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OAK RIDGE OPERATIONS OFFICE

ATOMIC ENERGY COMMISSION

STUDY NO. II-179-2

COOLANT FLOW DISTRIBUTION
PERMEATION OF COOLANT THROUGH GRAPHITE

EXPERIMENTAL GAS COOLED REACTOR

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N O T I C E

This report summarizes as of the date of the study the status of this phase of the design of the Experimental Gas Cooled Reactor under construction in the Oak Ridge Area. Since the data was developed prior to completion of all design, fabrication and construction, the information is subject to modification during the evolution of the complete design of the entire facility and no attempt has been made to revise, rewrite, edit or otherwise modify the study to maintain the data current with related research and development programs or subsequent design revisions. Users are cautioned to avoid interpretations and conclusions based on the incomplete data contained herein.

Study No. II-179-2
EGCR

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May 18, 1960

COOLANT FLOW DISTRIBUTION
PERMEATION OF COOLANT THROUGH GRAPHITE

I. OBJECTIVE

To determine the effects of helium leakage through graphite moderator columns and fuel element sleeves on the core coolant flow distribution reported in Study II-179-1.

II. CONCLUSIONS AND RESULTS

A. If no changes are made in the presently-planned annular orifice sizes (Study No. II-226), the total flow which will bypass the fuel elements because of permeability of the graphite blocks (graphite sleeves are assumed to be impermeable) varies with Darcy's Constant as shown below. These flows are in addition to those reported in Study II-179-1:

Permeability of the Graphite Brick (Darcy's Constant)	Increase in Bypass Flow Due to Penetration, lb/hr
--	---

0.2

3000

0.7

5760

(The Darcy Constant measured in A-C R & D Report 0200 is 0.2).

B. If the graphite sleeves are also permeable to helium, the bypass flow increases sharply. For a value of Darcy's Constant of 0.2 for both the bricks and the sleeves, the total additional bypass flow increases from 3000 to 7000 lb/hr.

C. The pressure in the annular space surrounding the fuel assembly sleeve is lowered by the permeation of helium through the graphite columns. If the fuel sleeves are impermeable, the pressure in the annuli of the center-zone channels will be 3.1 psi for 0.2 Darcy, and 1.8 psi for 0.7 Darcy.

III. RECOMMENDATIONS

It is recommended that the following two design changes be made so that the total coolant bypass will remain the same as reported in Study II-179-1.

A. It is recommended that the graphite fuel assembly sleeves be made essentially impermeable to helium at EGCR conditions (Darcy's Constant = 0.05).

B. It is recommended that the resistance of the bottom annular orifice be increased so that the flows listed in Paragraph IV, A, are obtainable with impermeable graphite sleeves and with an assumed graphite block Darcy Constant of 0.2.

IV. GIVEN DATA

A. Moderator coolant annuli are orificed in four regions of the core. Each annulus is orificed at the bottom and top dummy assembly, so that the annulus pressure is equivalent to the average fuel coolant passage pressure, assuming no leakage. The annulus flows in the four zones, with no leakage, are 90, 70, 50, and 30 lb/hr (see Study II-226).

B. The permeability constant (Darcy's Constant) for AGOT graphite is 0.2. This constant is the average obtained from A-C R & D Report O200 on two 29-inch long fuel assembly sleeves, in which the constant varied from 0.15 to 0.25.

V. ASSUMPTIONS

A. Flow through orifices and through the graphite is laminar and can be simulated by an electrical circuit analogy.

B. The operating core pressure drop is 10 psi.

C. The fuel column pressure drop, the pressure drop across the fuel orifice, and the average pressure in the fuel coolant passage (above exit plenum pressure) for the four zones are:

Zone	Fuel Column Pressure Drop psi	Fuel Orifice Pressure Drop psi	Average Pressure in Fuel Column psi
1	9	1	4.5
2	6.7	3.3	3.4
3	4.8	5.2	2.4
4	3.1	6.9	1.6

D. The leakage flow through the graphite fuel assembly sleeves is a small fraction of the fuel coolant flow, so that the average pressure in the fuel coolant passage may be assumed to remain constant.

