ABSOLUTE NEUTRON YIELD DETERMINATION FOR ASDEX USING In ACTIVATION AND MONTE CARLO CALCULATIONS

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The absolute neutron rate of a fusion plasma is usually measured with counter arrays calibrated in situ at low neutron rates with an appropriate neutron source inside the vessel. In actual fact, however, these counters are used up to the much higher rates produced by plasma discharges. It is thus of great importance that the calibration be independently checked at high neutron yields. This can be done by a yield determination using activation methods or nuclear emulsions. Results from activation measurements are available a few hours after the discharge, but they have a poor energy resolution. The advantage of emulsions is their good energy resolution, but it usually takes weeks till the results are available. - Our intention is to combine both methods on ASDEX.

Application of both methods, activation and emulsions, to tokamaks requires solution of three problems. Firstly, one has to measure either the absolute value of the number of activated nucleids N_{In} in the In sample or of the number of tracks N_p in the emulsion. Secondly, one has to determine the response of the detector, i.e. the relation between N_{In} or N_p and the neutron fluence Φ at the position of the detector. Thirdly, one has to know the relation between this neutron fluence Φ and the neutron yield Y of the discharge. The last two problems could be solved together by calibration with a strong neutron source in situ or by a numerical simulation. Such in situ calibration is not possible on ASDEX, and so we have to use Monte Carlo simulations.

Activation measurements

For the activation measurements the reaction $^{115}In(n,n')^{115}In^m$ and the subsequent γ emission of $^{115}In^m$ at 335 keV is used. The number of γ-ray emissions per disintegration is r_γ = 0.459 and the decay time $1/\lambda$ = 23319.72 s [1].

Our In samples are disk-shaped with a diameter of 5 cm and thickness of 0.3 cm. They were placed inside a Cd box with a wall thickness of 0.1 cm located in front of a large quartz window and exposed over series of n discharges. In order to account for the decay of $^{115}In^m$ during the shots of one series, a reduced yield of the series is calculated as

$$Y_{red} = \Sigma_i\, Y_i \exp\{-\lambda(t_n - t_i)\}, \quad i = 1,\ldots,n,$$

where t_i are the instants of the different shots and Y_i their neutron yields as determined by the counter array. This procedure is justified because we find a linear relation between the results of the counters and the yield.

The γ emission was measured with a Ge counter over a time interval Δt = 1000 s starting at t_c. The counter efficiency, i.e. the number of counts per γ decay, was determined by means of an absolutely calibrated source of the same size as the In samples but with a much smaller thickness of only 0.03 cm. The efficiency therefore had to be corrected for geometric effects due to the thickness of the samples and the γ absorption in the In. The final result at 335 keV is

$\varepsilon = Z / N_\gamma$ = 0.048 counts/decay ± 10%.

The activity of the sample at t_n in the γ-line considered is calculated from the measured number N_γ of γ decays by

$A_0 = N_\gamma \lambda \exp\{\lambda(t_c - t_n)\} / \{1 - \exp(-\lambda \Delta t)\}$.

Fig. 1 gives the reduced neutron yield per discharge Y_{red}/n determined with the different counters as a function of the activity per discharge and per gramme of the sample $A_0/n\,M$ in Bq/g. M is the mass of the sample. We get the linear relation $Y_{red} = 2.2\times10^{13}\ A_o/M$.

With the errors of all calibrations involved being taken into account, our final experimental result for the relation between the In activity and the total neutron yield is

$A_0/M\,Y = 4.6\times10^{-14}$ Bq/g Y ± 15%.

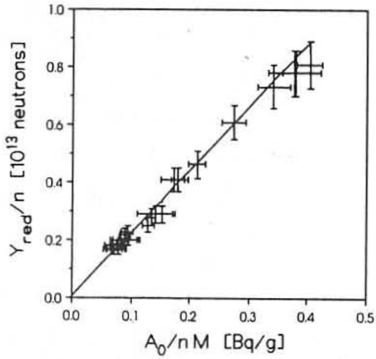
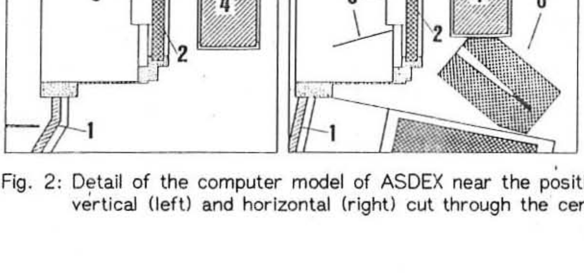


Fig. 1: Reduced neutron yield per discharge versus activity per discharge and per gramme of the sample.

