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Neutronic and Photonic Studies on Fusion Reactor Blankets with Low Lithium and Tritium Inventories

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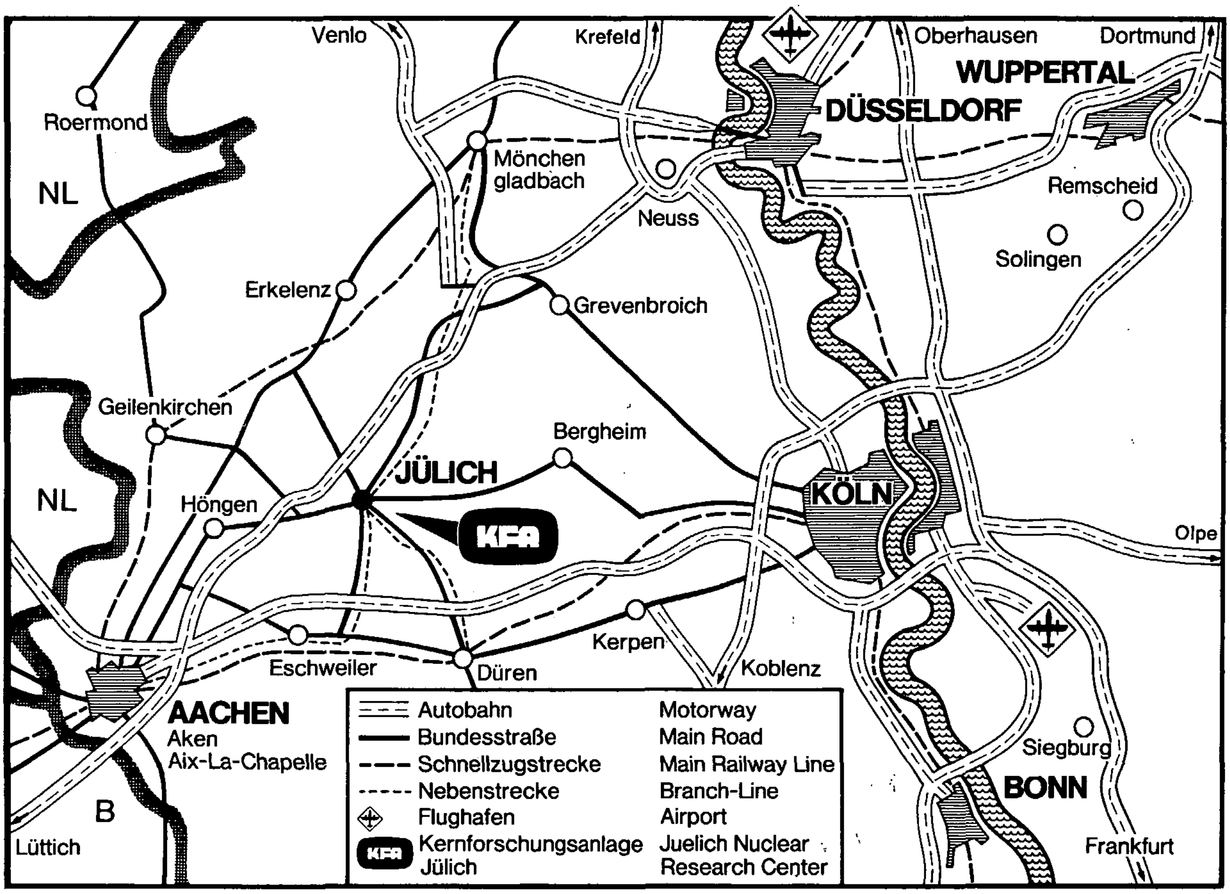

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NEUTRONIC AND PHOTONIC STUDIES ON FUSION REACTOR BLANKETS WITH LOW LITHIUM AND TRITIUM INVENTORIES

by

H. Brockmann
K.A. Verschuur*)

ABSTRACT

This report presents some model designs of fusion reactor blankets with low lithium and tritium inventories. The lithium inventory is minimized by using a thin breeding zone which is operated in a soft neutron spectrum. Enriched lithium (28 % up to 90 % ^{6}Li) is used as breeding material and beryllium is employed for neutron multiplication and moderation. Due to the low lithium inventory, the equilibrium tritium inventory can also be kept to a minimum provided the tritium extraction system is sufficiently efficient. A parametric study has been performed to investigate the relevant neutronic and photonic characteristics of this blanket concept. Different blanket models are compared with respect to their breeding potential, the nuclear heating, and the lithium, beryllium, and tritium inventories involved. The advantages of low lithium and tritium inventories from the safety point of view are weighed against the drawbacks, like the need of enriched lithium, the large beryllium inventory, and the contamination of the coolant with tritium produced in beryllium.

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CONTENTS

1. INTRODUCTION

The blanket concept proposed in Ref. /1/ to minimize the lithium and tritium inventories in the blanket of a fusion reactor, has been studied in more detail from the neutronic and photonic point of view. In this concept, the lithium inventory in the blanket of the reactor is reduced in comparison with previous designs by using only a thin layer of the breeding material lithium. As a consequence, highly enriched lithium must be used and the breeding zone must be operated in a soft neutron spectrum. In this case only the $^{6}Li(n,\alpha)t$ reaction makes a significant contribution to the total tritium breeding ratio. Since unavoidable parasitic neutron absorptions occur in the first wall and the structural materials, a neutron multiplier must be used to improve the neutron economy of the system. If one excludes the use of fissionable materials in the blanket, only beryllium is available as an appropriate material with the desired characteristics of a neutron multiplier. Due to the low lithium inventory in the blanket the tritium inventory in the breeding zone is also kept to a minimum, the equilibrium inventory being maintained by an efficient tritium extraction system.

In Ref. /1/ neutronic and photonic calculations for this type of blanket were performed using ENDF/B-I data. In this study more recent data from the ENDF/B-III data file /2/ and an improved method for the calculation of the neutron heat deposition in the blanket have been employed. These modifications lead to a significant change in the resultant tritium breeding ratio and in the spatial power density distribution with respect to the reference blanket of Ref. /1/. Therefore a parametric study has been performed to investigate the relevant characteristics of the blanket.

2. CODES AND NUCLEAR DATA

For the neutronic and photonic calculations the one-dimensional transport code ANISN/3/, in infinite cylinder geometry and in the P_3 - S_8 approximation, has been used with a coupled neutron and gamma-ray cross section library (100 neutron groups and 21 gamma-ray groups). The neutron group cross sections and scattering matrices were generated by the code SUPERTOG-III /4/ from ENDF/B-III data except for Ti, for which ENDF/B - I data were used. The neutron group kerma factors and reaction cross sections were calculated with the code MACK /5/, while the gamma-ray group cross sections and kerma factors were obtained with the code SMUG /6/. For the generation of the photon production cross sections the code POPOP-4 /7/ has been employed.

3. BLANKET CONCEPT

The study carried out has been based on a 5000 MW_{th} Tokamak fusion reactor whose major torus radius is 16.8 m and whose first wall radius is 5.79 m. The neutron wall loading was assumed to be 0.83 MW/m^2. The blanket consisted of a zone of metallic beryllium used as a neutron multiplier and moderator, an 80 cm thick graphite zone used as a moderator and reflector and a thin layer of enriched metallic lithium encased in 1 mm thick TZM (Mo,0.5Ti,0.08Zr) used to reduce tritium permeation. The alloy V, 10Cr, 10Ti was used as a first wall material and as a structural material in the beryllium- and graphite-zones because of its good characteristics with respect to a low activity blanket. The volume fraction of the structural material was assumed to be 6%. The dimensions of the other zones and their compositions have been varied in the parametric study. These are:

the thickness of the Be-zone;
the position of the Li-layer in the Be-zone;
the ^{6}Li-enrichment;
the TZM content of the Li-layer; and
the number of Li-layers.

The configuration of the different assemblies investigated is shown in Fig. 1. The material densities as used to determine the particle number densities are given in Table 1. In all cases the theoretical densities were used and in a more technical design the dimensions of the blanket zones could become larger depending upon the porosities and the void fractions of these materials.

