CONTROL ROD STUDIES IN SMALL AND MEDIUM SIZED FAST REACTORS

T.M.John, P.Mohanakrishnan, B.Mahalakshmi and R.Shankar Singh

Indira Gandhi Centre for Atomic Research,
Kalpakkam, 603102, Tamil Nadu, India

ABSTRACT

Control rods are the primary safety mechanism in the operation of fast reactors. Neutronic parameters associated with the control rods have to be evaluated precisely for studying the behaviour of the reactor under various operating conditions. Control rods are strong neutron absorbers discretely distributed in the reactor core. Accurate estimation of control rod parameters demand, in principle transport theory solutions in exact geometry. But computer codes for such evaluations usually consume exhorbitantly large computer time and memory for even a single parameter evaluation. During the design of reactors, evaluation of these parameters will be required for many configurations of control rods. In this paper, the method used at Indira Gandhi Centre for Atomic Research for estimating the parameters associated with control rods is presented. Diffusion theory solutions were used for computations. A scheme using three dimensional geometry represented by triangular meshes and diffusion theory solutions in few energy groups for control rod parameter evaluation is presented. This scheme was employed in estimating the control rod parameters in a 500 Mw(e) fast reactor. Error due to group collapsing is estimated by comparing with 25 group calculations in three dimensions for typical cases.

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1.1 Introduction

Control rods are the primary safety mechanism in the operation of fast reactors. Neutronic parameters associated with the control rods are mainly the reactivity worth of the rods for full and partial insertions and power shape tilt associated with these insertions. They have to be evaluated precisely for studying the behaviour of the reactor under various operating conditions. Control rods are strong neutron absorbers discretely distributed in the reactor core. Accurate estimation of control rod parameters demand, in principle transport theory solutions in exact geometry. But computer codes for such evaluations usually consume exhorbitantly large computer time and memory for even a single parameter evaluation. During the design of reactors, evaluation of these parameters will be required for many configurations of control rods. Hence devising methods for faster computation of control rod parameters is a problem worthy of detailed consideration.

In this paper we present the method used at Indira Gandhi Centre for Atomic Research for estimating the parameters associated with control rods. We have resorted to diffusion theory solutions for easiness of computation. The effect of this approximation is later estimated as a correction factor to be applied to the predicted parameters. Even in diffusion approximation doing fine group calculations (using 25 groups or more) is still too costly for routine evaluations. Hence we are presenting a scheme using three dimensional geometry represented by triangular meshes and diffusion theory solutions in few energy groups for control rod parameter evaluation. This scheme was employed in estimating the control rod parameters in a 500 Mw(e) fast reactor. Error due to group collapsing is estimated by comparing with 25 group calculations in three dimensions for typical cases.

2.1 Calculational Model and Results

Currently India is designing a 500 Mw(e) Prototype Fast Breeder Reactor(PFBR)[1]. It has a core volume of approximately 2800 litres made up of 181 fuel assemblies, with two enrichment zones. There are 12 control rods arranged in two rings. Nine control rods comprising of six from the outer ring and three from the inner ring form the primary shut down system while three other rods of the inner ring form the secondary shut down system. A schematic representation of the core configuration is given in Figure 1. In such geometries any lower dimensional modelling of control rod configurations will introduce unacceptably large errors in the predicted parameters. Also the control rods introduce localised disturbances in their neighbourhood. This necessitates the exact three dimensional simulation of the core geometry. For solutions within reasonable computer time, the number of groups used in three dimensional calculations was limited to four.

In this method, 25 group selfshielded cross sections were generated from the available cross section library, corresponding to the operating temperature, for the different materials present in the reactor, These cross sections were used in a two dimensional cylindrical geometry diffusion theory calculation. Cylindrical model of the reactor core is given in Figure 2. Since this calculation is meant for generating the spectrum to be used in collapsing the cross sections to fewer number of groups, coarse mesh structure was used to speed up the solution. The 25 group cross sections are collapsed to 4 groups using the above spectrum. These collapsed cross sections are used in the three dimensional diffusion calculations, using triangular meshes to represent the exact geometry. Since the spectrum generation and collapsing of cross section are done for each reactor configuration the error due to group collapsing is expected to be small for the evaluated parameters.

