

Fusion Alpha Performance in Advanced Scenario Plasmas

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Introduction

The fusion reaction rate and, thus, the energy production is strongly dependent on ion temperature and density. Therefore, optimizing these quantities is essential when designing a fusion reactor. However, if the plasma is hot close to the separatrix, lot of energetic particles will escape from the plasma, causing a threat to the first wall. Therefore, the ideal plasma profiles would have a broad hot and dense region around the plasma core, and a cool edge.

One way to maintain this kind of profiles is by creating a so-called internal transport barrier (ITB). Traditionally, ITBs are observed in advanced scenario plasmas, characterized by a reversed magnetic shear in the plasma center. Such a reversed q -profile can be created by a low or vanishing toroidal current in the plasma center, which decreases the poloidal magnetic field and, consequently, increases the widths of fast particle orbits.

In this work the effect of the q -profile to confinement and heating profile of fusion alphas was studied in realistic JET geometry. Two standard JET ELMy H-mode plasmas (discharges #50844 and #52009) with a monotonic q -profile, as well as two ITB plasmas (discharges #51976 and #66498) with a reversed q -profile were used as backgrounds for the simulations. The discharge #51976 was particularly interesting since it exhibited a current hole.

The work was carried out using the guiding-center-following Monte Carlo code ASCOT [1]. This work complements the earlier Fokker-Planck analysis [2] not only by using a completely different method but also by allowing the experimental flux surface structure which, in the center of an ITB plasma, does not easily render itself to simple parametrization.

Simulated discharges

In addition to the two advanced scenario discharges with reversed q -profiles (#51976 and #66498), two H-mode discharges were studied for comparison. Due to the importance of the poloidal magnetic field in confining the plasma, it was of interest to study an H-mode discharge (#50844) with the same plasma current, $I_p = 1.9$ MA, as the current hole discharge #51976.

*See the Appendix of M.L.Watkins et al., Fusion Energy 2006 (Proc. 21st Int. Conf. Chengdu, 2006) IAEA

Discharge #66498 ($I_p = 1.9$ MA) was chosen in order to also study one discharge with a reversed q -profile, but without a current hole, whereas the purpose of having another H-mode discharge, #52009, was to study the effect of increased plasma current ($I_p = 2.5$ MA). The temperature and density profiles of the simulated discharges are shown in Fig. 1.

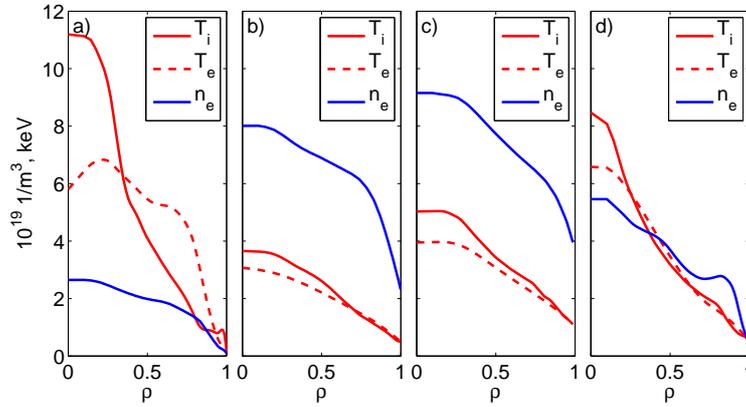


Figure 1: Temperature and density as functions of the normalized poloidal flux ρ for the discharges a) #51976 at $t = 4.8$ s, b) #50844 at $t = 21.5$ s, c) #52009 at $t = 21.0$ s, and d) #66498 at $t = 7.1$ s. The ion temperature profiles indicate that a) and d) are advanced scenario discharges with an ITB, whereas b) and c) are ELMy H-mode discharges.

Simulation procedure

In the simulations, *test particles* were initialized throughout the poloidal plane. Each test particle was given a weight factor, indicating the number of *real particles* it represents. The weight factors were assigned according to the local fusion reaction rate, i.e. alpha birth rate, at the point where the test particle was initialized. The local fusion reactivities, $\mathcal{R} = n_T n_D \langle \sigma v \rangle$, were calculated from the temperature and density profiles (Fig. 1) according to Ref. [3] and are shown in Fig. 2a). In the calculations the plasmas were assumed to be 50:50 mixtures of deuterium and tritium. The fusion reaction rates, depicted in Fig. 2b), can be calculated from the reactivities by multiplying them with the flux surface volumes. Since fusion-born alpha particles have their velocity vectors pointing in random directions, the test particles were initialized with random pitches ($\xi = v_{\parallel}/v$).

In the simulations, the 3.5 MeV alpha particles were followed from birth until they either hit the walls of the device or had cooled down to 100 keV. The energy transfer from the alphas to the plasma was recorded. At 100 keV the alphas had already lost over 97% of their energy and, thus, the rest was considered irrelevant.

