PARAMETER STUDIES OF NEUTRON PRODUCTION DURING ADDITIONAL HEATING IN ASDEX

K. Hübner, S. Lutz
Institut für Angewandte Physik, Universität Heidelberg, D-6900 Heidelberg
J. Kucinski
Institute for Nuclear Studies, PL-05400 Swierk
B. Bomba, S. Bosch, A. Eberhagen, H.-U. Fahrbach, O. Gehre, W. Herrmann, H. Murmann, H. Rapp, H. Röhr, K.-H. Steuer, O. Vollmer
Max-Planck-Institut für Plasmaphysik, EURATOM Association, D-8046 Garching

The neutron production in a deuterium plasma is determined solely by the ion distribution function. In the case of thermonuclear plasmas this distribution function is given by two simple plasma parameters, the ion density and the ion temperature. Unfortunately, neither is easy to measure and so they are not always available. Furthermore, in some situations we cannot expect a simple relation between the deuteron density and other plasma parameters. This situation complicates parameter studies for the neutron production in tokamaks and it is thus sometimes impossible to find clear correlations between the neutron rate and other experimental parameters such as the heating power, electron density, and plasma current.

Thermonuclear neutron production

The total neutron rate Q of a thermonuclear plasma is given by the volume integral

$$Q = \frac{1}{2}\int n_D^2(\mathbf{r})\,[\sigma v]_{\mathbf{r}}\,d\mathbf{r} = \frac{1}{2}\,n_D^2(0)\,[\sigma v]_0 \int f_D^2(\mathbf{r})\,f_{[\sigma v]}(\mathbf{r})\,d\mathbf{r}. \qquad (1)$$

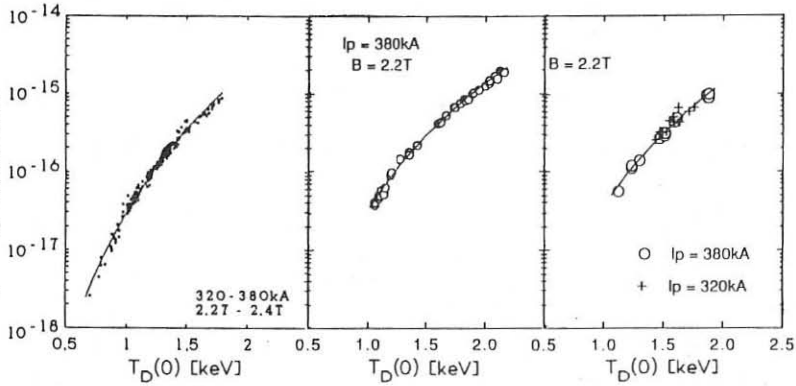
Here $n_D(\mathbf{r}) = n_D(0)\,f_D(\mathbf{r})$ and $[\sigma v] = [\sigma v]_0 f_{[\sigma v]}(\mathbf{r})$ are the local profiles of the deuteron density and reactivity. The profile function of the neutron rate is $f_Q(\mathbf{r}) = f_D^2(\mathbf{r}) f_{[\sigma v]}(\mathbf{r})$. The profile functions for the deuteron density and temperature have not been measured, but in ASDEX we have very flat profiles for Z_{eff} and so we can use the measured density profile function of the electrons for the ions as well. Furthermore, the same temperature profile function can be expected for electrons and ions with the heating methods considered here, namely minority ICRH and H injection [1].

We are using our NR code [2] to determine the deuteron density from the measured neutron rate Q. First we consider the ratio

$$Q^* = Q \Big/ \frac{1}{2}\,n_D^2(0) = [\sigma v]_0 \int f_Q(\mathbf{r})\,d\mathbf{r} = [\sigma v]_0\,\frac{V}{Q(0)/\langle Q\rangle}\,, \qquad (2)$$

where V is the plasma volume and $Q(0)/\langle Q\rangle$ the peaking factor of the neutron emission profile. The ratio Q^* is only a function of this peaking factor and the central deuteron temperature, which determines the central reactivity.

