ICRF MINORITY HEATING COMBINED WITH COUNTER NEUTRAL INJECTION IN ASDEX

F.Ryter, M.Brambilla, A.Eberhagen, O.Gehre, R.Nolte, J.-M.Noterdaeme, F.Wesner,
ICRH-Group, ASDEX-Group, NI-Group

Max-Planck-Institut für Plasmaphysik,Euratom Association,
D-8046 Garching,Fed. Rep. Germany

Introduction:

As reported in ref /1/, counter-injection in the ASDEX tokamak is able to induce density profile peaking and a subsequent improvement of both the energy and particle confinement. We discusse here is the application of ion cyclotron hydrogen minority heating (33.5 MHz) combined with D^o counter-injection to ASDEX deuterium plasmas containing a low percentage of hydrogen. The resonance layer was in the plasma center. The vacuum vessel was carbonised to handle the high impurity production due to ctr-NI.

1. Phenomenology of ICRH+ctr-NI discharges:

Figure 1 shows the time evolution of two discharges from an ICRH power scan (0.25-2.0 MW) combined with P_{NI}=1 MW ctr-NI (launched powers). As usual with ctr-NI, the discharges are not stationary. The line density increases monotonically, the plasma energy W_p reaches a maximum after which the impurity accumulation induces a rapid decrease of $T_e(0)$ and W_p, and the discharges end in a disruption, as discussed in ref /2/. The peaking factor $Q_n=n_e(0)/<n_e>$ increases as soon as the injection starts, decreases suddenly when the ICRH begins, due to a strong density increase at the plasma edge, and then increases up to about 1.8 at which time W_p reaches a maximum. For ICRH powers larger than ≈1 MW, an intermediate maximum is observed for Q_n, W_p and $T_e(0)$. When the plasma center is not strongly dominated by the radiation losses, W_p and $T_e(0)$ follow the time behaviour of Q_n. In contast to the cases with ctr-NI alone in which $T_e(0)$ remains constant or even decreases along the shot, with ICRH $T_e(0)$ increases despite the density increase. The soft X-ray emission from the central chord shows the strong radiation increase of the plasma center due to impurity accumulation towards the end of the discharge when the sawteeth disappear. The sawtooth behaviour clearly depends on the ICRH power. At low power the sawteeth tend to stabilise early in the heating pulse and the period is erratic. As the ICRH power is increased, the period evolves smoothly and increases with Q_n and $T_e(0)$ or decreases when they decrease. The possible mechanism for the sawtooth behaviour is discussed in a companion paper /3/. Figure 2 shows n_e, Q_n and $T_e(0)$ values measured at the when W_p is maximum (W_{max}), and immediately before the disruption plotted versus the total deposited heating power ($P_{tot}= P'_{OH} + \alpha_{NI}P_{NI} + \alpha_{IC}P_{IC}$), where α_{NI}=0.59 and α_{IC}=0.7 are the estimated absorption coefficients for ctr-NI and ICRH respectively. The values of Q_n and n_e at W_{max} are almost independent of $P_{IC.}$ The difference between $T_e(0)$ at W_{max} and at the disruption reflects the radiation losses due to impurity accumulation. At high power the clear decrease of Q_n prior to the disruption is due to an edge density increase.

As discussed in ref /1/, the peaking occurence is sensitive to the edge plasma and the role of the ICRH in peaking mechanisms is unclear. We observed, particularly with a fresh carbonisation for which the recycling is high, that ICRH can prevent the density peaking. This suggests that an apropiate ICRH power combined with ctr-NI could control the peaking effects. Obviously the density peaking results from the balance between the Ctr-NI influence which increases with P_{NI} and an opposing ICRH effect. For instance, with a new carbonisation and P_{IC}=1.6MW, peaking did not occur with P_{NI}=1MW but occurred with P_{NI}=1.6MW. The ICRH edge density increase certainly plays a role. However the electron density and temperature near the separatrix in cases with and without peaking were not measurably different. Appropriate conditioning of the wall and of the antennas would improve the combination ctr-NI+ICRH.

