MAR 18 1960

WID-18098
Study No. II-226
EGCR

APPROVED

AUG 31 1960

OAK RIDGE OPERATIONS OFFICE

ATOMIC ENERGY COMMISSION

STUDY NO. II-226

TEMPERATURE DISTRIBUTION
MODERATOR AND REFLECTOR
REACTOR CORE

MASTER

EXPERIMENTAL GAS COOLED REACTOR

LEGAL NOTICE

This report was prepared as an agent of Government sponsored by the United States, nor the Commission, nor any person acting on behalf of the Commission.

A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liability with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission to the extent that such employee or contractor prepares, handles or distributes, or provides access to, any information pursuant to his employment or contract with the Commission.

Facsimile Price \$ 8.10
Microfilm Price \$ 2.75

Available from the
Office of Technical Services
Department of Commerce
Washington 25, D. C.

Prepared By
ALLIS-CHALMERS MANUFACTURING COMPANY
Atomic Energy Division
Nuclear Power Department
Washington, D. C.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

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.

TEMPERATURE DISTRIBUTION MODERATOR AND REFLECTOR
REACTOR CORE

Prepared By: F. Cheng by [Signature] Date: 4-25-60
F. Cheng
Responsible Engineer

Approved By: [Signature] Date: 4-25-60
L. L. Kintner
Group Leader

Approved By: J. K. Davidson Date: 4-26-60
J. K. Davidson
Section Head

Approved By: W. F. Banks Date: 4-27-60
W. F. Banks
Project Manager

Approved for Kaiser Engineers:

By: W. J. Dodson Date: Aug. 22, 1960

Approved for Union Carbide Nuclear Company:

By: M. Bender Date: May 18, 1960

Approved for Atomic Energy Commission:

By: L. H. Jackson Date: May 18, 1960

APPROVED

May 25, 1960

TEMPERATURE DISTRIBUTION MODERATOR AND REFLECTOR
REACTOR CORE

I. OBJECTIVE

The purpose of this study is to determine the coolant flow required to prevent the temperature of the graphite moderator and reflector blocks from exceeding 1100 F at full-power operating conditions. The temperature distribution in the graphite blocks is also determined.

II. CONCLUSIONS

A. The moderator is primarily cooled by coolant flowing in the 1/8-inch annulus formed by the fuel-assembly sleeves and the fuel-channel holes in the moderator blocks. Coolant flow in the control-rod channels and in the experimental-tube coolant annuli also cools the moderator, and this effect was considered in setting moderator-annulus coolant flow. The coolant flows required for each of four zones in the reactor core are as follows:

<u>Zone(Refer to Fig. 1)</u>	<u>Coolant Flow Per Channel lb/hr</u>	<u>No. of Fuel Channels</u>	<u>Total Flow Each Zone, lb/hr</u>
1	90	80	7200
2	70	76	5320
3	50	44	2220
4	30	16	480

The total moderator-annulus coolant flow (excluding 16 unfueled channels) is 15,200 lb/hr.

B. The moderator-block temperature distributions for full-power reactor operation after 20 years of operation are given in Figure 2. The maximum temperature (1100 F average over the cross section) occurs near the top of the graphite block. The temperature in the majority of the graphite columns varies from 600 F to 1000 F over the lower half of the column and from 1000 F to 1100 F over the top half of the column. The maximum graphite surface temperature is less than 1100 F.

C. Reflector-block temperatures (average over the cross section) do not exceed 1050 F. The axial temperature distribution is approximately linear over the length of the column and varies from 550 F at the bottom to 1050 F at the top. Axial temperature distribution for each reflector column is also shown in Figure 2.

D. The maximum temperature difference over a column cross section is less than 150 F for normal full-power operation.

E. A maximum temperature difference of 450 F over a column cross section is calculated for the condition in which one of the fuel channels has 3500 lb/hr of coolant with no fuel assemblies. This situation will occur during unloading operations if the fuel-channel flow supplied by the charge machine is maintained at 3500 lb/hr after the fuel assemblies are removed from the core. The time required for this temperature difference to develop in the column is about 10 minutes after start of unloading. This time is short compared with the fuel-charging operation.

The thermal stresses caused by this temperature gradient are calculated in Reference 7. Cooling requirements during unloading are specified in Reference 8, in which this condition is taken into consideration.

IV. GIVEN DATA

<u>Designation</u>	<u>Data</u>	<u>Reference</u>
A. Coolant flow used for calculation of heat-transfer coefficient in models:*		3
1. Moderator coolant annulus	125 lb/hr	
2. Control-rod channel	205 lb/hr	
3. Small experimental channel	225 lb/hr	
4. Large experimental channel	750 lb/hr	
*Models were constructed prior to fixing of final flows. Final flows used in temperature calculation are given below.		
B. Coolant-channel diameters:		5
1. Fuel channel	5-1/4 in.	
2. Control-rod channel	4.0 in.	
3. Small experimental channel	5-1/4 in.	
4. Large experimental hole	10-1/4 in.	
C. Component diameters (outside)		3
1. Fuel-assembly sleeve	OD 5.0 in.	

<u>Designation</u>	<u>Data</u>	<u>Reference</u>
2. Small experimental tube	OD 4.5 in.	
3. Large experimental tube	OD 9.5 in.	
4. Control rod	OD 3.25	
D. Graphite-block geometry		5
E. Active core height	14.5 ft	
F. Heating and coolant flow used in temperature calculation		
1. Average heat generation of graphite block and fuel-assembly sleeve		4
2. Axial heat-flux distribution in graphite columns		4
3. Average heat generation in small experimental tube	2 watts/cm ³	6
4. Total heat per small tube	95.000 BTU/hr	6
5. Final flow per small tube	350 lb/hr	6
6. Average heat generation of large experimental tube	1 watt/cm ³	6
7. Total heat per large tube	105,000 BTU/hr	6
8. Final flow per large tube	430 lb/hr	6
9. Final flow per control rod	200 lb/hr	6

V. ASSUMPTIONS

A. In computing the average temperature over a column cross section the following assumptions are used:

1. The convective film heat-transfer coefficient calculated from Title I flow data (Section IV-1) is sufficiently accurate to determine average block temperature and fraction of block heat going to moderator, control rod, and experimental-tube channels.

2. Outer surfaces of graphite blocks are insulated. Axial leakage between columns is small (0.1% of total flow) and therefore will not influence block temperatures appreciably.

3. The coolant temperature in the small experimental tube annulus and the control-rod channel at any block cross section are equal.

4. The coolant temperatures in all moderator coolant annuli of one block are equal at any block cross section.

5. The thermal conductivity of the graphite is assumed to be approximately 15 BTU/hr-FT-F for the entire reactor after 20 years of operation. The physical properties of helium are evaluated at 780 F.

6. Heat generation at any cross section of a graphite block is assumed to be uniform.

B. In computing the axial temperature distribution of a column, the following assumptions are used:

1. Reactor inlet-coolant temperature is 510 F and outlet coolant temperature is 1050 F.

2. The heat generated in the graphite-block experimental tubes and a portion of that generated in the fuel-assembly sleeves (depending on moderator-annulus coolant temperature) is transported from the reactor by moderator-annulus coolant, control-rod coolant, and experimental-tube coolant.

3. Four different moderator-coolant-flow rates are used for the four zones in the core shown in Figure 1. The moderator-coolant flow is based on obtaining a maximum graphite temperature of 1100 F in the maximum power channel of each zone. All flows in a zone are equal.

4. Axial conduction of heat in the graphite block is negligible.

5. The temperature of coolant inside of a fuel column varies linearly from 510 F at the inlet to 1050 F at the outlet. This distribution approximates the actual distribution, which will depend on fuel and control-rod programming. The fuel-coolant temperature is not appreciably affected by the small quantities of heat transferred from it to fuel-assembly sleeves or vice versa.

VI. METHOD OF ANALYSIS

The temperature distribution in a cross section of the graphite-moderator blocks as a function of coolant temperature and volumetric heat generation is determined with a Teledeltos paper, electrical analog. The analog and general method are described in Reference 1 and 2. The axial temperature distribution

in the graphite-moderator blocks is calculated by numerical integration, using a Bendix G-15 Computer. The effect on graphite temperature of irregular block and coolant-channel geometries, different coolant temperatures in control-rod, experimental tube, and moderator annuli, and variation of volumetric heat generation with block location and axial position is included in the analysis. The detailed calculation procedure for one of the blocks is given in the calculations beginning with Sheet 18.

The reflector temperature distribution was calculated by the same general method. Details of the reflector analog model are shown in Calculation Sheet 14.

Three different outer-reflector-surface coolant conditions were considered: adiabatic outer surface (Table 15); maximum coolant temperature at top of outer-reflector surface (the same as outlet-plenum coolant temperature, Table 16); and outer-reflector-coolant temperature equivalent to inner-reflector-coolant temperature (moderator annuli at any cross section, Table 17). The assumption used to obtain Table 16 is believed most realistic and therefore is used to obtain the representative reflector temperatures plotted in Figure 2.

VIII. REFERENCES

1. ANL-5319, "Electrical Geometrical Analogue Techniques for Solution of Two-Directional Complex Heat Conduction Problems".
2. Bonilla, C. F., "Nuclear Engineering", McGraw-Hill Book Co., Inc.
3. A-C EGCR (Title I) Study No. 115, "Thermal Performance of Experimental Gas-Cooled Reactor".
4. Letter, Mr. C. A. Preskitt to Dr. R. A. Charpie, dated January 16, 1960.
5. A-C Drawing No. 5927-EGCR-MS-270, "Core Assembly Plan".
6. A-C Study No. II-179-1, "Core Coolant Flow Distribution".
7. A-C Study No. II-227, "Analysis - Graphite Core Structure".
8. A-C Study No. II-129, "Cooling Requirements for Fuel Assemblies During Handling Within Reactor".

VIII. CALCULATIONS

	<u>Sheets</u>
A. Heat-Transfer Coefficients for Teledeltos Model Construction	1-6
B. Geometric-Dimension Construction of Teledeltos Model for Moderator	7-13
C. Geometric-Dimension Construction of Teledeltos Model for Reflector	14-17
D. Teledeltos Model Analysis-Sample Calculations	18-21
E. Dissipation of the Heat Generated in Fuel-Element Sleeve	22-29
F. Heat Generation in Graphite Columns and Experimental Tubes	30-31
G. Graphite Moderator Column Temperature Distributions-Sample Calculations	32-33
H. Moderator Flow Requirements	34-37
I. Effect on Graphite Temperature due to Variation of Moderator-Coolant-Flow Rate	38-40
J. Heat-Transfer Coefficients for Fuel Unloading in One Channel	41-44

(I) FILM COEFFICIENT IN ANNULUS

Given Data:

- (1) Coolant flow per fuel Channel's ANNULUS ⁽³⁾ 125 $\frac{\text{lb}}{\text{hr}}$
- (2) Total control rod coolant (21 rods) ⁽¹⁾ 4300 $\frac{\text{lb}}{\text{hr}}$
- (3) Total experimental tube coolant ⁽¹⁾ 3900 $\frac{\text{lb}}{\text{hr}}$
 - Large tube = 750 $\frac{\text{lb}}{\text{hr}}$ - tube
 - Small tube = 225 $\frac{\text{lb}}{\text{hr}}$ - tube
- (4) Total Leakage Coolant ⁽¹⁾ 4700 $\frac{\text{lb}}{\text{hr}}$
- (5) ~~At~~ inlet Coolant temperature ⁽¹⁾ 510 F
- (6) Total Reactor Power ⁽¹⁾ 84.3 MW
- (7) Thermal Conductivity of New Graphite ⁽²⁾ 60 $\frac{\text{BTU}}{\text{FT-HR-F}}$

Assumption:

- (1) Thermal Conductivity of 20 years old Graphite 15 $\frac{\text{BTU}}{\text{FT-HR-F}}$
- (2) Film Coefficient, h = constant along axial position
 basing on ^{average} ~~mean~~ temperature of
 $\frac{510 + 1050}{2} = 780 \text{ F}$

(3) A-C Study No II-176.

Reference: (1) A-C Study No. 115

(2) A-C TASK No. 425

★ Discussion with L. L. Kintner

Film Coefficient For Tele deltas Model
 Based on Title I Data

A-C STUDY 226

DR'N F.C 1/10/60	CH'D LHO 2/22/60	APP'D <i>[Signature]</i>	SCALE = 12	SIMILAR TO	SHEET 1 OF 44	ISSUE
ALLIS-CHALMERS MFG. CO. DEPT.						

