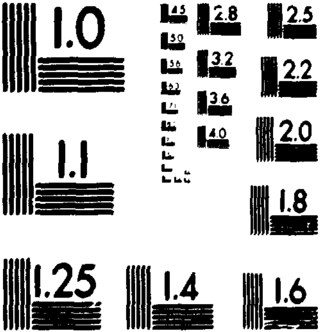

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CALCULATIONS OF TOTAL FUSION POWER AND SPATIAL DISTRIBUTION OF EMISSIVITY FOR A D-T THERMAL PLASMA (Part II)

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SYMMARY

The preliminary project of a diagnostic tool to measure the neutron emissivity profile for NET (Next European Torus) with an array of collimators is presented. With the help of a neutron transport code the maximum possible number of collimators, compatible with the crosstalk noise and the space available in the NET 2.2.B is determined within these constraints. An array of 17 collimators can be used, and some experimental results are simulated using a Monte Carlo code. These results are analyzed and an inversion procedure is used to obtain the emissivity profile and evaluate the total fusion power. The results show that the total fusion power can be measured within 10% for different emission profiles.

RIASSUNTO

In questo lavoro viene presentato il progetto preliminare di una diagnostica per la misura della emissività neutronica del plasma per il NET mediante un insieme di collimatori di neutroni. Con l'ausilio di un codice di trasporto neutronico viene studiato il massimo numero di collimatori compatibile con gli accessi disponibili ed il rumore di fondo risultante, per una macchina i cui parametri corrispondono a quelli del NET 2.2.B. Un insieme di 17 collimatori viene considerato fattibile e con l'ausilio di un codice Monte Carlo vengono simulati i risultati sperimentali. Con l'ausilio di una procedura di inversione i risultati vengono invertititi per ottenere il profilo d'emissività neutronica e la potenza totale di fusione. I risultati mostrano che con questo progetto è possibile ottenere una precisione della misura della potenza di fusione intorno al 10% per differenti condizioni di emissività neutronica.

INTRODUCTION

The present work represents a feasibility design of a monitor for the fusion power distribution in a thermal burning D-T plasma consistent with the NET 2.2.B configuration (see Table I). In a previous work [1] (hereafter referred to as Ref. 1), a simple monitor geometry consisting of five collimators was considered, and the neutron fluxes at the detectors were calculated by a Monte Carlo code, assuming three different spatial distributions of the emissivity. The fluxes were assumed as experimental data and the emissivity profiles and rates were calculated by an inversion procedure leading to the conclusion that choice of multicollimator apparatus was not suitable to reconstruct the spatial distributions with the required accuracy.

The development of the project is presented as follows:

- First (Chap. I), the largest possible number of collimators compatible with the access in the machine is determined by calculating, with a neutron transport code [2], the minimum distance between collimators allowing for sufficient shielding. This calculation leads to a new design of the multicollimator and to an evaluation of the cross talk scattering by considering two extreme physical conditions of the burning plasma (see Table II and Fig. 3) which seem to be the most critical. The first condition is characterized by flat profiles of density and temperature, and it is shown in Ref. 1 that in this case the notable indetermination in calculating the emissivity profile is due to the inversion procedure. This situation requires the largest possible number of collimators. The second condition is characterized by very peaked profiles of density and temperature, as suggested by the NET Team [3], and since in this case the largest crosstalk background is expected in the external channels, it requires the largest possible amount of shielding between channels, thus limiting the number of collimators.
- Then (Chap. II), a numerical experiment is carried out for the determination of the neutron fluxes at the detectors assuming the preceding physical situations. Finally the experimental data (sum of the signal and the crosstalk noise contributions) are inverted in order to obtain the emissivity profiles and evaluate the total fusion power.

