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EVALUATION OF NEUTRON STREAMING THROUGH INJECTION PORTS IN A TOKAMAK-TYPE FUSION REACTOR

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The effects of neutron streaming through injection ports in the fusion reactor designed in JAERI have been studied, especially those on tritium breeding ratio and the shielding of the superconducting magnet.

In placement of the injection ports in the blanket, the tritium breeding ratio decreases by up to 1.3 % , and shielding problem of the superconducting magnet is very important.

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核融合炉における中性子ストリーミング効果の検討

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原研の核融合動力炉の第2次試設計において中性粒子入射孔からの中性子ストリーミング効果を検討した。とくにトリチウム増殖比，超電導マグネットの遮蔽について計算を行った。その結果，直径1mの入射孔を設けた場合にはトリチウム増殖比は約1.3%減小し，超電導マグネットの遮蔽も厳しくなることが明らかになった。

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目次なし

1. INTRODUCTION

In a D-T fusion reactor, 14 MeV neutrons are released from the plasma zone, and they are slowed down in the blanket. In most blanket and shield designs, there are voids or ducts which may become additional sources of radiation leakage. These voids in the fusion reactor are injector, diagnostic ports, vacuum pumping ports and divertor channels. Through the voids or ducts in the blanket and shield, paths exist through which neutrons and gamma-rays stream out with little or no reduction of the energy. Such streaming influences the neutronic characteristics of a fusion reactor such as irradiation dose of the superconducting magnet, tritium breeding ratio and induced radioactivity in the structural materials.

The effects of neutron streaming through the neutral beam injection ports on tritium breeding ratio and superconducting magnet shielding have been studied for the fusion reactor designed in JAERI.(1) Three-dimensional calculations are necessary to estimate the effects of void streaming accurately, which is not possible by the limitation in computing time. Two-dimensional transport code TWOTRAN-GG(2) was thus used in the present study.

2. CALCULATIONAL MODEL AND PROCEDURE

Design of the fusion reactor in JAERI(1) for the present study is shown in Figs.1 and 2. The major radius is 10 m and the plasma radius is 2 m. The toroidal plasma is relatively narrow in sectional area. The blanket surrounding the toroidal plasma consists of a cellular structure, each cell made of a molybdenum vessel which contains Li_2O pebbles and graphite balls. The vessel has a dual shell structure as shown in Fig.3. The magnet shield, placed between the blanket and the magnets, consists of borated water, heavy concrete and lead. The injection ports serving also as evacuation ports are provided in the blanket region(Fig.2). There are twelve ports of diameter 1 m spaced at 30° intervals around the blanket.

Difficulty is involved in forming the model of plasma, blanket and injection ports in two-dimensional configuration. Therefore, the models employed are infinite concentric cylinders and layer disks, as shown in Figs.4 and 5, respectively. In the former named "cylindrical plasma model", the injection ports are not cylindrical but a hollow disk. This results in an overestimate of the neutron streaming when height of the disk is taken as equal to the diameter of injection ports. In the latter model named "disk plasma model" where the form of injection ports is cylindrical, the shapes of plasma and blanket are not the same as the fusion reactor.

Transport calculations were mostly made with two-dimensional discrete ordinates code TWOTRAN-GG(2) using 8-energy-group neutron cross sections and P_1-S_{12} approximation. The cross section set was obtained, as follows. The 42-energy-group neutron cross sections are first prepared from ENDF/B-III(4) by SUPERTOG(3) with 1/E as the weighting function. The 8-energy-group neutron cross sections, which are derived by using the neutron-energy spectrum as the weighting function, are thus produced by the one-dimensional transport code ANISN,(5) using the above 1/E weighted cross sections.

3. RESULTS AND DISCUSSION

3.1 Comparison of TWOTRAN-GG and ANISN

To examine the effect of reducing energy-group number and anisotropy degree on the calculated results in TWOTRAN-GG, the results were compared with those in one-dimensional transport code ANISN. Tritium breeding ratios of the blanket without injection ports were calculated using both the codes. They are in agreement, as shown in Table 1.

Fig.6 shows the neutron flux distributions in the blanket in both ANISN and TWOTRAN-GG by P_1-S_{12} approximation. The fluxes are all normalized to the nominal wall load of 5.82×10^{13} D-T $n/cm^2 \cdot s$. Values are in fairly good agreement, except slight differences in the region far away from the plasma axis.

3.2 Comparison of TWOTRAN-GG and the ray analysis method

To confirm the calculated results of TWOTRAN-GG in the blanket region with injection port, the neutron transmission through cylindrical duct was calculated, and compared with these by the ray analysis method.(6) The results of 14 MeV neutron transmission through cylindrical duct in an attenuating medium(graphite) calculated by TWOTRAN-GG, are compared with those by the ray analysis method in Fig.7. The values by TWOTRAN-GG fit well to the ray analysis curve near exit of the duct. However, the agreement is not good at the entrance where the ray analysis method does not give exact results.

In Figs.6 and 7 adequecy of the code TWOTRAN-GG for the calculations is evident.

3.3 The effect of neutron streaming on tritium breeding ratio

The tritium breeding ratio is generally calculated without considering the neutron streaming through the voids and ducts which exist in the blanket design. In the following, the change of tritium breeding ratio due to the neutron streaming through injection ports is evaluated by TWOTRAN-GG.

When injection ports exist in the breeding-zone of blanket, the tritium breeding ratio reduces compared with the case without them due to smaller breeding-zone volume and also to the deviation of the neutron spectrum caused by neutron streaming through ports. There is a threshold in ^{7}Li(n,n'α)t cross section at about 3 MeV, the reaction is more sensitive to neutron spectrum than the ^{6}Li(n,α)t reaction in the region near the first wall and injection ports.