(A) Fuel channel annulus

- Graphite sleeve O.D = 5.0 inches
- Moderator coolant annulus
- Graphite block

$$\left. \begin{aligned} C_p &= 1.25 \frac{\text{BTU}}{\text{lb-F}} \\ \mu &= 0.084 \frac{\text{lb}}{\text{ft-sec}} \\ k &= 0.141 \frac{\text{BTU}}{\text{ft-F}} \end{aligned} \right\} \text{At Average temperature of } 780\text{F}$$

Coolant rate, $W = 125 \frac{\text{lb}}{\text{hr}}$ ✓

$$\begin{aligned} \text{Area of Annulus} &= \frac{\pi}{4} (5.25^2 - 5.00^2) = 0.785 (27.6 - 25) \\ &= 2.04 \text{ in}^2 \approx (1.415)(10^{-2}) \text{ ft}^2 \end{aligned}$$

$$D_e = \frac{4 A_t}{W.P} = \frac{(4)(\frac{\pi}{4})(5.25^2 - 5.00^2)}{\pi (D_2 + D_1)} = D_2 - D_1$$

$$D_e = 5.25 - 5.00$$

$$D_e = 0.25 \text{ inch} \approx (2.08)(10^{-2}) \text{ ft} \quad \checkmark$$

$$G = \frac{W}{A} = \frac{(1.25)(10^2)}{(1.415)(10^{-2})} = (8.83)(10^3) \frac{\text{lb}}{\text{hr-ft}^2} \quad \checkmark$$

$$N_{Re} = \frac{D_e G}{\mu} = \frac{(2.08)(10^{-2})(8.83)(10^3)}{(8.45)(10^{-2})}$$

$$N_{Re} = (2.17)(10^3) \quad \dots \text{Transition region}$$

Heat transfer in Transition Region between Laminar and Turbulent Flow is given by the relation:

$$J = \frac{h_i}{G C_p} N_{Pr}^{\frac{2}{3}} \left(\frac{\mu_w}{\mu} \right)^{0.14} = 1.85 \left(\frac{D}{L} \right)^{\frac{1}{3}} N_{Re}^{-\frac{2}{3}} \quad \star \star$$

★ ★ Reference: McCabe and Smith "UNIT OPERATION OF CHEMICAL ENGINEERING" PP 452-453 MCGRAW-HILL BOOK CO. N.Y., N.Y.

Film Coefficient For Teledeltis Model
Based on Title I Data

A-C STUDY 226

DR'N	F. C. 9/10/62	CH'D	LHD / 2/22/60	APP'D	<i>[Signature]</i>	SCALE	= 12	SHEET	2 OF 44	ISSUE
ALLIS-CHALMERS MFG. CO.						DEPT.				

Using Graph in Figure 8-12 Page 453 (McCabe and Smith)
or Figure 9-22 Page 241 - McAdams "Heat Transmission" h_i
can be readily evaluated

At $N_{Re} = (217)(10^3)$

$J = 0.0018 = \left(\frac{h_i}{G C_p}\right) \left(\frac{C_p \mu}{k}\right)^{1/3} \left(\frac{\mu}{\mu_w}\right)^{0.14}$

$\therefore h_i = (0.0018)(G C_p) \left(\frac{C_p \mu}{k}\right)^{-1/3}$

$h_i = (1.8)(10^{-3})(8.83)(10^3)(1.25) \left[\frac{(1.25)(8.4)(10^{-2})}{(1.41)(10^{-1})} \right]^{-1/3}$

$h_i = (19.85) \left(\frac{1}{0.825}\right)$

$h_i = 24 \frac{BTU}{hr-ft^2-F}$

(B) Control Rod Channel

Total Flow Coolant (21 Rod) = $4300 \frac{lb}{hr}$

Flow per rod channel $\approx 205 \frac{lb}{hr}$

Area of Annulus = $0.785(4.0^2 - 3.25^2)$
 $= 0.785(16.0 - 10.56)$
 $= (0.785)(5.43)$
 $= 4.27 \text{ in}^2$
 $A \approx (2.97)(10^{-2}) \text{ ft}^2$

$G = \frac{(2.05)(10^2)}{(2.97)(10^{-2})} = (6.9)(10^3) \frac{lb}{hr-ft^2}$

$D_e = D_2 - D_1 = 4.0 - 3.25 =$

$D_e = 0.75 \text{ in}$

$= (6.25)(10^{-2}) \text{ ft}$

Film Coefficient For Teledeltos Model
Based on Title I Data

A-C STUDY 226

DR'N F.C. 1/14/60	CH'D LHD 2/22/60	APP'D <i>[Signature]</i>	SCALE = 12	SHEET 3 OF 44	ISSUE
ALLIS-CHALMERS MFG. CO.			DEPT.		

SIMILAR TO

$$\frac{De G}{\mu} = \frac{(6.25)(10^{-2})(6.9)(10^3)}{(8.45)(10^{-2})} = (5.1)(10^3)$$

$$\begin{aligned} h &= (0.023) \left(\frac{k}{De} \right) \left(\frac{De G}{\mu} \right)^{0.8} \left(\frac{C_p \mu}{k} \right)^{0.4} \\ &= (2.3)(10^{-2}) \left[\frac{(1.41)(10^{-1})}{(6.25)(10^{-2})} \right] [(5.1)(10^3)]^{0.8} (0.75)^{0.4} \\ &= (2.3)(2.26)(10^{-2})(9.33)(10^2)(8.92)(10^{-1}) \\ h &= 43 \frac{\text{BTU}}{\text{hr-ft}^2-\text{F}} \end{aligned}$$

C. Experimental Hole

(1) Small Tube

Channel Diameter = 5.25" in.
Tube O.D. = 4.50 in

$$W = 225 \frac{\text{#}}{\text{hr.}}$$

$$\begin{aligned} De &= D_2 - D_1 \\ &= (5.25 - 4.50) \\ &= 0.75 \text{ in} \\ &= (6.25)(10^{-2}) \text{ ft} \end{aligned}$$

$$\begin{aligned} \text{Area of Annulus} &= 0.785 (5.25^2 - 4.50^2) \\ &= 0.785 (27.56 - 20.25) \\ &= (0.785)(7.30) \\ &= 5.73 \text{ in}^2 \\ &= (3.98)(10^{-2}) \text{ ft}^2 \end{aligned}$$

Film Coefficient For Teledekos Model
Based on Title I Data

A-C STUDY 226

DR'N F.C. 1/19/60	CH'D LHD 2/22/60	APP'D. <i>[Signature]</i>	SCALE = 12	SHEET 4 OF 44	ISSUE
ALLIS-CHALMERS MFG. CO. DEPT.			SIMILAR TO		

$$G = \frac{W}{A} = \frac{(2.25)(10^2)}{(3.98)(10^{-2})} = (5.67)(10^3) \frac{\text{lb}}{\text{in}^2 \cdot \text{ft}^2}$$

$$N_{Re} = \frac{D_e G}{\mu} = \frac{(6.25)(10^{-2})(5.67)(10^3)}{(8.45)(10^{-2})} = (4.2)(10^3)$$

$$h = (0.023) \left(\frac{k}{D_e} \right) (N_{Re})^{0.8} \left(\frac{C_p \mu}{k} \right)^{0.4}$$

$$= (2.3)(2.26)(10^{-2})(7.9)(10^2)(8.92)(10^{-1})$$

$$h_i = 37 \frac{\text{BTU}}{\text{in}^2 \cdot \text{ft}^2 \cdot \text{F}}$$

(2) Large Tube

Channel Diameter = 10.25 IN
Tube O.D. = 9.50 IN

$$D_e = D_2 - D_1$$

$$D_e = 10.25 - 9.5$$

$$D_e = 0.75 \text{ IN}$$

$$= (6.25)(10^{-2}) \text{ ft}$$

$$W = 750 \frac{\text{lb}}{\text{hr}}$$

$$\text{Annulus Area} = 0.785 (D_2^2 - D_1^2)$$

$$= 0.785 (10.25^2 - 9.5^2)$$

$$= (0.785)(105.06 - 90.25)$$

$$= 11.63 \text{ IN}^2$$

$$= 8.08 (10^{-2}) \text{ ft}^2$$

$$G = \frac{W}{A} = \frac{(7.5)(10^2)}{(8.08)(10^{-2})} = (9.28)(10^3) \frac{\text{lb}}{\text{in}^2 \cdot \text{ft}^2}$$

Film Coefficient For Teledeltos Model
Based on Title I Data

A-C STUDY 226

SIMILAR TO

DR'N F. C. 1/10/60 CH'D LHO 2/22/60 APP'D *[Signature]* SCALE = 12 SHEET 5 OF 44 ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

$$N_{Re} = \frac{D_o G}{\mu} = \frac{(6.25)(10^{-2})(9.28)(10^3)}{(8.45)(10^{-2})}$$

$$\frac{D_o G}{\mu} = (6.85)(10^3)$$

$$h = (0.023) \left(\frac{k}{D_o} \right) (N_{Re})^{0.8} (N_{Pr})^{0.4}$$

$$h = (2.3)(2.26)(10^{-2}) [(6.85)(10^3)]^{0.8} (0.75)^{0.4}$$

$$h = (2.3)(2.26)(10^{-2})(1.18)(10^3)(8.92)(10^{-1})$$

$$h = 55 \frac{\text{BTU}}{\text{m}^2 \cdot \text{ft}^2 \cdot \text{F}}$$

Film Coefficient For Telehelios Model
Based on Title I Data

A-C STUDY 226

DR'N	F.C. 1/10/60	CH'D LHO 2/22/60	APP'D <i>SK</i>	SCALE = 12	SIMILAR TO	SHEET 6 OF 44	ISSUE
------	--------------	------------------	-----------------	------------	------------	---------------	-------

* ALLIS-CHALMERS MFG. CO. DEPT.

CONSTRUCTION OF ELECTRIC ANALOG MODEL

A. INDIVIDUAL GRAPHITE BLOCK

Cross Section Dimension: (see sketch)

Scale Factor of Model = 1

$$k_{\text{graphite}} = 15 \frac{\text{BTU}}{\text{hr-ft-F}}$$

Assumption:

Adiabatic outer surface.

LENGTH OF FILM COEFFICIENT IN MODEL

Basis: $k = 15 \frac{\text{BTU}}{\text{hr-ft-F}}$ for graphite

(1) Fuel Channel

$$h = 24 \frac{\text{BTU}}{\text{hr-Ft}^2}$$

$$\text{Length} = x = \frac{k}{h} = \frac{15}{24} = 0.625 \text{ ft} = 7.5 \text{ inches}$$

Telodettes Model Construction of Moderator

A-C STUDY 226

SIMILAR TO

DR'N F.C. 1/15/60 CH'D LHD 2/22/60 APP'D *[Signature]* SCALE = 12 SHEET 7 OF 44 ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

A

B

A-C MFG. CO., MILWAUKEE, WIS. FORM NO. 6833-3

Resistance Calculation:

$$R = \rho \frac{X}{A} = \rho \frac{X}{WL}$$

Where

R = resistance

ρ = resistivity

X = Length of flow path

A = cross-sectional area normal to the flow path

For Teledeletos paper:

Basis: 1 foot Depth. thus $L = 1$

ρ = constant or unity (because all construction are base on one kind of paper)

$$\therefore R = \rho \frac{X}{WL}$$

become $R = \frac{X}{W}$

In this Case $W = \pi D = (3.14)(5.25) = 16.5$

If W is equal in both terminal of the flow path, the cross-section area, A , normal to the flow path is constant

Thus $R = \frac{7.5}{16.5} = 0.445 \frac{\text{HR-FT}^2}{\text{BTU}}$

However in the teledeletos model, the actual flow length X , is limited to a maximum of 2 inches, and it has a cylindrical geometry. Therefore a mean cross-section area, A_m , normal to the flow path should be use.

Teledeletos Model Construction of Moderator

A-C STUDY 226

DR'N F. C/1/15/60 CH'D LHO/2/22/60 APP'D *[Signature]* SCALE = 12 SHEET 8 OF 44

ALLIS-CHALMERS MFG. CO.

DEPT.

