AN EVALUATION OF FAST REACTOR BLANKETS

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ABSTRACT

A comperative study of different types of fast reactor radial blankets is presented Included are blankets of fertile material UO_2 THO_2 and Th metal blankets of pure reflectors C, BeO, Ni and combinations of reflecting and fertile blankets The results for 1000 MWe cores indicate that there is no incentive to use other than fertile blankets The most favorable fertile material is thorium due to the prospective higher price of U 233

1 INTRODUCTION

The first fast reactors were designed as very compact cores with a high power density They were high leakage cores and the blanket was important to obtain a high breeding ratio The present designs have more dilute and large cores This is caused by the use of oxide fuel to obtain larger burnups, larger structural material fractions based on safety considerations and larger coolant fractions to accomodate the strutural material swelling Another development in recent years is the idea of symbiotic fuel cycles To produce U 233 in fast breeders and use this in thermal reactors it likely that the HTGR will be used as a source of process heat long after the introduction of the fast breeder reactor

The Institute of Atomic Energy in São Paulo is cooperating with General Atomics in the evaluation of thorium blankets The scope of the study has been amplified in order to come to an understanding of the effects that are involved and to verify the conclusions reached for the first generation of fast reactors(7 5) He and sodium cooled reactors are include as are blankets of thorium metal, thorium oxide and uranium oxide The results of this study are summarized in table I

2 DESCRIPTION OF THE MODEL AND THE METHODS USED

We opted for a nominal 1000 MWe design to compare the performance of the different blankets The basic parameters are given in table II And the dimensions in fig 1 We feel that the values reasonably reflect the present trends in fast reactor design and although one might differentiate between LMFBR and GCFR we preferred to have the same dimensions for a simpler comparison between the two

The enrichment was varied to achieve a minimum criticality of about 1 00 during burnup. After each cycle of 300 EFPD or y at 80% load factor 1/3 of the core was removed and replaced with fresh material No blanket management has performed

Cross sections generated with ETOX III(8)based on ENDF/B III were used The self shielding factors of the core were applied for all zones and the resulting effective cross sections collapsed to 4 groups using the fundamental mode spectrum of the central zone

Although this approach seems to be rather crude it yielded good agreements with the GCFR benchmark case[6]

As an indicator for the economic perfomance of the blankets we have chosen the inverse of the reactor doubling time[10] This is a physical return on investment and independent of inflation

3. BURNUP EFFECTS

Burnup results in reactivity swings due to the depletion of the fuel in the core and the buildup of fission products These reactivity swings will be compensated by control rods that are of B-10, Ta or EuO_2 Neutrons absorbed by them are lost for breedin purposes. This effect of the control rods can be simulated by reducing the number of neutrons per fission in the way this is done in the diffusion codes according to the amount of excess reactivity

The reactivity swing due to the build-up of fission products is of the order of 2% for both LMFBR and GCFR

The internal conversion ratio is generally lower than one so that in the core a certain fuel depletion can be observed This is compensated by the fissile material bred in the blankets The breeding ratio must be well over to asset the depletion of the core since the worth of the fissile material is lower in the blanket than in the core.

The resulting reactivity swing due to fission products and depletion is 2% for the GCFR with a breeding ratio of 1 3 and 1 5% for the LMFBR with a breeding of 1 2

The initial excess reactivity of the new core that is required to keep the system at all times critical becomes an important factor The reactivity swing of the third cycle is only 1% when we start off with a critical new system (fig 2) We need to increase the reactivity with at least 4% to maintain the system at all times critical and observe that the reactivity swing becomes 1 5% The breedings ratio of 1 22 for the new critical core drops to 1 17 The same can be observed for the GCFR

4. REFLECTORS

It was thought that reflectors can minimize the reactivity swing The enrichment can be reduced somewhat due to the lower leakage from the core This results in a higher internal conversion ratio as the bred fuel is in the core rather than in the reflector

The reflectors specially Ni or clad BeO - tend to absorb neutrons More neutrons will leak out of the core due to the fact that the blankets are fairly thin and will thus not contribute to the breeding The neutrons that return to the core have a lower energy caused by elastic and inelastic moderation They will not contribute to the fast fissions of U-238 and thus the fast fission bonus to the breeding ratio will be smaller The reduced leakage from the core and the lower energy of the neutrons that return to the core from the blanket soften the spectrum so that η-239 is reduced

The overall result is an improvement of 0 5 in the internal conversion ratio for the GCFR, in fact a slight positive reactivity swing can be observed for the LMFBR the effects balance (fig 3)

The reduction in the overall breeding ratio is however so significant that reflecting do not form an economic proposition Attempts to reduce the leakage out of the reactor by fertile material lead to the same results for all fertile blankets as the reflecting zone became very thin (15 cm)

