Study of runaway electron dynamics at the ASDEX Upgrade tokamak during impurity injection using fast gamma-ray spectrometry

A. Shevelev¹, E. Khilkevitch¹, M. Iliásova¹, M. Nocente², G. Pautasso³, G. Papp³, A. Dal Molin², S. P. Pandya³, V. Plyusnin⁵, L. Giacomelli⁶, G. Gorini⁶, E. Panontin⁶, D. Rigamonti⁶, M. Tardocchi⁶, G. Tardini⁶, A. Bogdanov⁶, I. Chugunov⁶, D. Doinikov⁶, V. Naidenov⁶, I. Polunovsky⁶

¹Institute for Plasma Science and Technology, National Research Council, Milan, Italy; ²Institute of Plasma Research, Bhat, near Indira Bridge, Gandhinagar 362428, India; ³See the author list of H. Meyer et al. 2019 Nucl. Fusion 59, 112014; E-mail: Shevelev@icra.iffc.ru

Max-Planck-Institut für Plasmaphysik, D-85748 Garching, Germany

ABSTRACT

Two high-performance gamma-ray spectrometers with fast LaBr₃(Ce) scintillation-detectors, advanced electronics and analysis algorithms have been developed and commissioned at the ASDEX Upgrade tokamak (AUG). HXR measurements were carried out in the RE beam generation regimes by injecting argon gas into a deuterium plasma. The electron energy distributions were reconstructed from the measured HXR spectra by deconvolution methods. Argon density in AUG plasma after Massive Gas Injection was estimated using HXR measurements. The experimentally obtained maximum RE energies at different discharge stages were compared with relativistic test particle simulations that include the effects of toroidal electric field, plasma collisional drag force, synchrotron deacceleration.

BACKGROUND

Gamma-ray spectroscopy of hot plasma allows estimation of the energy distribution of runaway electrons (RE). Observation of confined REs is possible on medium and large tokamaks such as DIII-D, ASDEX Upgrade (AUG) and JET. Experiments of RE generation and suppression, following the onset of plasma disruptions, are conducted in ASDEX Upgrade to validate theoretical models, which can then be used to evaluate post-disruption levels of RE current and design RE mitigation schemes in larger devices like ITER and DEMO. This report is devoted to using gamma-spectrometric measurements provided by two high-performance LaBr₃(Ce) gamma-ray spectrometers and the RE dynamics analysis based on the data obtained in experiments with gas injection the AUG plasma.

INSTRUMENTATION AND APPLIED METHODS

Instrumentation
Two LaBr₃(Ce) spectrometers are used in the HXR measurements in different experiments at AUG with M3I in deuterium plasmas. They allow measuring y-ray measurement in the range of 0.1-30 MeV with energy resolution ~3.5% (at 662 keV) and counting rate up to ~10⁶ s⁻¹.

REDF reconstruction
ML-EM (maximum likelihood estimation using expectation maximization) method was realized in the DeGaSum code for the RE distribution function (REDF) reconstruction

\[ y(c) = \int dx h_x(c',c) \int dx' h_z(c,c',f(c') + n(c). \]

\[ y \] - recorded HXR spectrum; \( c, c', f \) - energies; \( n(c) \) - statistical noise; \( f \) - runaway electron distribution function; \( h_x \) - gamma-ray detector response function; \( h_z \) is HXR generation function, \( h_x \) and \( h_z \) are calculated with MCNP code in the range of 0.1-30 MeV

CONCLUSIONS

- Two high-performance LaBr₃(Ce) spectrometers have been developed
- HXR measurements were carried out in M3I experiments with RE beam generation
- RE distributions were reconstructed from measured HXR spectra using the DeGaSum code
- Two spectrometers with small scintillators made it possible to analyze gamma radiation caused by runaway electrons in the energy range up to 30 MeV
- The evolution of RE Max was studied for various amounts of injected argon: runaway electrons attain their maximum energies of about 20 MeV within 50-100 ms after the gas injection. After that it gradually decreases
- The density of argon interacting with the RE beam was estimated
- Test particle calculations demonstrated that \( E_{\text{max}} \) correspond to the measured values, the argon density must be by order of magnitude lower than the values provided by HXR measurements
- The realized system allowed testing the technical solutions and data processing algorithms for ITER runaway diagnostics.