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Results of 3D Fokker-Planck modelling of alpha particle loss in JET

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1. INTRODUCTION

The envisaged fusion experiments in JET invoke the interest in theoretical predictions and numerical simulations of charged fusion product (CFP) behaviour in this device. Here we present results on alpha particle loss in JET DT plasmas numerically modelled by a 3D Fokker-Planck code. This 3D Fokker-Planck approach, at first developed for the investigation of CFP transport in TFTR [1-3], has been extended for a JET-like geometry to take into account the flux surface noncircularity and up-down asymmetry [4]. The distribution function of confined energetic alphas is calculated as well as the pitch-angle distributions of classical MeV alpha loss caused by collisions and orbital effects in the presence of TF ripples. Loss variations with flux surface elongation, triangularity and up-down asymmetry are investigated. The ripple induced alpha loss distribution over the pitch-angle is shown to be extremely sensitive to the flux surface noncircularity. The numerical approach proposed in the present report may be used for theoretical predictions of CFP confinement in JET as well as for the comparison of steady state modelling with a time dependent simulation that may be carried out using the numerical approach of Ref. [5].

2. METHOD USED

The method used in our study for the determination of fast alpha loss is based on the numerical solution of the orbit averaged 3-D Fokker-Planck equation for this particle distribution function in the constants-of-motion space,

$$\frac{\partial f_\alpha}{\partial t} = \frac{1}{\sqrt{g}} \frac{\partial}{\partial c^i} \sqrt{g} \left(D^{ij} \frac{\partial f_\alpha}{\partial c^j} + d^i f_\alpha \right) + S_\alpha . \tag{1}$$

Here c^1, c^2 and c^3 are the alpha particle energy, the normalised magnetic moment and the maximal flux surface radius on the trajectory, S_α is the thermonuclear source of alpha particles and $\sqrt{g}$ the bounce averaged Jacobian. The averaging procedure takes into account finite banana width effects as well as the noncircularity of flux surfaces. The geometry of the latter was considered using the results of Ref. [4] when the flux surface (FS) is determined by the parametric dependence of the cylindrical coordinates of the form

$$\begin{aligned} R &= R_0 + \Delta(r) + r\cos\chi \\ Z &= k(r)\, r \sin\chi \left(1 - \Lambda(r)\cos\chi\right)^\alpha \left(1 + \eta(r)\sin\chi\right) \end{aligned} \tag{2}$$

Here R and Z represent the spatial variables of the cylindrical coordinate system $[R, Z, \varphi]$, R_0 is the major plasma radius, r denotes the FS radius in the equatorial plane that contains the magnetic axis and χ is the poloidal angle. Four parametric functions, the Shafranov shift $\Delta(r)$, the elongation $k(r)$, the triangularity and up-down asymmetry parameters $\Lambda(r)$ and $\eta(r)$, resepectively, describe the flux surface shape. Following Ref. [4] the value of α was chosen as 0.5. The proper choice of these functions permits to describe a broad class of equilibrium configurations. The present report, however, is subjected to a JET-like configuration.

Equation (1) treats alpha particle slowing down, pitch-angle and radial diffusion caused by Coulomb collisions and finite banana width effects, and accounts for ripple induced stochastic and resonant collisional radial diffusion. In considering the ripple induced diffusion in a noncircular geometry the Goldston-White-Boozer stochasticity threshold was modified as

$$\delta_{GWB} = \left(\frac{r}{\pi R N q_*}\right)^{3/2} \frac{1}{\rho_L q_*'} = \delta(R,Z), \qquad q_* = \frac{\sqrt{g_r}}{\psi'} \tag{3}$$

Here N is the number of toroidal field coils, $\delta(R,Z)$ the toroidal field ripple value, ρ_L the particle gyro radius, ψ the poloidal flux, $\sqrt{g_r}$ represents the radial component of the Jacobian and the prime designates the radial derivative with all values calculated at the trapped particle turning point. In this study the elliptic cross section of the toroidal field coils and the ripple profile was taken close to that of JET. To simplify the equation we look for the steady state distribution function of high-energy (E_α>0.5MeV) alpha particles and neglect the diffusion in energy. The numerical method of the solution is based on the implicit method of alternative directions with matching conditions on the separatrix between trapped and untrapped particles. This method was used and discussed in Refs. [1-3].