5 THORIUM BLANKETS

In recent years it has become clear that a number of reactor types will coexist It can be envisaged that the HTGR will still be built for process heat applications a long time after the fast breeder reactor has been comercially introduced for electricity generation There is thus a longterm demand for thermal reactor fuel U 233 is excellently suited for these purposes

There will be plenty of plutonium at least to the end of the century due to the rate at which plutonium producing thermal reactors presently are built It is only after the fast breeder reactor reaches an economic breakthrough and in conjunction with a high growth rate of the energy sector that plutonium may become in short supply Thus the plutonium price can be espected to be close to the indifference value with respect to other thermal reactor fuels This is about 50% of the U 233 value

In view of the medium and long term prospects it thus seems advantageous to breed U 233 instead of Pu 239 in the blankets(9) We have restricted ourselves to radial thorium blanket elements as they are separate from the fuel element They can thus easily be reprocessed in the HTGR reprocessing facilities (fig 4)

A problem is the buildup of U 232 as its daughters Bi 212 and Tl 208, both dacay with highly penetrating γ rays The U 232 content is a linear function of time (fig 5) and for a standtime of 6 years the concentration is of the same order of magnitude as in the HTGR (4)

The more advanced Th metal blanket(2) is only somewhat better than the conventional ThO_2 blanket and it appears that secondary considerations will determine the acceptance of thorium metalic blankets

The economic advantage of thorium can be estimated to be of the order of 2 M $/a for a price difference of 8 $/gm between U 233 and Pu 239

6. POWER DISTRIBUTIONS

The power distributions in the blanket for some typical cases are given in (fig 7) at the end of the fifth cycle It can be noted that a factor of two exists between the power generated at the outside of the blankets demonstrating the excellent attenuation properties of Th-metal It can also be observed in the leakage losses of table 1 and the capture rate of the iron radial reflector

7. STREAMING EFFECTS IN THE GCFR

The low scattering cross sections of the coolant leads to sifnificant streaming effects in the coolant channels, these reduce the breeding. Eisemann[1] calculates that the increased leakage reduces criticality by about 1%. Effects on the blanket performance were however not reported.

As a first step we therefore calculated directional dependent diffusion coefficients using the same methods as in[3]. Here we obtained good agreement with sodium void experiments with different plate orientations. These calculations are very sensitive to the directional diffusion coefficients.

In a next step a modified version of CITATION was used in which different diffusion coeficients were used for the axial and radial directions. K_{eff} was reduced by 1%. The axial leakage increased by 10%. A 3% higher production of U 233 reflects the increased radial leakage.

8 CONCLUSIONS

This study has confirmed that the concept of fertile blankets is still valid. Reflecting blankets offer no prospects for improved breeding ratios or reactor doubling times. The combination of reflecting and fertile blankets give the same performance as pure fertile blankets. Thorium blankets offer savings of the order of 2 M $/a for the GCFR and 1 M $/a for the LMFBR. Streaming effects in GCFR's are important and should be a design consideration.

SUMÁRIO

Um estudo comparativo envolvendo diferentes tipos de blankets radiais de reatores rápidos foi realizado. Dentre os blankets considerados figuram os de material fertil UO$_2$, ThO$_2$, torio metalico, os de refletores puros C, BeO, Ni, os constituidos de uma combinaçao de refletores e materiais ferteis. Os resultados para reatores de 1000 MWe indicam que não existe nenhum incentivo para blankets que não sejam de materiais ferteis. O material mais favoravel e o torio devido as perspectivas de altos preços para o U 233.

RESUMÉ

Une etude comparative de differents types de couverture de reacteurs rapides est présentée. Elle inclue des couvertures en materiaux fertiles UO$_2$, ThO$_2$ et thorium metallique, des couvertures de reflecterus purs C, BeO, Ni et des combinaisons de materiaux reflecteurs et fertiles. Les resultats pour des coeurs de 1000 MWe indiquent qu'il n'y a aucun avantage a utiliser autre chose que des couvertures fertiles.

En raison du prix de prospection eleve de l'U 233, le materiau fertile le plus favorable est le thorium.

