MODELLING OF RIPPLE LOSS OF PARTIALLY THERMALIZED CHARGED FUSION PRODUCTS IN TFTR

V.A.YAVORSKIJ[a], S.J.ZWEBEN[b], V.Ya.GOLOBOROD'KO[a], J.W.EDENSTRASSER[c], S.N.REZNIK[a], R.B.WHITE[b]

[a]Institute for Nuclear Research, Kiev, Ukraine
[b]Princeton Plasma Physics Laboratory, Princeton University, Princeton, New Jersey, United States of America
[c]Institute for Theoretical Physics, University of Innsbruck, Innsbruck, Austria

Abstract

The results of the numerical modelling of the ripple loss of partially thermalized charged fusion products in TFTR are presented. The measured loss of partially thermalized alphas is explained at least qualitatively by a ripple transport mechanism that includes collisional radial diffusion of toroidally trapped particles with D^{sb} = 10^2-10^3 $cm\ s^{-1}$ and stochastic ripple diffusion. The carried out Fokker-Planck simulations of the alpha loss dependencies on the plasma current and on the fusion power as well as the radial and poloidal dependencies of the fusion product losses are shown to agree satisfactorily with the corresponding measurements and Monte-Carlo calculations.

1. INTRODUCTION

Fokker-Planck modelling of the collisional TF ripple loss of partially thermalized charged fusion products in TFTR [1] has recently explained the main features of the ”delayed” loss observed previously in TFTR [1-3]. The key to understanding the origin of a low energy fusion product loss to the vessel bottom is the effect of the inward shift of the vacuum flux surfaces in plasmas with minor radii less than the vessel radius. The calculated ripple induced loss of partially thermalized charged fusion products is strongly dependent on the poloidal angle, as well as on both the plasma major radius and the plasma current. These losses also turn out to be extremely sensitive to the radial position of the detector, due to the poloidal shadowing by the outer part of the vessel wall. These new calculations help to explain the measurements of charged fusion product loss in both DD [2] and DT [3-5] experiments in TFTR.

The present paper is a continuation of the Fokker-Planck modelling of the ripple induced loss of partially thermalized fusion products in TFTR, an investigation which has been initiated in Ref.[1]. The main purpose here is an investigation of the poloidal distributions of the loss as well as the loss dependencies on the plasma current and Shafranov shift and on the radial position of detectors. The present modelling takes into account the ripple induced transport of charged fusion products in the presence of Coulomb collisions with the particles of the bulk plasma, including the effect of the inward shift of the vacuum flux surfaces on the poloidal and velocity distributions of the loss [1].

2. RIPPLE LOSS MODEL

The Fokker-Planck calculations of ripple induced loss of charged fusion products are based on the 3D Fokker-Planck model of the paper [1] and the TRANSP ripple loss model [6] is applied for the Monte Carlo modelling. The transport coefficients of the present Fokker-Planck simulation include the axisymmetric contributions to the transport coefficients [7] as well as the ripple induced ones both the superbanana diffusion of toroidally trapped particles in the central plasma region [8] and the stochastic diffusion [9] of them at the periphery.

Finally the model of the vacuum magnetic field with the inward shift of the flux surfaces corresponding to a currentless gap [7] as well as the TRANSP bulk plasma parameters [10] are used in the present modelling.

3. SIMULATION RESULTS

3.1. Poloidal distribution of the alpha loss

Fig. 1 shows the calculated poloidal distributions of ripple induced loss of alpha particles with $E > 0.35\,E_O = 1.23\ MeV$ at $I = 2\ MA$ (Fig. 1*a*) and $I = 2.5\ MA$ (Fig. 1*b*). Curves *1* and *2* correspond to Fokker-Planck and Monte-Carlo calculations, respectively. It can be seen that both distributions are in agreement with each other. The maximum loss takes place at poloidal angles of 60-70° below the outer midplane at $I = 2\ MA$ and shifts to 70-80° at 2.5 *MA*. Nevertheless for $I = 2.5\ MA$ some weak loss level (< 10% of the maximum) is observed at 90° also. It should be pointed out that in the case of a low inward shift of the vacuum flux surfaces the losses at $I \cong 2\ MA$ are peaked poloidally within 30°-40° below the outer midplane, in agreement with previous Monte-Carlo calculations [6].