In a real blanket design a fraction of the blanket volume of about 2o% may be occupied by "voids" due to the presence of vacuum pumps, the injection system, etc. Since the calculated values do not include the presence of these voids, a tritium breeding ratio of about 1.2o may represent an orientation value to be achieved in these simple model calculations.

3.1 Blanket with one Li-layer

Using ENDF/B-III data the calculations show that the required tritium breeding ratio of about 1.2o cannot be achieved for the design proposed in Ref. /1/. This is mainly due to the changed energy distribution for the secondary neutrons in the $^{9}Be(n,2n)2\alpha$ reaction given in the ENDF/B-III data file, as compared to ENDF/B-I, leading to a much lower neutron multiplication in Be. To illustrate the modifications, the (n,2n) -scattering probability for Be based on the two different data files is shown in Fig. 2. The plotted values were obtained from SUPERTOG calculations using the GAM-II/8/group structure.

To increase the tritium breeding ratio, modifications to the original design were made with the following results:

1) Increasing the amount of Be is not very effective to enhance the neutron multiplication. With 2o cm of Be the neutron multiplication is already 9o % of the theoretical maximum for an infinite Be-zone.

2) Placing the Li-layer in a position where, in the absence of the Li-layer, the thermal neutron flux has its maximum value is very effective. Moving the Li-layer outwards to a distance of 7 cm from the first

wall results in a doubling of the tritium breeding ratio.

3) However, to attain the required tritium breeding ratio of about 1.2o the ^{6}Li enrichment has to be increased to 9o %.

In the following, the blanket with these dimensions is termed design I for which the above results are compiled in Fig. 3 and Table 2.

According to Table 3 (column 1) the energy deposited in the blanket considerably exceeds the energy of the source neutrons. For this design the energy deposited in the blanket is about 83 % greater than the incident energy. The spatially dependent heating rates are presented in Fig. 4 and the power generation per region is given in Table 4 (column 1). The heating rates are based on a source of 14-MeV neutrons equal to o.83 MW/m^2 incident on the first wall. With the exception of the first wall, where the heat deposition is almost entirely due to gamma-rays, neutron heating dominates in the blanket. About 51 % of the total energy is deposited in the Be-zone and about 24 % is deposited in the breeding zone. In the breeding zone almost the entire heating arises from the ^{6}Li(n,α)t reaction (Q-value 4.8 MeV) and the radial power density distribution shows a sharp peak in this region. The average heating rate in the breeding zone is 36 W/cm^3.

Two additional calculations were carried out; one with the 1o mm Li-zone replaced by a homogeneous mixture of 9 mm Li and 1 mm TZM (Mo,o.5 Ti,o.o8 Zr), and one with a 2o mm thick Li-zone. These two blankets are termed designs IA and IB and the results of the calculations are presented in Table 3. In spite of the thermal neutron flux depression in and around the Li-layer the parasitic absorption in the Mo-layer cannot be neglected, as would be the case if vanadium had been used. This is due to the capture resonances of Mo in the epithermal energy range. The other calculation shows that doubling the thickness of the Li-layer gives an increase of about 7% in the tritium breeding ratio.

The proposed blanket is not a thermal but rather an epithermal system. 64 % of the $^{6}Li(n,\alpha)t$ reactions take place above a neutron energy of 5 eV, and 22.6 % above 75o eV (Table 5). Since thermal neutrons contribute only 21.5 % to the total tritium breeding ratio, it seems unnecessary to subdivide the thermal energy group into finer groups so as to take into account neutron upscattering in the thermal energy range in order to improve the accuracy of the calculations.

3.2 Blanket with two Li-layers

Using two Li-layers in the Be-zone, the neutron economy is less stringent and there is room to decrease the thickness of the Be-zone and/or the Li enrichment. Theoretically, the most effective Be-Li arrangement would be a homogeneous mixture in which the $^{6}Li(n,\alpha)t$ reaction can compete more effectively with the parasitic absorption reactions in the Be and the structure material. In a heterogeneous arrangement, a cell structure is very effective. In this case, the ratio of the thermal neutron flux in the Be (+structure) to the thermal neutron flux in the Li (which may be regarded as a "disadvantage factor") has its smallest value.

Due to the asymmetric flux distribution in the Be-Li-zone, a slightly asymmetric cell structure would give optimal tritium breeding. This is a small effect, however, and for simplicity two identical cells have been used.

Calculations were performed varying the total thickness of the Be-zone from 1o to 2o cm for a ^{6}Li-enrichment of 28 %, and from 6 to 1o cm for an enrichment of 9o %. Results are given in Figs. 5 and 6. It can be seen that a tritium breeding ratio of 1.2o can be attained with 12 cm of Be if the enrichment is 28 % (design II), and with 8 cm of Be if the enrichment is 9o % (design III). In decreasing the total Be-thickness, the tritium breeding ratio decreases primarily due to the decrease of the Be(n,2n) reaction rate, the parasitic absorption remaining practically constant. As can be seen from Fig. 6 , the decrease of the parasitic absorption in the first wall and the Be(+ structure) is compensated by the increase of the parasitic absorption in the graphite (+ structure).

Figure 7 presents the radial neutron flux distribution for such an arrangement for three energy ranges which clearly shows the strong flux depression in the breeding zone with decreasing neutron energy.

The energy multiplication for designs II and III is smaller than for design I. The total energy deposited in these cases is larger than the incident energy by 57 % and 47% respectively. The radial power density distribution and the power generation by zone for these designs are given in Fig. 8, Fig. 9, and Table 4 (columns 2 and 3). The total heating in the breeding zones is nearly the same in all three cases considered, but the energy deposited in the Be-zone decreases for designs II and III due to the decrease of the contribution of the exothermic reactions in the structure material. This is partly compensated for by a larger heat deposition in the reflector and a larger energy leakage from the system. Since two breeding zones are present the peak in the radial power density distribution is smaller and the average power density in the Li-layers is reduced to about 19 W/cm^3.

4. COMPARISON OF INVENTORIES FOR THE DIFFERENT DESIGNS

The main concern of the proposed blanket concept is to minimize the lithium and tritium inventories in the fusion reactor. These quantities are compiled in Table 7 for the previous standard blanket, consisting of a 6o cm thick zone of natural lithium followed by a 3o cm graphite reflector and a second 6 cm thick zone of natural lithium, and the three blanket designs investigated here. The recorded data, including those for the standard blanket, are based upon the reactor parameters used for this design, and assuming a tritium concentration in lithium of 1o ppm.

In comparison with the standard blanket, the lithium inventory is reduced by a factor of 67 for design I and by a factor of 34 for designs II and III. The tritium inventories in the lithium zones are correspondingly lower. These figures are not as promising as those given in Ref. /1/ since the dimensions of the reactor are larger than those in Ref. /1/ due to the reduced wall loading, and since two breeding zones are assumed in designs II and III.

The new blanket concept, however, also has some less advantageous aspects. First, enriched lithium must be used. In designs I and III a ^{6}Li enrichment of about 9o % is probably necessary which will have an influence on the cost of the lithium inventory. Furthermore, the low lithium inventory is achieved at the expense of having a large amount of Be in the blanket. For the proposed reactor dimensions the required Be inventory will be about $1o^{5}$ kilograms, independent of the details of the reactor design. This is about o.1 % of the known world Be resources. After 2o years of reactor operation, about 1-3 % of the Be-inventory will be burnt up. In a cost estimate, the cost of the Be-make up can probably be neglected, but the initial inventory will significantly penalize the investment costs.

A further problem is the tritium generated in the Be-zone. One source is the $^{9}Be(n,t)^{7}Li$ reaction, but also a non-negligible amount of ^{6}Li is produced in the Be-zone by the reaction

$$^{9}Be(n,\alpha)^{6}He \xrightarrow[8o2\ ms]{\beta^-} {}^{6}Li$$

which will be a second tritium source. The resulting ^{6}Li- and T-production rates are compiled in Table 8 assuming that the neutron flux distribution in the Be-zone is not changed by the ^{6}Li-build up. The time-dependent tritium production rates due to these processes are shown in Fig. 1o. The contribution from the ^{7}Li generated in the Be can be neglected in comparison with the two other sources.