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TABLE I

Summary of the Calculations

fissile inventory (kg) · 3rd cycle

He COOLED	Total	fissile/a	U233/a	Absortion rad. refl.	1/RDT	fractional leackage	BR	ICR	η_{239}	ϵ_{238}	Fast fissions ϵ_{232}
Uo_2	4172	312		.00091	.096	.034	1.30	.95	2.31	143	
Tho_2	4187	305	190	.00091	.094	.032	1.30	.94	2.32	.128	.004
Th	4046	336	221	.00042	.102	.030	1.33	93	2.32	.130	.006
Th*	4124	308	217	.00042		.030	1.30	.90	2.32	.129	.006
Ni	3554	147		.00223	.041	.041	1.13	.97	2.30	.133	
BeO	3488	162		.00157	.046	.030	1.15	.985	2.27	.133	
C	3462	169		.00166	.049	.060	1.15	1.02	2.27	.132	
C-Th	3916	314	183	.00045	.080	.029	1.30	.95	2.30	.131	
Na COOLED											
UO_2	4271	180		.00073	.004	.017	1.17	.89	2.20	.124	
UO_2**	4088	236		.00074	.006	.018	1.22	93	2.19	.124	
BeO	3776	45		.00114	.001	.056	1.04	.91	2.19	.115	
BeO-UO_2	4088	168		.00130	.004	.022	1.16	.91	2.19	.122	
Th	4118	198	180	.00033	.005	.017	1.20	.88	2.21	.113	.004

*K_{init} = 1.02

**K_{init} = 1.00

TABLE II

Parameters of the Reactor Design

Peak linear rating	500 w/cm
Average rating	350 w/cm
Pellet diameter	6 mm
Fuel volume fraction	3
Steel volume fraction	2
Coolant volume fraction	5
Core volume	10 m^3

