Parameters of Runaway Electrons in JET

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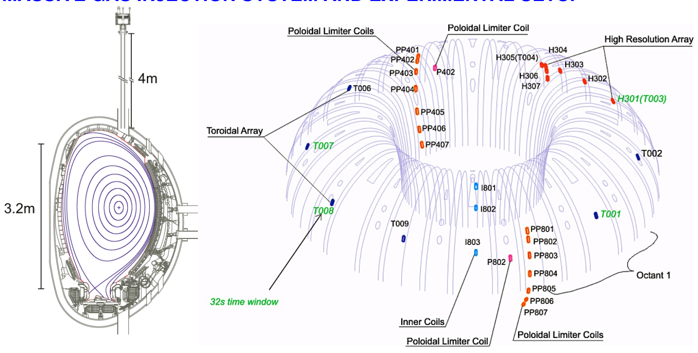
*See the Appendix of F. Romanelli et al., Proceedings of the 25th IAEA Fusion Energy Conference 2014 Saint Petersburg, Russia

INTRODUCTION

- High-energy runaway electrons (RE) generated in major disruptions could result in severe melting of the Be-based plasma-facing components (PFC) in ITER. Therefore, an avoidance or suppression of RE generation is a task of high priority for ITER.
- Massive Gas Injection (MGI) from specially designed Disruption Mitigation Valve (DMV) is considered to be the most promising candidate method for suppression of RE generation and disruption mitigation [1].
- The latest results on studies of RE generation during disruptions in JET with full-metal ITER-like wall (JET-ILW) are presented. The database on RE generated at major disruptions in JET with carbon-fibre composite (CFC) tiles (JET-C) [2-4] has been used as reference for development of disruption scenarios for RE generation study in JET-ILW [5].
- Experiments provided new results on disruption physics and sufficient data for comparison to JET-C results. The influence of MGI and ITER-Like wall conditions on RE generation process is analysed. Large RE current densities (up to 1.5 MA/m^2) have been evaluated from measured data.

MASSIVE GAS INJECTION SYSTEM AND EXPERIMENTAL SETUP



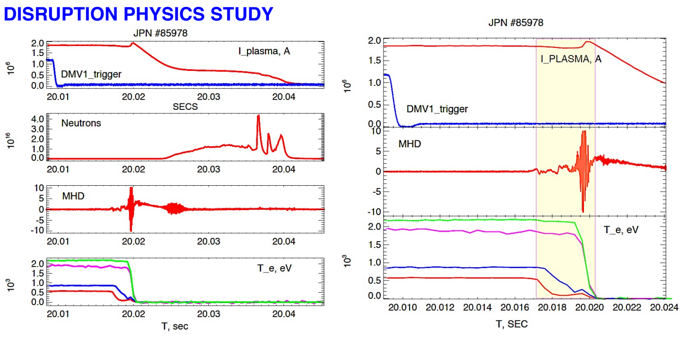
Disruption Mitigation Valve (DMV) Setup for Massive Gas Injection at JET and layout of MHD diagnostics

DMV parameters:

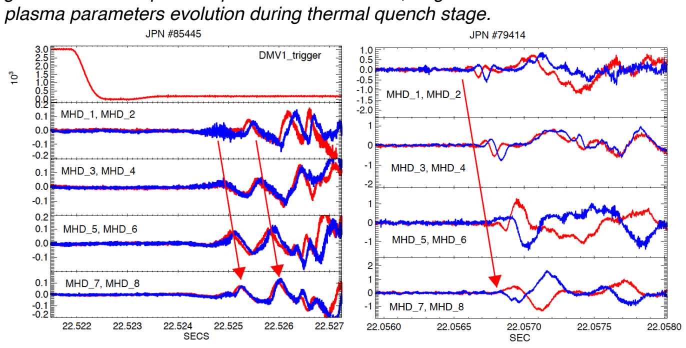
- Injection volume - 650 ml, maximum pressure – 36 bar;
- Injected Particles = 2.5x10^{23} ~ 100x N_{e_tot};
- Injected species: Ar, Ne, He, D_2, Ar/D_2, Ne/D_2

The number of injected argon or Ar+D_2 atoms has been varied from (4-6)*10^{22} to (21-24)*10^{22}. The total number of injected argon atoms in GIM scenarios did not exceed (2÷8) ×10^{20} particles. The L-mode target plasmas in divertor and limiter configurations were used: 1.2 MA ≤ I_{pl} ≤ 2 MA; 1 T ≤ B_0 ≤ 3 T; 1.E19 ≤ n_e ≤ 4.5E19 m^{-3}, and central T_e ~ 1.5÷3 keV immediately preceding the MGI.

