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Energetic Particle Confinement in Burning Plasmas

核燃焼プラズマにおける高エネルギー粒子閉じ込め

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Energetic particle confinement in burning plasmas done at mainly JT-60U is reviewed, where neutron diagnostics is an effective tool for this study. The slowing down process of NB-injected fast ions was studied by the NB blip experiments at JT-60U, where toroidal ripple effect on the energetic ion confinement was confirmed. Triton burn-up measurement was carried out with the 14-MeV neutron measurement in the DD plasma, which showed that the behavior of 3.5-MeV tritons was almost classical. Also collective effects of the energetic particles such as Alfven Eigenmode were investigated in the D-D plasma with 400-keV neutral beam injection.

1. Introduction

Energetic particle confinement especially 3.5 MeV alpha particle produced in D-T burning plasma is very important in account of the alpha –heating of the plasma. In order to understand the energetic particle behaviors in burning plasmas, many studies have been carried out in D-D plasma. Single particle behaviors of neutral beam (NB)-injected energetic ions and 1 MeV tritons produced by d(d,p)T reactions were investigated by NB–blip and triton burn-up experiments, respectively. Also collective effects of the energetic particles such as Alfven Eigenmode were investigated in the D-D plasma with negative-ion-based 400-keV NB injection.

2. Toroidal Ripple Effect on the Energetic Ion Confinement

The transport of energetic particles in toroidal field (TF) ripple in a tokamak is one of the most important issues as single particle behavior of alpha particles in burning plasmas. In burning plasmas, ripple loss of alphas not only will reduce the alpha heating power but also can cause serious localized heat deposition on the first wall.

Therefore, TF ripple effect on the NB injected energetic particles was investigated in D-D plasma of the JT-60U. Cross-section of the D-D reaction is a strong function of the deuteron energy, so the time history of the neutron intensity after shot-pile injection of D NB injection into the D plasma is determined by the slowing down and the confinement of the NB injected energetic ions, which is called “NB-blip” method [1].

Figure1 shows neutron decay following an NB-blip injection for a 0.7 MA, 65m^3 plasma compared with the classical sowing down model with out loss and the Monte Carlo calculation (OFMC)[2] taking account of the TF ripple. The measured neutron decay was faster than the classical slowing down (solid line), and agreed with the OFMC calculation. The discrepancy between the measurement and the classical sowing down model is considered due to the effect of a TF ripple.

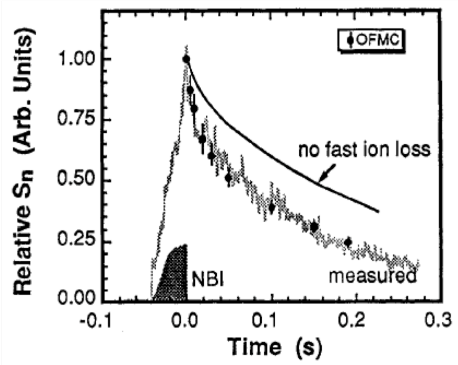

Fig.1. Neutron decay following an NB-blip injection compared with the classical sowing down model with out loss and the OFMC calculation.

In case that the energetic D ion loss is negligible, neutron intensity is proportional to exp(-2.3/τ_s), where τ_s is a classical slowing down time. Figure 2 shows the decay constant of the neuron intensity τ_n after NB-blip injection plotted against the τ_s/2.3 for the plasma volume 40 m^3, 55 m^3 and 80 m^3, which corresponds to low, medium and high TF ripple plasma. It was found that decay constant of the neuron intensity decreased with increase in the TF ripple.

In ITER, TF ripple effect on alphas and NB injected energetic ions caused by ferritic materials of the test blanket modules is under discussion [3,4].

Recent calculation result of the effect will be shown in the presentation.

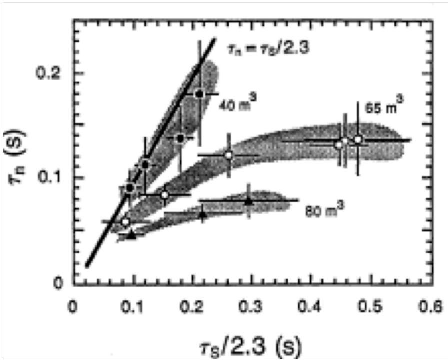

Fig.2. Neutron decay time plotted against the slowing down time in different volume plasmas.

3. Triton Burn-up in D-D plasma

Collective effects of the energetic particles such as Alfven Eigenmode driven by 400-keV neutral beam injection were investigated. Tritons of 1.0 MeV are produced in the d(d,p)t reaction at approximately the same rate as the 2.5 MeV neutrons from the d(d,n)^{3}He reaction. The behavior of 1 MeV tritons is important to predict the properties of D-T produced 3.5 MeV alphas because 1 MeV tritons and 3.5 MeV alphas have similar kinematics properties, such as Larmor radius and precession frequency. The 1 MeV tritons slow down and may undergo a D-T fusion reaction, emitting 14 MeV neutron. The confinement and slowing down of the fast tritons can be investigated by measuring the 14 MeV and the 2.5 MeV neutron production rates. The time resolved triton burn-up measurements have been performed using a new type 14 MeV neutron detector based on scintillating fibers with high time response at JT-60U. Figure 3 shows the decay curve of the 14 MeV neutron emission rate measured by the scintillating fiber detector after NB injection, where a diffusivity of fast tritons was evaluated to be ~0.1 m^2/s [5].

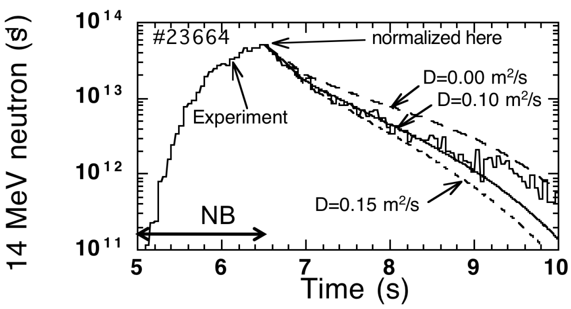

Fig.3. Experimental and calculated 14 MeV neutron emissions in the NB heated JT-60U Plasma.

4. Collective Effect on the Energetic Particle Confinement

The confinement degradation and transport of energetic ions due to Alfven eigenmodes (AEs) destabilized by negative-ion-based NB injection are quantitatively evaluated. AEs were observed in JT-60U weak shear plasmas with frequencies sweeping up to 30–50 kHz on a time scale of a few hundred milliseconds as the safety factor at the plasma center, q (0), decreases from 1.75 to 1.5. Then as q (0) decreases from 1.5 to 1.25 in about 600 ms, the AE frequencies are saturated and the AEs are identifiied as the TAEs. The measured total neutron emission rate (Sn) in the presence of these AEs is compared with that predicted by classical theory. As a result, the confinement degradation of energetic ions is confirmed and the reduction rate in Sn is largest when AEs are destabilized and are located at the large fast ion pressure gradient region in the plasma core. In order to investigate the energetic ion transport due to these AEs, line-integrated neutron emission profiles measured with a large neutron collimator array are compared with the classical confinement calculations. It is found that energetic ions are transported from the plasma core region to the outer region due to these AEs. Furthermore, changes in the energy distribution of charge exchange energetic neutral particle fluxes suggest that the radial energetic ion transport is due to the resonance interaction between the energetic ions and the AEs [6].

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