NUMERICAL AND EXPERIMENTAL INVESTIGATION OF NEUTRON SCATTERING ON ASDEX

K. Hübner, R. Bätzner, H. Hinsch, L. Ingrosso, R. Klein, M. Roos, B. Wolle
Institut für Angewandte Physik II, Universität Heidelberg, D-6900 Heidelberg
B. V. Robouch
Associazione EURATOM-ENEA sulla Fusione,
Centro Ricerche Energie Frascati, I-00044 Frascati
B. Bomba, H. Rapp, W. Herrmann, H. Murmann, A. Eberhagen, H.-U. Fahrbach,
O. Gehre, R. Preis, H. Röhr, K.-H. Steuer, O. Vollmer
Max-Planck-Institut für Plasmaphysik, EURATOM Association, D-8046 Garching

In the past we used the VINIA-3DAMC and NEPMC software [1] to treat the birth, migration and detection of neutrons for the ASDEX facility and compared the results with nuclear emulsion measurements. The agreement between numerical and experimental results was very good, in particular for neutron energies above 2 MeV, despite the fact that we have used a rather simplified ASDEX structure and some approximations in the description of the plasma neutron source.

The VINIA-3DAMC software was improved in order to treat more complex geometric structures, so that a more realistic ASDEX model is now being used. The plasma neutron source was improved, too. Furthermore, the NEPMC software was extended in order to allow arbitrary positions for the nuclear emulsion. Collimators viewing tangentially or in arbitrary directions to the plasma can thus also be interpreted now.

ASDEX model

In our new ASDEX model we distinguish six different groups of the structural components according to their significance for the scattering of neutrons. The model is described in detail in a forthcomming IPP report [2].

Group 1 consists of the core (central screw and wooden core), the 16 toroidal field coils, the ohmic coils OH1 to OH8, and the vertical field coils V1 to V4 together with the central multipole correction coils MC1. The remaining coils and the support structure are neglected, mainly because they contribute only small masses in relation to the vessel and the multipole coils. Furthermore, for most of the measurements they are located outside the aperture fields. The vessel (vacuum chamber and its thermal insulation) forms group 2 and the divertor group 3. Group 4 consists of the torus hall, its foundations, walls, roof, and the air. As yet the roof has not been installed at ASDEX, and so for the calculations presented here we filled the roof volume with air.

Group 5 gives the necessary details of the ports. Here we take into account only the port for the YAG light scattering system, near which most of our neutron diagnostics is at present located. Finally, group 6 contains all the details of the nuclear emulsion equipment, i.e. their supports and collimators.

Plasma neutron source

In the VINIA software, the neutron birth points are determined stochastically by reproducing the measured plasma data. To do so, the NR software [3] is used to calculate the neutron emission profile from the measured density and temperature profiles, the Shafranov shift, and the neutron rate. Only discharges with H^0-injection into deuterium plasmas are considered here. It is thus assumed that the ion and electron temperatures have the same radial profiles and time dependences. The ion temperature and the rotation velocity were determined by nuclear emulsion measurements [4]. Owing to the integration over different neutron emission angles the emulsion measurement delivers a mean value for the rotation velocity and there is no simple way to determine the velocity on axis. Therefore we used this mean value in the VINIA calculations as input for the central velocity. The rotation velocity profile is assumed to be parabolic.

The angle of emission and the energy of the neutrons are determined with the rotation velocity at the place of birth being taken into account. For H^0-injection we have purely thermonuclear production [4] and in the frame of the rotating plasma the neutron energy distribution is a Gaussian with a half-width determined by the local ion temperature.

The calculations presented here were done for two different shot series, no. 16744-16748 for collimators 3 and 4 (tangential, and antiparallel and parallel to the direction of injection, respectively) and no. 18949-18959 for position 5 (uncollimated, radially directed nuclear emulsion). The corresponding results of the nuclear emulsion measurements are discussed in [4].