In the design I the epithermal and thermal neutron fluxes in the Be-zone are higher than in the other two designs. Therefore, the tritium production rate increases more rapidly and after one year the tritium production rate is about one half of the ^{6}Li production rate, and after five years the tritium production rate is nearly equal to the ^{6}Li production rate. From this point of view design III is more advantageous, since the production rate increases only slowly. After five years of operation the tritium production from this reaction is nearly equal to the tritium production from the $^{9}Be(n,t)^{7}Li$ reaction and saturation will not be reached during the lifetime of the blanket. The properties of design II are intermediate between those of the two other designs.

The tritium produced in Be is most likely to be found in the coolant gas. In order to maintain a low equilibrium level of tritium both in the Be-zone and the coolant loop an efficient system for extracting tritium from the coolant must be designed.

In addition, the high helium production rates in the Be-zone, which are also given in Table 8, will lead to a severe swelling of the material, the consequences of which must be studied.

5. SUMMARY AND CONCLUSIONS

Fusion reactor blanket designs with low lithium and tritium inventories have been studied from the neutronic and photonic point of view. These calculations can be considered to be a first step to a more detailed technical design of the blanket based on the present results.

Despite the fact that with the more recent nuclear data the neutron multiplication of the system is smaller than calculated in Ref. /1/, the original blanket concept still yields adequate tritium breeding if the breeding zone is placed within the Be-zone and the ^{6}Li enrichment is increased up to 9o %. Alternately, one may introduce two breeding zones of enriched Li with a trade-off between ^{6}Li enrichment and Be-inventory. The nuclear data for Be, especially the energy distribution of secondary neutrons from the (n,2n) reaction have a considerable influence on the neutronic results. Hence, sensitivity studies with respect to these data and perhaps even new measurements are required to check the accuracy of the results and to consolidate the conclusions.

A further problem is the large Be-inventory in the blanket and the additional production of tritium in the Be-zone. The success of the concept will depend upon finding an efficient tritium extraction method in order to maintain the desired low tritium inventory.

Depending upon the extraction method used to remove tritium from the lithium zone it would also be of interest to study solid lithium compounds with low hydrogen solubility as breeder materials. Also important from the neutronic point of view is a study of the influence of the heterogenity of the structural material in the beryllium and graphite regions, which will result in lower parasitic neutron absorption.

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7. FIGURES AND TABLES

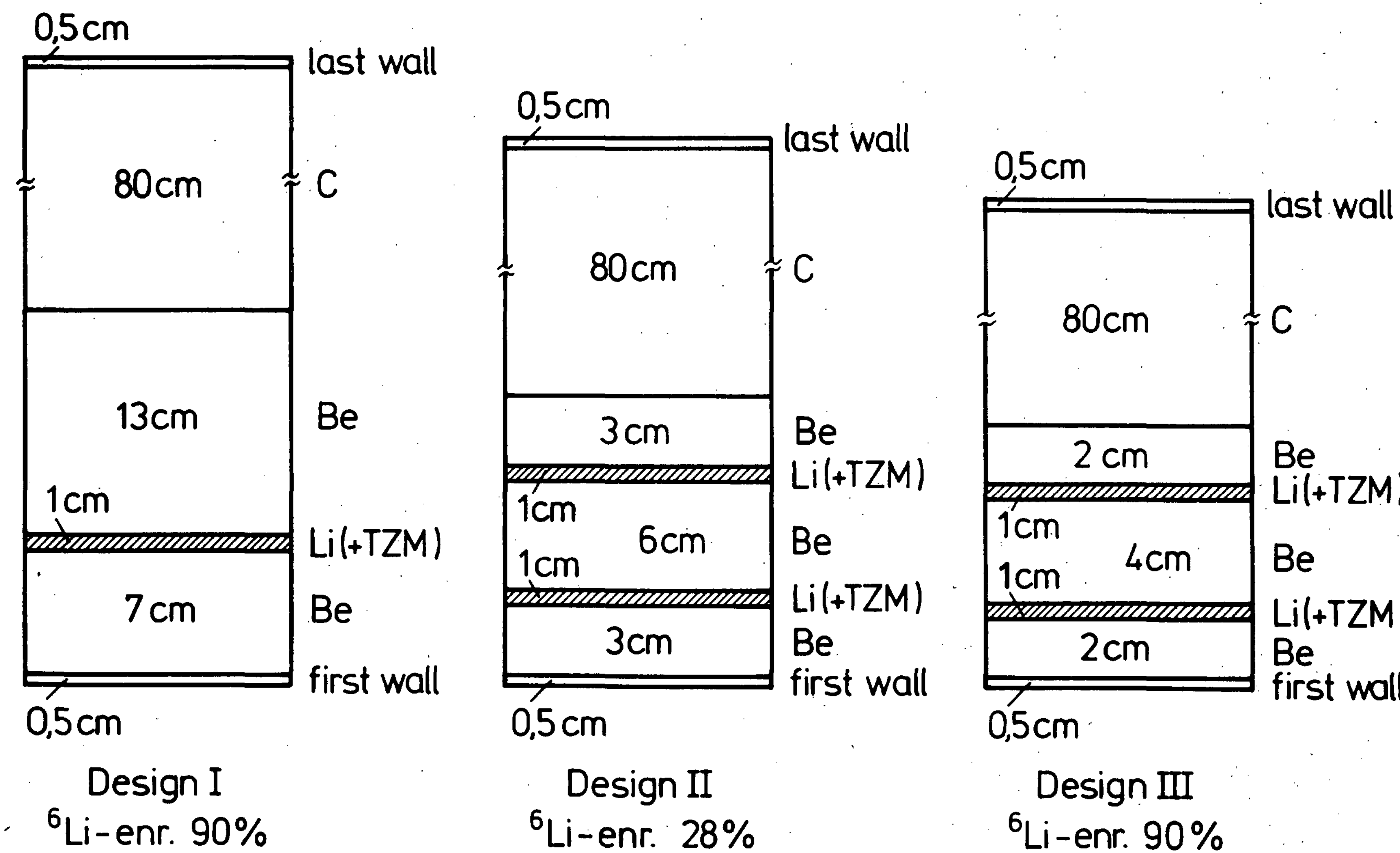


Fig. 1 : Blanket Configuration of Several Designs with Low Lithium Inventories.

