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EFFECT OF HORIZONTAL CONTROL RODS
IN TOTAL CONTROL COMPENSATION

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EFFECT OF HORIZONTAL CONTROL RODS
IN TOTAL CONTROL COMPENSATION

INTRODUCTION

This document provides a method for calculating the compensating effects of horizontal control rods in highly shadowed cases encountered in total control administration.

The two-dimensional diffusion theory computer code "9 ANGIE" was used to calculate the reactivity effects of the horizontal control rod geometry with respect to total control requirements at B, D, F, and DR Reactors. This document includes a graph which shows the compensating effect of the horizontal control rods when inserted through the center "B" section of the pile as defined in the "square pile" approximation method¹.

SUMMARY

For total control requirements in the center section of B, D, F, and DR Reactors the horizontal control rods will compensate approximately 25 per cent of the buckling increase presently due to enriched fuel at the top and bottom of the pile. If the enrichment is already compensated by adjacent supplementary poison, the inserted horizontal control rods will reduce the center "B" section buckling by an amount equivalent to charging 2 PCCF tubes in the center zone. The direct compensating effect of the horizontal control rods with respect to the enriched fuel on the near side of the "square pile" remains unchanged.

DISCUSSION

Total control calculations have always been conservatively based on a one-dimensional calculational method involving a cylindrical approximation of the safety system plane. Therefore, horizontal control rods, which pass perpendicular to the vertical safety rods, were considered as a factor of conservatism and not included as a calculable amount of supplementary control except as a direct compensation for enriched fuel which is specifically adjacent to the control elements.

A two-dimensional, diffusion theory, computer code "9 ANGIE" was recently tested for possible usage in nuclear safety analysis. One neutron energy group calculations of the safety and control system capacities measured during the K Pile startup tests² were calculated by the program. The calculated and measured results are compared in Table I.

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¹HW-46100, Vol. I - "Pile Physics Manual of Standard Practices, Chapter B-1, Square Pile Theory," A. D. Vaughn

²HW-37158, "K Pile Startup Experiments - Part IV - Evaluation of Safety and Control System Capacities," C. L. Miller, July 2, 1956

Table I

Calculated vs. Measured Values of K Pile
Control Capacities

Case #	Number Controls	Load Dimensions (Lattices)	Results in Terms of Excess Reactivity Available with Controls Inserted		Ratio of Calcu System Strength vs. Measured System Strength
			Experimental	"9 ANGIE"	
1	28 VSR's	58x23	0.55 mk	0.37 mk	100.4%
2	27 VSR's	58x23	Subcritical	-0.44 mk	_____
3	Same as Case 2 ex- cept pull VSR #31	58x23	+1.39 mk	+1.04 mk	100.9%
4	37 VSR (50% C Column density at sides)	58x23	0	+0.83 mk	_____
5	Same as Case 4 ex- cept pull VSR's #23 and #69	58x23	+0.35 mk	+1.15 mk	98%
6	41 VSR's and 4 steel ball columns (50% C Column density at sides)	58x23	+0.19 mk	+0.18 mk	100.0%
7	43 Steel Ball Columns	Full pile	+0.13 mk	+0.70 mk	98.6%
Average					99.6%

The comparison of measured system strength vs. calculated system strengths indicate that control strengths can be estimated to approximately 99 per cent accuracy in a lattice that is uniform along the axial dimension.

The same code has been used to make a two-dimensional analysis of the horizontal control rod effects in B, D, F Reactors. Since the code is limited to a uniform material in the third dimension, the results can only apply to a region similar to the center "B" section as defined in square pile theory. The horizontal rods do not enter the far side of the reactor anyway, and credit is already taken for the control effect with respect to the near side enrichment.

The calculations were done for a slab reactor with an enriched fuel zone near each end. These zones represent the enriched fuel in the top and bottom of the reactors. The horizontal controls were assigned an area-weighted local control strength as defined by Wheeler's equation³. The control and enrichment zones are depicted in Figure 1.

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³N-2292, "Chapter 22: Control Theory" - J. A. Wheeler

Figure - I
Horizontal Control System Plane
B - D-F Reactors

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The calculational method followed the procedure previously used to estimate top and bottom enrichment effects for total control calculations. However, the local control strength of the horizontal control rods was included as one of the input parameters. The bucklings due to various densities of enriched fuel in the enrichment zones were input with a variable number of inserted control rods and the solutions were in terms of the uniform change in buckling over the pile. The input bucklings are listed in Table I.

Table I

Bucklings - B, D, DR, F Reactors

B _g (Geometric buckling of dry pile)	= 29.4 μ b
ΔB_E (Change in material buckling due to replacing natural uranium fuel with 0.947% enriched fuel)	= +222.0 μ b
ΔB_C (Buckling of horizontal control rods)	= -65.0 μ b
ΔB_{TB} (Uniform buckling increase due to top and bottom enrichment)	

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Figure 2- Effect of top and bottom enrichment and horizontal control rod compensation.

Note: Horizontal control rod compensation is already assumed for near side E ring, and should be used only in center "B" section calculation.

f = fraction of tubes in layer 2-1/2 units thick charged with enriched fuel.

Curve (a) Uniform reduction in buckling inside the enrichment ring required to compensate for enrichment.

Curve (b) Equivalent increase in pile lattice material buckling caused by top and bottom enrichment.

Instructions for Use of Figure 2

Curves a and b in Figure 2 are the same as previously used to estimate the uniform buckling increase due to top and bottom enrichment and consequently the negative buckling necessary in the flat zone to compensate for the effect due to the top and bottom enrichment.

When calculating the reactivity status of the center "B" section for total control estimates the following procedure is applicable.

1. Calculate fraction of enriched fuel in a slab 2.5 lattices thick.

For example:

$$f = \frac{x}{2.5(2w)}$$

where x = total number of enriched fuel columns in the top and bottom enriched zones of the reactor 2.5 lattices thick and w lattices wide.

2. Find f on curve b and locate buckling increase over the center "B" section.

For example:

$$\text{If } f = 75\%$$

$$\Delta B_{TB} = +16.4 \text{ } \mu\text{b}$$

where ΔB_{TB} is the change in the effective pile buckling due to top and bottom enriched fuel.

3. Redetermine ΔB_{TB} based on controls that will be inserted through "B" section during outage.

For example:

If 9 rods are inserted

$$\Delta B_{TB} = +3.0 \text{ } \mu\text{b}$$

If 7 rods are inserted

$$\Delta B_{TB} = +5.0 \text{ } \mu\text{b}$$

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4. Caution: If control rods are moved out of the slab at any time their compensating effect is no longer valid. Thus, the allowance could not be used during a startup when horizontal control rods are being withdrawn.

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Concurrence with above method to be used in administering total control calculations:

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