The nuclear emulsions were exposed for the whole duration of the discharges. They thus integrate over the time history of the neutron production. In the VINIA calculation this could be simulated by using appropriate time intervals during which the plasma parameters and therefore the neutron production properties do not change considerably and by creating a number of neutrons, for each interval, proportional to the different total neutron yields. An example of this procedure is given in Figure 1 for the shot series no. 16744-16748. Figure 1 shows the time evolution of the neutron rate (mean value for the five discharges). We considered four time intervals, indicated by the vertical lines, using the plasma parameters corresponding to the times indicated by the dots.

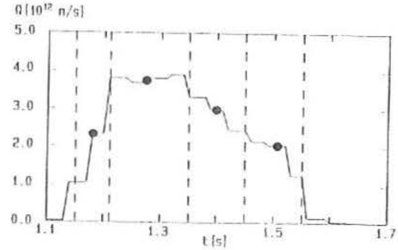

Fig.1: Time dependence of neutron rate and intervals for VINIA calculations

Results of VINIA calculations

We present here the results of VINIA test runs for the two collimators 3 and 4 (2830 neutrons each) and the unshielded position 5 (4000 neutrons). So far we looked for qualitative tendencies only and limited our calculations to small numbers of neutrons.

Figure 2 shows the VINIA calculation of the spectral neutron fluences arriving at the emulsions from the full solid angle. The essentially higher contribution of collided fluence at the unshielded emulsion is obvious. The relative shift of the main line from the emitted neutrons in collimators 3 and 4 is caused by the plasma rotation.

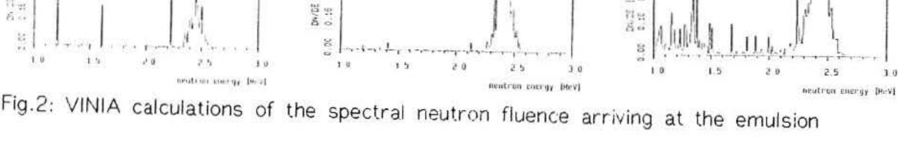

Fig.2: VINIA calculations of the spectral neutron fluence arriving at the emulsion

Table 1 compares the emitted and collided contributions normalized to the number of emitted neutrons for the full energy interval considered (1 to 3 MeV) at each of the three positions. For positions 3 and 4 the values without collimator in place are also given.

Table 1 Neutron fluences per emitted neutron in 10^{-7} cm^{-2}

	Coll. 3	Coll. 4	Pos. 3	Pos. 4	Pos. 5
emitted	0.56± 6%	0.68± 6%	2.28± 5%	2.30± 5%	3.78± 3%
collided	0.49±52%	0.10±22%	4.22±21%	2.83±12%	6.82±11%
ratio c/e	0.88	0.15	1.85	1.23	1.80

Position 5 is near the quartz window and positions 3 and 4 are near the toriodal field coils, and the reduction of the fluences at the unshielded positions 3 and 4 compared with position 5 is mainly an effect of shielding by the field coils. The big scatter of the results for the collided fluence inside the collimators is caused by collisions in the collimator material. Because these collisions are rare, their treatment needs an essentially higher number of neutron histories. This is also evident also from Table 2, where we give the contributions of the different groups of constituents of the ASDEX facility to the collided fluence.

Table 2 Collided neutron fluences per emitted neutron in 10^{-7} cm^{-2}

Group	Regions	Coll. 3		Coll. 4		Pos. 5	
		1 to 2	2 to 3	1 to 2	2 to 3	1 to 2	2 to 3 [MeV]
1	core, coils	0.0030	0.0053	0.0054	0.0113	1.33	0.44
2	vessel	0.0075	0.0111	0.0087	0.0162	0.55	0.53
3	divertor	0.0021	0.0013	0.0004	0.0006	0.16	0.21
4	hall	0.0048	0.0018	0.0061	0.0037	0.032	0.022
5	quartz window	0.0014	0.0121	0.0007	0.0145	0.39	1.26
5	rest of port 1	0.0009	0.0107	0.0041	0.0403	0.73	1.08
6	coll. 3, 4	0.0108	0.0307	0.2079	0.1790	0.067	0.001
	total	0.0305	0.0730	0.2333	0.2656	3.26	3.56

Results of NEPMC calculations and measurements

The NEPMC software is used to simulate the response of the nuclear emulsion [1], taking the VINIA results as input. Figure 3 gives the NEPMC results for collimators 3 and 4 compared with the experimental results. In the calculated spectra the line shift caused by plasma rotation is smaller than in the measured spectra by a factor of about 1.9. Hence the true central rotation velocity was about 4×10^7 cm/sec. A more accurate determination would be possible by detailed VINIA calculations.