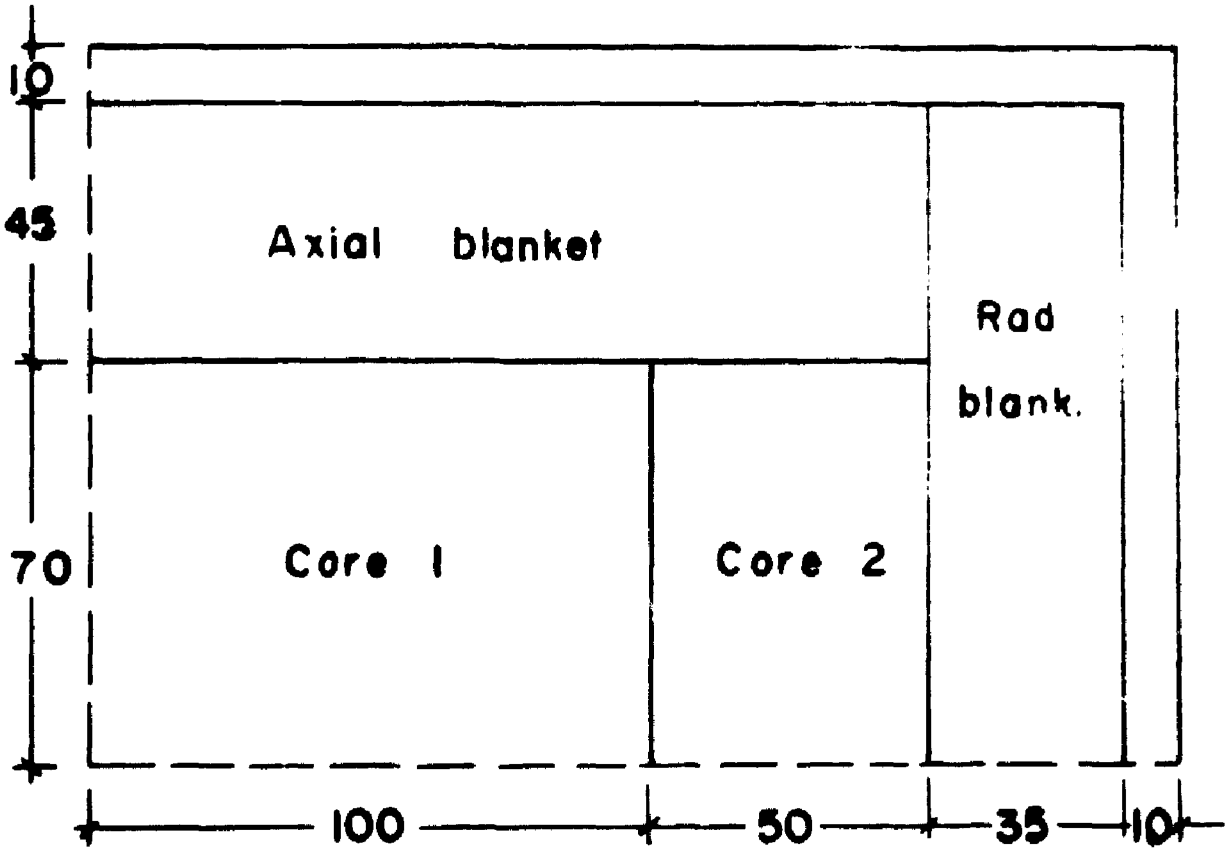

Fig 1 - Core Model

unit : cm

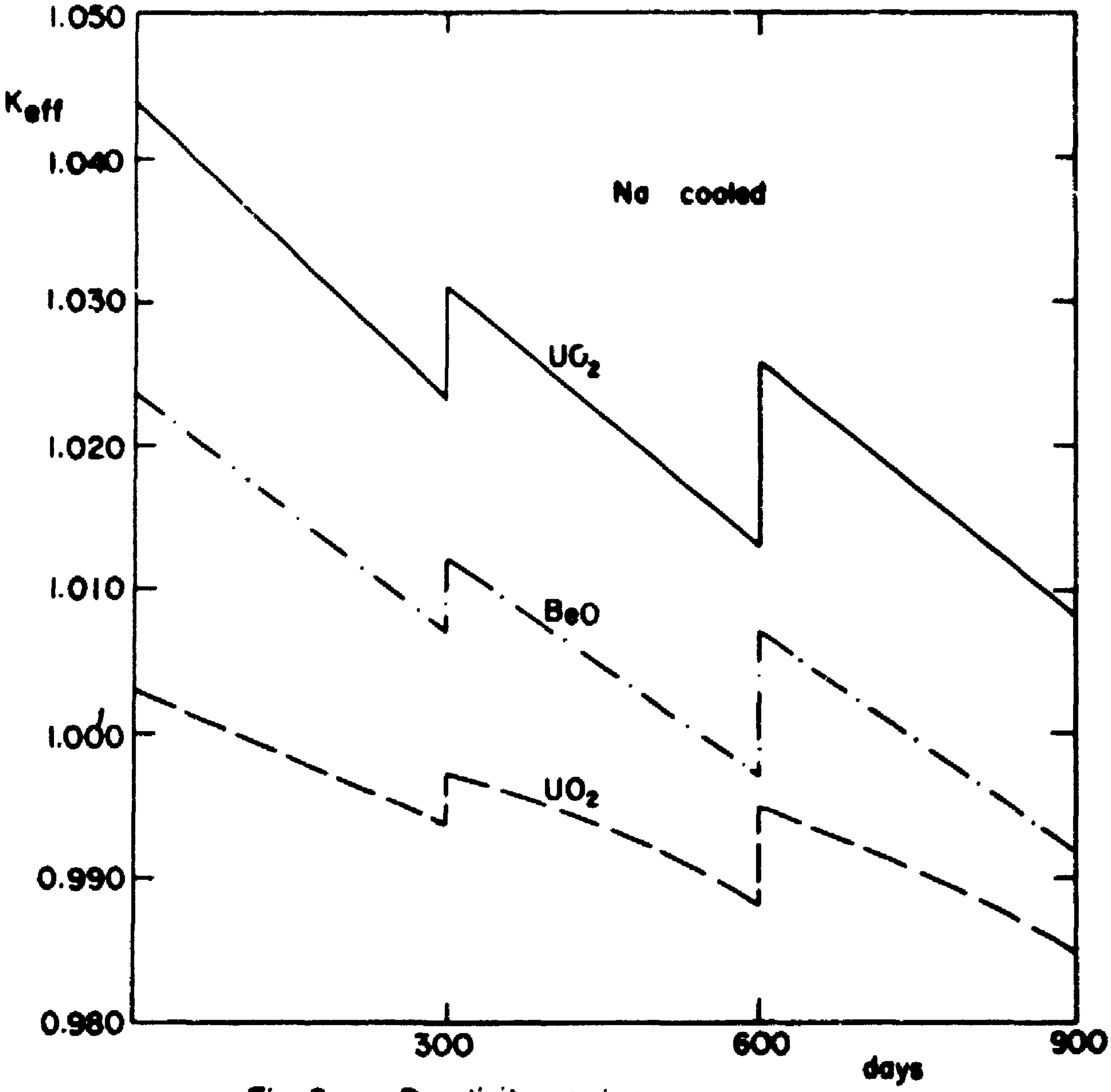