The code ALCIALMI[2] was used for 25 group calculation in two dimensional cylindrical model. Code combination of ALTOTR-TREDFR[3] was used for collapsing the cross section and performing 4 group three dimensional calculations. 25 group three dimensional calculations for typical cases, taken for comparison with the 4 group results, were performed using code 3DB[4]. Comparisons of 4 group and 25 group results were done for the total worth of the rods and also the power distribution among the different fuel assemblies in the core for two cases namely, (i) the 9 primary control rods fully inserted in the core and (ii) all the 12 control rods of the primary and secondary shutdown system simultaneously inserted in the core. Table I gives the general features of the core. Table II compares control rod worths for the above cases computed by 25 group calculations with 4 group results. The reactor configuration used in this study had the 54 gas expansion module(GEM) assemblies immediately follwing the fuel assemblies (see figure 1) replaced with blanket assemblies. Figure 3 gives a graphical representation of the percentage difference in the power production in the core fuel assemblies, predicted by 4 group calculation with that of 25 group result, corresponding to the case when all control rods are out of the core. Maximum difference in the power distribution is 4% near the boundary between core and blanket region. The control rod worths also agree with the 25 group results, the maximum error being less than 1%, thus validating our model.

3.1 Shadowing Effects

The parameters evaluated using the 4 group calculation for PFBR are worths and power distributions for the following configurations namely, (i) all rods in the inner/outer control rod ring fully inserted (ii) single control rod in inner/outer ring fully inserted (iii) all three control rods forming the secondary shut down system fully inserted and (iv) all nine control rods of the primary shut down system simultaneously inserted to various depths into the core. Table III gives the worths of control rods for the cases mentioned above. The above Table also contains the shadow effects between the control rods for the given configurations. Shadow effect is defined as,

$$\text{Shadow} = 1 - \frac{\text{worth of n rods inserted together}}{\text{(n times the worth of a single rod)}}$$

Results in the Table show high antishadowing (9-19%) for most of the cases, especially when the rods of the outer ring are involved. This shows that the rods in the outer ring are neutronically well separated. Similar effect is also seen when the secondary control rods alone are inserted in the inner ring. But when all the 6 rods in the inner ring are simultaneously inserted the antishadowing effect is only 0.3% due to cancellation of antishadowing between well seperated control rods by the shadowing between adjacent rods.

4.1 Effect on Power Distribution

To study the effect of control rods on the power profile the change in the power produced in each sub assembly was estimated, when all rods of the primary control system were inserted. For the purpose of comparing the shape, total power from the reactor with all primary rods inserted was normalised to 1140 Mw(th), the maximum allowed power when all control rods are out of the core. Figure 4 gives the percentage change in the power produced from the fuel assemblies when all the primary rods are inserted. This case represents the extreme case of power tilt. Results of the power shape change estimation show that power of that part of the fuel assembly touching the absorber part of the control rods are severely affected by control rods (15-20 %), while in the second row of fuel around the control rods the effect is small. If the power shapes are normalised such that the peak point in the distribution always produces the maximum rated linear power of 770 watts/cm., then the configuration with all control rods out of the reactor core produces 1140 Mw(th) power, while the configuration with primary control rods inserted by 30 cms into the core (corresponds to the expected position of the control rods at the beginning of cycle) produces 1102 Mw(th) power. By the same normalisation, the power from the core, for all primary rods down configuration is 1060Mw(th). Thus even though the absorber elements produce local power tilts of approximately 20%, the overall power from the reactor is affected only by 4% for the operating configuration.

5.1 Conclusions

Results of the study show that 4 group analysis, with the 4 group cross sections generated for each case using the spectrum from a lower dimensional calculation, predict the control rod worths to good accuracy, the error being less than 1%. Power distribution is also predicted within an error of 4% with respect to the 25 group results. The same accuracy margin is preserved even for the maximum distorted power shape, when all primary control rods are fully inserted in the core. In reactors with large control rods, effect of transport theory on control rod worths can be treated as correction factors, which can be evaluated again by lower dimensional calculations[5].

6.1 References

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Table I

General Description of the Reactor Core

Fuel type	- PuC/UC
Number of fuel assemblies in core1/core2	- 91/90
Number of primary control rods	- 9
Number of secondary control rods	- 3
Fuel/Sodium/S.S. volume fractions in core	- 35.9/40.6/23.5
Pu. enrichments in core1/core2	- 15.72/22.46
B_4C/Sodium/S.S. in control rods (Primary and Secondary)	- 34.1/45.5/20.4
Boron-10 enrichment in B_4C	- 50%
Width across the flats of hexagonal assembly	- 13.63 Cms.
Height of fuel portion of assembly	- 101.2 Cms.

