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FLUX DISTRIBUTIONS WITH TYPICAL ROD AND LOADING PATTERNS

AUTHOR

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FLUX DISTRIBUTIONS WITH TYPICAL ROD AND LOADING PATTERNS

By

J. C. Bryner and G. R. Parkos

September 11, 1959

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FLUX DISTRIBUTIONS WITH TYPICAL ROD AND LOADING PATTERNS

Introduction

Slab geometry and one group diffusion theory flux matching methods were used to calculate typical flux distributions: (1) side-to-side with all rods out, and (2) front-to-rear with various equilibrium rod configurations. Results are general and cover all of the Hanford reactors. Since the purpose of this report is to disseminate the flux distribution information, no specific recommendations are made.

Side-to-side flux distortions may prevent scram recoveries even though adequate reactivity is available. Side-to-side flux profiles calculated for the current reactor loading patterns are presented in this report.

The front-to-rear flux distribution during operation is largely determined by the control rod pattern used. Since a wide variety of control rod patterns is possible, the longitudinal flux profile should be considered before a rod pattern is selected, or changed. Longitudinal flux profiles corresponding to rod patterns which bracket the possible extreme configurations and which include those configurations in current use are presented.

Summary

Side-to-side flux distributions calculated for "rods out" operation are compared to the normal equilibrium distributions in figures 1-3. The results are highly sensitive to enrichment and flattening unbalance. Near side tube power limits are reached at total pile powers as low as 39%, and as high as 85% of the normal equilibrium power. The calculations indicate that, with the current loading patterns, B, D, DR, F, H, and KW, theoretically could make rods out scram recoveries without exceeding tube power limits, whereas C and KE could not.

Longitudinal flux profiles corresponding to possible control rod and mixing piece configurations are compared to the ideal cosine distribution in figures 4-7.

Peak fluxes for a given column power vary from 86 to 111 per cent of a cosine maximum. The position of the maximum flux varies from 115 cm (5.1 slugs) downstream to 131 cm (5.8 slugs) upstream of the center line of the slug column. The effects of non-uniform (front-to-rear) enrichment and flattening charges are not considered. Enrichment effects were considered in Reference 1.

The longitudinal distributions represent the best slab geometry estimates of the average front-to-rear distributions in the radial plane. Therefore, the curves are not representative near rod banks and in regions where the rod pattern differs appreciably, such as next to rod tips on the near side. In general, this method underestimates the distorting effects of the control rods within the rod regions, and overestimates the distorting effects in the fringe regions; however, the results usually compare favorably with actual flux traverse data for comparable rod configurations.

