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O. Asunta, T. Kurki-Suonio, T. Tala, S. Sipilä, R. Salomaa
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O. Asunta[1], T. Kurki-Suonio[1], T. Tala[2], S. Sipilä[1], R. Salomaa[1]
and JET EFDA contributors*

JET-EFDA, Culham Science Centre, OX14 3DB, Abingdon, UK

[1]*Helsinki Univ. of Technology, Association Euratom Tekes, PO Box 4100, 02015 TKK, Finland*
[2]*VTT Technical Research Centre of Finland, Association EURATOM-Tekes, P.O.Box 1000, FIN-02044 VTT, Finland*
** See annex of M.L. Watkins et al, "Overview of JET Results ",*
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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 (Pulse No's: 50844 and 52009) with a monotonic q-profile, as well as two ITB plasmas (Pulse No's: 51976 and 66498) with a reversed q-profile were used as backgrounds for the simulations. The Pulse No's: 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.

1. SIMULATED DISCHARGES

In addition to the two advanced scenario discharges with reversed q-profiles (Pulse No's: 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 (Pulse No's: 50844) with the same plasma current, I_p = 1.9MA, as the current hole Pulse No's: 51976.

Pulse No: 66498 (I_p = 1.9MA) 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, Pulse No's: 52009, was to study the effect of increased plasma current (I_p = 2.5MA). The temperature and density profiles of the simulated discharges are shown in Fig.1.

2. 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 were the test particle was initialized. The local fusion reactivities, $R = n_T n_D \langle s_v \rangle$, 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 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 ($\xi = v_{\|}/v$).

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

3. 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 Pulse No: 51976, the total wall load was 11.3kW, which represents 16% of the fusion power carried by the alpha particles.

For the Pulse No: 66498 the same figures were 4.1kW and 10%. In the H-mode Pulse No: 50844 with the same plasma current as in the discharges with a reversed *q*profile, the wall loads were notably smaller: only 0.75kW (6%) of the alpha power was deposited to the walls. In Pulse No: 52009 with a larger I_p, the wall loads were further reduced to 2.9kW (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 Pulse No: 52009, majority of lost particles were born on the outer flux surfaces ($\rho_{pol} > 0.6$), whereas for the Pulse No: 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 *Ip* resulting in a more central power deposition in the H-mode Pulse No: 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 Pulse No: 51976 the losses represented approximately 16%, and in Pulse No: 66498 about 10% of the total alpha particle power. For the H-mode Pulse No: 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 1.9MA to 2.5MA reduced the alpha losses to about one half, i.e. from 6% to 3% of the total alpha power.

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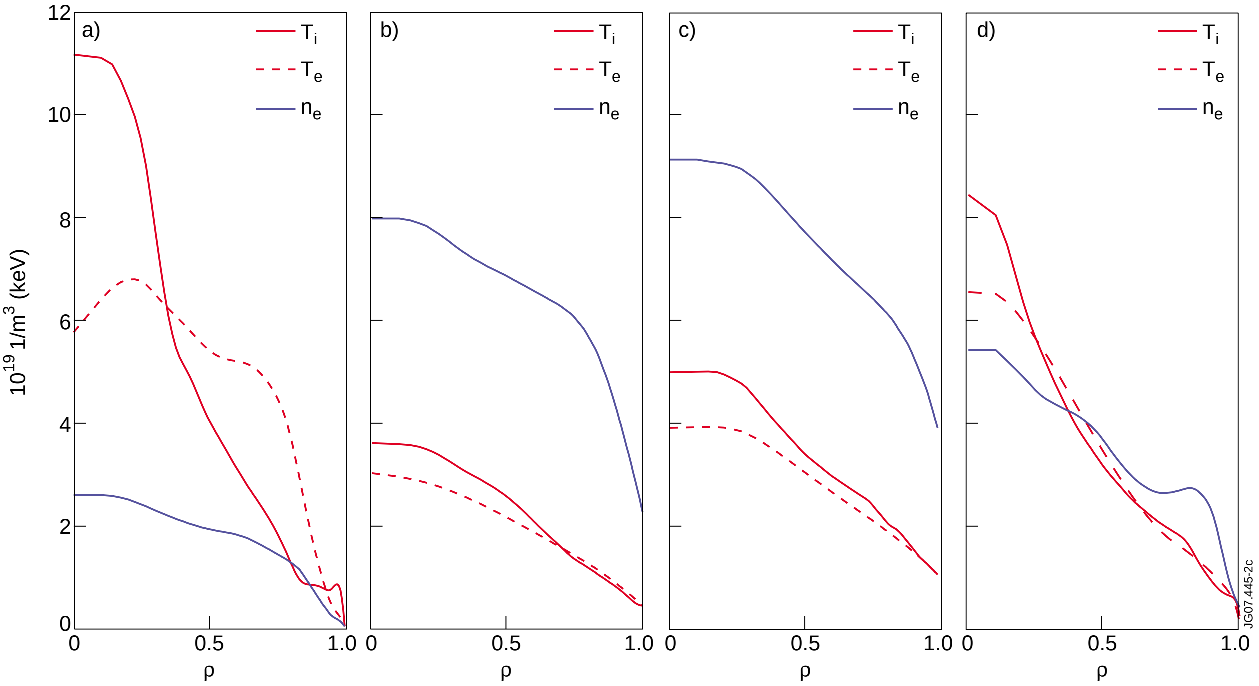

