out feed-forward in healthy plasmas; a few of them with locked mode trigger before density limit disruptions. With the injection of

180 mbarl of Ar the pressure measured in the NI boxes reached 10^{-3} mbar; therefore this quantity represents the upper limit to the quantity of gas injected in this experiment. In several cases we measured the pressure of the gas in the valve before and after the puff and derived, as a rule of thumb, that 2/3 of the gas in the valve is usually released during the fast opening of the valve.

Current quench. A first series of experiments was made by puffing gas in the ramp-down phase of the discharge when the plasma is already circular and touching the inner limiter. The current quench of such plasmas after disruptions without gas impurity puffing can be slower by one order of magnitude than in the case of disruptions of elongated plasmas followed by a VDE. Therefore the rate of current quench of these plasmas is strongly determined by the quantity and type of impurity gas injected and less from the plasma wall interaction. Using 180 mbarl of gas we could observe that: 1) the rate of current quench is about 20 MA/s in the case of He puff and increases to 60 and 78 MA/s in the case of Ar and Ne puff (see Fig. 1); 2) the time of flight of the gas, from injector to plasma edge, is proportional to the square root of the atomic mass (as expected); 3) the time delay between the appearance of the gas at the plasma edge and the disruption is of 12, 4 and 2 ms for He, Ne and Ar respectively; 4) the increase of the line integrated density before disruption depends strongly on the sort of gas: the He, Ne and Ar puffs increase the line average density of a factor of 3, 2 and less than 0.5 respectively. This is probably a consequence of the different penetration length of Ar, Ne and He.

The retention of Ar in the machine after impurity puff was higher than for Ne and He. Traces of Ne could barely be observed in discharges following strong gas puff; however in shots following Ar puff the fraction of the input power radiated was observed to be significantly higher than in the previous shot because of impurity contamination.

Due to the 1) the smaller effect of He in accelerating the current quench, 2) the smaller sound velocity of Ar, 3) the higher Ar contamination of the next discharge with respect to Ne and He and 4) the lower penetration of Ar in the plasma it was decided to concentrate further the experiments with elongated plasmas on Ne.

Mechanical forces. The machine structures are subject to strong vertical forces during disruptions of X-point plasmas followed by VDE. In a series of disruptions caused by density limit (800 kA, 1.5 and 2 Tesla,), the locked mode signal was used to trigger the fast valve and inject 30, 60 and 120 mbarl of Ne. The maximal force on the vessel, measured at 8 suspension roads decreased with the increase of the gas quantity from 190 kN down to 65 kN (see Fig. 2). The halo currents decreased in a similar way from 300 kA down to 120 kA. Their degree of asymmetry on a small scale did not change significantly with the injection of gas. We conclude that the injection of 120 mbarl of Ne and the reduction of 34 % of the forces on the vessel is a suitable mitigation scenario for ASDEX Upgrade.

Thermal loads. The radiated energy was measured by the bolometer and the energy deposited on the divertor plates by the thermography system. The foils of the bolometer were apparently cooled by the gas, the radiated energy measured is only 70 before the disruption and the radiation profiles modified by this effect. This effect must be quantified with a dedicated measurements and the bolometer data must eventually be corrected. In addition, the heat deposited to the divertor plates by conduction must be evaluated by subtracting from the thermography measurements the contribution due to radiation. This part of the work is still in progress.

Runaway electrons. The generation of runaway electrons (RE) have been observed in a few discharges with densities lower than 4 10^{19} m^{-3} and magnetic field larger than 2 Tesla before and after thermal quench with the injection of Ar and Ne. Two main scenarios of RE generation have been observed. After Ar puffing, spatially and temporally localized bursts in the SXR are observed before and after thermal quench; after approx. 6 ms from the thermal quench at a plasma current of 200 kA (originally 600 or 800 kA) then all SXR channels see an emission of a few kW/m^2 peaked at the edge (see Fig. 3). The HXR detectors also see a flux of photons with energies above 500 keV.

After Ne puffing, all SXR channels show the massive production of RE al the plasma edge which are lost (and seen by the HXR detectors) even before the thermal quench. In these experiments the RE do not generate a current plateau (not even in circular and limited plasmas) and do not seem to develop in the plasma core as observed in JET [3] at low plasma elongation. The hard X-ray diagnostic consists of four detectors on the walls of the torus hall. The detectors are between 9 and 12 m from the torus axis and are mounted at the height of the plasma axis; they are 266-Ne liquid scintillators combined with a photo-multiplier.

Bursts in the SXR spatially and temporally localized are seen before and after thermal quench in plasmas with a higher density and without the generation of HXR emission,

Future work. A smaller gas valve, built by S. Egorov, has been installed permanently on ASDEX Upgrade and integrated in the safety/ control system of the machine. It allows the puff of impurity gas within 1 ms and operates at somehow larger pressure (5-7 bar). This valve will allow to continue investigating the mechanisms of interaction of the gas with the plasma and the generation/suppression of RE.