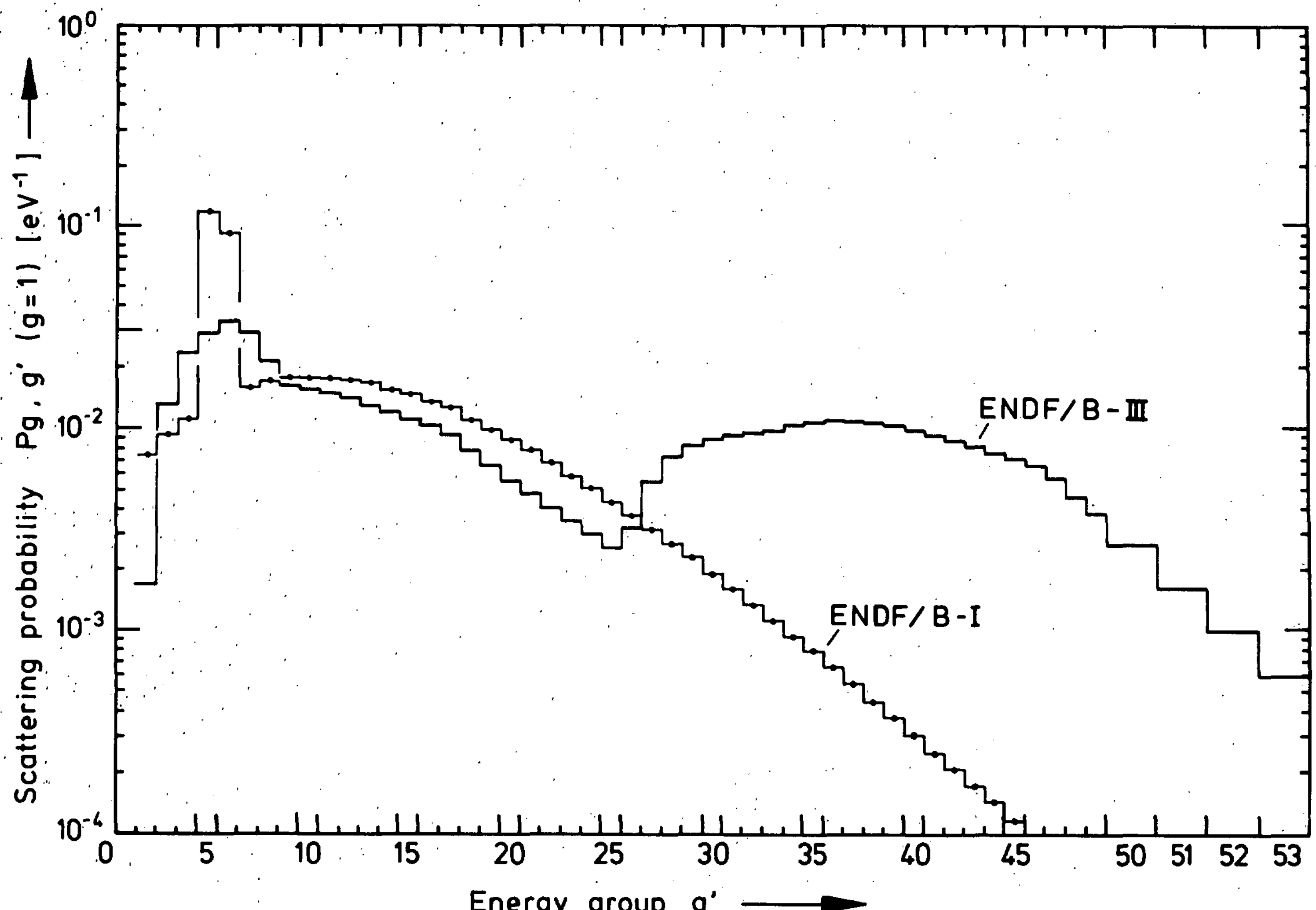


Fig. 2: (n,2n)-Scattering Probability $P_{g,g'}(g=1)$ for Beryllium Using the GAM-II Energy Group Structure.

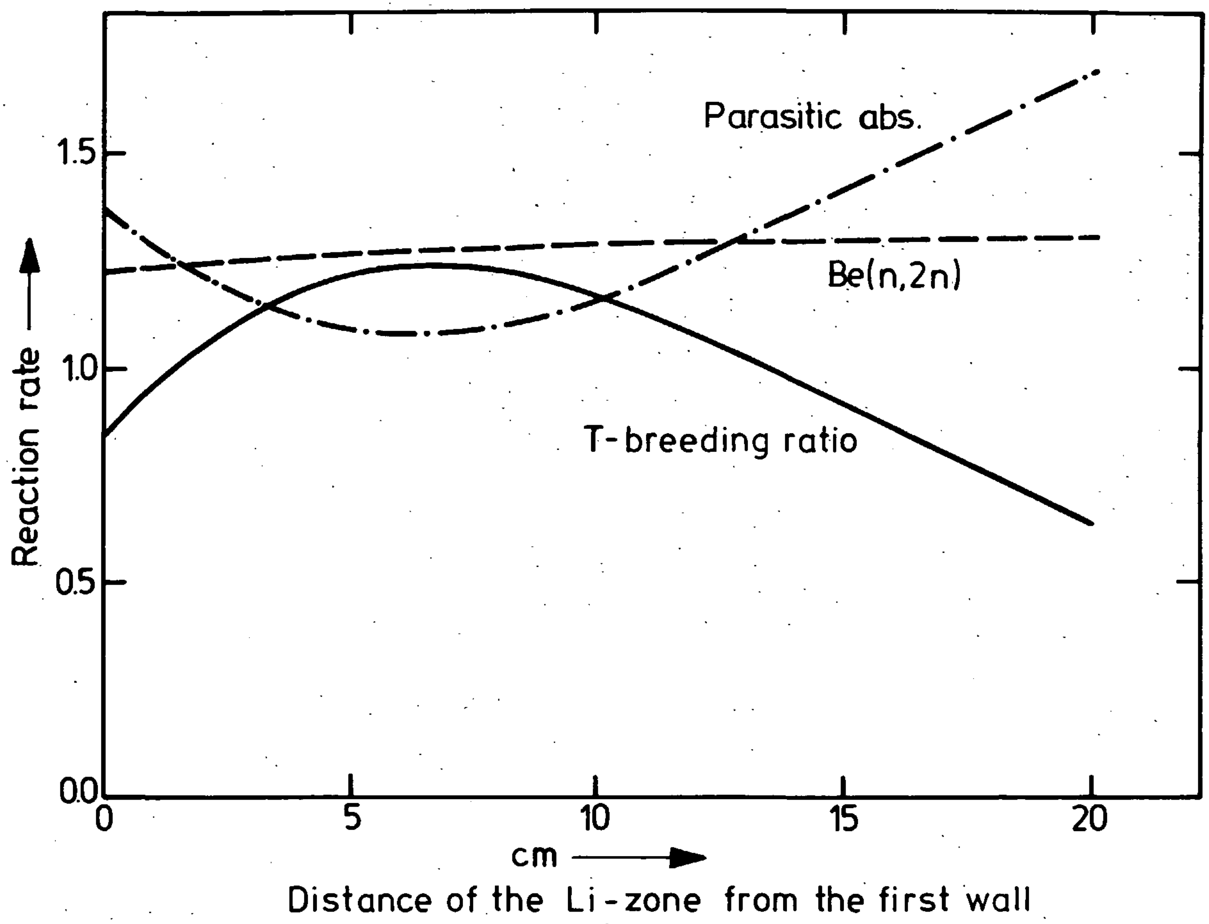
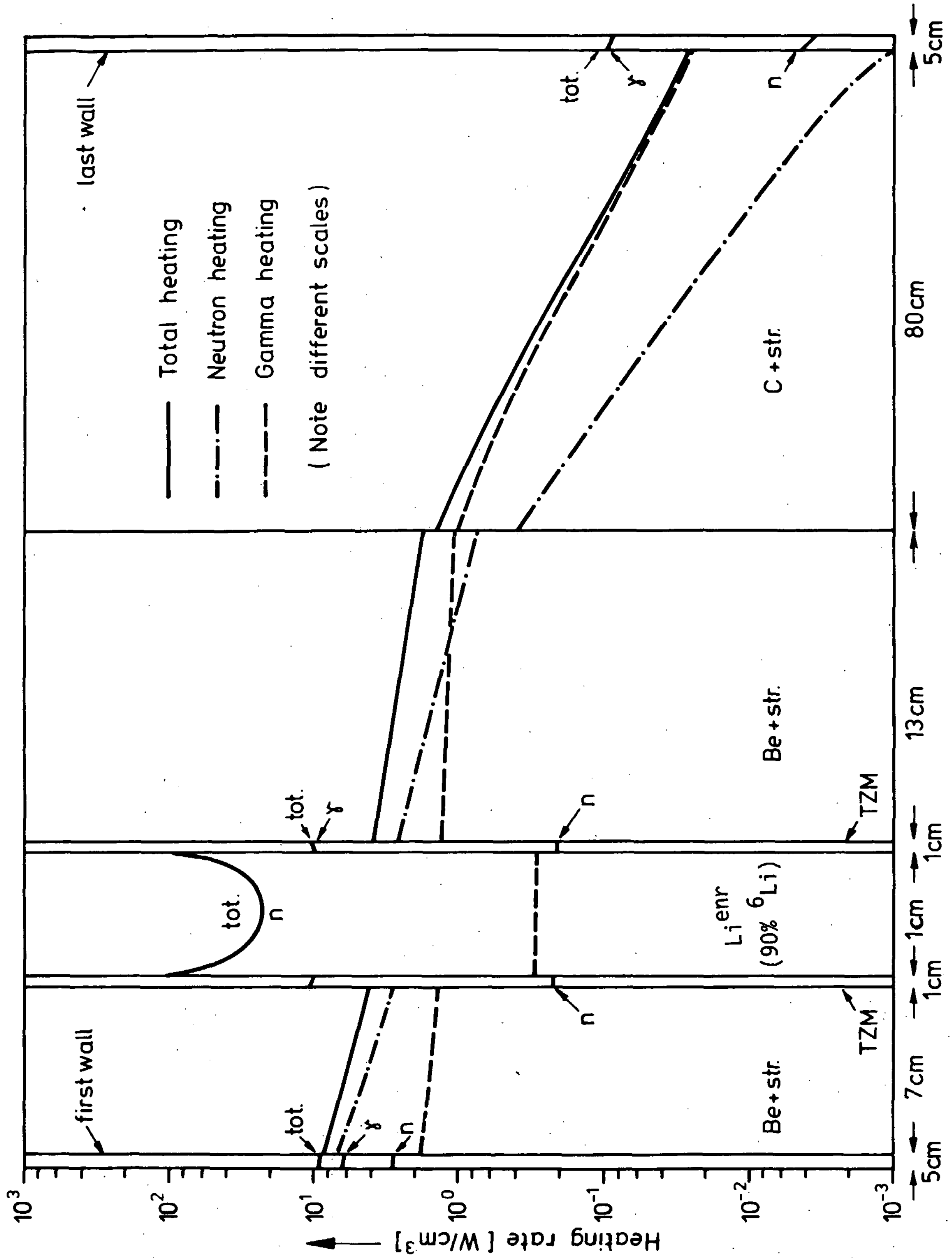