2. Heating and confinement properties:

The heating properties of the series described in §1 are illustrated in figure 3. The maximum plasma energy follows the off-set linear scaling law as already observed with co-NI (see Fig. 4 and ref /4/). The incremental confinement time is about 37 ms. The same behaviour is found for the electron temperature and electron plasma energy which contributes about 70% of the total plasma energy. The radiation in the center increases more strongly with the power than in the co-NI case. W_{max} is determined by th opposing effects of the confinement improvement related to the density peaking and the radiation increase in the central part of the plasma. The ICRH contribution to the radiation in the center is around 0.8 Wcm^{-3} for 1 MW deposited ICRH power, which is to be compared with 1.3 Wcm^{-3}, the theoretical estimate of the absorbed power density in the center (for 1 MW). The radiation and RF power deposition profiles in the central part of the plasma (not shown here) have a comparable shape with a width of about r=10 cm.

Ctr-NI+ICRH and co-NI+ICRH are compared in figure 4 for various NI and ICRH powers in different series: Co1=co-NI+ICRH fresh carbonisation, Co2=co-NI+ICRH older carbonisation, Ctr1=ctr-NI+ICRH fresh carbonisation, Ctr2=ctr-NI+ICRH older carbonisation. The values of W_{max} for each ctr-NI discharge and W_p in the stationary phase for the co-NI discharges are plotted versus P_{tot}, (α_{NI}=0.85 for co-NI). No ctr-NI+ICRH dischargehas yet reached the highest plasma energy values obtained in Co1.However, all the ctr-NI+ICRH discharges lie within the range of the Co2 discharges. The Ctr1 discharges showed no clear peaking ($Qn\approx1.6$). The peaking factor for Co1 and Co2 lies at ≈1.5.

The co-NI+ICRH discharges have comparable hollow radiation profiles for which the central radiation is low. Therefore radiation effects cannot explain the difference between series Co1 and Co2. The difference is probably due to edge and wall conditions and/or to better RF absorption due to a more favourable hydrogen concentration. In contrast, the radiation plays an important role for ctr-NI discharges and in comparing the intrinsic confinement properties of co-NI+ICRH and ctr-NI+ICRH discharges it is important to take the central radiation into account. For this purpose, we correct the deposited power by substracting from it the radiation power inside a volume of a given radius, both for the co-NI and ctr-NI cases.The Ctr2 plot $W_p=f(P_{tot})$ becomes equal to or somewhat better than the Co1 one when r is taken in the range 15cm≤r<39cm. For r=15cm, the correction is 15% and 3% of Ptot for the ctr-NI and co-NI cases respectively. This indicates that the confinement of Ctr2 and Co1 is comparable. It must however be stressed that the plasma energy is clearly correlated with the peaking factor for the ctr-NI+ICRH discharges. Indeed, figure 1 shows that W_p improves when Q_n increases. The RF absorption coefficent, a parameter which could play a role, is measured with an uncertainty of ≈20% which is not sufficiently precise to allow a difference between co-NI and ctr-NI casesto be detected. The NI absorption is well documented but a decrease could come from RF coupling to injected ions which would enhance orbit losses and contribute to losses of both the NI and ICRH power. It is however doubtful that this could be more than 20% of the NI-power.

3. Conclusion

The combination of ICRH minority heating with D^o counter injection is able to produce peaked density discharges in which the confinement increases with the peaking factor. ICRH clearly heats the plasma center where the electron temperature reaches high values despite the high density and prevents an early radiation collapse of the discharges. The discharges follow the off-set linear scaling law, as previoulsy observed for co-NI+ICRH for which comparable values of the incremental confinement time are measured. The results could certainly be improved by a conditioning method of the wall and antennas which would reduce the impurity production and the recycling.

