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Measurements of runaway electrons in the TEXTOR tokamak

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Introduction

The main interest to study runaway electrons in the tokamaks results from high and very localized heat flux density on plasma facing materials during a plasma disruption [1]. The estimates have shown that up to 700 MJ of energy of runaway electrons can be loaded in the plasma facing materials in the ITER tokamak [1].

Two main mechanisms are responsible for the runaway electrons production: i) the primary generation process [2], where electrons diffuse in the momentum space. The production rate for the primary production is given in [2]:

$$\dot{n}_r^{pr} = \frac{n_e}{\tau}\left(\frac{m_e c^2}{2T_e}\right)^{3/2}\left(\frac{E_D}{E_\parallel}\right)^{3/8}\exp\left(-\frac{E_D}{4E_\parallel}-\sqrt{\frac{2E_D}{E_\parallel}}\right), \quad (1)$$

where $\tau = 4\pi\varepsilon_0^2 m_e^2 c^3/n_e e^4 \ln\Lambda$ is the relativistic electron collision time, $E_\parallel$ is the parallel electric field and $E_D = m_e^2 c^3/e\tau T_e$ the Dreicer field; ii) in the secondary process, the runaway electrons are generated due to the interaction of the runaway electrons with thermal electrons [3] and the production rate can be approximated as [3]:

$$\dot{n}_r^{sec} \simeq n_r\left(\frac{\pi}{2}\right)^{1/2}\frac{E_\parallel/E_c - 1}{3\tau\ln\Lambda}, \quad (2)$$

where $E_c = m_e c/(e\tau)$ is the critical electric field [2].

Experiments have shown that the runaway generation depends not only on the plasma density but also on the toroidal magnetic field B_t; the B_t dependence was in particular found in the current quench of disruptions [5]. Therefore during the recent campaign, measurements of runaway electrons have been preformed a) at stationary, low density conditions.

Runaway electron production at different plasma densities

The production of runaway electrons at several densities has been studied using two different diagnostics: a synchrotron radiation [6] and a scanning probe [7]. The synchrotron radiation has

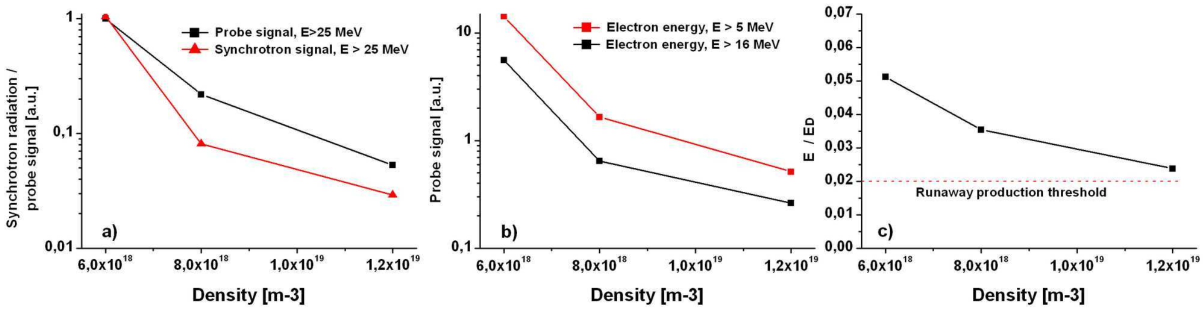

Figure 1: *a) Synchrotron radiation and probe measurements of runaway electrons with energies higher than 25 MeV at 2.15 s into the discharge; b) The probe measurements of runaway electrons with electron energies higher than 5 MeV and 16 MeV. The probe was placed at the last closed flux surface (LCFS) at 2.15 s during the discharge; c) Ratio of the electric field to the Dreicer field.*

been measured by an IR-camera. The IR-camera, recording the synchrotron radiation, yields spatially and temporally (1 kHz) resolved measurements of runaway electrons with energies above 25 MeV between 1.4 m and 1.9 m of the major radius inside the plasma. The probe consists of 10 YSO ($Y_2SiO_5 : Ce$) crystals, which are shielded by tungsten filters of different thicknesses, allowing to detect electrons with different energies between 4 MeV and 30 MeV at the plasma edge. The probe possesses a temporal resolution of 0.05 ms and a spatial resolution of 2 mm. It has been shown that the number of runaway electrons reduces with increasing plasma densities, see Fig. 1 a); b). From (Eq. 1) it is seen that the production rate is an exponential function of the Dreicer field E_D, which is proportional to the plasma density n_e. Thus by increasing density the number of primary generated runaway electrons is reduced. Estimates of the ratio of the electric field to the Dreicer field, for corresponding densities, with the following other parameters: $\ln\Lambda = 16$, $T_e = 1.5\ keV$ [4], are shown in Fig. 1 c). Although the secondary generation does not directly depend on n_e, the reduction of the primary produced runaway electrons leads to a decrease of secondary electron production (Eq. 2).

