NUCLEAR EMULSION NEUTRON DIAGNOSTICS AT ASDEX

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We are using nuclear emulsions at ASDEX to investigate neutron energy spectra and emission profiles and to determine the absolute neutron yield of a discharge. The emulsions are exposed in collimators which define the observed plasma region and shield them against neutrons emitted and scattered in the rest of the experiment. Two collimators view radially and two others tangentially to the plasma axis, one in the direction of injection (co-collimator), the other in the counter-direction (counter-collimator). An unshielded emulsion was used for the emission profile measurement. One of the radial collimators observes the plasma through the wall of the vessel; all others are positioned in front of the quartz window at the large port.

Neutron diagnostics with nuclear emulsions

In emulsions neutrons are detected by their recoil protons. Measurement of the track length (proton energy) and scattering angle delivers the neutron energy. The energy

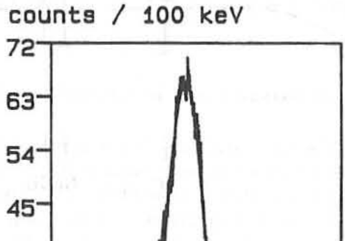

Fig.1: Neutron energy spectrum measured with co-collimator

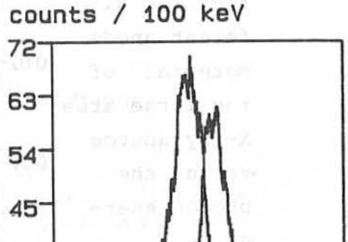

Fig.2: Neutron energy spectra measured with both collimators

resolution is determined by range straggling of the proton tracks and the statistical errors in the measurement of the length and angle. The tracks are bent and therefore good resolution requires measurement of the tangent at the beginning of the track and restriction to small scattering angles. For large track numbers this can be avoided because the neutron energy spectrum could also be obtained by differentiating the proton energy spectrum. Furthermore for flux measurements energy resolution is not essential and it is sufficient to determine the scattering angle from the start and end point of the track. Examples of spectra measured in this way are used and discussed in [4].

Neutron spectra during H-injection

We studied neutron emission from many ASDEX H-type discharges with plasma currents of 380 kA and injection powers of 3.6 MW. Fig. 1 gives the neutron energy spectrum measured with the tangential co-collimator. It is integrated over five disruption-free discharges (no. 16744-16748). The FWHM of the line determined from a fit to a Gaussian is 180 ± 10 keV. Defolding the broadening caused by counting the neutrons in 100 keV intervals reduces the FWHM to 165 ± 11 keV.

Our energy resolution was determined from measurements at the Gothenburg accelerator. It depends on the maximum scattering angle of the tracks used. Here we have choosen $\Theta_{max} = 10^{o}$, which gives an energy resolution of 86 ± 8 keV.

We thus get a temperature broadening of 141 keV ± 10%, corresponding to an ion temperature of 2.9 keV ± 20%. The electron temperature determined from ECE measurements is 2.4 keV.

The hump at the low-energy wing of the line in Fig. 1 may be caused both by scattered neutrons and by strongly bent tracks [1]. The line is not centred at 2.45 MeV but shifted to lower energies. We interpret this as a shift caused by plasma rotation. Fig. 2 shows the same spectrum together with that measured simultaneously with the tangential counter-collimator. The later one is shifted to higher energies. The energy difference of the two line centres is 47.5 ± 5 keV, and this gives a rotation velocity of $2.1 \cdot 10^{7}$cm/s ± 10%. Within the error limits, the same ion temperature as above is determined from the second spectrum, namely 2.5 keV ± 20%.

Fig.3 shows a neutron spectrum measured radially during a series of 11 discharges (no. 18949-18959) with the same plasma data as in the previous series. The spectrum was determined by differentiating the proton energy spectrum from an emulsion exposed unshielded for emission profile measurement. This spectrum is well centred at 2.45 MeV. The high-energy wing gives 3.2 keV ± 20% for the ion temperature. The line broadening is asymmetric, being stronger in the low-energy part. This may be caused by two effects. First, the bent shape of the tracks causes a systematic reduction of

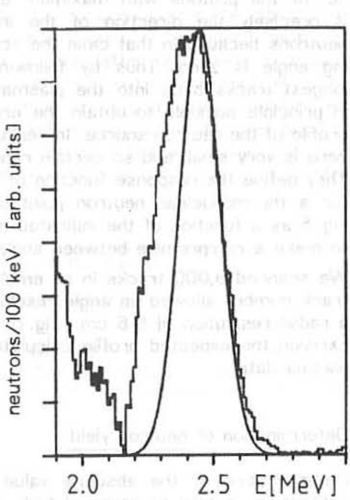

Fig. 3: Neutron energy spectrum from uncollimated exposure near quartz window

the measured track length. This effect is much stronger here than in the spectra in Fig. 1 and Fig. 2 because here we are also using tracks with large scattering angles. Second, due to our work on neutron scattering in the ASDEX device [1] we have to expect in the low-energy wing a strong contribution of neutrons scattered in the quartz window.

n_D/n_H ratio from neutron rate

Having measured the ion temperature, we can determine the mean ion density and thus, in the case of H-injection, the mean value of the ratio n_D/n_H from the measurements of the neutron rate. Using our interpretation code for the neutron rate [2], we calculated for 4 discharges of the series considered the n_D/n_H ratios which are given in Fig. 4 as a function of time. The shaded region indicates the injection pulse. The bars give the errors due to our temperature determination.