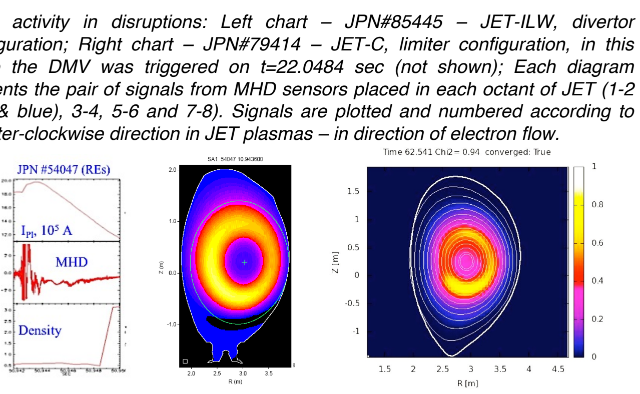
DISRUPTION PHYSICS STUDY



Disruption of JPN#85978 triggered by MGI with 100% of Ar in DMV1. Left chart – general view of plasma parameters evolution; Right chart – detailed view of plasma parameters evolution during thermal quench stage.



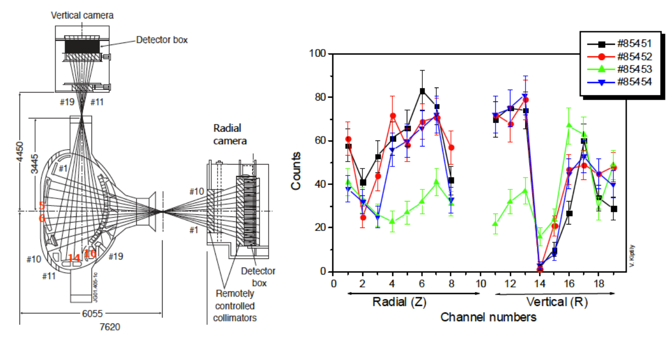
MHD activity in disruptions: Left chart – JPN#85445 – JET-ILW, divertor configuration; Right chart – JPN#79414 – JET-C, limiter configuration, in this pulse the DMV was triggered on t=22.0484 sec (not shown); Each diagram presents the pair of signals from MHD sensors placed in each octant of JET (1-2 (red & blue), 3-4, 5-6 and 7-8). Signals are plotted and numbered according to counter-clockwise direction in JET plasmas – in direction of electron flow.



THERMAL QUENCH STUDY: SXR tomography of TQ of disruptions in JET-C (JPN#54047, slow injection of Ar from GIM) and JET-ILW (JPN#85020, MGI). Reconstructions were performed during TQ stage immediately at the beginning of current bump

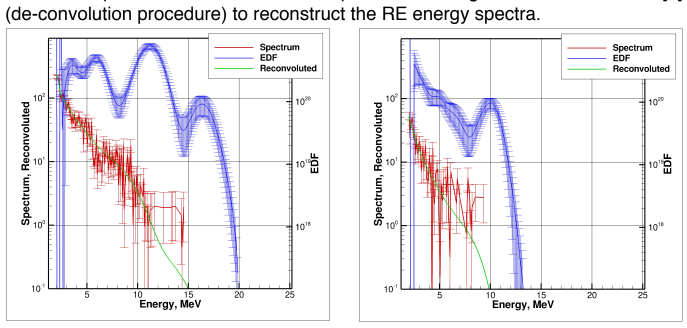
HXR AND NEUTRON DIAGNOSTICS

5 scintillation time-resolved HXR monitors and neutron rate fission chamber monitors (^{235}U and ^{238}U) at 3 different locations (Oct. 2,6,8) operating in a current mode with 0.1 ms time resolution. Horizontally and vertically viewing NaI(Tl), Bi_4GeO_{12} (BGO, Oct. 8) and $LaBr_3$ spectrometers. JET neutron/gamma profile monitor comprises 2 cameras, vertical and horizontal, with 9 and 10 lines of sight, respectively (Oct.1). Each camera has 2 detectors: NE213 – for neutron and HXR measurements, and CsI detector for HXR registration.