1. HW-56858, E Metal Makeup Optimization Study, W. S. Nechodom.

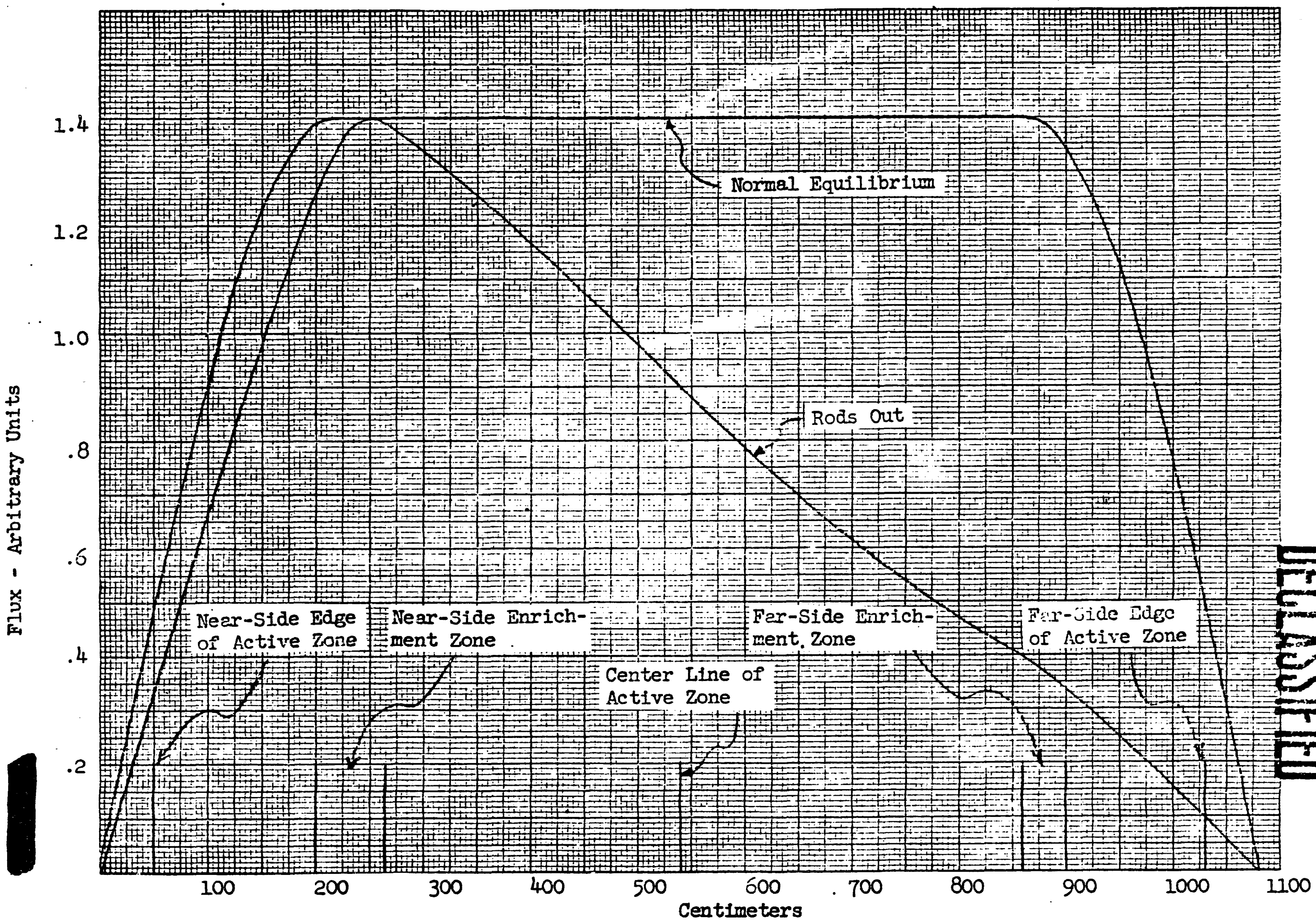

Figure 1

B, D, and F Reactors, Side-to-Side Distribution (See Table II).

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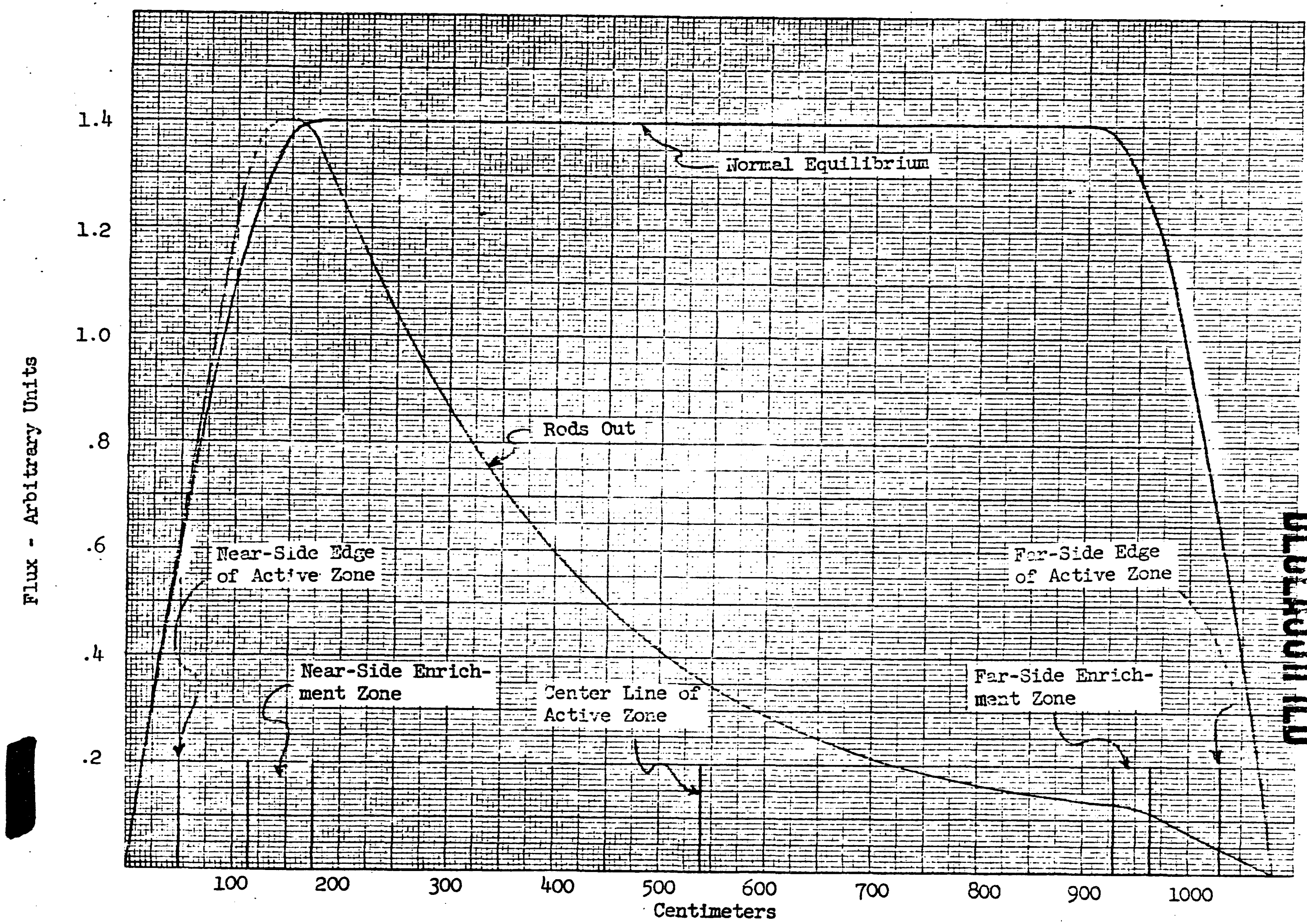

Figure 2

C Reactor, Side-to-Side Distribution (See Table II).