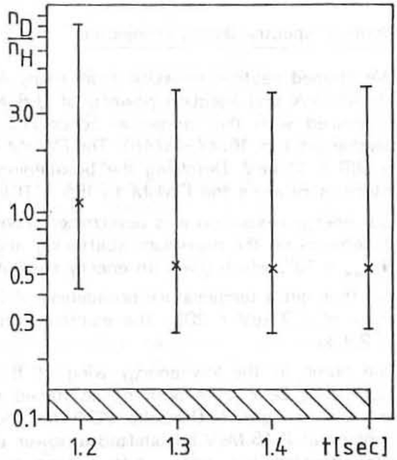

Fig. 4: n_D/n_H ratio from neutron rate

Neutron emission profile

The direction of the longest proton tracks, i.e. of the protons with maximum energy, is precisely the direction of the incident neutrons because in that case the scattering angle is zero. Thus by following the longest tracks back into the plasma, it is in principle possible to obtain the emission profile of the neutron source. In reality the number of protons scattered at angles around zero is very small and so certain ranges of energy and scattering angle have to be used. They define the response function of the measurement. The calculated response function for a thermonuclear neutron point source with a temperature of 2.5 keV is given in Fig. 5 as a function of the indicated energy range for the protons used. Clearly one has to make a compromise between angle resolution and number of tracks in the profile.

We scanned 8,000 tracks in an emulsion exposed unshielded at the quartz window. This track number allowed an angle resolution of 5^o for the emission profile, corresponding to a radial resolution of 9.6 cm. Fig. 6 shows the measured emission profile and for comparision the expected profile calculated with the appropriate response function from the plasma data.

Determination of neutron yield

Determination of the absolute value of the neutron yield is of great importance for calibrating neutron counters at high yields. To measure the yield with nuclear emulsions, we use the two radial collimators, observing the total plasma cross-section. The proton track density delivers the neutron flux at the position of the emulsion during its exposure.

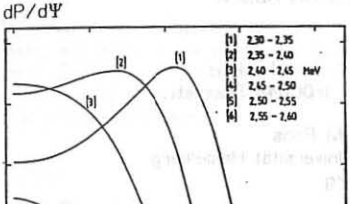

Fig. 5: Calculated response function for profile measurement

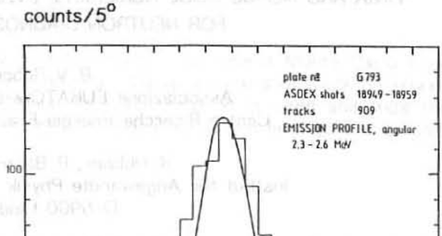

Fig. 6: Measured and calculated emission profile

To recalculate the neutron yield from this value, one has to account for the absorption of neutrons between plasma and emulsion and for the background of scattered neutrons. The former may be done by analytical estimation but for the latter one needs a detailed calculation of the neutron scattering in the experiment. From our calculations with the VINIA-3DAMC software we determine the neutron flux arriving at the emulsion per emitted neutron in the ASDEX plasma [1]. From the VINIA calculation and the neutron flux measured with the emulsion we get the following results. They agree well with the values measured with a U-counter calibrated by a neutron source and successive plasma discharges.

ASDEX discharge	no. 16910, coll. 1	no. 19111, coll. 2	
VINIA calculation	$0.250 \cdot 10^{-7} \pm 3.7\%$	$0.891 \cdot 10^{-7} \pm 8\%$	cm^{-2}
measured flux	$3.41 \cdot 10^{5} \pm 13\%$	$2.55 \cdot 10^{6} \pm 13\%$	neutrons/cm^2
resulting yield	$1.36 \cdot 10^{13} \pm 14\%$	$2.86 \cdot 10^{13} \pm 17\%$	neutrons
measured yield	$1.3 \cdot 10^{13} \pm 15\%$	$3.2 \cdot 10^{13} \pm 15\%$	neutrons

References

[1] B. V. Robouch, et al, this conference

[2] K. Hübner, et al, 12th Europ. Conf. on Controlled Fusion and Plasma Physics, Budapest 1985, part 1, p. 231-23