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FAST ELECTRON DYNAMICS IN THE TORE-SUPRA PLASMA EDGE

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Tore-Supra 1999 experimental campaign was curtailed as a result of a large water leak on the inboard main limiter. The location of the leak was correlated with Lower Hybrid (LH) fast electrons, lost to the wall in very focalised beams. The acceleration and loss of these electrons are quite different from previous observations, such as:

i) very high energy runaway electrons created during disruption [1]

ii) low energy electrons accelerated in the front of the LH launcher [2]

A qualitative study of the phenomenon has been performed, as it might prove deleterious for any large machine, where fast electrons impinge water cooled components.

I) Observation of high power flux damages on the first wall

Tore Supra high field side inner first wall (IFW) is a full toroidal and poloidal belt limiter, shown on figure 1. It is built with stainless steel water cooled tubes (150 °C, 28 bars), and graphite tiles brazed with an intermediate copper foil. Old panels with amorphous graphite have been partially replaced by new panels with carbon fibre composite (CFC), with a higher power flux capability.

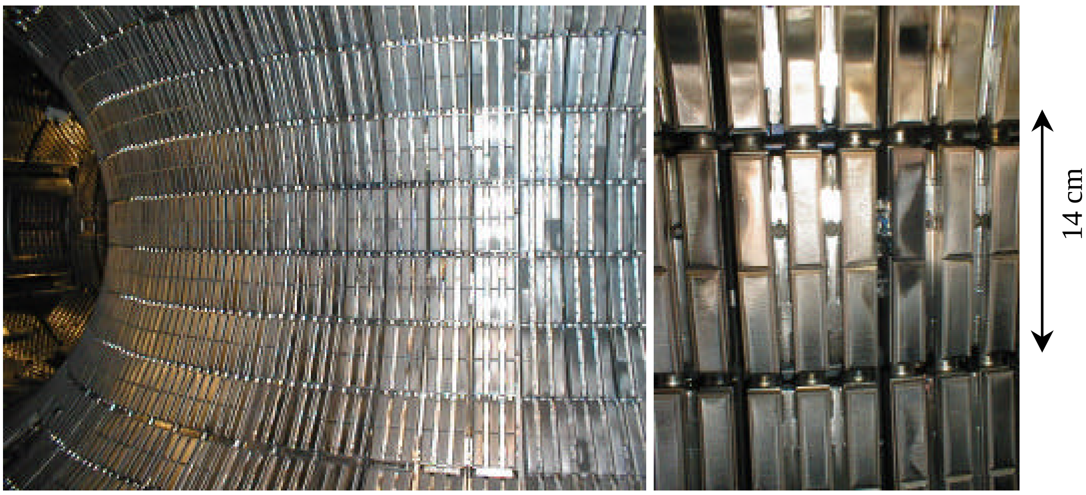

Figure 1: Tore-Supra Inner First Wall : General view and Localised electron impacts

After the 1999 plasma campaign, several localised burn marks have been observed on a few CFC tiles, with a distinctive triangular shape, as shown on the figure 1 (right). The most intense of these was connected with the water leak, caused by a melting of the copper foil and steel tube. A thermo-mechanical simulation of the tile on its structure indicates that a power flux around 10 MW/m^2, during several seconds, can lead to such a break-down. The origin of such a flux peaking, as the mean value on the IFW is lower than 1 MW/m^2, and the extreme localisation of the power deposition (a 2 x 5 cm^2 surface) raises several questions.

A CCD camera, looking at the IFW during high power Lower Hybrid (LH) current drive, shows very bright spots (figure 2). Although the water leak location is not viewed by the CCD camera, the two observations shared several properties:

i) a poloidal location close to the equatorial plane, plus or minus 10 degrees;
ii) a toroidal location between a port and a coil, where the pitch angle of the field line is at its maximum, due to the combined effects of the field ripple and the polygonal shape of the IFW. Relative intensities between modules are correlated with slight radial misalignments (0.5-1.5 mm) of the IFW panels relative to the toroidal field lines;
iii) a very small spatial extension, connected to a weak diffusivity (see chapter II).