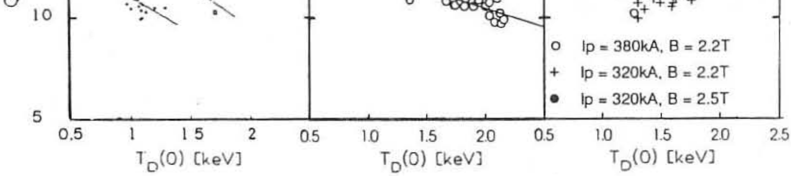
Figs. 1, 2 and 3 give Q^* as a function of the deuteron temperature for minority ICRH and H injection L-mode and H-mode discharges in deuterium plasmas. For H injection the deuteron temperature was determined from CX measurements. For ICRH this was only possible for some dicharges but from these we found $T_D = T_e$ for the parameter region used in Fig. 1. L-mode results are given for a single set of plasma current I_p = 380 kA and toroidal magnetic field B_{tor} = 2.2 T. H-mode results are given for two different currents and fields, and ICRH results for all currents and magnetic fields used in the minority heating experiments.



Figs. 1 to 3: $Q^* = Q \Big/ \frac{1}{2} n_D^2(0)$ as a function of the deuteron temperature,

1) minority ICRH, 2) H injection, L-mode, 3) H injection, H-mode.

For fixed temperature the influences of the current and magnetic field on Q are only due to the influences on Q(0)/‹Q›. In order to show this more clearly, in Figs. 4 to 6 Q(0)/‹Q› is given on a linear scale as a function of the deuteron temperature. Q(0)/‹Q› ranges between 10 and 18 and is thus essentially larger than the peaking factors for the density and temperature profiles owing to the quadratic dependence of Q on n_D and the strong



Figs. 4 to 6: Q(0)/‹Q› as a function of the deuteron temperature,

4) minority ICRH, 5) H injection, L-mode, 6) H injection, H-mode.

temperature dependence of [σv]. Furthermore, $Q(0)/\langle Q\rangle$ decreases with increasing ion temperature because the reactivity [σv] rises faster for the lower temperatures in the outer regions of the profiles than for the maximum temperature in the centre.

At present, our data base is not sufficient to derive scaling laws for $Q(0)/\langle Q\rangle$ with I_p and B_{tor}, but Figs. 4 and 6 show a clear increase of $Q(0)/\langle Q\rangle$ with B_{tor} for fixed I_p. There also seems to be an increase with I_p for fixed B_{tor}. Owing to eq. 2 an increasing peaking factor for the neutron rate results in a decrease of Q^*. - For comparable currents and fields $Q(0)/\langle Q\rangle$ and hence Q^* are the same for minority ICRH and H injection.

If the ion temperature is known, the measured neutron rate Q offers the most direct way of determining the deuteron density; it is given by $n_D(0) = \sqrt{2Q/Q^*}$. This expression directly demonstrates the problems of this procedure; errors in the determination of T_D will essentially affect the results for n_D. For ICRH our results for n_D are in general too high. This may by caused by a systematic error in the ion temperature or by non-thermonuclear effects and needs further investigation. The results for H injection are more reasonable. We restrict the discussion here to the L-mode case with the single current and field set used above. Fig. 7 gives n_D as a function of T_D. A decrease of n_D with increasing temperature is expected because the plasma is heated by H injection, but it may be overestimated owing to the problems mentioned. Nevertheless n_D decreases and T_D increases as the heating power per mean electron density $P_{Inj}/\langle n_e\rangle$ (Fig. 8), and so the results do not seem to be affected too much by errors in temperature determination.

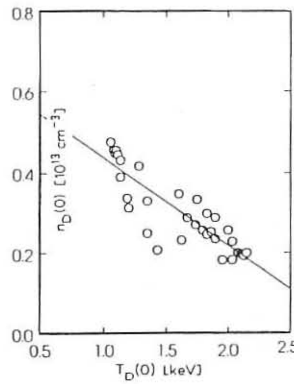


Fig. 7: n_D as a function of the ion temperature.

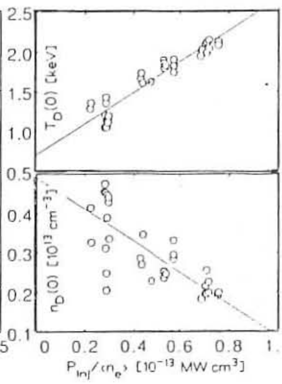


Fig. 8: n_D and T_D as a function of $P_{Inj}/\langle n_e\rangle$.