Fig. 3: Reaction Rates of Interest vs Position of the Breeding Zone for Design I (reactions per D-T fusion neutron).

Fig. 4: Space-Dependent Heating Rates for Design I.


Heating rate [W/cm³]
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
Total heating
Neutron heating
Gamma heating
(Note different scales)
first wall
last wall
Be + str.
Be + str.
C + str.
Li^enr
(90% ^6Li)
TZM
TZM
tot.
n
γ
5cm
7cm
1cm
1cm
1cm
13cm
80cm
5cm

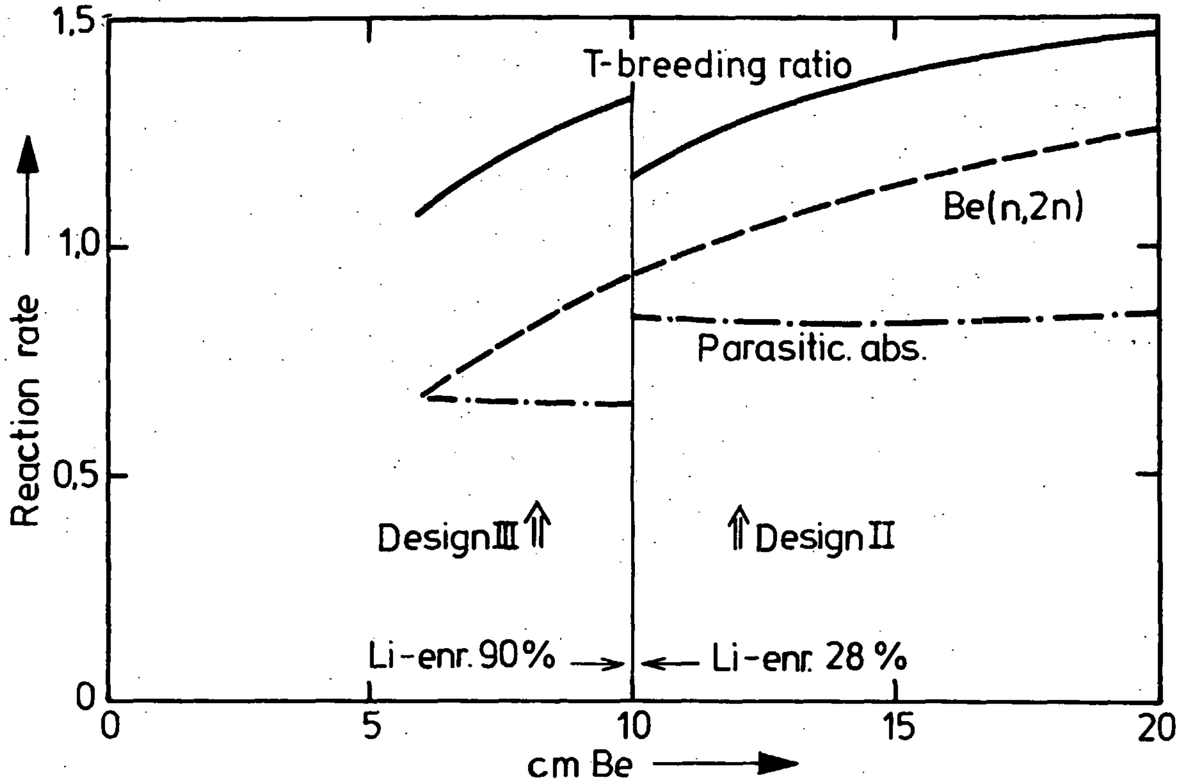


Fig. 5: Reaction Rates of Interest vs Thickness of the Be-Zone for Design II and III (reactions per D-T fusion neutron).

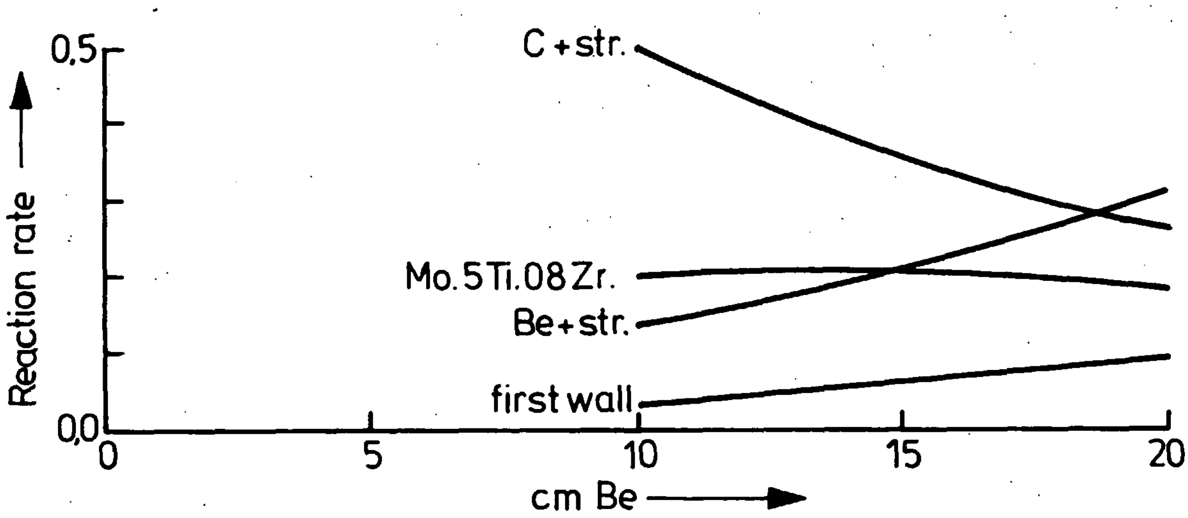


Fig. 6: Parasitic Neutron Absorption by Zone vs Thickness of the Be-Zone for Design II (reactions per D-T fusion neutron).

