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DEVELOPMENT REPORT

POISON PATTERNS FOR COUNTERACTING ROD FAILURES

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Date: June 19, 1947

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FROM: C. V. Larrick and G. C. Fullmer

POISON PATTERNS FOR COUNTERACTING ROD FAILURES

Introduction:

This report contains the calculation of the number and spacing of poison columns required to hold a 105 pile in the following cases:

- (1) Complete failure of horizontal rods.
- (2) Complete failure of all rods.

Summary of Results:

Using 10% Cd 90% Pb poison columns of 1.44-inch diameter, it is found that 17 poison columns are required to hold the pile in case of complete failure of horizontal rods, and 65 poison columns are required to hold the pile in case of complete failure of all rods.

Details:

The calculation of number and spacing of poison columns is based on the requirement to counteract excess reactivities of 1.8% and 5.8% δk in a 105 pile, where the strengths of the rods are assumed to be as follows:

Vertical Rods	4.0% δk
Horizontal Rods	0.8% δk
Permanent Poison Columns	1.0% δk

The poison patterns calculated in this report are accordingly not in addition to the normal P-columns of the pile, but represent the total poison pattern required to hold the pile under the conditions stated.

The method of calculation is that given in "Principles of Nuclear Power", Chapter 22, by John A. Wheeler, to which the figure and equation numbers below refer.

The necessary data on the pile and the rods are as follows:

Radius of pile = R_0 = 57.4 cm
Diameter of poison column = 1.44" = 3.66 cm
Radius of poison column = r_0 = 1.83 cm

Since the column is surrounded by water and aluminum we assume that the

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moderator comes up to the surface of the column. If water is absent, the column becomes spherical.

Effective radius of column (from Eq. 22.4.20 c) is

$$r_{eff} = r_0 \cdot \left\{ \frac{\lambda}{3r_0} \frac{J_0(1.84r_0)}{-1.84J_1(1.84r_0)} \right\}$$

where λ = mean free path of neutron in the moderator

= 2.7 cm for graphite

$$\chi = \sqrt{3} \pi \Sigma$$

$\Sigma \Sigma$ = absorption cross section in cm²/cm³ of poison column

= 17.02 cm⁻¹ for 10% Cd, 90% Pb, column

$$r_{eff} = 0.772 \text{ cm}$$

The following values for the pile lattice constants have been used in the calculations.

$$\text{Moderator area} : a_m = A_{md} = \pi = 3.14 \text{ cm}^2$$

$$\text{Thermal fission area} : a_{ft} = A_{ft} = \pi^2 = 9.87 \text{ cm}^2$$

$$\text{Fission area} : a_f = \pi^2 = 9.87 \text{ cm}^2$$

$$(A_{md}^{-1} + A_{ft}^{-1})^{\frac{1}{2}} = 0.0623 \text{ cm}^{-1}$$

$$(A_{md}^{-1} + A_{ft}^{-1})^{\frac{1}{2}} r_{eff} = 0.0644$$

$$\frac{a_m}{A} = 0.23$$

A single poison column at the center of an unflattened pile reduces the reactivity by 67 inches, of which 7 inches are caused by loss of metal. Since the formulas for the number of poison columns required do not include the effect of loss of metal, the number calculated must be multiplied by the factor 60/57 = 0.896.

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The following table shows the steps in the calculations:

	Case I	Case II
Excess Reactivity δk	1.8%	5.8%
Excess Buckling $\Delta B = \frac{\delta k}{k_0}$	$29.65 \times 10^{-6} \text{ cm}^{-2}$	$95.55 \times 10^{-6} \text{ cm}^{-2}$
Critical Buckling $B_1 = (2.4048/R_0)^2$	$17.55 \times 10^{-6} \text{ cm}^{-2}$	$17.55 \times 10^{-6} \text{ cm}^{-2}$
Total Buckling $\Delta B + B_0 = B_1 = k^2$	$47.2 \times 10^{-6} \text{ cm}^{-2}$	$113.1 \times 10^{-6} \text{ cm}^{-2}$
$b_1 = \sqrt{B_1}$	$6.87 \times 10^{-3} \text{ cm}^{-1}$	$10.63 \times 10^{-3} \text{ cm}^{-1}$
R_0 (from fig. 22.3.45) = radius of region of control	317 cm 125 inches	416 cm 164 inches
πR_0^2 = Area of region of control	16,000 cm^2	144,000 cm^2
R = Radius of control of single column	74.09 cm	49.20 cm
πR^2 = Area of control of single column	17,245 cm^2	7,609 cm^2
Number of poison columns required	18.3	71.5
Corrected for removal of metal = 60/67	0.8955	
Corrected radius of control of single column R'	16.4 cm 78.3 inches	64.1 cm 25.2 inches
Rectangular lattice spacing of columns = 1.772 R'	34.6 inches	36.3 inches

The radius of control of a single column may be obtained from the nomogram Fig. 22.3.23 or it may be calculated from the formula

$$R = 3.93 \sqrt{\frac{0.4816}{b_1}} \quad \text{for values of}$$

δk between 1.0% and 5.8% or from the formula

$$R = 9.92 \sqrt{\frac{0.4694}{b_1}}$$

for values of δk between 0 and 1%. *

This may be seen from the accompanying plot of $b_1 R$ as a function of b_1 , which may be closely approximated by two straight lines.

A simple rule accurate to within a few percent for the usual Pd - Cd Column is that $R_{b_1} = \frac{1}{b_1}$

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R = Radius of control of a 10% Cd 90% Pb poison column of effective radius 0.781 cm., actual radius 1.83 cm.

$b_1 = \sqrt{B_1}$ where B_1 = buckling to be compensated

Curve C = Plot of $\frac{N_1(b_1 R)}{J_1(b_1 R)} = -2.482 - 1.456 \log_{10} \left(\frac{1.1220}{b_1 R} \right)$

Curve d = Straight line representing average slope of curve (c) in range of excess k 1.8% to 5.8%.

Curve e = Straight line representing average slope of curve (c) in range of excess k 0% to 1.8%.

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The quantities needed in laying out the pattern are:

- (1) The radius of region of control, r_c .
- (2) The rectangular lattice spacing of the columns.

In the pattern for 1.8% δk , the central nine columns are arranged at approximately the theoretical lattice spacing of 34.6 inches. The eight outside columns are arranged to fill as nearly as possible the remaining area of the region of control. Only three of the normal p-columns can be worked into this pattern.

The pattern for 5.8% δk contains 65 columns arranged at approximately the theoretical lattice spacing of 36.3 inches. All the normal p-columns are fitted into the pattern.

Chris V Larrick

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17-COLUMN POISON PATTERN: COUNTERACTING 1.8% k

This pattern would be required in event of complete failure of horizontal rods.

- Code:
- ☒ Permanent poison columns used in this pattern.
 - ☒ Permanent p-columns not used in this pattern.
 - ☒ All other columns replaced with poison columns.

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65-COLARE POISON PATTERN COUNTERACTED 5.8% 6k

This pattern would be required in event of complete failure of all vertical and horizontal rods.

- Code ☒ Permanent poison columns used in this pattern.
- ☒ All other columns replaced with poison columns.

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46

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