TABLE I

Plasma minor radius (a)	136.8 cm
Plasma major radius (b)	518.3 cm
Plasma aspect ratio	3.79
Plasma elongation	2.09
Triangolarity	0.7
Average ion temperature	10 keV
D-T density (volume average)	1.0E+14 cm^{-3}

TABLE II

Flat Profile

$$T(r) = \hat{T}\,(1-(r/a)^2)^{\alpha_T}$$

$$N(r) = \hat{N}\,(1-(r/a)^2)^{\alpha_N}$$

$\hat{T} = 15$ keV	$\alpha_T = 1$	$\langle T\rangle = 10$ keV
$\hat{N} = 1.3\times10^{14}$ cm^{-3}	$\alpha_N = \frac{1}{2}$	$\langle N\rangle = 10^{14}$ cm^{-3}

Peaked Profile

$$T(r) = \hat{T}_1\,(1-(r/a)^2)^{\alpha_T} + \hat{T}_2(1-2r/a)$$

$$N(r) = \hat{N}_1\,(1-(r/a)^2)^{\alpha_T} + \hat{N}_2(1-2r/a) \qquad 0 \le r \le \frac{a}{2}$$

$$T(r) = \hat{T}_1\,(1-(r/a)^2)^{\alpha_T}$$

$$N(r) = \hat{N}_1\,(1-(r/a)^2)^{\alpha_N} \qquad \frac{a}{2} < r \le a$$

$\hat{T}_1 = 7.5$ keV	$\hat{T}_2 = 16.5$ keV	$\alpha_T = \frac{1}{2}$	$\langle T\rangle = 10$ keV
$\hat{N}_1 = 0.65\times10^{14}$ cm^{-3}	$N_2 = 3.35\times10^{14}$ cm^{-3}	$\alpha_N = \frac{1}{2}$	$\langle N\rangle = 10^{14}$ cm^{-3}

The sensitivity of the experimental method is discussed in relation to the different cases considered by comparing the inverted emissivity and calculated rates with the theoretical ones, the minimum requirement being that the calculated rates should differ by less than 10% from the theoretical ones.

I. MULTICOLLIMATOR DESIGN

The NET plasma is an extended neutron source. The possibility of detecting neutrons coming from a specific volume of plasma requires an accurate design of the multicollimator system. Neutrons in fact, have a finite probability of crossing bulk materials without losing much energy. Two possible sources of noise can affect the true signal of the detectors at the end of an array of collimators: the crosstalk between the channels, and the background coming from those neutrons scattered by the structure around the detectors and the shield of the multicollimator itself. In the present work only the crosstalk noise is considered and the amount of material necessary to reduce it below a specific value is calculated. Crosstalk limitation requires a minimum spacing between the channels for a given material of the shield and a given length and diameter of the channels. Some analytic calculations have been performed to get a first tentative choice of the thickness of the shield and the spacing between the channels. The requirement was that a neutron coming from a region not seen from the central channel should be attenuated at least a factor one thousand before giving a contribution to the central detector, neglecting scattering and energy degradation of the neutron. This preliminary calculation leads to a design which consists of a bulk shield of borated SS316 cooled with water (the same type of outboard shield proposed for NET [4]) located inside an RF port flush with the vacuum chamber. The shield fills the whole height of the port and is 60 cm thick and 60 cm wide. Seventeen channels of length 425 cm and internal diameter 11 cm, spaced 25 cm apart, pass through the shield (Fig. 1). The diameter and the length of the channels, and therefore the number of the collimators, have been chosen in such a way a spectrometer with an efficiency of about 10^{-5} [5] could be used at the end of each collimator.