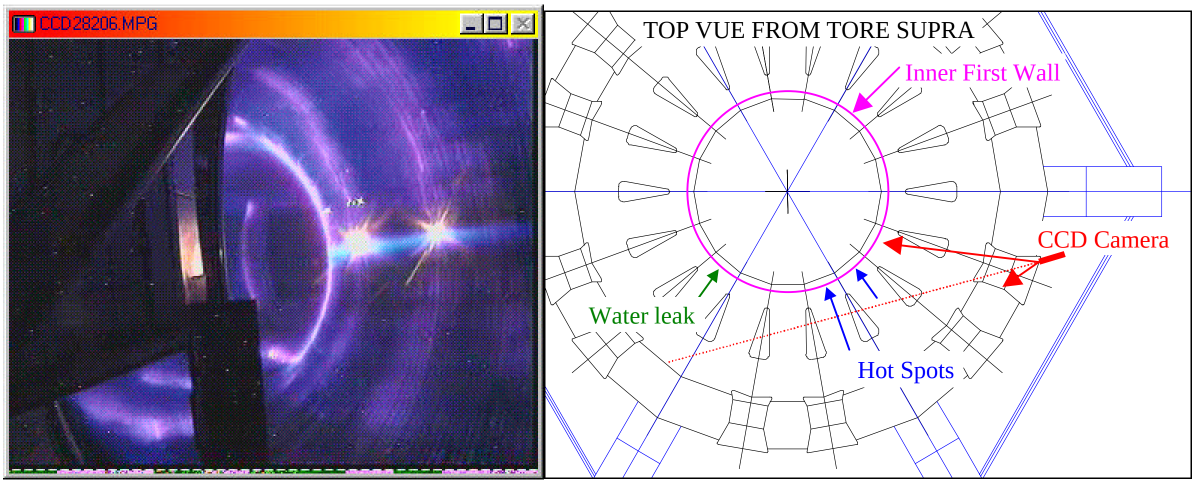

Figure 2 : Hot spots observed with a CCD camera during LH current drive / Camera location.

The temporal evolution of these bright spots is slow (typically one second), suggesting a thermal phenomenon. They are sometimes accompanied by brief luminous trails, shown on figure 2, which last only one video frame and are correlated with small copper injection in the plasma, as observed by a UV spectrometer.

The recording of the video picture does not allow any quantitative analysis, due to the limited range and rapid saturation of the signal. But an array of optical fibres, installed in a top port to measure bremstrahlung and Z-effective, shows an exponential increase on some channels, as represented on figure 3. This is interpreted as a reflection of the light emitted by the hot spots on the external first wall (XFW) made of steel. It shows a clear temporal correlation between the emission of the hot spots and the turning on and off of the LH power. Fast electrons accelerated by the waves are though the best candidates to explain this anomalous power flux on the IFW.

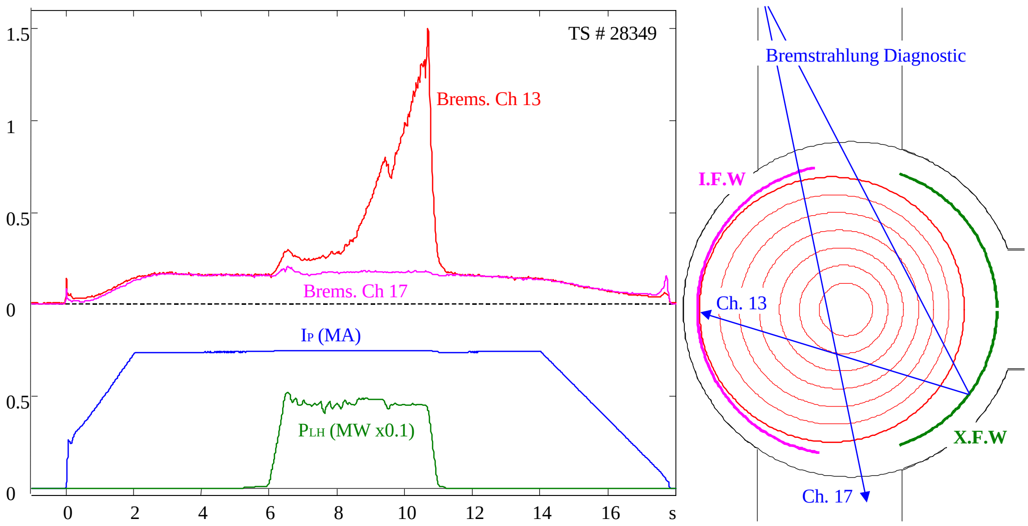

Figure 3: Time evolution of the light emitted by the hot spots / Diagnostic configuration

II) Electron Characterisation through Hard X-ray Signal Analysis

On Tore Supra, fast electrons in the 20-200 keV range are diagnosed with a hard X-Ray (HX) camera [3] with 51 channels allowing a full 2-D tomography. When the light spots are observed on the CCD, a strange feature appears on only one channel of the HX camera: usually channel 5, which intersect the IFW close to the equatorial plane (figure 4), but sometimes also on channel 2 or channel 8. This can be related to the appearance of small X-ray hot spots observed in the JT-60 divertor, in similar plasma conditions [4].