Fig 2 - Reactivity swing

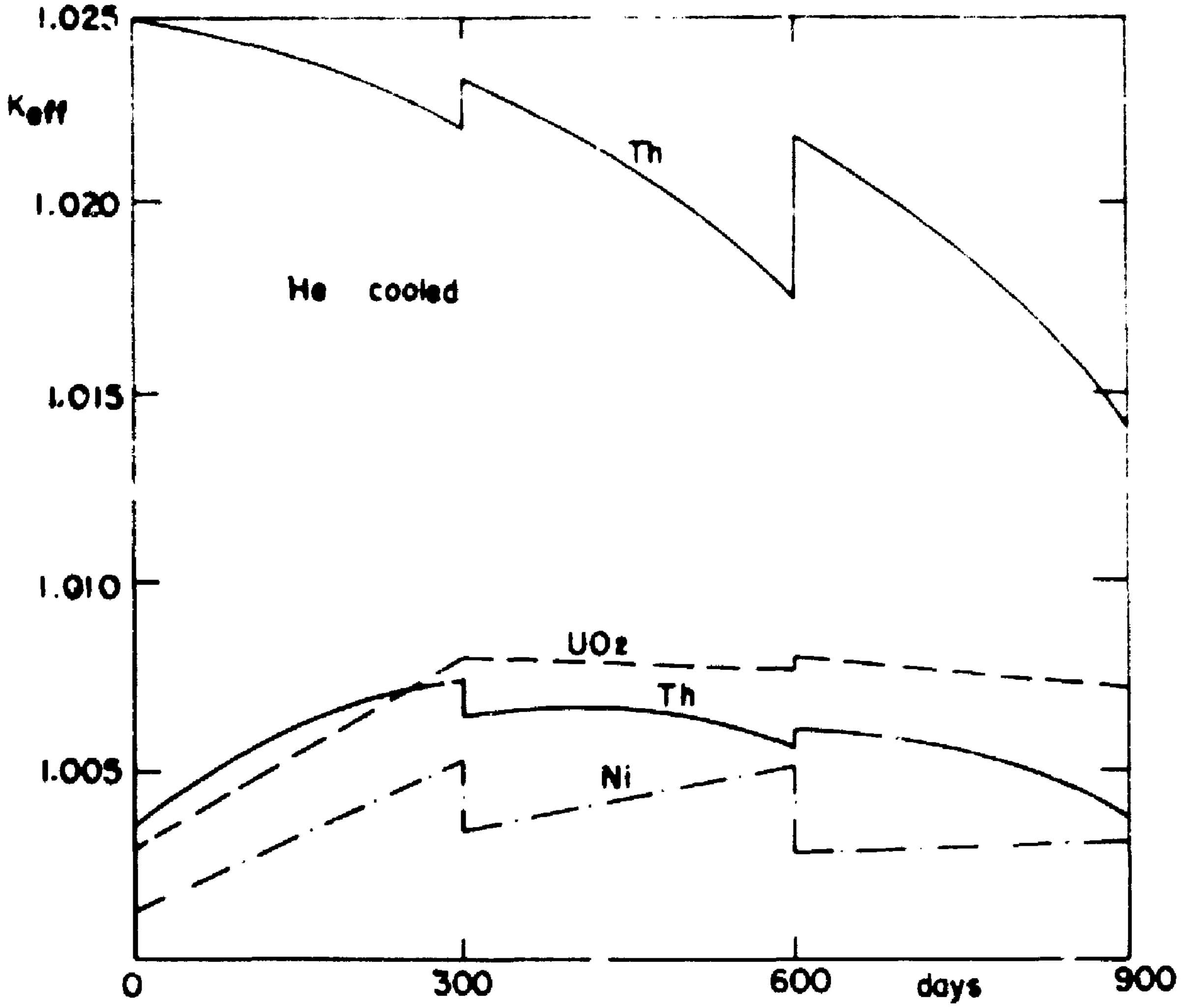

Fig 3 - Reactivity swing

