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SHIELDING ANALYSIS OF THE ITER/EDA NBI DUCT

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This report discusses the shielding properties of the ITER／EDA NBI ducts based on the current JCT design of the 24 superconductive toroidal field coils (the 24 TFC). The two-dimensional transport calculations have been performed by DOT 3.5. First, the neutron fluxes, dose to insulator and peak nuclear heating rate were calculated in the TFC and the NBI duct. The X-Y calculational model with detail description of the neutron source shape and the TFC geometry is used for that calculation. Second, the R-Z calculational model with detail description of the NBI components was set up. The nuclear heating in the NBI cryo panels and displacement damage in NBI copper grids were obtained in that calculation. In summary, it is concluded that the shielding performance of the current NBI duct design is enough to decrease all considered neutronics responses below the limits.

Keywords ; ITER, Neutrons, NBI Duct, Total Nuclear Heating, Neutron Transport Calculations, Neutron Streaming.

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ITER／EDAにおけるNBIポートの遮蔽解析

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（1994年7月29日受理）

ITER／EDA設計における中性粒子加熱（NBI）ポートの遮蔽解析を行った。対象とした設計はトロイダル磁場コイル（TFC）個数24であり，DOT3.5を用いた2次元解析を実施した。先ず，全体モデルにてTFCにおける絶縁材吸収線量，核発熱率，及びNBIポートにおける中性子束の評価を行い，続いてNBI詳細モデルにて，NBIポート内部におけるクライオパネルの核発熱と銅電極の損傷率（dpa）を評価した。解析の結果，現ITER／EDA設計におけるTFC及びNBIポートの核的応答は全て許容値を下回ることが分かった。

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1. INTRODUCTION

The four neutral beam injector (NBI) ducts are envisaged for the current ITER EDA design. Those ducts may affect the shielding properties needed to protect the superconductive toroidal field coils (TFC). Another concern is the nuclear heating in the NBI cryo panels and displacement damage in its copper grids due to the neutron streaming through the more than 11 meters NBI duct.

The streaming effect through the ITER CDA NBI duct has been examined [1] recently regarding the increase of neutronics responses in the TFC. However the design of ITER EDA NBI duct has been changed drastically. Thus we performed the neutronics analysis of current NBI design based on the concept of 24 TFC, as shown in Fig. 1.

The neutronics analysis is conducted in the two independent calculations as follows:

- First, the X-Y (plane) two-dimensional calculational model is used to obtain a detail information on the neutronics responses in the TFC adjacent to the NBI duct.
- Second, the R-Z (cylinder) two-dimensional calculational model is used to obtain an information on the total nuclear heating in the NBI cryo pump and the dpa numbers in copper grids behind the NBI neutralizer.

The DOT3.5 [2] neutron transport code with the FUSION-40 [3] library of multigroup constants (42 neutron + 21 photon) are used in this report. All transport calculations are performed using the discrete ordinate method with 166 (biased up) angular quadrature set and a P_5 Legender expansion for the scattering cross sections.

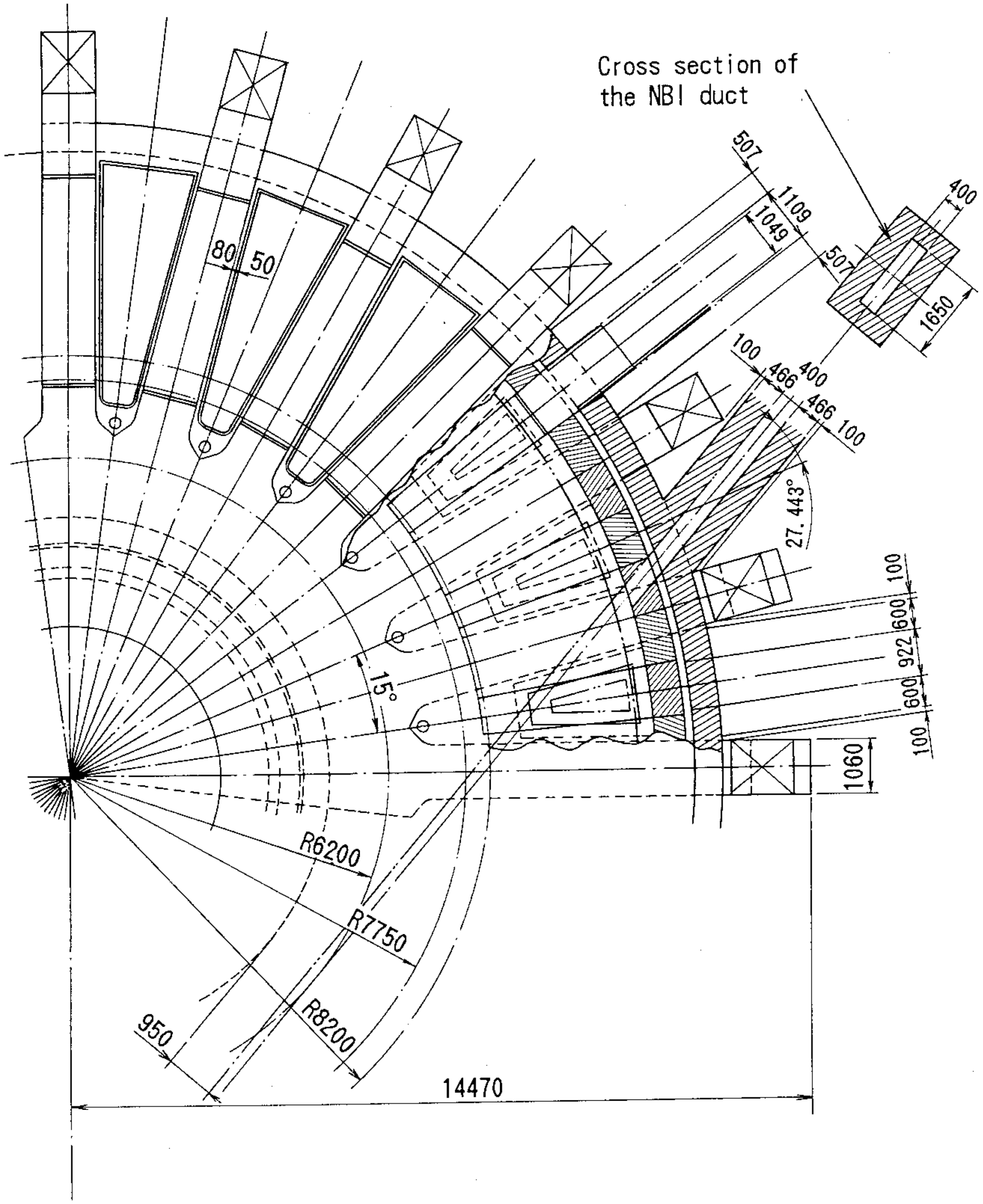


Fig. 1 Cross-section of the ITER/EDA NBI duct.

All calculational results are normalized on the 1 MW/m^2 average neutron wall load on the first wall. The dose and displacement damage are calculated for the 3 $MW \cdot a/m^2$ operation fluence.

2. FIRST CALCULATIONAL MODEL

The first calculational model, as discussed above, is shown in Fig. 2 together with the most vulnerable to radiation damage points A and B. The neutronics responses in the TFC reach maximum values at those points. The two-dimensional contour maps of 14-MeV, fast (E>0.1 MeV) and total neutron and total gamma-ray fluxes are shown in Figs. 3-6, respectively. Contour lines in those figures represent values corresponding to $1\cdot10^n\ 1/cm^2\cdot s$. The arrows show the direction of the downward gradient of neutron or gamma-ray fluxes. The one-dimensional distributions of neutron&gamma-ray fluxes and dose rates for the cuts C-C and D-D shown in Fig. 2 are shown in Figs. 7,8 and 9,10 respectively.

The neutronics responses at the points A and B are given in Table 1 together with the design limits adopted for the ITER CDA design [4]. The results given in Table 1 are expected to be conservative due to modelling the NBI duct as an infinite slot of 40 cm width, while the ITER EDA design, as shown in Fig. 1, envisages the rectangular NBI duct with a cross section of H=165 cm by W=40 cm. Those responses are given without any safety factors. However, even with the safety factor of 3 adopted for one-dimensional calculations of dose and dpa during ITER CDA [2], the results of Table 1 are still below the limits.

Table 1. Neutronics responses in the TFC adjacent to the NBI duct (3 MW·a/m^2 operation fluence, **no safety factors are included**).

	Point A (Fig. 2)	Point B (Fig. 2)	Design limits (Ref. 4)
Fast neutron fluence to Nb_3Sn superconductor, n/cm^2	$1.5 \cdot 10^{18}$	$3.3 \cdot 10^{17}$	$1 \cdot 10^{19}$
Dose to electrical insulator, rad	$1.6 \cdot 10^{9}$	$3.3 \cdot 10^{8}$	$5 \cdot 10^{9}$
Displacement damage in copper stabilizer, dpa	$1.2 \cdot 10^{-4}$	$2.4 \cdot 10^{-5}$	$6 \cdot 10^{-3}$

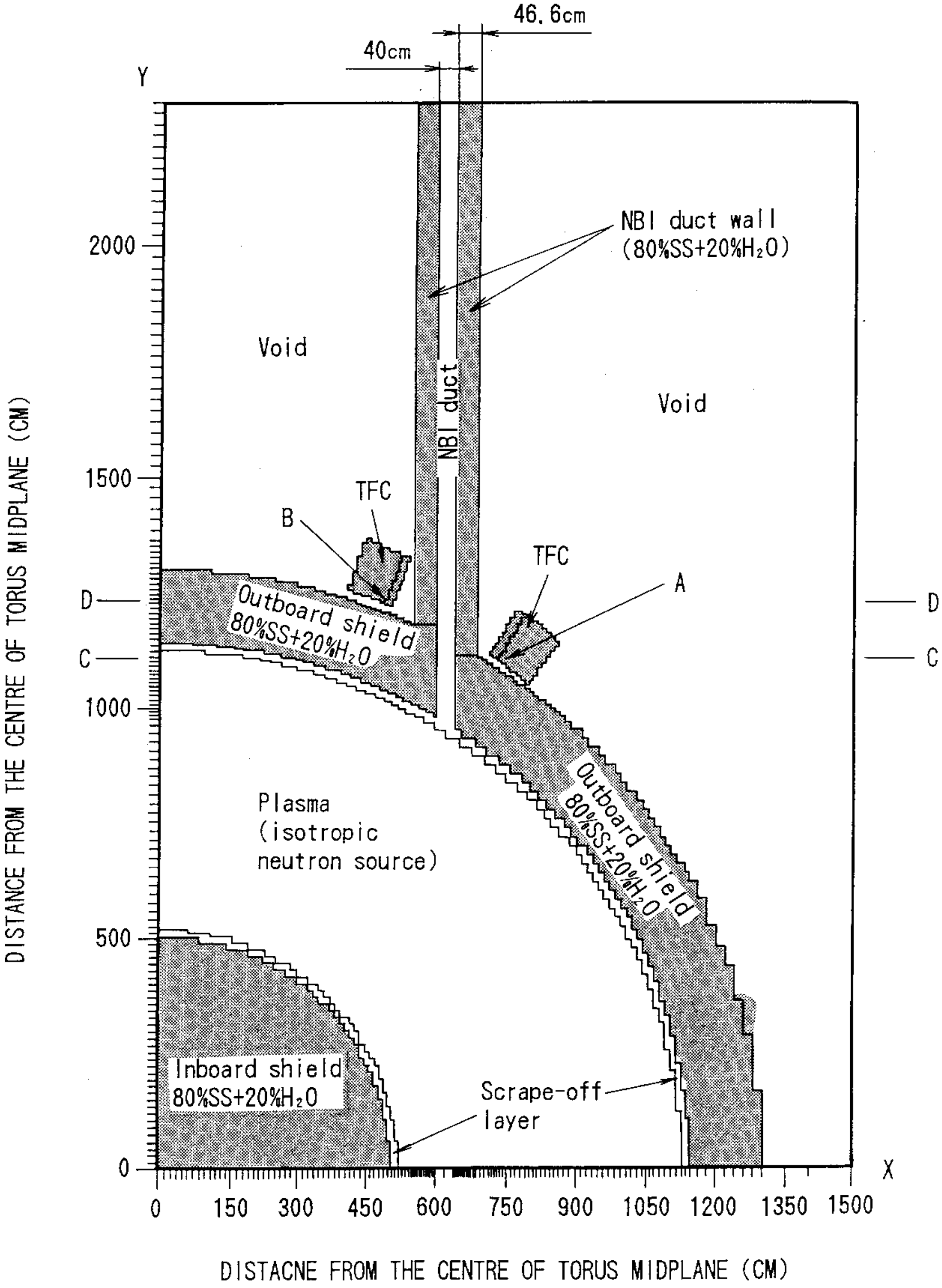


Fig. 2 First calculational model of a neutral beam injector.