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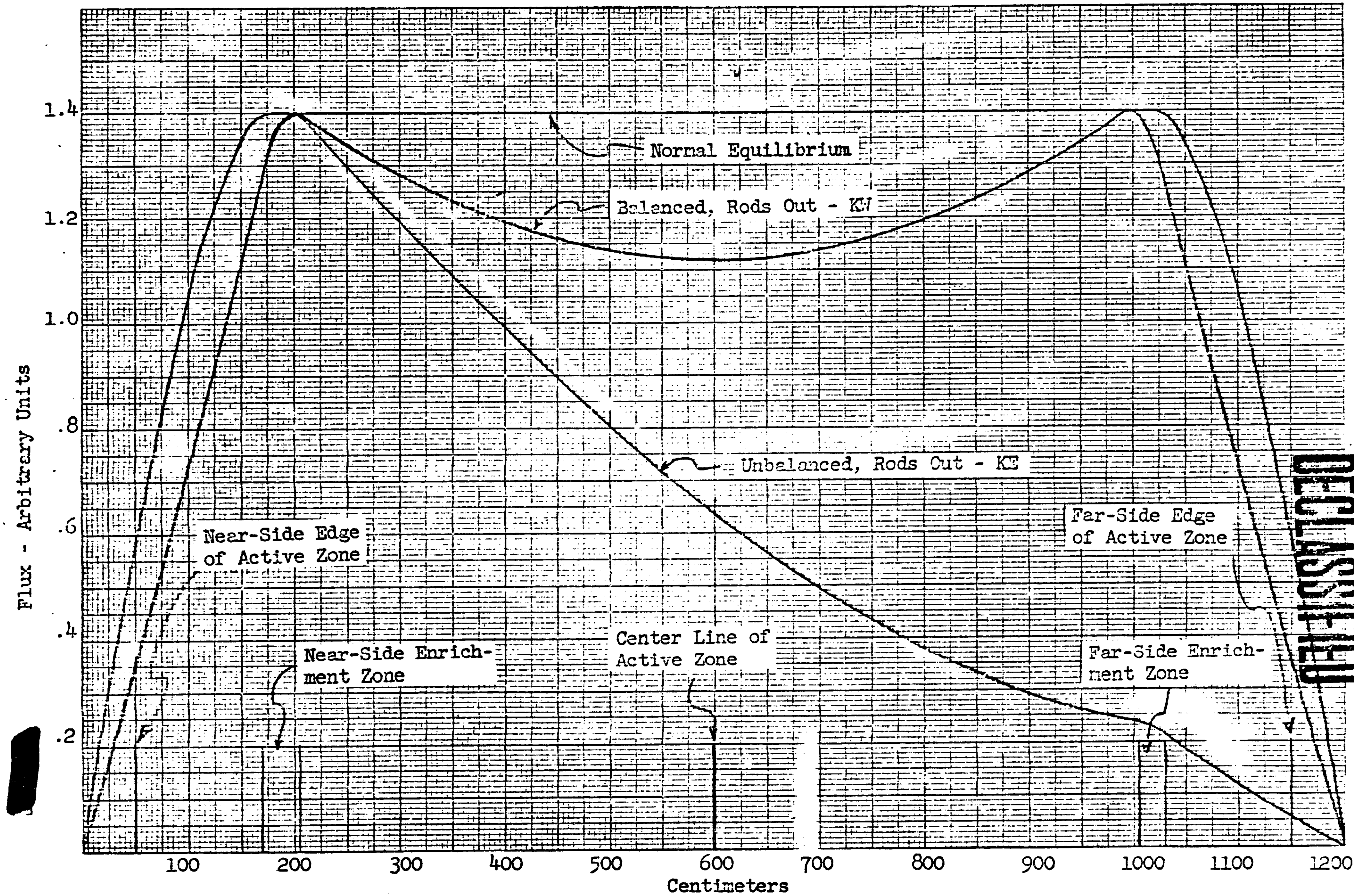

Figure 3

K Reactor, Side-to-Side Distribution (See Table II).