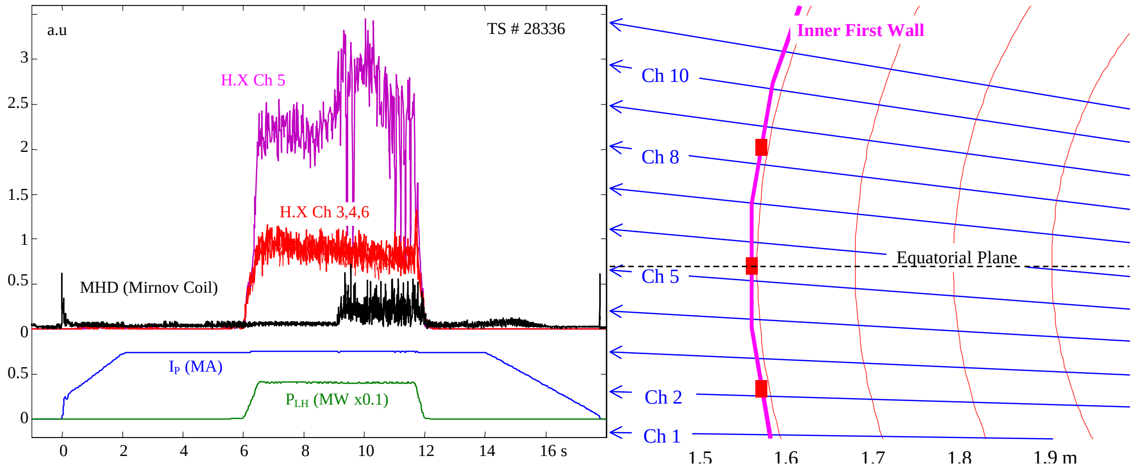

Figure 4: Hard X-ray count rates ($E_X \in$ [80 - 100 keV]) / Diagnostic lines of sight

The spectral analysis of the HX fluxes, performed with 20 keV energy bins between 50 and 150 keV, shows that the photon temperature is much higher in the additional signal in channel 5 than in the bulk signals from channel 3 to 7 (figure 5). Although this is not an absolute proof that electrons lost on the IFW have a higher energy (pitch angle scattering in the graphite tiles might contribute to the increase), it allows nonetheless to estimate their energy range: at least 150 keV, which is much higher than the edge electrons previously reported in [2], with energies in a 5-10 keV range. This signal is interpreted as the loss of the fast electrons accelerated by the LH waves in the plasma (to create the current), through collision or turbulence. The high focalisation, as well as the effect of panel alignment, can be understood if the diffusion coefficient for these electrons is around 0.1-0.2 m^2/s, providing a radial decay length of their flux in the scrape-off layer smaller than 1 mm.