Using a more sensitive detector these dimensions could be changed

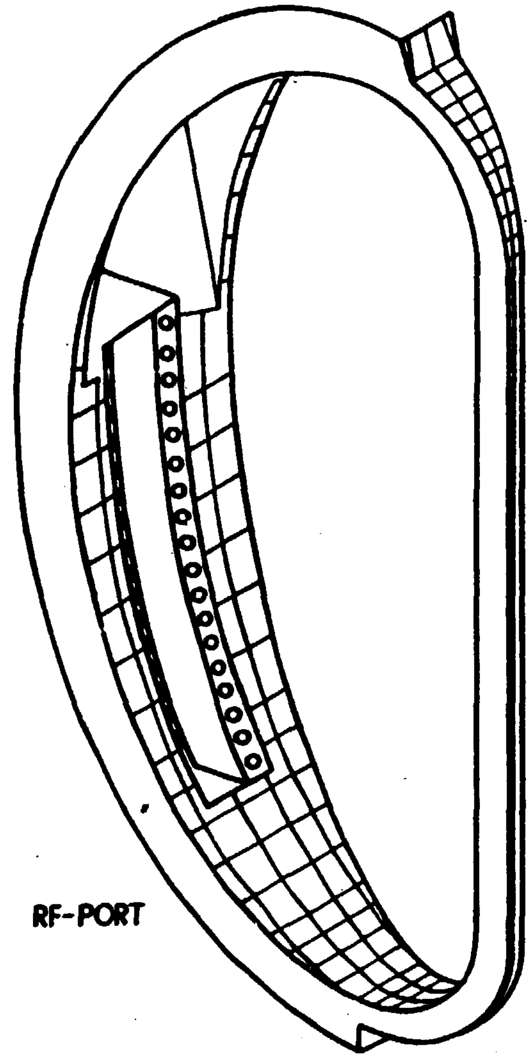


Fig. 1 Schematic view of a toroidal segment containing the front part of the multicollimator in a radio frequency port

and the spacing between the channels could be reduced, permitting a greater number of collimators. Also the choice of a better shield material, compatible however with the NET environment, can improve the performance of the multicollimator.

For this configuration the crosstalk has been calculated in a simplified way. A neutron transport code MCNP [2] has been used to give an estimate of the noise expected. A neutron point source has been moved along the vertical axis of the poloidal section, from the axis of the central channel up to the plasma edge. In Table III the fluence per source neutron in the central channel is reported as a function of

TABLE III

Source Distance from Central axis (cm)	Neutron Fluence per Unit Source in the Central Channel (n/cm^2)
0.0	1.4×10^{-9}
12.5	1.0×10^{-9}
25.0	2.2×10^{-10}
37.5	1.5×10^{-10}
50.0	7.4×10^{-11}
62.5	5.2×10^{-11}
75.0	2.9×10^{-11}
87.5	2.2×10^{-11}
100.0	1.5×10^{-11}
112.5	1.0×10^{-11}
125.0	7.5×10^{-12}
137.5	5.5×10^{-12}
150.0	4.0×10^{-12}
162.5	2.9×10^{-12}
175.0	2.2×10^{-12}
187.5	1.7×10^{-12}
200.0	1.4×10^{-12}
212.0	1.1×10^{-12}

the distance of the source from the axis of the central channel. The energy cutoff of the calculation is 12.0 MeV, which is supposed to be the cutoff threshold of the detectors. In Table III the signal from the source located on the axis of the central channel is due to the neutrons scattered in the channel itself, while the direct (uncollided) fluence is 2.48×10^{-7} n/cm^2. The different neutron source profiles have been sketched as 35 point sources (2x17+1) (see Fig. 2), uniformly distributed along the vertical axis of the poloidal section, assigning to each one the corresponding emission intensity. The total background due to the crosstalk has been calculated for every detector by summing all the contributions. Figure 4a shows that in the case of the flat