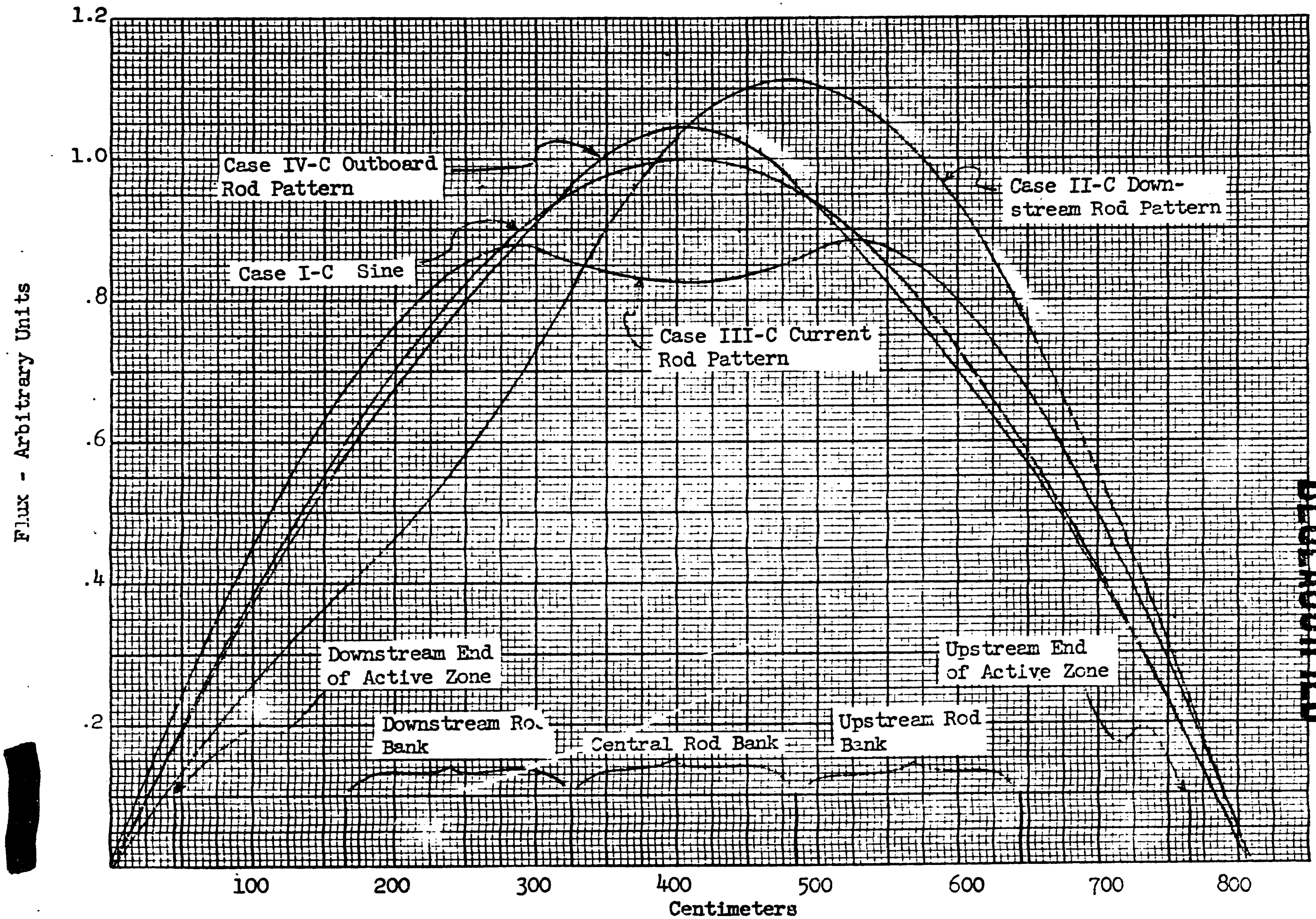

Figure 4

C Reactor, Front-to-Rear Distribution (See Table III).

