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ROUGH DRAFT

This document consists of
11 pages.

AN ANALYSIS OF THE SUITABILITY
OF VARIOUS CORING PATTERNS FOR
INCLUSION IN "C" REACTOR

by

George M. Roy
Richard K. Andersen

April 13, 1951

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INTRODUCTION AND SUMMARY:

Preliminary meetings on coring of the graphite have been held with interested parties of the Technical and Production Divisions at which time the advantages and problems of coring were discussed. The advantages and the problems which must be surmounted in order to core have been presented to the working committee. A study of the means of accomplishing coring has been made considering only the central and maximum fringe coring. It is important that the minimum and maximum coring be established as soon as possible so that the total coring pattern can be worked out and the design completed.

From the studies that have been made thus far the 10 mil center core - 60 mil fringe core appears to be the most favorable choice. The advantages and disadvantages of several possible coring combinations (central to fringe) are tabulated. The statements and graphs of temperatures made in this tabulation are based on the results of the analogue tests. The estimates of pile expansion resulting from various coring patterns are based on report HDC-1987 by R. K. Andersen. These results are summarized in Figures 1, 2, and 3.

The results of the analysis which Technical plans to make on the DR graphite sample will be compared with what would be predicted from this study.

NOTATION:

- W = Power of pile
 W' = Specific power at center of pile
 W'' = Specific power at fringe of pile
 T_{2-4} = Temperature drop across core
 T_{2-3} = Temperature drop as shown sketched
 T_H = Water temperature
 l' = Coring at center
 l'' = Coring at fringe
 K = Conductivity of gas
 $*$ = Symbol for proportional to

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An approximate relationship of Kw/ft - center to power level is tabulated below:

MAX. Kw/ft	MAX. Kw/tube	Pile Power (MW)	*(about 400 i.h. of flattening)
15	243	300 MW	
20	324	398	
25	405	498	
30	486	596	
35	566	695	
40	648	795	
45	729	895	
50	810	995	
55	890	1105	

* 15% allowed for hot-spots.

The choice of the coring pattern is affected principally by the maximum permissible coring. This value is set by the size of the holes in the thermal shield. With no change in the dimension of these holes and assuming the tube block has no strength, the maximum coring permissible with the enlarged tube is:

- a) 60 mils with a 120 mil undercut
- b) 90 mils with a 60 mil undercut

Another possibility is to enlarge the holes through the thermal shield and use a sleeve around the gun-barrels. The permissible coring in this case was taken as:

- c) 120 mils with a 120 mil undercut
- d) 150 mils with a 60 mil undercut

For a given maximum coring the choice of central coring affects graphite temperatures as follows:

Using any given maximum value of coring the choice of coring at the center determines the ratio of central coring to fringe coring. This ratio - and not the absolute values - is the important factor when CO₂ is present in the gas. Briefly the reasons are these:

The maximum temperature must be kept below 380°C by the proper proportion of He - CO₂. The temperature at 3 is:

$$T_3 = T_4 + T_{2-3} + T_{2-4}$$

The temperature from 2-3 is not affected by K to the first power by any means since the bulk of the heat does not cross the undercut but reaches the tube from the bottom. Therefore, for a fixed power T₂₋₃ is essentially constant. Thus T₂₋₄ is the controlling portion and

$$T_{2-4} \propto \frac{W}{K}$$

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The same reasoning hold for the fringe so that the controlling factors are $\frac{W' l'}{K}$ and $\frac{W'' l''}{K}$. For a constant flattening, W'/W'' is essentially constant and as K is the same throughout the pile, then T'/T'' is governed by l'/l'' . Since T' runs its maximum value, the greater the ratio of l''/l' the higher the resulting fringe zone temperatures (although not exactly linearly).

The advantages in having a large core at the center of the pile are:

- a) The use of 100% helium can be realized at lower power levels. With pure helium the maximum temperature is no longer 330°C.
- b) The ratio of maximum to average temperature of the lattice at the center of the pile (for a given maximum) is raised slightly. This is true because for a given power and maximum T the larger core sizes require higher K for gas which is also in the under-cut. As pointed out before, the T_{2-3} will be affected some by K . In so far as K affects T_{2-3} , the average temperature will be higher.

The analogue results give the quantitative effect of these considerations and the advantages and disadvantages of several choices are tabulated. The 10-60 combination is recommended. The reasoning behind the tabulated statements is given in the Appendix and from the results shown in figures 1, 2, and 3.

I.	<u>Max. Coring</u>	<u>Coring at Center</u>	<u>Advantages</u>	<u>Disadvantages</u>
	60	10	<ol style="list-style-type: none"> 1. Fringe temperatures are high (180°C at 35 KW/ft) because of the high ratio of central to fringe coring. 2. No sleeve is required in the thermal shield. 3. A preliminary estimate indicates that a 60 mil core through the reflector would be tolerated. (Information received verbally from W.R. Lewis.) 	<ol style="list-style-type: none"> 1. Pure helium would never be used as the temperatures would be low. 380°C is not reached with He at any power level conceivable for "C" reactor.