The change of tritium breeding ratio due to injection ports, ΔT, can be divided into two components; i.e. ΔT^v due to the reduced volume of breeding-zone, and ΔT^s due to deviation of the neutron spectrum in the blanket.

$$\Delta T = \Delta T^v + \Delta T^s \tag{1}$$

On the other hand, tritium is produced in the lithium by nuclear reaction, ^{6}Li(n,α)t and ^{7}Li(n,n'α)t. The total breeding ratio, T is thus the sum of ^{6}Li breeding ratio, T_6 and ^{7}Li breeding ratio, T_7.

$$T = T_6 + T_7 \tag{2}$$

$$\Delta T = \Delta T_6 + \Delta T_7 \tag{3}$$

where ΔT_6 is the change of T_6 and ΔT_7 the change of T_7. The relation (1) also applies to ΔT_6 and ΔT_7. Then,

$$\Delta T_6 = \Delta T_6^v + \Delta T_6^s \tag{4}$$

$$\Delta T_7 = \Delta T_7^v + \Delta T_7^s \tag{5}$$

In Table 2 are compared the tritium breeding ratios with and without injection ports calculated by the cylindrical plasma model(Fig.4). As already described in section 2, the model overestimates the volume of injection ports when the height of the disk is taken as equal to the diameter of the injection ports. In the table, the values in case II are corrected by the correction factor f, which is defined as the ratio of the volume of an injection port in the design to that in the model.

The ^{6}Li breeding ratio, T_6, the ^{7}Li breeding ratio, T_7 and the total tritium breeding ratio, T calculated by the disk plasma model with and without injection ports, are shown in Table 3. In this model, the shapes of plasma and blanket are not the same as those in the design, so the absolute values of neutron fluxes and reaction rates may not be adequate. However, the shape of injection ports is similar to that of the design, and information may be thus obtained on the relative changes due to injection ports.

As seen in Tables 2 and 3, the ^{6}Li breeding ratio calculated by the disk plasma model is somewhat larger than that by the cylindrical plasma model. However, the result is the opposite for the ^{7}Li breeding ratio. The differences may be ascribed to the differences of plasma geometry which introduce a variation of the neutron angular distribution.

Table 4 shows the relative changes in the tritium breeding ratio. The negative sign implies an increase of the values in the absence of injection ports. ΔT_7 in the disk plasma model is an increment but ΔT_7 in the cylindrical plasma model a decrement. The above difference is due to the difference in shape of the injection ports in both the models. In the design, if the volume fraction of an injection port is small enough compared with that of the breeding-zone, ΔT_7^s will be an increment. To clarify whether ΔT_7 is an increment or a decrement, three-dimensional calculations are necessary.

In both the models, the existence of injection ports is found to introduce a net decrement of about 1.3 % in the total tritium breeding ratio.

3.4 The effect of neutron streaming on shielding of the superconducting magnets

In the design(Fig.2), the shielding region which protects superconducting magnets from fast neutrons and gamma-rays is on the outside of the blanket. If there is enough space for the shield, radiation damage to the magnets is not of much problem. The size of magnets depends on the shield thickness, so the shield must be as thin as possible.

Neutral beam injection ports penetrate the blanket region such that a straight void exists from plasma region to shield region. As a result, a substantial fraction of the neutron flux streams through these ports. In the region of superconducting magnets close to the ports, the shielding problem is quite considerable. In this section, shielding calculations of superconducting magnets were made in the layer disk plasma model shown in Fig.8.

Neutron penetration through the shield region and injection ports was analyzed. Neutron flux contours plotted by JGPCP(8) are shown in Figs.9, 10 and 11 for the different neutron energies, respectively. As described, the plasma shape in the disk plasma model is different from that in the design. However, it is possible to estimate the relative changes of neutron flux associated with the injection ports in the region of superconducting magnets. In Fig.10, it is seen that the neutron flux of energy over 0.1 MeV which may affect the superconductor,(7) at the surface of superconducting magnets close to the ports become about 24 times that away from the ports. In addition, at the outer edge of injection ports, the neutron flux of energy over 0.1 MeV is $\sim 10^{13}$ n/cm^2•s.

The above results show that the injection ports result in difficult shielding problem of the superconducting magnets and injectors.

4. SUMMARY

The effects of neutron streaming through injection ports in neutronic calculations for a tokamak-type reactor designed in JAERI were studied.

(1) The two-dimensional transport code TWOTRAN-GG is useful for neutronic calculations for the fusion reactor, as is the one-dimensional transport code ANISN.

(2) The tritium breeding ratio decreases by as much as 1.3 % when the injection ports of a diameter 1 m exist in the blanket design.

(3) Injection ports increase the neutron flux of energy over 0.1 MeV at the surface of the superconducting magnets close to the ports, to about 24 times that away from ports. Shielding for the magnets adjacent to the ports have thus to be increased.

(4) Calculations give a flux level of $\sim 10^{13}$ n/cm^2•s having energy over 0.1 MeV at the surface of the neutral beam injectors. Sufficient shielding is necessary for the radiation damage.

ACKNOWLEDGEMENTS

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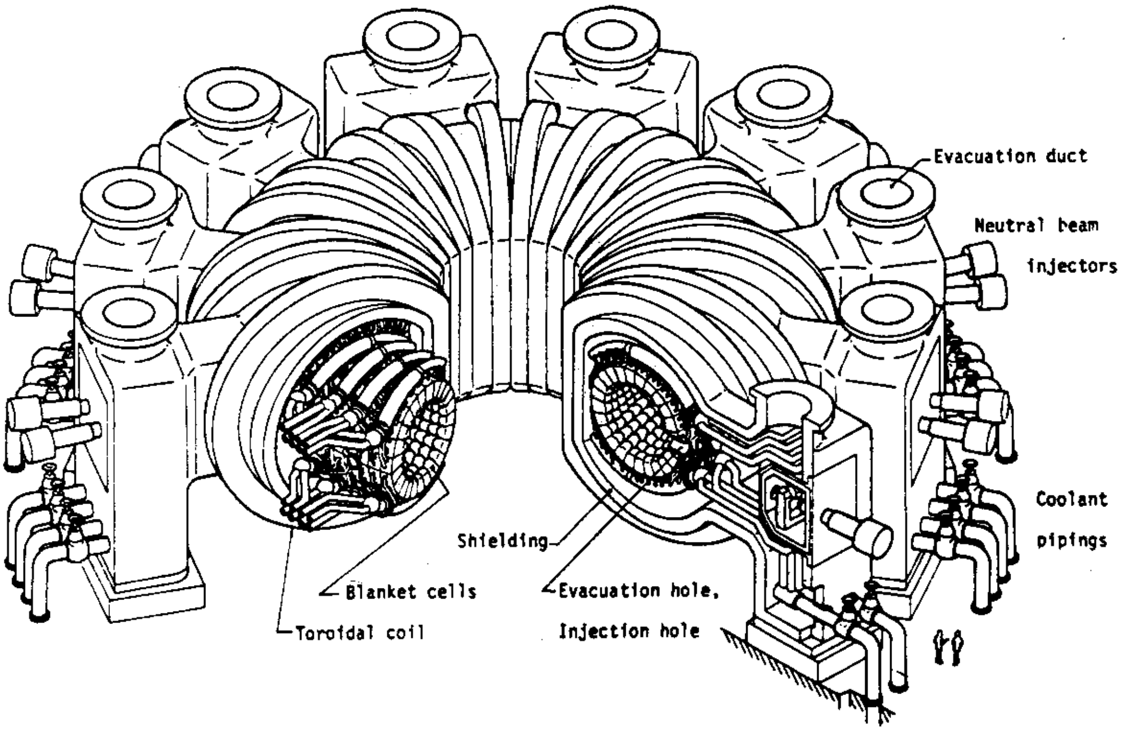


Fig. 1 Overall view of the reactor.

