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FINAL REPORT
PRODUCTION TEST 105-528-A
ALTERATION OF TWO C-PILE HORIZONTAL SAFETY
RODS FOR TEMPERATURE DISTRIBUTION
CONTROL

BY
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TECHNICAL SECTION
ENGINEERING DEPARTMENT

JUNE 11, 1953

HANFORD ATOMIC PRODUCTS OPERATION
RICHLAND, WASHINGTON

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FOR TEMPERATURE DISTRIBUTION CONTROL

By

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Pile Engineering Unit
Pile Technology Sub-Section

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HANFORD ATOMIC PRODUCTS OPERATION
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INTRODUCTION

The current policy of operating the piles at the highest possible power level consistent with the various temperature limits places a premium on the optimum control of temperature distribution. Because the horizontal rods all enter the pile from one side, referred to as the near side, the far-side columns tend to have higher heat generation rates and, hence, to be more limiting to pile power level. This condition is normally counteracted by loading the poison columns used for pile flattening more heavily on the far side, distorting the heat distribution sufficiently to avoid the occurrence of limiting tubes in that region. A complete analysis of the distortion effects of control rods and poison columns is complicated, but, in general, the tendency for one region of the pile to be hotter than another is described in terms of the temperature "moment", a concept which is applied to test the actual pile temperature distribution for symmetry. If all the excess reactivity could be compensated within the central region, temperature "moments" could effectively be eliminated, and increased flattening efficiency should result.

Pile temperature control is normally maintained by using four horizontal rods, two "long" rods extending to the far side of the pile and two "short" rods whose tips are on the near side. ⁽¹⁾ This procedure prevents cycling of "hot spots" about the pile, but does not achieve symmetrical horizontal temperature distribution. Prior to pile operation the

(1) HW-21310, "Rod Control Techniques for Adjusting Temperature Distribution," G. C. Fullmer, June 11, 1951.

cadmium-containing cans were removed from the near ends of the two "long" control rods, numbers 5 and 11, at C pile, so that when these rods were in the "full in" position their poisoning effect outside the flattened region at the near side of the pile would be small. By using these "half-rods" in conjunction with "short" rods it was expected that a nearly symmetrical horizontal temperature distribution could be maintained.

SUMMARY

A comparison of near-to-far temperature distribution at C-pile with other piles indicates that gains in production of 4% during early operation of a pile and 3% during later equilibrium operation can be realized by using the half-rods.

Similar gains made by enrichment would cost on the order of \$30,000 per year per pile in depletion of U-235 at a specific tube power generation rate of 400 kilowatts. This cost would vary according to the specific tube power limit.

On the basis of these observations "half-rods" are to be incorporated in the K-piles currently under construction. It is recommended that the "long" control rods in existing piles be replaced by rods altered in an equivalent manner.

DETAILS

The horizontal control rods at C-pile consist of thimbles filled with cadmium-containing cans each six inches in length. Aluminum spacers were substituted for the outer 28 cans in each of two rods, so that the portions of the rods from the near side of the pile to within four feet of the pile center contain only cooling water and aluminum as poison when the rods are fully inserted into the pile. Control of the temperature moments in a pile is normally accomplished by having the tip of a rod in each of the quadrants of the pile, so that two "long" rods control the far side temperatures and two "short" rods control the temperatures on the near side of the pile. The two "long" rods were converted to half-rods (see Figure 1).

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PILE WITH CONVENTIONAL RODS

PILE WITH TWO HALF-RODS

EQUILIBRIUM ROD CONFIGURATION

A - 10 RODS NORMALLY USED
AS "SHORT" RODS

5 - 11 HALF - RODS

POSITIONS OF HALF - RODS

Figure 1.

The use of half-rods during equilibrium operation results in better side-to-side temperature distribution as expected. In order to evaluate the gains, the proportion of total pile production on the near side of the pile and that on the far side were determined from outlet-tube temperature data. It was assumed that the production rate on the near side could be brought up to that on the far side if the temperature moment could be balanced out, and that this increase would represent the potential gain in pile power level from altering the control rods. The following table shows these data from representative temperature maps for various piles under a range of flattening conditions.

PILE POWER DISTRIBUTION

<u>Pile</u>	<u>Date</u>	<u>Flattening</u>	<u>Near Side</u>	<u>Far Side</u>	<u>Difference</u>	<u>Potential Power Gain with Perfect Balance</u>
DR	10-25-50	No poison columns 130 ih in rods	47.7% 46.8	52.3% 53.2	4.6% 6.4	5.5%
DR	1-28-51	Average	48.2	51.8	3.6	.
	2-27-	Amount of	47.9	52.1	4.2	
H	6-15-52	Flattening	47.9	52.1	4.2	
	9-5		48.7	51.3	2.6	
	10-19		48.2	51.8	3.6	
	11-3		46.5	53.5	6.9	
	11-14		47.1	52.9	5.8	4.4
F	2-18-53	Maximum	49.5	50.5	1.0	
	2-28	Amount of	49.0	51.0	2.0	
	3-8	Flattening	49.0	51.0	2.0	1.7
C	12-7-52	Half rods, no	49.8	50.2	0.4	
	12-13	poison columns	51.0	49.0	-2.0	
	12-26	250-350 ih in	48.7	51.3	2.6	
	1-14-53	rods	49.0	51.0	2.0	
	2-28		49.8	50.2	0.4	0.7