Table II

Comparison of Control Rod Worths in 4 Group and 25 Group Studies

Case	No. of groups	K-eff	Worths (milli k)
All control rods out of core	25	1.04216	--
	4	1.04248	--
All primary rods inserted in the core	25	0.95224	89.92
	4	0.95180	90.68
All primary and secondary rods inserted	25	0.92000	122.16
	4	0.92026	122.22

Every run of 25 group calculation consumed more than 15 hours of CPU on a Norsk Data -560 computer where as the 4 group calculations took 2 hours each.

Table III

Control Rod Worths for Different Rod Combinations and Shadowing Effects Calculated by 4 Group Calculations.

Case description	Worth of control rods (milli k)	Shadow effect (%)
One control rod of inner ring fully inserted	11.38	--
One control rod of outer ring fully inserted	7.10	--
Adjacent two rods of inner ring fully inserted	20.24	11.1
All control rods of inner ring fully inserted	68.47	-0.3
All control rods of outer ring fully inserted	50.99	-19.7
All primary control rods fully inserted	89.95	-17.2
All secondary control rods fully inserted	37.32	-9.3
All primary and secondary control rods fully inserted	123.33	-11.2
All primary control rods inserted into the core by a length of		
(i) 30 cms.	19.58	--
(ii) 50 cms	44.52	--
(iii) 80 cms.	81.89	--
(iv) 100 cms.	89.95	--

