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PHYSICS EFFECTS OF WATER MIXING PIECES

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PHYSICS EFFECTS OF WATER MIXING PIECES

INTRODUCTION

The effects of "water mixing" pieces on the axial flux distributions and reactivities of the K Reactors are discussed in this report. Two mixing piece configurations in the K piles are compared to provide a basis for determining the optimum configuration with respect to rupture control, reactivity cost and temperature cycling effects.

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SUMMARY AND CONCLUSIONS

The following chart summarizes the results of a study of the physics effects of water mixing pieces:

Condition	Calculated Maximum Specific Power	Reactivity Effect
No mixing pieces, current rod pattern	4% greater than the cosine maximum	--
One mixing piece per charge. Mixer located at pile center line, present rod pattern.	1% less than the cosine maximum	-112 ih
Two mixing pieces per charge. Mixers located at the outboard rod positions. Present rod pattern.	10% greater than the cosine maximum	-112 ih

No attempt is made to weigh the changes in pile stability and rupture potential associated with the changes in flux distribution.

DISCUSSION

Charging mixing pieces into the K Reactors is equivalent to introducing a slab(s) of water and aluminum lattice about 2.2 inches thick and perpendicular to the fuel channels. The effects of the mixing pieces on the flux distribution and reactivity will depend upon their number and locations. Two cases are considered here: (1) One mixing piece per charge. Mixer located at the pile center line. (2) Two mixing pieces per charge. Mixers located at the outboard rod position ($\sim$210 cm from the center line).

The method of evaluation used was developed by C. L. Miller for multi-region analyses. The reduction in lattice material buckling associated with the control rods and the mixing pieces is evaluated from the K pile start-up data. The effective buckling of a region is derived from:

$$(1)\quad B_i = \frac{(B_n - B_c)\int_c \phi^2 dy + B_n \int_{natural} \phi^2 dy - B_{mixers} \int_{mixers} \phi^2 dy}{\int_{Region} \phi^2 dy}$$

$$(2)\quad b_i = \sqrt{B_i - B_{HW}}$$

B_i = Buckling of i^{th} region

B_n = Natural uranium buckling

B_c = Buckling effect of controls

B_{mixers} = Buckling effect of mixers

B_{HW} = Horizontal and vertical buckling components = $(\pi/H)^2 + (\pi/W)^2$ = 13.6 μb.

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DISCUSSION (Continued)

(2) H = Pile height, including augmentation distance.

W = Pile width, including augmentation distance.

The side-to-side and top-to-bottom flux distributions are assumed to be given by $\phi(x \text{ or } y) = \cos \frac{\pi(x \text{ or } y)}{(H \text{ or } W)}$. The axial flux distributions are given by: (From solutions of the expression $\nabla^2\phi + b^2\phi = 0$.)

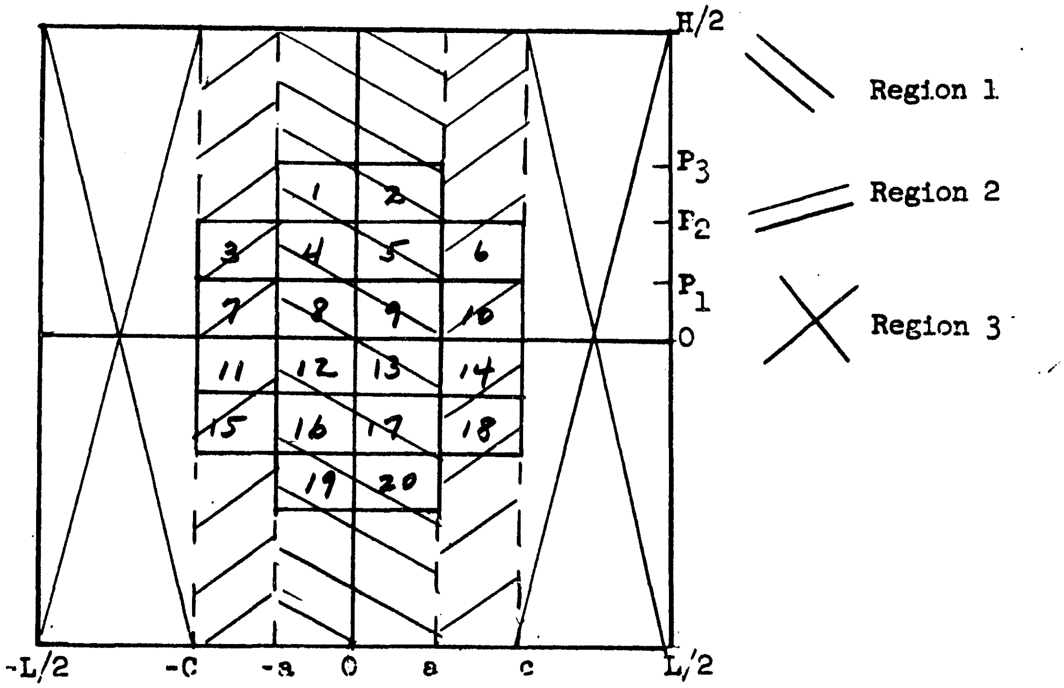
(3) $\phi_i = A_i \sin(b_i x + \alpha_i)$, or $\phi_i = A_i \cos(b_i x + \alpha_i)$