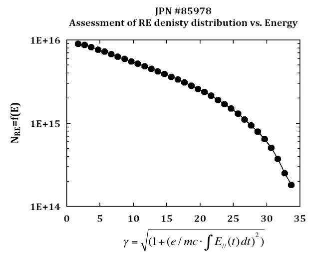


DISTRIBUTION FUNCTION OF RUNAWAY ELECTRONS

The BGO spectrometer data has been processed using the DeGaSum code [6] (de-convolution procedure) to reconstruct the RE energy spectra.



JPN#85978: HXR spectra and Runaway Electron Distribution Functions (REDF) at the beginning of RE current plateau (t=20.024-20.035 s, left chart) and at the end of RE plateau (t=20.035-20.045, right chart). Measured HXR spectra (in red), compared to the spectra (in green) inferred from reconstructed REDF (in blue): the loss of high-energy RE population is detected.

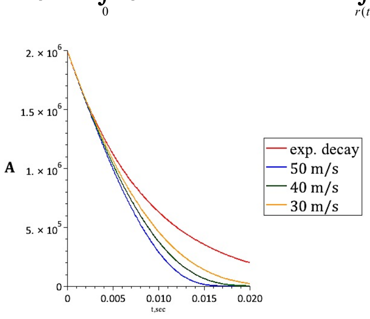


RE density vs. energy has been analysed using measured plasma RE current plateau and plasma current decay rate. In this assessment the substitution effect of plasma current by RE current and spatial plasma geometry evolution have been included.

Electric field $E_{//}(t)=E_{//0}(t)\times(1-j_{RE}(t)/(j_{pl}(t)+j_{RE}(t)))$, where $E_{//0}(t)$ is inferred from the following equation: $2\pi R_0 E_{0//}(t)+L_p\frac{dI_p}{dt}+0.5*I_p\frac{dL_p}{dt}=0$.

Total plasma inductance is not constant: $L_p(t)=\mu_0\cdot R_0\cdot(t)(\ln(8R_0(t)/a_p(t))+l_i(t)/2-7/4)$. Therefore, plasma current decay should be depending on L_p evolution during disruptions. As well the current peeling effect is the result of plasma motion:

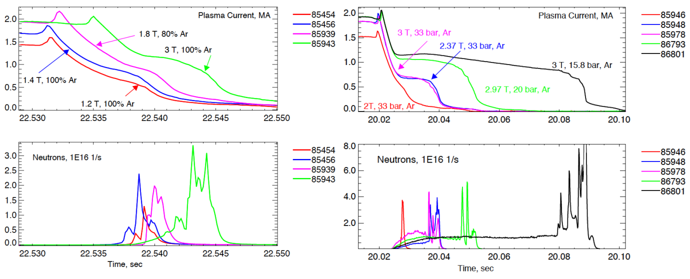
$$\Delta I_p(t)=\int_0^{a(t)}(j_p(r,t)+j_{RE}(r,t))\cdot 2\pi r dr-\int_{r(t)}^{a(t)}(j_p(r,t)+j_{RE}(r,t))\cdot 2\pi r dr$$



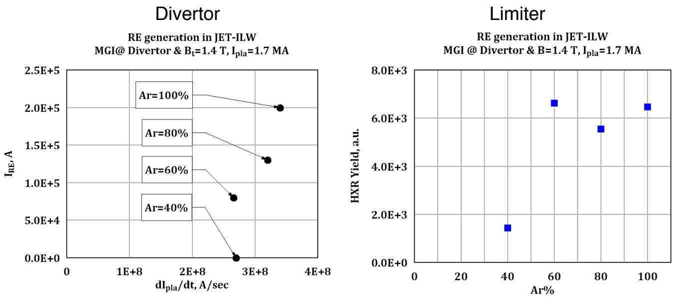
EFFECT OF PLASMA MOTION ON DECAY EVOLUTION OF PLASMA CURRENT

Simulation of resistive plasma current decay assuming different velocities of the plasma motion: Resulting electric fields are lower in comparison to static R/L plasma column model [4].