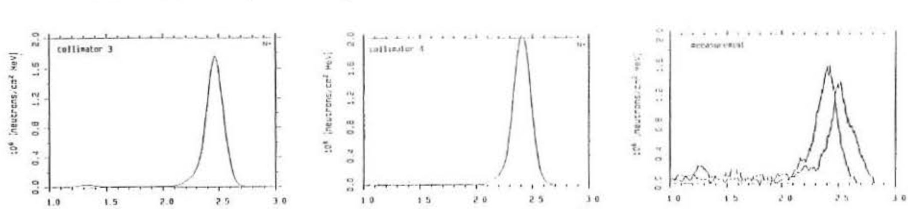

Fig.3: NEPMC results for collimators 3 and 4 and experimental results

The collided fluence is reduced by the NEPMC response calculations. This needs further investigation; it may be caused by the directional response of emulsions.

Table 3 compares the normalized calculated and measured neutron fluences for the two energy intervals 1 to 2 and 2 to 3 MeV separately. Good agreement is obtained for the high-energy range, but for the low-energy range the statistical error in the calculation is too large for a comparision.

Table 3: Calculated and measured normalized neutron fluences [10^{-7} cm^3] for collimators 3 and 4

	VINIA calculation		Emulsion measurement	
	1 to 2	2 to 3	1 to 2	2 to 3 [MeV]
Coll. 3	0.24	0.81	0.22	0.68
Coll. 4	0.03	0.74	0.23	0.72
mean value	0.14	0.77	0.23	0.70

Figure 4 gives the results of NEPMC calculations for the proton and neutron energy spectra compared with the experimental results. For an uncollimated nuclear emulsion measurement, the neutron energy spectrum is determined by differentiating the proton energy spectrum. The agreement between numerical and experimental spectra is good; unfortunately owing to limitations during scanning of this plate the measured proton enrgy spectrum is meaningless for energies below 2.2 MeV and therefore a determination of the absolute values is not possible.

The low-energy wing of the measured neutron energy spectrum is broader than the numerical spectrum. This is probably caused by an underestimation of the measuring errors for the track length in the NEPMC software.

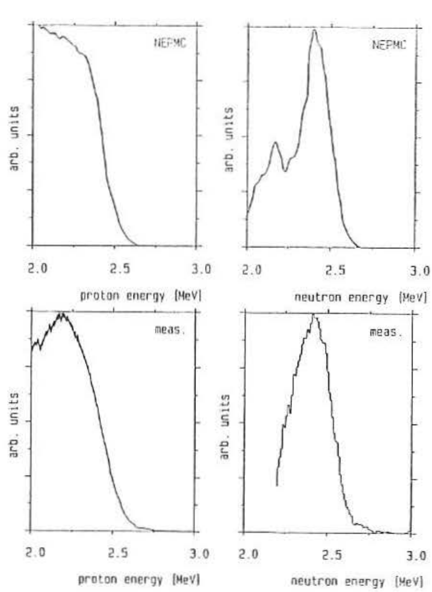

Fig.4: NEPMC results for position 5 compared with experimental results

References

[1] K. Hübner, e.a., 14th Europ. Conf. on Controlled Fusion and Plasma Physics, Madrid 1987, part 3, pp 1298-1301, and Report IPP III/122, August 1987

[2] B. V. Robouch, e.a., Report IPP III/132, in preparation

[3] K. Hübner, e.a., this conference

[4] K. Hübner, e.a., 14th Europ. Conf. on Controlled Fusion and Plasma Physics, Madrid 1987, part 3, pp 1294-1297