Figure 1: Temperature and density as functions of the normalized poloidal flux ρ for the discharges a) Pulse No's: 51976 at t = 4.8s, b) 50844 at t = 21.5s, c) 52009 at t = 21.0s, and d) 66498 at t = 7.1s. The ion temperature profiles indicate that a) and d) are advanced scenario discharges with an ITB, whereas b) and c) are ELMy H-mode discharges.

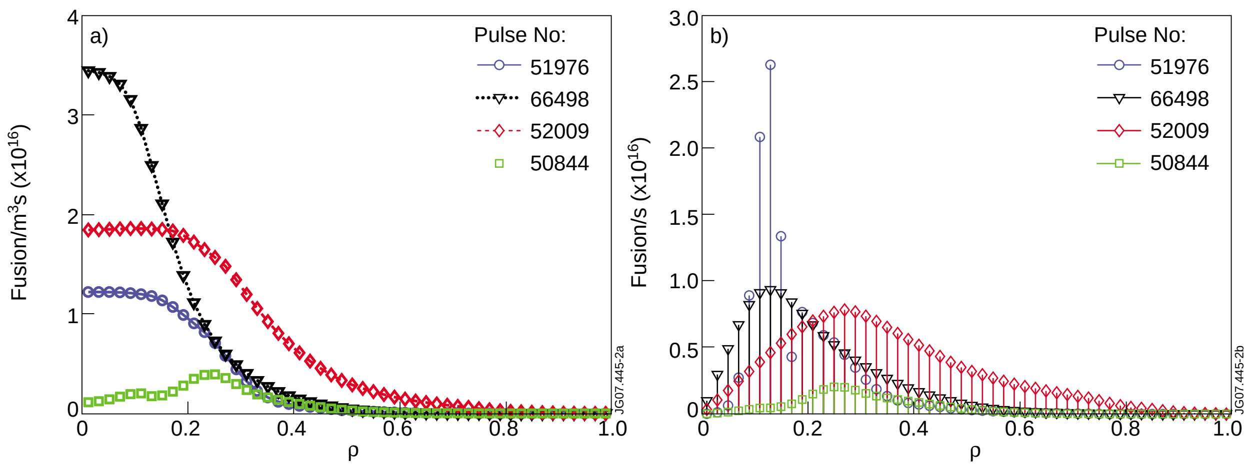

Figure 2: a) fusion reactivities and b) fusion reaction rates of the studied discharges. Total power to alpha particles, obtained summing up the fusion rates in b), and multiplying them by 3.5MeV were: 69.5kW (Pulse No: 51976), 13.6kW (Pulse No: 50844), 87.8 kW (Pulse No: 52009), and 42.1 kW (Pulse No: 66498).