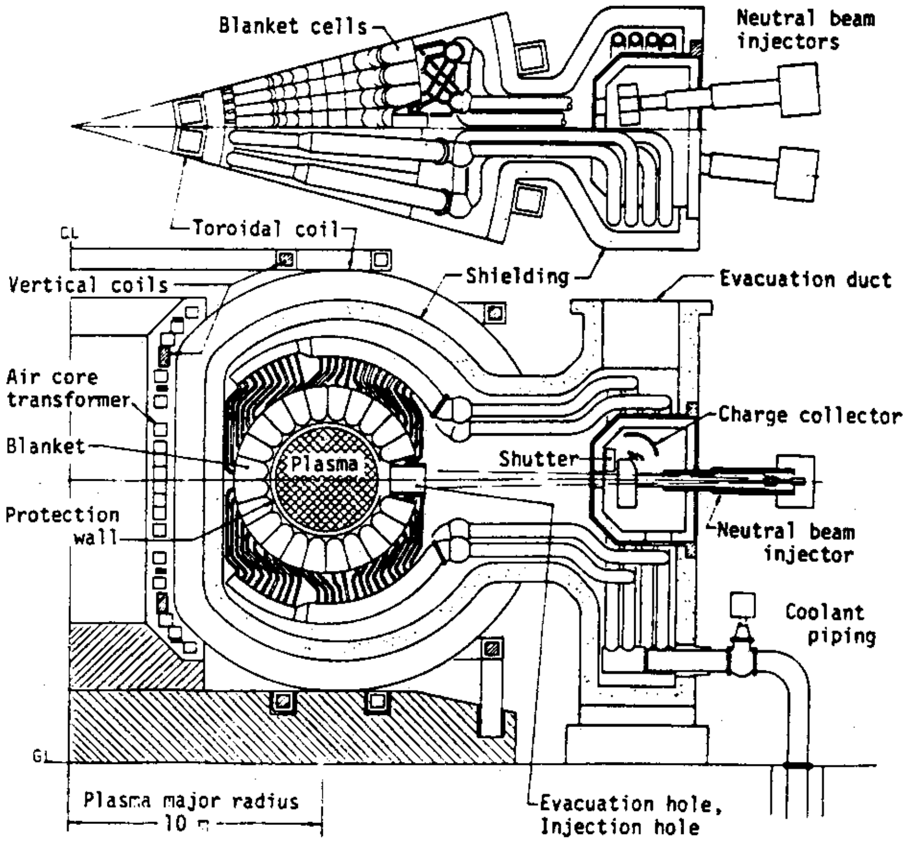
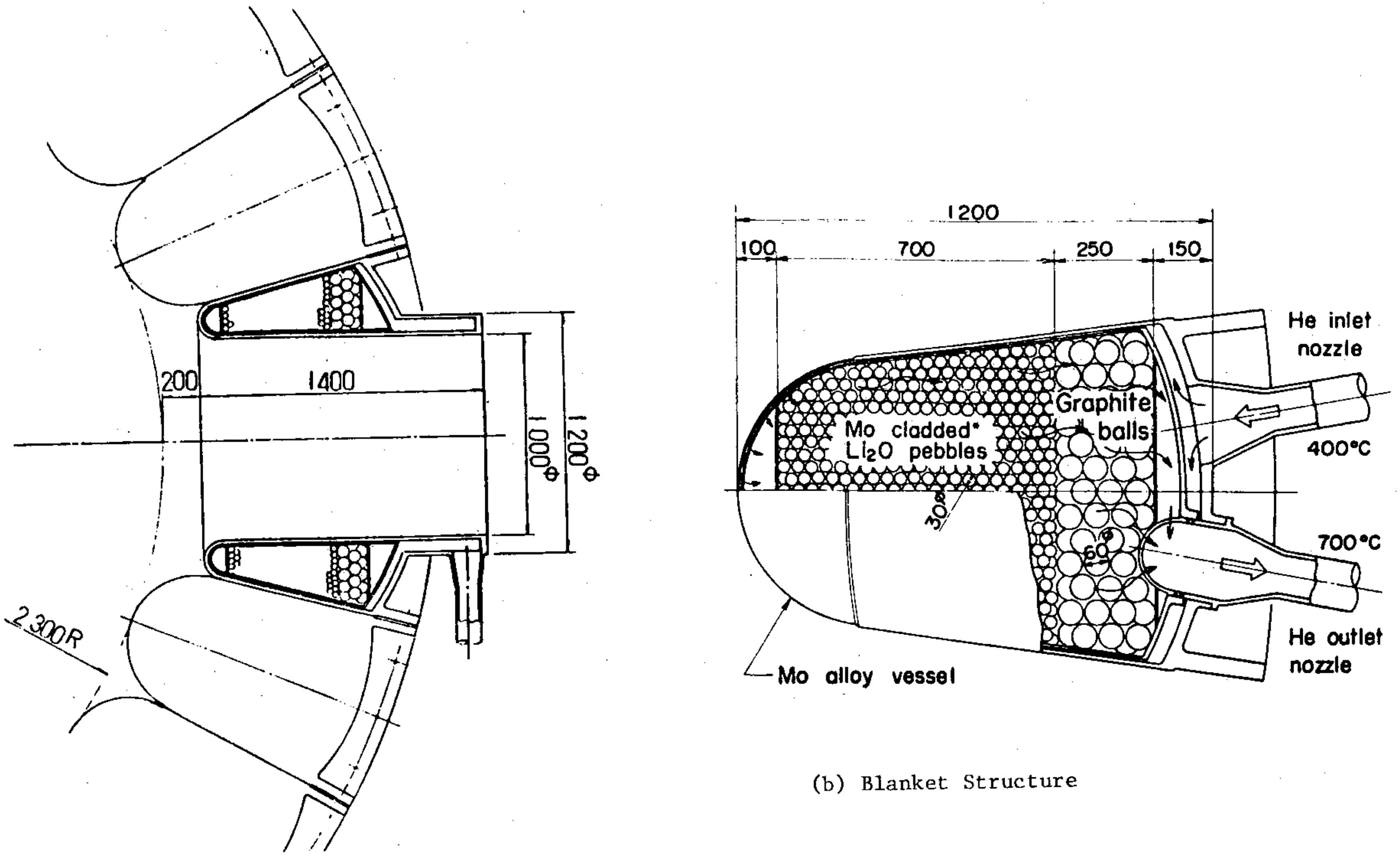


Fig. 2 Cross section of the reactor module.