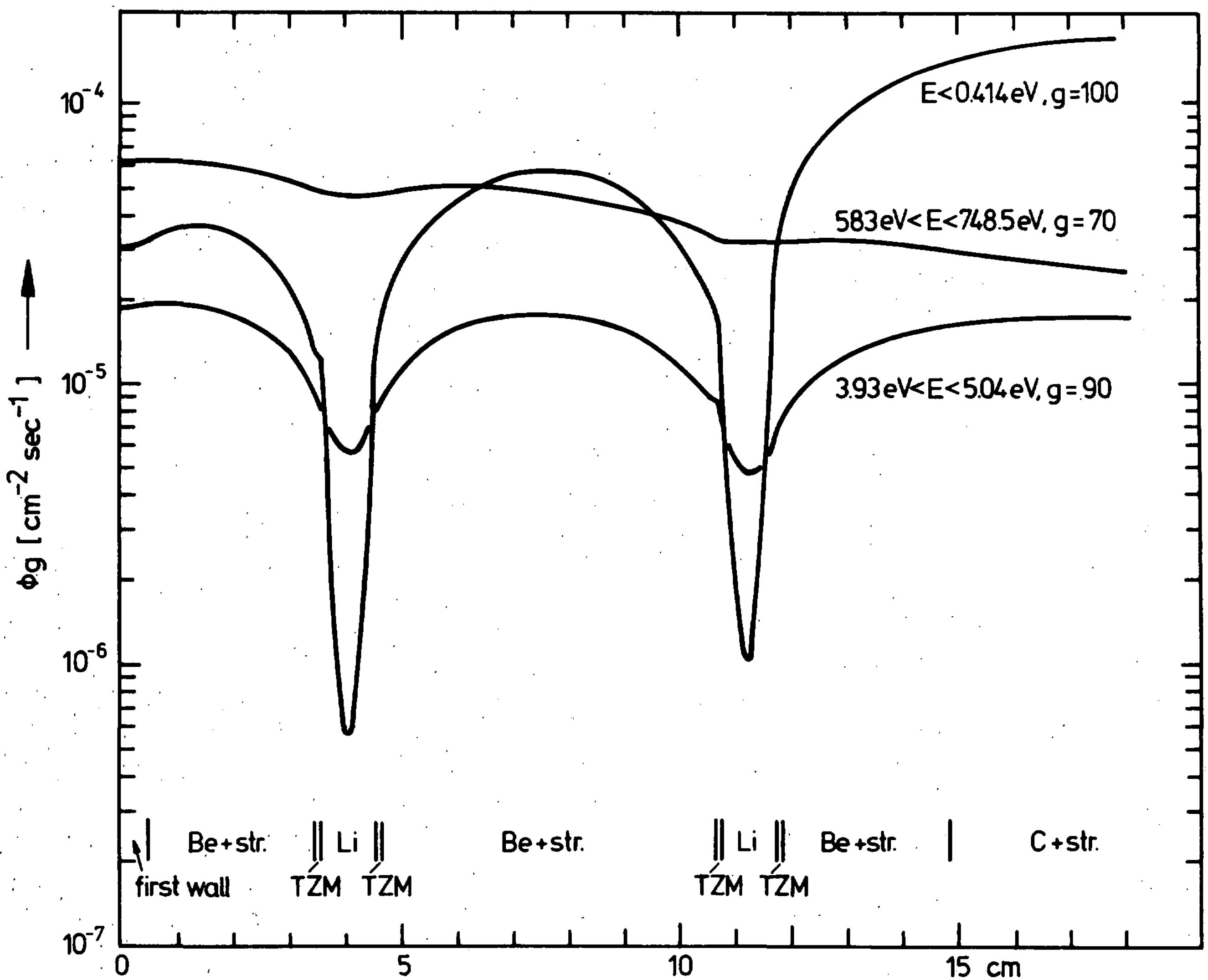


Fig. 7: Radial Neutron Flux Distribution for Three Energy Ranges for Design II (source normalized to one 14.1 MeV source neutron per cm and sec).

Fig. 8: Space-Dependent Heating Rates for Design II.

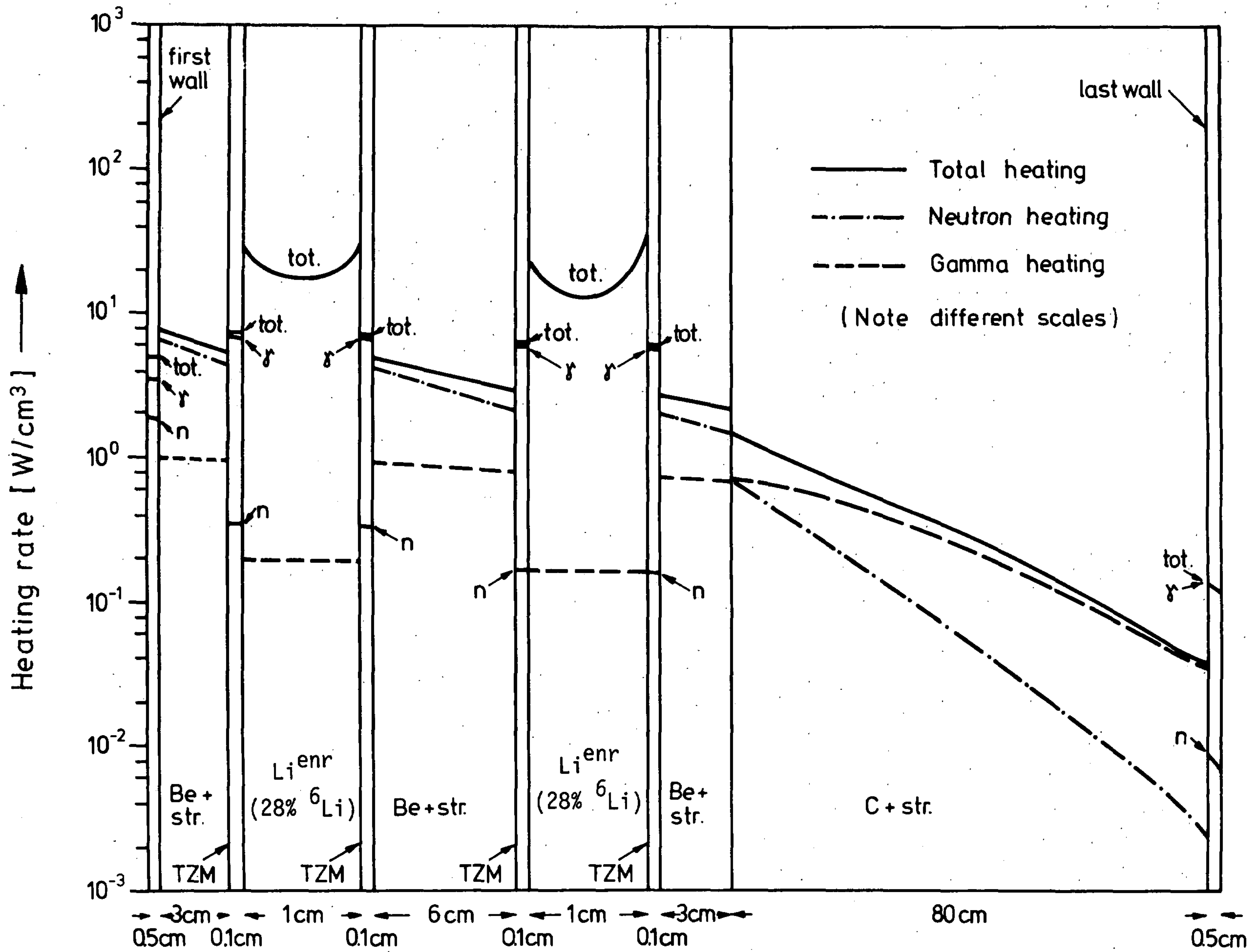
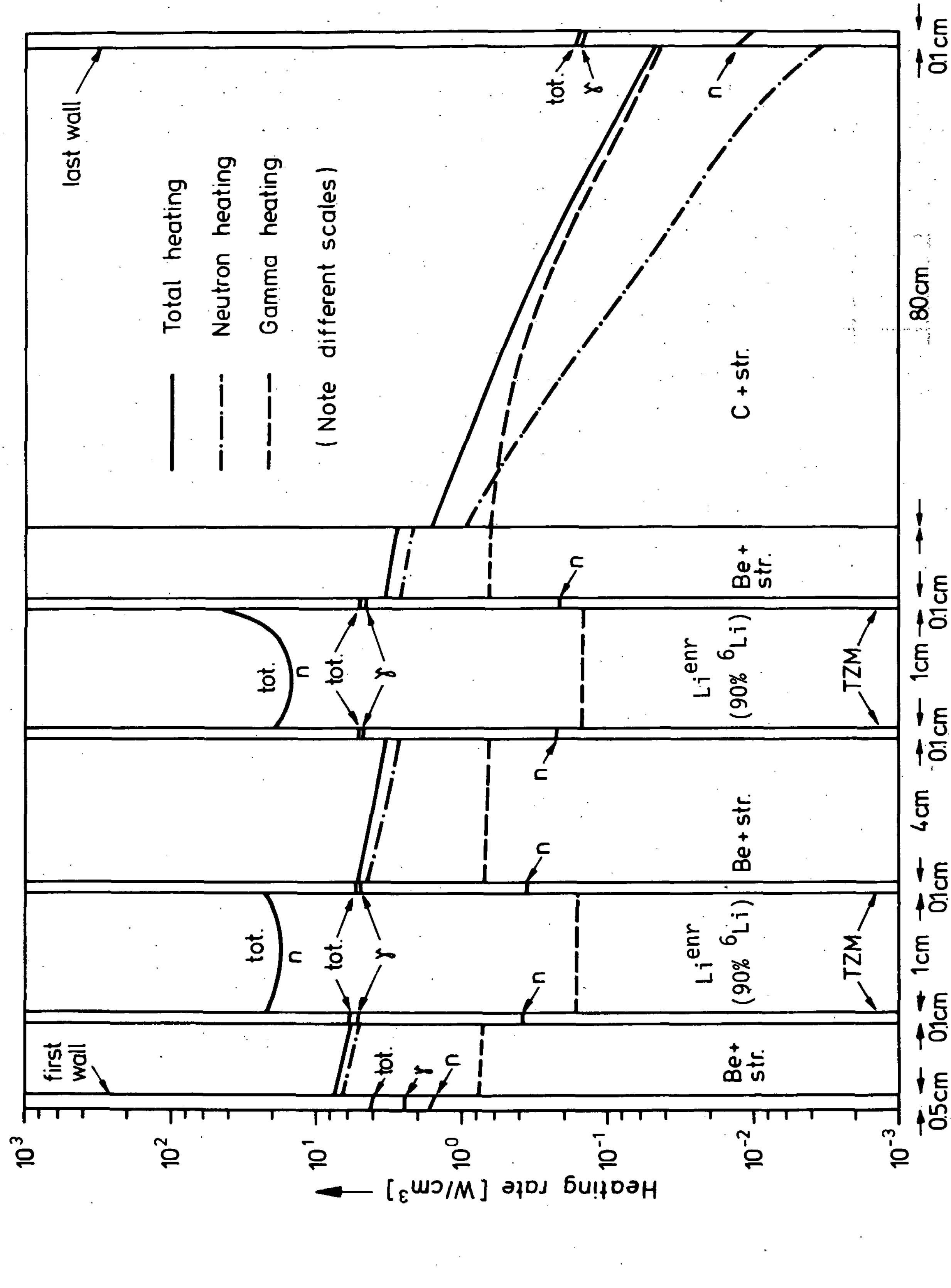