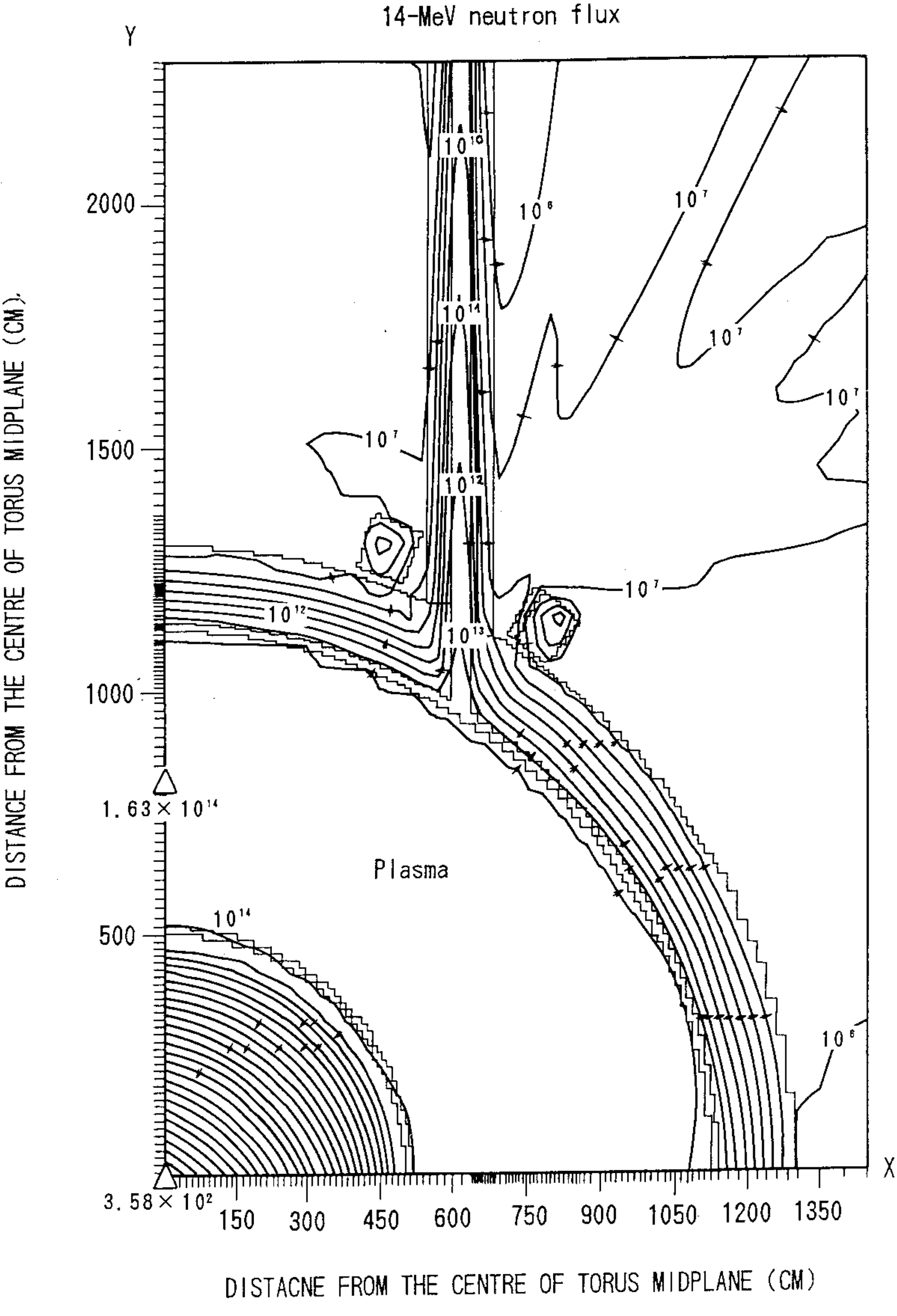


Fig. 3 14-MeV neutron flux distribution.

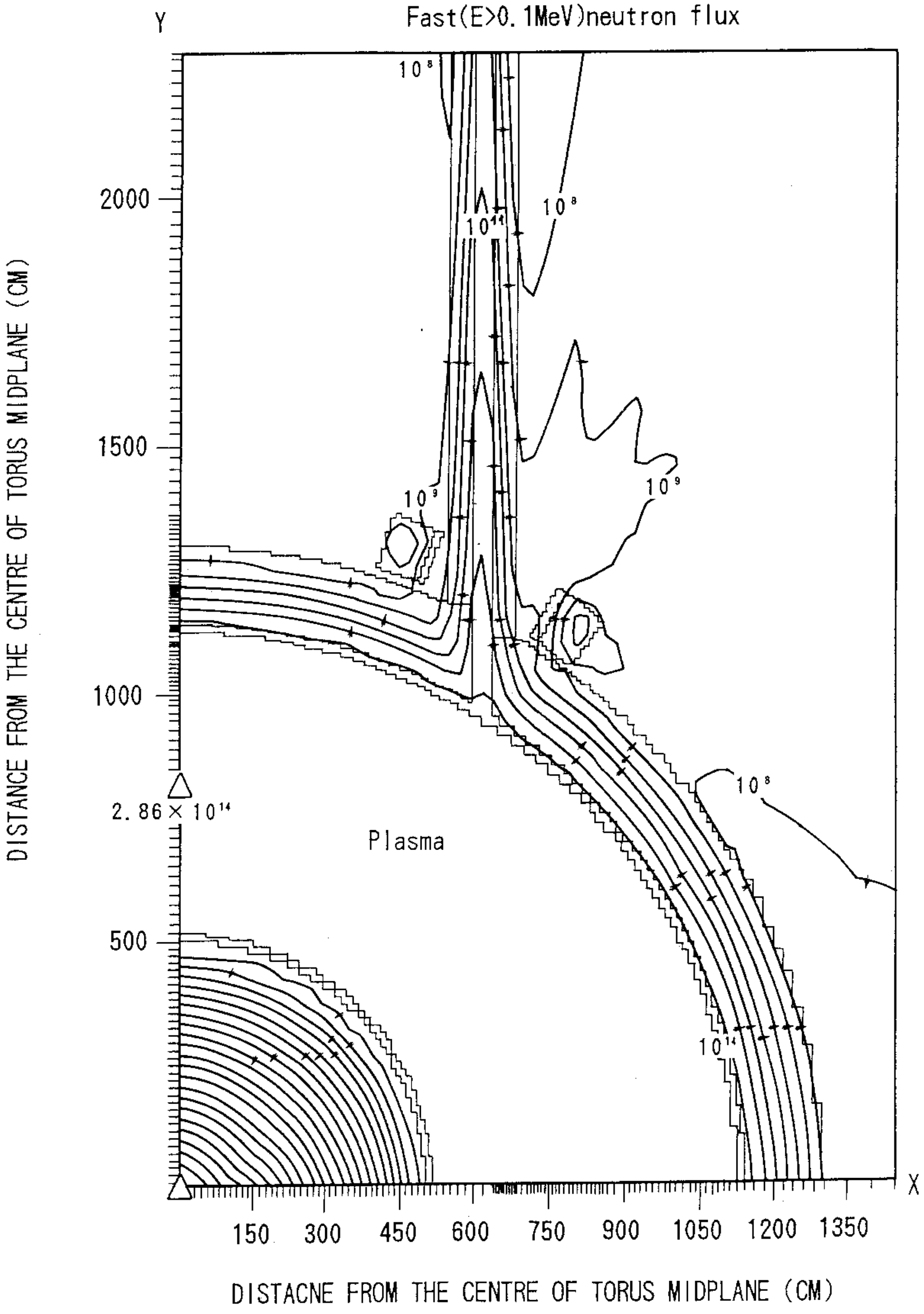


Fig. 4 Fast neutron flux distribution.

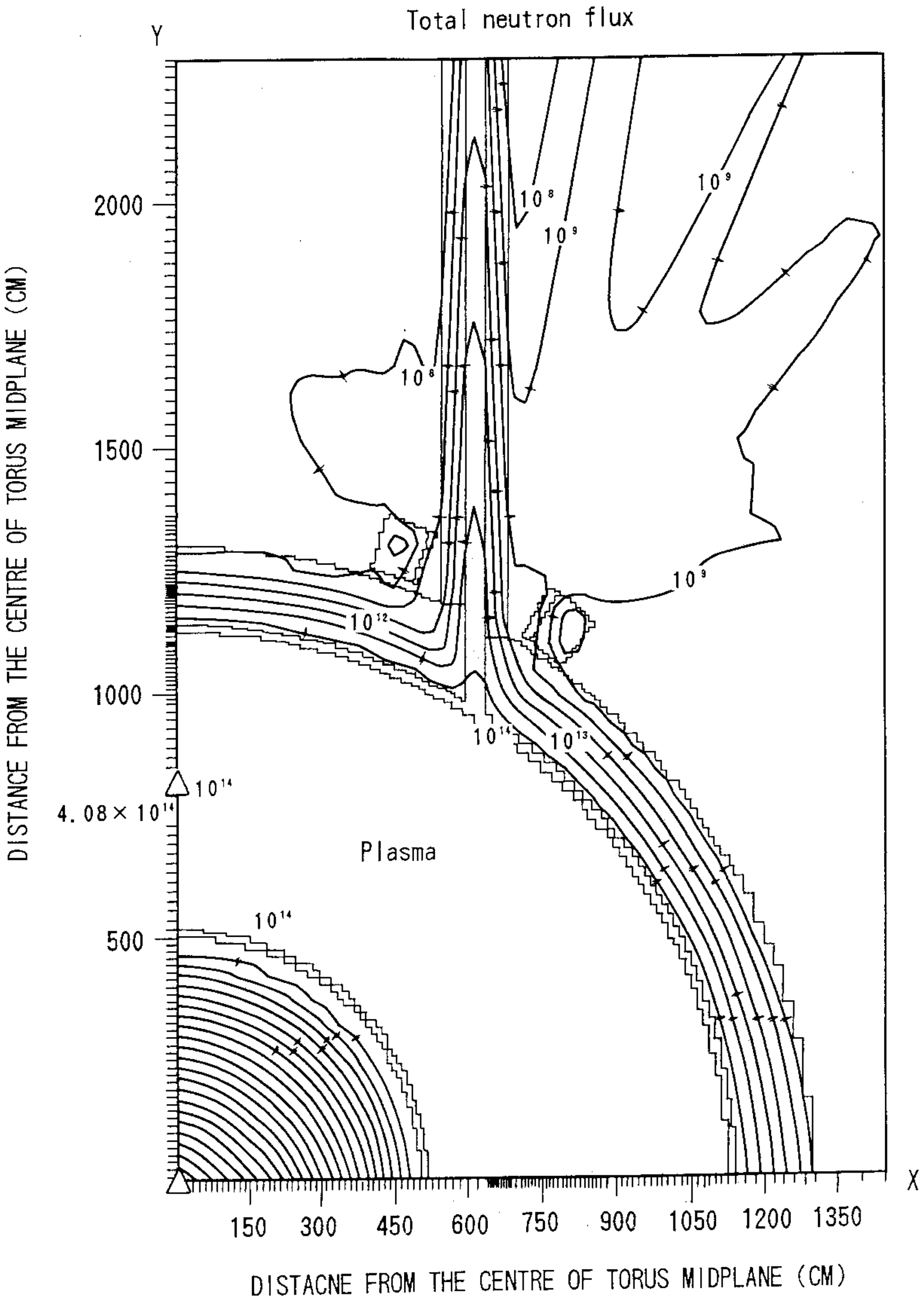


Fig. 5 Total neutron flux distribution.