Monte Carlo calculations

The relation of the neutron fluence Φ at the position of the In sample and the total neutron yield Y of the discharge is to be determined in three steps. Firstly, one has to calculate the fluence factor $f_{obs} = \Phi_0/Y$ from the observed part of the plasma volume and its corresponding neutron fluence $\Phi_0 = \int\{Y(\mathbf{r})/4\pi s(\mathbf{r})^2\}d\mathbf{r}$ at the detector position. Here $Y(\mathbf{r})$ is the local source strength and $s(\mathbf{r})$ is the distance between the point of emission and the detector.



1: vessel,
2: quartz window,
3: flange,
4: lens (BK7, Al casing, (light scattering system)
5: shields and shutters for protection of quartz
6: nuclear emulsion collimators (PE)
7: In sample with Cd box

Fig. 2: Detail of the computer model of ASDEX near the position of the In sample, vertical (left) and horizontal (right) cut through the centre of the quartz window.

Secondly, one has to take into account the fluence attenuation factor F_{abs} for the neutron absorption between the plasma and detector. Thirdly, one has to determine the fluence enhancement factor F_{col} caused by the background of scattered neutrons. So we have $\Phi = \Phi_0 F_{abs} F_{col}$ and the absolute neutron yield is given by $Y = \Phi / f_{obs} F_{abs} F_{col}$.

For ASDEX all three factors are simultaneously determined by neutron migration calculations using the VINIA software [2]. The results of these calculations are used as input for the 3DMCSC-RWR software which simulates the response of the In sample to the incoming neutron fluence and gives the activation of the sample as output.

As ASDEX provides no observation port for the neutron diagnostics, the In sample was exposed in front of the large quartz window for the Thomson light scattering system, as shown schematically in Fig. 2. It is this the same position which we are using for emulsion measurements and allows thus for a comparison of activation and emulsion measurements. At this position we find from the Monte Carlo calculation for the neutron fluence

$f_{obs} = 1.75 \times 10^{-6}$ neutr./cm^2 Y ± 2%, $F_{abs} = 0.28 \pm 2.5\%$,
$F_{col} = 4.5 \pm 24\%$, $\Phi/Y = 2.2 \times 10^{-6}$ neutr./cm^2 Y ± 19%.

Since the fluence enhancement factor for this position is so large, the most sensitive point in the calculation of the activation is the contribution of the scattered fluence. However, the strong decrease of the In activation cross-section below 2 MeV (Fig. 3) somewhat reduces the relative contribution of the scattered fluence to the activation.

The detecting points inside the In sample, i.e. the points where the activation reaction takes place, were already randomly selected in the Monte Carlo simulation of the neutron migration through the ASDEX device. The neutron absorption inside the In sample is taken into account in calculating the number of activated nuclei N_a. From this number an effective activation cross-section $\langle\sigma\rangle$ could be deduced by means of the relation $N_a = N_{In} \Phi \langle\sigma\rangle$, where N_{In} is the total number of ^{115}In nuclei in the sample. Furthermore, the activity A of the sample is calculated by $A = r_\gamma \lambda N_a$. - The numerical results for fluence, activation and $\langle\sigma\rangle$ are given in Table 1.

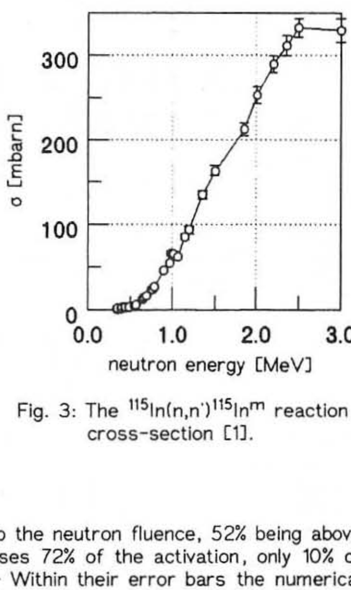


Fig. 3: The ^{115}In(n,n')^{115}In^m reaction cross-section [1].