(a) Cross section of injection port

(b) Blanket Structure

Fig. 3 Structure of injection port and blanket.

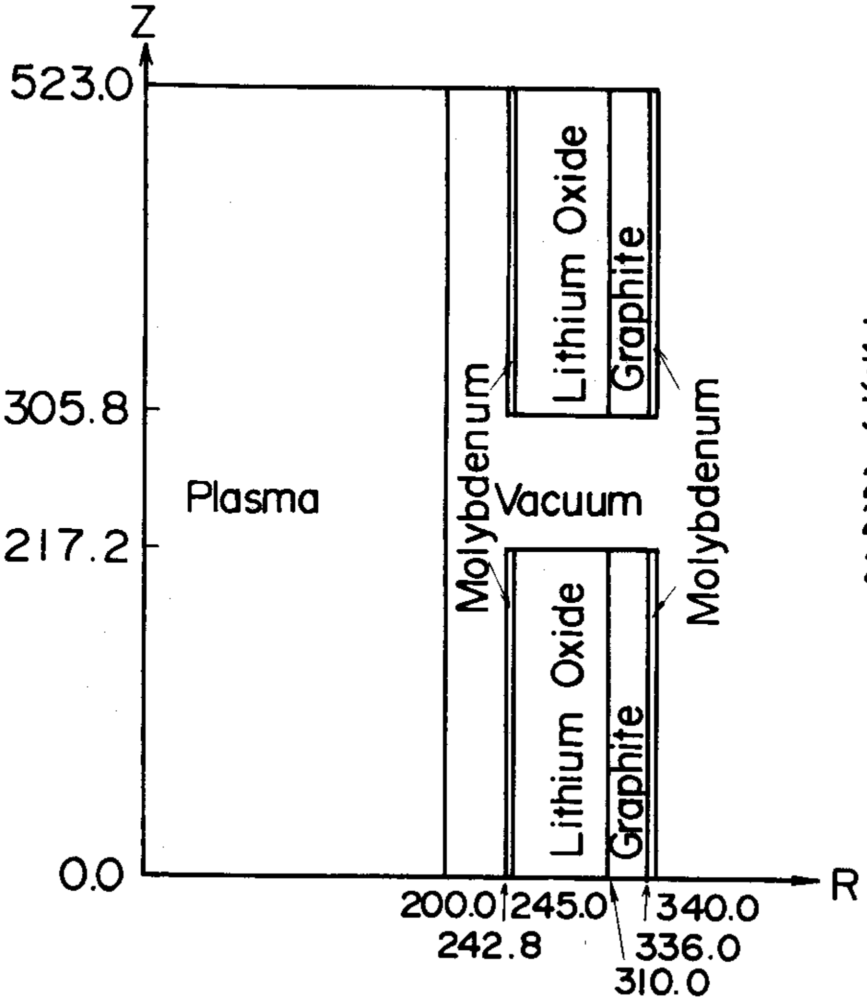


Fig. 4 Cylindrical plasma model.

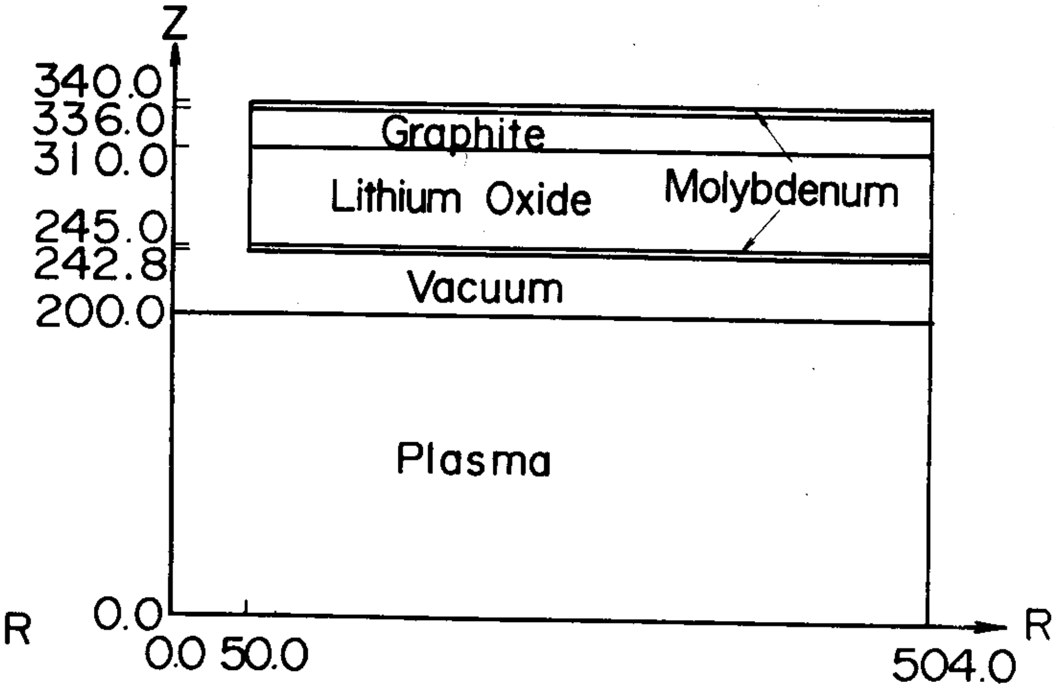


Fig. 5 Disk plasma model.