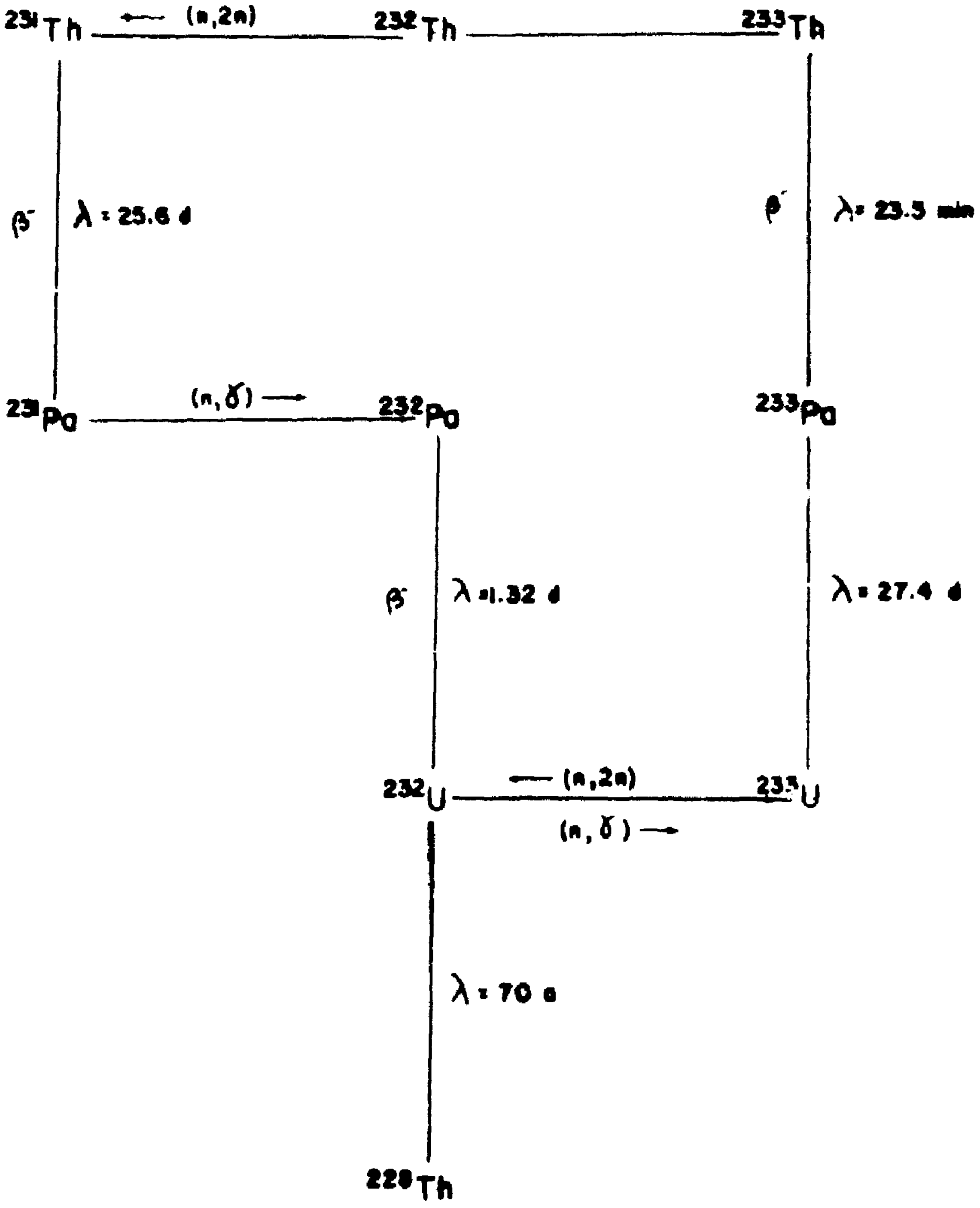

Fig 4 - Production of U-232 and U-233

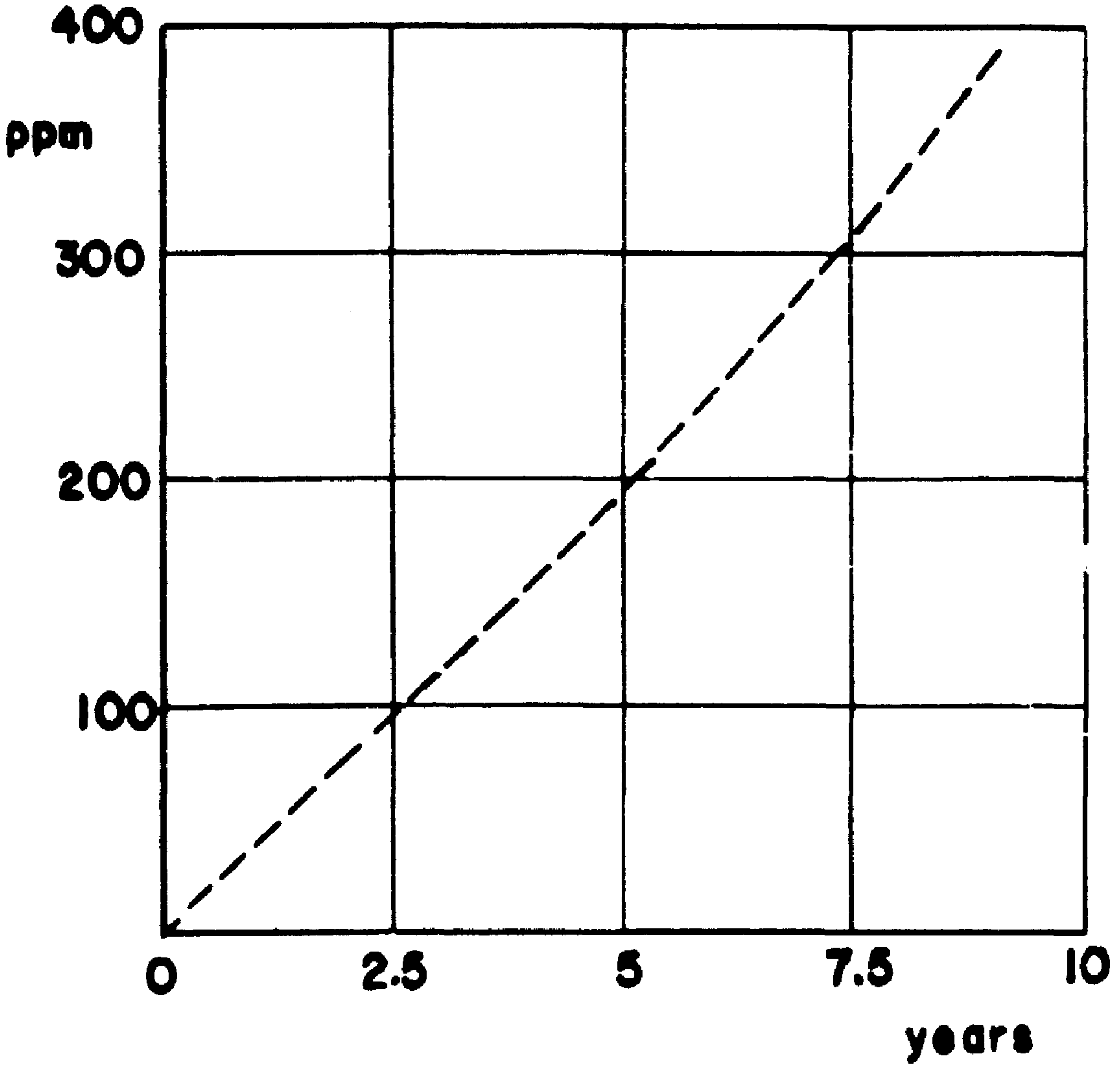

