

# PLASMA ROTATION EFFECTS ON NEUTRON PRODUCTION AND MEASUREMENT ON ASDEX

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Three principal effects of plasma rotation on neutron production and measurement on ASDEX are discussed in this paper: firstly, the change of the neutron rate during D injection into D plasmas; secondly, the shift of the neutron energy spectra; and, thirdly, changes in the neutron absorption in quartz associated with the energy shift.

## D Injection Into deuterium plasma

The dependence of the neutron rate  $Q$  during D injection on the plasma rotation velocity is investigated by means of our neutron rate interpretation and prediction code (NR code) [1]. For the ASDEX plasma parameters during D injection the neutron rate is dominated by beam-target reactions of the injected ions with the thermal plasma [1]. It is given by

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

Here  $D(r)$  is the profile of the deposition rate of the injected ions and  $(D \tau_W / W)$  their velocity distribution function resulting from the classical energy relaxation;  $n_D$  is the target deuteron density,  $n_e$  the electron density and  $\tau_W$  the energy relaxation time; the energy relaxation parameter  $n_e \tau_W$  is a function of  $W$  and  $T_e$  and is independent of the density;  $[\sigma v]_{inj} = f(W, T_D)$  is the fusion reactivity for a deuteron with energy  $W$  in a target plasma with ion temperature  $T_D$ . Plasma rotation causes a reduction of the relative energy  $W$  and therefore a reduction of  $[\sigma v]_{inj}$  and  $n_e \tau_W$ , but for the parameters of the ASDEX plasma an increase in  $n_e \tau_W / W$ . The effects of the plasma rotation on the fusion reactivity and fast ion distribution function thus partially compensate each other.

Fig. 1 shows the dependence of  $[\sigma v]_{inj}$  on the rotation velocity for the injection energy  $W_{inj} = 45$  keV used on ASDEX

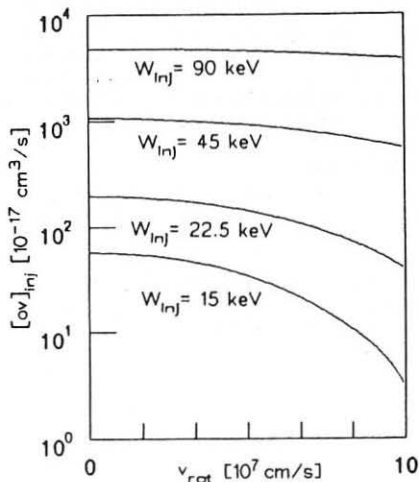


Fig. 1: Fusion reactivity as a function of the rotation velocity.

and for one-half and one-third of this energy, because the neutral beam always contains ions with these three energies. Furthermore, as an example of higher injection energies the curve for  $W_{inj} = 90$  keV is given. Since  $\langle \sigma v \rangle_{inj} = f(W)$  rises faster for low  $W$  than for higher values, and the influence of the rotation on the reactivity is more pronounced at low injection energies.

As an example we consider ASDEX discharge #24896 at 1.25 s with an injection power  $P_{inj} = 2.8$  MW,  $T_e = 1.7$  keV, and  $T_D = 2.0$  keV. For the same plasma parameters but with H injection the rotation velocity determined by CXRS measurements was  $v_{rot} = 2.2 \times 10^7$  cm/s. As  $v_{rot}$  is proportional to the square root of the mass of the injected ions [2], we expect  $v_{rot} = 3.1 \times 10^7$  cm/s for D injection. Table 1 gives the neutron rate for the three species of the beam calculated with and without allowance for this plasma rotation. As the neutron production is dominated by the ions with the largest injection energy, the overall effect is a reduction of less than 4% in the neutron rate. The measured neutron rate is  $3.3 \times 10^{13}$  neutr./s, but its error is essentially larger than the rotation effect.

Table 1: Neutron rates for ASDEX discharge #24896

injection energy	45.0	22.5	15.0	keV
neutron rate, without rotation	$2.78 \times 10^{13}$	$3.70 \times 10^{12}$	$4.24 \times 10^{11}$	neutr./s
neutron rate, with rotation	$2.68 \times 10^{13}$	$3.41 \times 10^{12}$	$3.61 \times 10^{11}$	neutr./s
decrease in neutron rate	3.6	7.8	14.9	%

The plasma rotation velocity increases with the injection power and is inversely proportional to the plasma density [2]. For illustration Fig. 2 shows the dependence of the neutron rate for the 45 keV species as a function on  $v_{rot}(0)$ . As the relative energy  $W$  decreases quadratically with  $v_{rot}$ , the effect of rotation on the neutron rate appreciably increases with  $v_{rot}$ . According to these results we would expect for high injection powers and low plasma densities an observable effect of plasma rotation on the neutron rate.

Obviously, the neutron rate will depend on the rotation velocity profile. But assuming

$$v_{rot}(r) = v_{rot}(0) \{1 - (r/a)^{\alpha}\}^{\beta}$$

( $a$  = normalization radius), we find for variations of  $\alpha$  and  $\beta$  between 0.1 and 2 only an effect of at most 2.5% on the neutron rate.

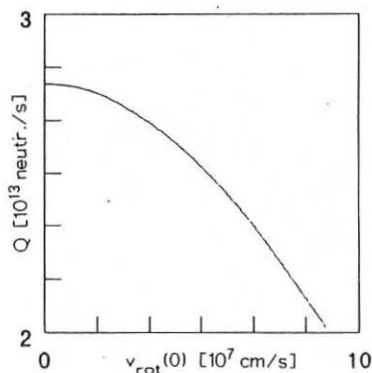


Fig. 2: Neutron rate as a function of rotation velocity.