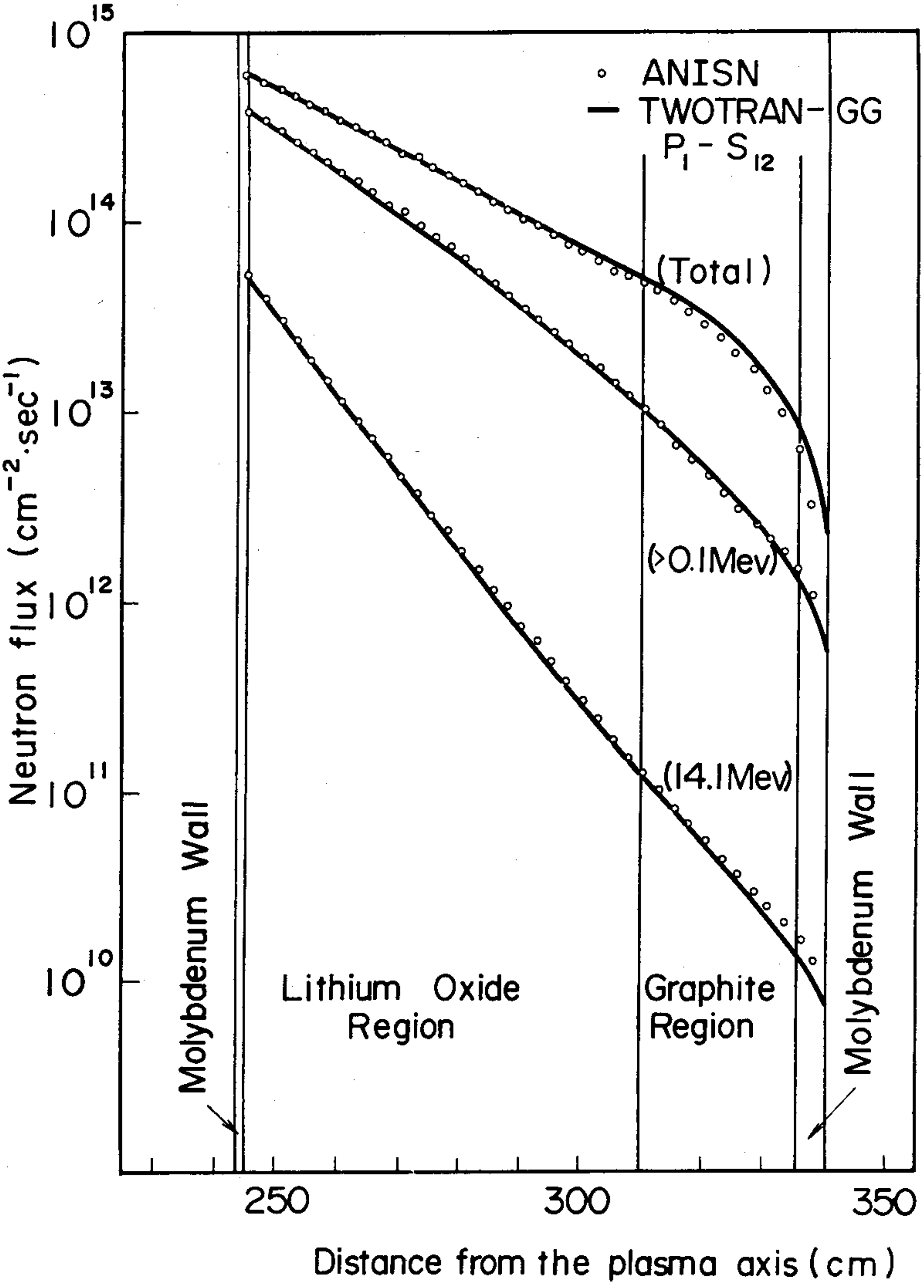


Fig. 6 Comparison of neutron fluxes calculated by ANISN and TWOTRAN-GG.

Table 1 Comparison of tritium breeding ratios calculated by ANISN and TWOTRAN-GG.

	ANISN	ANISN	TWOTRAN-GG
NEUTRON ENERGY GROUP	42	8	8
ORDER OF ANGULAR QUADRATURE	8	12	12
ORDER OF SCATTER	5	1	1
NUMBER OF MESH POINTS	55	55	35 x 29
T_6*	0.9331	0.9315	0.9315
T_7**	0.2939	0.2952	0.2940
T***	1.2270	1.2267	1.2255

* Breeding Ratio by $^6Li(n,\alpha)t$ Reaction.

