*36th EPS Conference on Plasma Phys. Sofia, June 29 - July 3, 2009 ECA Vol.**33E**, P-4.205 (2009)*

Control of Runaway Electron Beams on Tore Supra

F. Saint-Laurent, C. Reux, J. Bucalossi, A. Loarte[§], S. Bremond, C. Gil, P. Moreau, JL. Ségui

CEA, IRFM, F-13108 Saint-Paul-lez-Durance, France

[§] ITER organisation, JWS Cadarache, F-13108 Saint-Paul-lez-Durance, France

During the thermal quench of a disruption, the plasma current profile flattens and a huge toroidal electric field appears in the core plasma region. Thus fast electrons experiencing low collisionality can be freely accelerated up to several tens MeV. During the current quench an avalanching process takes place leading to a multiplication of these runaway electrons (RE). The impact of RE on the first wall is well localized due to their small pitch angle. The energy deposition may be huge and plasma facing components (PFC) damages are currently reported. The RE formation and their consequence on the machine components have been identified as a major issue for ITER operation [1].

RE beams lasting several seconds can be observed on Tore Supra for disruption occurring during the plasma current ramp-up [2]. A current of several hundred of kilo amps, corresponding to 20-60% of the pre-disruptive plasma current can be associated to these beams. Experiments have been recently carried out to better characterize these RE beams and to assess different means for mitigating the effects of their impacts on the first wall: a control of the RE beam position such as driving the RE on dedicated PFC, a time spreading of the energy loss associated to a decelerating electric field for reducing the thermal loads, the use of massive noble gas injection (He and Ar) for slowing-down the RE were investigated. The photoneutron production, associated with electrons above 8-10 MeV, was used as an indicator of the amount of RE hitting the wall.

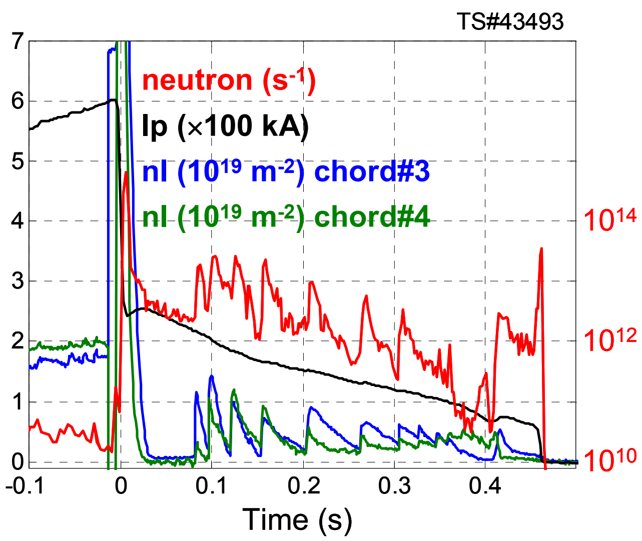

Figure 1: RE plateau showing photoneutron bursts associated to electron line density rise. Photoneutron fluxes are plotted using a logarithmic scale (on the right)

1. Characterization of the RE plateau regime: The line integrated electron density profile during the RE flat-top regime was assessed using IR interferometer. Its typical behaviour is a decrease below 10^{18} m^{-2} at the end of the current quench, and then it recovers to 1-1.5 10^{19} m^{-2} after 50 ms, without any gas puffing (figure 1). Several density oscillations are also observed and correlated to photoneutron emission. From the RE current the relativistic electron density is estimated to be a few 10^{17} m^{-2}, well below the measured value. Therefore, an additional process explaining the observed density must be introduced. At the end of the disruption the plasma neutralized and neutrals have no time to be pumped before their subsequent re-ionization by the RE (ionization is the dominant slowing-down process in this RE energy range). Free electrons are also generated by the RE-wall interaction. These processes generate a cold background plasma which superimposed the RE and might carry a part of the total current. The RE density rises from IR interferometry are found to be in good agreement with the visible observation using a fast-framing camera. The RE localization is identified using the interaction of the fast electrons with the dusts filling the vacuum chamber after the

