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I1.103 MeV range particle physics studies in tokamak plasmas using gamma-ray spectroscopy

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Energetic particles in the MeV range are ubiquitous in fusion devices [1]. On one hand, they can be suprathermal ions born from the fusion reactions or accelerated by ion cyclotron resonance heating. On the other hand, they can be runaway electrons (REs) that are spontaneously generated, for example, during a disruption. Both species lead to gamma-ray emission by different means. Fast ions interact with impurities naturally found in the plasma and result in nuclear reactions where a heavy nucleus in an excited state is born. This in turn decays instantaneously, leading to the emission of gamma-rays at several discrete energies and whose detailed properties embed information on the fast ions that triggered the reactions. Confined suprathermal electrons, instead, emit gamma-rays by bremsstrahlung as they collide with ions or extrinsic impurities along their orbit in the tokamak. The resulting gamma-ray spectrum extends over a broad energy range and is continuous, with a detailed shape that reflects the RE distribution function and its temporal dynamics. In this presentation, we show how fast particle physics is studied using gamma-ray spectrometry [2]. In radio-frequency heating experiments at the Joint European Torus (JET), gamma-ray measurements reveal the acceleration of ions to the MeV range by the exploitation of finite Larmor radius effects in schemes that rely on resonances at multiple harmonics of the ion cyclotron frequency and determine the maximum fast ion energy [3]. In novel, so called 3 ion radio-frequency heating scenarios, gammaray spectra prove the existence of a multi MeV fast ion population [4]. Images of the gamma-ray emission from the plasma demonstrate the existence of a pinch effect, which squeezes the ions towards the core depending on the applied antenna phasing. The same images help at determining the spatial redistribution of the energetic ions, whenever their pressure is sufficient to drive instabilities. In RE physics experiments, the inversion of time resolved bremsstrahlung spectra in the gamma-ray energy range yield the evolution of the RE current and maximum energy in a disruption, which is used to understand the effect of the external actuators on the RE velocity space. An example is a recent DIII-D experiment, where gamma-ray measurements during the current quench shed light on the correlation between the presence of a high-energy RE population, the power of RE-driven kinetic instabilities and the likelihood of a post-disruption RE beam formation [5]. We finally address the prospects for particle measurements in plasmas with tritium, both at JET and ITER. Here gamma-ray measurements have a unique role, as they can in principle provide both the profile and the distribution function of the particles. In the latter case, the combination of a radial and tangential gamma-ray view is predicted to reveal pitch angle asymmetries of the distribution function, which are of interest to disentangle the effect of the Alfvenic instabilities on co and counter going ions at ITER [6].

References

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