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II.	<u>Coring at</u>		<u>Advantages</u>	<u>Disadvantages</u>
	<u>Max. Coring</u>	<u>Center</u>		
	120 mils	40 mils	<ol style="list-style-type: none"> 1. The use of 100% helium can be realized at reasonable power levels (about 750 MW). With pure He there would no longer be a limitation on graphite temperature. 2. The ratio of average lattice temperature to max. lattice temperature is higher for 40 mil center coring than for smaller central coring. This effect is small however. 	<ol style="list-style-type: none"> 1. Use of a sleeve in the thermal shield is required. 2. The temperatures in the fringe are low (130°C at 35 KW ft.) because of the low ratio of center to fringe coring. 3. The neutron streaming through the moderator may be high. If the coring is choked down in the reflector, then the full effect of the 120 mil core is not realized because of heat flow axially from the edge of active zone through reflector and then to tube.
III.	<u>Coring at</u>		<u>Advantages</u>	<u>Disadvantages</u>
	<u>Max. Coring</u>	<u>Center</u>		
	90	20	<ol style="list-style-type: none"> 1. No sleeve is required. 2. A slight advantage over the 10 - 60 because of higher average lattice temperature. 	<ol style="list-style-type: none"> 1. Undercut is 60 mils and therefore not as much allowance for growth. 2. The ratio of fringe to central coring is less than for the 10-60. 3. The advantage of reaching pure He is not realized at any reasonable power level.

The following cases were not analyzed quantitatively, but are discussed generally to provide a complete analysis.

IV.	<u>Coring at</u>		<u>Remarks</u>
	<u>Max. Coring</u>	<u>Center</u>	
	10 mils	10 mils	<p>The fringe temperatures would be lowered somewhat by the addition of He which is necessary at the higher power levels. This effect is not pronounced however (see Appendix 1 or figures 1 and 2) and the best estimate of fringe growth is that it would be slightly more than a direct proportion to total exposure. The growth at the center would be slightly higher because of the lower average lattice temperature. Thus a pile operating a 2W would have less than half the life of one operating at W.</p>

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V. <u>Max. Coring</u>	<u>Coring at Center</u>	<u>Remarks</u>
120	Less than 40 mils	Although this would improve the ratio of center coring to fringe coring and therefore improve fringe temperature, its main advantage (see #1 for the 120-40) would be lost. Furthermore, a ratio of greater than about 5 or 6 to 1 gains very little in the way of reducing graphite fringe growth as can be seen from figure 3. Thus a coring of 120 to 20 would lose advantage (1) of the 120-40, would give slightly higher average lattice temperatures at the center, and would result in fringe temperatures very slightly above those of the 60-10 coring. Disadvantages (1) and (3) would remain. This coring is not recommended.
VI. <u>Max. Coring</u>	<u>Coring at Center</u>	<u>Remarks</u>
120	Greater than 40 mils	The fringe temperatures are too low. Fringe growth would be high. Not recommended.
VII. <u>Max. Coring</u>	<u>Coring at Center</u>	<u>Remarks</u>
90	10	Figure 3 shows only small gains over the 10-60 in the fringe. There would be negligible gains in the center. This coring pattern limits the undercut to one-half that of the 10-60 pattern or requires a sleeve in the shield. It is not recommended.
VIII. <u>Max. Coring</u>	<u>Coring at Center</u>	<u>Remarks</u>
90	Greater than 20	No real advantage would be gained below a center coring of about 40 mils. The ratio of fringe to center is then too low. Not recommended.

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APPENDIX

Several basic arguments can be used to determine effects of power level, coring, ratio of coring, etc. The effects of these factors were studied using the analogue to determine temperatures within a lattice unit. The ratio of W'/W'' with variation in W was studied from temperature maps and by actual measurement by G. E. Hays at "B" Pile. In discussing the effects of these factors many of the statements made in comparing possible coring combinations are explained.

Once the limiting temperature of 380°C is reached further power increase requires the addition of He. The effect is a slight reduction in both the average lattice temperature - center and fringe. The maximum temperature at 3 is given by:

$$T_3 = T_4 + T_{2-3} + T_{2-4}$$

and is fixed at 380°C when any CO_2 is present. Raising W' requires addition of He which in turn improves the effective conductivity from 2-3 slightly* because of the gas in the undercut. So:

$$T_{2-3} \propto (W')^n$$

where n is less than one. For a fixed maximum this larger gradient means a lower average temperature.

In the central zone, since T_{2-3} increases, T_4 is constant, and T_3 is fixed at 380°C , then T_{2-4} must decrease. But:

$$T_{2-4} \propto \frac{W''}{K}$$

therefore the conductivity must be increased by a greater percentage than the percentage increase in W' . This affects the fringe temperatures, since:

$$T_{2-4} \propto \frac{W''^n}{K}$$

is also reduced. The value of T_{2-3} at the fringe rises somewhat but does not offset the decrease in core temperature. The total effect is appreciable - the temperature at the core in the fringe being about 62° at 25 KW/ft - center and 36° at 50 KW/ft-center for the 10-10 coring pattern. The change in average lattice temperature would be less than this because of the greater T_{2-3} at 50 KW/ft center.

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* It does not have too great an effect because the bulk of the heat reaches the tube via the contact rather than via the gap.

The effect of low graphite conductivity is to increase the temperature T_{2-3} and thereby lower the average temperature at the center so long as 380°C is the maximum.

For a given power level larger central coring gives somewhat higher average lattice temperature. This is because larger coring requires a higher percentage of He which improves the effective conductivity from 2-3. This lowers T_{2-3} . For a given maximum T_3 , this means a higher average lattice temperature.

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Figure 1
Central Temperatures of Various
Loading Patterns as a Function
of Power Level

(Values are Minimum Observed Core
Temperatures)

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Figure 2

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Fringe Temperatures of Various
Coring Patterns as a Function
of Power Level

(Values are Minimum Graphite Bore
Temperatures)

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Figure 3

Relative Growth for Various Coring Patterns after 10,000 MWDC/CT of Operation at 800 MW Level

Apparent Total Expansion (Inches)

Edge of Tracking

Active Zone

Edge of Pile

Coring Pattern

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