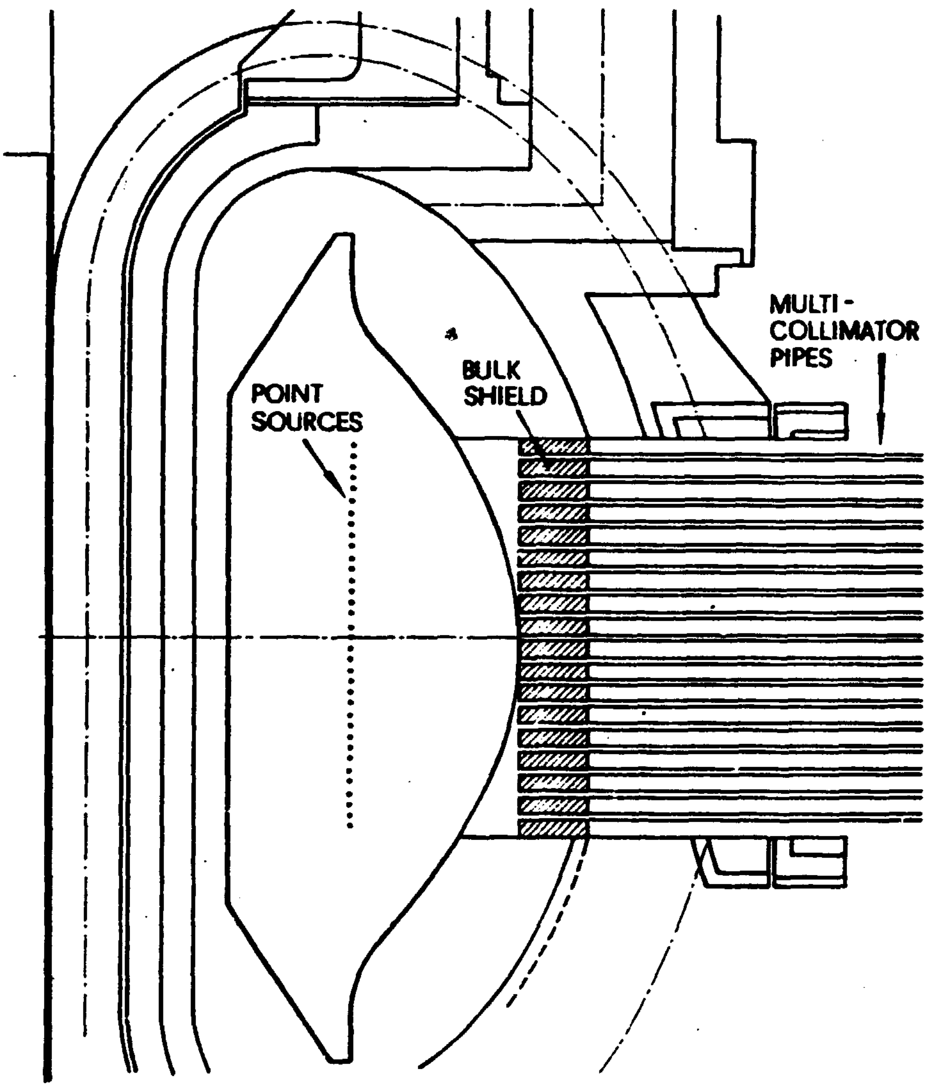


Fig. 2 Section of the multicollimator array showing the point sources location used for the calculation of the crosstalk noise

profile, the largest noise to signal ratio is obtained for the most external channels but still at a very acceptable level (~ 2%).For the peaked profile, on the contrary, high noise to signal ratios ($\lesssim$ 30%) are obtained for the outer channels because of the steep slope of the source profile (see for comparison Fig. 3 and Fig. 4b).

Whether these relative values of the background are acceptable or not is evaluated by reconstructing the source spatial distribution including the crosstalk background, and comparing it with the theoretical distributions.