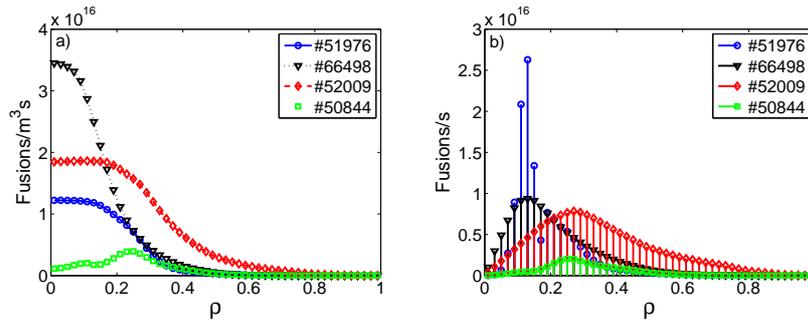


Figure 2: a) fusion reactivities and b) fusion reaction rates of the studied discharges. Total power to alpha particles, obtained summing up the fusion rates in b), and multiplying them by 3.5 MeV were: 69.5 kW (#51976), 13.6 kW (#50844), 87.8 kW (#52009), and 42.1 kW (#66498).

Losses and power deposition

The total power deposited on the walls of the device, by the alpha particles were substantial in the discharges with a reversed q -profile. In discharge #51976, the total wall load was 11.3 kW, which represents 16% of the fusion power carried by the alpha particles.

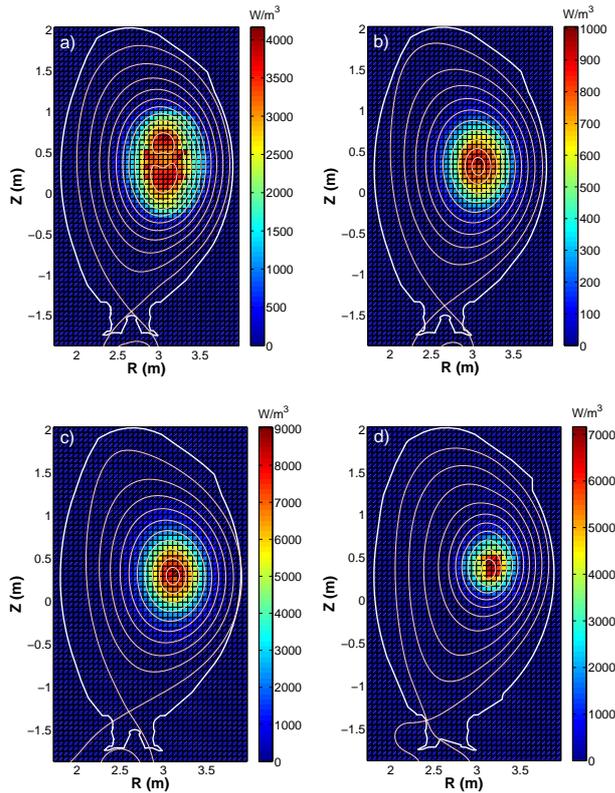


Figure 3: The alpha power deposition profiles in discharges a) #51976, b) #50844, c) #52009, and d) #66498.

For the discharge #66498 the same figures were 4.1 kW and 10%. In the H-mode discharge #50844 with the same plasma current as in the discharges with a reversed q -profile, the wall loads were notably smaller: only 0.75 kW (6%) of the alpha power was deposited to the walls. In discharge #52009 with a larger I_p , the wall loads were further reduced to 2.9 kW (3%). The fraction of first orbit losses was observed to be slightly over 90% of the total alpha losses in all the discharges. These results are qualitatively similar to the earlier results from three-dimensional predictive Fokker-Planck [2] and orbit-following Monte Carlo simulations [4].

A distinctive difference in the initial location of the lost particles was detected from

the simulations. In the H-mode discharge #52009, majority of lost particles were born on the outer flux surfaces ($\rho_{pol} > 0.6$), whereas for the discharge #50844 with a lower I_p particles from $0.2 < \rho_{pol} < 0.6$ dominated the wall loads. The effect of reversed q -profile and the resulting worse fast particle confinement could be seen in the advanced scenario discharges, where a substantial amount of particles from the innermost flux surfaces also escaped the plasma.

The power deposition profiles depicted in Fig. 3 are consistent with the fusion rates. The main difference is the broadness of the power deposition in the current hole discharge due to wide particle orbits and large extent of the innermost flux surfaces. Also the confining effect of higher I_p resulting in a more central power deposition in the H-mode discharge #52009 should be noted.

Conclusions

Compared to H-mode plasmas, the confinement of alpha particles in ITB plasmas was found out to be substantially worse. In discharge #51976 the losses represented approximately 16%, and in discharge #66498 about 10% of the total alpha particle power. For the H-mode discharge #50844 with the same plasma current as the ITB plasmas, the losses were only about 6% of the alpha power. Still, even with higher losses, ITB plasmas deposit more power to the plasma. First orbit losses comprised over 90% of all the alpha particle losses in all the discharges, and it is worth noting how, in the plasmas with reversed q -profiles, significant amount of even the particles born in the plasma core experience first orbit losses. Therefore, having a cold edge with very few fusion reactions is not enough to protect the first wall from the fusion alphas. In the H-mode plasmas studied in this work, an increase of the plasma current from 1.9 MA to 2.5 MA reduced the alpha losses to about one half, i.e. from 6% to 3% of the total alpha power.

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