SIMILAR TO

ISSUE

therefore the resistance equation becoming

$$R = \rho \frac{x}{A_m} \quad \text{or} \quad R = \frac{x}{A_m}$$

From heat conduction across a hollow cylinder

$$q = \frac{2\pi k L (\Delta t)}{\ln \frac{r_o}{r_i}} = k A_m \frac{\Delta t}{r_o - r_i}$$

Whence

$$A_m = \frac{A_o - A_i}{\ln \frac{A_o}{A_i}} = \frac{2\pi r_o L - 2\pi r_i L}{\ln \left(\frac{2\pi r_o L}{2\pi r_i L} \right)}$$

Letting $L = 1$

$$A_m = \frac{2\pi (r_o - r_i)}{\ln \frac{r_o}{r_i}}$$

Substitute A_m into the Resistance equation

$$R = \frac{x}{A_m} = \frac{r_o - r_i}{\frac{2\pi (r_o - r_i)}{\ln \frac{r_o}{r_i}}}$$

$$R = \frac{r_o - r_i}{1} \cdot \frac{\ln \frac{r_o}{r_i}}{2\pi (r_o - r_i)}$$

$$R = \frac{\ln \frac{r_o}{r_i}}{2\pi}$$

Tele Delta's Model Construction of
Moderator

A-C STUDY 226

DR'N	F. C./4/15/61	CH'D LHD	2/22/60	APP'D	<i>[Signature]</i>	SCALE	= 12	SIMILAR TO		ISSUE	
ALLIS-CHALMERS MFG. CO. DEPT.								SHEET 9 OF 44			

Therefore the resistance of the fuel channel annulus, if continued with a flow path length $x = 2$ inches will be

$$R = \frac{\ln \left(\frac{2.625}{0.625} \right)}{6.28} = \frac{\ln 4.2}{6.28} = \frac{1.435}{6.28}$$

$$R_{\text{mod}} = 1.2285$$

The ratio of Model's resistance to the calculated resistance

$$\frac{R_{\text{mod}}}{R_{\text{cal}}} = \frac{0.2285}{0.455} = 0.502$$

from the relation

$$R_M A_M = R_C A_C$$

$$A_M = \frac{R_C}{R_M} A_C$$

$$A_M = \frac{A_C}{0.502} \cong 2.0 A_C$$

This shows the cross sectional area normal to the flow path in the model is twice that of the calculated.

In the teledektos model, the over cross-section area (radial area) of the paper is proportional to the flow area which is normal to the flow path. Therefore one can accomplish the simulation by uniformly perforating or uniformly cutting out radially one half (50%) of the over cross section area of the teledektos paper representing the film coefficient length.

Teledektos Model Construction of
Moderator

A-C STUDY 226

SIMILAR TO

DR'N

F. C. 1/1/64 CH'D LHO 2/22/60

APP'D

SCALE

= 12

SHEET 10 OF 44

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

A

B

A-C MFG. CO., MILWAUKEE, WIS. FORM NO. 6833-3

Final Continuation of fuel Channel film Coefficient Length

$$\text{Length} = 2.0 \text{ inches}$$

$$r_o = 2.625$$

$$r_i = 0.625$$

$$\text{perforation} = 50\%$$

$$\text{equivalent } h = 24 \text{ BTU}/\text{hr-ft}^2$$

$$\text{calculated } h = 24$$

THE ABOVE CALCULATIONS WAS CHECKED, BY MEASURING THE RESISTANCE OF A CUT OUT MODEL, and comparing it to rectangular standard (7.5 X 16.5). The error is less than 10%, this could due to human error in cutting the Teledeltas model.

(2) Control rod channel

$$\text{calculated } h = 43 \text{ BTU}/\text{hr-ft}^2$$

$$\text{use } h = 45$$

$$L = \frac{15}{45} = 0.333 \text{ ft} = 4.0 \text{ inches} \quad \checkmark$$

$$R_c = \frac{x}{W} = \frac{4.0}{(\pi)(D)} = \frac{4.0}{(3.14)(4)} = 0.319 \quad \checkmark$$

$$\text{Let } x = 1.5$$

$$R_m = \frac{\ln \frac{2}{0.5}}{6.28} = 0.221 \quad \checkmark$$

$$\frac{R_m}{R_c} = \frac{0.221}{0.319} = 0.697 \approx 0.7 \quad \checkmark$$

Teledeltas Model Construction of Moderator

SIMILAR TO

DR'N F.C. 1/15/60 CH'D NHD 2/22/60 APP'D *SK* SCALE = 12 SHEET 11 OF 44 ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

Control Rod Channel

$$A_M = \frac{R_C}{R_M} A_C$$

$$A_M = \frac{A_C}{0.7} = 1.43 A_C$$

$$A_C = 0.7 A_M$$

° Perforation = 30%

$$x = 1.5 \text{ inches}$$

$$r_o = 2.0 \text{ "}$$

$$r_i = 0.5 \text{ "}$$

(3) Small experimental Channel

Calculated $h = 37$

use $h = 38$

$$x = \frac{15}{38} = 0.395 \text{ ft} = 4.74 \text{ "}$$

$$R_C = \frac{x}{W} = \frac{4.75}{16.5} = 0.287$$

$$R_M = \frac{\ln\left(\frac{2.625}{0.625}\right)}{6.28} = 0.2285$$

$$\frac{R_M}{R_C} = \frac{0.2285}{0.287} \approx 0.8$$

Teledeltos Model Construction of
Moderator

A-C STUDY 286

SIMILAR TO

DR'N

F. C. J. / 1/15/60

CH'D LMD 2/22/60

APP'D

[Signature]

SCALE

= 12

SHEET 12 OF 44

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

A

B

A-C MFG. CO., MILWAUKEE, WIS. FORM NO. 6833-3

Small experimental Channel

$$\text{Perforation} = 20\%$$

$$X = 2.0 \text{ inches}$$

$$r_o = 2.625 \text{ "}$$

$$r_i = 0.625 \text{ "}$$

(4.) Large Exponential Tube

$$\text{Calculated } h = 55 \text{ BTU/hr-ft}^2$$

$$X = \frac{h}{k} = \frac{15}{55} = 0.273 \text{ ft} = 3.28 \text{ inch}$$

$$R = \frac{X}{W} = \frac{3.28}{(3.14)(10.25)} = \frac{3.28}{32.2} = 0.102$$

$$R_M = \frac{\ln \frac{r_o}{r_i}}{2\pi}$$

$$0.102 = \frac{\ln \frac{5.125}{r_i}}{6.28}$$

$$0.64 = \ln \frac{5.125}{r_i}$$

$$e^{0.64} = \frac{5.125}{r_i}$$

$$1.895 r_i = 5.125$$

$$r_i = \frac{5.125}{1.895}$$

$$r_i = 2.7 \text{ inch}$$

$$\% \text{ perforation} = 0.0\%$$

$$X = 2.425$$

$$r_o = 5.125$$

$$r_i = 2.7$$

Teledeltos Model Construction
of Moderator

A-C STUDY 226

SIMILAR TO

DR'N F.C. 1/15/60

CH'D LHD 2/22/60

APP'D

SCALE

= 12

SHEET 13 OF 44

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

A

B

A-C MFG. CO., MILWAUKEE, WIS. FORM NO. 6833-3

B. THE REFLECTOR

Cross Section Dimension

(Sketch not drawn to scale)

Scale Factor of Model = $\frac{1}{4}$

$$h = 15 \frac{\text{BTU}}{\text{sq-ft-F}}$$

MODEL REPRESENT OCTANT OF
REFLECTOR SHOWING THE RESPECTIVE FILM COEFFICIENT

Teledeltos Model Construction of
Reflector

A-C STUDY 226

DR'N	F.C.P./H.D.	CH'D LHD 2/22/60	APP'D	SCALE	= 12	SHEET	14 OF 44	ISSUE
ALLIS-CHALMERS MFG. CO.			DEPT.					

A

B

REFLECTOR OUTER SURFACE FILM COEFFICIENT

From McAdam page 181, for Natural Convection in enclosed space

$$\frac{h_o X}{k_f} = \frac{C}{(L/X)^{1/4}} \left[\frac{X^3 \rho_f^2 g \beta_f \Delta t}{\mu_f^2} (N_{Gr})_f \right]^n$$

Where :

$$X = \text{clearance} = 1'-10'' = 1.835 \text{ ft}$$

$$\rho = \text{density} = 0.084 \text{ lb/ft}^3$$

$$\beta = \frac{1}{F}$$

$$\Delta t = \text{Temperature difference between enclosed surface}$$

$$\mu = \text{Viscosity} = 0.091$$

$$k = \text{thermal conductivity} = 0.15$$

$$C = \text{constant} \rightarrow f(N_{Gr})$$

$$n = \text{constant} \rightarrow f(N_{Gr})$$

$$L = \text{height} = 14.5 \text{ ft}$$

Assumption : Average film temp. = 875 F

Average $\Delta t = 250 \text{ F}$

$$\begin{aligned} N_{Gr} &= \frac{X^3 \rho_f^2 g \beta_f \Delta t}{\mu^2} \\ &= \frac{(1.835)^3 (0.084)^2 (10)^{-4} (4.18)(10^8) (\frac{1}{875})(10^{-3}) (2.5)(10)^{-2}}{(0.091)^2 (10^{-4})} \\ &= \frac{(6.2)(70.5)(4.18)(1.14)(10^3)(10^8)}{83} \\ &= (2.52)(10^8) \end{aligned}$$

Teledehlos Model Construction of
Reflector

A-C STUDY 226

SIMILAR TO

DR'N	F.C./5/6	CH'D LHD 2/22/60	APP'D <i>[Signature]</i>	SCALE = 12	SHEET 15 OF 24	ISSUE
ALLIS-CHALMERS MFG. CO.				DEPT.		

A

B

$$\therefore \left. \begin{array}{l} C \approx 0.71 \\ n \approx \frac{1}{3} \end{array} \right\} \text{From Mc Adam}$$

$$\therefore \frac{h'x}{k} = \frac{0.071}{\left(\frac{145}{1.835}\right)^{\frac{1}{4}}} \left[(2.52)(10^8)(0.76) \right]^{\frac{1}{3}}$$

$$h'_c = \frac{(1.5)(10^{-1})}{1.835} \frac{(7.1)(10^{-2})}{(7.43)^{\frac{1}{4}}} \left[(1.93)(10^8) \right]^{\frac{1}{3}}$$

$$h_c = \frac{(5.8)(10^{-3})}{1.25} \left[(5.8)(10^8) \right]$$

$$h_c = 2.7 \text{ BTU/hr-ft}^2$$

Assume radiation will contribute $h_r = 1.5$

$$\therefore h_c + h_r \approx 4.5 \text{ BTU/hr-ft}^2$$

$$\text{Length of flow Path } L = \frac{r_c}{h} = \frac{1.5}{4.5} = 3.33 \text{ ft}$$

$$\text{Scale factor of } \frac{1}{4} \quad L = \frac{3.33}{4} = 0.832 \text{ ft} = 10 \text{ inches}$$

$$R = \frac{x}{W} = \frac{10}{W}$$

If $x = 5$ — find % of perforation

Let w' = new wetted perimeter

$$R = \frac{10}{W} = \frac{5}{w'}$$

$$w' = \frac{5}{10} W = 0.5 W$$

$$\therefore \text{Perforation} = 50\%$$

Teledeltos Model Construction of
Reflector

A-C STUDY 226

DR'N	F. C. [signature]	CH'D AND 2/22/60	APP'D	[signature]	SCALE	= 12	SHEET	16	OF	44	ISSUE
ALLIS-CHALMERS MFG. CO.					DEPT.						

SIMILAR TO

NUMERICAL VALUE OF RESISTOR FOR NON-UNIFORM HEAT GENERATION IN REFLECTOR

Heat Generation Equation

$$g_o''' = \frac{I_o^2 R_o}{V_o} = \frac{I_o^2 R_o}{A_o L_o}$$

Since $I = \frac{E}{R}$

$$g_o''' = \frac{I_o^2 R_o}{A_o L_o} = \frac{\frac{E^2}{R_o^2} R_o}{A_o L_o} = \frac{\frac{E^2}{R_o}}{A_o L_o}$$

Then $\frac{g_o'''}{g_i'''} = \frac{\frac{E^2}{R_o A_o L_o}}{\frac{E^2}{R_i A_i L_i}}$

but $A_i = A_o$ $L_i = L_o$

$$\frac{g_o'''}{g_i'''} = \frac{R_i}{R_o}$$

$$R_i = \frac{g_o'''}{g_i'''} R_o$$

BLOCK POWER KW	$g_o''' \frac{BTU}{HR-FT^3}$	$\frac{g_o'''}{g_i'''}$	R_i	Resistor Value
~0.5	~70 = g_o'''	1.0	$1.0 = R_o$	10.00×10^6
3.4	560	0.125	0.125	$\sim 1.25 \times 10^6$
2.7	357	0.195	0.195	$\sim 1.95 \times 10^6$
1.1	145	0.482	0.482	$\sim 4.82 \times 10^6$
475	9,675	0.0073	0.0073	$\sim 0.073 \times 10^6$ (73K)
39.1	8117	0.0086	0.0086	$\sim 0.086 \times 10^6$ (86K)
14.6	2576	0.0272	0.0272	$\sim 0.272 \times 10^6$ (270K)

Telecellos model Construction of Reflector

A-C STUDY 286

SIMILAR TO

DR'N F.C./H/60	CH'D L40 4/22/60	APP'D	SCALE = 12	SHEET 17 OF 44	ISSUE
ALLIS-CHALMERS MFG. CO.			DEPT.		

