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PROPOSED GRAPHITE CORING PATTERNS

FOR B,D,F,DR, AND H REACTORS

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PROPOSED GRAPHITE CORING PATTERNS

FOR B,D,F,DR, AND H REACTORS

June 20, 1963

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Reactor Design Analysis Unit
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PROPOSED GRAPHITE CORING PATTERNS
FOR B, D, F, DR, AND H REACTORS

INTRODUCTION

Currently during reactor operation the graphite stacks at B, D, F, DR and H Reactors are subjected to large front-to-rear temperature gradients. The portion of each graphite stack that is maintained at temperatures above the annealing temperature, 300°C, dimensionally contracts at rates that are dependent upon the fast neutron flux. It is assumed by some investigators that the contraction rates are entirely independent of temperature^{(3)*}. Other investigators attribute this lack of dependence to a failure in isolating the temperature effect because of the overlapping influence of other dependent variables of the experimental systems⁽⁵⁾. At temperatures below 300°C the graphite exhibits a net dimensional expansion, the rate of which is dependent upon both temperature and fast neutron exposure.

The combination of dimensional expansion in the fringe and contraction in the central portion of the graphite stacks has resulted in a sine curve shaped front-to-rear distortion of the process channels. The magnitude of this distortion is accumulative from the bottom of the stack to the top. Thus, some of the process tubes in the upper portion of the stacks, particularly at B, D, and F Reactors, exhibit alarming distortion. The final result of this steadily increasing distortion will be the necessity of manufacturing shorter than normal fuel elements for charging in the top portion of the affected reactors. Such a manufacturing program has been estimated to cost in excess of one million dollars annually⁽¹⁾.

This study was instigated to determine whether or not an effective front-to-rear graphite coring pattern or patterns could be adopted at the old reactors to either eliminate the net dimensional expansion in the fringes of the graphite stacks or significantly reduce the rate of expansion in the fringe.

SUMMARY

Heat transfer calculations were performed with the aid of the IBM 7090 to determine whether or not feasible graphite channel coring patterns could be adopted at the five older Hanford Reactors. The purpose of front and rear process channel coring is to significantly reduce or eliminate net expansion of the fringe graphite by raising the operating temperature above the annealing temperature of 300°C.

The results of the study show that such coring patterns are possible. Also, it was found to be possible, and indeed desirable, to standardize the patterns into one front face coring pattern and one rear face coring pattern for all five of the reactors: B, D, F, DR and H. The resulting coring patterns are given in Table IV.

These coring patterns will significantly reduce the net rate of expansion in the filler blocks and consequently reduce the inlet and outlet humps in the process channels. This will allow standard 8" fuel elements to be charged in all tubes.

* The numbers in parenthesis refer to the bibliography.

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The afore-mentioned coring patterns will limit the pile gas atmosphere to a range of between 90% He - 10% CO₂ and 100% He. If a greater percentage of CO₂ were used following the adoption of the coring patterns, the possibility of exceeding the maximum graphite temperature limit in the fringes would exist with reactor operation at the same or higher power level.

It is recommended that the rear coring be done simultaneously with the front coring.

Future reactor power level increases will not be restricted as a direct result of the proposed coring patterns. The primary effect will be to reduce the front-to-rear graphite temperature gradients. The present limitations to power level increases would still be the limiting conditions after the completion of the channel coring.

The number of channels to be cored should be determined from a process channel inventory at each reactor as the coring proceeds. All channels should be cored except the following:

1. Permanent problem channels
2. Permanent ball valve channels
3. Fringe poison channels
4. All channels containing fuel loaded process tubes with a power factor less than 0.58.
5. Channels containing graphite stringers
6. Traverse channels
7. All channels containing process tubes permanently loaded with non-fissionable material.

DISCUSSION

A. Method of Approach to the Problem

The ground rules for determining effective coring patterns were chosen to best represent the present operating conditions of B, D, F, DR and H Reactors and also to represent modest variations of the present conditions. Fringe graphite coring should not be extended to such a point as to unduly restrict future reactor power levels. The following items comprise the ground rules that were used:

1. The range of flux distribution is limited to that presently in effect at the old reactors. Figure IV shows a plot of heat generations versus distance. These curves are proportional to thermal neutron flux distributions.
2. The pile gas composition is limited to a range between 90% He - 100% He, although a wider range of pile gas compositions was used during the calculations, i.e. 70% He - 30% CO₂ to 100% He.
3. The bulk average graphite temperature of the filler blocks plus the tube blocks will represent the index temperature for the study. The goal is to maintain this index temperature above the annealing temperature of graphite at all positions in the graphite stack as close to the front and rear faces as is feasible.