Heating rate [W/cm³]
10³
10²
10¹
10⁰
10⁻¹
10⁻²
10⁻³
first wall
last wall
Total heating
Neutron heating
Gamma heating
(Note different scales)
tot.
γ
n
Be + str.
Li^enr (28% ⁶Li)
Be + str.
Li^enr (28% ⁶Li)
Be + str.
C + str.
TZM
0.5cm
3cm
0.1cm
1cm
0.1cm
6cm
0.1cm
1cm
0.1cm
3cm
80cm
0.5cm

Fig. 9: Space-Dependent Heating Rates for Design III.



Heating rate [W/cm³]
10³
10²
10¹
10⁰
10⁻¹
10⁻²
10⁻³
Total heating
Neutron heating
Gamma heating
(Note different scales)
first wall
last wall
tot.
γ
n
Be + str.
Li^enr (90% ⁶Li)
TZM
C + str.
0.5cm
0.1cm
1cm
4cm
80cm

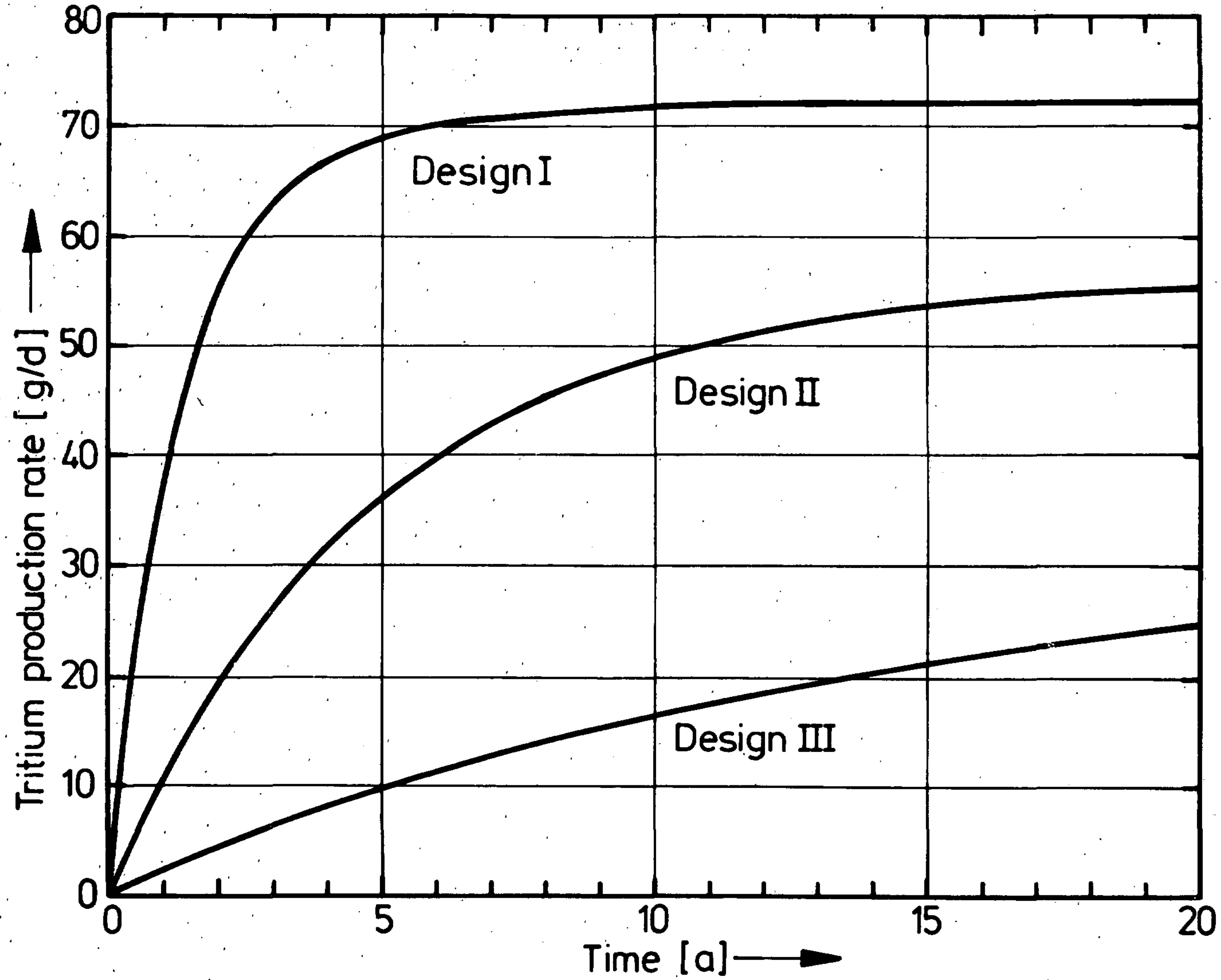


Fig.1o: Time-Dependent Tritium Production Rates in the Be-Zones for the Various Designs.