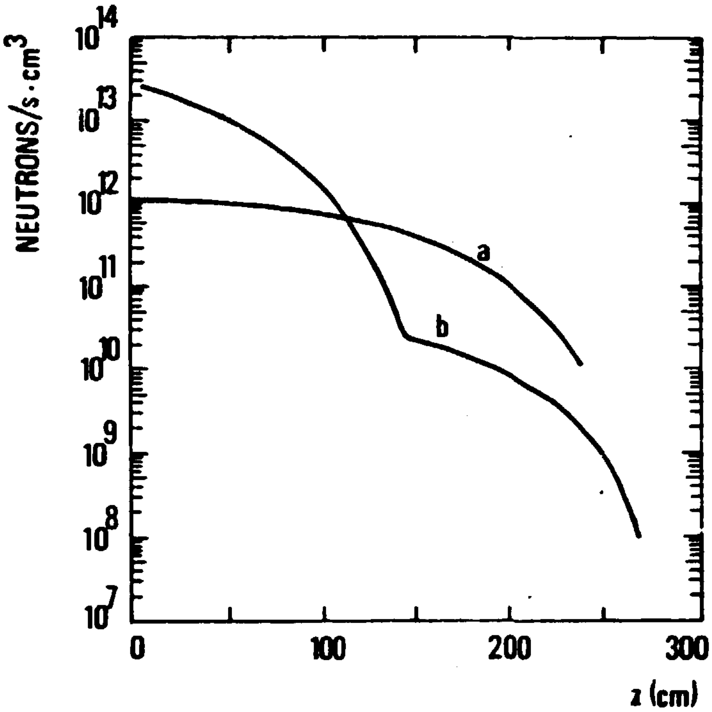


Fig. 3 Theoretical emissivity profiles considered in the computation

II. THE NUMERICAL EXPERIMENT

In order to evaluate the sensitivity of the experimental method for the determination of the fusion power distribution, an experimental measurement is simulated for the NET D-T maxwellian plasma. The neutron fluxes at the detectors locations are determined taking into account the true spatial distribution of the burning plasma. With the assumed multicollimator geometry, there is no overlapping of the plasma volumes seen by the channels. The direct signals at the detectors are calculated by a Monte Carlo code (see Ref. 1 for more details) by dividing the plasma volume into D-shaped shells in which density and temperature, and then emissivity [6] are considered constant. Figures 5a and 5b show for both cases the ideal fluxes and the true ones which include the crosstalk noise previously evaluated. These results are then treated as experimental data and are used to reconstruct the emissivity profiles by means of a standard inversion procedure, assuming that the shape of the magnetic flux surfaces is symmetric with respect to the equatorial plane and known from magnetic measurements.

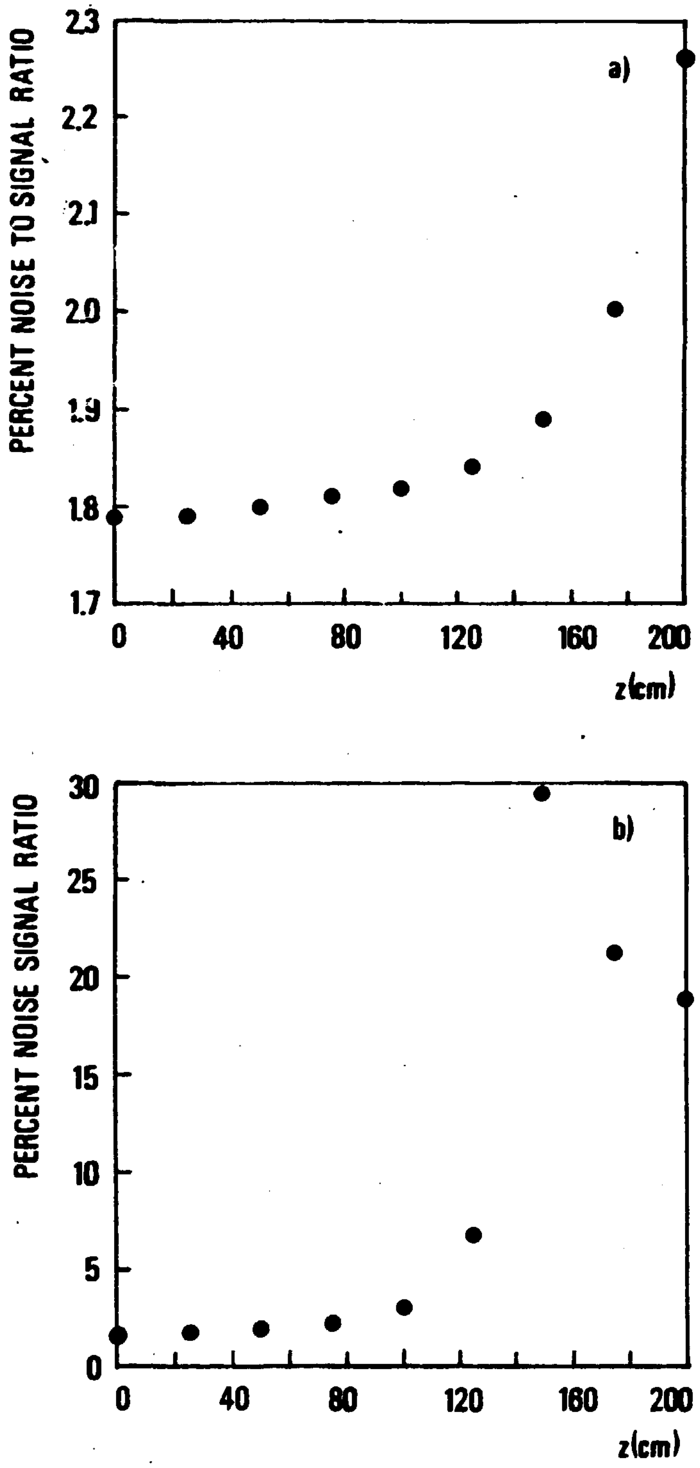
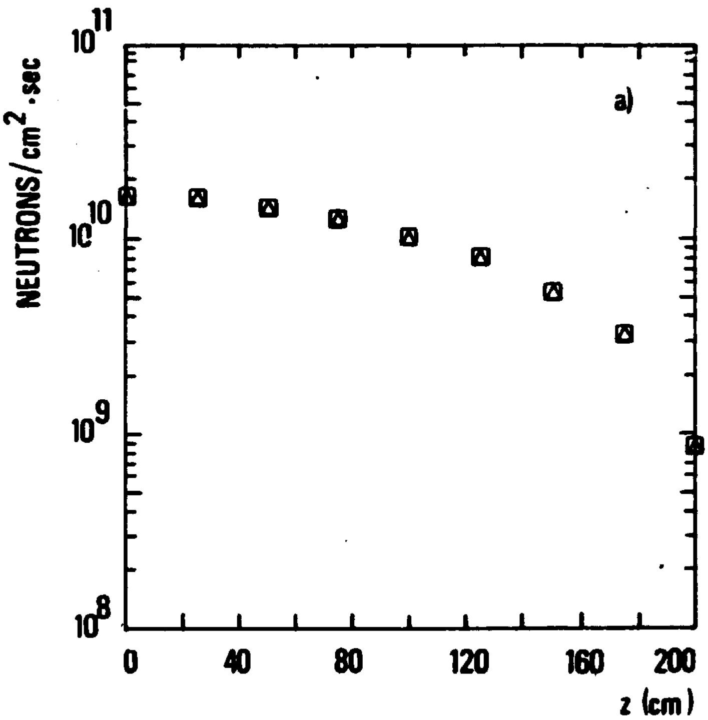