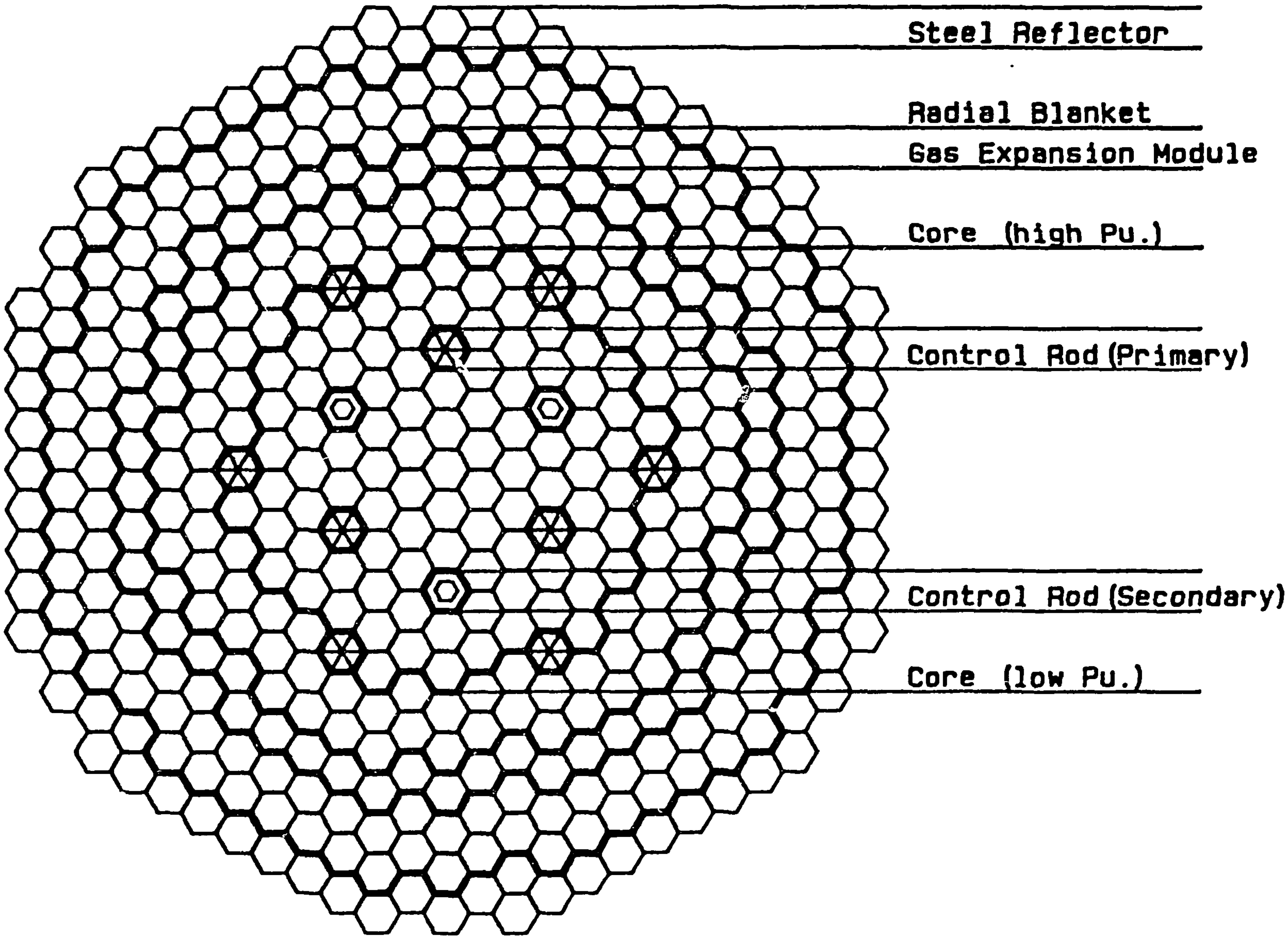

Fig. 1 PFBR Core Configuration

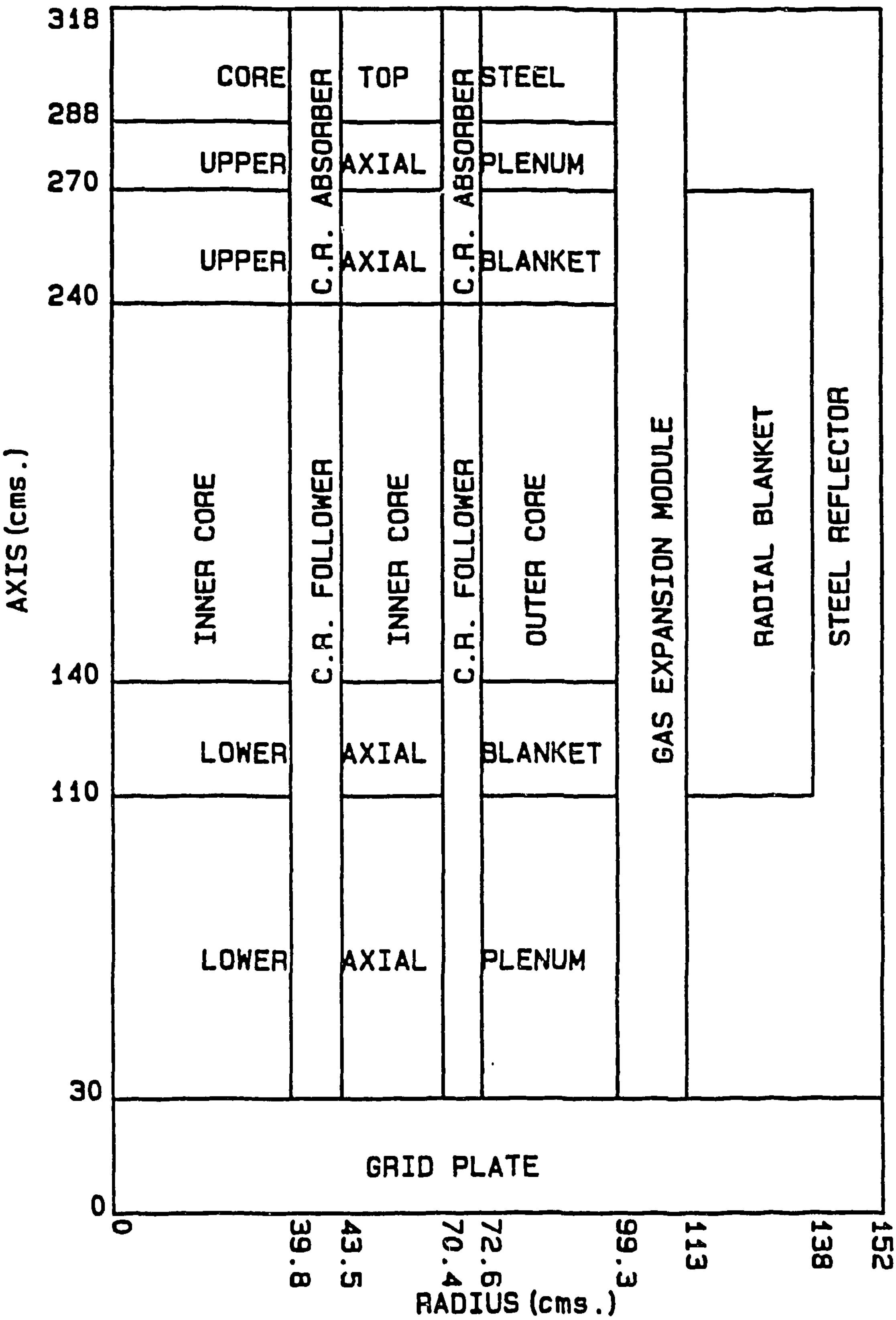

Fig.2 Cylindrical Geometry Model of PFBR Core