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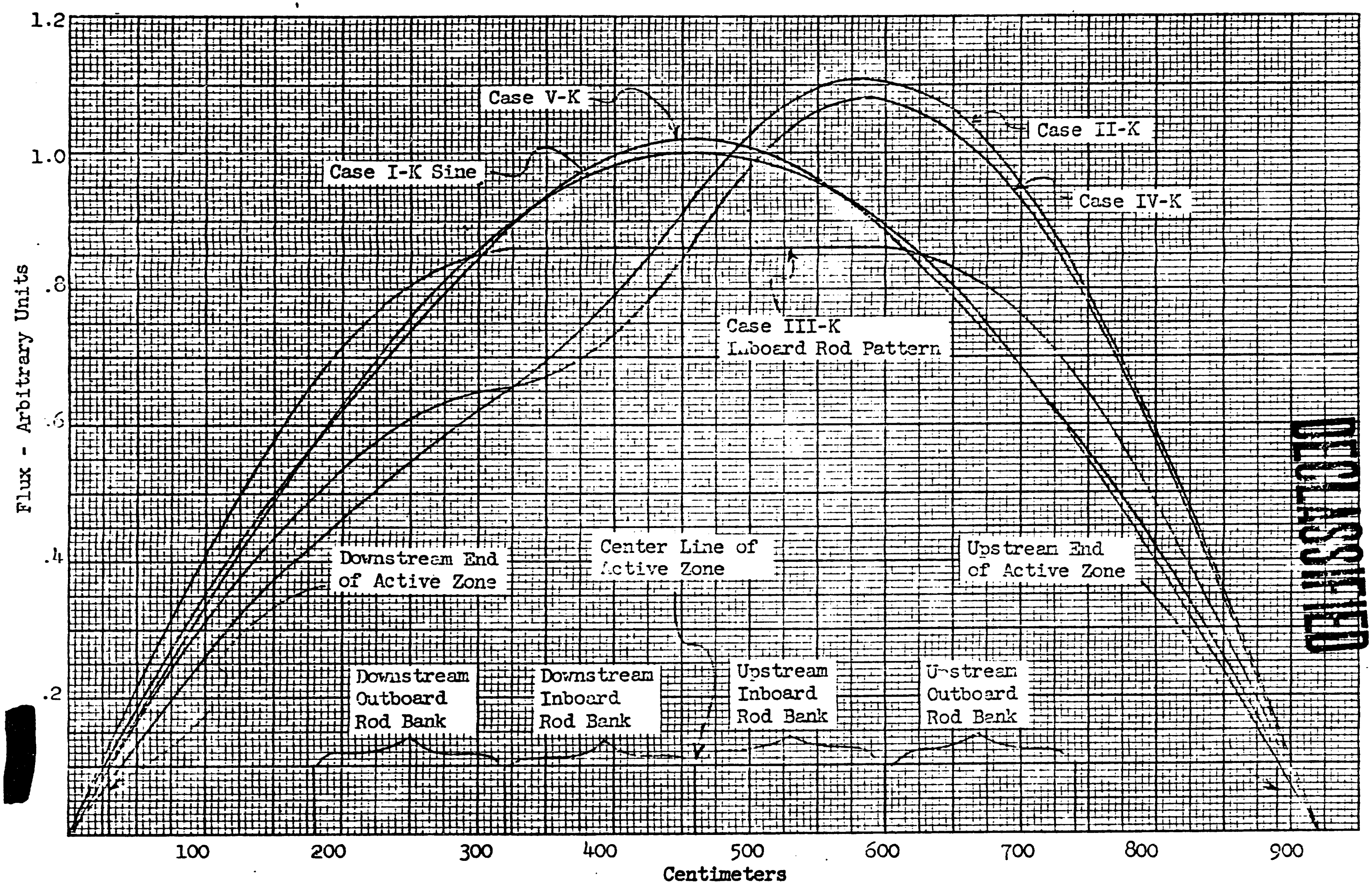

Figure 5

K Reactor, Front-to-Rear Distribution (See Table IV).