VI. METHOD OF ANALYSIS

The flow resistances of a unit cell consisting of one fuel column and its associated graphite block are set up in a flow network. Flow resistances are calculated for the graphite sleeve permeability, graphite block permeability, and annulus orifices at the top and bottom dummy assemblies. The network equations are solved to obtain the unknowns: moderator annulus pressure, coolant flow through the bottom orifice, and coolant flow through the permeable graphite sleeve.

Helium flow resistance through the graphite is calculated in accordance with equations given in "The Industrial Graphite Engineering Handbook," by National Carbon Company, P5A.08.01.

VIII. CALCULATIONS

Calculations are given on attached Work Sheets 1-11.

FROM "IND. Graphite Engr. Handbook," gas flow through graphite is given by:

$$Q = K \frac{A}{L} \frac{P}{\mu} \Delta p \quad (1)$$

where Q = flow, cc/sec at one atmosphere

K = Darcy's constant

A = Flow area, cm^2

L = Length, cm

p = pressure, atmospheres

μ = viscosity, centipoise

Δp = pressure difference, atmospheres

Expressing (1) in lb/hr.

$$W = \rho \left(\frac{A}{L} \right) \frac{3600}{28,400} \frac{\Delta p}{14.7} \frac{K}{\mu}, \text{ lb/hr} \quad (2)$$

where $\rho = 0.1 \text{ lb/ft}^3$:

$\Delta p = \text{psi}$

$A = \text{cm}^2$

$L = \text{cm}$

$\mu = 0.033 \text{ cp}$

$$W = \frac{0.1 \times 3600}{28,400 \times 14.7 \times 0.033} \left(\frac{A}{L} \right) \Delta p \cdot K$$

$$W = 0.0261 \left(\frac{A}{L} \right) \Delta p \cdot K \quad (3)$$

Gas Flow Through Graphite

SIMILAR TO

DR'N JKD

CH'D

JHK

APP'D

JHK

SCALE

= 12

SHEET 1 OF 11

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For the a 1/4 segment of the Graphite column

$$L' = \frac{8 - 5.25}{2} = 1.37$$

$$L'' = \frac{8\sqrt{2} - 5.25}{2} = 3.00$$

$$L \approx \frac{L' + L''}{2} = \frac{1.37 + 3.00}{2} = 2.18 \text{ in}$$

Per foot Length:

$$A' = \frac{\pi \times 5.25^2}{2} = 8 \text{ in}^2$$

$$A'' = 8 + 8 = 16 \text{ in}^2$$

$$A \approx 19.4 \left(\frac{A' + A''}{2} \right) = 19.4 \text{ ft}^2$$

$$\therefore \frac{A}{L} = \frac{19.4}{2.18} \times 12 \times 30.5 = 3,250 \text{ cm}.$$

For the graphite sleeve,

$$\frac{A}{L} = \frac{2\pi L}{\ln \frac{r_2}{r_1}} = \frac{2\pi \times 30 \times 6 \times 2.54}{\ln \frac{2.5}{1.5}} = 5,600 \text{ cm}$$

.513

Gas Flow Through Graphite

SIMILAR TO

DR'N

JKD

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The Flow equation can be written

$$W = \frac{\Delta P}{R}$$

where R is the Flow Resistance term

The network model simulating a fuel cell is:

sing Assumptions given under 4 of the report

P_i = inlet plenum pressure = 10. psi

P_f = average fuel column pressure, psi

P_a = moderator annulus pressure, psi

P_0 = outlet plenum pressure = 0

Gas Flow Through Graphite

SIMILAR TO

DR'N

SK

CH'D

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APP'D

SK

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3

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R_1 = Resistance of bottom annular orifice, which varies with zones in the cone

Zone	Design DP, PSI (No Leakage)	Design Flow, lb/hr (No Leakage)	R_1 = $\Delta P / W$
1	5.5	90	.061
2	6.7	70	.096
3	7.6	50	.152
4	8.5	30	.283

R_2 = Resistance of Graphite block.