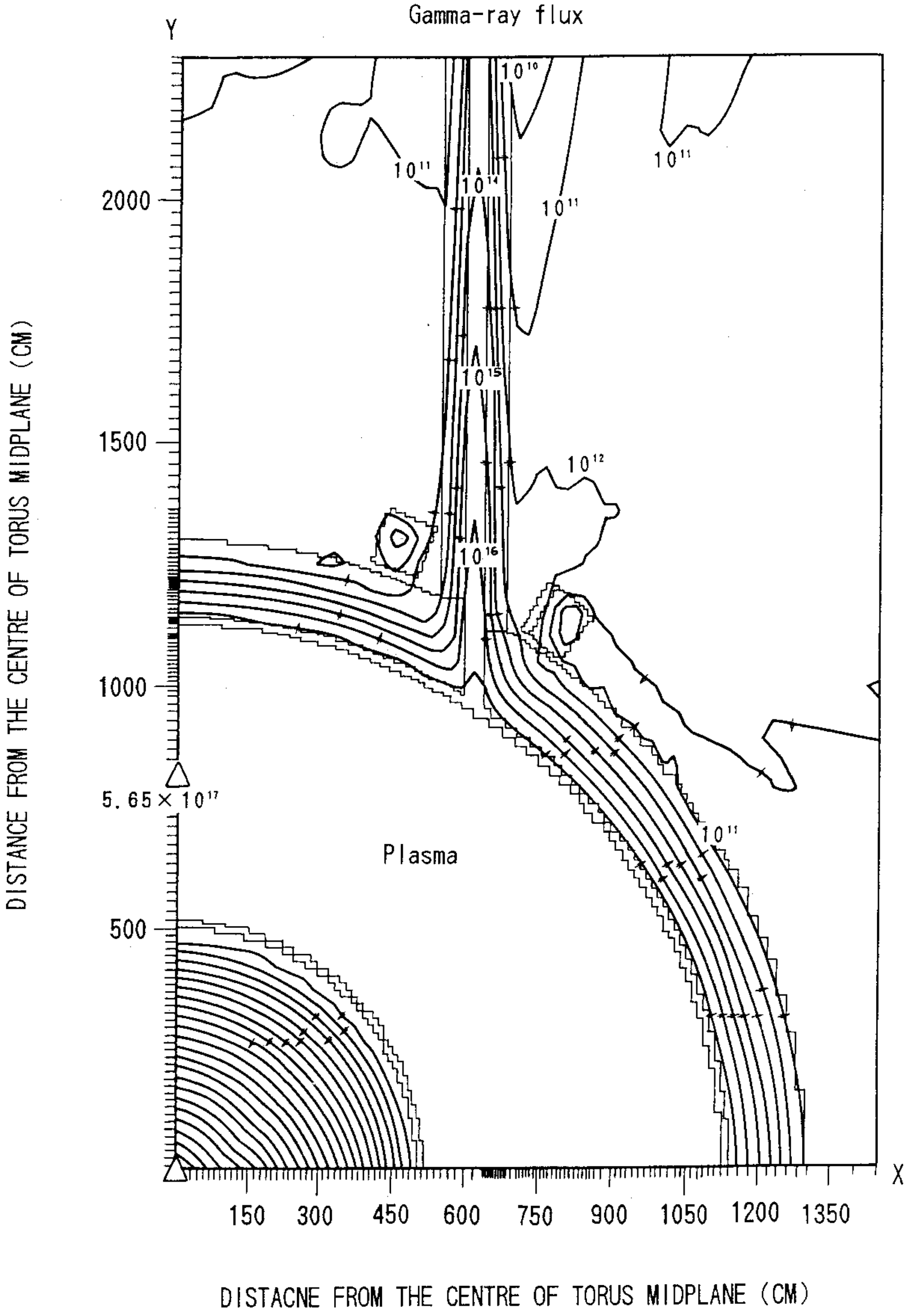


Fig. 6 Gamma-ray flux distribution.

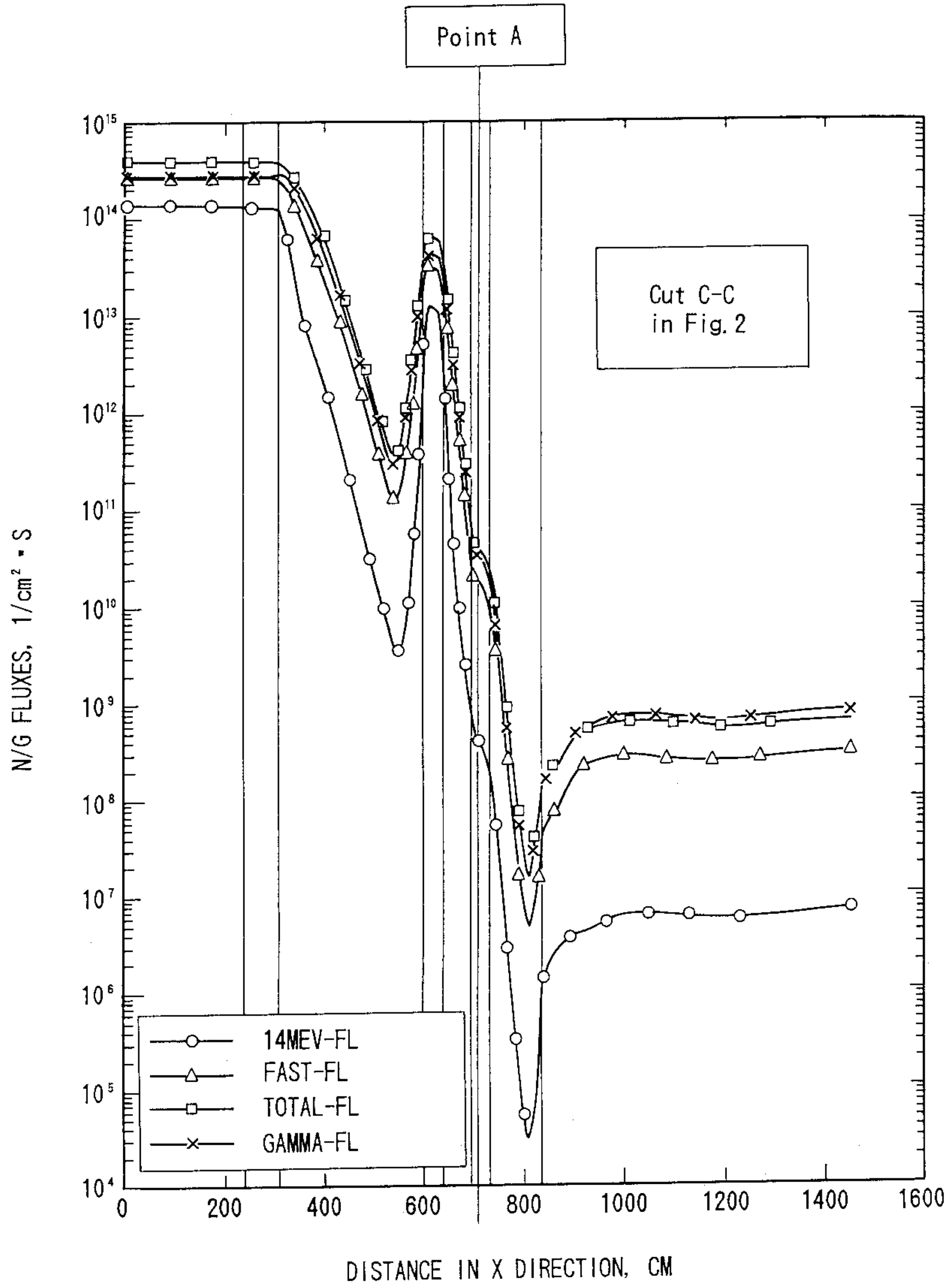


Fig. 7 Neutron fluxes (Cut C-C in Fig. 2).

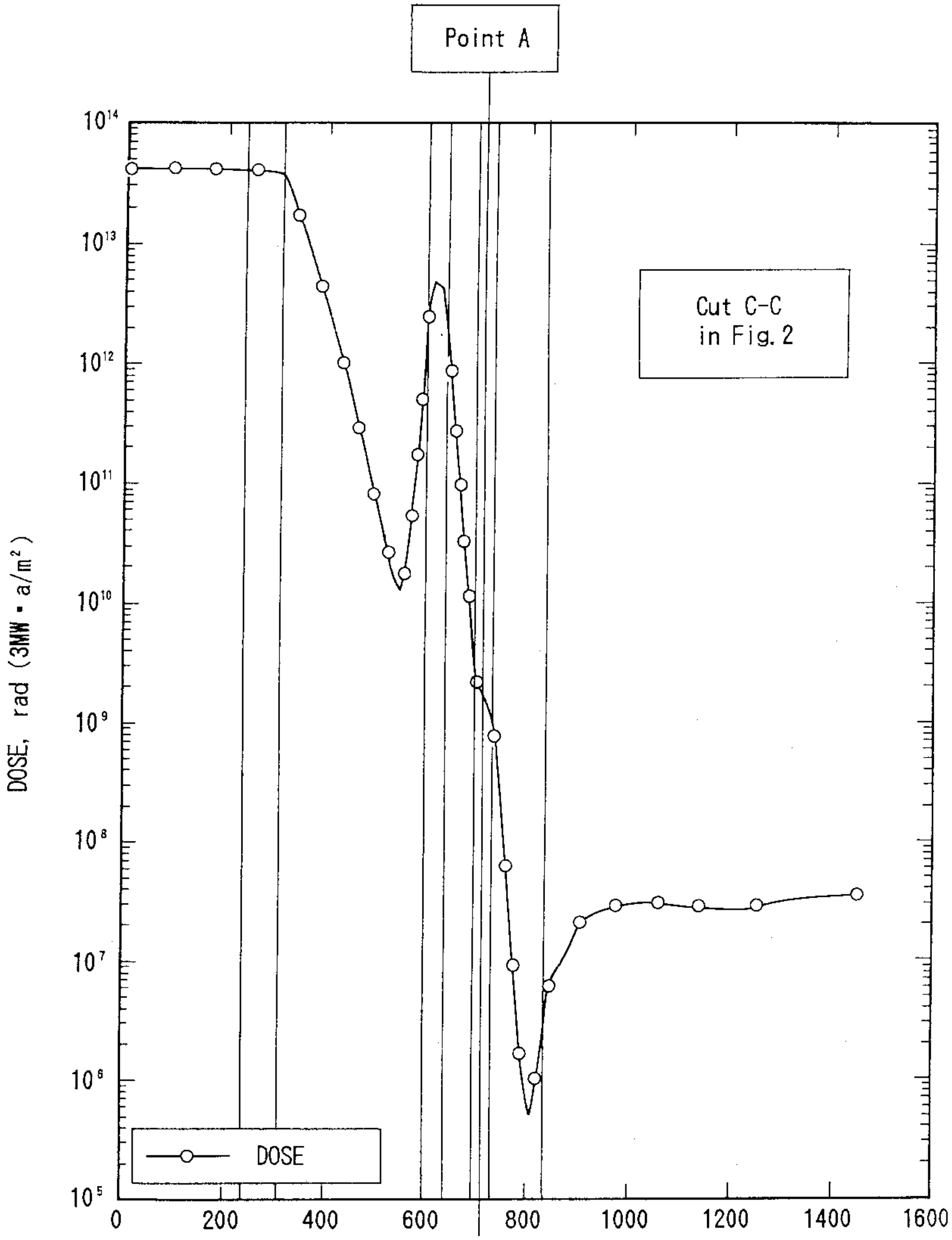


Fig. 8 Dose distribution (Cut C-C in Fig. 2).

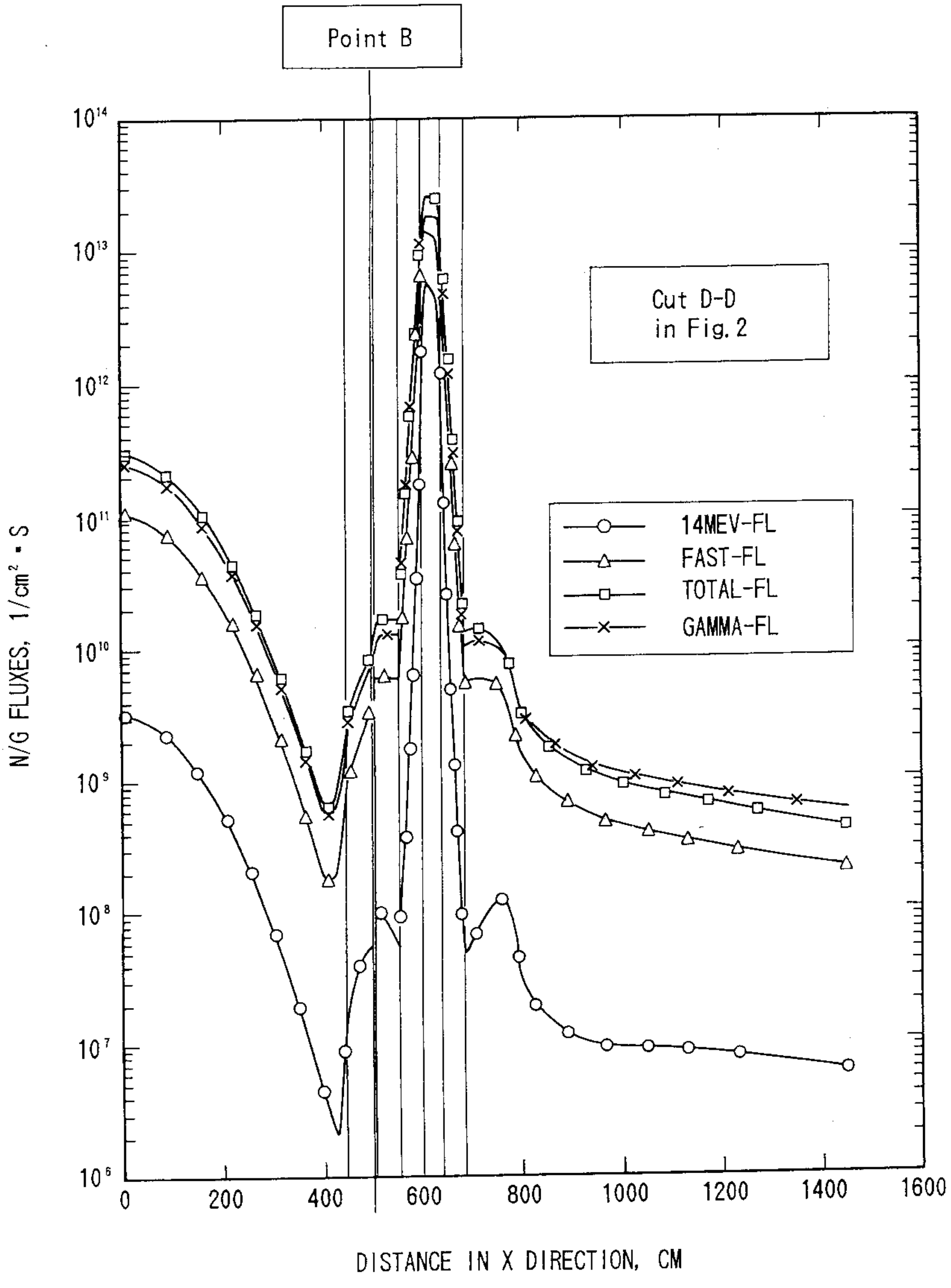


Fig. 9 Neutron fluxes (Cut D-D in Fig. 2).