3. RESULTS OF SIMULATION

For the investigation of the influence of FS noncircularity on fast alpha confinement we choose to refer to four noncircular configurations corresponding to JET discharges. The flux surface noncircularity parameters considered are given in Table 1.

case	shift	ellipticity	triangularity	up-down	loss fraction
1	$\Delta=0.07(1-r^2)$	$\kappa=1.4$	$\Lambda=0$	$\eta=0$	3.58%
2	$\Delta=0.07(1-r^2)$	$\kappa=1.4+0.3r^2$	$\Lambda=0$	$\eta=0$	3.31%
3	$\Delta=0.07(1-r^2)$	$\kappa=1.4+0.3r^2$	$\Lambda=0.25r^2$	$\eta=0$	3.22%
4	$\Delta=0.07(1-r^2)$	$\kappa=1.4+0.3r^2$	$\Lambda=0.25r^2$	$\eta=0.04r^2$	3.29%

Table.1. Radial dependencies of flux surface noncircularity parameters used in the numerical simulation and calculated loss fractions of high energy alphas (E_α>0.5MeV).

It was found that the stochasticity threshold alters significantly for different plasma shapes, which may affect the ripple induced collisionless and collisional radial transport of alphas. Fig. 1a illustrates the dependence of the solution of Eq. (3) on the flux surface shape in the confinement domain of co-moving alphas (with their longitudinal velocity having the sign "+1" at the point of the maximal radial co-ordinate on the trajectory). It is evident from this figure that noncircularity increases the stochasticity domain in phase space and thus enhances the alpha loss compared to the case of circular flux surfaces. Concurrently, triangularity reduces the stochastic region far from the separatrix in comparison to the case of only elliptic flux surfaces, which may improve the confinement. In Fig. 1b we display the variation of the stochastisity threshold for a JET-like configuration (nonuniform ellipticity, triangularity and up-down asymmetry) in the confinement domain depending on the alpha particle velocity. For particles near the separatrix the stochastic domain is seen to increase as their energy decreases, at least in high-energy intervals, while elsewhere the opposite is true.

One may therefore conclude that, for alphas in the high energy range, the ripple induced transport will always play the dominant role.

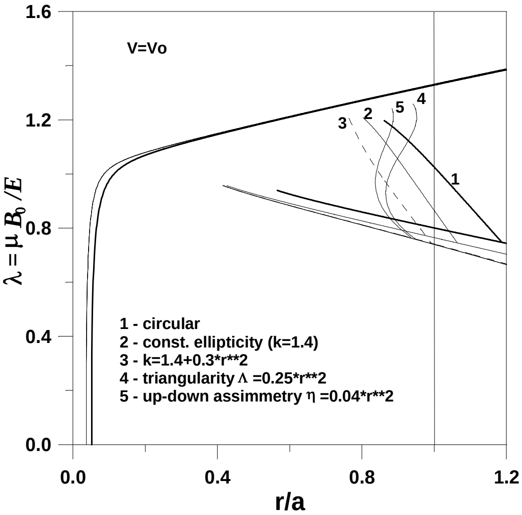

Fig.1a. Curves 1-5 represent the solution of Eq.(3) in the phase space for different FS shapes. The upper curve corresponds to the boundary of the confinement domain of co-moving particles.

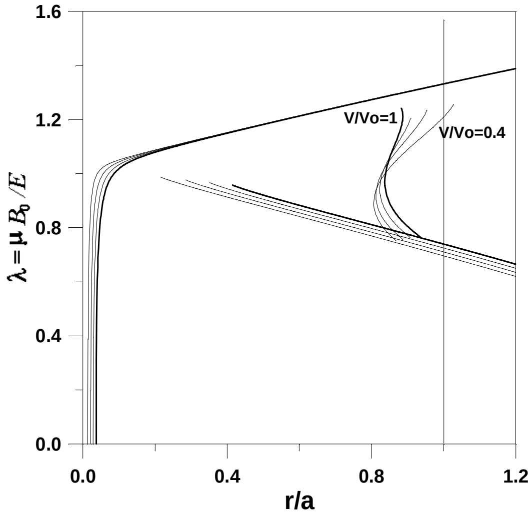

Fig.1b. Energy dependence (V_0=birth velocity) of the stochastisity threshold for the case of a JET-like flux surface configuration. The vertical line corresponds to the radius of the last closed surface.