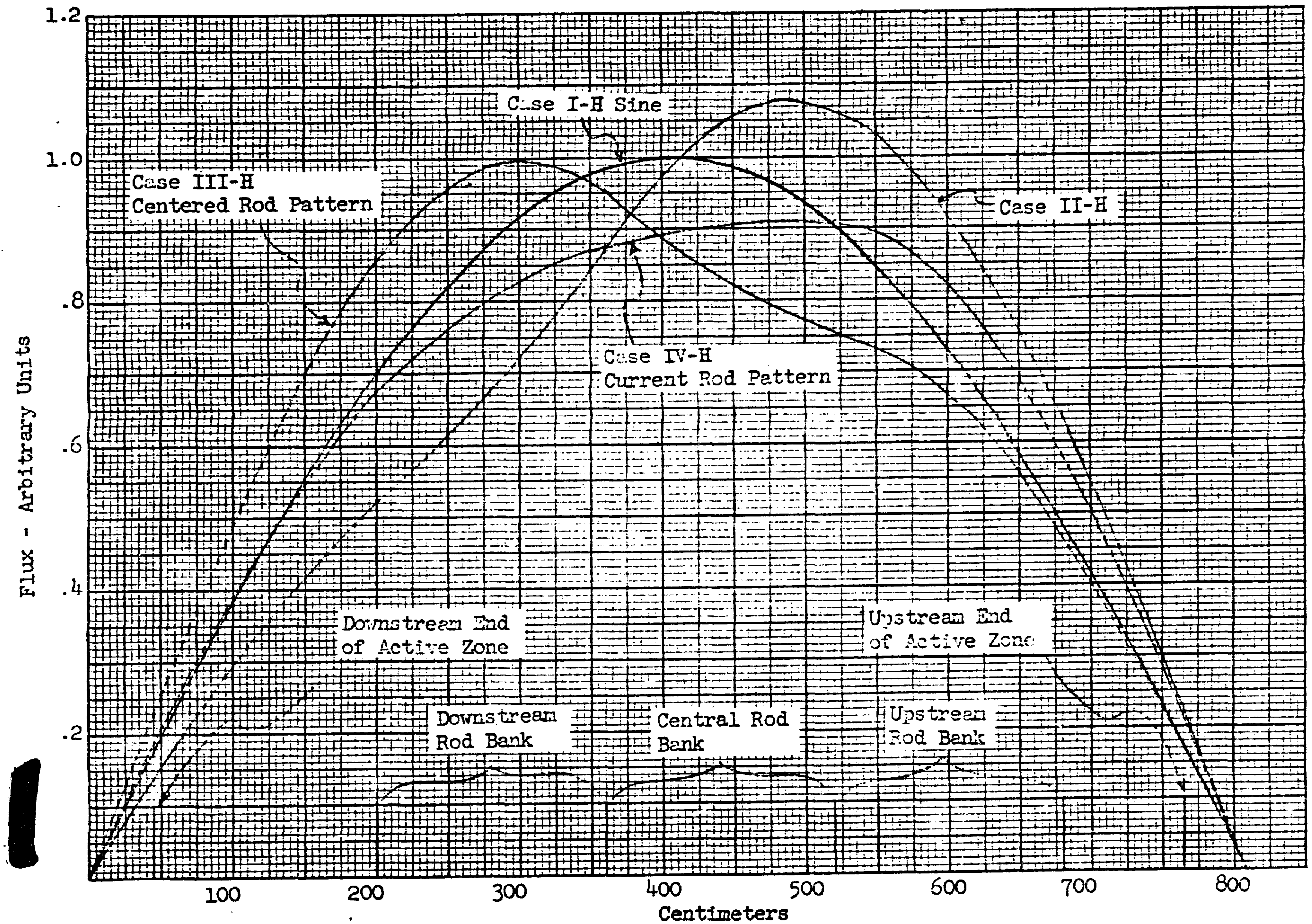

Figure 6

H Reactor, Front-to-Rear Distribution (See Table V).

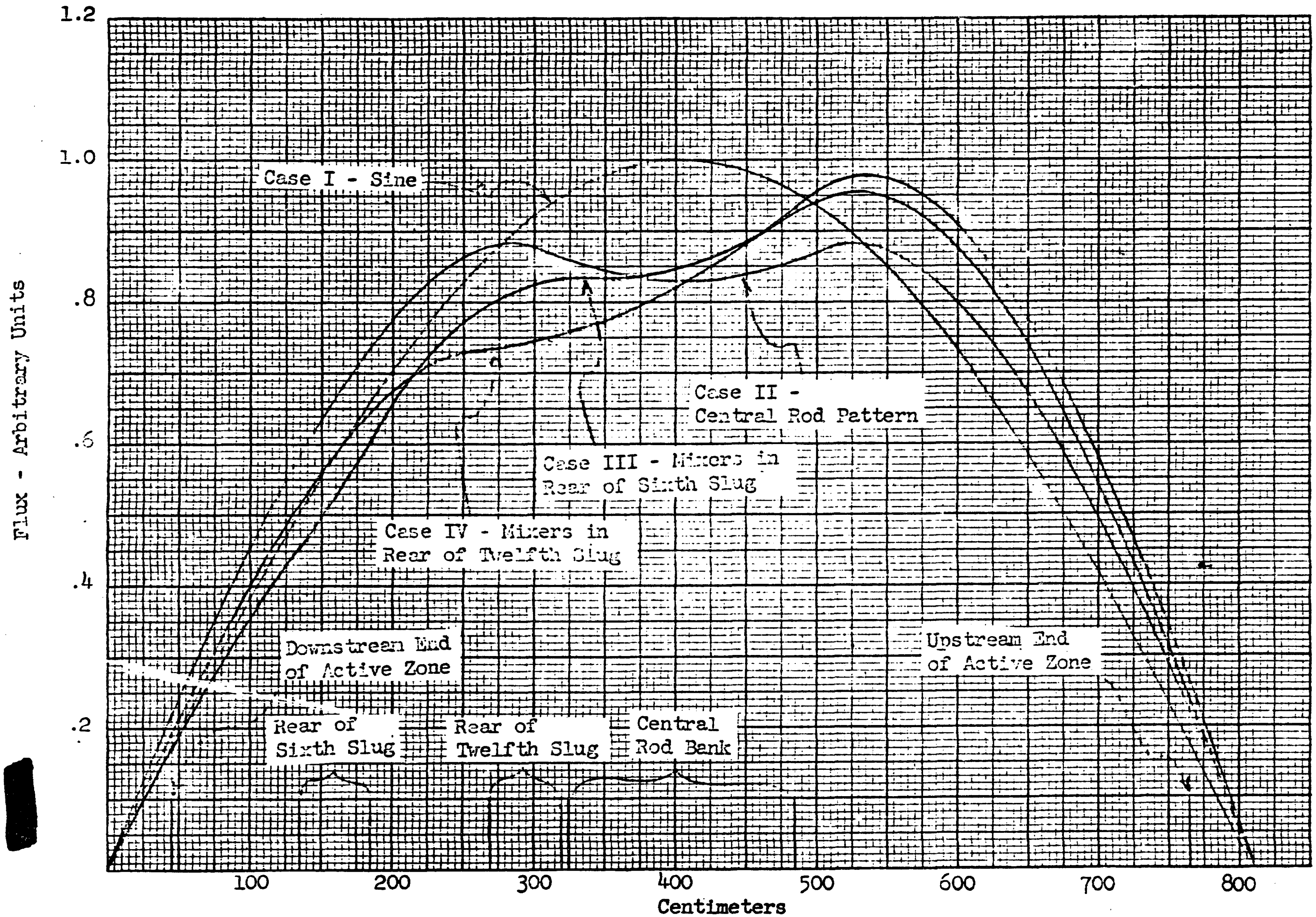

Figure 7

C Reactor, Front-to-Rear Distribution with Mixing Pieces (See Table VI).