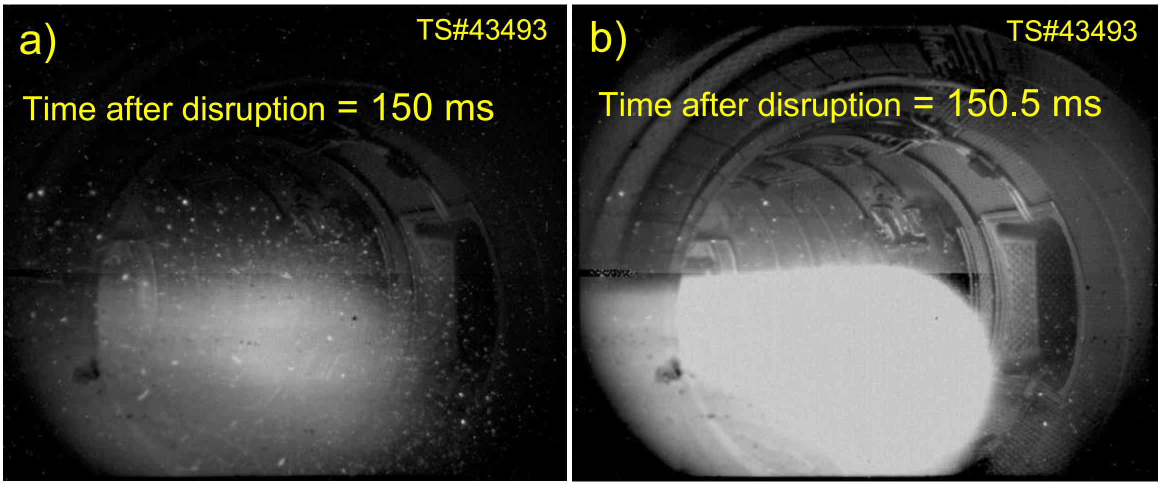

Figure 2: fast-framing camera pictures. a) The RE beam is identified by its interaction with the carbon dusts filling the vacuum chamber after the disruption. b) Radiating events occur during the RE flat-top.

disruption. These dusts are heated by the RE and a snow shower picture is recorded (figure 2). On the movie the visible dust density is thus correlated to RE density. On the figure 2a, the RE beam can be located in the middle of the chamber, below the equatorial plane, and a minor radius of 40 cm can be deduced. On the RE plateau several photoneutron bursts are often observed (figure 1). These bursts are associated with an electron density rise. Such events are also visible using the fast camera. They are associated with highly radiating plasma as shown on figure 2b. The amount of impurity (mainly carbon dust) in the background plasma might be a source of such a radiating pattern. These events increase the transverse transport of RE towards the first wall.

2. Control of RE beam position: During standard disruption on Tore Supra, a huge photoneutron peak is observed 5 ms after the thermal quench when no RE flat-top develops. This peak is reduced when a RE tail occurs. Another photoneutron peak is also always observed at the end of the RE plateau. These peaks are associated with a large energy deposit.

Thus the wall component at the impact localization and the capability to control the RE beam are of major importance. Figure 3 compares the current barycentre of two shots, with and without the active position control. Without any control the RE beam is found to move horizontally toward low or high field side depending on the shot. The control of the current barycentre is switch on 30 ms after the disruption. It demonstrates that the location of the RE impact on the first wall components can be freely chosen. Such a control enable us to save time to mitigate the RE effects.

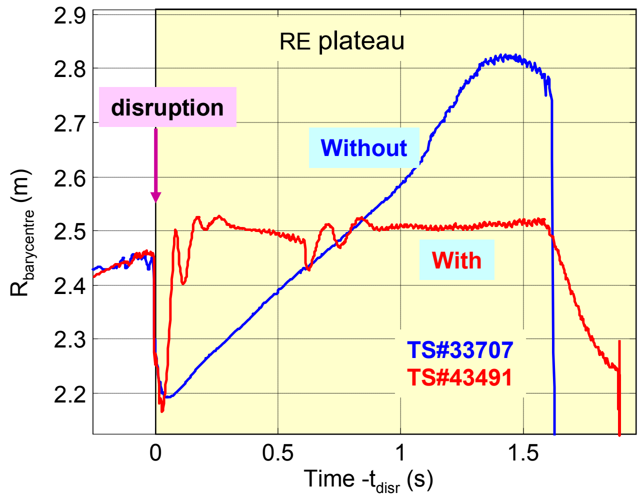

Figure 3: The plasma position active control is switch on 30 ms after the disruption. No current control was set in and the gas fuelling was switch off.

3. Effect of a decelerating electric field: This effect was investigated by varying the central solenoid voltage while controlling the RE beam position. It was found that an increase of the decelerating toroidal electric field leads to a reduction of the RE plateau duration associated to an increase of the neutron flux (figure 4). For the same initial RE current the total amount of neutrons remains roughly constant, indicating that the slowing-down is not effective.