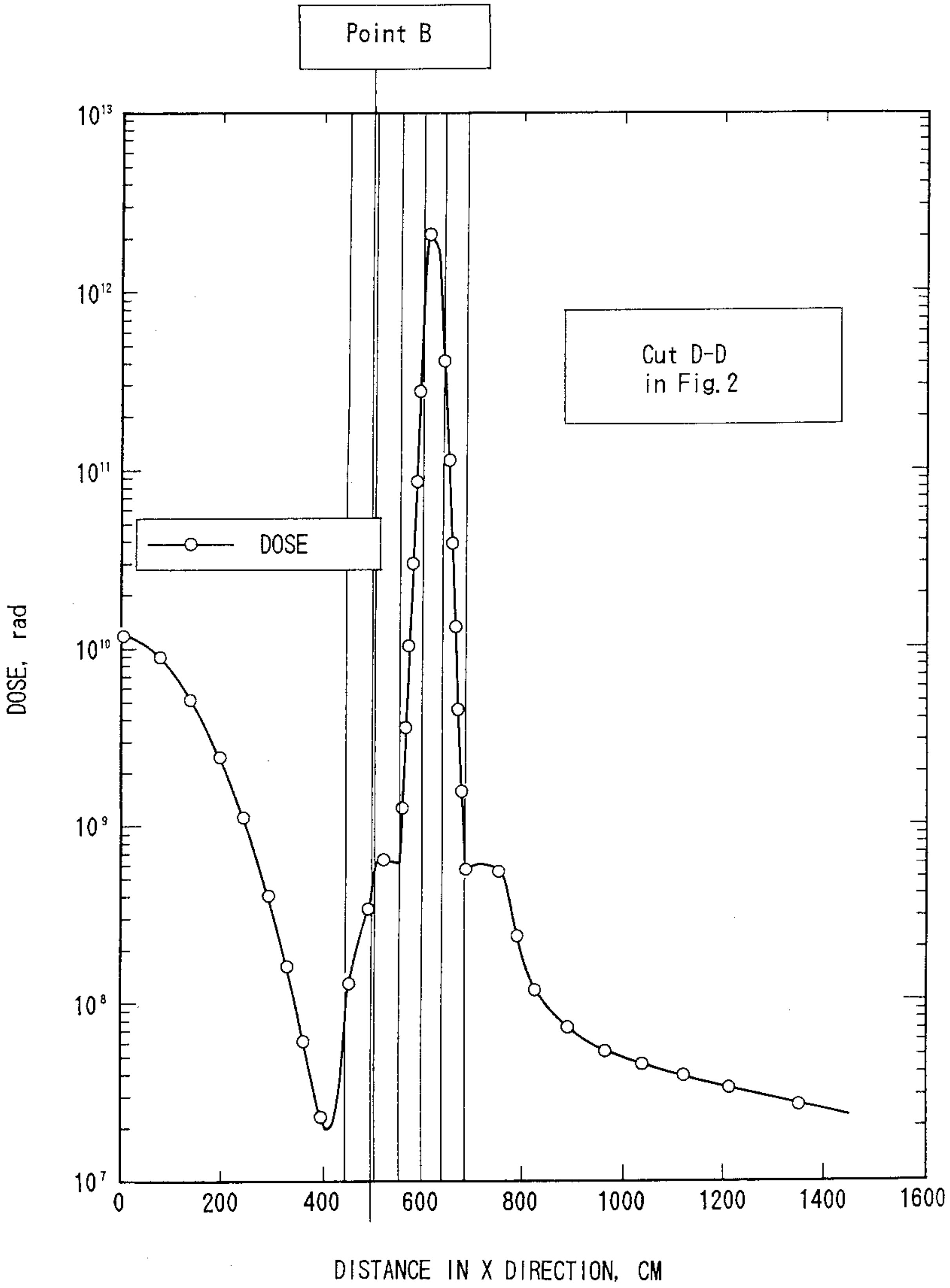


Fig. 10 Dose distribution (Cut D-D in Fig. 2).

3. SECOND CALCULATIONAL MODEL

The schematic of a neutral beam injector for ITER EDA is shown in Fig. 11 [5]. The second calculational model, as discussed in the Introduction, is shown in Fig. 12. This model employs the most vulnerable option of the NBI duct having only 5.5 meters length. The NBI ducts having the 10, 11 and 11.3 meters length are calculated as well to estimate the impact of the NBI duct length on the total nuclear heating in the cryo pump.

The NBI duct in Fig. 12 is modelled by the cylinder duct of such radius that the cross section area of that duct is equal to the cross section area of the rectangular NBI duct designed by the ITER EDA JCT with a cross section of H=165 cm by W=40 cm, as shown in Fig. 1.

The NBI cryo pump in Fig. 12 has been modelled by the cylinder ring. The total volume of that cylinder ring is equal to that of the two stretched cylinders, as envisaged for the NBI cryo pump and shown in Fig. 13. The details of neutralizer and source/accelerator structure are shown in Fig. 14.

The two-dimensional contour maps of 14-MeV, fast and total neutron and gamma-ray fluxes in and around the NBI duct having 11.3 and 5.5 meters length are shown in Figs. 15-18 and Figs. 19-22, respectively.

Distributions of nuclear heating rate in the cryo pump behind the 11.3 meter NBI duct are obtained for the three representative cuts (shown in Fig. 12 as C-C, F-F and D-D) and shown in Figs, 23-25, respectively.

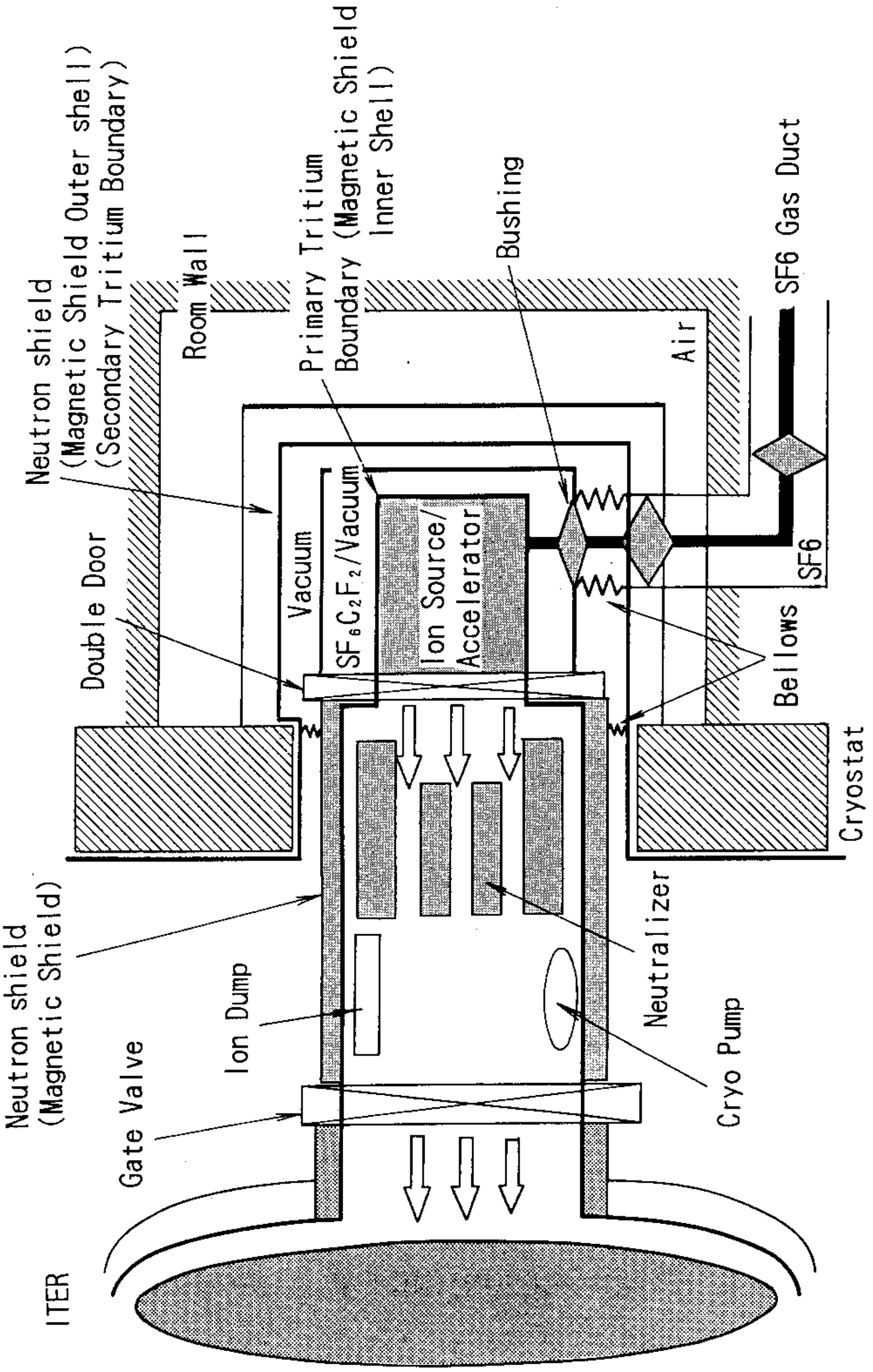


Fig. 11 Schematic of a neutral beam injector for ITER.

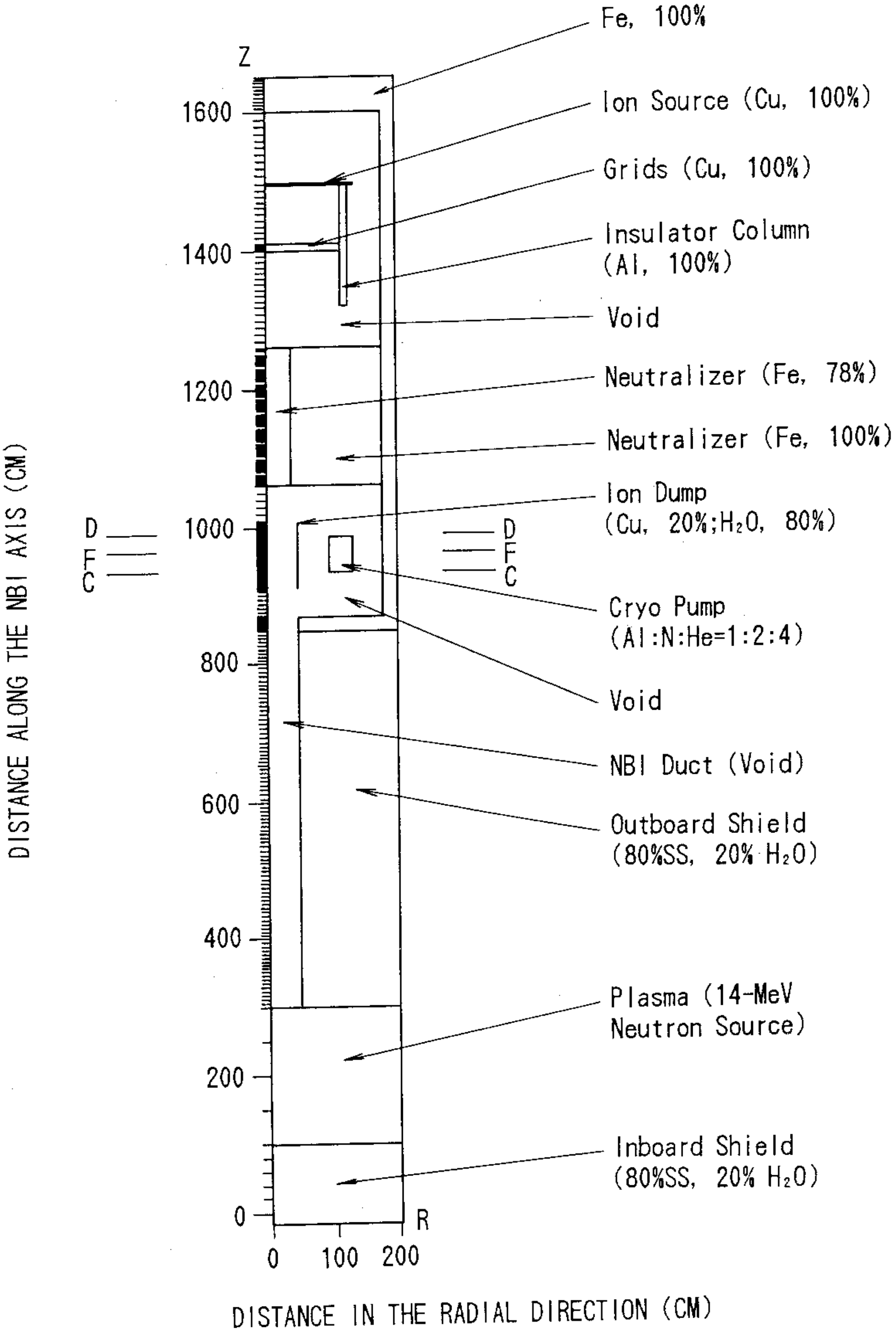


Fig. 12 Second calculational model of a neutral beam injector.