$$= \frac{1}{.0261 \left(\frac{A}{L}\right) K} = \frac{1}{.0261(3,250)0.2} = 0.059$$

R_3 = Resistance of top annular orifice = $\frac{4.5}{90} = 0.05$

R_4 = Resistance of Graphite sleeves

$$= \frac{1}{.0261(5,600)0.2} = 0.034$$

The equations for the Network are:

$$R_A = \frac{R_2 R_3}{R_2 + R_3} = \frac{.059 \times .05}{.059 + .05} = 0.027$$

$$W_4 = \frac{P_f - P_a}{R_4} \quad (4)$$

$$W_1 = \frac{P_i - P_a}{R_1} \quad (5)$$

Gas Flow Through Graphite

SIMILAR TO

DR'N

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APP'D

JHK

SCALE

= 12

SHEET 4 OF 11

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II-179-2

$$W_2 + W_3 = W_1 + W_4 = \frac{P_a - P_i}{R_A} \quad (6)$$

Substituting (4) and (5) into (6) and solving for P_a ,

$$P_a = \frac{P_f/R_A + P_i/R_i}{(1/R_A + 1/R_i + 1/R_A)} \quad (7)$$

Using values of P_f from Assumption C of the report.

For Zone 1

$$P_a = \frac{4.5/.034 + 10/.061}{1/.034 + 1/.061 + 1/.027} = 3.59 \text{ psi}$$

$$W_4 = \frac{4.5 - 3.59}{.034} = 26.8 \text{ lb/hr}$$

$$W_1 = \frac{10 - 3.59}{.061} = 105.0 \text{ lb/hr}$$

$$W_1 + W_4 = 131.8 \text{ lb/hr.}$$

For Zone 2

$$P_a = \frac{3.4/.034 + 10/.096}{1/.034 + 1/.096 + 1/.027} = 2.55 \text{ psi}$$

$$W_4 = \frac{3.4 - 2.55}{.034} = 25 \text{ lb/hr.}$$

Gas Flow Through Graphite

SIMILAR TO

DR'N

JHK

CH'D DRL

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APP'D

JHK

SCALE

= 12

SHEET

5

OF

11

ISSUE

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II-179-2

$$W_1 = \frac{10 - 2.55}{.096} = 77.5 \text{ lb/hr}$$

$$W_1 + W_4 = 102.5 \text{ lb/hr}$$

Zone 3

$$P_a = \frac{2.4/.034 + 10/.152}{1/.034 + 1/.152 + 1/.027} = 1.88 \text{ psi}$$

$$W_4 = \frac{2.4 - 1.88}{.034} = 15.3 \text{ lb/hr}$$

$$W_1 = \frac{10 - 1.88}{.152} = 53.5 \text{ lb/hr}$$

$$W_1 + W_4 = 68.8 \text{ lb/hr}$$

Zone 4

$$P_a = \frac{1.6/.034 + 10/.283}{\frac{1}{.034} + \frac{1}{.283} + \frac{1}{.027}} = 1.18$$

$$W_4 = \frac{1.6 - 1.18}{.034} = 12.4 \text{ lb/hr}$$

$$W_1 = \frac{10 - 1.18}{.283} = 31 \text{ lb/hr}$$

$$W_1 + W_4 = 43.4 \text{ lb/hr}$$

Gas Flow Through Graphite

SIMILAR TO

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HK

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SCALE

= 12

SHEET 6 OF 11

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From Study .226, the number of channels per zone are as follows. The total flow due to permeability is the difference between that for no leakage and as calculated here.