SAMPLE CALCULATIONS OF TELEDELTO'S PAPER ELECTRIC ANALOG

BLOCK NO. 5

BY SYMMETRY ONLY $\frac{1}{4}$ OF MODEL WAS MOCK-UP ON THE BOARD

Procedure of Analysis

- (1) The Mocked-up model was divided into 1 square inch cross-hatch and assuming the temperature at the center of the square is its average temperature
- (2) Measure the Potential drop (ΔE_m) at each square
- (3) Using equation $\Delta T_i = \frac{Q_i}{k} \frac{\Delta E_m}{\Delta E_s}$ Calculate $\frac{\Delta T}{Q} = \frac{\Delta E_m}{k \Delta E_s}$
- (4) The average temperature of the block was obtained by equation $\frac{\Delta E_m}{k \Delta E_s} = \frac{\sum (\Delta E_m)_i A_i}{A_{total}}$

Teledehlo's Model Analysis - Sample Calculations

A-C STUDY 226

SIMILAR TO

DR'N F.C. 2/15/60

CH'D LHP 2/22/60

APP'D

SCALE = 12

SHEET 18 OF 44

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

continued - Procedure of Analysis

(5) By connecting a variable resistor between the coolant isotherm of the fuel assembly channel and the central rod channel, the temperature difference, $(T_{f.c} - T_{c.r})$ between the two coolants was simulated. Repeat step 2, 3, and 4

(6) Heat dissipation into each channel

(a) measured circumferential surface potential drop ΔE_m of each channel

(b) Calculate q from equation $q' = h \int_0^{360} \left(\frac{\Delta E_m}{k \Delta E_s} \right) dC$

$C = \theta (\text{angle})$

$$\text{or } q' = h \sum \frac{\Delta E_m}{k \Delta E_s} \Delta C$$

(7) Plot: $\frac{\overline{\Delta E_m}}{k \Delta E_s}$ VS $\frac{T_{f.c} - T_{c.r}}{Q'}$

and

$\frac{q'}{Q'}$ VS. $\frac{T_{f.c} - T_{c.r}}{Q'}$

Graphs of each typical moderator block are given as FIG 3 to 9.
Graph of Block No. 6 during Fuel Unloading is given as FIG. 10
Graph of Reflector (treated as a unit) is given in FIG. 12

The relationship between the average temperature over the cross section of each reflector column to the average temperature in the reflector is given in FIG 13

The detailed procedure for obtaining the axial temperature distribution in the columns is given on calculation sheet 32.

Teledeltos Model Analysis - Sample Calculations

AC STUDY 226

DR'N	F. C 2/15/61	CH'D LHO 4/22/60	APP'D <i>[Signature]</i>	SCALE	= 12	SIMILAR TO	
ALLIS-CHALMERS MFG. CO.				DEPT.		SHEET 19 OF 44	ISSUE

DATA OF ELECTRIC ANALOG — BLOCK NO. 5 AND CALCULATIONS

CONSTANT CONDITION		$\Delta E_{SH} = (33.80)(2)$		$\frac{T_{FC} - T_{CR}}{Q'} = 0$		$\Delta E_S = (2)(33.85)$ $\Delta E_{RR} = 24.35$		$\frac{T_{FC} - T_{CR}}{Q'} = 240 (10^{-3})$		$\Delta E_S = 33.70$ $\Delta E_{RR} = -33.55$		$\frac{T_{FC} - T_{CR}}{Q'} = -32.20 (10^{-3})$		
POINT	AREA	ΔE_M	$(\Delta E)(A)$	$\left[\frac{1}{2k \Delta E_S} \right] \left[(\Delta E_M)(A_i) \right]$	ΔE_M	$(\Delta E)(A)$	$\frac{(\Delta E_M)(A_i)}{k \Delta E_S}$	ΔE_M	$(\Delta E)(A)$	$\frac{\Delta E_M(A_i)}{k \Delta E_S}$		ΔE_M	$(\Delta E)(A)$	$\frac{\Delta E_M(A_i)}{k \Delta E_S}$
1	0.5	42.05	21.03		39.25	19.63		45.55	22.78					
2	1.0	40.85			38.25			44.60						
3	1.0	39.15			36.45			43.10						
4	1.0	37.70			34.80			41.95						
5	1.0	36.90			33.45			41.85						
6	1.0	36.70			32.75			42.45						
7	1.0	36.75			32.30			43.30						
8	1.0	36.90			32.25			44.00						
9	0.5	39.75	19.88		37.50	18.75		43.40	21.70					
10	0.475	37.40	32.73		37.00	32.38		41.25	36.09					
11	0.438	36.10	15.81		33.30	14.59		40.25	17.63					
12	0.438	35.30	15.46		32.05	14.02		40.15	17.59					
13	0.875	34.90	30.54		30.75	26.91		40.55	35.48					
14	1.0	35.55			30.80			42.25						
15	1.0	35.85			30.85			43.20						
16	0.875	32.75	28.66		27.55	24.11		40.20	35.18					
17	1.0	33.65			27.75			41.75						
18	0.438	29.50			23.05	10.10		38.60	16.91					
19	1.0	30.30			23.45			40.05						
20	0.438	25.55	11.19		17.30	7.58		36.45	16.14					
21	1.0	26.65			18.15			38.60						
22	0.875	22.05	19.24		12.15	10.63		35.65	31.19					
23	1.0	22.45			12.25			37.40						
24	0.375	20.15	7.56		8.70	3.26		35.50	13.31					

$$\sum A_i = 19.63 \quad \sum = 655.55 (10^{-3})$$

$$\frac{\overline{\Delta E_M}}{k \Delta E_S} = \frac{\sum \frac{\Delta E_M A_i}{k \Delta E_S}}{\sum A_i}$$

$$= 3.34 (10^{-2})$$

$$\sum \frac{(\Delta E_M)(A_i)}{k \Delta E_S} = 571.63 (10^{-3})$$

$$\frac{\overline{\Delta E_M}}{k \Delta E_S} = \frac{571.63 (10^{-3})}{19.63}$$

$$= 2.91 (10^{-2})$$

$$\sum \frac{(\Delta E_M)(A_i)}{k \Delta E_S} = 799.31 (10^{-3})$$

$$\frac{\overline{\Delta E_M}}{k \Delta E_S} = \frac{799.31 (10^{-3})}{19.63}$$

$$= 4.072 (10^{-2})$$

Tele-delta Model Analysis — Sample Calculations

A-C STUDY 226

DR'N F.C. 2/15/60 CH'D LHO 2/22/60 APP'D *[Signature]* SCALE = 12 SHEET 20 OF 44

ALLIS-CHALMERS MFG. CO. DEPT.

SIMILAR TO

ISSUE

Continued

DATA and CALCULATION — BLOCK NO 5

			$\Delta E_s = 33.80(2) \quad \frac{T_{Fe} - T_{CR}}{Q'} = 0$ $\Delta E_R = 0$	$\Delta E_s = 33.85(2) \quad \frac{T_{Fe} - T_{CR}}{Q'} = 240(10^{-3})$ $\Delta E_R = 24.35$	$\Delta E_s = 33.7(2) \quad \frac{T_{Fe} - T_{CR}}{Q'} = 332(10^{-3})$ $\Delta E_M = 33.55$			
CHANNEL	$\Delta \theta$	ΔC (FT)	ΔE_M	$\frac{\Delta E_M}{k \Delta E_s}$	ΔE_M	$\frac{\Delta E_M}{k \Delta E_s}$	ΔE_M	$\frac{\Delta E_M}{k \Delta E_s}$
Fuel	30°	0.1145	36.45		34.00		39.95	
			35.25		32.20		39.20	
			33.90		30.05		39.25	
			31.90		26.70		38.80	
			27.40		20.1		37.00	
			21.90		12.15		34.50	
			$\Sigma = 184.18 (10^{-3})$ $2 \Sigma = 368.36 (10^{-3})$ $g' = k R \Sigma \frac{\Delta E_M}{k \Delta E_s} (\Delta C)$ $g' = (24)(0.1145)(368.36)(10^{-3})$ $g'_{F.C.} = 1.015$	$\Sigma = 152.87 (10^{-3})$ $2 \Sigma = 305.74 (10^{-3})$ $g' = k \Delta C 2 \Sigma \frac{\Delta E_M}{k \Delta E_s}$ $g'_{F.C.} = (2.749)(305.74)(10^{-3})$ $g'_{F.C.} = 0.838$	$\Sigma = 226.18 (10^{-3})$ $2 \Sigma = 452.36 (10^{-3})$ $g' = k \Delta C 2 \Sigma \frac{\Delta E_M}{k \Delta E_s}$ $g' = (2.748)(452.36)(10^{-3})$ $g' = 1.244$			
CONTROL ROD	30°	0.08722	20.25		32.35		3.05	
			19.50		31.90		1.75	
			21.10		34.05		2.45	
			$\Sigma = 60.00 (10^{-3})$ $g = (k)(\Delta C) \Sigma \frac{\Delta E_M}{k \Delta E_s}$ $g = (45)(0.08722)(60)(10^{-3})$ $g'_{C.R.} = 0.235$ $\frac{g'_{F.C.}}{\Sigma g'} = \frac{1.015}{1.250} = 0.812$ $\frac{g'_{C.R.}}{\Sigma g'} = \frac{0.235}{1.250} = 0.188$	$\Sigma = 96.83 (10^{-3})$ $g' = (k)(\Delta C) \Sigma \frac{\Delta E_M}{k \Delta E_s}$ $g'_{C.R.} = (45)(0.08722)(96.83)(10^{-3})$ $g'_{C.R.} = 0.380$ $\frac{g'_{F.C.}}{\Sigma g'} = \frac{0.838}{1.218} = 0.688$ $\frac{g'_{C.R.}}{\Sigma g'} = \frac{0.38}{1.218} = 0.312$	$\Sigma = 7.17 (10^{-3})$ $g' = (k)(\Delta C) \Sigma \frac{\Delta E_M}{k \Delta E_s}$ $g'_{C.R.} = (45)(0.08722)(7.17)(10^{-3})$ $g'_{C.R.} = 0.0282$ $\frac{g'_{F.C.}}{\Sigma g'} = \frac{1.244}{1.272} = 0.978$ $\frac{g'_{C.R.}}{\Sigma g'} = \frac{0.0282}{1.272} = 0.022$			

Teledeltos Model Analysis — Sample Calculations

A-C STUDY 226

DR'N

F.C. 9/5/60

APP'D

H.D. 2/22/60

SCALE

= 12

SIMILAR TO

SHEET 21 OF 44

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

A

B

A-C MFG. CO., MILWAUKEE, WIS. FORM NO. 6833-3

CONTRIBUTION OF HEAT GENERATED IN THE FUEL ELEMENT SLEEVE

Flow rate of Fuel element Coolant

$$\left. \begin{array}{l} \text{Max.} \sim (2.18)(10^3) \text{ lbs/hr.} \\ \text{Min.} \sim (1.40)(10^3) \text{ " } \end{array} \right\} *$$

$$\frac{h d_c}{k} = 0.023 (Re)^{0.8} (Pr)^{0.4}$$

$$\frac{(2.18)(10^3) \text{ #/hr.}}{k} \text{ ---- } Re = \frac{d_c G}{\mu} = \frac{(5.12)(10^{-2}) (2.18)(10^3) 1.44 (10^2)}{0.93 (10^{-1}) 3.98}$$

$$Re = 435 (10^4)$$

$$Pr = 0.75$$

$$k = 0.155 \text{ BTU/HR.-FT.-F}$$

$$d_c = 5.12 (10^{-2}) \text{ FT}$$

$$(Re)^{0.8} = \log Re = 4.639 \quad = (Re)^{0.8} = 5.13 (10^3) \checkmark$$

$$\frac{0.8}{3.7112}$$

$$(Pr)^{0.4} = 0.892 \checkmark$$

$$h = \frac{(2.18)(10^3) 1.55 (10^{-1})}{5.12 (10^{-2})} 5.13 (10^3) (0.892)$$

$$h = 317 \text{ BTU/HR.-FT}^2 \checkmark$$

$$\frac{(1.40)(10^3) \text{ #/hr.}}{k} \text{ --- } Re = \frac{(5.12)(10^{-2}) (1.40)(10^3) (1.44)(10^2)}{0.93 (10^{-1}) 3.98} = (2.80) (10^4) \checkmark$$

$$Re^{0.8} = \log Re = 4.447$$

$$\frac{0.8}{3.5576}$$

$$(Re)^{0.8} = 3.63 (10^3) \checkmark$$

* A-C STUDY NO. 115

Distribution of Heat Generated in Fuel Element Sleeve

A-C STUDY 226

SIMILAR TO

DR'N F.C. 1/14/64 CH'D LHO 1-26-60 APP'D SCALE = 12 SHEET 22 OF 44 ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

$$h = \frac{(2.3)(10^{-2})(1.55)(10^{-4})}{(5.12)(10^{-2})} \quad (3.63)(10^3)(0.892)$$

$$h = 225$$

$$\underline{h_{avg}} \approx \frac{317 + 225}{2} = \underline{271}$$

HEAT DISSIPATION :