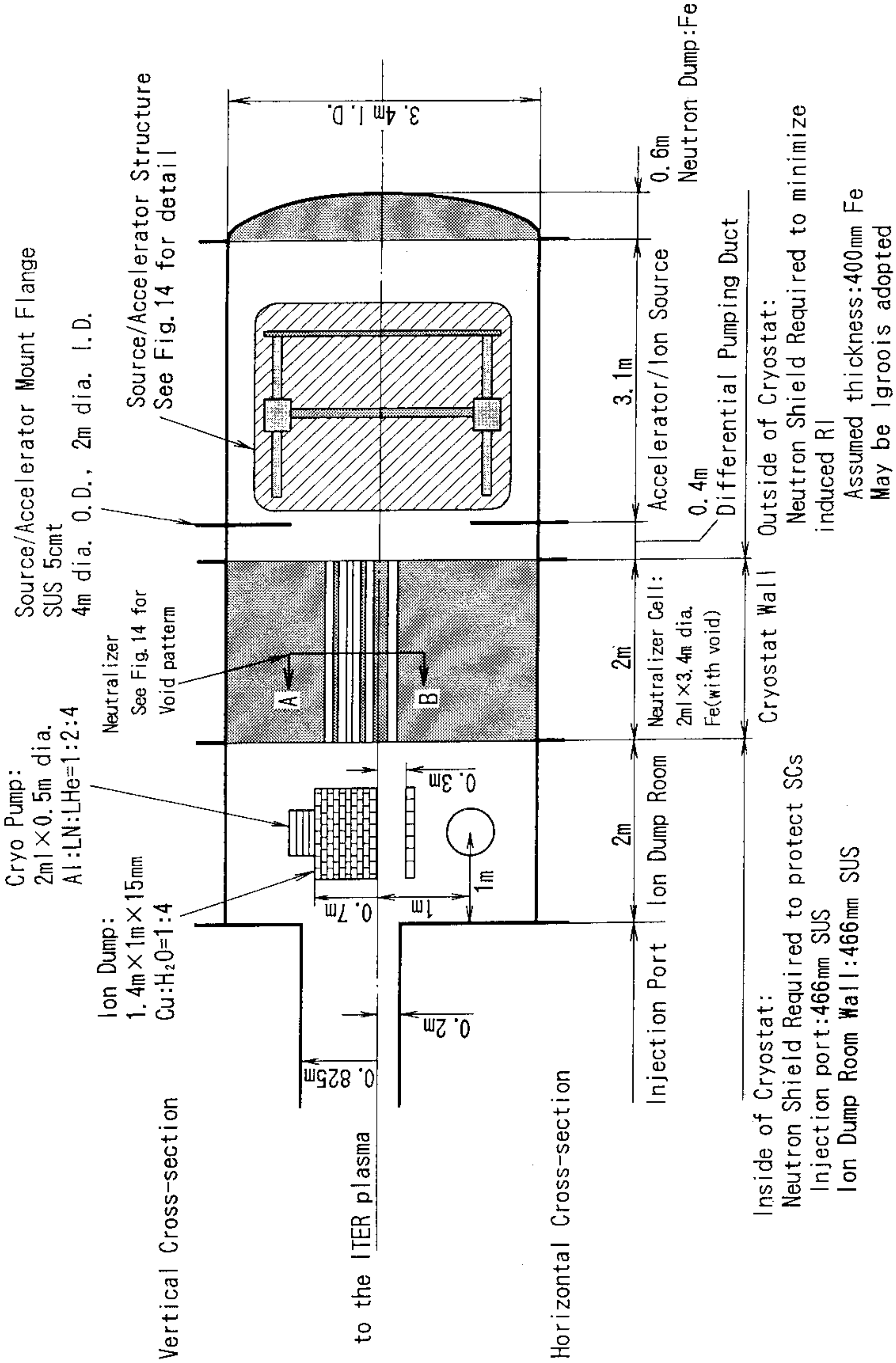


Fig. 13 Some schematic details of a neutral beam injector.

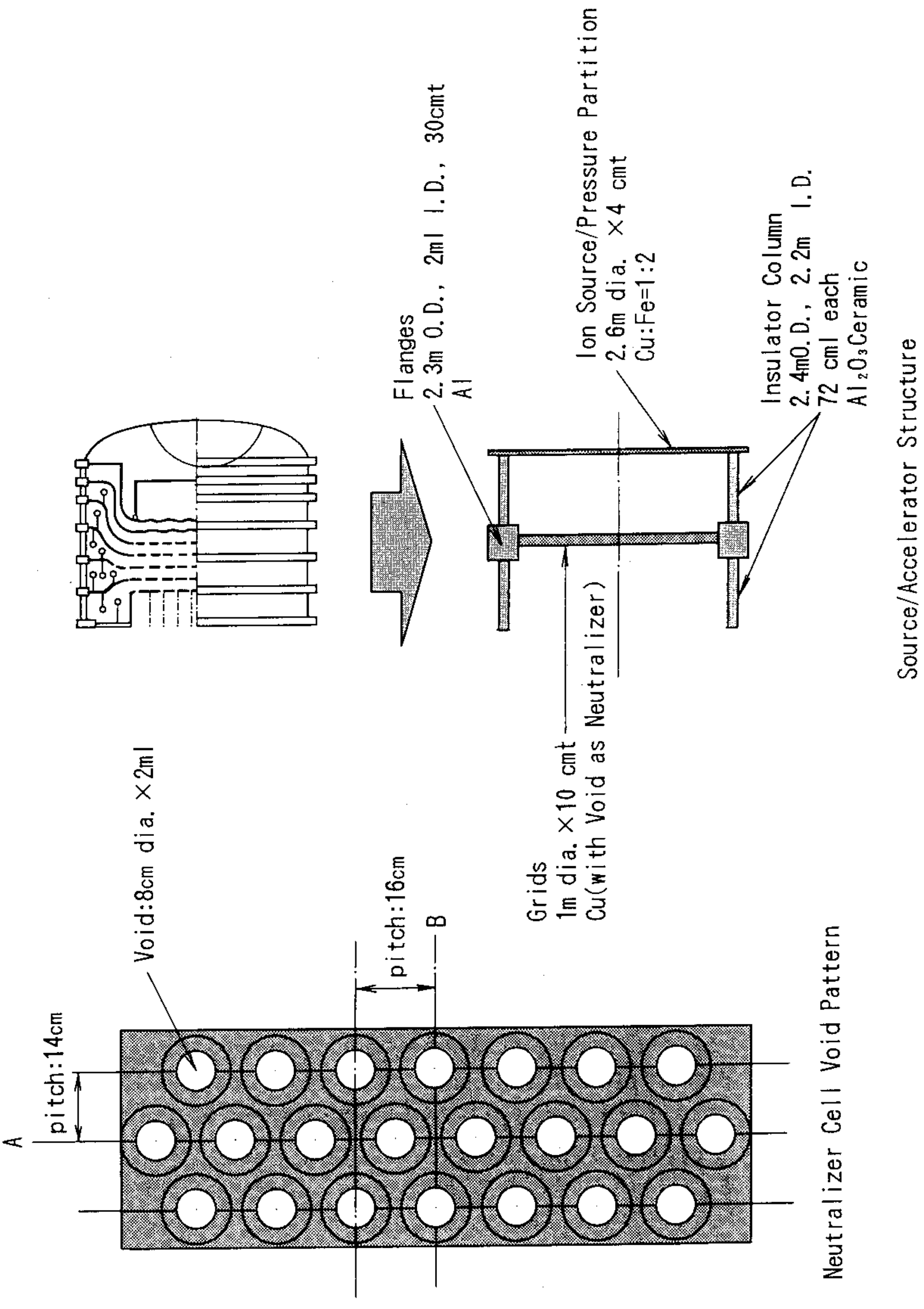


Fig. 14 Some schematic details of neutralizer and accelerator of a neutral beam injector.

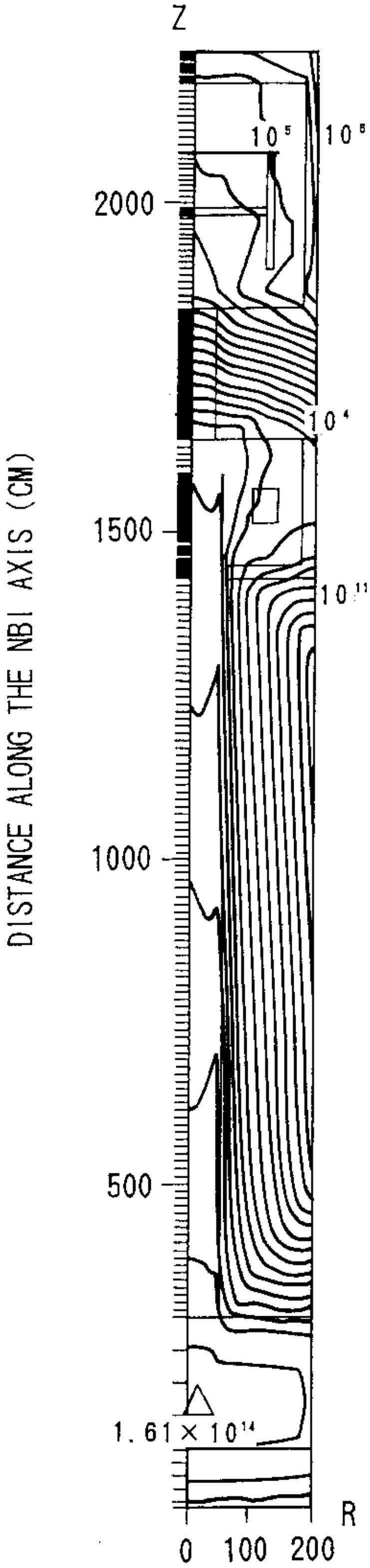


Fig. 15　14-MeV neutron flux distribution.

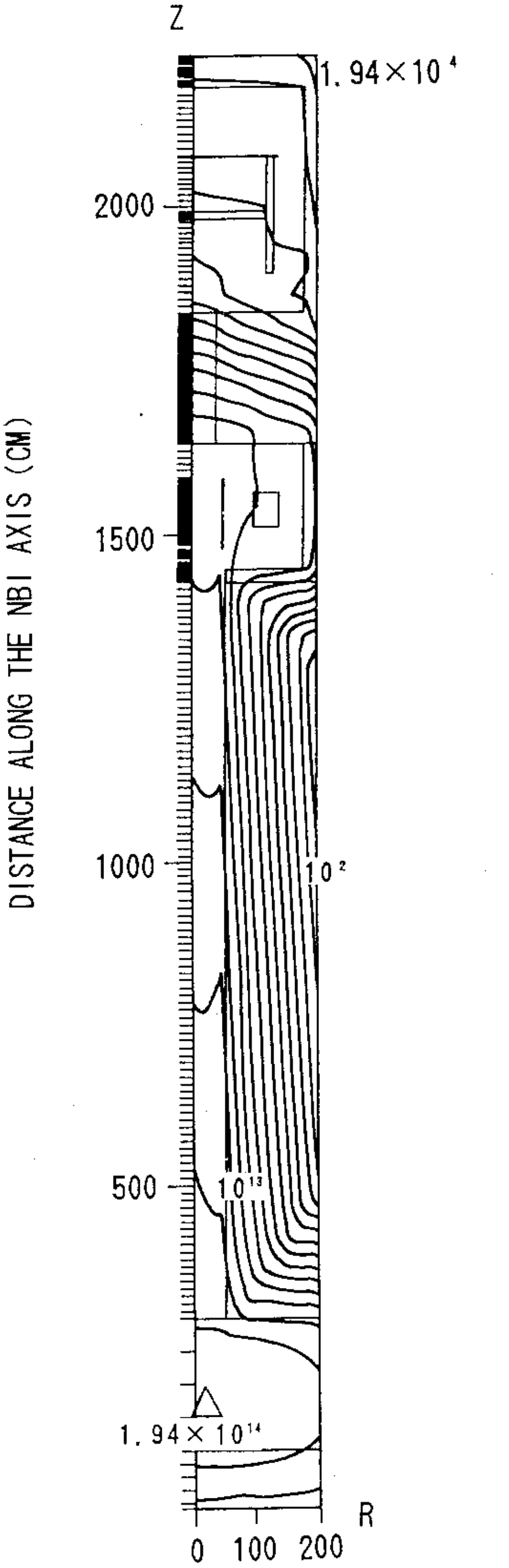


Fig. 16 Fast neutron flux distribution.

