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Measurements of Energetic Confined Alphas and Tritons on TFTR

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1.0 Introduction

In a collaboration involving General Atomics, the A. F. Ioffe Physical-Technical Institute, and the Princeton Plasma Physics Laboratory, the energy distribution of the fast-confined alpha particles in DT experiments on TFTR is being measured by active neutral particle analysis using the ablation cloud surrounding an injected impurity pellet as the neutralizer[1]. Recent papers reported the first measurements of the energy distribution fast confined alpha particles[2] and examined the influence of magnetic field ripple and sawtooth oscillations on the behavior of the alpha energy spectra and radial density distributions[3]. This paper focuses on alpha and triton measurements in the core of quiescent TFTR discharges where the expected classical slowing down and pitch angle scattering effects are not complicated by stochastic ripple diffusion and sawtooth activity.

2.0 Pellet Charge Exchange (PCX) Diagnostic and Data Analysis

A toroidally extended ablation cloud forms around the pellet when it is injected into a plasma. A small fraction of the fusion alphas incident on the cloud are converted to helium neutrals as a result of electron capture processes. The escaping helium neutrals are mass and energy analyzed using a high energy (0.5 - 4.1 MeV for ^{4}He) neutral particle analyzer developed by the Ioffe Institute[4]. The neutral particle analyzer views the radially injected pellet from behind at a toroidal angle of 2.75^o to the pellet trajectory. Thus only near perpendicular energetic ions with velocities close to $v_{||}/v = 0.048$ are detected by the PCX diagnostic. The radial position of the pellet as a function of time is measured using a linear photodiode array situated on the top of the vacuum vessel. By combining this measurement with the time dependence of the PCX signal, radially resolved fast ion energy spectra and density radial profiles can be derived with a radial resolution of ~ 5 cm. Further details on the PCX diagnostic have been presented elsewhere[5,6], including results obtained on the measurement of RF-generated energetic ion energy distributions.

By measuring of the energy distribution, dn_o/dE, of helium neutrals escaping from the plasma, the energy distribution of the incident alpha particles, dn_α/dE, can be determined using:

$$dn_{\alpha}/dE \sim dn_o/dE\ [F_o(E)]^{-1}$$

where $F_o(E)$ is the equilibrium fraction of incident alphas neutralized in the cloud as a function of alpha energy. The value of $F_o(E)$ is obtained from modeling calculations[9]. The experimental data are compared with modeling results obtained with the TRANSP[7] Monte-Carlo Code and with a specially developed Fokker-Planck Post Processor (FPP) code. TRANSP follows the orbits of alphas as they slow down and pitch angle scatter by Coulomb collisions and takes into account the spatial and temporal distributions of background plasma parameters for each particular shot. Since the Monte-Carlo methods used in TRANSP give noisy results, we developed the FPP post processor code based on a numerical solution of the drift-averaged Fokker-Planck equation[8] which uses the pitch angle integrated alpha source distribution provided by TRANSP. The TRANSP and FPP calculations agree well when the modeling basis for both codes are applicable.

3.0 Alpha Particle and Triton Measurements

The alpha particle distributions measured by the PCX diagnostic can be influenced by the effects of classical slowing down and pitch angle scattering, toroidal magnetic field ripple and sawtooth activity. In order to separate the classical behavior from the other effects, PCX Li pellet active measurements of the slowing down alpha spectrum were obtained in the plasma core during a quiescent DT discharge (#78607) and the triton spectrum from a similar DD discharge(#78601) as shown in Fig. 1. Note that the error bars in Fig. 1 only reflect the statistical errors due to the counting statistics. The basic discharge parameters were: R = 2.52 m, a = 0.8 m, P_b ~ 20 MW with I_p ramped down from 1.7 MA to 1.0 MA during the 1.3 s duration NBI pulse. The absolute scale for dn/dE was derived from normalization of the PCX data with the TRANSP modeling results and was made only once for the alpha data as noted in the figure. The same normalization is used for the triton spectrum. Both the shape of the energy spectra as well as the ratio of the alpha-to-triton signal agree well with TRANSP simulations. This result corroborates the expectation that fusion generated alphas and tritons in the core of quiescent TFTR plasmas are well-confined and slow down classically.