Discussion

A. Calculational Methods

Standard slab calculations were used throughout this report. The method consists of picking appropriate solutions to the diffusion equation for each region of interest, and applying the boundary conditions to obtain the "critical" equations. Details of the procedure for multi-region flux matching calculations are contained in reference 2.

1. Calculating Bucklings

a. Buckling Effect of Control Rods

The reduction in buckling caused by the control rods within the area of control (δB_c) has been calculated theoretically.[3] The results of these calculations are listed in Table I. These values, which are in good agreement with past empirical observations, are used in this report.

The δB_c values are based on the assumption that the rod effect is uniformly smeared out over the area which it controls in the control rod pattern. To perform a slab calculation, the equivalent uniform slab buckling of each region must be known. Hence the rod regions must be replaced by slabs with an equivalent uniform buckling. This is done by using the flux squared weighting theorem:

$$B_i = B_m - \delta B_c \left[\frac{\int_{rods} \phi^2 dv}{\int_{pile} \phi^2 dv} \right]$$

where:

B_i = Effective buckling of the ith region.

B_m = Unpoisoned (by rods) buckling.

δB_c = Buckling change caused by rods.

The "flux squared weight" (term in parentheses) was evaluated by numerically integrating data from temperature maps taken at equilibrium. Since the reactor is approximated by a series of slabs in the front-to-rear direction, the integrations were performed in the vertical direction. The appropriate values were obtained from Reference 4 and also appear in Table I.

2. HW-37158 PT 4, K Pile Startup Experiments Part IV, C. L. Miller.

3. HWN-2167, Personal Notes, D. E. Simpson.

4. HWN-2237, Personal Notes, G. R. Parkos.

[redacted]

TABLE I

δB_c Values and Vertical Weighting Factors

Reactor	δB_c	Flux Squared "Weight" of a Rod Bank
C	72.5 μb	.146 any bank
KE, KW	59.0 μb	(.138 for the top and bottom banks. .144 for all other banks)
H	59.5 μb	.146 any bank
B, D, DR, F	59.5 μb	.158 any bank

2. Buckling Effects of Water Mixing Pieces

A detailed discussion of the procedure used here is given in reference 5. The mixing piece effect is approximated by assuming that the mixing pieces are spread uniformly throughout a "control zone". The equilivalent uniform reduction in buckling caused by the mixing pieces (δB_m) within this control zone is estimated by standard techniques. For a control zone 50 cm wide, the mixing pieces in use, and the 8 3/8 inch lattice piles, δB_m = 47.9 μb This value was used in the mixing piece calculations.

3. Setting up Buckling of Regions

The method used for setting up the buckling of regions is discussed in detail in reference 6. The δB_c values used are those listed in Table I.

B. Side-to-Side Flux Profiles

The flattening and enrichment patterns are usually arranged so that a side-to-side flux distribution which is flat in the center and symmetrical can be obtained during normal equilibrium operation. Since the control rods enter from the near side, the enrichment and/or flattening patterns must be unbalanced to compensate for the near-side rod trips. This results in near-side flux peaking when the rods are withdrawn during scram recovery attempts and minimum outages. Slab calculations were used to estimate the side-to-side flux profiles which result at the reactors when the control rods are withdrawn. The buckling arrangements used in the calculations were representative of the current loading patterns. The estimated flux distributions are presented in Figures 1 through 3, and the data are summarized in Table II.

The rods out flux profiles were compared to the normal equilibrium flux profiles by integrating with a planemeter, and normalizing to the same maximum flux. Note that the calculated side-to-side flux profile is very sensitive to the degree of near-to-far enrichment unbalance. The only difference between the KE and KW cases is the enrichment unbalance indicated in the table. KW, with balanced enrichment, reaches equilibrium tube power limits at 85% of the normal

5. HW-59056, Physics Effects of Water Mixing Pieces, G. R. Parkos.

6. HW-60439, Operational Reactivity Accounting by One Group Theory, G. R. Parkos.

TABLE II

Side-to-Side Flux Distortion During Rods Out Operation

Reactor	Figure	% of Equil. Power at Equil Flux Level	% Power Generated on Near-Side of C_L	Remarks
B, D, DR, F	1	61	69	
C	2	39	82	$\frac{\text{Far E}}{\text{Near E}} = .60$
KE	3	50	75	$\frac{\text{Far E}}{\text{Near E}} = .65$
KW	3	85	50	Balanced Enr.

equilibrium power level. KE, with an enrichment unbalance equivalent to about 1.5 near side E columns for every far side column, reaches equilibrium tube power limits at only 50% of the normal equilibrium power level. (See figure 3).