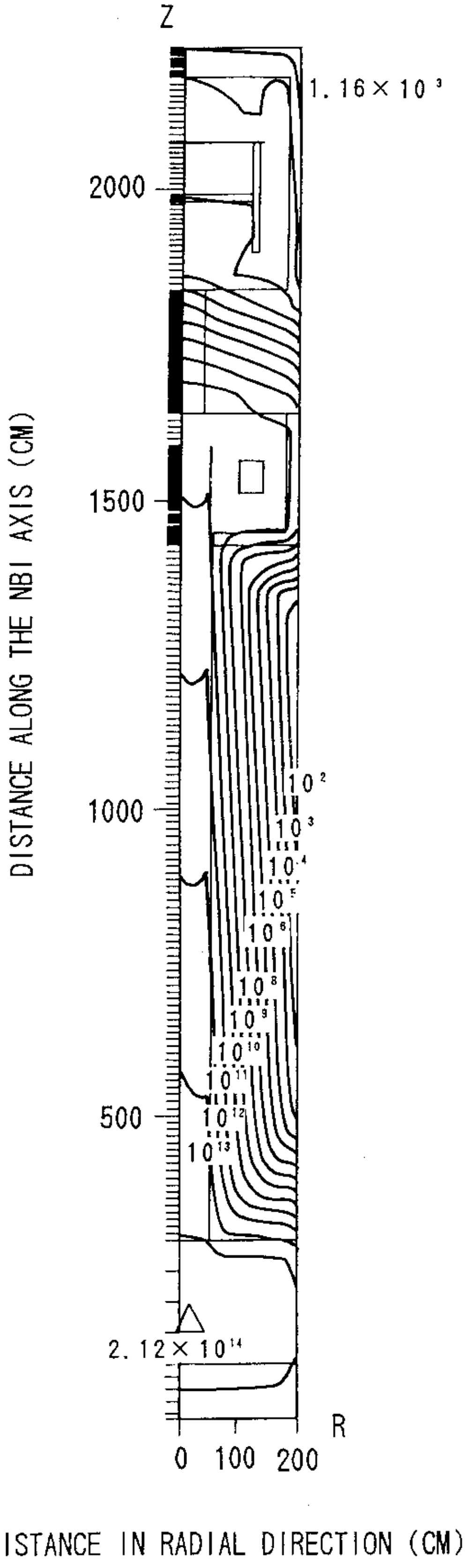
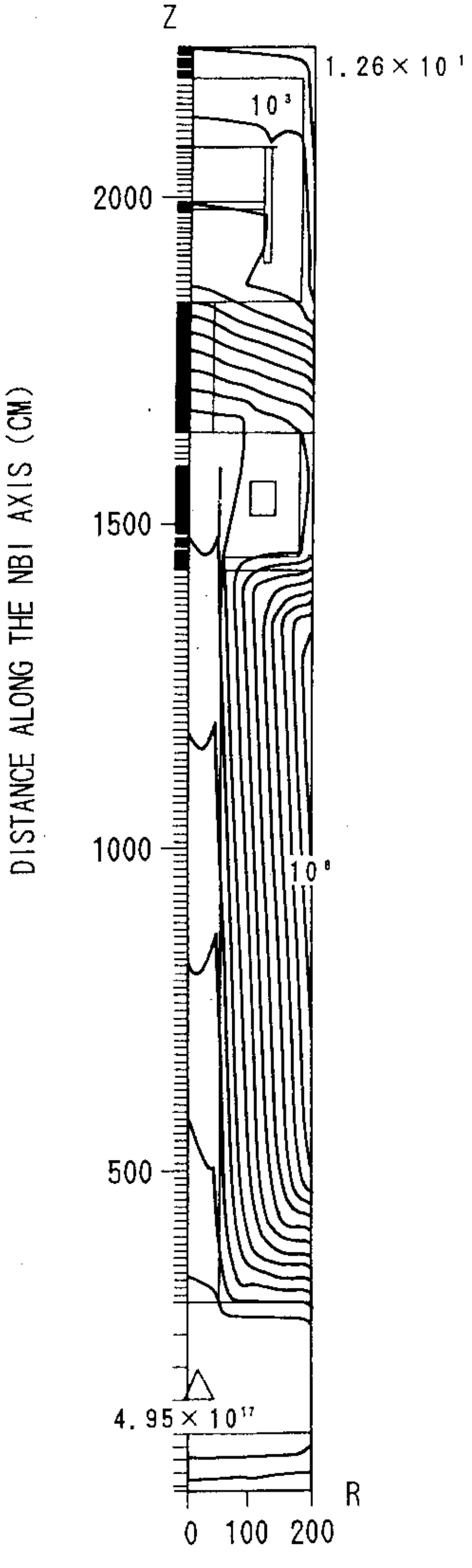


Fig. 17 Total neutron flux distribution.



DISTANCE IN RADIAL DIRECTION (CM)

Fig. 18 Total gamma-ray flux distribution.

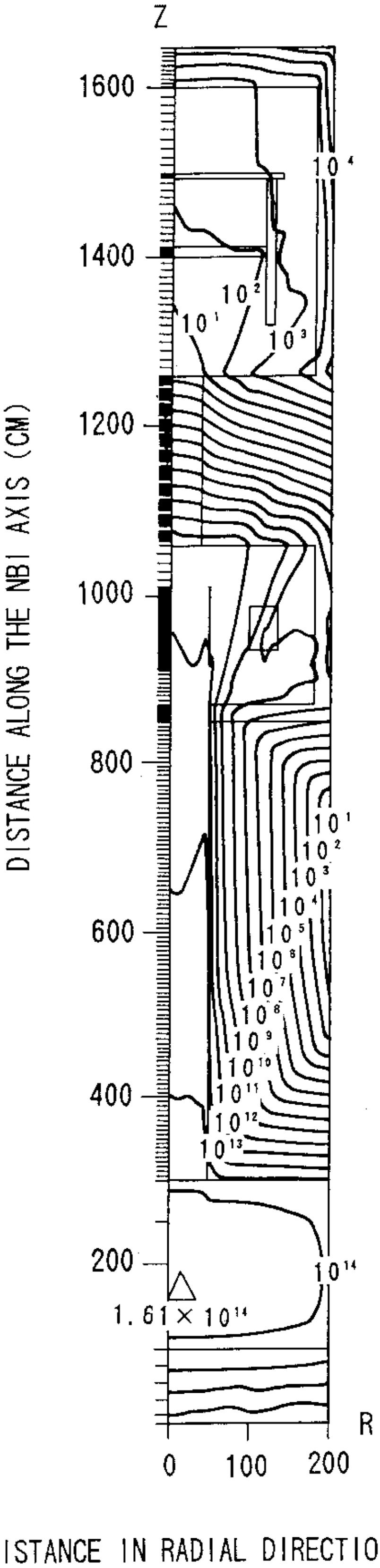


Fig. 19 14-MeV neutron flux distribution.

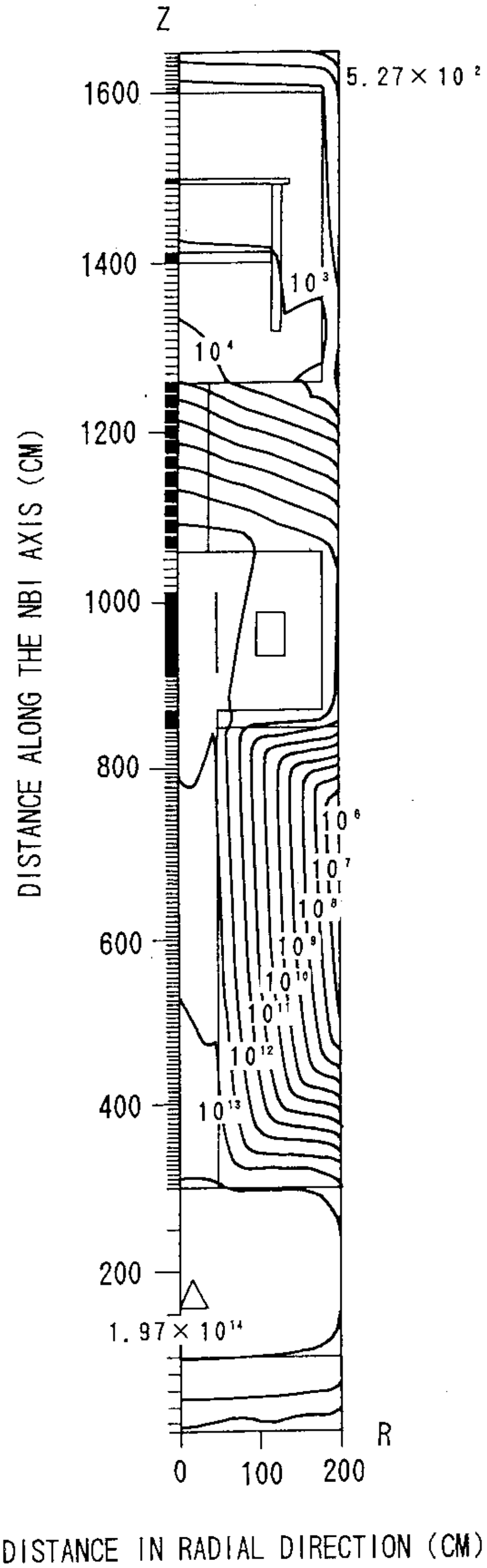


Fig. 20 Fast neutron flux distribution.

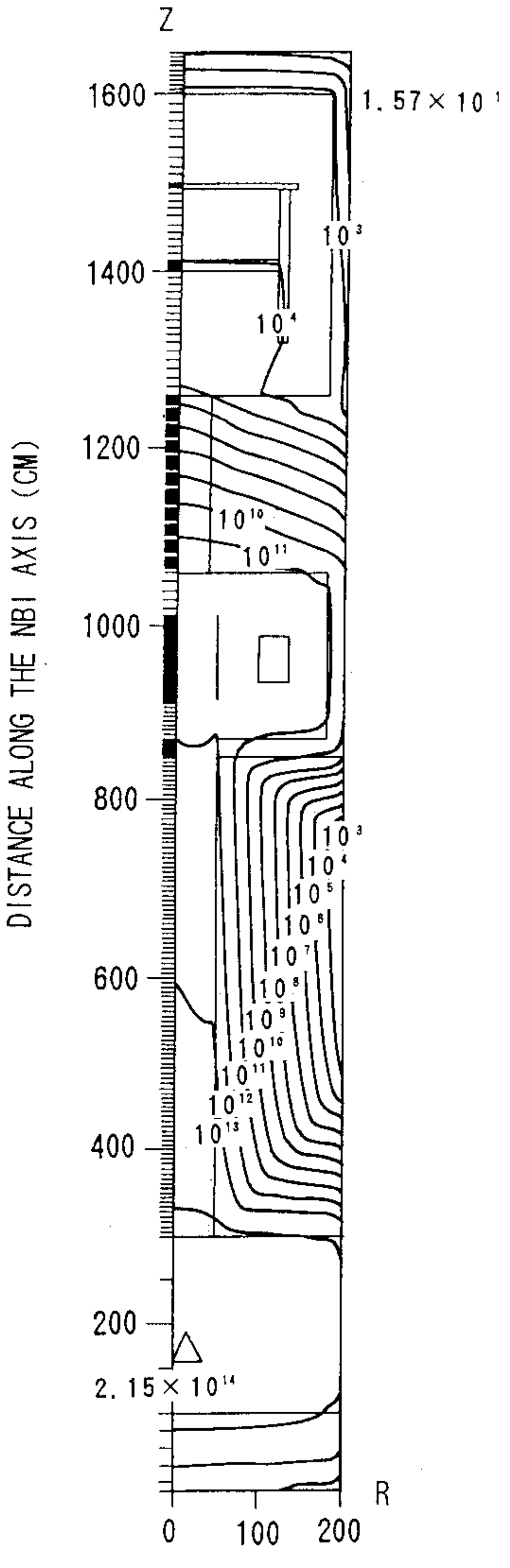


Fig. 21 Total neutron flux distribution.