** Breeding Ratio by $^7Li(n,n'\alpha)t$ Reaction.

*** Total Breeding Ratio (T_6+T_7).

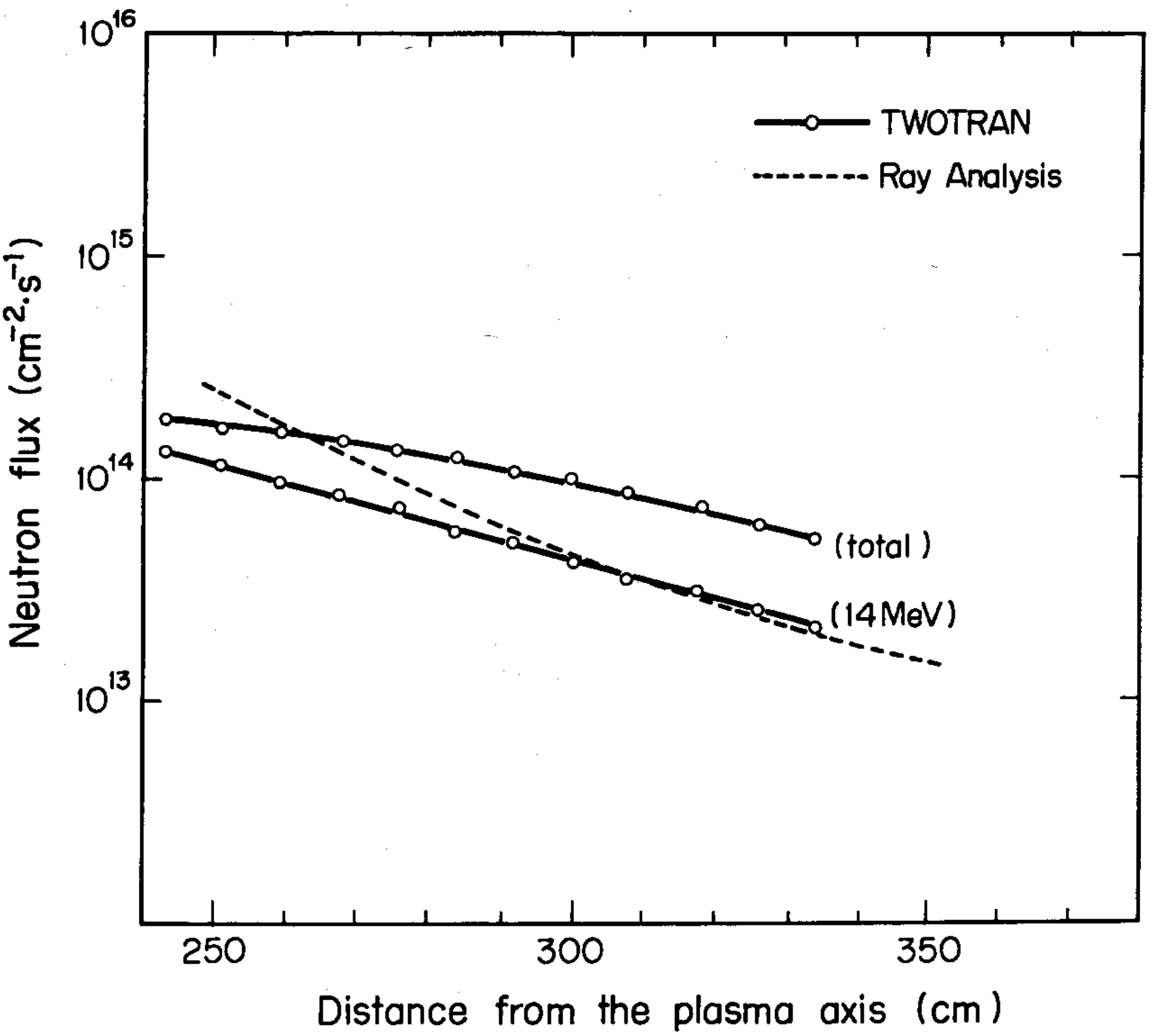


Fig. 7 Comparison of 14 MeV neutron fluxes along axis of cylindrical injection port calculated by TWOTRAN-GG and the ray analysis method.

Table 2 Tritium breeding ratios calculated by cylindrical plasma model

Case	T_6	T_7	T
Case I*	0.9315	0.2940	1.2255
Case II**	0.9173	0.2927	1.2101

* Absence of injection port

** Presence of injection port

Table 3 Tritium breeding ratios calculated by disk plasma model

Case	T_6	T_7	T
Case III*	0.9822	0.2541	1.2363
Case IV**	0.9660	0.2544	1.2204

* Absence of injection port

** Presence of injection port

Table 4 Comparison of relative differences[*] of tritium breeding ratios calculated by cylindrical plasma model and disk plasma model.

	CYLINDRICAL PLASMA MODEL	DISK PLASMA MODEL
ΔT	0.0154	0.0159
ΔT^v	0.0106	0.0122
ΔT^s	0.0049	0.0037
ΔT_6	0.0142	0.0163
ΔT_6^v	0.0080	0.0097
ΔT_6^s	0.0061	0.0066
ΔT_7	0.0013	-0.0004
ΔT_7^v	0.0025	0.0025
ΔT_7^s	-0.0013	-0.0029
$\Delta T/T$	1.26 %	1.29 %
$\Delta T^v/\Delta T$	68.4 %	76.5 %
$\Delta T^s/\Delta T$	31.6 %	23.5 %

[*] (Ratios without injection port) - (Ratios with injection port).

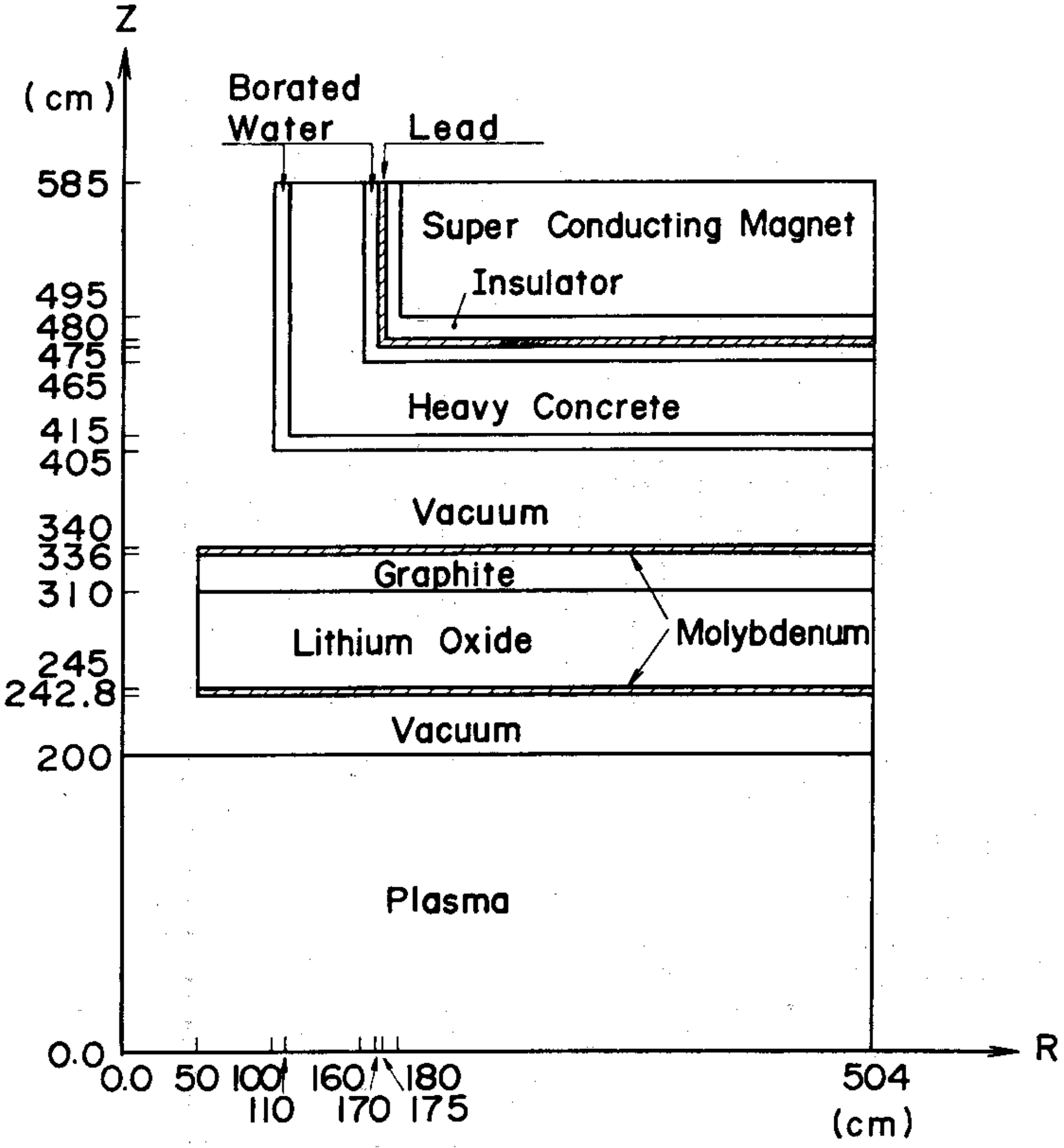


Fig. 8 Disk plasma model used in shielding calculation of superconducting magnet.