Measurements of the runaway spectrum

The runaway electron spectrum have been measured with the following plasma parameters: plasma density $n_e = 0.9 \cdot 10^{19}\ m^{-3}$; plasma current $I_p = 300$ kA and magnetic field $B_t = 2.25\ T$. The probe was inserted at the LCFS at 1.15 s during the discharge. The measured runaway electron spectrum is shown in Fig. 2. It is the first successful attempt to determine the runaway energy spectrum over a wide range. The presented electron distributions are very preliminary results as more measurements are necessary in order to get better statistics for the data analysis

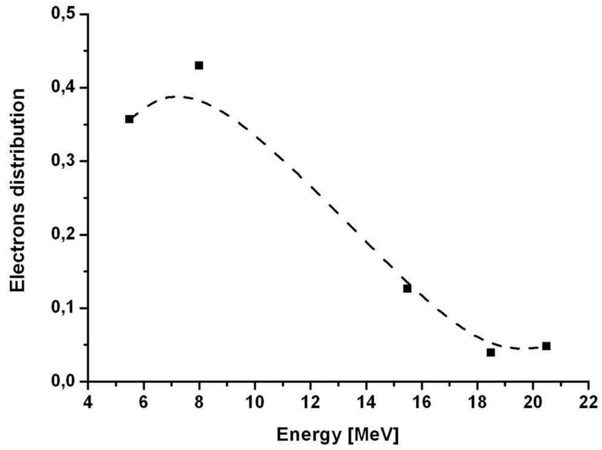

Figure 2: *Runaway electron spectrum measured during a low density plasma discharge. The probe was inserted at the Last Closed Field Surface at 1.15 s into the discharge.*

and an absolute calibration of the probe is required.

Runaway electron production at different toroidal magnetic fields

Measurements of runaway electrons at different toroidal magnetic fields have been performed using the IR-camera and neutron detectors. Runaway electrons have been registered by both diagnostics at B_t higher than 2 T, B_t has been changed between 2 T and 2.7 T; $B_t = 2.8\ T$ is the technical limit of TEXTOR. The observed maximum was at 2.6 T , see Fig. 3 a). Fig. 3 b) represents the loop voltage in the stationary part of the discharge. One observes a slight decrease of the loop voltage with increase of B_t.

Tentatively, we explain the maximum of the runaway production with respect to the B_t - varia-

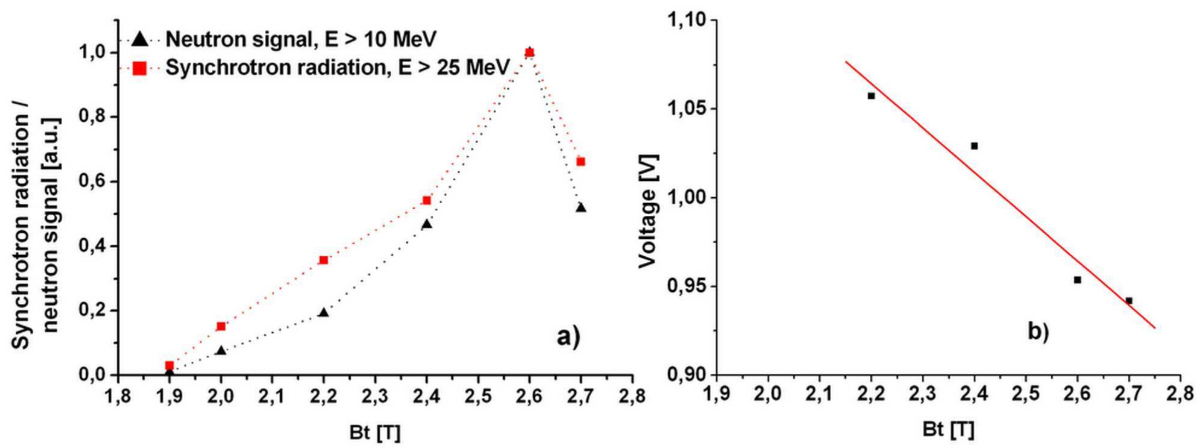

Figure 3: *a) Neutron detector signal; synchrotron radiation measurements; b) Time averaged loop voltage in the stationary part of the discharge.*

tion as a competition of the reduction of the diffusive losses of the runaways with an increasing B_t [8] and of the lowering of runaway production by lowering the loop voltage.

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