Because C-pile has two more columns enriched in U-235 on the near side than on the far side, the power distribution indicated above may be slightly better than that expected with no enrichment. For this reason

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a 0.4% gain due to the improved near-side distribution was assumed due to enrichment; potential gains indicated from the use of half-rods alone are therefore approximately 4% in a pile with no poison columns, 3% in a pile with an average amount of flattening, and 1% in a pile with maximum flattening. The data from DR-pile in October and November of 1950 corresponding to the initial operating period of C-pile are shown graphically in Figure 2. The reason for the poor temperature distribution at this time is that there is insufficient excess reactivity following the startup of a new pile to invest in flattening to counteract the horizontal rod distortion effects. For this reason half-rods would be particularly valuable during the first few months of pile operation. The conditions at F-pile followed a complete revision of the poison pattern during an extended shutdown for installation of a supplementary pile control system. It is expected that the effectiveness of the poison pattern will decrease with operating time and that such a favorable temperature distribution can not be maintained indefinitely by poison loading alone.

A gain inherent in a balanced temperature distribution is that the conductivity of the graphite is affected symmetrically rather than becoming worse on the near side of the pile. The lack of symmetry which developed at DR and H piles following their original startups is undesirable as it may cause the near side of the pile, which does not contain the hottest tubes, to limit the pile power because of graphite temperature.

The total strength of the half-rods under equilibrium conditions is about 15 inhours per rod less than the full long rods, but this loss of control is shadowed when the entire rod system is inserted and should not be a problem in a 15-rod pile. In a pile with 9 horizontal rods the loss of as much as 20 inhours of control could be significant to pile operation during transient conditions. If the strength of the horizontal rods is just sufficient to control the reactivity transient during startup, as is usually the case, removal of this amount of poison from the rod system would necessarily require the availability of poison in some other form during the

Figure 2. COMPARISON OF NEAR TO FAR FLUX DISTRIBUTION DURING EARLY OPERATION OF C AND DR PILES

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peak of the reactivity transient. The additional control could be obtained by the use of temporary poison columns or some system of variable control. Using additional temporary poison columns could mean an increase in time to reach equilibrium conditions equivalent to a loss of total production of 1%, thereby reducing the net gain due to half-rods to the order of 2%. The use of variable control columns would mean a loss in production during later equilibrium operation of possibly two process tubes, or up to 0.2% of the total pile power, but this is small compared to the gains from using the half-rods.

During operation of a pile there is an increase in pile reactivity due to the favorable effect of plutonium buildup outweighing U-235 depletion and fission poison formation. This reactivity rise must be balanced by a continual movement of rods into the pile, superimposed on the normal movement of rods which controls pile temperatures. In a pile with normal rods the power level must be cut when the full control of the long rods is used up, because attempting to balance the reactivity rise with short rods distorts the flux to the far side of the pile. This difficulty is not encountered at C-pile. The relation of the half-rods to the rest of the rod system is such that, after the half-rods are completely into the pile, the reactivity increase can be compensated by the short rods without distorting the flux, because the tips of the short rods have reached the center of the pile by this time, and they have effectively become "long" rods. The result is that C-pile can operate longer at the highest power level consistent with the normal temperature limits of the pile.

The improved flux distribution realized by using the half-rods could be obtained by placing columns enriched in U-235 in the near side of the pile, and an estimate of the value of the half-rods system, other than the production gains realized, may be calculated by determining the cost of the enrichment required to give the same near-side effect. It is estimated that at least four Al - U-235 columns would be required to produce the desired increase in flux, and the cost of this enrichment is calculated as the amount of U-235 depleted in these columns. For a period of one year this would be:

Enriched column exposure x U-235 depletion per unit exposure

x unit cost of U-235 = (4 columns) x $\frac{(.4 \text{ MW})}{(\text{col.})}$ x (90% of

column heat generated in enriched portion) x $\frac{(365 \text{ days})}{\text{year}}$

x (90% pile operating efficiency) x $\frac{(1.21 \text{ gm U-235 depleted})}{\text{MWD}}$

x $\left(\frac{\$50 *}{\text{gm U-235}} \right) = \$30,000 \text{ per year}$

It should be noted that the worth of the half-rod system does not depend upon the technical factors which dictate the power level of the pile. If the tube outlet water temperature rather than the specific tube heat generation rate were the limiting factor, optimum control of temperature moments would still be important in order to take full advantage of all available cooling water.

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* Rough estimate of cost when used for pile enrichment.

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ABSTRACT

"Half-rods" were incorporated into the C-Pile horizontal safety rod system by altering two normal control rods in order to improve the near-to-far temperature distribution and thereby increase the pile production rates. A comparison of pile production efficiency with "half-rods" and with conventional rods is presented with recommendations that alteration of the "long" control rods in existing piles be considered.

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