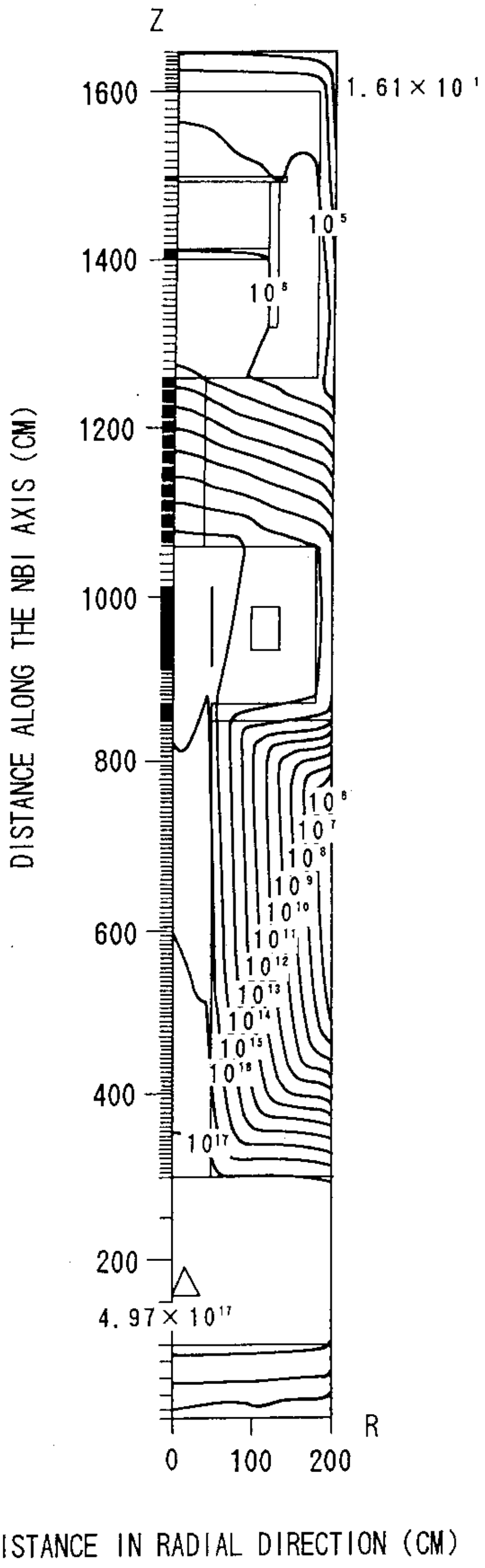


Fig. 22 Total gamma-ray flux distribution.

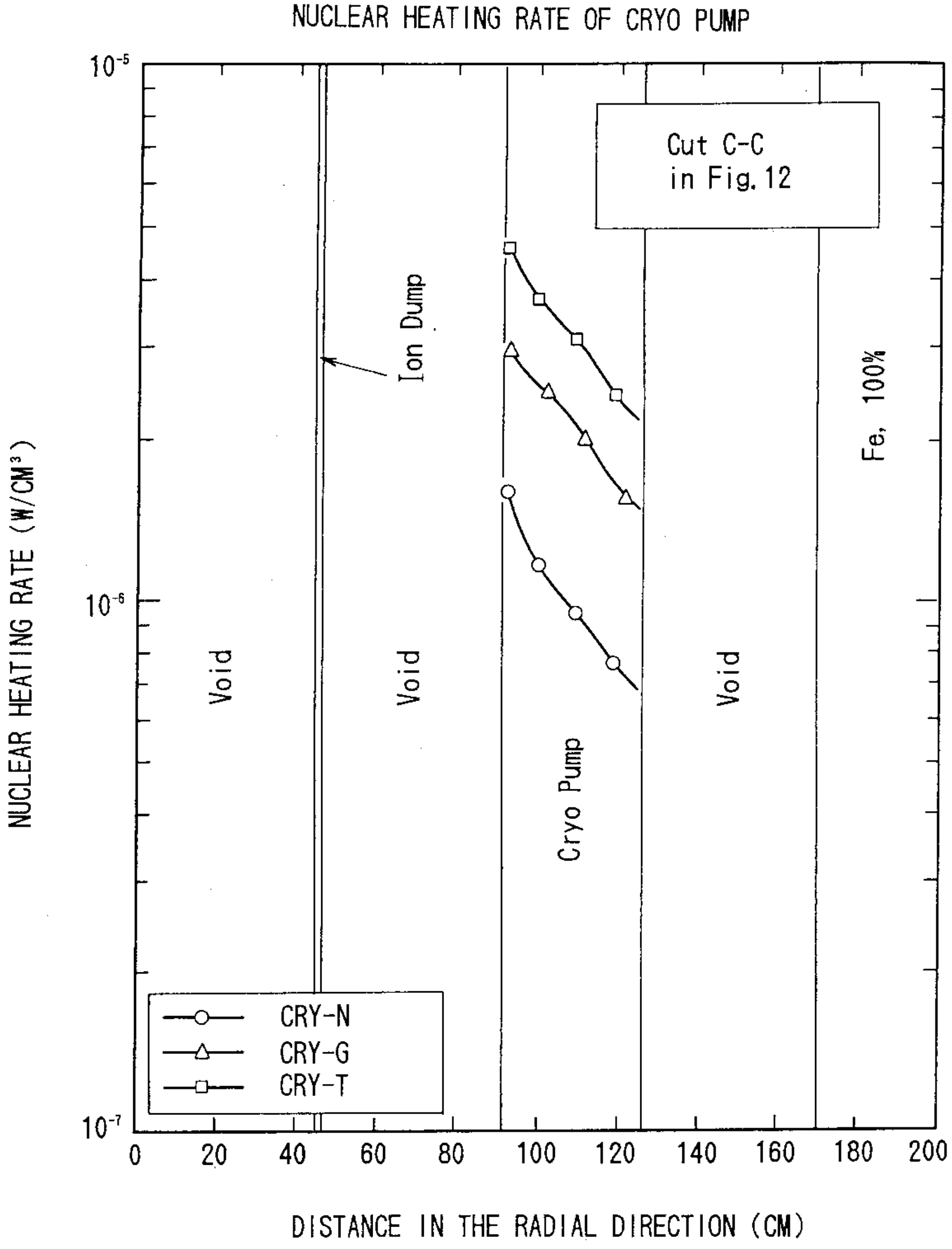


Fig. 23 Nuclear heating rate of cryo pump (Cut C-C in Fig. 12).

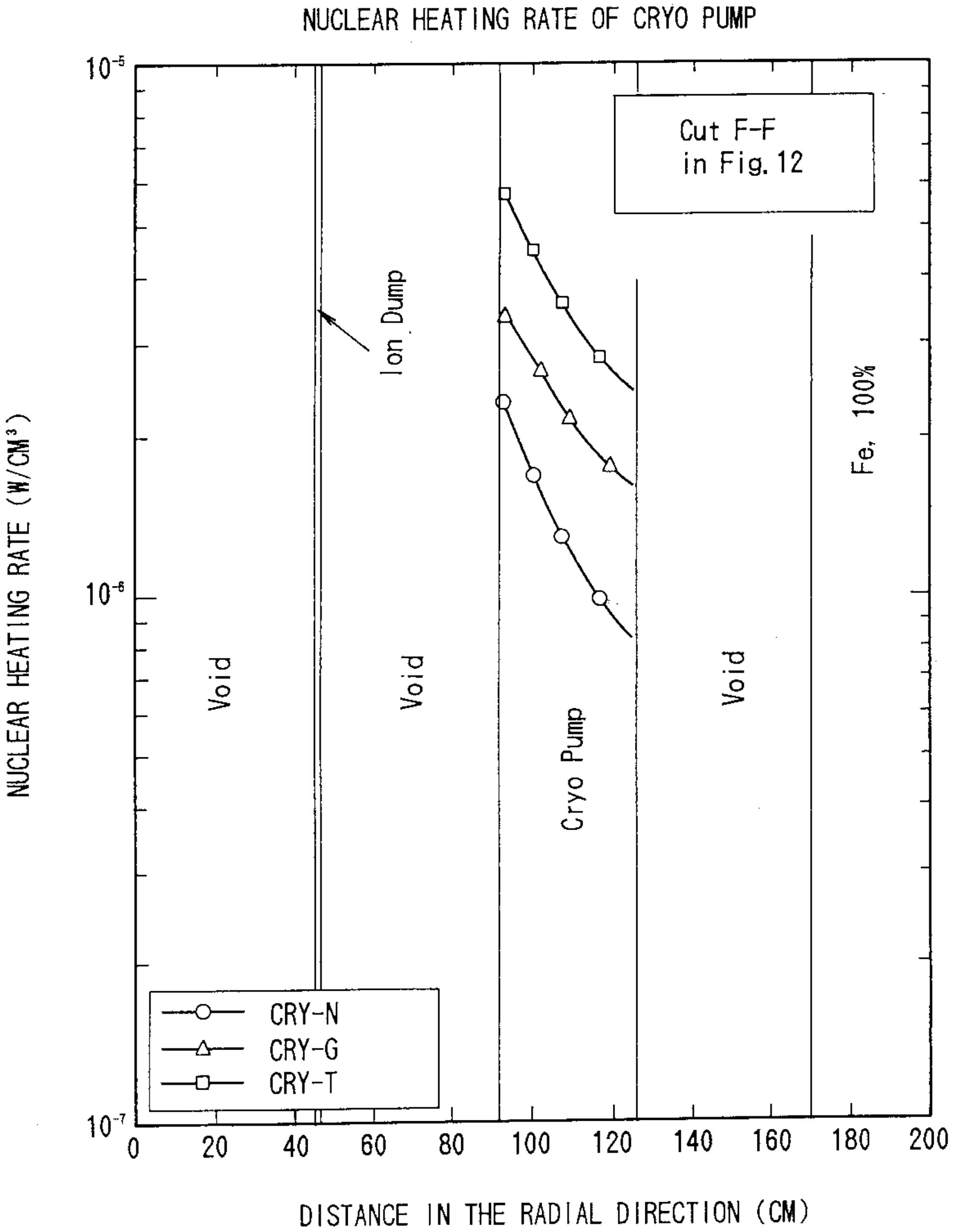


Fig. 24 Nuclear heating rate of cryo pump (Cut F-F in Fig. 12).

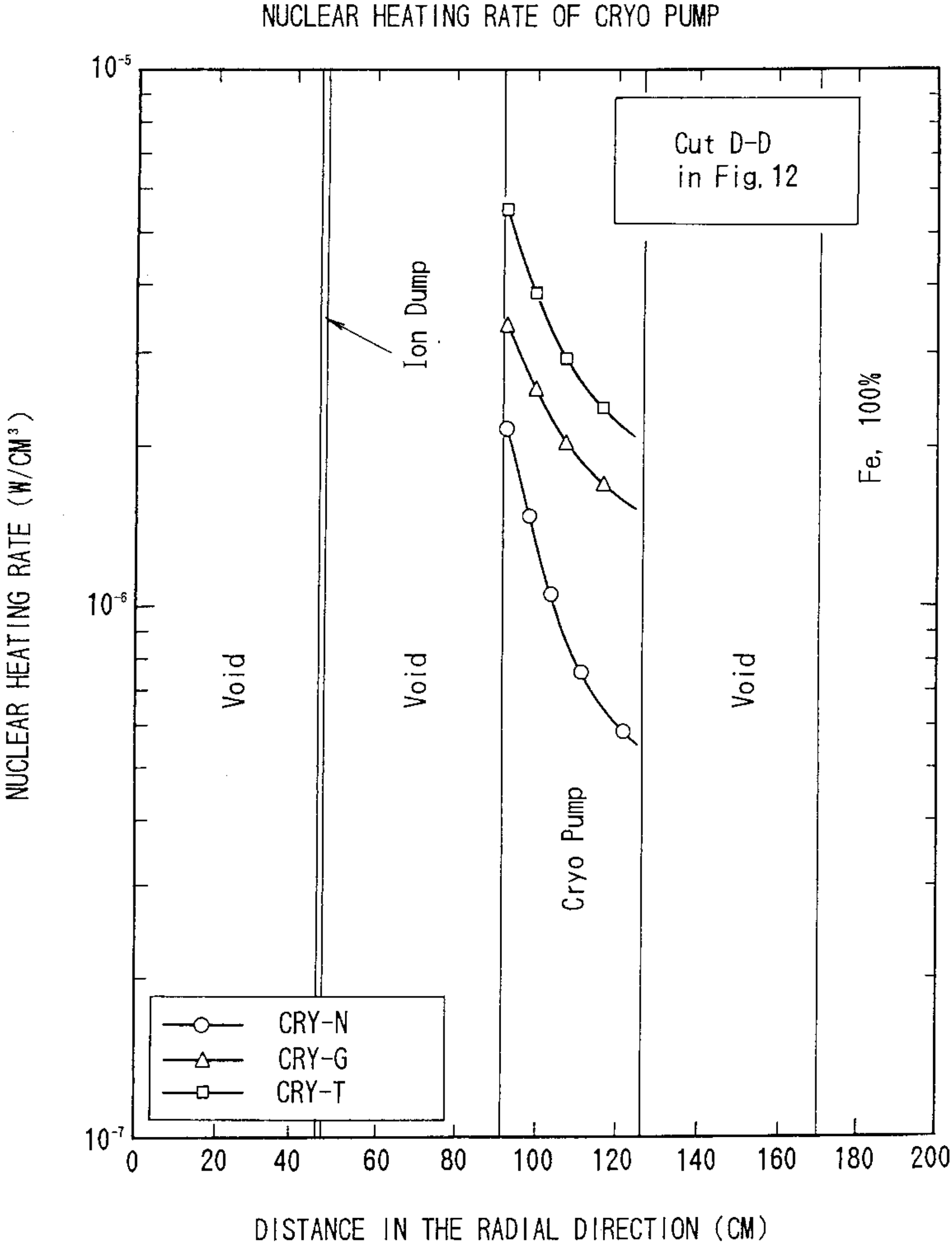


Fig. 25 Nuclear heating rate of cryo pump (Cut D-D in Fig. 12).