$b_i^2 > 0.$

(4) $\phi_i = A_i \operatorname{Sinh}(|b_i| x + \alpha_i)$, or $\phi_i = A_i \operatorname{Cosh}(|b_i| x + \alpha_i)$.

$b_i^2 < 0.$

The following diagram and data are applicable to the conditions of interest.



a = 140.5 cm
c = 281 cm
L/2 = 459 cm
P_1 = 133.3 cm
P_2 = 266.6 cm
P_3 = 400.0 cm
H/2 = 600 cm = W/2

Note: The slight difference in distance between the rod banks is ignored here. a is actually at 138.1 cm rather than 140.5 cm.

DISCUSSION (Continued)

$$\frac{\int_0^{P_1} \cos^2 \frac{\pi x}{H}\,dx}{\int_0^{H/2} \cos^2 \frac{\pi x}{H}\,dx} = 0.427$$

$$\frac{\int_0^{P_2} \cos^2 \frac{\pi x}{H}\,dx}{\int_0^{H/2} \cos^2 \frac{\pi x}{H}\,dx} = 0.757$$

$$\frac{\int_0^{P_3} \cos^2 \frac{\pi x}{H}\,dx}{\int_0^{H/2} \cos^2 \frac{\pi x}{H}\,dx} = 0.943$$

For the purposes of this evaluation the mixing pieces are assumed to be spread throughout the control regions. If the mixing pieces are located at the pile center line, they are assumed to be spread throughout region 1. If they are located at 210.8 cm, they are assumed to be spread throughout region 2.

The boundary conditions for a three-region problem are:

(5) $\phi_1 \big|_a = \phi_2 \big|_a$

(6) $\phi_2 \big|_c = \phi_3 \big|_c$

(7) $\phi_1' \big|_a = \phi_2' \big|_a$

(8) $\phi_2' \big|_c = \phi_3' \big|_c$

(9) $\phi_1 \big|_x = \phi_1 \big|_{-x}$

(10) $\phi_3 \big|_{L/2} = 0$

These conditions result in the following expressions if $b_1^2, b_2^2, b_3^2 > 0$.

[redacted]

DISCUSSION (Continued)

(11) $-b_1 \tan b_1 a = b_2 \cot (b_2 a + \alpha_2)$

(12) $b_2 \cot (b_2 c + \alpha_2) = b_3 \cot \left[b_3 (c - L/2) \right]$

(13) $\cos b_1 a = A_2 \sin (b_2 a + \alpha_2)$

(14) $A_2 \sin (b_2 c + \alpha_2) = A_3 \sin \left[b_3 (c - L/2) \right]$

For $b_1^2, b_3^2 > 0$, $b_2^2 < 0$, the expressions are:

(15) $-b_1 \tan b_1 a = |b_2| \text{Coth} (|b_2| a + \alpha_2)$

(16) $|b_2| \text{Coth} (|b_2| c + \alpha_2) = b_3 \cot \left[b_3 (c - L/2) \right]$

(17) $\cos b_1 a = A_2 \text{Sinh} (|b_2| a + \alpha_2)$

(18) $A_2 \text{Sinh} (|b_2| c + \alpha_2) = A_3 \sin \left[b_3 (c - L/2) \right]$

The method of solution of these expressions is as follows:

One of the B's is the unknown. Select a reasonable value and

(a) Compute the B_i's and the b_i's from equations 1 and 2.

(b) Substitute the b_i's into equations 11 and 12, or 15 and 16. If 11 and 12 or 15 and 16 are satisfied then the B_i's are the proper ones. If 11 and 12 or 15 and 16 are not satisfied, try different values of the unknown B. Continue this process until the conditions are satisfied.

(c) Once the proper B's and b's are determined, the constants may be determined from 13 and 14 or 17 and 18, and the fluxes computed from 3 and 4.

Since the flux distributions obtained above are normalized to $\phi = 1$ at $x = 0$, the areas (and hence the total power of tubes operating in these distributions) under the curves are different. The relative specific flux (power) is usually referred to a simple unperturbed flux distribution. Normalizing to the area under a cosine, relative specific power = $\phi(x) \frac{A'}{A}$.