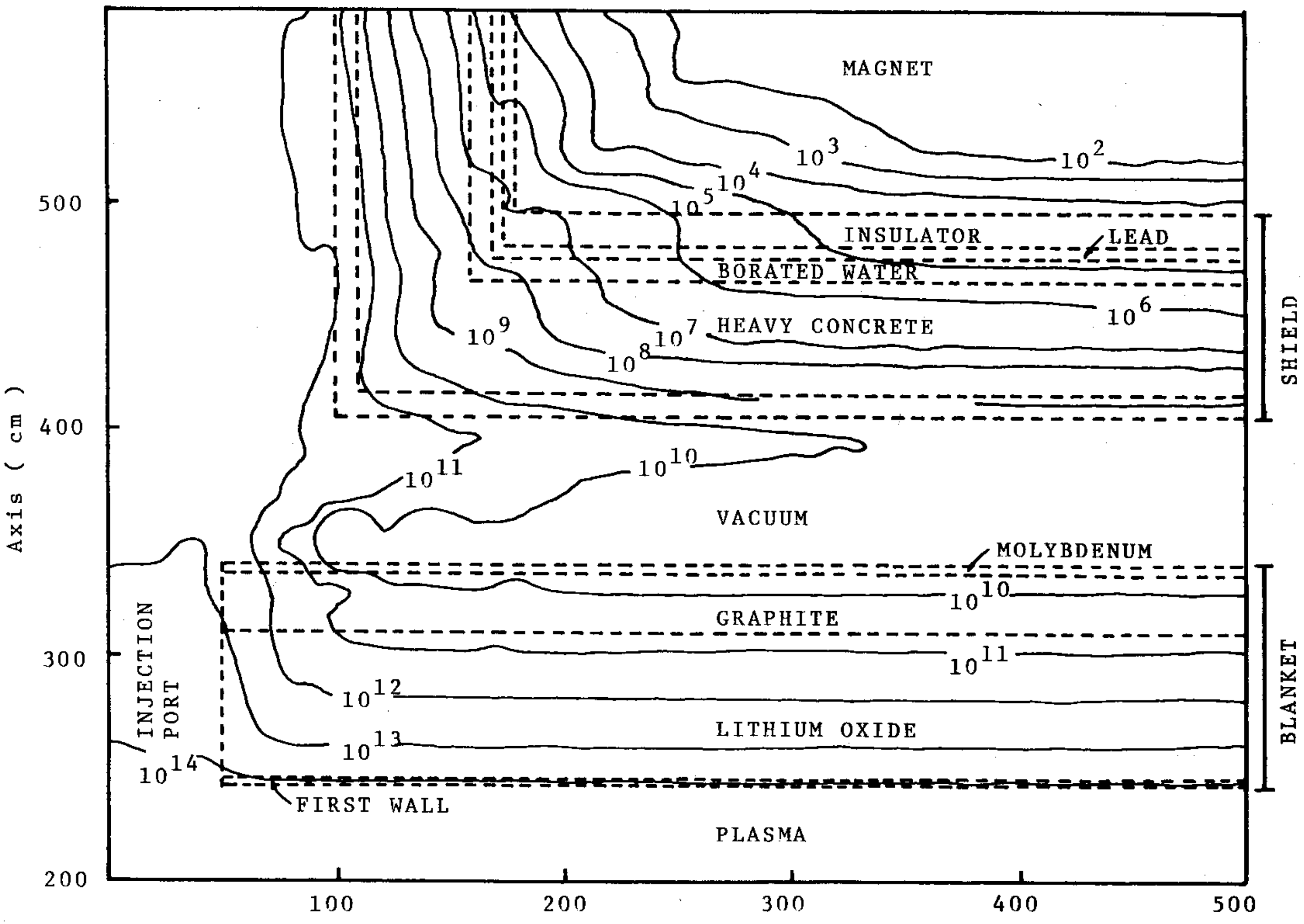


Fig.9 Flux contour plot due to neutrons with energy 14 MeV. (n/cm^2-s)