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4. The fuel element charge length is 32 pieces of standard 8" fuel with the appropriate down stream dummy charge for each reactor. The present dummy charge lengths are as follows:

<u>DSD</u>	<u>Reactor</u>
136"	B
117"	D
136"	F
117"	DR
136"	H

5. The coring patterns will be based upon the present administrative reactor power level⁽⁴⁾ limit of 2090 MW for the older piles.
6. The present maximum graphite temperature limit as presented in Process Standards will be adhered to.

Some discussion is warranted at this point on the reason for choosing the index temperature to be that calculated as the bulk average temperature of the filler blocks plus the tube blocks or in other words, as the average temperature of the bulk of the graphite associated with the system models as given in Figures I, II, and III. Several approaches to this index temperature are possible. One could use the calculated process channel surface temperature, or the bulk average temperature of the tube block alone, or the filler block alone, or the bulk average temperature of the tube and filler blocks together, or one could use the maximum filler block temperature. The ideal approach is to use the process channel surface temperature as the index temperature. If a coring pattern were developed based upon this index, then for all practical purposes the total graphite stack would be maintained at a temperature above the annealing temperature. This index would place a very narrow range-of-operation restriction upon the reactor after the coring were completed because of the maximum graphite temperature limit imposed by Process Standards. This latter limit is based upon a maximum point temperature in the filler block.

Since the dimensional expansion of the graphite is highly temperature dependent, a bulk average temperature will suffice as an index for developing a coring pattern. Even though not all of the tube block may be above the annealing temperature, the gross expansion rate of the blocks will be adequately reduced. This bulk index temperature should include the effect of the filler blocks as well as that of the tube blocks. The graphite stacks at the established Hanford Reactors are wholly supported by the filler blocks and a change from a net expansion to a net contraction of the filler blocks will significantly decrease the present process channel distortion.

The calculations were performed with the aid of a FORTRAN heat transfer program that was written for the IBM 7090⁽²⁾. The heat transfer model chosen to represent each reactor was limited to a two dimensional system, i.e., heat transfer in the radial direction towards the process tube and in a circumferential direction in the same plane. The complexity of the calculations that would be associated with a three dimensional heat transfer system would not be justified by the small amount of heat transferred in the longitudinal direction. Under ideal conditions, i.e., complete continuity of tube and filler blocks, less than 10% of the heat generated in the graphite stack in

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FIGURE 2.2

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ALL DIMENSIONS ARE IN INCHES
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the vicinity of the point of maximum front-to-rear temperature gradient will be transferred in the longitudinal direction. The front-to-rear temperature gradients in the graphite will be considerably lessened after front and rear coring is completed.

Since the calculations were performed for a two dimensional system, the front-to-rear graphite temperature gradients were determined by changing various system parameters in such a manner as to represent the actual system conditions in incremental distances along the length of a process channel. The mathematical models are shown in Figures I - III. The tube blocks contained in DR and H Reactors were originally undercut; consequently, the system models are different than those for B, D, F Reactors. The undercutting for H-Reactor was the most significant; the depth of cut was similar to that for the C and K Reactors.

Since the tube blocks for the B, D, F Reactors were not originally undercut, an unknown heat transfer contact coefficient exists between the tube blocks and the surrounding filler blocks. To determine these coefficients, the program was assembled to use such coefficients as parameters and the values were changed until the programmed temperatures coincided with actual measured values at B and D Reactors. The effective thermal contact coefficients obtained in this manner were subsequently used in the coring calculations.

B. Parametric Values and Calculations

As mentioned earlier, the calculations were performed in a parametric manner. System parameters such as heat generation rate, sink temperature, pile gas composition, and diametral clearance of the process tube in the graphite process channel were each varied over the present reactor operating range and were extended to future operation just above the administrative old pile limit, or 2,100 MW. If higher power levels were desired than those used in the study, the coring pattern that has been determined as a result of this study will not limit operation more than will the maximum temperature of the graphite in the high flux or uncored regions of the piles, that is, provided the charge length is not increased.