Fig 5 - U-232 content

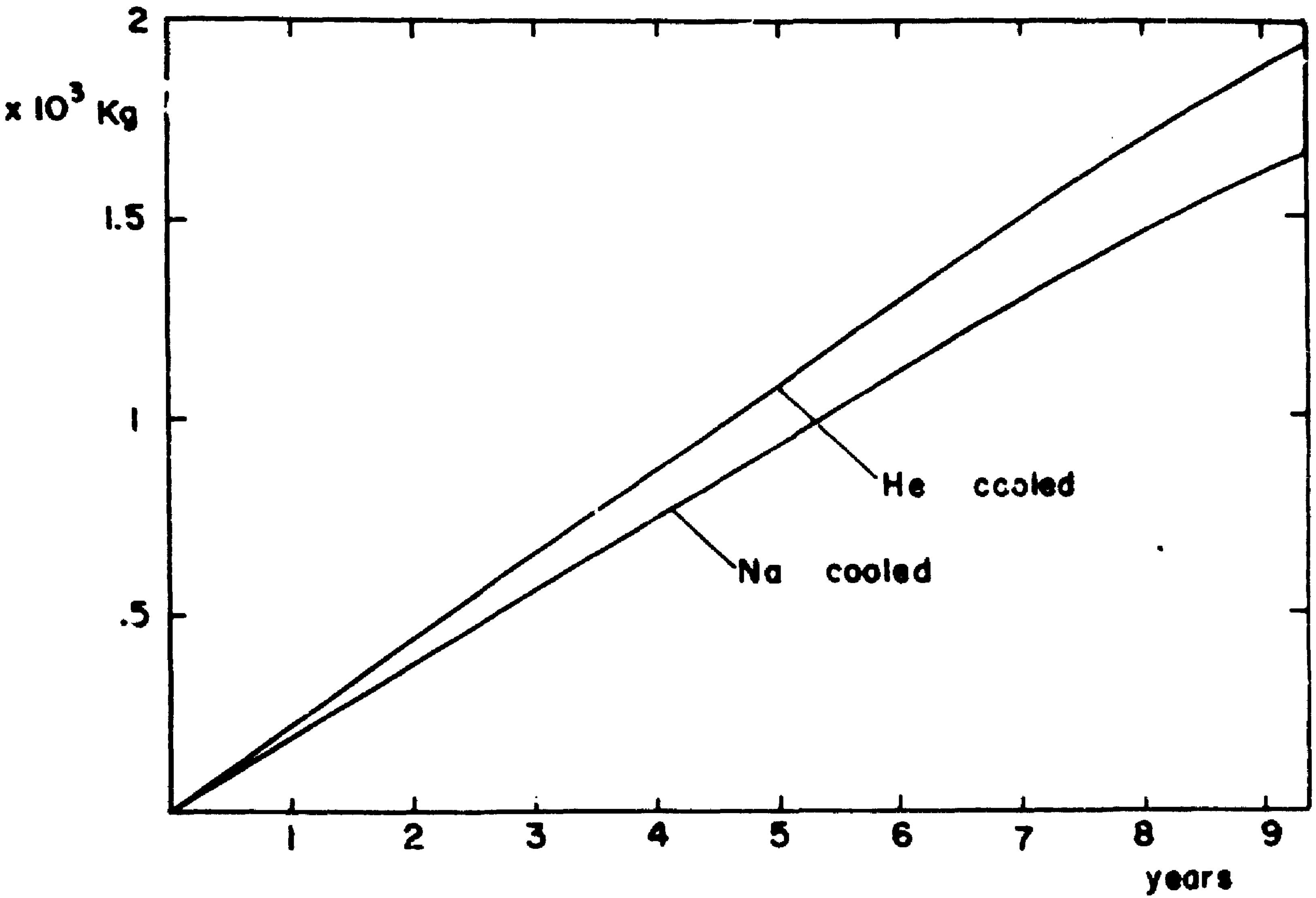

Fig 6 - Production of U-233