Discussion of results

The scattered neutron background contributes 78% to the neutron fluence, 52% being above 2.1 MeV and 26% below. The scattered fluence causes 72% of the activation, only 10% of which comes from the background below 2.1 MeV. - Within their error bars the numerical and experimental results for the activity per emitted neutron agree very well. In the past we measured the neutron energy spectrum at the position of the In samples by means of nuclear emulsion [3]. This will allow us to check the Monte-Carlo calculations in detail. Furthermore, the determination of Φ from the emulsion measurements suffers much less from the scattered background. Here we will use only the energy region above 2.3 MeV where we have $F_{col} = 1.57 \pm 4\%$ and $\Phi/Y = 7.7 \times 10^{-7}$ neutr./cm^2 Y ± 3.5%. The combination of In activation, nuclear emulsion and Monte Carlo simulation is expected to offer a possibility of checking the counter calibration in situ at high neutron rates.

The effective activation cross-section essentially depends on the scattered neutron spectrum as is obviously seen from the results in Table 1. Our overall result of $\langle\sigma\rangle$ = 252 mbarn agrees well with the value given by Gentilini et l. [4]; they found $\langle\sigma\rangle$ = 266 mbarn for a plasma focus device using the neutron energy spectrum measured with nuclear emulsions. In their work on PLT Zankl et al. [5] used $\langle\sigma\rangle$ = 343 mbarn, i.e. the value for 2.5 MeV, but they expected a correction of 15 to 40% due to scattered fluence.

The main problem in Monte Carlo simulations are the large contributions to the scattered background coming from parts of the device which are very close to the detector; they introduce large error bars in the result. Therefore a new technique is now being used to improve the statistical fluctuations. In our case the most critical contributors are the quartz window and its flange (see Table 2). It is obvious that the contribution of the scattered fluence to the activation could not be reduced by means of shields or collimators, because the main sources are in front of the In sample and a shield would essentially contribute to the scattered background. An improvement is expected to be obtained by exposing the In inside the vessel at a distance of about 10 cm from the plasma edge. Preliminary results for this position are also given in Table 1. There the contribution of the scattered fluence to the activity now coming mainly from the vessel will be less than 30%, while the total activity is enhanced by a factor 6, thus essentially improving the statistics.

Table 1: Numerical results

	direct neutrons	scattered neutrons 0.3...2.1 MeV	scattered neutrons 2.1...3.0 MeV	total	
outside the vessel (position 7 in Fig. 2)					
Φ/Y	4.91 ± 1.5%	5.68 ± 25%	11.46 ± 61%	22.04 ± 48%	10^{-7} neutr./cm^{2}Y
A/MY	15.23 ± 4%	5.53 ± 25%	33.38 ± 61%	54.13 ± 48%	10^{-15} Bq/g Y
$\langle\sigma\rangle$	316	99	295	252	mbarn
inside the vessel (10 cm from plasma edge)					
Φ/Y	45.0 ± 8%	18.2 ± 46%	13.6 ± 17%	76.8 ± 13%	10^{-7} neutr./cm^2 Y
A/MY	142.8 ± 9%	14.1 ± 46%	40.7 ± 18%	197.6 ± 14%	10^{-15} Bq/g Y

Table 2: Contributors to the scattered neutron fluence and corresponding activity

	scattered fluence [10^{-7}neutr./cm^{2}Y] 0.3 ... 2.1 MeV	scattered fluence 2.1 ... 3.0 MeV	activity [10^{-15} Bq/g Y] 0.3 ... 2.1 MeV	activity 2.1 ... 3.0 MeV
quartz	1.24 ± 40%	7.20 ± 77%	0.96 ± 40%	21.56 ± 77%
port *	2.08 ± 43%	2.80 ± 48%	2.41 ± 43%	7.96 ± 48%
core, coils	1.23 ± 31%	0.63 ± 28%	0.98 ± 31%	1.62 ± 28%
vessel	0.43 ± 16%	0.49 ± 10%	0.58 ± 17%	1.41 ± 11%
divertor	0.27 ± 10%	0.26 ± 9%	0.27 ± 11%	0.77 ± 10%
collimators	0.26 ± 10%	0.0	0.16 ± 11%	0.0
rest**	0.11 ± 19%	0.02 ± 31%	0.18 ± 20%	0.06 ± 31%

* parts 3, 4, and 5 from Fig. 2, ** Tokamak hall, air, diagnostics

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