A' = Area under a cosine

A = Area under the distribution of interest.

The normalized flux distributions calculated for the cases of interest are plotted in Figure 1.

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CALCULATIONS AND RESULTS

A. The Effect of Mixing Pieces

$$\delta B_{mixers} \int_{mixers} \phi^2 \, dA = \delta B_{pile} \int_{pile} \phi^2 \, dA$$

$$\frac{\delta B_{mixers}}{\delta B_{pile}} = \frac{\int_{pile} \phi^2 \, dA}{\int_{mixers} \phi^2 \, dA} \cong \frac{R_p^2 \, J_1^2(2.40)}{R_m^2 \left[J_o^2\left(\frac{2.40 \, R_m}{R_p}\right) + J_1^2\left(\frac{2.40 \, R_m}{R_p}\right) \right]}$$

for a cylindrical pile.

δB = Change in material buckling

R_p = Effective pile radius

R_m = Effective radius of mixers

Since the mixers are 2.16 inches long, and extend the full height of the pile,

$$\frac{\text{Area of region}}{\text{Area of mixers}} = \frac{(140.5)(2)}{(2.54)(2.16)} \cong (2)(25.57) \text{ for mixers at the pile center line.}$$

$$\frac{\text{Area of region}}{\text{Area of mixers}} = 25.57 \text{ for mixers at the outboard rod positions.}$$

(In this evaluation the mixers are assumed to be spread uniformly throughout the control regions.) For the pile size used during the K-pile start-up tests*,

$$\frac{\delta B_{mixers}}{\delta B_{pile}} = 6.56 \text{ for mixers in region 1.}$$

$$\frac{\delta B_{mixers}}{\delta B_{pile}} = 12.76 \text{ for mixers in region 2.}$$

From the K-pile start-up test results:

Empty tube = -33.6 ih.

Wet SA = -22.1 ih.

If mixers are assumed to be half water and half SA,

Mixers $\cong$ -27.9 ih $\cong$ 1.368 µb.

Therefore, $\delta B_{mixers} \cong (1.368)(6.56) \cong 9.0$ µb for mixers at the pile center line, and $\delta B_{mixers} \cong (12.76)(1.368) \cong 17.4$ µb for mixers at the outboard rod positions.

---

* HW-37158 PT 3, "K Pile Start-up Experiments Part III - Reactivity Effects of Fuel and Target Materials," C. L. Miller, 4-2-56.

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CALCULATIONS AND RESULTS (Continued)

This is the reduction in lattice material buckling caused by mixing pieces charged with the densities indicated (51.14 and 25.57 LU^2 per mixer).

B. The Effect of Control Rods

The green, fully loaded K Reactors were held just sub-critical by about 18 HCR's (all rods except 6 and 15). B_n = 61.5 µb, B_{HW} = 13.6 µb. B_c = 50.0 µb satisfies the appropriate conditions. Therefore, the reduction in lattice material buckling associated with the control rods is 50.0 µb.

C. No Mixers, Present Rod Pattern (2 and 19, 3 and 18, 10 and 11 in during equilibrium operation)

B_n = 34.0 µb satisfies the conditions

$b_1 = 3.96 \times 10^{-3}$

$b_2 = 1.23 \times 10^{-3}$

$b_3 = 4.52 \times 10^{-3}$

$\phi_1 = \text{Cos } 3.96 \times 10^{-3}x$

$\phi_2 = 1.91 \sin (1.23 \times 10^{-3}x - .63)$

$\phi_3 = -0.734 \sin \left[4.52 \times 10^{-3} (x-459)\right]$

$\frac{A'}{A} = 1.04$

The calculated maximum flux is four per cent greater than the cosine maximum.

D. Mixers at the Pile Center Line (in Region 1), Present Rod Pattern

B_n = 39.5 µb

$b_1 = 3.49 \times 10^{-3}$

$b_2 = 2.65 \times 10^{-3}$

$b_3 = 5.09 \times 10^{-3}$

ΔB_n = 5.5 µb $\cong$ 2.93 mk $\cong$ 112 ih

$\phi_1 = \cos 3.49 \times 10^{-3}x$

$\phi_2 = -1.08 \sin (2.64 \times 10^{-3}x - 1.33)$

$\phi_3 = -0.743 \sin \left[5.09 \times 10^{-3} (x-459)\right]$

$\frac{A'}{A} = 0.99$

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CALCULATIONS AND RESULTS (Continued)

The calculated maximum flux is one per cent less than the cosine maximum.