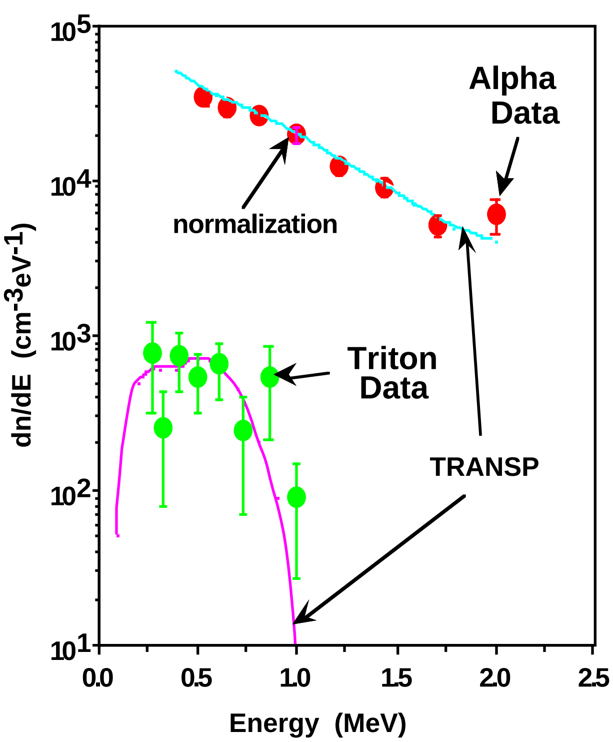

Fig. 1 Comparison of measured alpha and triton spectra with TRANSP simulation.