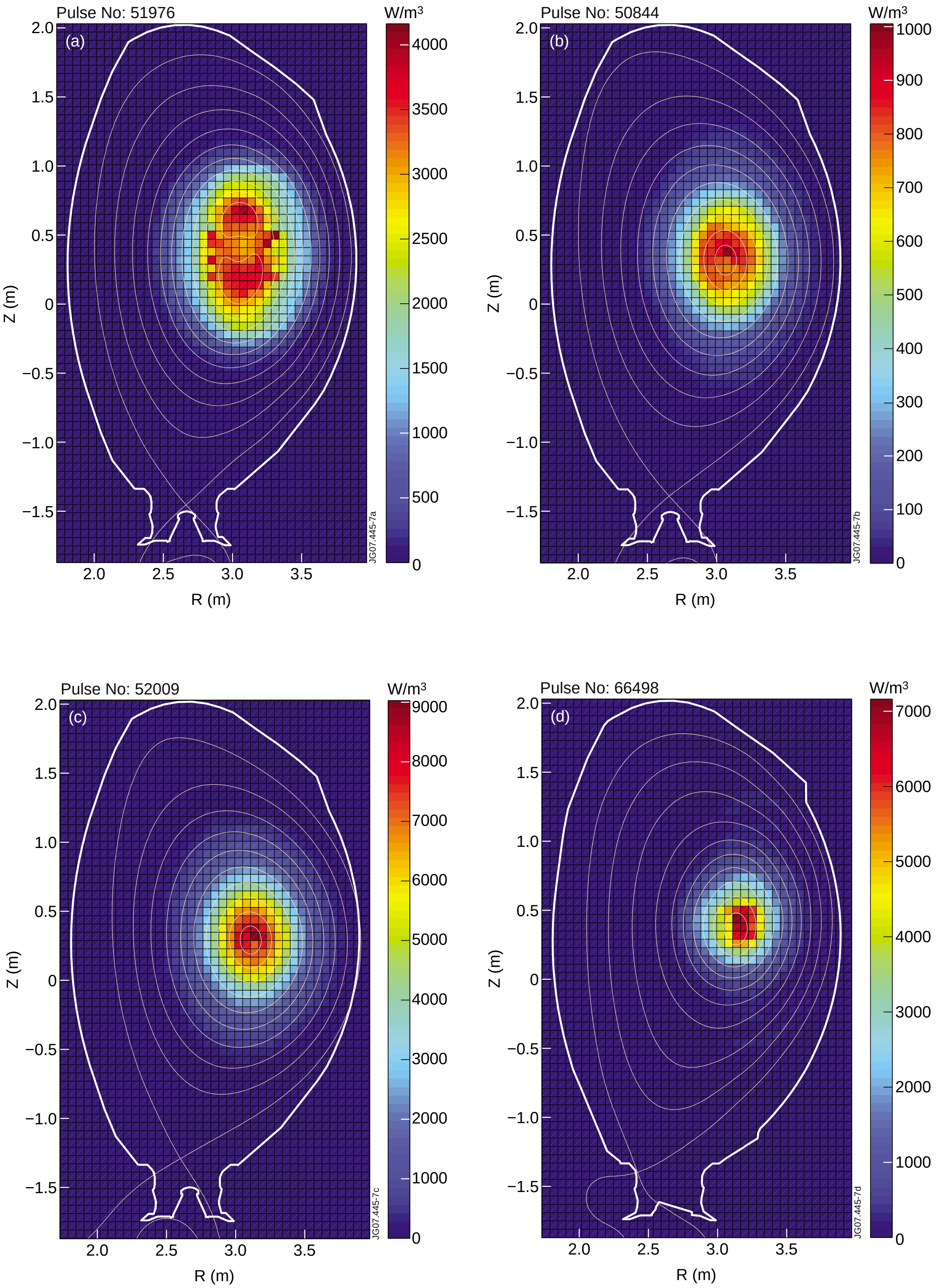

Figure 3: The alpha power deposition profiles in Pulse No's: a) 51976, b) 50844, c) 52009, and d) 66498.