Tables I, II and III list the values of physical constants used in the calculations.

TABLE I
MISCELLANEOUS PHYSICAL CONSTANTS

<u>Item</u>	<u>Value</u>	<u>Units</u>
Contact coefficient of B, D, F tube blocks on top and sides	14*	BTU/hr - ft ² - °F
Contact coefficient of all reactor tube blocks on bottom	500	BTU/hr - ft ² - °F
Emissivity of Graphite	0.80	-----
Emissivity of Aluminum Tube	0.25	-----
Heat transfer coefficient - water side of tube	∞	BTU/hr - ft ² - °F
Thermal conductivity of Aluminum	119	BTU/hr - ft ² - °F/ft

* This value was determined, as described earlier, from in-pile temperature measurements at the older reactors.

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TABLE II
GRAPHITE THERMAL CONDUCTIVITY

<u>BTu/hr-ft²-°F/ft</u>	
<u>T(°F)</u>	<u>K</u>
140	15.0
356	17.0
464	17.5
572	18.0
662	18.0
752	18.0
842	18.0
1,110	17.0
2,160	15.0

TABLE III
PILE GAS THERMAL CONDUCTIVITY

<u>BTu/hr-ft²-°F/ft</u>		
<u>T(°F)</u>	<u>K(100% He)</u>	<u>K(70% He - 30% CO₂)</u>
32	0.087	.036
212	0.103	.045
392	0.118	.054
572	0.135	.064
752	0.150	.074
932	0.166	.083
1,112	0.182	.093

Curves of heat generation rates in the graphite versus distance from the front face of the particular graphite stack for each reactor are shown in Figure IV. These values were determined from representative front-to-rear thermal neutron flux distribution curves. With each value of heat generation rate in the graphite, there is a corresponding value for the heat generation rate in the aluminum tube which is not shown. Both heat generation rates were included in the calculations, but the graphite heat generation rates were used as a comparison index to allow front-to-rear temperature gradients in the graphite stacks to be plotted.

The sink temperature or process cooling water temperature was varied from 20°C to 100°C during the calculations. It was found that for diametral clearances around the process tube varying from 15 mils to 100 mils the only effect is to increase the graphite temperature about 25°C for every 50°C increase in sink temperature. The effect of sink temperature changes for the larger diametral clearances is small enough to be neglected. The reason for the latter is that the principle mode of heat transfer at large diametral clearances is radiation.

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FIGURE IV
FRONT TO REAR FLUX DISTRIBUTION

H- REACTOR
 D- DR REACTOR
 B- REACTOR
 F- REACTOR

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As mentioned earlier, the range of gas compositions used during the calculations was varied between 100% He and 70% He - 30% CO₂. These compositions represent the two extremes used during present reactor operation. As the maximum graphite temperature becomes limiting with future power increases, the trend will be towards the use of 100% He or the substitution of N₂ for CO₂. In the latter case, the maximum graphite temperature limit will be increased considerably over the present limit. The effect of changing the gas composition was most evident in the range of diametral clearances from 40 mils to 400 mils. A graphite temperature change of 300°C would occur in the region of maximum heat generation rate and a ΔT of about 175°C would occur with a heat generation rate of 22% of the maximum. The temperature variation is the result of the large differences in thermal conductivities of the two compositions of gas as shown in Table III.

The diametral clearances of the process tube in the graphite channel was varied between 15 mils and 600 mils. This resulted in obtaining a family of curves of bulk average graphite temperature versus heat generation rate for different diametral clearances. These curves constituted the working curves from which the coring patterns were determined.

C. Coring Pattern

The large variation of flux distribution curves at the existing Hanford Reactors, as shown in Figure IV, indicates that such a range of curves is possible at any one reactor. As modes of operation change from time to time, significant changes in system parameters, such as neutron flux distribution, will also occur. The coring pattern for any one reactor should not be determined in such a manner as to cause fringe graphite temperatures to become limiting if the corresponding flux distribution curve is changed. The flux gradients at the given reactors are about the same and the various flux curves could be made to coincide if the appropriate system parameters were changed. There is no apparent reason why the five reactors could not all be operating with the same flux distribution curve at some future time. Therefore, one of the primary considerations of front and rear coring patterns for the older reactors is that of standardization. Such a standardization would allow more latitude during future operation.

