

## **Modeling and analysis of the ICRH heating experiments in JET ITB regimes**

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### **Introduction**

In order to establish if the physical mechanism involved in the electron ITB (Internal transport Barrier) is the same as in an ion ITB, a direct heating of the plasma ions by ICRH (Ion Cyclotron Resonance Heating) in the "minority heating regime" (<sup>3</sup>He minority in Deuterium), without NBI (Neutral Beam Injection), has been provided in an experiment on JET. Such discharges are characterized by a well developed electron ITB in presence of non-monotonic q-profile [1]. In this work we will present an improvement of the calculation performed to analyze the previous experiment based on the use of the 2D full wave code TORIC which takes into account both the JET magnetic field structure and the antenna radiated power pattern. These new evaluations have been used to re-visit the experimental data of the last campaign (C13 2004) and to prepare the next JET experiment. Moreover, a code that solves the 2D quasi-linear Fokker-Planck equation

(SSQLFP) has been applied in order to establish the redistribution of the power from the minority to the principal species of the plasma (electrons and majority ions) by collisions. Transport calculation that uses the above power deposition profiles as the starting point have been also performed.

### **Modeling using TORIC numerical code**

The key point for this kind of experiment set-up, is to launch the maximum ICRH power and to maximize the coupled power on the majority ions. The most suitable scheme in order to have an efficient ion heating is to work in a “minority heating regime”. In this scheme the ICRH frequency is chosen to resonate at the fundamental cyclotron harmonic of the minority species ( $^3\text{He}$ ) located near the plasma centre while the fundamental or the first harmonic of the majority (deuterium), is out of the plasma (or in the very edge). The ICRH power will be absorbed mainly by the minority ions in a very central layer (near the resonance layer) in competition with the electrons that will absorb the power via electron Landau damping in a wider region included between the edge and the cut-off layer. As the fraction of power absorbed by the species depends strongly from the minority concentration it is necessary to establish the level of  $^3\text{He}$  that maximizes the ion absorption. An analysis has been done by using the 2D code TORIC [2,3]. TORIC is a linear code that solves the full-wave equation relevant for ICRH propagation and absorption in two dimensions, taking into account the magnetic field structure and the plasma geometry. TORIC works essentially by keeping a single toroidal component of the Fourier spectrum, while in the poloidal direction an elevated number of poloidal modes can be taken into account in order to include the poloidal mode coupling due to the dependence of the magnetic field on  $\psi$  (the poloidal flux) and  $\chi$  (the generalized poloidal angle). The analyzed scenario is characterized by  $I_p = 2.5$  MA,  $B_t = 3.45$  T, LHCD: prelude (current hole), and main heating phase (2 MW); ICRH, up to 6 MW, and 37 MHz dipole configuration for  $^3\text{He}$ -D; NBI: diagnostic beam only (2.7 MW);  $^3\text{He}$  concentration: range 3%-15%, RTC (Real Time Control) is used to monitor the  $^3\text{He}$  concentration during the discharge. An electron ITB is present and shrinking in radius during the evolution of the discharge. The fundamental resonance of  $^3\text{He}$  is at  $r/a = -0.164$ , while the fundamental of Deuterium is at the edge  $r/a = -0.912$  (the sign minus means high field side). In Fig. 1 the power fraction coupled to the minority ions and to electrons is plotted vs the  $^3\text{He}$  concentration at a fixed value of the parallel wave-number (or toroidal mode number)  $n_{||} \approx 9$

which corresponds to the peak of power spectrum, and when considering in the absorption rate the real launched spectrum (full circles for ions and full triangles for electrons). The 2D geometry is responsible for a different location of the maximum of ion absorption. The peak is centred around a minority concentration of 6% (80% on minority ions), drops to a very low level for concentration  $\leq 1\%$ , while for concentration higher than 7% the absorption seems to reach a limiting value. Indeed, for minority concentration  $> 7\%$ , TORIC is inaccurate to predict the ion and electron absorption. In this situation it is necessary to run the parallel version of the code with 128 or 256 poloidal modes. A couple of runs with 128 modes for  $^3\text{He}$  concentration of 5%, and 128 & 256 modes at concentration of 7% and 9%, have been done on the MIT cluster "Marshall" using 32 processors. These runs have shown that the result obtained for a concentration up to 7%, are essentially correct. At higher concentrations the ion absorption drops abruptly to the concentrations obtained by using the 1D code FELICE. The effect of the spectrum on the absorption rate is shown on the same figure. The ion absorption drops around 70% of the total launched power (80% without  $n_{||}$ -dispersion) for a  $^3\text{He}$  concentration of 6%. Moreover the pronounced peak of ion absorption around concentration of 6% disappears, the curve seems to be flatter than before.