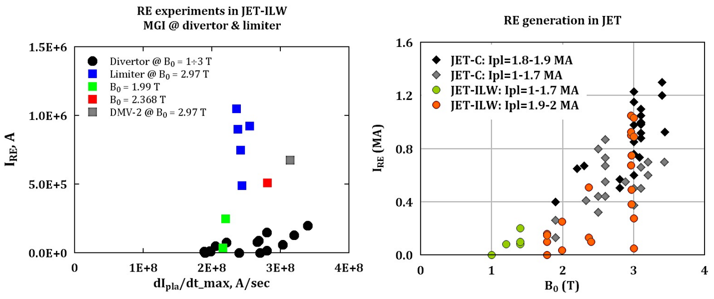
RE GENERATION PROCESS MAPPING IN JET WITH ILW



Divertor | Limiter

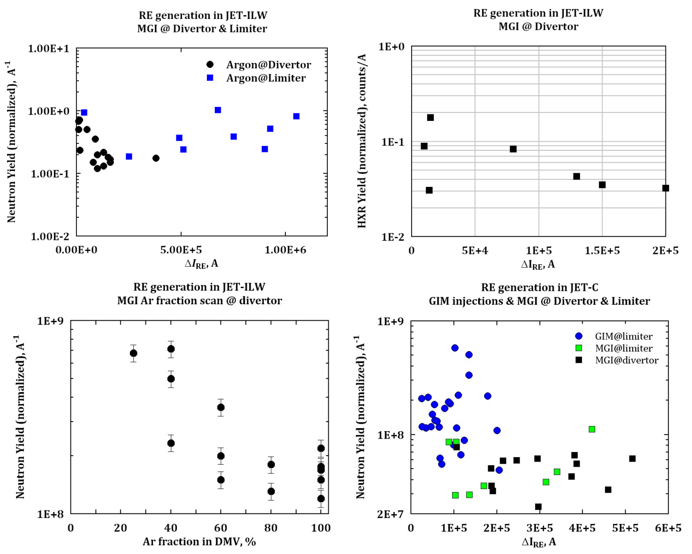


Disruption scenarios development for RE generation studies in JET with ILW

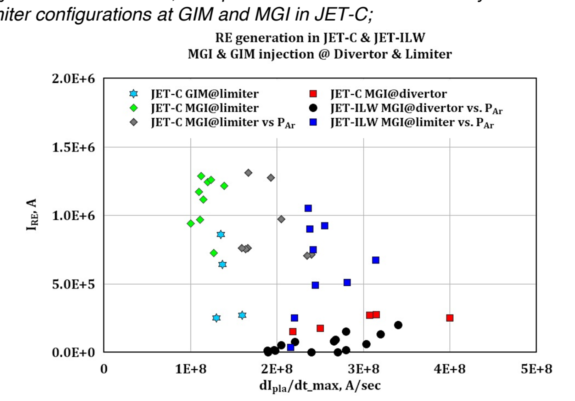


RE generation in divertor (circles) and limiter (boxes) configurations in JET-ILW. *RE generation space in JET-ILW (circles) and JET-C (diamonds, [3]) vs. toroidal field value B_0.*

EFFECT OF MGI ON RUNAWAY ELECTRON PARAMETERS

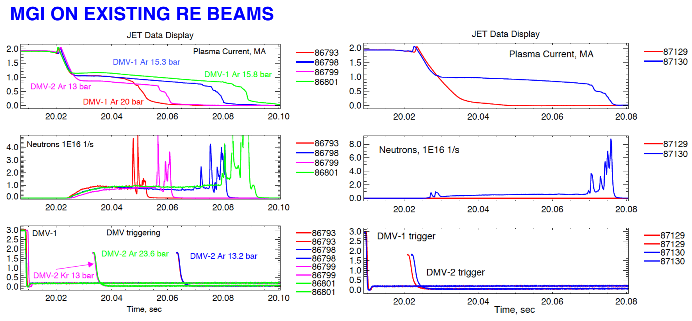


Normalized HXR and neutron yields vs. RE currents and impurity gas (Ar) quantity at MGI in JET-ILW; Comparison of normalized neutron yields for divertor and limiter configurations at GIM and MGI in JET-C;



RE generation trends in JET-C and JET-ILW for GIM and MGI cases of disruption triggering;

OPERATION WITH TWO DMVs – A STUDY OF DISSIPATION EFFECTS OF MGI ON EXISTING RE BEAMS



First attempts to achieve the suppression of existing RE plateau with the aid of direct MGI into beam channel from the second DMV (in Octant 3, using D_2, argon and krypton) were hindered by poor penetration of the injected gas into the core of RE current-carrying channel. MGI into TQ allowed complete suppression of RE generation.

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