Equation for the Temperature Distribution in a constant heat generation hollow cylinder.

$$h_A = 270$$

$$h_B = 25$$

$$r_o^2 = \frac{r_1^2 \left[\frac{1}{h_A r_1} - \frac{1}{2K} \right] + r_2^2 \left[\frac{1}{h_B r_2} + \frac{1}{2K} \right] - \frac{2(t_A - t_B)}{q'''}{\frac{1}{h_A r_1} + \frac{1}{h_B r_2} + \frac{\ln \frac{r_2}{r_1}}{K}}$$

$$r_1 = 1.5'' = 0.125 \text{ ft} \quad \checkmark$$

$$r_2 = 2.5'' = 0.2083 \text{ ft} \quad \checkmark$$

$$r_1^2 = 0.0156 \text{ ft}^2 \quad \checkmark$$

$$r_2^2 = 0.0434 \text{ ft}^2 \quad \checkmark$$

$$\frac{1}{h_A r_1} = \frac{1}{(270)(0.125)} = (2.96)(10^{-2}) \quad \checkmark$$

$$\frac{1}{2K} = \frac{1}{(2)(15)} = (3.33)(10^{-2}) \quad \checkmark$$

$$\frac{1}{h_B r_2} = \frac{1}{(25)(0.208)} = (19.23)(10^{-2}) \quad \checkmark$$

$$\frac{\ln \frac{r_2}{r_1}}{K} = \frac{\ln \frac{0.2083}{0.125}}{15} = (3.89)(10^{-2}) \quad \checkmark$$

Distribution of Heat Generated in Fuel Element Sleeve

A-C STUDY 226

DR'N F.C. / 1/15/60	CH'D LHD 1-27-66	APP'D	SCALE = 12	SIMILAR TO	SHEET 23 OF 44	ISSUE
ALLIS-CHALMERS MFG. CO. DEPT.						

$$r_o^2 = \frac{(1.56)(10^{-2}) [2.96(10^{-2}) - (3.33)(10^{-2})] + (4.34)(10^{-2}) [(19.23 + 3.33)(10^{-2})] - \frac{2(t_A - t_B)}{f'''}}{(2.96 + 19.23 + 3.33)(10^{-2})}$$

$$= \frac{[(1.56)(10^{-2}) (-0.37)(10^{-2})] + [(4.34)(10^{-2}) (22.56)(10^{-2})] - \frac{2(t_A - t_B)}{f'''}}{(25.58)(10^{-2})}$$

$$= \frac{(-0.58)(10^{-4}) + (97.91)(10^{-4}) - \frac{2(t_A - t_B)}{f'''}}{(25.58)(10^{-2})}$$

$$= \frac{(97.33)(10^{-4}) - \frac{2(t_A - t_B)}{f'''}}{(25.58)(10^{-2})}$$

$$r_o^2 = (3.81)(10^{-2}) - \frac{t_A - t_B}{(12.79)(10^{-2}) f'''}$$

Evaluation of f''' BTU/HR-FT³ in sleeve

Length of each Fuel Element Sleeve = 29.4" ~ 30"

Total Length (6 Assembly) = (6)(30) ~ 180"

$$\begin{aligned} \text{Area of Graphite Heat} &= \frac{\pi}{4} (D_o^2 - D_i^2) = 0.785 (5^2 - 3^2) \\ &= (0.785)(16) = 12.56 \text{ sq inches} \\ &= 0.0873 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{Graphite Volume of one Column of Fuel element sleeve} &= (8.73)(10^{-2}) \frac{(1.8)(10^2)}{12} \\ &= 1.31 \text{ ft}^3 \end{aligned}$$

Distribution of Heat Generated in Fuel Element Sleeve

A-C STUDY 226

DR'N	F.C. 4/15/60	CH'D	LHP 1-27-60	APP'D	<i>[Signature]</i>	SCALE	= 12	SHEET	24 OF 44	ISSUE
ALLIS-CHALMERS MFG. CO.						DEPT.				

SIMILAR TO

AVERAGE HEAT DEPOSITION IN EACH FUEL ELEMENT SLEEVE **

GRAPHITE BLOCK NO.	AVERAGE HEAT DEPOSITION PER COLUMN F.E. SLEEVE	$\frac{q'''}{\delta} \left(\frac{\text{BTU}}{\text{HR-FT}^3} \right)$	$\frac{q'}{\delta} \left(\frac{\text{BTU}}{\text{HR-FT}} \right)$
0	7.49 KILOWATTS	19.52 (10^3)	17.04 (10^2)
1	7.65	19.94 (10^3)	17.41 (10^2)
2	7.09	18.48 (10^3)	16.13 (10^2)
3	5.58	14.55 (10^3)	12.70 (10^2)
4			
5	7.30	19.03 (10^3)	16.61 (10^2)
6	6.20	16.16 (10^3)	14.11 (10^2)
7	4.58	11.94 (10^3)	10.42 (10^2)
8	4.65	12.12 (10^3)	10.58 (10^2)
9	3.42	8.92 (10^3)	7.79 (10^2)

$$\frac{q'''}{\delta} = \frac{(7.49)(10^3)(3.415)}{1.31} = (7.49)(10^3)(2.607)$$

$$\frac{q'''}{\delta} = (19.52)(10^3)$$

$$\frac{q'}{\delta} = \left(\frac{q'''}{\delta} \right) (A_T) = (19.52)(10^3)(8.73)(10^{-2})$$

$$\frac{q'}{\delta} = 17.04 (10^2)$$

** MEMO FROM C.A. PRESKITT (ORNL) TO Dr. Charlie (ORNL) Ref 4
A-C (L. KINTNER)

Distribution of Heat Generated in Fuel
Element Sleeve

A-C STUDY 226

SIMILAR TO

DR'N F.C. 1/15/61 CH'D LHD 1-27-60 APP'D *[Signature]* SCALE = 12 SHEET 25 OF 44 ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

A

B

A-C MFG. CO., MILWAUKEE, WIS. FORM NO. 6833-3

$$r_o^2 = (3.91)(10^{-2}) - \frac{z_A - z_B}{(12.79)(10^{-2})} g''$$
$$q''' = (1.952)(10^4) \frac{\text{BTU}}{\text{HR-FT}^3}$$

$$r_o^2 = (3.81)(10^{-2}) - \frac{t_A - t_B}{(25.0)(10^2)}$$

$$** : \frac{q_{ANNULUS}^{IN}}{q_{TOTAL}^{IN}} = \frac{A_{2-0}}{A_{TOTAL}} = \frac{\pi(r_2^2 - r_0^2)}{\pi(r_2^2 - r_1^2)} = \frac{r_2^2 - r_0^2}{(4.34 - 1.56)(10^{-2})}$$

$$= \frac{r_2^2 - r_0^2}{(2.78)(10^{-2})} \quad \checkmark$$

A-C STUDY 226

DR'N	F.C. 11/15/60	CH'D	L.H.D. 1-27-60	APP'D	<i>[Signature]</i>	SCALE	= 12	SHEET	26	OF	44	ISSUE
------	---------------	------	----------------	-------	--------------------	-------	------	-------	----	----	----	-------

A-C MFG. CO., MILWAUKEE, WIS. FORM NO. 6833-3

HEAT DISSIPATION OF FUEL ELEMENT SLEEVES (Plotted in Fig 11)

$$r_o^2 = (3.81)(10^{-2}) - \frac{z_A - z_B}{(12.79)(10^{-2})} q'''$$

$z_A - z_B$	q'''	$\frac{z_A - z_B}{(12.79)(10^{-2})} q'''$	r_o^2 (FT ²)	r_o (FT)	$r_2^2 - r_o^2$	$\frac{q''' \text{ ANNUALS}}{q''' \text{ TOTAL}}$	
	$(3.50)(10^4)$	$\frac{z_A - z_B}{(12.79)(10^{-2})} q'''$					
0		0	$(3.81)(10^{-2})$	0.195	$(0.53)(10^{-2})$	0.191	
20		$(0.447)(10^{-2})$	$(3.363)(10^{-2})$		$(0.977)(10^{-2})$	0.352	✓
40		$(0.894)(10^{-2})$	$(2.916)(10^{-2})$		$(1.424)(10^{-2})$	0.513	
80		$(1.788)(10^{-2})$	$(2.022)(10^{-2})$		$(2.318)(10^{-2})$	0.834	
120		$(2.682)(10^{-2})$	$(1.128)(10^{-2})$		$(3.212)(10^{-2})$	1.156	
-20		$-(0.447)(10^{-2})$	$(4.257)(10^{-2})$		$(0.083)(10^{-2})$	0.030	
-40		$-(0.894)(10^{-2})$	$(4.704)(10^{-2})$		$-(0.364)(10^{-2})$	-0.131	
-60		$-(1.341)(10^{-2})$	$(5.151)(10^{-2})$		$-(0.811)(10^{-2})$	-0.292	
	$(3.00)(10^4)$	$\frac{z_A - z_B}{(12.79)(10^{-2})} q'''$					
20		$(0.521)(10^{-2})$	$(3.289)(10^{-2})$		$(1.051)(10^{-2})$	0.378	
40		$(1.042)(10^{-2})$	$(2.768)(10^{-2})$		$(1.572)(10^{-2})$	0.566	
80		$(2.084)(10^{-2})$	$(1.726)(10^{-2})$		$(2.614)(10^{-2})$	0.941	
120		$(3.126)(10^{-2})$	$(0.684)(10^{-2})$		$(3.656)(10^{-2})$	1.316	✓
-20		$-(0.521)(10^{-2})$	$(4.331)(10^{-2})$		$(0.009)(10^{-2})$	0.003	
-40		$-(1.042)(10^{-2})$	$(4.852)(10^{-2})$		$-(0.512)(10^{-2})$	-0.184	
-60		$-(1.563)(10^{-2})$	$(5.373)(10^{-2})$		$-(1.033)(10^{-2})$	-0.372	
	$(2.5)(10^4)$	$\frac{z_A - z_B}{(12.79)(10^{-2})} q'''$					
20		$(0.625)(10^{-2})$	$(3.185)(10^{-2})$		$(1.155)(10^{-2})$	0.416	
40		$(1.250)(10^{-2})$	$(2.560)(10^{-2})$		$(1.780)(10^{-2})$	0.641	
80		$(2.500)(10^{-2})$	$(1.310)(10^{-2})$		$(3.038)(10^{-2})$	1.091	
120		$(3.750)(10^{-2})$	$(0.060)(10^{-2})$		$(4.280)(10^{-2})$	1.541	
-20		$-(0.625)(10^{-2})$	$(4.435)(10^{-2})$		$-(0.094)(10^{-2})$	-0.034	
-40		$-(1.250)(10^{-2})$	$(5.060)(10^{-2})$		$-(0.720)(10^{-2})$	-0.259	
-60		$-(1.875)(10^{-2})$	$(5.685)(10^{-2})$		$-(1.345)(10^{-2})$	-0.484	

Distribution of Heat Generated in Fuel Element Sleeve

A-C STUDY 226

DR'N F.C./1/15/60 CH'D LWD 2/22/60 APP'D SCALE =12 SHEET 27 OF 44 ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