Fig. 4 Noise (due to crosstalk) to signal ratios for a) flat profile, b) peaked profile



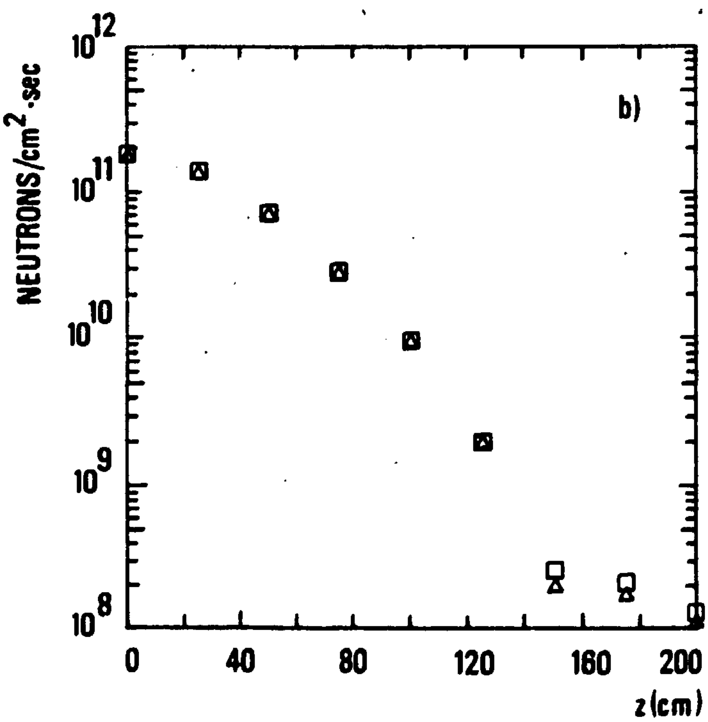
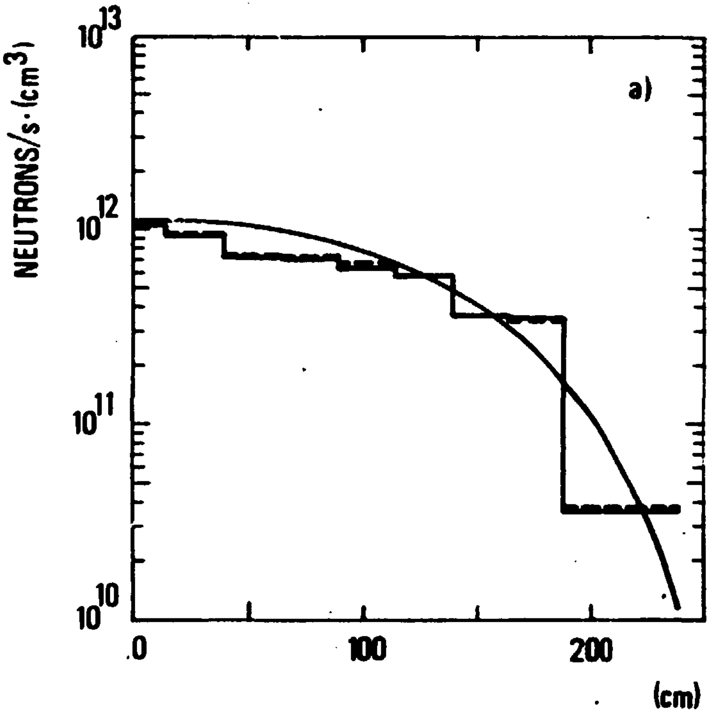