### Shift of the neutron energy spectra (H injection)

The shift of the neutron energy spectra is well known. It could be observed by means of tangentially orientated measurements of the spectra. In the past [3] we simultaneously measured spectra with nuclear emulsions while observing the plasma in the forward and backward directions with respect to the direction of injection (Fig. 3). For tangential measurements the resulting energy shift is determined by integration along the lines of sight over different rotation velocities as well as over different angles of neutron emission with respect to the direction of rotation.

As it is very complicated to calculate the resulting spectral fluence at the position of the detector by analytical methods, we are using a reduced output of the VINIA-3DAMC software in which we consider only the emission and absorption, but not the scattering of neutrons in the ASDEX facility. The plasma data necessary for the input are taken from measurements on typical plasma discharges with H injection in deuterium plasmas with a plasma current of 380 kA. The neutron emission profile is calculated from these data with the NR code. For the rotation velocity profile we are using  $a = 42$  cm,  $\alpha = 2.0$ ,  $\beta = 0.9$  [4].

The resulting line shift is obviously expected to be determined mainly by  $v_{rot}(0)$ ,  $T_D(0)$  and the profile parameters of  $Q$ ,  $v_{rot}$ , and  $T_D$  will be of minor importance. This is confirmed by the numerical results. Fig. 4 gives the calculated relative energy shift  $\Delta E$  (circles) between the two tangential spectra as a function of  $v_{rot}(0)$ . Variation of  $T_D(0)$  between 1 and 5 keV only resulted in changes of the line shift smaller than the energy resolution of the calculations, presently taken as 10 keV. The influences of the velocity profile are still under investigation. For comparison in Fig. 4 the values of the total line shift are shown which would result from exact tangential observation of the central rotation velocity alone (dotted line).

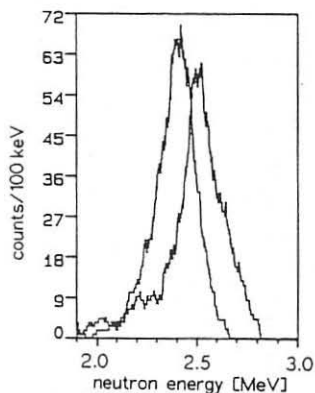


Fig. 3: Measured neutron energy spectra.

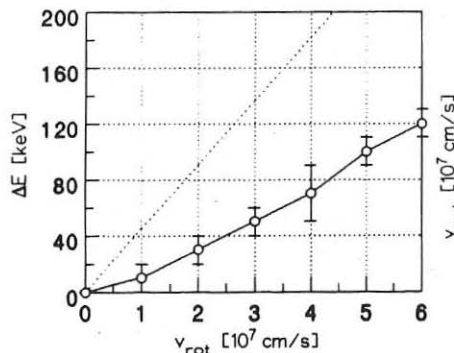


Fig. 4: Line shift as a function of the central rotation velocity.

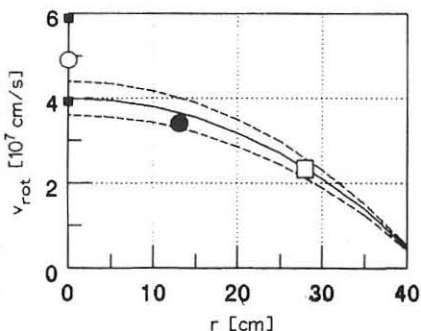


Fig. 5: Measured rotation velocities ( $P_{inj} = 3.6$  MW).

From Fig. 3 the measured line shift is found to be  $\Delta E = 95 \pm 10$  keV. The injection power for these measurements was 3.6 MW. This value yields in Fig. 4 a central rotation velocity of  $v_{\text{rot}}(0) = 4.9 \times 10^7$  cm/s  $\pm 20\%$ . This is essentially higher than the value deduced earlier [3], because we have now taken into account the integration over the different angles of neutron emission. In Fig. 5 we compare our results from the neutron energy spectra with CXRS measurements and mode frequency determination; they agree very well.

### Absorption effects in quartz

We measured the neutron spectra through a quartz window. Owing to the strong increase of the neutron cross-section of oxygen at 2.45 MeV (Fig. 6) the absorption for the two spectra in the quartz is different and thus the ratio of the observed neutron fluences in the two directions mentioned becomes a function of the rotation velocity. This ratio was also calculated with the VINIA software. The results are given in Fig. 7 together with the value determined from the neutron spectra in Fig. 3. The agreement is good, thus this effect may offer a new possibility for measuring the rotation velocity.

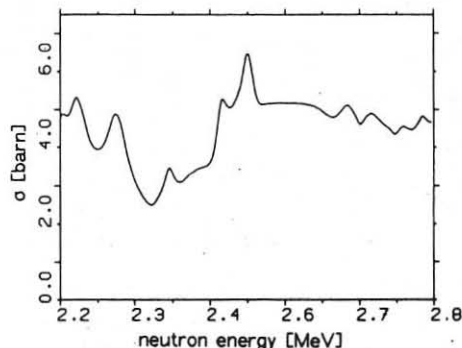


Fig. 6: Cross-section for neutron scattering in quartz.

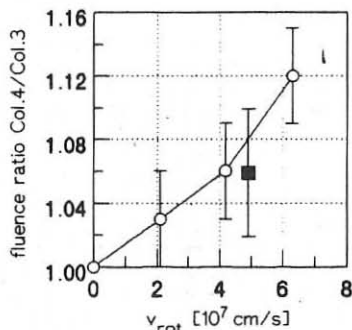


Fig. 7: Ratio of tangentially observed neutron fluence versus central rotation velocity.

### References

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- [2] W. M. Stacey, et al., Nuclear Fusion, **26**, 293-302 (1986)
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