Table 1: Blanket Composition of Several Designs with Low Lithium Inventory

No.	Region	Density $\rho(g/cm^3)$	Thickness (cm)		
			Des. I	Des. II	Des. III
1	First Wall (V,1oCr,1oTi)	5.96	o.5	o.5	o.5
2	Be+6 vol.%(V,1oCr,1oTi)	2.1o	7.o	3.o	2.o
3	TZM (Mo,o.5Ti,o.o8Zr)	1o.2	o.1	o.1	o.1
4	Li (enriched)	o.454	1.o	1.o	1.o
5	TZM (Mo,o.5Ti,o.o8Zr)	1o.2	o.1	o.1	o.1
6	Be+6 vol.%(V,1oCr,1oTi)	2.1o	13.o	6.o	4.o
7	TZM (Mo,o.5Ti,o.o8Zr)	1o.2		o.1	o.1
8	Li (enriched)	o.454		1.o	1.o
9	TZM (Mo,o.5Ti,o.o8Zr)	1o.2		o.1	o.1
1o	Be+6 vol.%(V,1oCr,1oTi)	2.1o		3.o	3.o
11	C +6 vol.%(V,1oCr,1oTi)	1.86	8o.o	8o.o	8o.o
12	Last Wall (V,1oCr,1oTi)	5.96	o.5	o.5	o.5

Table 2: Influence of the ^{6}Li-Enrichment upon the Tritium Breeding Ratio and the Parasitic Neutron Absorption in Design I (reactions per D-T fusion neutron)

^{6}Li-Enrichment	28 %	5o %	9o %
Tritium Breeding Ratio	1.o69	1.157	1.244
Paras. Abs.	1.274	1.182	1.o84

Table 3: Summary of Results for the Various Designs (reactions per D-T fusion neutron)

	Des. I	Des.II	Des.III	Des.IA[xx]	Des.IB[xxx]
^{6}Li(n,α)t	1.244	1.248	1.218	1.213	1.336
^{7}Li(n,n'α)t	o.oo2	o.o24	o.oo4	o.oo1	o.oo3
T-Breeding Ratio	1.246	1.272	1.222	1.214	1.339
Be(n,t)	o.o2o	o.o17	o.o14	o.o2o	o.o2o
Be(n,2n)	1.281	1.o34	o.815	1.274	1.256
Mo(n,2n)	o.oo9	o.o22	o.o28	o.o13	o.oo9
V(n,2n)	o.o56	o.o56	o.o57	o.o56	o.o56
Cr(n,2n)	o.oo2	o.oo2	o.oo2	o.oo2	o.oo2
Ti(n,2n)	o.oo1	o.oo1	o.oo1	o.oo1	o.oo1
Total (n,2n)	1.349	1.115	o.9o3	1.346	1.324
V(n,γ)	o.682	o.396	o.337	o.685	o.612
Cr(n,γ)	o.o52	o.o31	o.o26	o.o52	o.o47
Ti(n,γ)	o.1o7	o.o61	o.o52	o.1o8	o.o96
Mo(n,γ)	o.o72	o.2o2	o.o92	o.o98	o.o52
Be(n,α)	o.119	o.o94	o.o72	o.118	o.11o
C(n,α)	o.o19	o.o44	o.o69	o.o18	o.o18
Paras. Abs.	1.o84	o.847	o.666	1.114	o.973
Neutron Leakage	o.oo4	o.oo8	o.o11	o.oo4	o.oo4
Neutron Heating [x]	16.13	15.29	14.75	15.92	16.53
Gamma Heating [x]	9.65	6.81	5.86	9.75	8.78
Total Heating [x]	25.78	22.1o	2o.61	25.67	25.31

x in MeV per D-T fusion neutron

xx Li-zone: 9o vol. % Li, 1o vol.% TZM

xxx Li-zone 2 cm thick

Table 4: Power Generation by Region (in MW/cm)

	Region	Des. I	Des. II	Des. III
1	First Wall	0.017	0.009	0.007
2	Be + Structure	0.155	0.072	0.048
3	TZM	0.004	0.002	0.002
4	Li	0.134	0.075	0.071
5	TZM	0.004	0.002	0.002
6	Be + Structure	0.128	0.086	0.065
7	TZM		0.002	0.002
8	Li		0.063	0.069
9	TZM		0.002	0.002
10	Be + Structure		0.027	0.023
11	C + Structure	0.113	0.131	0.151
12	Last Wall			
	Total	0.555	0.471	0.442

Table 5: Fraction F(E) of the Tritium Breeding Ratio Due to Neutrons with Energies above E

E (eV)	F (E)
0.414	0.785
5.04	0.641
61.4	0.430
748.5	0.226
$9.119 \cdot 10^3$	0.106
$111.1 \cdot 10^3$	0.053
$14.92 \cdot 10^6$	0.000

Table 6: Parasitic Neutron Absorption Reactions by Zone
(reactions per D-T fusion neutron)

No.	Region	Reaction	Design I	Design II	Design III
1	First Wall	V(n,γ)	0.107	0.033	0.009
		Ti(n,γ)	0.016	0.004	0.0009
		Cr(n,γ)	0.008	0.003	0.0010
		Total Abs.	0.137	0.046	0.017
2	Be+Structure	Be(n,α)	0.068	0.034	0.023
		V(n,γ)	0.086	0.011	0.0020
		Ti(n,γ)	0.013	0.002	0.0002
		Cr(n,γ)	0.007	0.001	0.0002
		Total Abs.	0.182	0.050	0.027
3	TZM	Mo(n,γ)	0.039	0.059	0.024
5	TZM	Mo(n,γ)	0.034	0.058	0.023
6	Be+Structure	Be(n,α)	0.051	0.045	0.035
		V(n,γ)	0.190	0.023	0.0038
		Ti(n,γ)	0.030	0.003	0.0004
		Cr(n,γ)	0.015	0.002	0.0004
		Total Abs.	0.299	0.076	0.042
7	TZM	Mo(n,γ)		0.044	0.021
9	TZM	Mo(n,γ)		0.042	0.023
10	Be+Structure	Be(n,α)		0.014	0.013
		V(n,γ)		0.016	0.0062
		Ti(n,γ)		0.002	0.0009
		Cr(n,γ)		0.001	0.0005
		Total Abs.		0.035	0.022
11	C + Structure	C(n,α)	0.019	0.044	0.069
		V(n,γ)	0.299	0.314	0.315
		Ti(n,γ)	0.048	0.050	0.050
		Cr(n,γ)	0.023	0.024	0.024
		Total Abs.	0.392	0.437	0.464
12	Last Wall	Total Abs.	0.0004	0.0009	0.0012
	Blanket	Total Abs.	1.084	0.847	0.666

Table 7: Comparison of Materials Inventories of the Standard Blanket and the Blanket Designs with Low Lithium Inventories

	Standard Blanket	Blankets with Low Lithium and Tritium Inventories		
		Design I	Design II	Design III
Lithium Inventory	$1.24 \cdot 10^{6}$ kg	$1.85 \cdot 10^{4}$ kg	$3.69 \cdot 10^{4}$ kg	$3.68 \cdot 10^{4}$ kg
Tritium Inventory in the Lithium-Zone (10 ppm assumed)	6.2 kg	80 g	160 g	160 g
Time Required to Build-up Inventory (T=1.01 assumed)	8 d	3 h	6 h	6 h
Beryllium Inventory	-	$1.33 \cdot 10^{6}$ kg	$7.94 \cdot 10^{5}$ kg	$5.28 \cdot 10^{5}$ kg
Beryllium Burn-up per D-T Fusion Neutron	-	1.44	1.15	0.90
Beryllium Consumption after 20 Years of Operation	-	$2.12 \cdot 10^{4}$ kg	$1.70 \cdot 10^{4}$ kg	$1.33 \cdot 10^{4}$ kg

Table 8 : Summary of Lithium-6, Tritium, and Helium Production Rates in Beryllium

	Design I	Design II	Design III
^{6}Li-Production	146 g/d	115 g/d	89 g/d
T-Production ($^{9}Be(n,t)^{7}Li$)	12.5 g/d	1o.6 g/d	8.8 g/d
T-Production ($^{6}Li(n,\alpha)t$)			
after 3 Months	12.6 g/d	2.9 g/d	o.6 g/d
6 Months	23.o g/d	5.6 g/d	1.2 g/d
12 Months	38.1 g/d	1o.6 g/d	2.4 g/d
He - Production	1.34 . $1o^{3}$ppm/yr	1.82 . $1o^{3}$ppm/yr	2.15 . $1o^{3}$ppm/yr