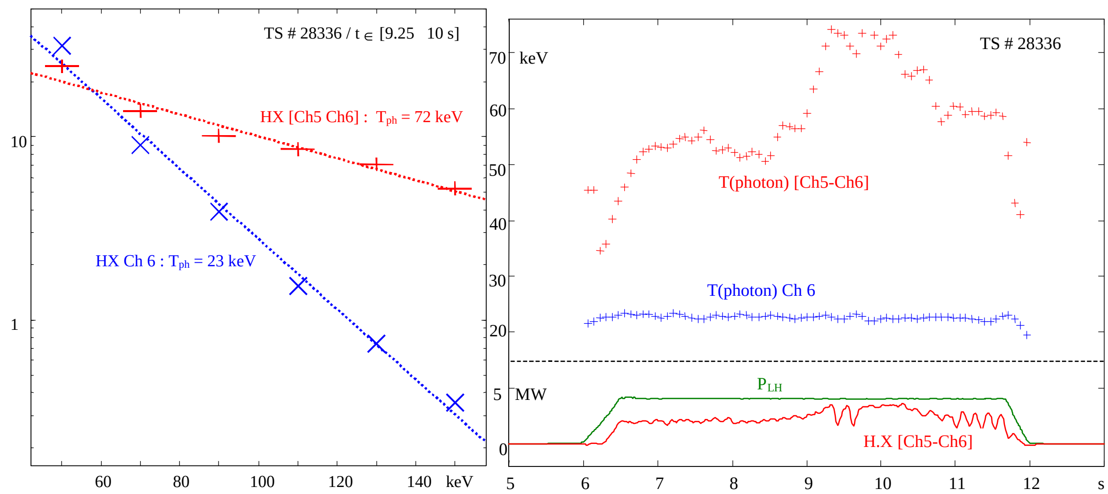

Figure 5: Temperature of the hard X-ray photons measured on the central channels

Optimal conditions to observe these fast electrons are a combination of high LH power with low density, as required for fully non inductive operation. Helium operation seems more favourable than deuterium, suggesting an effect of the edge density. A large dispersion in the HX additional fluxes is observed for given macroscopic plasma parameters, while large change like the appearance of a m=2 strong MHD activity in the plasma core does not affect the signal much, as seen in figure 4.

A statistical analysis of a large database (11000 time points from 160 shots) shows the effect of the plasma current, yet unexplained (figure 6). When the mean level of HX in channel 3 to 7 depends only moderately on the current (the maximum around 700 kA is due to higher LH power used during a few shots at this current value), the extra signal in channel 5 exhibits a more peaked optimum between 600 and 800 kA. This optimum is also observed during a single shot (TS #28194), where a ramp down of the plasma current was performed with a steady LH power and density.

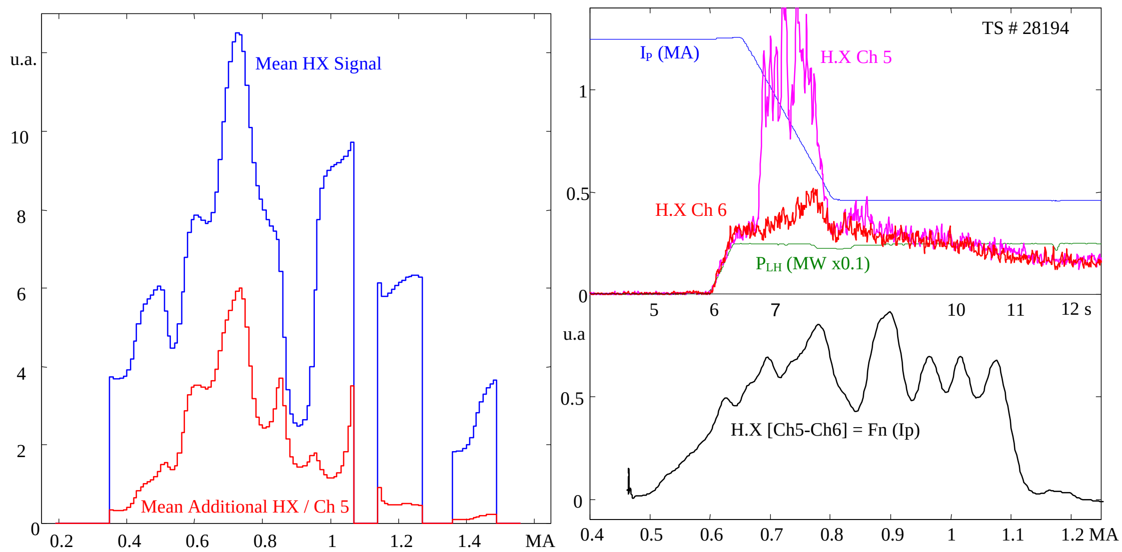

Figure 6: Statistical analysis and Single shot evolution of the HX signal versus plasma current

III) Conclusions

Large losses of supra-thermal electrons have been observed on the first wall of Tore Supra with several diagnostics. These electrons, with a typical energy around 100-200 keV are accelerated in the plasma core by LH waves, and lost to the wall through a slow diffusive process. The combination of high LH power with a low edge density is the worse scenario, which can ultimately lead to the burning of the first wall, with thermal fluxes higher than 10 MW/m^2. The phenomena is probably not new, but was not properly analysed before, first due to the lack of the right diagnostics (CCD and HX camera), and secondly due to the breaking of the amorphous graphite tiles prior to the melting of the steel tube. This self protection feature disappears with the much stronger CFC tiles. More attention will be given to the study of these electrons in the future, especially as long pulse operation might be performed in the high LH power and low density plasma conditions.

[1] G. Martin, Proc. 25th EPS Conf. on Plasma Physics, p651, [1998].
[2] V. Fuchs, & al.: Phys. Plasmas 3, p4023, [1996].
[3] Y. Peysson & F. Imbaux, Rev. Sci. Instrum. 70, p3987, [1999].
[4] K. Ushigusa & al., Nuclear Fusion 32, p1977, [1992].