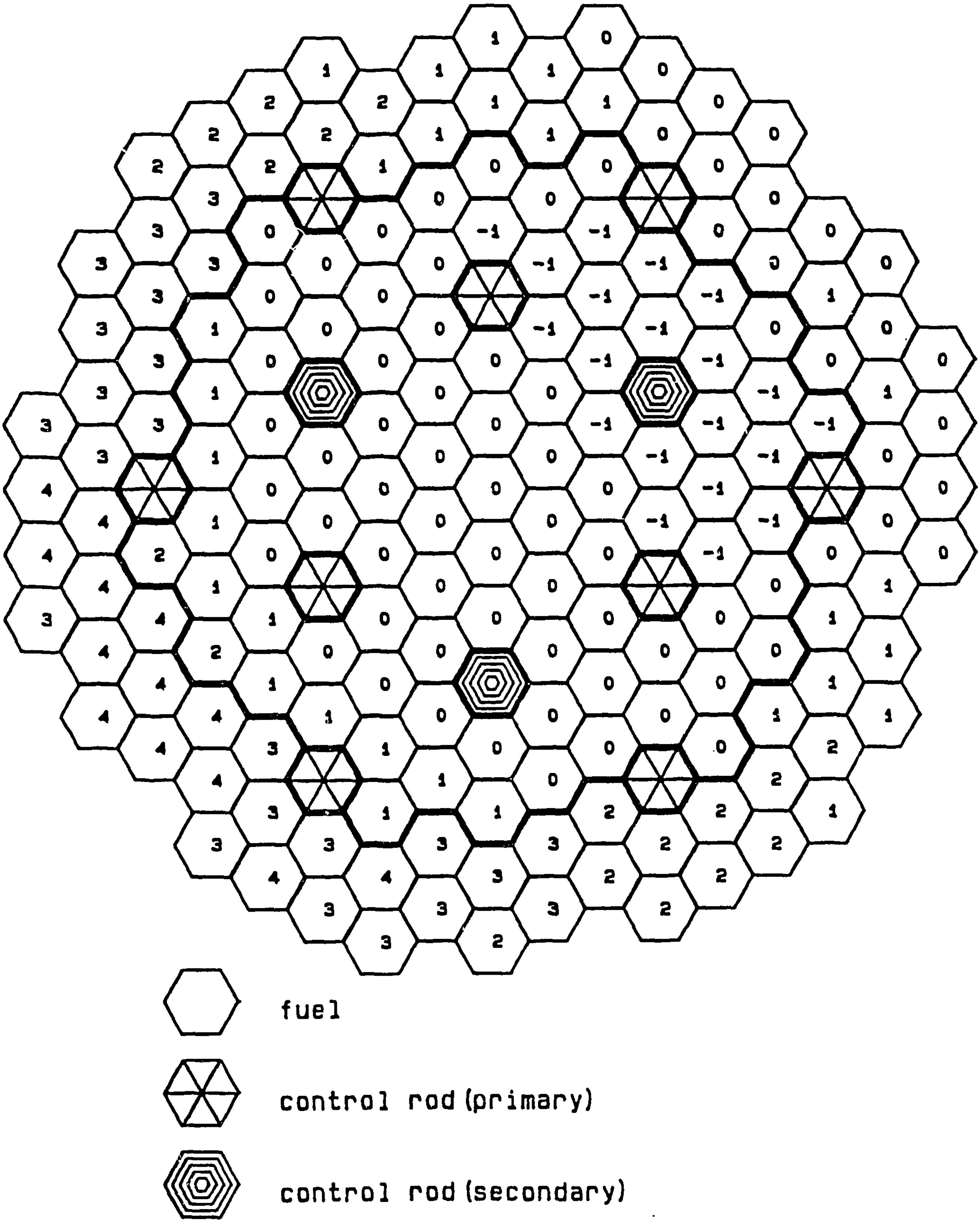

Fig. 3 Percentage Difference in the subassemblywise power distribution, between 4 group and 25 group values, for the control rods fully withdrawn case