E. Mixers at the Outboard Rod Positions (Region 2), Present Rod Pattern

$$B_n = 39.5\ \mu b$$

$$b_1 = 4.60 \times 10^{-3}$$

$$b_2 = 3.23\ i \times 10^{-3}$$

$$b_3 = 5.09 \times 10^{-3}$$

$$\triangle B_n = 5.5\ \mu b \cong 2.93\ mk \cong 112\ ih$$

$$\phi_1 = \text{Cos}\ 4.60 \times 10^{-3}x$$

$$\phi_2 = -0.332\ \text{Sinh}\ (3.23 \times 10^{-3}x - 2.06)$$

$$\phi_3 = -0.598\ \sin\left[5.09 \times 10^{-3}(x-459)\right]$$

$$\frac{A'}{A} = 1.10$$

The calculated maximum flux is 10% greater than the cosine maximum.

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Research and Engineering
IRRADIATION PROCESSING DEPARTMENT

GR Parkos:mwe

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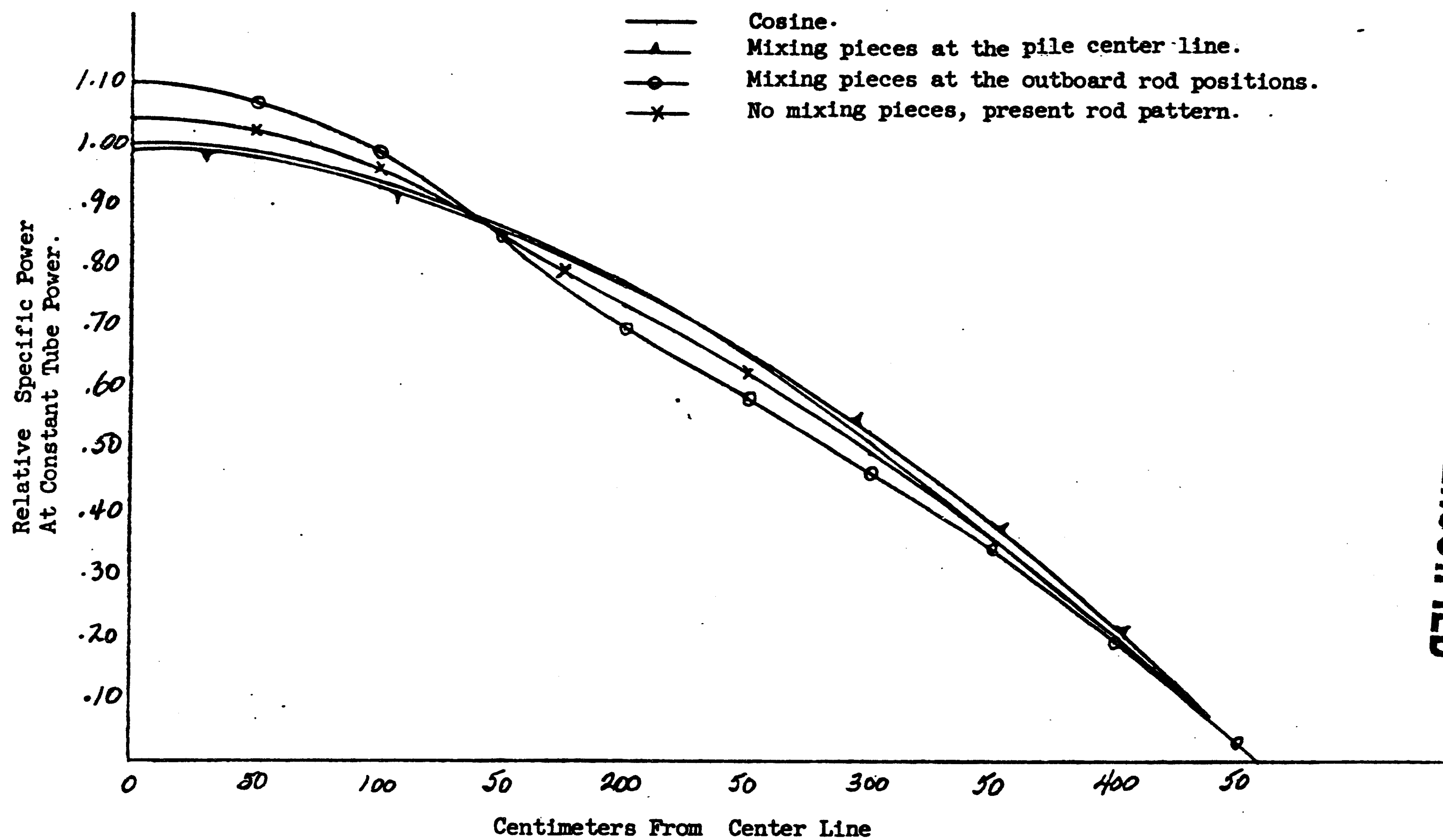
Figure I

SPECIFIC POWER PROFILES FOR VARIOUS MIXING PIECE CONFIGURATIONS



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