<u>Zone</u>	<u>No. Channels</u>	<u>W/channel lb/hr</u>	<u>W/channel (No Leakage)</u>	<u>Total due to Permeability</u>
1	80	131.8	90	3350
2	76	102.5	70	2470
3	44	68.8	50	830
4	16	43.4	30	214
				<u>6864 lb/hr</u>

Gas Flow Through Graphite

SIMILAR TO

DR'N

CH'D

3/17/60

APP'D

SCALE

=12

SHEET 7 OF 11

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II-179-R

Assuming that sleeves are impregnated to reduce permeation through them to negligible quantities, the network becomes

$$R_A = \frac{R_2 R_3}{R_2 + R_3} = 0.027$$

$$R = R_1 + R_A$$

$$W = \frac{\Delta P}{R}$$

Zone	R	$W/\text{channel},$ $= 10/R$	P_a	$W/\text{channel}$ (w. Leakage)	No. of Channels	Total Flow due to Permeability
1	.089	113	3.1	90	80	1840
2	.124	81	2.2	70	76	830
3	.180	56	1.5	50	44	265
4	.311	32	1.0	30	16	32
						<u>2967</u> <i>cf/hr.</i>

Gas Flow Through Graphite

SIMILAR TO

DR'N

CHK'D

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APP'D

SCALE

= 12

SHEET

8 OF 11

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II-179-2

Recalculation ^{Assuming Impermeable Sleeves} Assuming $K = 0.7$ for Graphite Blocks

Since $K = 0.7$, $R_2 = 1.0161$

Zone	R_1	R_2	R_3	R_4	R
1	.061	.0169	0.05	∞	.074
2	.096	"	"	"	.109
3	.152	"	"	"	.165
4	.283	"	"	"	.296

$$R = R_1 + \frac{R_2 R_3}{R_2 + R_3}$$

$$R_a = \frac{R_2 R_3}{R_2 + R_3} = \frac{(1.0161)(.05)}{1.0669} = .0124$$

P_a = Annulus Pressure = $10 - WR_1$

Zone	R	W/channel #/hour	P_a	W/channel (No leakage)	No of Channels	total Flow due to permeability
1	.074	135	1.8	90	80	3600
2	.109	91.5	1.2	70	76	1640
3	.165	60.5	0.8	50	44	460
4	.296	34.0	0.4	30	16	64

Gas Flow Through Graphite

5764

SIMILAR TO

DR'N

JKD

CH'D

JKK

APP'D

JKK

SCALE

= 12

SHEET

9 OF 11

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II-179-2

In order to adjust flow back to original values it would be possible to increase the resistance of the bottom annulus steel;
Calculation of Case with:

Darcy = 0.2

Impermeable sleeves

Normal gap in the top annulus

Flows as originally specified:

Zone	w/hr
1	90
2	70
3	50
4	30

Zone	w/channel #/hr	R 10/w	R _a	R _i	P _a	W ₃ #/hr
1	90	0.111	0.027	.084	2.4	48
2	70	0.143	0.027	.116	1.9	38
3	50	0.200	0.027	.173	1.3	26
4	30	0.333	0.027	.306	0.8	16

Case when the annulus gap in the top is closed.

Zone	w/channel #/hr	R	R _a	R _i	P _a	W ₃ #/hr
1	90	0.111	0.059	.052	5.3	0
2	70	0.143	0.059	.084	4.1	0
3	50	0.200	0.059	.141	3.0	0
4	30	0.333	0.059	.274	1.8	0

Gas Flow Through Graphite

SIMILAR TO

DR'N JKD

CH'D

HK

APP'D

HK

SCALE

=12

SHEET 10 OF 11

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II-179-A

Estimate of Flow if Darcy is 0.7 but
 orifice in bottom drumming is sized for 0.2 (pore 10)

Zone	<u>R₁</u>	<u>R_a</u>	<u>R</u>	<u>W</u>	<u>P_a</u>	<u>W₃</u>
1	.084	.013	.097	103	1.4	28
2	.116	"	.129	77.5	1.0	20
3	.173	"	.186	53.7	0.7	14
4	.306	"	.319	31.3	0.4	8

Excess leakage at design conditions

Zone	<u>W</u>	<u>W (Design)</u>	<u>No of Joints</u>	<u>Leak</u>
1	103	90	13	80
2	77.5	70	75	76
3	53.7	50	3.7	44
4	31.3	30	13	16
				<u>21</u>

additional bypass due to permeation 1794 lbs/hour

Gas Flow Through Graphite

SIMILAR TO

DR'N JKD

CH'D

HK

APP'D

HK

SCALE

= 12

SHEET 11 OF 11

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