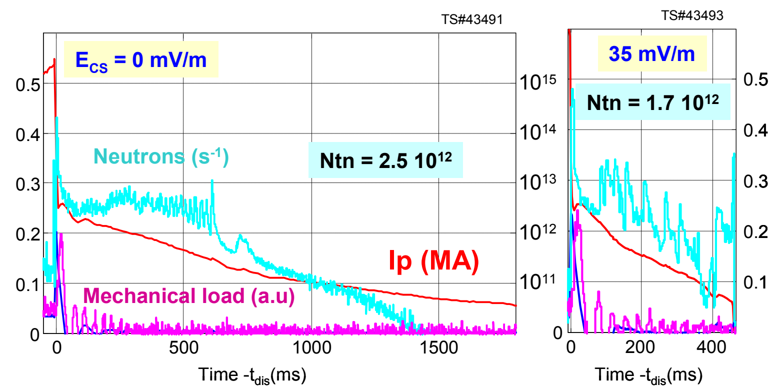

Figure 4: Effect of a toroidal electric field for slowing-down the REs. The RE flat top is reduced but the total number of neutrons stay roughly constant. Neutron yields are plotted using a logarithmic scale. Mechanical loads on toroidal main limiter are also shown.

The modest electric field created by the central solenoid might be reduced by the loop voltage associated with the RE current variation. A better control of the loop voltage is thus requested for further investigations.

4. Effect of a massive gas injection (MGI): the MGI technique is widely used for disruption mitigation studies. Effect of He MGI on already accelerated RE has been reported in [2]. The use of a heavier slowing-down gas (Ar) is assessed in the present experiment. Whatever the injected gas is, the behaviours are comparable (figure 5). The MGI is triggered 200 ms (He) and 300 ms (Ar) after the disruption. In both case a faster decrease of the RE current, larger for the Ar case, is observed leading to a shorter RE plateau duration. At the same time a large rise of the photoneutron flux is seen (a factor 10 for He and a factor 50 for Ar). A neutron burst remains at the plasma termination. The total amount of photoneutrons scaled by the RE current when the MGI is triggered is found to be roughly the double for He gas case. But large fluctuation on neutron production is observed (factor 2 to 4) and a statistical analysis on a larger set of shots must be performed. Nevertheless the photoneutron production is not strongly reduced using MGI mitigation, indicating that the slowing-down by neutrals is not as much effective as expected. The main MGI effect is the dramatic rise of the neutron flux. The increase of RE-neutral collisions explains such an effect. Multiple Coulomb scattering is responsible of the deflection. Following the Molière theory the deflection angle scales as the square root of the path length expressed in radiation length unit [3]. The radiation lengths are 94.3 g/cm^{-2} and 19.5 g/cm^{-2} for He and Ar respectively, and the path length scales as the pressure times density factor, assuming the same initial energy spectrum for RE. Thus the deflection angle is found to be 3 times larger for Ar injection than for the He case, in qualitative agreement with the neutron flux measurements. Because the deflection is stochastic the RE are spread over a very large wall surface, leading to a huge reduction of the heat load, despite the RE number does not decrease. This benefit effect, essential for mitigating RE loads, will be studied in more details in further experiments, as well as detailed calculations of RE-neutral and RE-wall interaction.

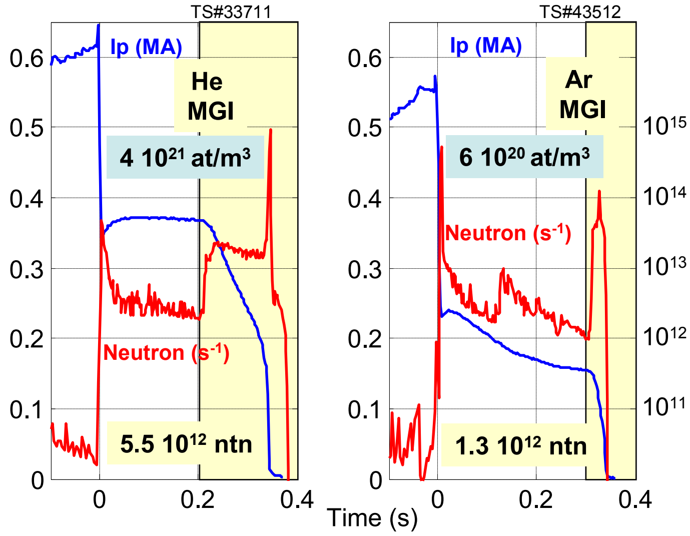

Figure 5: effect of a He (left) and a Ar (right) massive gas injection on RE plateau. The RE flat-top is reduced and the photoneutron flux is enhanced. The amount of injected gas and the total number of neutrons detected after the MGI trigger are indicated.

References:

[1] ITER Physics Basis 2007, Nucl. Fusion 47 S178

[2] F. Saint-Laurent et al, 32nd EPS on Plasma Physics, (2005, Tarragona, Spain)

[3] C. Amsler et al, Physics Letters B667 (2008) chapter 27