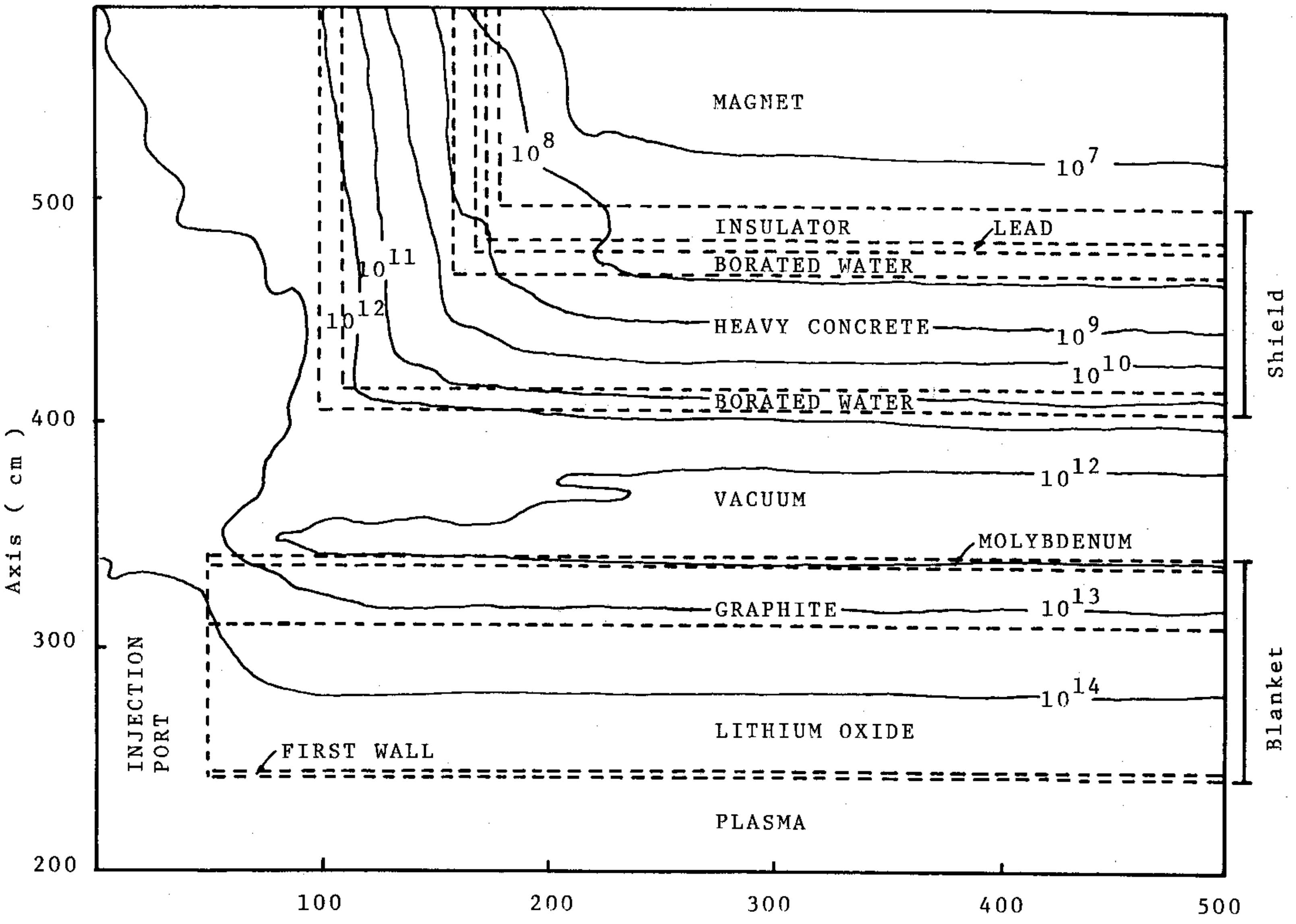


Fig.10 Flux contour plot due to neutrons with energy over 0.1 MeV. (n/cm^2-s)

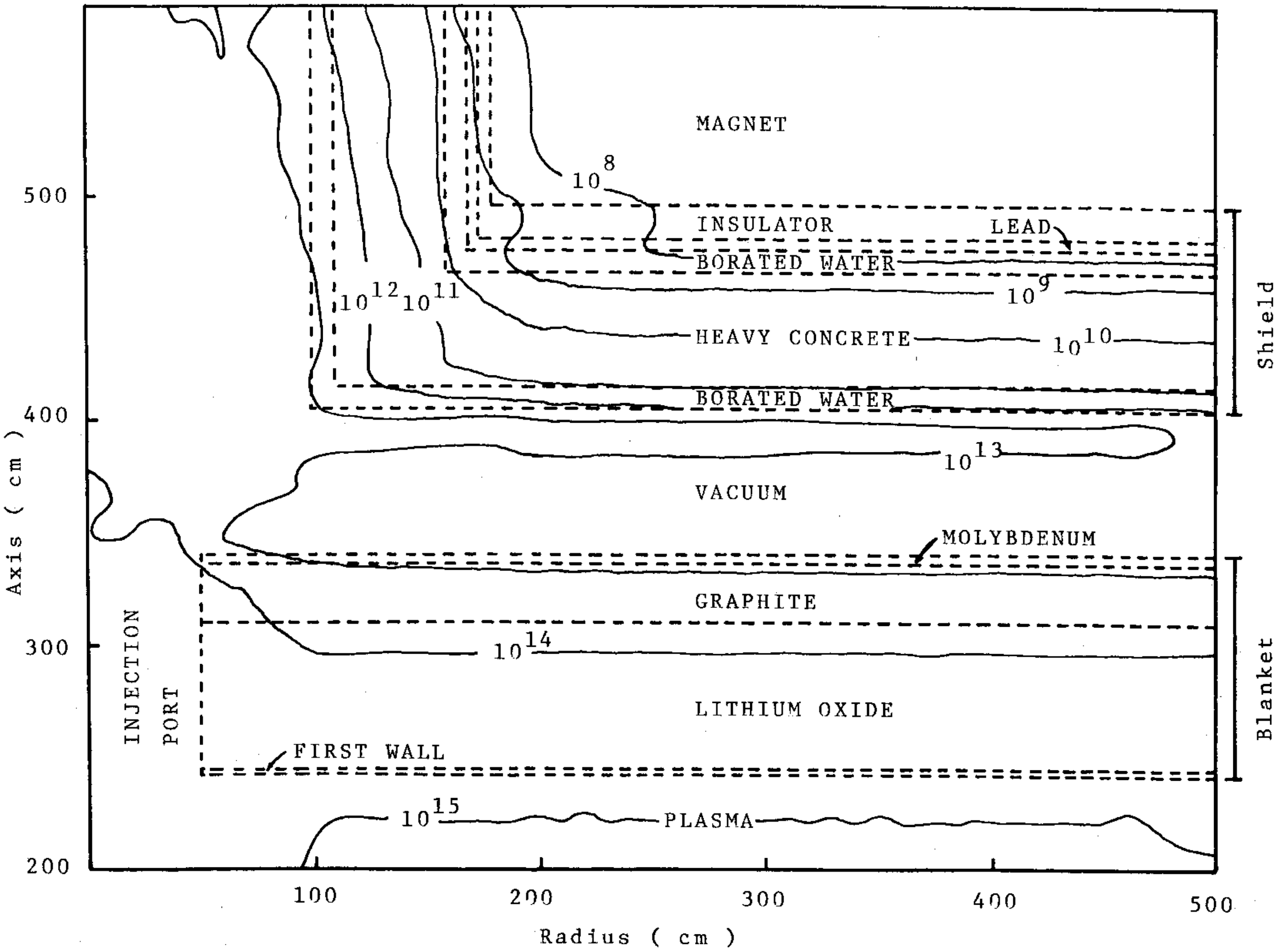


Fig.11 Total neutron flux contour plot. (n/cm^2-s)