Fig. 5 Fluxes at the detectors (n/sec·cm^2) for a) flat profile, b) peaked profile. The dots represent the ideal fluxes, while the squares represent the true (ideal plus crosstalk) fluxes



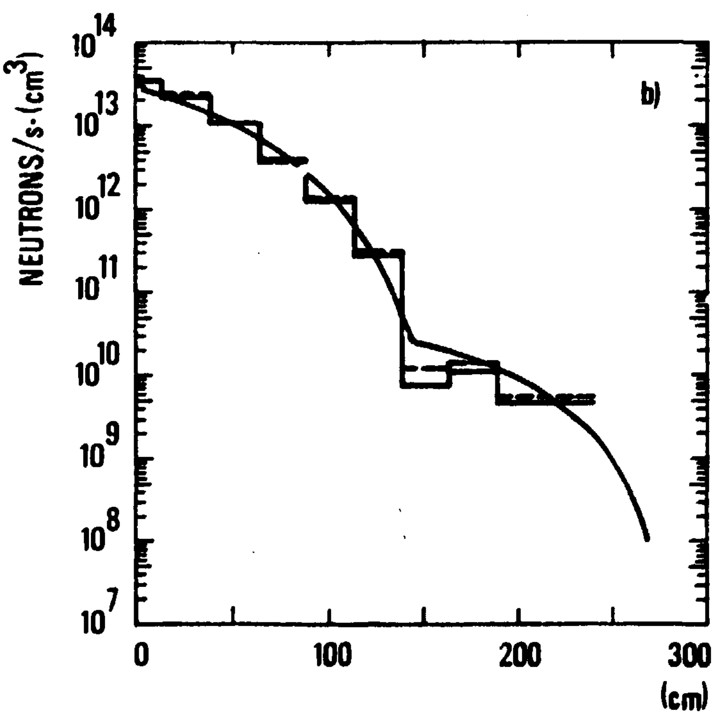


Fig. 6 Comparison between theoretical emissivity ditribution (curve) and distribution calculated by Abel inversion starting from ideal data (full line histogram) and true data (dashed line histogram) for a) flat profile, b) peaked profile

TABLE IV

	Theoretical rate	Calculated rate without crosstalk	Calculated rate with crosstalk
Flat Profile	0.97×10^{20}	0.91×10^{20}	0.92×10^{20}
Peaked Profile	0.36×10^{21}	0.38×10^{21}	0.39×10^{21}

III. RESULTS AND CONCLUSIONS

The results are presented in Figs. 6 and show good agreement in the case of the peaked profile and acceptable agreement for the flat one. The total rates reported in Table IV are also in accordance with the theoretical rates within 10%. The presence of crosstalk noise is negligiable in the flat case and has very few consequences even in the peaked case since the higher noise to signal ratios are found only for the external channels where the emissivity is three orders of magnitude smaller than for the central channel.

In the present work the feasibility of a neutron source profile monitor has been investigated for the NET machine. The projected multi-collimator consisting of 17 channels fits the required accuracy (10%) in the measurement of the total fusion power.

A complete project would require a suitable choice of detectors compatible with the magnetic noise constraints, and an investigation of the background noise coming from the machine itself and from the structure around it.

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