### Quasi-linear 2D Fokker-Planck calculation

In this section the following question is addressed: how the energy on the minority species, on the collisional time scale, will be transferred to electrons and ions? Which fraction goes to electron? The quasi-linear analysis is crucial to answer to that question. To this end we have coupled TORIC to the 2D quasi-linear Fokker-Planck code SSQLFP. The result of this analysis shows that most of the power (95%) flows from minority to the bulk ions. At this point we are able to obtain the global power balance after including in the above calculation the collisional transfer from high energetic minority tail to bulk electrons and ions. The relevant plot is shown in Fig. 2 where the fraction of power on the majority ions (bulk deuterium) and electrons is shown vs the minority concentration. No more than 65% of the coupled power can be transferred to the ion population. The best range of minority concentration is included between 5-7%. Transport calculation by JETTO code using the power deposition profile for the bulk ion as obtained above has shown that there is a reduction from 2.5 to 1  $\text{m}^2/\text{s}$  in the ion conductivity at barrier location.

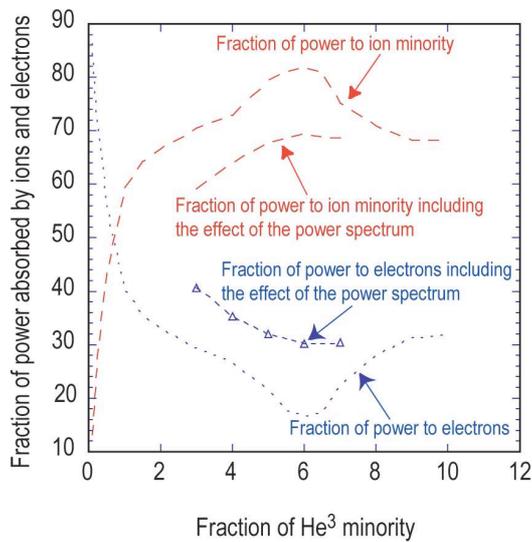


Figure 1 Power fraction on the minority ions and electrons vs the  $^3\text{He}$  fraction for  $n_{\parallel} \approx 9$  and when considering the launched spectrum.

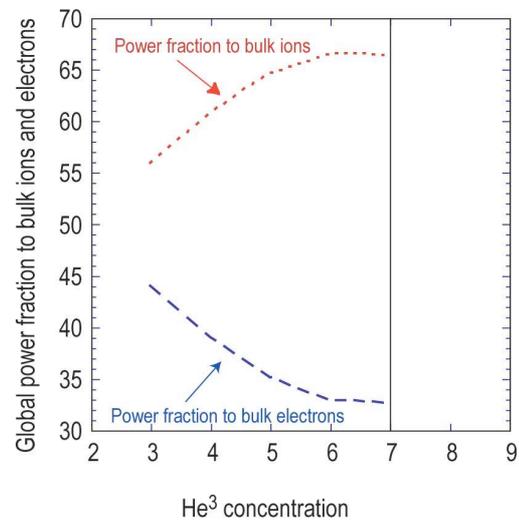


Figure 2 Fraction of power on the majority ions (bulk deuterium) and electrons vs the minority concentration.

### Conclusions

Analysis of the ICRH absorption in minority heating regime has been applied to the results obtained in the last experimental campaign at JET (C13 2004). The relevant result we have obtained is that with a fraction of  $^3\text{He}$  minority in the range of 5-8% we can transfer to the bulk majority ions a fraction of about 65% of the coupled power. Preliminary transport calculations which uses the power deposition profiles obtained with TORIC have shown that there is a reduction of the  $\chi_i$  with a consequent increase of the ion temperature. Nevertheless the power coupled to the ions results to be marginal to observe any large effect on the global performance of the discharges. For this reasons and for the fact that the old experimental campaign provided a limited number of discharges due to diagnostics and operation problems it is envisaged to repeat this experiment with same objectives keeping in mind the relevant results of the above discussed analysis.

### References

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