Acknowledgement

The authors wish to thank the operation teams of the ICRH, ASDEX and NI groups.

References:

/1/ G.Fussmann at al., 12th IAEA Conf. Plasma Phys. Contr. Fus., Nice 1988
/2/ A.Stäbler et al., this conference.
/3/ R.Nolte at al., this conference.
/4/ J.-M.Noterdaeme et al., 12th IAEA Conf. Plasma Phys. Contr. Fus., Nice 1988

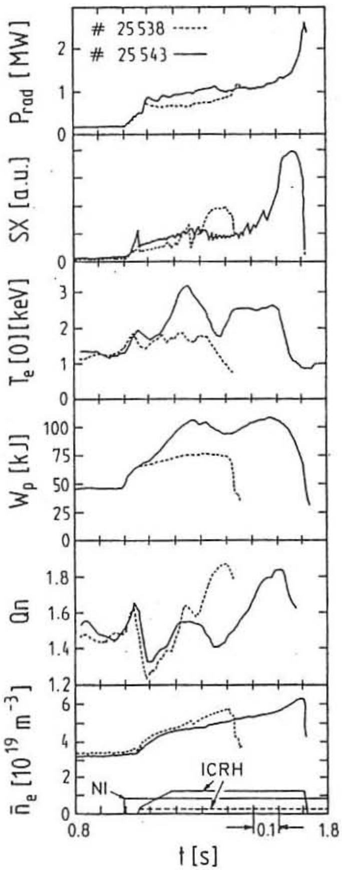

Fig.1 Time evolution of discharges with P_{NI}=1MW, P_{IC}=0.25Mw broken line, P_{IC}=1.7MW solid line. $\bar{n}_e$= line averaged density , W_p= plasma energy, Qn= density peaking factor, Te(0)=central electron temperature from laser scattering, probably somewhat over-estimated by the fit extrapolation, SX= line integrated central soft X ray signal, P_{rad}= volume averaged plasma radiation

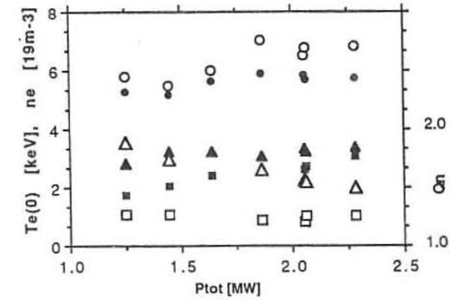

Fig.2 Q_n (triangles), n_e (circles), $T_e(0)$ (squares) at plasma energy maximum (closed symbols), before the disruption (open symbols), versus total power.

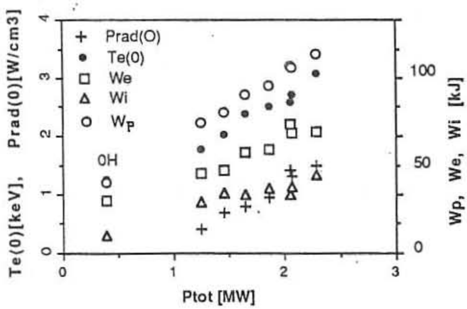

Fig.3 W_p, electron plasma energy We, Wi = Wp-We, central radiation power $P_{rad}(0)$, at W_{max} , versus total deposited heating power.

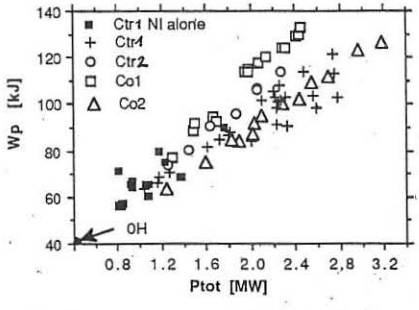

Fig.4 Plasma energy versus total deposited heating power for co-NI+ICRH and ctr-NI+ICRH discharges.