In the TFTR DT experiments, pellets

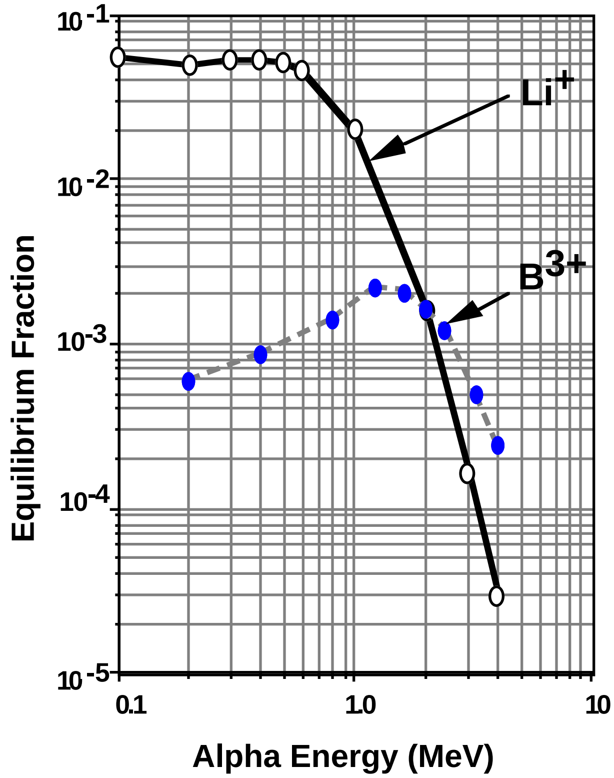

Fig. 2 *Calculated equilibrium fractions for Lithium and Boron.*

typically are injected 0.2 to 0.5 sec after termination of neutral beam heating. This timing delay leads to deeper penetration of the pellet as a result of decay of the electron temperature as well as to enhanced signal-to-noise ratio because the neutron background decays significantly faster than the confined alpha population. Even so, it is advantageous for PCX measurements to enhance the pellet penetration further and also to increase the signal level at higher alpha energies. For these reasons we investigated the use of boron pellets in place of lithium. As shown in Fig. 2, for alpha energies above ~ 2 MeV the calculated equilibrium fraction for boron is significantly higher than for lithium. The higher heat of ablation energy of 5.3 eV/atom for boron compared with 1.6 eV/atom for lithium should increase the pellet penetration. In practice, this gain is offset by lower pellet velocity from the injector due to the larger mass of boron relative to lithium. Nevertheless, an increased penetration for boron pellets ranging up to 20% (~ 12 cm) relative to lithium pellets of comparable mass is observed experimentally. In order to validate the use of boron, alpha energy spectra were compared for DT discharges using both lithium (#86225) and boron (# 86228, 89, 81) pellets as shown in Fig. 3. The boron spectra for the three discharges were normalized to account for small differences in the plasma conditions. As can be seen, the shapes of the alpha energy spectra for lithium and boron pellets are essentially the same. These measurements also confirm that for alpha particle energies above ~ 2 MeV, boron pellets provide a more effective neutralization target that lithium pellets. Both pellet types are now routinely used in PCX diagnostic measurements.

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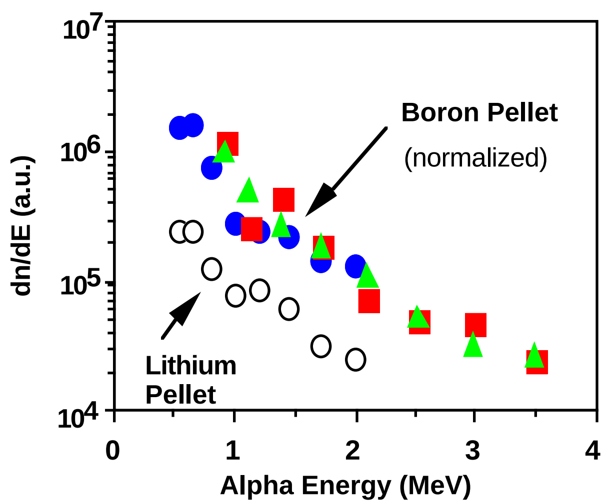

Fig. 3 *Comparison of alpha spectra obtained using Boron and Lithium pellets.*

Alpha spectra during the birth and slowing down phases are shown in Fig. 4.

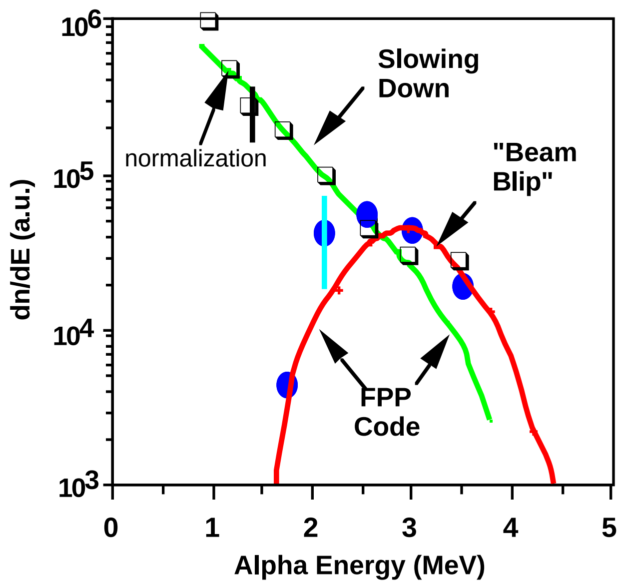

Fig. 4 *Alpha energy spectra during birth and slowing down phases.*

For the slowing down case (#86291, P_b = 15 MW), the alpha distribution from 1-3.5 MeV was obtained using a boron pellet 200 ms after termination of a 1.0 s beam pulse while for the "beam blip" case (#86299, P_b = 20 MW), the boron pellet was injected 20 ms after a 0.1 s beam pulse. Reasonable agreement is seen between the data and the FPP code results which include Doppler broadening of the alpha particle birth energy, E_α, given by $\Delta E(\text{keV}) = 182(T_{eff})^{0.5}$ where T_{eff} = 30 keV is the effective temperature of the deuterium and tritium ions.

4.0 Conclusions

In the core of quiescent DT discharges in TFTR, good agreement is observed between the PCX measurements of the confined, trapped alpha particles and tritons and TRANSP and FPP simulations. This indicates that alphas and tritons are well confined and slow down classically.

Acknowledgments

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