The numerical solution of the bounce averaged 3-D Fokker-Planck equation demonstrates the above-mentioned influence of the ripple-induced transport on the steady state distribution function of alpha particles and on their loss. In Fig. 2 we show the calculated

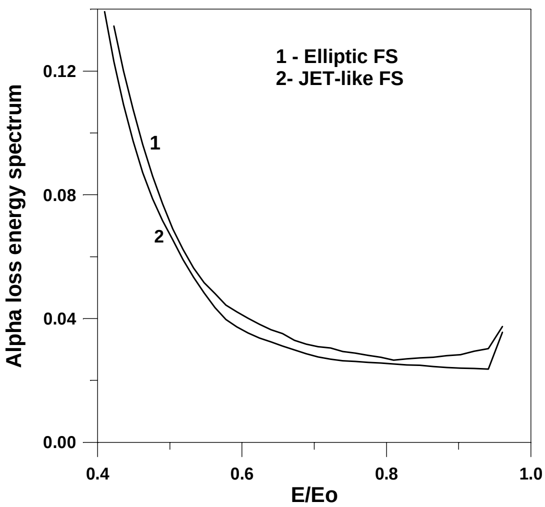

Fig.2. Calculated alpha loss energy spectrum vs. particle energy for different plasma shapes. E_o is the alpha birth energy.

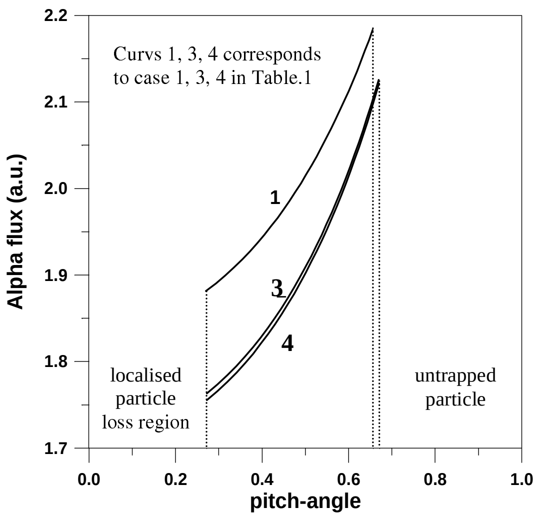

Fig.3. Calculated pitch-angle dependence of the alpha loss flux to the first wall in the plasma midplane for different plasma shapes.

energy dependencies of the alpha loss energy spectrum for the noncircular configurations of Case 1 and Case 4 from Table 1. The rapid increase with lower energies is attributable to the intensified involvement of trapped alphas in ripple induced resonant collisional diffusion. The inspection of Fig. 2 suggests that even small values of triangularity and up-down asymmetry can affect the alpha loss energy spectrum. The same conclusion is rendered by comparison of the total alpha losses for different noncircular configurations as listed in Table1. Further, as illustrated in Fig. 3, our calculations demonstrate the effect of FS noncircularity on the pitch-angle distribution of alphas escaping at the equatorial midplane. Whereas FS triangularity affects considerably the pitch-angle distribution of lost alphas, the additional up-down asymmetry has negligible effect on this distribution because it results mainly in shifting the position where alphas will hit the first wall.

4. CONCLUSIONS AND DISCUSSIONS

The results reported in the present paper demonstrate that the numerical approach used may be successfully applied for calculations of the behaviour of confined charged fusion products in real tokamak configurations with noncircular flux surfaces. This method permits to calculate the total loss of CFP's as well as their poloidal and pitch-angle distributions at the first wall. Further the essential influence of FS noncircularity on the stochasticity threshold in phase space could be demonstrated. FS triangularity decreases the total alpha loss and the pitch-angle distribution of lost alphas in comparison with the case of only elliptical plasma shape. On the other hand it was shown that up-down asymmetry has no essential effect at least on the high-energy alpha particle loss in JET-like devices, it only shifts the loss distribution over the first wall.

We note that the numerical code used for the reported calculations was adapted for operation to the numerical equilibrium data in the format reconstructed by the EFIT-JET code [6]. Thus the numerical modelling is directly applicable to actual tokamak discharges. For a further study, it is suggested that the stochasticity threshold be verified as ripple induced transport is one of the most important classical mechanism of high energy charged fusion product loss.

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REFERENCES

[1] V.Ya. Goloborod'ko, et al, Nucl. Fusion **35** (1995) 1523.
[2] V.A. Yavorskij, et al, Nucl. Fusion **38** (1998) 1565.
[3] J.W. Edenstrasser, et al, Czech. J. Phys. **48** (1998) 177.
[4] V.A.Yavorskij, et al, *Analytical Models of Axisymmetric Toroidal Magnetic Fields with Noncircular Flux Surfaces*, submitted to Plasma Phys. & Contr. Fusion
[5] F.S.Zaitsev, et al, J. Comput. Phys. **147** (1998) 239.
[6] W.Zwingmann, et al, preprint JET-P (1997) 57.