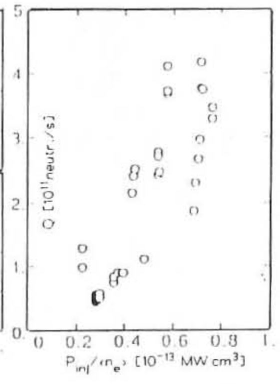


Fig. 9: Q as a function of $P_{Inj}/\langle n_e\rangle$

Finally, we want to demonstrate in Fig. 9 that the large scattering of the values for n_D and T_D in Figs. 7 and 8 results in widely spread values if one tries to scale the measured neutron rate Q with the heating power. As Fig. 9 gives the results for a fixed current and field set, it is obvious that one cannot expect to find scaling laws of the measured Q with the direct parameters of the discharge, such as the heating power, current, magnetic field, and electron density.

Neutron production during D injection

There are always two contributions to the neutron rate during D injection in deuterium plasmas, the thermonuclear production and the beam-target production. As the target temperatures in ASDEX are mostly below 3 keV, the thermal contribution only amounts to a few per cent [2] and is therefore neglected in the following considerations. The beam-target neutron rate is given by

$$Q_{inj} = \frac{n_D}{n_e} \int D(\mathbf{r}) \left[\int (n_e \tau_W / W) \, [\sigma v]_{inj} \, dW \right] d\mathbf{r} \, . \qquad (3)$$

The deposition rate profile $D(\mathbf{r})$ gives the radial distribution of the injected ions. It is directly proportional to the injected power absorbed. $(D\tau_W/W)$ is their velocity distribution function resulting from the classical energy relaxation. n_D is the target deuteron density, n_e the electron density, and τ_W the energy relaxation time. $[\sigma v]_{inj} = f(W,T_D)$ is the fusion reactivity for monoenergetic deuterons with energy W in a target plasma with ion temperature T_D. The energy relaxation parameter $n_e \tau_W$ is mainly a function of the electron temperature T_e. Thus Q_{inj} is mainly a function of the injection power and the electron and ion temperatures.

For D injection we find from CX measurements $T_D = 1.2\,T_e$. In the parameter region considered here we have approximately $n_e \tau_W \sim T_e$. It is therefore sufficient to discuss Q_{inj} as a function of the product $P_{inj} T_e$, as shown in Fig. 10. For the L-mode discharges we are in the region where T_e saturates and becomes independent of the injection power and plasma density. Therefore, Q_{inj} is proportional to $P_{inj} T_e$. For the H-mode discharges T_e still depends on P_{inj}, and so Q_{inj} in Fig. 10 becomes larger for H-mode discharges than the extrapolated values for L-mode discharges.

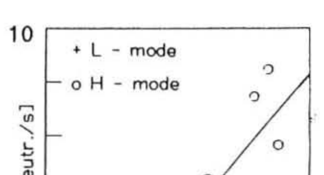


Fig. 10: Neutron rate during D injection as a function of $P_{inj}\,T_e$.

The peaking factor $Q(0)/\langle Q \rangle$ for the neutron rate for D-injection is also dominated by the beam-target reactions and therefore it shows behaviour completely different to that for H injection. The small thermonuclear contribution has $Q_{therm}(0)/\langle Q_{therm} \rangle \approx 10$ as for H injection. The peaking factors of the deposition profile and density are of the same order, namely $D(0)/\langle D \rangle \approx n(0)/\langle n \rangle \approx 2...3$. The fusion reactivity $[\sigma v]_{inj}$ is a linear function of T_D for the parameter region considered and we thus have $Q_{D-inj}(0)/\langle Q_{D-inj} \rangle \approx 5$ for D injection.

References

[1] F. Wagner, et al., Report IPP III/86, March 1983
[2] K. Hübner, et al., 15th Europ. Conf. on Controlled Fusion and Plasma Physics, Dubrovnik 1988, part 3, pp 1191-1194