SIMILAR TO

A			B		C	
$t_A - t_B$	$\frac{q'''}{\delta'''} \text{ (10}^4\text{)}$	$\frac{t_A - t_B}{(12.79)(10^{-2})} \frac{q'''}{\delta'''} \text{ (10}^4\text{)}$	r_o^2	r_o	$r_i^2 - r_o^2$	$\frac{q'' \text{ ANNULUS}}{q'' \text{ TOTAL}}$
	(2.0)(10 ⁴)	$\frac{t_A - t_B}{(25.58)(10^{-2})}$				
10		(0.391)(10 ⁻²)	(3.419)(10 ⁻²)		(0.921)(10 ⁻²)	0.331
20		(.782)(10 ⁻²)	(3.028)(10 ⁻²)		(1.312)(10 ⁻²)	0.472
40		(1.564)(10 ⁻²)	(2.246)(10 ⁻²)		(2.094)(10 ⁻²)	0.753
60		(2.346)(10 ⁻²)	(1.464)(10 ⁻²)		(2.876)(10 ⁻²)	1.032
80		(3.128)(10 ⁻²)	(0.682)(10 ⁻²)		(3.658)(10 ⁻²)	1.315
-20		-(0.782)(10 ⁻²)	(4.592)(10 ⁻²)		-(0.242)(10 ⁻²)	-0.087
-40		-(1.564)(10 ⁻²)	(5.374)(10 ⁻²)		-(1.034)(10 ⁻²)	-0.372
-60		-(2.346)(10 ⁻²)	(6.156)(10 ⁻²)		-(1.816)(10 ⁻²)	-0.654
	(1.5)(10 ⁴)	$\frac{t_A - t_B}{(19.19)(10^{-2})}$				
10		(0.521)(10 ⁻²)	(3.289)(10 ⁻²)		(1.051)(10 ⁻²)	0.378
20		(1.042)(10 ⁻²)	(2.768)(10 ⁻²)		(1.572)(10 ⁻²)	0.566
40		(2.084)(10 ⁻²)	(1.726)(10 ⁻²)		(2.614)(10 ⁻²)	0.941
60		(3.126)(10 ⁻²)	(0.684)(10 ⁻²)		(3.656)(10 ⁻²)	1.316
-20		-(1.042)(10 ⁻²)	(4.852)(10 ⁻²)		-(0.512)(10 ⁻²)	-0.184
-40		-(2.084)(10 ⁻²)	(5.894)(10 ⁻²)		-(1.554)(10 ⁻²)	-0.559
-60		-(3.126)(10 ⁻²)	(6.936)(10 ⁻²)		-(2.596)(10 ⁻²)	-0.935
	(1.0)(10 ⁴)	$\frac{t_A - t_B}{(12.79)(10^{-2})}$				
10		(0.782)(10 ⁻²)	(3.028)(10 ⁻²)		(1.312)(10 ⁻²)	0.472
20		(1.564)(10 ⁻²)	(2.246)(10 ⁻²)		(2.094)(10 ⁻²)	0.754
40		(3.128)(10 ⁻²)	(0.682)(10 ⁻²)		(3.658)(10 ⁻²)	1.317
-10		-(0.782)(10 ⁻²)	(4.592)(10 ⁻²)		-(0.252)(10 ⁻²)	-0.091
-20		-(1.564)(10 ⁻²)	(5.374)(10 ⁻²)		-(1.034)(10 ⁻²)	-0.372
-40		-(3.128)(10 ⁻²)	(6.938)(10 ⁻²)		-(2.598)(10 ⁻²)	-0.935
	(0.5)(10 ⁴)	$\frac{t_A - t_B}{6.40(10^{-2})}$				
10		(1.563)(10 ⁻²)	(2.247)(10 ⁻²)		(2.093)(10 ⁻²)	0.753
20		(3.125)(10 ⁻²)	(0.684)(10 ⁻²)		(3.656)(10 ⁻²)	1.316
40		(6.250)(10 ⁻²)	-(2.44)(10 ⁻²)		(6.780)(10 ⁻²)	2.440
-10		-(1.563)(10 ⁻²)	(5.373)(10 ⁻²)		-(1.033)(10 ⁻²)	-0.372
-20		-(3.125)(10 ⁻²)	(6.936)(10 ⁻²)		-(2.596)(10 ⁻²)	-0.935
-40		-(6.250)(10 ⁻²)	(10.061)(10 ⁻²)		-(5.721)(10 ⁻²)	-2.060

Distribution of Heat Generated in Fuel Element Sleeve

A-C STUDY 226

DR'N F.C. 1/15/60	CH'D LMD 2/22/60	APP'D <i>[Signature]</i>	SCALE = 12	SIMILAR TO	SHEET 28 OF 44	ISSUE
ALLIS-CHALMERS MFG. CO. DEPT.						

A		B		C		
$t_A - t_B$	$\frac{q'''}{\delta}$	$\frac{t_A - t_B}{(12.79)(10^{-2})\delta''}$	r_o^2	r_o	$r_i^2 - r_o^2$	$\frac{q''' \text{ ANNULUS}}{\delta'' \text{ TOTAL}}$
	$(0.2)(10^4)$	$\frac{t_A - t_B}{(2.56)(10^{-2})}$				
5		$(1.953)(10^{-2})$	$(1.857)(10^{-2})$		$(2.483)(10^{-2})$	0.894
10		$(3.906)(10^{-2})$	$-(0.096)(10^{-2})$		$(4.436)(10^{-2})$	1.597
15		$(5.859)(10^{-2})$	$-(2.049)(10^{-2})$		$(5.389)(10^{-2})$	2.300
-5		$-(1.953)(10^{-2})$	$(5.763)(10^{-2})$		$-(1.423)(10^{-2})$	-0.512
-10		$-(3.906)(10^{-2})$	$(7.716)(10^{-2})$		$-(3.376)(10^{-2})$	-1.215

Contribution of Heat Generated in Fuel
Element Sleeve

A-C STUDY 286

SIMILAR TO

DR'N F.C. 1/15/60	CH'D LHD 2/22/60	APP'D <i>[Signature]</i>	SCALE = 12	SHEET 29 OF 44	ISSUE
ALLIS-CHALMERS MFG. CO. DEPT.					

A

B

HEAT GENERATION IN GRAPHITE CORE COLUMNS OF EGCR

CROSS SECTION AREA OF SOLID COLUMN = $(16)(16) = 256 \text{ in}^2$ ✓

CROSS SECTION AREA OF 4 FUEL CHANNEL = $(4)(0.785)(5.25^2)$
 $= 86.35 \text{ in}^2$ ✓

CROSS SECTION AREA OF CONTROL ROD CHANNEL = $(0.785)(4^2)$
 $= 12.56 \text{ in}^2$ ✓

CROSS SECTION AREA OF LARGE EXPTL. HOLE = $(0.785)(10.25^2)$
 $= 82.43 \text{ in}^2$ ✓

LENGTH OF GRAPHITE CORE COLUMN = $19' 4''$
 $= 19.333'$

Graphite Block No.	HEAT DEPOSITION		EFFECTIVE GRAPHITE CROSS SECTION AREA	C-SECTION AREA ft^2	TOTAL VOLUME (ft^3)	BASE ON L=19'-4"	BASE ON L=19'-4"	BASE ON L=14'-6"	
	KILOWATTS	BTU HR				$\frac{\text{BTU}}{\text{HR-FT}^3}$	$\frac{\text{BTU}}{\text{HR-FT}^3}$	$\frac{\text{BTU}}{\text{HR-FT}^3}$	
0	47.8	$(63.24)(10^3)$	166.51 in^2	1.1563 ft^2	22.355	$7.302 (10^3)$	9736	11,258	
1	65.1	$222.32 (10^3)$	163.37 in^2	1.1345	21.934	$10.136 (10^3)$	13,515	15,333	
2	60.4	$206.27 (10^3)$	166.51 in^2	1.1563	22.355	$9.227 (10^3)$	12,303	14,226	
3	47.5	$162.21 (10^3)$	166.51 in^2	1.1563	22.355	$7.256 (10^3)$	9,675	11,187	
4	3.4	$11.61 (10^3)$	206.55 in^2	1.4344	27.732	$0.419 (10^3)$	560	803	
5	62.2	$212.41 (10^3)$	157.09 "	1.0909	21.091	$10.071 (10^3)$	13,428	14,649	
6	52.5	$179.29 (10^3)$	163.37 "	1.1345	21.934	$8.174 (10^3)$	10,900	12,361	
7	39.1	$133.53 (10^3)$	163.37 "	1.1345	21.934	$6.088 (10^3)$	8,117	9,205	
8	29.7	$101.43 (10^3)$	170.63 "	1.1852	22.914	$4.426 (10^3)$	5,901	6,994	
9	14.6	$49.86 (10^3)$	192.22 "	1.3348	25.806	$1.932 (10^3)$	2,576	3,438	
10	< 0.5	$1.70 (10^3)$	240.00 "	1.6667	32.223	$\sim 0.050 (10^3)$	~ 70	~ 115	
11	2.7	$9.22 (10^3)$	256.00 "	1.7778	34.371	$0.268 (10^3)$	357	635	
12	0.5	$1.70 (10^3)$	188.00 "	1.3056	25.242	$\sim 0.050 (10^3)$	~ 70	~ 90	
13	1.1	$3.76 (10^3)$	256.00 "	1.7778	34.371	$0.109 (10^3)$	145	258	
14	0.5	$1.70 (10^3)$	100.00 "	0.6944	13.425	$\sim 0.050 (10^3)$	~ 70	~ 50	
15	0.5	$1.70 (10^3)$	256.00 "	1.7778	34.371	$\sim 0.050 (10^3)$	~ 70	~ 115	
16	0.5	$1.70 (10^3)$	197.00 "	1.3681	26.450	$\sim 0.050 (10^3)$	~ 70	~ 95	

Heat Generation of Graphite Columns

A-C STUDY 226

DR'N F.C. 1/15/60	CH'D LHD 2/24/60	APP'D <i>[Signature]</i>	SCALE = 12	SHEET 30 OF 44	ISSUE
ALLIS-CHALMERS MFG. CO. DEPT.					

Heat Generation In Small Experimental Tube

$$2 \text{ Watts/cm}^2$$

$$O.D. = 4.50''$$

$$I.D. = 3.75''$$

$$\begin{aligned} \text{Area} &= 0.785 (4.50^2 - 3.75^2) \\ &= 0.785 (6.19) \\ &= 4.86 \text{ in}^2 = 31.35 \text{ cm}^2 = 0.03375 \text{ ft}^2 \end{aligned}$$

$$\begin{aligned} \text{Volume} &= 14.5 (30.48) (31.35) \\ &= (13.86) (10^3) \text{ cm}^3 = 0.489 \text{ ft}^3 \end{aligned}$$

$$\begin{aligned} \therefore \bar{Q} &= (13.86) (10^3) (2) \\ &= 27.72 (10^3) \text{ WATTS} \end{aligned}$$

$$\bar{Q} = (94.66) (10^3) \frac{\text{BTU}}{\text{HR}}$$

$$\bar{Q}''' = 193.58 (10^3) \frac{\text{BTU}}{\text{HR FT}^3}$$

$$\bar{Q}' = 6.533 \frac{\text{BTU}}{\text{HR FT}}$$

HEAT GENERATION IN LARGE EXPERIMENTAL TUBE

$$1 \text{ WATT/cm}^2 \quad O.D. = 9.50'' \quad I.D. = 8.75''$$

$$\begin{aligned} \text{Area} &= 0.785 (9.50^2 - 8.75^2) \\ &= 0.785 (13.69) = 10.75 \text{ in}^2 = 69.36 \text{ cm}^2 = 0.0747 \text{ ft}^2 \end{aligned}$$

$$\text{Volume} = (14.5) (30.48) (69.36) = 30.65 (10^3) \text{ cm}^3 = 1.082 \text{ ft}^3$$

$$\bar{Q} = (30.65) (10^3) \text{ Watts} = 104.67 (10^3) \frac{\text{BTU}}{\text{HR}}$$

$$\bar{Q}''' = 96.74 (10^3) \frac{\text{BTU}}{\text{HR FT}^3}$$

$$\bar{Q}' = 7.23 (10^3) \frac{\text{BTU}}{\text{HR FT}}$$

Heat Generation of Experimental Tubes

A-C STUDY 226

SIMILAR TO

DR'N F.C. 1/15/60 CH'D LHD 2/22/60 APP'D *[Signature]* SCALE = 12 SHEET 31 OF 44 ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

MODERATOR TEMPERATURE DISTRIBUTION CALCULATIONS PROCEDURES

Specific Example: Graphite Block No. 5

- Assumptions:
1. All inlet coolant temperature = 510°F
 2. Coolant rise of fuel assembly is linear 510 to 1050°F

PROCEDURES

1. Divide effective moderator length, 14.5 ft. into 14 one foot and 2 quarter foot section.
2. Establish $\bar{q}_{avg}$ for each axial position and calculate $\dot{Q}_B$, heat generation of graphite block BTU/HR-FT, $\dot{Q}_S^m$ and $\dot{Q}_S^s$, heat generation of fuel assembly BTU/HR-FT² and BTU/HR-FT respectively
3. From Figure 7, at $\frac{T_{mod} - T_{c,r}}{\dot{Q}_B} = 0$, find $\bar{q}_B'$ for moderator channel and control rod channel, then calculate $(\bar{q}_B')_B$ the heat dissipated into each respective channel
4. From Figure 10, at $T_{fuel} - T_{annulus} = 0$ establish $\bar{q}_S'$ and calculate $\bar{q}_S'$ the heat dissipated into moderator annulus from the fuel assembly sleeve.
5. Add $\bar{q}_B'$ the heat dissipated into moderator annulus from graphite block to $\bar{q}_S'$.
6. Calculate $\Delta T_{A,i}$, the local coolant temperature rise of each channel then calculate $\Delta T_{A,i}$, the overall coolant temperature rise of each channel and ΔT_F the overall coolant temperature rise in the fuel assembly side.
7. Calculate $T_{mod} - T_{c,r}$, the temperature difference between Moderator coolant and control rod coolant, and $\frac{T_{mod} - T_{c,r}}{\dot{Q}_B}$
8. From Figure 7 at $\frac{T_{mod} - T_{c,r}}{\dot{Q}_B} = x$ find $\frac{\overline{\Delta E_m}}{K \Delta E_s}$ and calculate $\overline{\Delta T}_{graphite}$ the average graphite temperature excess above the moderator coolant from the relation $\overline{\Delta T}_{graph} = \frac{\overline{\Delta E_m}}{K \Delta E_s} \cdot \dot{Q}_B$
9. Assume the resulting temperature differences between Moderator coolant and control rod coolant, $T_{mod} - T_{c,r}$; Between fuel assembly coolant and Moderator coolant $T_{fuel} - T_{annulus}$ in axial position 1 will apply to the calculation of position 2, Repeat from 3 to 9

Sample Calculations of:

1. Coolant Temperature rise
 2. Graphite Column Temperature distribution
- A-C Study 226

SIMILAR TO

DR'N	FIC 2/20/60	CH'D LWA 2/22/60	APP'D <i>[Signature]</i>	SCALE	= 12	SHEET 32 OF 44	ISSUE
ALLIS-CHALMERS MFG. CO.				DEPT.			