A standard front coring pattern has been determined that will adequately meet the requirement of increasing the fringe graphite temperature above the annealing temperature at all of the older reactors, B, D, F, DR and H, and will allow reactor operation without exceeding the present maximum graphite temperature limit. A standard rear coring pattern has also been determined in a similar manner. The coring patterns are presented below in Table IV.

TABLE IV

FRONT AND REAR CORING PATTERNS - B,D,F,DR,H

<u>Distance* From Front (Rear) Face</u>	<u>Diametral Tube Clearance</u>	
	<u>Front</u>	<u>Rear</u>
0 - 2 feet	500 mils	
2 - 3.5 feet	300 mils	
3.5 - 6 feet	100 mils	
0 - 2.5 feet		500 mils
2.5 - 4 feet		300 mils
4 - 6.5 feet		100 mils

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* The distance is measured from the front of the graphite stack for the front coring pattern and from the rear for the rear coring pattern.

It must be stressed that the above coring patterns will not cause undue restrictions if operation at the particular reactor corresponds to a front-to-rear neutron flux within the range given in Figure IV and if the gas composition is limited to 90 - 100% He. If a completely abnormal flux distribution is required at one or more of the reactors in the future, chances are that the present reactor operating restrictions must also be changed. This would eliminate any possibility of restricted reactor operation caused by the proposed coring patterns, provided that the fuel column is limited in length to a 32 element column of standard 8" metal. A considerable number of studies have been done in the past in an attempt to optimize the length of a fuel column in the Hanford Reactors. The results of production tests and the analytical studies mentioned above have somewhat established that the 32 element column is optimum. There is still enough indecision in the operation of the reactors to cloud the issue, but the 32 piece column is the presently accepted charging length.

A pile gas composition in the range of 90% He - 10% CO₂ to 100% He must be adhered to with the above coring pattern until such time as the present maximum graphite temperature limit is increased or the power level decreased. If the pile gas composition were to be changed to 70% He - 30% CO₂ after the coring patterns were incorporated, the maximum measured graphite temperature would increase and the maximum temperature limit would decrease. The maximum graphite temperature at H-Reactor, for example, would then exceed the upper limit set by Process Standards, if operating with the present flux distribution and the present power level. Since adherence to the present maximum graphite temperature limit, without coring, requires a gas atmosphere of at least 83% He at most of the reactors, such a restriction would work little hardship. If the use of nitrogen instead of CO₂ were allowed at the older piles, then graphite temperature limits would increase more than the resulting graphite temperatures provided the power level remains the same. The use of N₂ would eliminate a large portion of the graphite burnout problem⁽⁶⁾.

The front and rear coring patterns, as given in Table IV, take advantage of the full temperature band between the maximum graphite temperature limit and the graphite annealing temperature. This means that the reactors, such as H-Reactor with the flux distribution skewed towards the front, will operate with fringe graphite temperatures riding the maximum limit. The same is true for a reactor with the flux skewed towards the rear.

Front-to-rear temperature profiles for each of the older Hanford Reactors are shown in Figures V through IX. These calculated temperature profiles incorporate the proposed coring patterns. It should be noted that both the bulk average temperatures and the maximum temperatures are plotted for a pile gas composition of 100% He. When comparing these maximum temperatures with those presently measured in the reactors, the gas composition should be included in the correlation. A 20% decrease in helium concentration would increase the maximum temperature 50°C to 300°C, depending upon the diametral clearance and/or the heat generation rate.

The coring patterns as given, minimize the coring passes that are necessary during the coring operation and consequently will result in the slightly erratic temperature profiles that are shown. Smaller temperature gradients can be obtained by increasing the number of coring passes and decreasing the step changes of the diametral clearances. The position of always main-