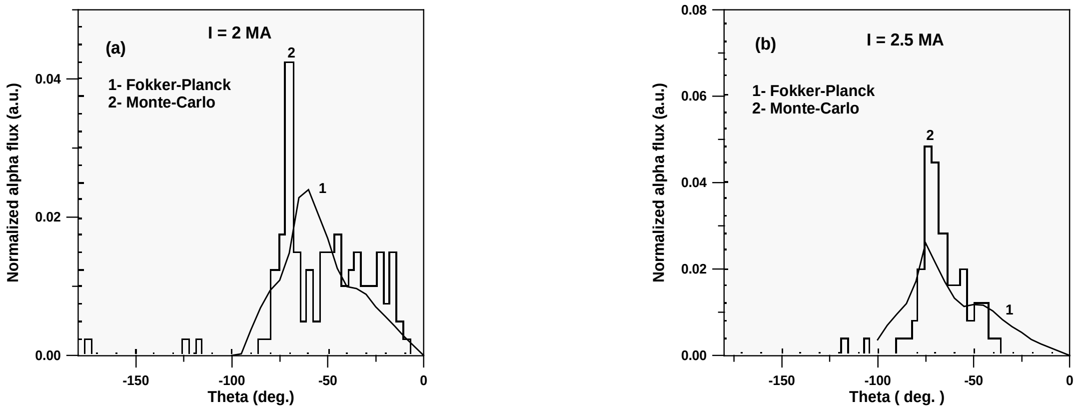

FIG.1. Poloidal distributions of the loss of partially thermalized (E/E_O>0.35) alphas for a major plasma radius R=2.52 m. Cirves 1 and 2 correspond to the Fokker-Planck and Monte-Carlo simulations, respectivelly.

3.2. Radial dependence

Measurements of partially thermalized alpha loss at the bottom of TFTR showed a ”delayed” loss only when the detector port was radially above the shadow of the limiter [4]. The calculated variation of the diffusive alpha loss detected at $\theta = 90°$ due to the poloidal shadowing of the detector is shown in Fig. 3. The radial size of the shadow of alphas with $1.2\ MeV < E < 3.5\ MeV$ is less than 1 *cm* and increases to 2 *cm* at $E > 0.5\,E_O$. One can see that the increase of the port height, H_{col}, from 1 *cm* to 3 *cm* results in a five time increase of the loss of alphas with $1.2\ MeV < E < 3.5\ MeV$. This strong radial dependence of calculated loss agrees qualitatively with the alpha collector loss measurements of Ref.[4].

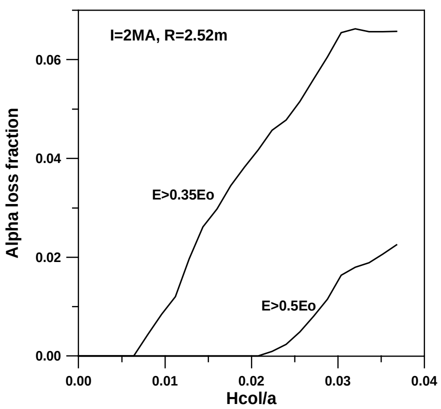

FIG.2. Alpha loss fraction versus the radial position of the detector. In the abscissa H_{col}/a is the distance of the detector from the chamber wall.

3.3. Plasma current dependence

The plasma current dependencies of the measured and modelled alpha loss at q = 45° and at q = 20° below the midplane are shown in Fig. 3. It can be seen that the maximums of the ripple induced loss corresponding to Fokker-Planck calculations (Fig. 3b and Fig. 3d) are in satisfactory agreement with the observations (Fig. 3a and Fig. 3c). The reasons for the loss degradation at $I > 2$ *MA* (Figs. 3a, 3b) and at $I > 1$ *MA* (Figs. 3c, 3d) are mainly the poloidal shadowing of the 45° and 20° detectors from the loss of partially thermalized alphas and only partially the improvement of their confinement. The reasons for the increase of the ripple loss with I at low plasma currents are the increase of the population of the toroidally trapped particles contributing to the ripple loss and the shift of the ripple loss to the vessel bottom with plasma current increase.