BLOCK NO. 5

$$\frac{Q'_{Block}}{4} = 3,650 \frac{BTU}{HR-FT}$$

$$Q'_{Steam} = 1,9030 \frac{BTU}{HR-FT^2}$$

$$W_{MOD} = 90 \frac{LB}{HR}$$

SAMPLE CALCULATIONS

Sheet 33 of 44

$$Q'_{Steam} = 1,660 \frac{BTU}{HR-FT}$$

$$W_{C.R.} = 205 \frac{LB}{HR}$$

SAMPLE CALCULATION -- MODERATOR TEMPERATURE DISTRIBUTION

CHANNEL	ΔX (FT)	ϕ/ϕ_{max}	Q'_{Block}	q'_0/Q'_{Block}	q'_0	θ	Q'_{Steam}	Q'_{Steam}	q'_s/q'_0	q'_s	q'_s/q'_0	ΔT_A Local Temp. Rise	ΔT_A (Moderator & Cont. Rod)	ΔT_F	$T_{MOD} - T_{C.R.}$	$\frac{T_{MOD} - T_{C.R.}}{Q'_A}$	$\frac{\Delta E_m}{k \Delta E_s}$	$\Delta T'_{graph}$
1 Fuel*	1/4	0.632	2307	0.815	470	0.0	12027	1049/4	0.191	50.0	520	4.63	4.63	930	2.95	1.27×10^{-3}	3.34×10^{-2}	77.05
1 Cont. Rod	1/4	0.632	2307	0.185	107	0.0	12027	1049/4	0.191	50.0	107	1.68	1.68	930	2.95	1.27×10^{-3}	3.34×10^{-2}	77.05
2 Fuel*	1	0.644	2351	0.805	1893	~4.7	12,255	1069	0.325	347	2240	19.95	24.58	46.50	15.75	6.7×10^{-3}	3.22×10^{-2}	75.70
2 C. Rod	1	0.644	2351	0.195	458	~4.7	12,255	1069	0.325	347	458	7.16	8.84	46.50	15.75	6.7×10^{-3}	3.22×10^{-2}	75.70
3 Fuel*	1	0.791	2887	0.780	2252	~22.0	15,053	1313	0.60	788	3040	27.07	51.65	83.70	32.86	11.38×10^{-3}	3.2×10^{-2}	92.40
3 C. Rod	1	0.791	2887	0.220	635	~22.0	15,053	1313	0.60	788	635	9.92	18.76	83.70	32.86	11.38×10^{-3}	3.2×10^{-2}	92.40
4 Fuel*	1	0.937	3420	0.755	2582	32.0	17,831	1555	0.67	1,042	3624	32.27	83.92	120.90	52.06	15.22×10^{-3}	3.03×10^{-2}	103.60
4 C. Rod	1	0.937	3420	0.245	838	32.0	17,831	1555	0.67	1,042	838	13.10	31.86	120.90	52.06	15.22×10^{-3}	3.03×10^{-2}	103.60
5 Fuel*	1	1.064	3884	0.742	2842	37.0	20,248	1766	0.72	1,272	4154	37.00	120.92	158.10	73.40	18.90×10^{-3}	2.95×10^{-2}	114.58
5 C. Rod	1	1.064	3884	0.258	1002	37.0	20,248	1766	0.72	1,272	1002	15.66	47.52	158.10	73.40	18.90×10^{-3}	2.95×10^{-2}	114.58
6 Fuel*	1	1.165	4,252	0.715	3040	37.0	22,170	1,934	0.68	1315	4355	38.78	159.70	195.3	93.2	21.9×10^{-3}	2.88×10^{-2}	122.46
6 C. Rod	1	1.165	4,252	0.285	1212	37.0	22,170	1,934	0.68	1315	1212	18.94	66.46	195.3	93.2	21.9×10^{-3}	2.88×10^{-2}	122.46
7 Fuel*	1	1.234	4,504	0.700	3153	35.6	23,483	2048	0.64	1311	4464	39.75	199.45	232.5	111.88	24.84×10^{-3}	2.82×10^{-2}	127.0
7 C. Rod	1	1.234	4,504	0.300	1351	35.6	23,483	2048	0.64	1311	1351	21.11	87.57	232.5	111.88	24.84×10^{-3}	2.82×10^{-2}	127.0
8 Fuel*	1	1.271	4,639	0.685	3178	33.0	24,187	2,110	0.56	1182	4360	36.82	238.27	269.7	124.37	26.8×10^{-3}	2.80×10^{-2}	129.9
8 C. Rod	1	1.271	4,639	0.315	1461	33.0	24,187	2,110	0.56	1182	1461	22.82	113.90	269.7	124.37	26.8×10^{-3}	2.80×10^{-2}	129.9
9 Fuel*	1	1.271	4,639	0.675	3131	31.5	24,187	2,110	0.55	1161	4292	38.22	276.49	306.9	139.03	29.96×10^{-3}	2.72×10^{-2}	126.2
9 C. Rod	1	1.271	4,639	0.325	1508	31.5	24,187	2,110	0.55	1161	1508	23.56	137.46	306.9	139.03	29.96×10^{-3}	2.72×10^{-2}	126.2
10 Fuel*	1	1.234	4,504	0.660	2973	30.4	23,483	2,048	0.55	1126	4099	36.50	313.00	344.1	151.62	33.67×10^{-3}	2.64×10^{-2}	118.9
10 C. Rod	1	1.234	4,504	0.340	1531	30.4	23,483	2,048	0.55	1126	1531	23.92	161.38	344.1	151.62	33.67×10^{-3}	2.64×10^{-2}	118.9
11 Fuel*	1	1.165	4,252	0.640	2721	31.0	22,170	1,934	0.57	1102	3823	34.04	347.04	381.3	161.72	38.02×10^{-3}	2.55×10^{-2}	108.4
11 C. Rod	1	1.165	4,252	0.360	1532	31.0	22,170	1,934	0.57	1102	1532	23.94	185.32	381.3	161.72	38.02×10^{-3}	2.55×10^{-2}	108.4
12 Fuel*	1	1.064	3884	0.620	2408	34.3	20,248	1,766	0.68	1201	3609	32.14	379.18	418.5	170.80	43.98×10^{-3}	2.42×10^{-2}	94.0
12 C. Rod	1	1.064	3884	0.380	1476	34.3	20,248	1,766	0.68	1201	1476	23.06	209.38	418.5	170.80	43.98×10^{-3}	2.42×10^{-2}	94.0
13 Fuel*	1	0.937	3420	0.590	2018	39.3	17,831	1,555	0.86	1327	3355	29.88	409.06	455.7	178.77	52.27×10^{-3}	2.23×10^{-2}	76.3
13 C. Rod	1	0.937	3420	0.40	1402	39.3	17,831	1,555	0.86	1327	1402	21.91	230.29	455.7	178.77	52.27×10^{-3}	2.23×10^{-2}	76.3
14 Fuel*	1	0.791	2887	0.545	1574	46.6	15,053	1,313	1.05	1379	2953	26.30	435.26	492.9	184.55	63.92×10^{-3}	1.98×10^{-2}	59.2
14 C. Rod	1	0.791	2887	0.455	1313	46.6	15,053	1,313	1.05	1379	1313	20.52	250.81	492.9	184.55	63.92×10^{-3}	1.98×10^{-2}	59.2
15 Fuel*	1	0.644	2351	0.490	1152	57.5	12,255	1,069	1.50	1604	2756	24.54	459.90	530.10	190.36	80.97×10^{-3}	1.63×10^{-2}	38.32
15 C. Rod	1	0.644	2351	0.510	1199	57.5	12,255	1,069	1.50	1604	1199	18.73	269.54	530.10	190.36	80.97×10^{-3}	1.63×10^{-2}	38.32
16 Fuel*	1/4	0.632	2307	0.400	231	70.2	12,027	1049/4	1.90	511	742	6.61	466.51	540	191.56	83.03×10^{-3}	1.57×10^{-2}	36.22
16 C. Rod	1/4	0.632	2307	0.600	346	70.2	12,027	1049/4	1.90	511	346	5.41	274.95	540	191.56	83.03×10^{-3}	1.57×10^{-2}	36.22

NOTE Fuel* represent The Moderator Annulus

CHECKED BY BANDIX COMPUTER

Cal. by F. Cheng 4/24/60

MODERATOR ANNULUS FLOW ~~XXXX~~

FOR 1050 F OPERATION

Core Quadrant Showing Graphite Block By Zone Numbers
And its Heat Generation

* 47.8 2 ** 7.48	* 65.1 1 ** 7.65	* 60.4 1 ** 7.09	* 47.5 2 ** 5.58
* 65.1 1 ** 7.65	* 62.2 1 ** 7.30	* 52.5 2 ** 6.20	* 39.1 3 ** 4.45
* 60.4 1 ** 7.09	* 52.2 2 ** 6.20	* 29.7 3 ** 4.65	* 14.6 4 ** 3.42
* 47.5 2 ** 5.58	* 39.1 3 ** 4.58	* 14.6 4 ** 3.42	

* Graphite Block Power in KW

** Fuel Assembly Sleeve Power in KW

RANGE OF POWER IN EACH ZONE

ZONE	GRAPHITE BLOCK POWER, KW	Fuel Assembly Sleeve Power, KW	Number of Fuel Assembly
1	47.8 → 65.1	7.09 → 7.65	80
2	47.5 → 52.2	5.58 → 6.20	76
3	29.7 → 39.1	4.45 → 4.65	44
4	14.6	3.42	16

Preliminary Moderator Flow Requirement

A-C STUDY 226

SIMILAR TO

DR'N F.C. 2/20/60	CH'D LHD 2/22/60	APP'D XXXX	SCALE = 12	SHEET 34 OF 44	ISSUE
ALLIS-CHALMERS MFG. CO. DEPT.					

A

B

A-C MFG. CO., MILWAUKEE, WIS. FORM NO. 6833-3

The following procedure was used to obtain the initial trial value of Moderator Coolant annulus flow rate:

1. All heat from fuel assembly sleeve will dissipated into Annulus
2. 90% of the heat generated in graphite block will equally dissipated into each channel excluding the control rod channel
3. Over the active length of moderator the average $\frac{q'}{q_0} = 1.0$
4. Δt of Annulus coolant = 540 F

Solution:
$$\Delta t = \frac{(q')_{\text{Total}} (\text{Length})}{W C_p} = \frac{(q'_{\text{Block}} + q'_{\text{Sleeve}}) (\text{Length})}{W C_p}$$

$$\therefore W = \frac{q'_{\text{Total}} (\text{Length})}{\Delta t C_p}$$

$$W = \frac{q'_{\text{Total}}}{(540)(1.75)} \cdot 14.5$$

$$W = q'_{\text{Total}} (2.148)(10^{-2})$$

ZONE 1

USE

$KW_{\text{Block}} = 62.2$

$KW_{\text{sleeve}} = 7.30$

$q'_{\text{Block}} = 14,650 \frac{\text{BTU}}{\text{Hr-FT}}$

$q'_{\text{sleeve}} = 1660 \frac{\text{BTU}}{\text{Hr-FT}}$

$$W = \left[\frac{(14,650)(0.9)}{4} + 1660 \right] (2.148)(10^{-2})$$

$$W = (4.955)(10^3) (2.148)(10^{-2})$$

$$W = 105 \text{ lb/hr}$$

Preliminary Moderator Flow Requirement

A-C STUDY 226

DR'N F.C. 2/20/60

CH'D LHO 2/22/60

APP'D

[Signature]

SCALE

= 12

SIMILAR TO

SHEET 35 OF

44

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

ZONE 2

$$W = (g'_{total}) (2.148) (10^{-2})$$

$$KW_{Block} = 52.2$$

$$KW_{Sleeve} = 6.20$$

$$g'_{Block} = 12,366$$

$$g'_{Sleeve} = 1410 \frac{BTU}{HR-FT}$$

$$W = \left[\frac{(12,366)(0.9)}{4} + 1410 \right] (2.148) (10^{-2})$$

$$W = (4.193)(10^3)(2.148)(10^{-2})$$

$$W = 90 \text{ lb/Hr.}$$

ZONE 3

$$KW_{Block} = 39.10$$

$$KW_{Sleeve} = 4.58$$

$$g' = 9205$$

$$g' = 1042$$

$$W = \left[\frac{(9,205)(0.9)}{4} + 1,042 \right] (2.148)(10^{-2})$$

$$W = (3.113)(10^3)(2.148)(10^{-2})$$

$$W = 67.5 \text{ lb}$$

Preliminary Moderator Flow Requirement

A-C STUDY 226

DR'N F.C. / 2/20/60

CH'D LHD 2/22/60

APP'D *[Signature]*

SCALE = 12

SIMILAR TO

SHEET 36 OF 44

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

ZONE 4

$$KW_{\text{Block}} = 146$$

$$KW_{\text{slant}} = 3.42$$

$$g' = 3438 \frac{\text{BTU}}{\text{Hr Ft}}$$

$$g' = 780$$

In the case assume all heat is equally distributed to each channel — 2 fuel channel + 4 large Exptl Channel

$$W = \left[\frac{3438}{3} + 780 \right] (2.148) (10^{-2})$$

$$W = (1.926) (10^3) (2.148) (10^{-2})$$

$$W = 41 \text{ lb/hr.}$$

The initial trial flows (given below) were used in the procedure outlined on page 32 to calculate moderator temperature. The procedure was repeated using lower flow rates until the maximum moderator temperature approached 1100 F.