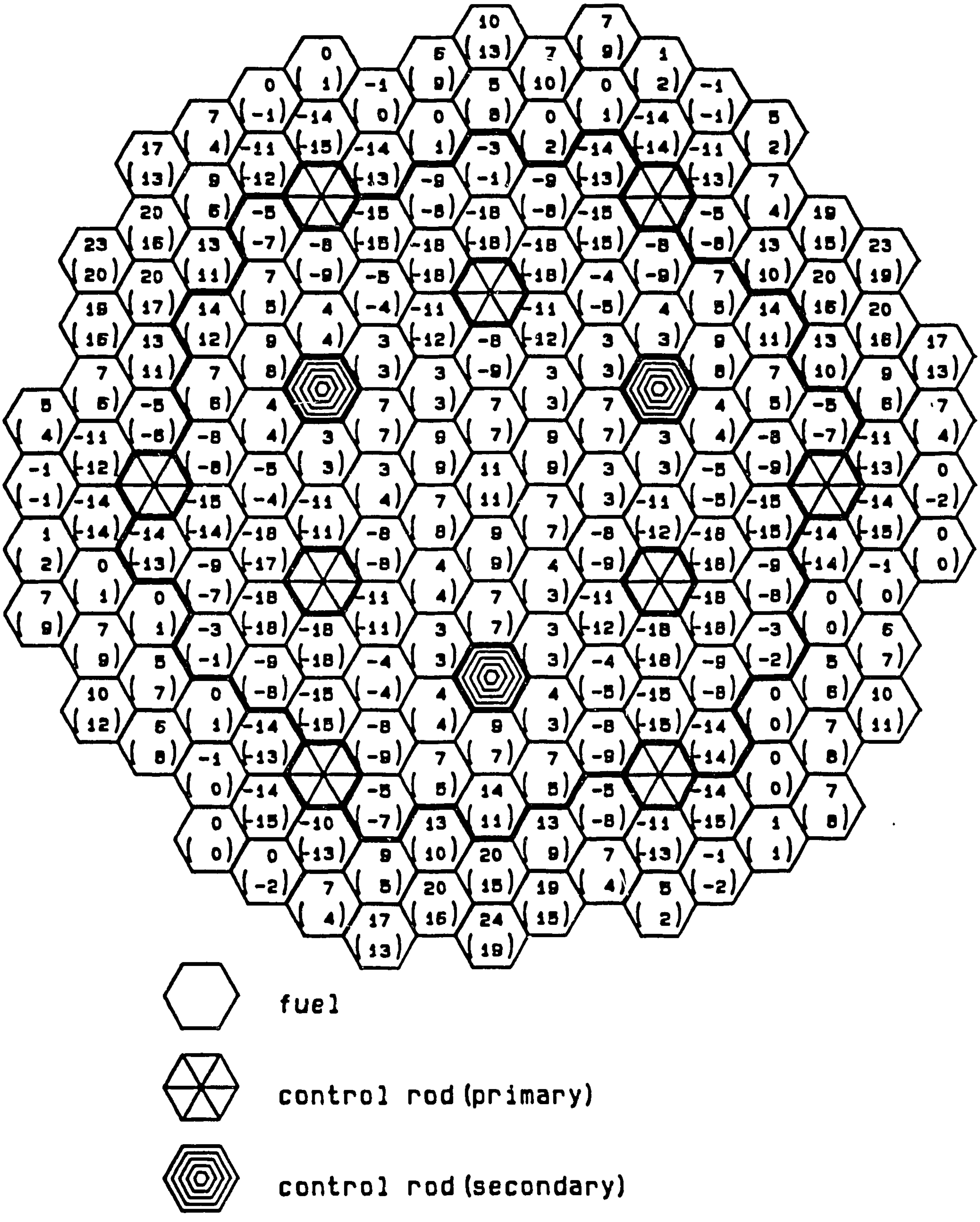

Fig.4 Percentage change in the power per subassembly when all the prima: control rods are fully inserted. The total power is normalised to the value corresponding to the all control rods out configuration (values given in bracket are obtained by 25 group).