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FIGURE V
FRONT-TO-REAR GRAPHITE TEMPERATURE GRADIENT
B REACTOR

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FIGURE VI
FRONT-TO-REAR GRAPHITE TEMPERATURE GRADIENT
D REACTOR

— MAXIMUM TEMPERATURE
— BULK AVERAGE TEMPERATURE
100% He
100% C SINK TEMPERATURE
WITH GORING

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FIGURE VII
FRONT-TO-REAR GRAPHITE TEMPERATURE GRADIENT
DR REACTOR

--- MAXIMUM TEMPERATURE
--- BULK AVERAGE TEMPERATURE
--- 100% HP
--- 100°C SINK TEMPERATURE
WITH CORING

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FIGURE VIII FRONT-TO-REAR GRAPHITE TEMPERATURE GRADIENT F REACTOR

--- MAXIMUM TEMPERATURE
--- BULK AVERAGE TEMPERATURE
100% He
100°C SINK TEMPERATURE
WITH CORING

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taining fringe temperatures below the maximum limit during heat cycles was sacrificed for the simple patterns that will accomplish the primary goal of annealing the graphite in the front and rear fringes. A flat temperature profile, while desirable from a theoretical standpoint, may not be practical from a monetary standpoint. Heat cycles can be minimized by operational procedures and graphite temperatures during the large majority of operating time will be maintained below the limit. There will be some increased effort necessary to prevent heat cycles if the proposed coring patterns are incorporated at the reactors.

The number of process channels that should be cored at each reactor must be determined from a channel inventory as the coring proceeds. Thus, changes in the modes of reactor operation will be accounted for in the coring patterns. All process channels should be cored except those channels listed in Table V. Graphite temperatures in the vicinity of these latter channels will not be significantly changed if the listed channels are cored.

TABLE V

PROCESS CHANNELS ELIMINATED FROM CORING PATTERNS

1. Permanent problem channels
2. Permanent ball valve channels
3. Fringe poison channels
4. All channels containing fuel loaded process tubes with a power factor less than 0.58.
5. Channels containing graphite stringers
6. Traverse channels not containing fuel.
7. All channels containing process tubes permanently loaded with nonfissionable material.

A proposed plan for the coring operation is to incorporate the operation with the various tube replacement programs that exist at each reactor. This plan will certainly ensure that the central process channels are cored before much of the fringe, which is desired. This plan requires a long delay time in completely annealing the entire fringe of each graphite stack since a large portion of the process tubes at most reactors have recently been replaced. Some temporary relief may be obtained by coring the known problem channels as charging difficulties become evident. The enlarged process channel will require slightly less curvature of the replaced process tube.

A minimum period of about one year is necessary to completely realize the full effect of annealing the fringe graphite. This means that the inlet hump, which is accumulative from the bottom to the top of the graphite stack, will not be reduced to the lowest possible level until about one year after the major portion of the channels have been cored. This time requirement is based upon the initial operating data of the old reactors. About one year was required to completely anneal the central portion of the graphite stacks following the initial expansion. It has been suggested that the anticipated fringe annealing will follow the same time pattern.

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The discussion thus far has been conducted along the lines that both front and rear coring are necessary. Actually, only the front fringe graphite is dangerously close to limiting normal charge-discharge operational procedures. The inlet hump coupled with the central sag of the graphite is beginning to distort process tubes in the top central portion of the old reactors such that some charging difficulty is being experienced. The rear hump of the graphite stacks is somewhat smaller and as such, does not limit the charging of normal 8" fuel elements. However, if the central contraction continues at the present rate, the rear hump will become limiting. How far in the future is hard to predict, but it is most certain to occur. Therefore, it is suggested that the rear coring be incorporated with the front coring procedure. The time required to anneal the graphite stack should be incentive enough to complete the coring pattern in the rear before it becomes absolutely necessary. Such has not been the case with the front coring at the older reactors.

CONCLUSIONS

It was concluded, prior to this study, that a front coring pattern and possibly that a rear coring pattern were necessary at the five older reactors. The following conclusions are based upon the results of this study:

1. Effective front and rear coring patterns are possible at the five older reactors. Furthermore, the coring patterns can be standardized to one front pattern and one rear pattern as is shown in Table IV.
2. The coring patterns incorporate a limited range of pile gas composition: 90% He - 10% CO₂ to 100% He with the present maximum graphite temperature limit.
3. The process channel coring can best be accomplished in conjunction with a process tube removal program. If relief is needed immediately, the restricted channels should be cored as the trouble arises. The channel enlargement may allow enough reduction in process tube bending to afford temporary relief.
4. The rear face graphite should be cored at the same time as the front.
5. The coring patterns as given will not restrict future reactor operation if the gas compositions and the range of flux distributions are maintained as suggested.

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Reactor Design Analysis
N-Reactor Project

JD Agar:bw

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