References.

1) A. Savtchkov et al., Poster at this conference.

2) J. Wesley, D.G. Whyte et al., *MHD, Disruption and Plasma control ITPA Meeting,* JAERI Naka, Japan 6-8.2.2002

3) R. Gill et al., Nuclear Fusion **40** 163 (2000).

Acknowledgments. The authors wish to thank P. Cierpka, R. Neu and C.J. Fuchs for their precious advices.

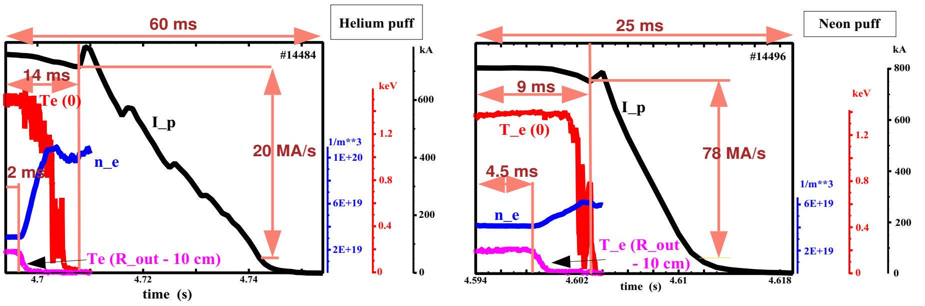
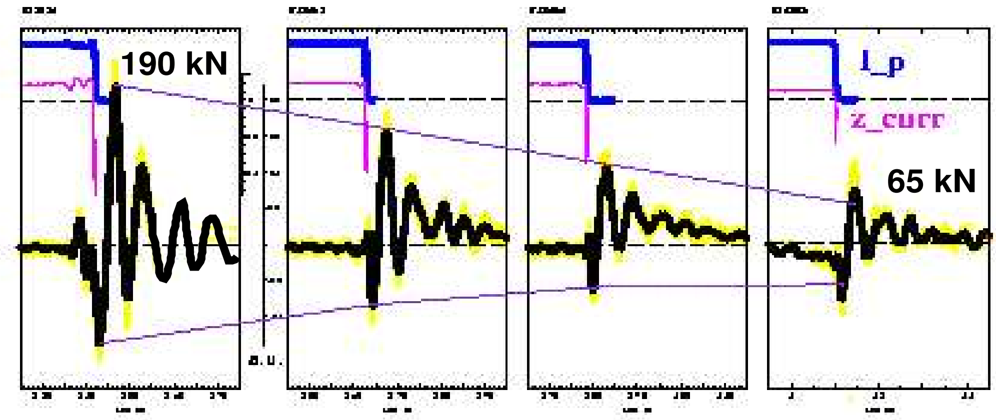


Figure 1. Current quench after He (left) and Ne (right) puff; n_e , T_e and I_p are respectively the line averaged density, the electron temperature and the plasma current.



no gas **30 mbarl** **60 mbarl** **120 mbarl**

Figure 2. Reduction of the vertical forces on the vessel with Ne puff

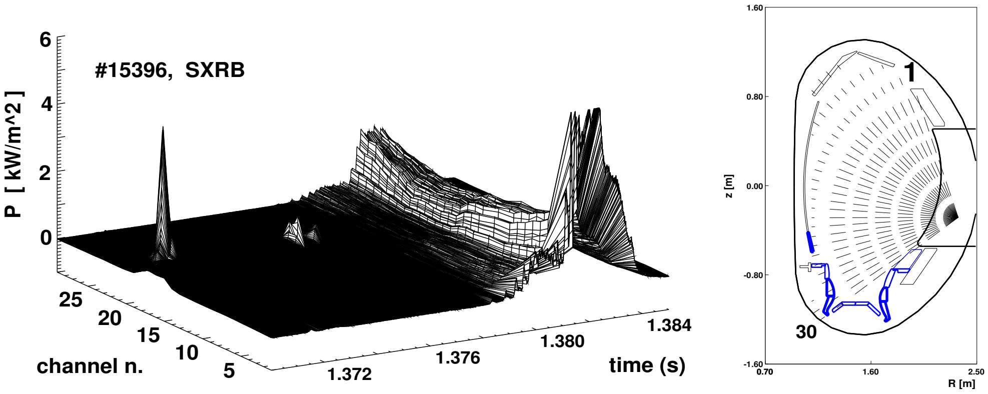


Figure 3. Line integrated SXR emission (left) seen by the orizontal camera (right). At t= 1.372 s is the disruption after Ar puff.