As shown in those figures, the nuclear heating rate at the cut D-D is the largest. It is both due to larger effect of neutron streaming through the NBI duct and larger reflection of neutron&gamma-ray fluxes from the NBI neutralizer.

The total nuclear heating in the cryo pump is shown in Table 2. These results are well below the limit of ~40 W [6] for the NBI duct length more than 10 meters. Even with the safety factor of 2 (adopted during ITER CDA to account the calculational uncertainty of total nuclear heating in TFC) the total heating in the cryo pump in those cases is well below the limit. On the contrary, in the case of the 5.5 meters NBI duct the total nuclear heating in the cryo pump is larger the limit.

However, it should be underlined that, as shown in Figs. 23-25, the nuclear heating in the cryo pump is very sensitive to the distance between the cryo pump surface and the edge of the NBI duct. Once that distance is decreased (increased), the total nuclear heating in the cryo pump will be sharply increased (decreased). Therefore, if the cryo pump would be moved father from the NBI duct axis, even in the case of 5.5 meters NBI duct the total nuclear heating in the cryo pump could be decreased below the limit, subject of a distance from the cryo pump to the NBI duct edge.

The one-dimensional distributions of neutron&gamma-ray fluxes and displacement damage in copper grids behind the NBI duct of 10 meters length are shown in Figs. 26 and 27, respectively. The neutron streaming through numerous straight-through channels of NBI neutralizer, as shown in Fig. 14, was not calculated. That effect may rise the results (at the channels exits) by orders of magnitude.

Table 2. Nuclear heating in the NBI cryo pump (**no safety factors are included**).

Nuclear heating, W NBI length, m	Neutron	Gamma-ray	Total
5.5	98	175	273
10.0	3.5	6.8	10.3
11.0	1.6	3.3	4.9
11.3	1.3	2.6	3.9

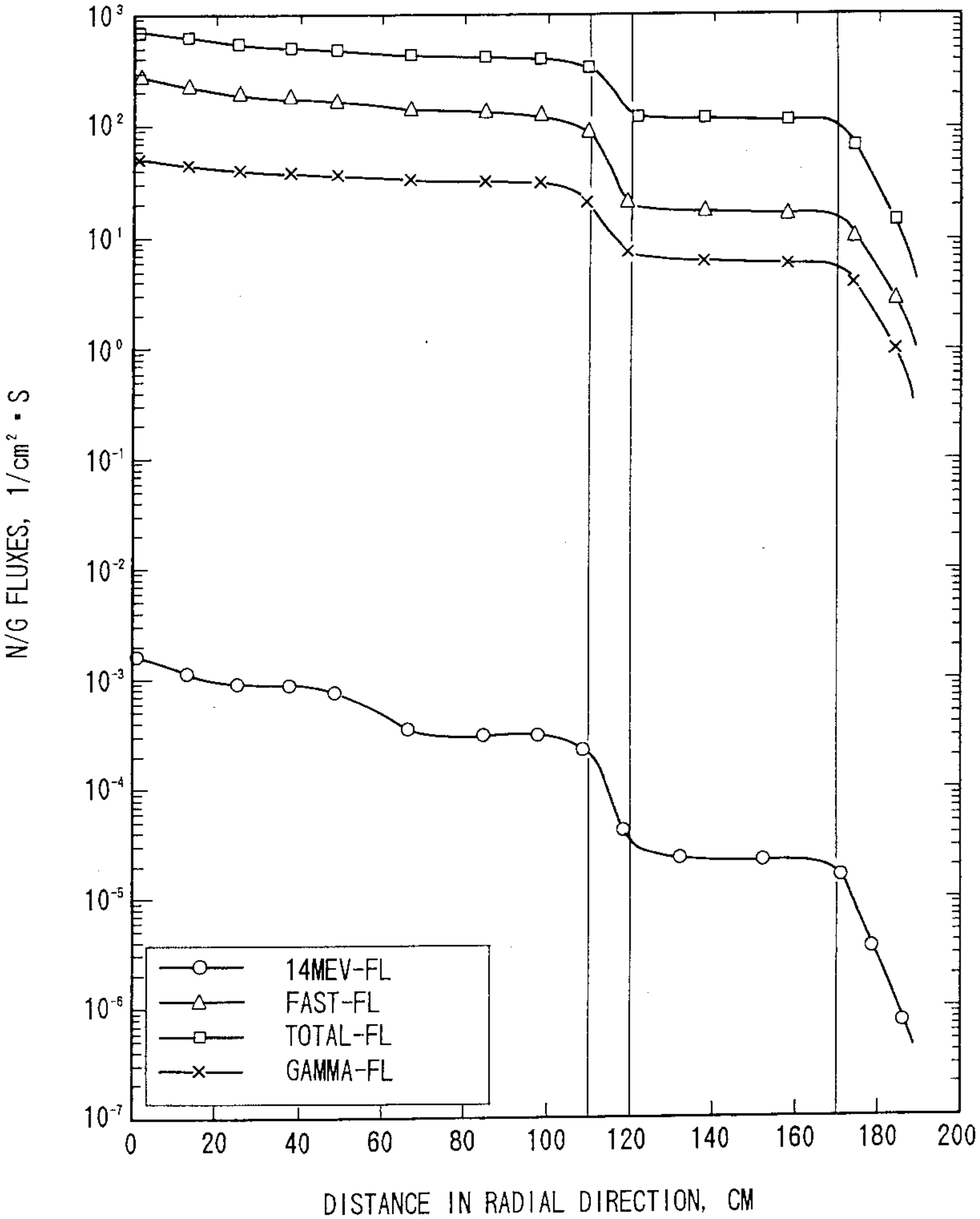


Fig. 26 Distribution of neutron/gamma-ray fluxes behind the neutralizer.

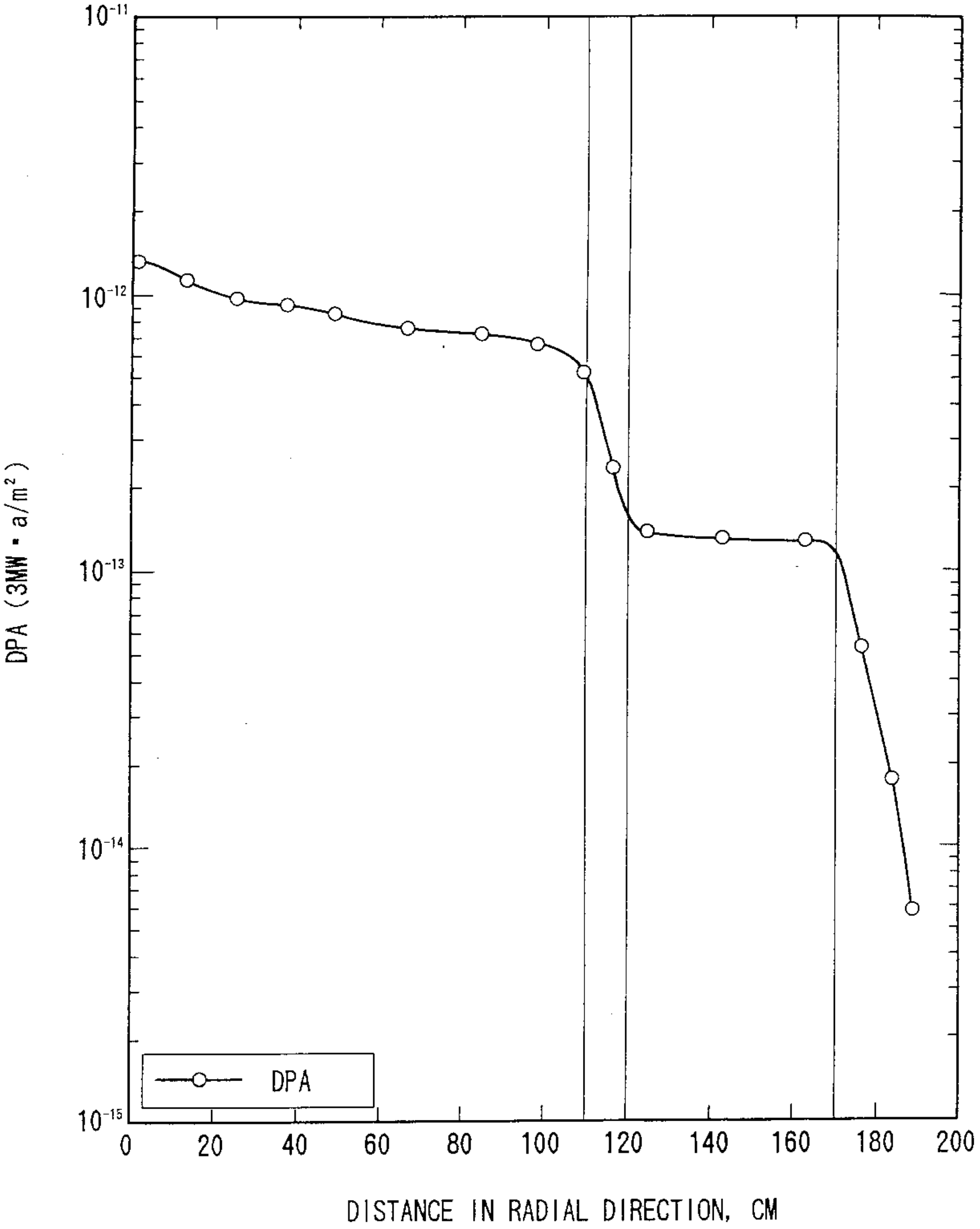


Fig. 27 Distribution of displacement damage rate (dpa) in copper plates behind the neutralizer.

However, even with that corrections the displacement damage in the copper grids are expected to be below the limit of 1 dpa [4] (for 3 $MW \cdot a/m^2$ operation fluence) at least by 6-4 orders of magnitude if the NBI duct length is 11-5.5 meters, respectively.

Thus, it is concluded that the displacement damage in copper grids behind the NBI neutralizer is not a subject of any concern and, in spite of a very rough calculations and followed estimations in this report, no more detail neutronics calculations of that displacement damage are necessary.

4. CONCLUSION

The neutronics calculations with the first calculational model confirm the viability of the current NBI duct design regarding the radiation damage of TFC adjacent to the NBI duct. However, that conclusion is based on a water-cooled stainless steel design option of ITER EDA. An advance lithium/vanadium blanket could rise the dose to insulator of TFC adjacent to the NBI duct behind the limit due to a poor shielding effectiveness of liquid lithium.

The neutronics calculations with the second calculational model show no need to investigate further the displacement damage in copper grids behind the NBI neutralizer due to the very small radiation damage of those components comparing with the design limit.

The total nuclear heating in the cryo pump behind the NBI duct of more that 10 meters length is calculated to be less the limit even with the safety factor of 2 adopted to account the calculational error of total nuclear heating in the TFC during ITER CDA. For the NBI duct of 5.5 meters length the total nuclear heating in the cryo pump is larger the limit even without safety factors.

Acknowledgements

This work was performed as part of the design study of ITER conducted by the Department of ITER Project of JAERI which is under the leadership of Dr. S. Matsuda.

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6. I. Inoue, Private communication, JAERI, NBI Lab., March 7, 1994.

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