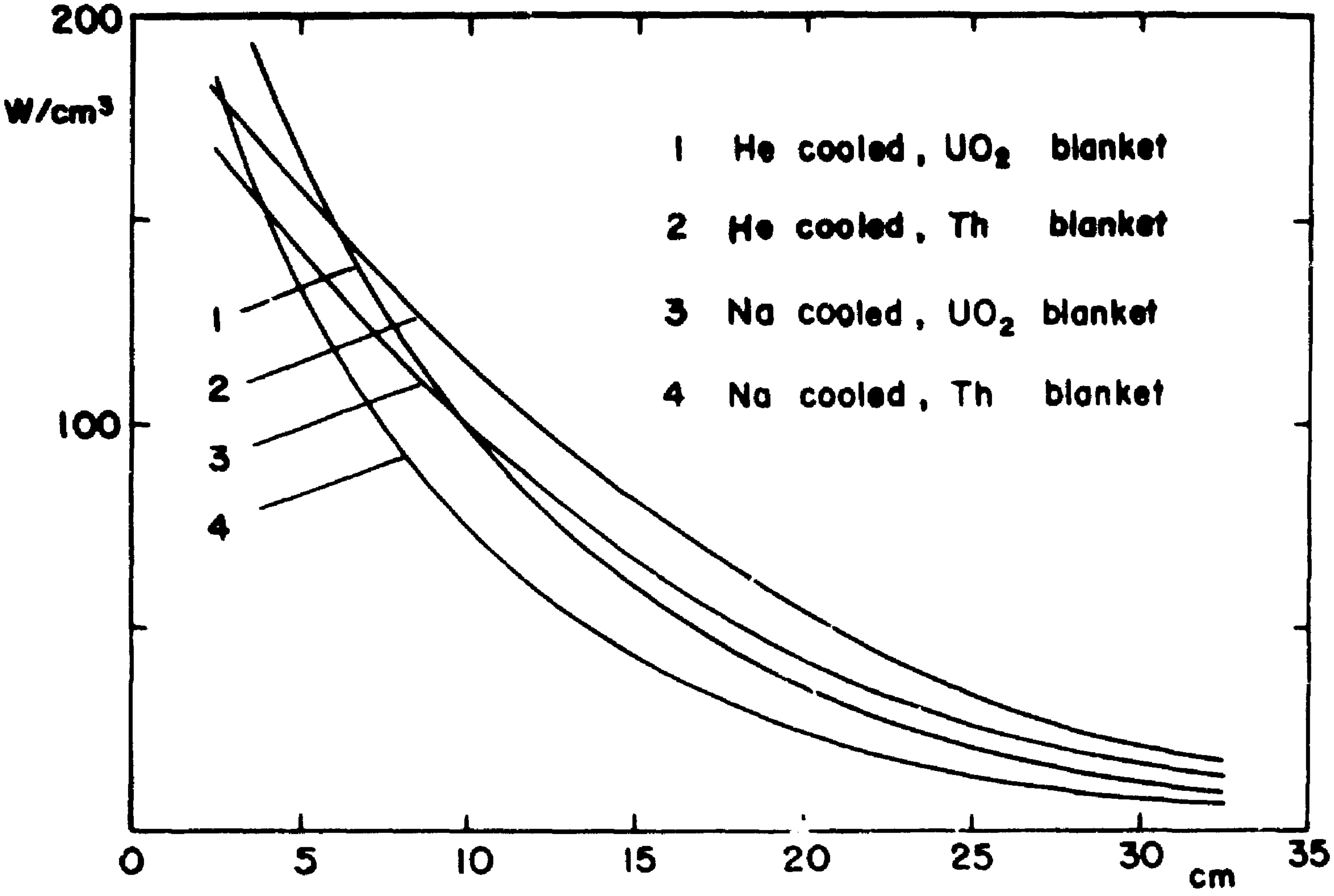

Fig 7 - Power density distribution in the blanket after 6 cycles