Since minimum scram recovery levels are about 60 per cent of the normal equilibrium power, these calculations indicate that C and KE reactors cannot make rods out scram recoveries without exceeding equilibrium tube power limits. The data in Table II also indicates that KW and the nine-rod piles can make rods out recoveries. However, the nine-rod piles should be very close to equilibrium tube power limits at recovery level during the rods out condition; this is verified by scram recovery experience.[7] No calculations were made for H reactor. H should be able to make rods out recoveries because its side-to side loading is more balanced than the BDF loadings.

C. Front-to-Rear Flux Distributions

Longitudinal flux profiles were calculated for a range of rod patterns at C, H, and the K reactors. The patterns used in the calculations bracket the possible extreme arrangements, and include the configurations in current use. The data are summarized in Tables III, IV, and V, and the flux profiles are presented in graphic form in figures 4, 5, and 6.

At the 8 3/8 inch lattice reactors, the center rod bank is located about 14" upstream of the geometric center of the stack. Thus, the rod system is usually not symmetrical about the center line of the slug column. Symmetry may be forced by displacing the slug column upstream. The following is a brief summary of the current charge centering status of the reactors:

Reactor	Charge Length	Location of Center Rod Bank Relative to C_L of Slug Column.
B, D, DR, F	34 slugs	14" upstream
H	32 slugs	14" upstream
C	32 slugs	Identical

7. Personal Communication, D. I. Monnie.

No calculations were made for B, D, DR, and F because the results given for H reactor are roughly applicable to the nine-rod piles. The distributions at B, D, DR, and F will be slightly less distorted for a given type of rod pattern because the H calculations assume four long rods whereas the nine-rod piles use only three. The flux distributions at B, D, DR, F, and H could be forced in the direction of the C distributions by merely displacing the slug column to the front (forcing symmetry).

TABLE III

Representative C Pile Front-to-Rear Distributions

Case	Rods Full In	B_m for Critical	$\frac{\phi_{max}}{\phi_{max\ cosine}}$	Position of Flux Peak from C_L	Remarks
I-C	None	15.1 μb	1.00	0	Sine curve
II-C	1, 4, 10, 13	23.0 μb	1.11	77 cm upstream	Downstream rod pattern
III-C	2, 5, 11, 14	29.3 μb	.88	113 cm up and down	Current rod pattern
IV-C	1, 6, 10, 15	25.8 μb	1.04	0	Outboard rod pattern

TABLE IV

Representing K Pile Front-to-Rear Distributions

Case	Rods Full In	B_m for Critical	$\frac{\phi_{max}}{\phi_{max\ cosine}}$	Position of Flux Peak From C_L	Remarks
I-K	None	11.7 μb	1.00	0	Sine curve
II-K	1, 4, 8, 12, 16, 19	22.8 μb	1.08	130 cm upstream	
III-K	1, 5, 8, 13, 16, 20	24.7 μb	.86	143 cm up and down	Symmetrical "inboard" rod pattern used during initial K operation
IV-K	1, 3, 7, 11, 15, 19	21.7 μb	1.11	123 cm upstream	
V-K	1, 6, 7, 14, 15, 20	22.1 μb	1.02	0	Current "outboard" rod pattern

TABLE V

Representative H Pile Front-to-Rear Distributions

Case	Rods Full In	B_m for Critical	ϕ_{max} / ϕ_{max} cosine	Position of Flux Peak from C_L	Remarks
I-H	None	15.1 µb	1.00	0	
II-H	1, 4, 10, 13	24.0 µb	1.08	82 cm upstream	
III-H	2, 5, 11, 14	26.7 µb	1.00	101 cm downstream	"centered rod pattern used for years at F
IV-H	2, 4, 8, 10, 14	29.6 µb	.91	117 cm upstream	Rod pattern in current use

The flux distributions were all normalized to the area under the cosine curve. That is, the same tube power is maintained in all cases (for a given reactor).

D. Mixing Piece Effects

Mixing pieces are being used to reduce tube corrosion in the rear at C Reactor. The optimum mixing piece location is determined by tube corrosion, flux distribution and gross pile reactivity considerations. Calculations were made to determine the effect of mixing pieces in the sixth and twelfth slugs from the rear on the longitudinal flux profile and pile reactivity. The results are summarized in Table VI, and the flux profiles are presented in figure 1.

TABLE VI

Effects of Mixing Pieces at C Pile on Flux Distribution and Reactivity

Case	Mixing Piece Location	B_m for Critical	$\delta\rho$*	$\phi_{max}/\phi_{max\ sine}$	Position of Flux Peak from C_L	Rods Full In
I	None	15.1 µb	--	1.00	0	None
II	None	29.3 µb	0	.88	115 cm up and downstream	2, 5, 11, 14
III	Sixth slug from rear	31.5 µb	-1.4 mk	.95	123 cm upstream	2, 5, 11, 14
IV	Twelfth slug from rear	33.4 µb	-2.5 mk	.98	131 cm upstream	2, 5, 11, 14

*$\delta\rho$ reactivity loss caused by mixing pieces

Note that the sixth slug from the rear is a better location that the twelfth from both reactivity and flux distribution considerations. Although the calculations were made for C reactor, the conclusions are applicable to all of the 8 3/8 inch lattice piles.

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