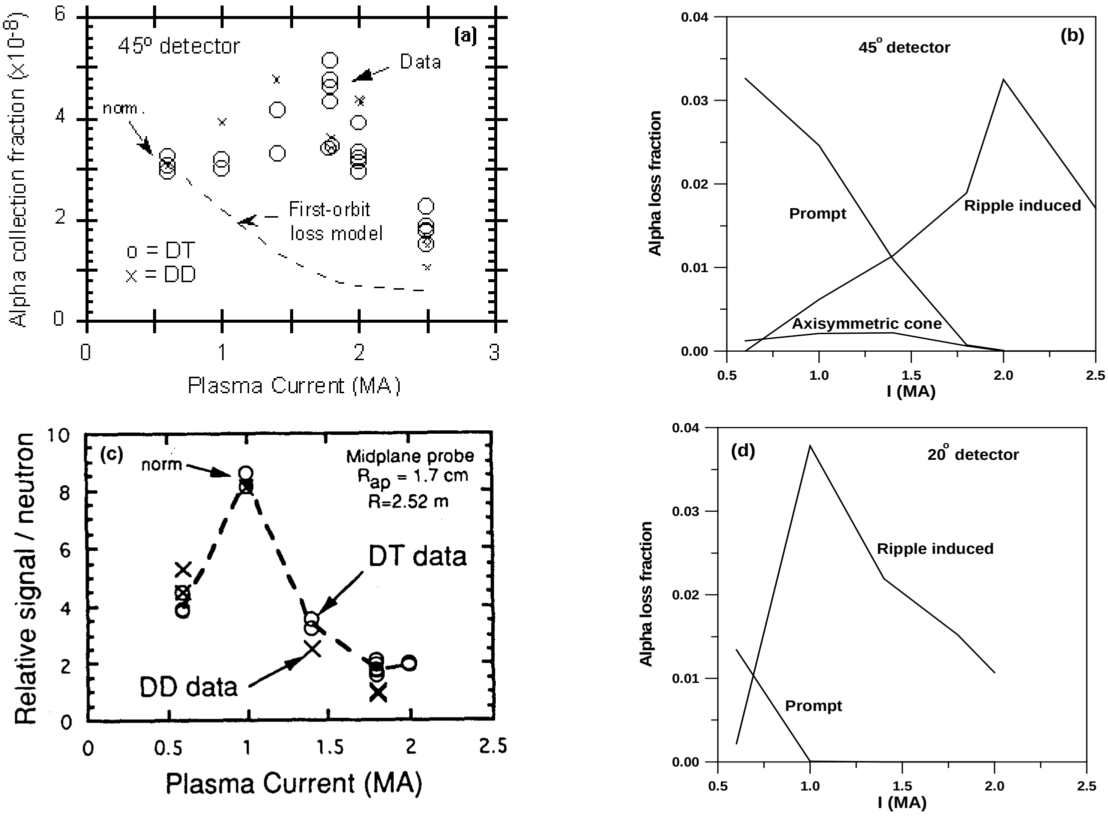

FIG.3. The plasma current dependence of the loss of the partially thermalized ($E/E_o>0.35$) charged fusion products to the 45^o and 20^o detectors. (a) and (c) (see [5]) represent the results of the measurements. (b) and (d) show results ofthe Fokker-Planck calculations.

3.4. Dependence on the Shafranov shift and the electron temperature

Measurements of DT alpha particle loss near the outer midplane of TFTR [5] have demonstrated the alpha loss degradation with increasing fusion power (Fig. 4a). This loss decrease may be qualitatively explained by the increase of the inward shift of vacuum flux surfaces and the corresponding enhancement of the poloidal shadowing of the midplane probe with increasing fusion power. It can be seen that the calculated Shafranov shift dependence of the alpha loss (Fig. 4b) for fixed electron temperature are in the satisfactory agreement with corresponding midplane probe measurements (Fig. 4a) [5]. Really the 50% increase of Shafranov shift for fixed $T_e(0)$ results in more than 50% decrease of alpha loss at 20^o detector while the total alpha loss increases about 10%. Fig. 4c shows the calculated electron temperature dependence of the alpha loss for fixed Shafranov shift . It can be seen that the 50% increase of $T_e(0)$ (from 10 *keV* to 15 *keV*) results only in about

15% increase of the loss. The reason of the loss increase is the decrease of the ratio of the pitch angle scattering time to the slowing down one [1].

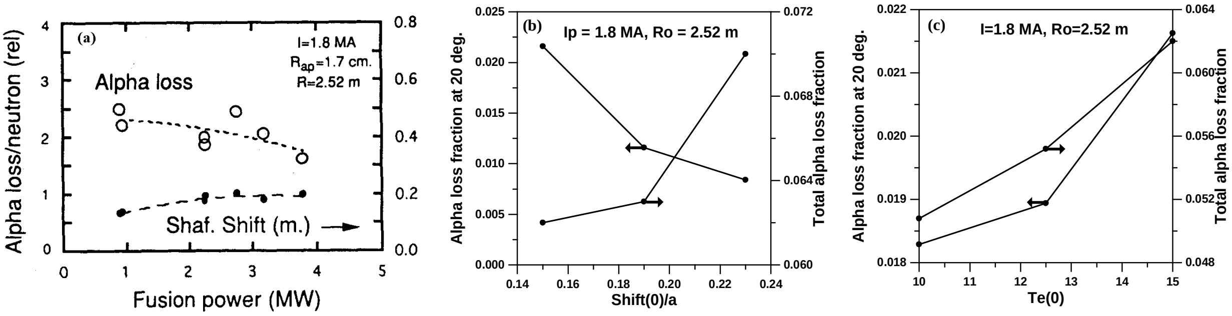

FIG.4. Dependensies of the loss of partially thermalized alphas on the Shafranov shift and on the electron temperature. (a) shows the measured Shafranov shift dependence of DT alpha particle loss near the outer midplane region of TFTR [5]. (b) and (c) represent the results of the Fokker-Planck calculations.

4. CONCLUSIONS

The measured loss of partially thermalized alphas in TFTR is explained at least qualitatively by a ripple transport mechanism that includes collisional radial diffusion of toroidally trapped particles with $D^{sb} = 10^2\text{-}10^3\ cm\ s^{-1}$ and stochastic ripple diffusion. The inward shift of the vacuum flux surfaces strongly affects both the poloidal and radial distribution of the lost fusion products, and permits the modelling results to agree with observations. Results of the carried out Fokker-Planck simulations of the alpha loss dependencies on the plasma current and on the fusion power as well as the radial and poloidal dependencies of the fusion product losses, agree satisfactory with the corresponding measurements and Monte Carlo calculations.

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