ZONE	Trial Initial Flow, lb/hr	Final Flow Required/Annulus, lb/hr
	Initial Flow, lb/hr	Required/Annulus, lb/hr
1	110	90
2	90	70
3	70	50
4	40	30

Final Flow requirements are tabulated above.

Resulting Moderator Temperatures for each typical column are given in Tables 1 through 9 and for the special case of fuel unloading in Tables 10 through 14.

Resulting Reflector Temperatures for B Assumed Boundary conditions are given in Tables 15, 16, 17.

Preliminary Moderator Flow Requirement

A-C STUDY 226

SIMILAR TO

DR'N F.C. 12/20/60 CH'D LHD/2/22/60 APP'D *[Signature]* SCALE = 12 SHEET 37 OF 44 ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

The teledeltos models were made, using a film heat transfer coefficient in the moderator coolant annulus of 24 BTU/hr-ft²-F, based on 125 lb/hr/annulus.

Base: $W = 125 \frac{LB}{HR}$

$NR_e = 2.17 \times 10^3 \rightarrow$ Transition Region

$h = 24 \text{ BTU/hr-ft}^2$

The effect of lower flow rates on the temperature difference between moderator and coolant is considered below:

For $W = 90 \frac{LB}{hr}$

$NR_e = 1.55(10^3)$ Laminar Flow

$\frac{hD}{k} = 2 \left(\frac{WCP}{kL} \right)^{1/3}$

$h = 2 \left[\frac{(90)(1.25)}{(0.141)(14.5)} \right]^{1/3} \frac{0.141}{6.25(10^{-2})}$

$h_{90} \approx 17$

$W = 70 \quad h = 17 \left(\frac{70}{90} \right)^{1/3} \approx 16$

$W = 50 \quad h \approx 14$

$W = 30 \quad h \approx 12$

In Teledeltos Model

$W=125$ Length of Film Coefficient = $L = \frac{k}{h} = \frac{15}{24} = 0.625$
 The effective conductivity of graphite for lower flow rates is:
 $W=90 \quad \frac{k}{17} = 0.625 \rightarrow k_{90} = 10.6 \frac{BTU}{HR-FT-F}$

$k_{70} = 10$

$k_{50} = 8.75$

$k_{30} = 7.5$

Effect on Graphite Temperature — due to variation of Coolant Flow Rate

A-C Study 226

DR'N	F.C. 2/2/60	CH'D LHO 2/23/60	APP'D	SCALE	=12	SHEET 38 OF 44	ISSUE
ALLIS-CHALMERS MFG. CO.				DEPT.			

SIMILAR TO

Overall heat transfer Coefficient

$$U = \frac{1}{\frac{1}{h} + \frac{x}{k}}$$

$$x_{\text{Avg}} = 1.5''$$

$$U_{125} = \frac{1}{\frac{1}{20} + \frac{1.5}{12(15)}} = \frac{1}{0.0417 + 0.0083}$$

$$U_{125} = 20$$

$$U_{90} = \frac{1}{\frac{1}{17} + \frac{1.5}{12(15)}} = \frac{1}{0.0588 + 0.0083} = \frac{1}{0.0671}$$

$$U_{90} = 14.9$$

$$U_{70} = 14.1$$

$$U_{50} = 12.6$$

$$U_{30} \cong 11.0$$

$$\text{Then } q_0 = U A \Delta t \rightarrow q' = U D \Delta t$$

$$\frac{q'_0}{q'_1} = \frac{U_0 W \Delta t_0}{U_1 W \Delta t_1}$$

$$1 = \frac{20}{14} \frac{\Delta t_{025}}{\Delta t_{90}}$$

$$\Delta t_{90} = \frac{20}{14.9} \Delta t_{125} = 1.34 \Delta t_{125}$$

EFFECT OF Graphite Temperature — due to variation of Coolant Flow Rate

A-C STUDY 226

SIMILAR TO

DR'N F.C./2/2/60 CH'D LHO 2/22/60 APP'D ~~XXX~~ SCALE = 12 SHEET 39 OF 44 ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

$$\Delta t_{70} = \frac{20}{14.1} \Delta t_{125} = 1.42 \Delta t_{125}$$

$$\Delta t_{50} = \frac{20}{12.6} \Delta t_{125} = 1.59 \Delta t_{125}$$

$$\Delta t_{30} = \frac{20}{11} \Delta t_{125} = 1.82 \Delta t_{125}$$

These correction factors have been applied to the temperature difference between graphite and coolant to correct for the lower flow rates than those used in the model (see tables 1 through 9)

Effect of Graphite Temperature due
to variation of Coolant Flow Rate

A-C STUDY 226

DR'N F.C. 2/20/60	CH'D LHD 2/22/60	APP'D <i>[Signature]</i>	SCALE = 12	SIMILAR TO	SHEET 40 OF 44	ISSUE
ALLIS-CHALMERS MFG. CO.			DEPT.			

Revised Heat Transfer Coefficient For Control Rod channel

Condition : Flow Rate = 200 $\frac{LB}{HR}$ (Total Flow $\rightarrow 100 + 75 + 25$) $\checkmark$
Control Rod not inserted

$$Area = (0.785) \left(\frac{4}{12} \right)^2$$

$$= 0.087 ft^2$$

$$G = \frac{(2.0)(10^2)}{(4.7)(10^{-2})} = 2.36 (10^3)$$

$$\frac{DG}{\mu} = \frac{(4)(2.36)(10^3)}{(12)(8.45)(10^{-2})} = \frac{(2.36)(10^5)}{25.4}$$

$$N_{Re} = 9.3 (10^3)$$

$$h = (0.023) \left(\frac{k}{D_e} \right) (N_{Re})^{0.8} (N_{Pr})^{0.4}$$

$$(N_{Re})^{0.8} \rightarrow 0.8 \log 9.3(10^3) = (0.8)(3.97)$$

$$= 3.18$$

$$(N_{Pr})^{0.4} = (0.75)^{0.4}$$

$$= 8.92(10^{-1})$$

$$(N_{Re})^{0.8} = 1520 \checkmark$$

$$h = (0.023) \left[\frac{141(10^{-1})}{3.33(10^{-1})} \right] [152(10^3)] [8.92(10^{-1})]$$

$$h = 13.2 \text{ BTU/HR.FT}^2$$

$$\text{Length of film} = x = \frac{15}{13.2} = 1.135 \checkmark$$

$$R_{std} = \frac{(1.135)(12)}{12.56} = 1.085 \checkmark$$

$$Re_y = \frac{\ln \frac{2}{0.15}}{6.28}$$

$$Re_y = 0.1221 \checkmark$$

$$\frac{Re_y}{R_{std}} = \frac{0.1221}{1.085} \approx 0.12$$

$\therefore$ Perforation = 80%

Film Coefficient — Fuel unloading
Electrical Analog Analysis

A-C STUDY 226

DR'N	F.C 2/18/60	CH'D LHD 2/22/60	APP'D	SCALE	= 12	SIMILAR TO	SHEET 41 OF 44	ISSUE
ALLIS-CHALMERS MFG. CO.			DEPT.					

During fuel unloading, gas flow rate = 3500 LB/HR

$$\text{Area} = (0.785) \left(\frac{5.25}{12} \right)^2 = 0.785 \left(\frac{27.6}{144} \right) \\ = 0.151 \text{ ft}^2 \quad \checkmark$$

$$G = \frac{3500}{0.151} = 23,200 \text{ LB/HR-FT}^2 \quad \checkmark$$

Assume Average temperature during unloading = 600 F

$$\mu = 0.075$$

$$k = 0.128$$

$$N_{pr} = 0.73$$

$$N_{Re} = \frac{5.25 (2.32)(10)^4}{(12)(10)(7.5)(10^{-2})} = 1.36 (10^5) \quad \checkmark$$

$$h = 0.023 \left(\frac{k}{D_o} \right) (N_{Re})^{0.8} (N_{pr})^{0.4}$$

$$(N_{pr})^{0.4} = (0.73)^{0.4} \\ = (0.884) \quad \checkmark$$

$$(N_{Re})^{0.8} \rightarrow 0.8 \log (1.36)(10^5) = (0.8)(5.133) \\ = 4.11$$

$$(N_{Re})^{0.8} = 1.29 (10^4) \quad \checkmark$$

$$h = 2.3(10^{-2}) \left[\frac{(0.128)(12)}{5.25} \right] \left[(1.29)(10^4) \right] (0.884)$$

$$h = (2.3)(10^{-2}) (2.93)(10^{-1}) (1.14)(10^4)$$

$$h = 77 \quad \checkmark$$

Film Coefficient — Fuel unloading
Electrical Analog Analysis

A-C STUDY 226

DR'N F.C. 2/18/60	CH'D LHD 2/22/60	APP'D	SCALE = 12	SIMILAR TO	SHEET 42 OF 44	ISSUE
ALLIS-CHALMERS MFG. CO.			DEPT.			

$$\text{Length of film } x = \frac{k}{h} = \frac{15}{77} = 0.195 \text{ ft } \checkmark$$

$$\text{W.P of channel} = \pi D = (3.14 \left(\frac{5.25}{12} \right)) = 1.375 \text{ ft } \checkmark$$

$$R = \frac{x}{W} = \frac{0.195}{1.375} = 0.142 \quad \checkmark$$

$$R_{01} = \frac{\ln \frac{r_o}{r_i}}{2\pi}$$

$$0.142 = \frac{\ln \frac{2.625}{r_i}}{6.28}$$

$$0.892 = \ln \frac{2.625}{r_i} \quad \checkmark$$

$$e^{0.892} = \frac{2.625}{r_i}$$

$$r_i = \frac{2.625}{2.44}$$

$$r_i = 1.076 \text{ inches } \checkmark$$

Film Coefficient — Fuel Unloading

A-C STUDY 226

SIMILAR TO

DR'N F.C. 2/18/60 CH'D LHD 2/22/60 APP'D *[Signature]* SCALE = 12 SHEET 43 OF 44 ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

Zone 1

$$W = 90 \frac{LB}{HR}$$

With Fuel Assembly

$$h = 17 \frac{BTU}{HR-FT^2}$$

$$\text{Length of Film} = X = \frac{k}{h} = \frac{15}{17} = 0.883 \text{ ft} = 10.6 \text{ inches}$$

$$R_{std} = \frac{X}{W} = \frac{10.6}{16.5} = 0.643$$

$$R_{cy} = \frac{\ln \frac{2.625}{0.625}}{6.28} = \frac{\ln 4.2}{6.28} = 0.2285$$

$$\frac{R_{cy}}{R_{std}} = \frac{0.2285}{0.643} = 0.356 \approx 0.36$$

$$\% \text{ Perforation} = 64\% \sim 65\%$$

Film Coefficient For Fuel Unloading

A-C STUDY 226

SIMILAR TO

DR'N F.C. 2/18/60 CH'D LHD 2/22/60 APP'D *[Signature]* SCALE = 12 SHEET 44 OF 44 ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

IX. TABLES

Nomenclature used in Tables 1 to 17:

Δt moderator	Moderator annulus coolant temperature above coolant inlet temperature, °F
Δt experimental	Experimental tube coolant temperature above coolant inlet temperature, °F
Δt control rod	Control rod coolant temperature above coolant inlet temperature, °F
$\overline{\Delta t}$ graphite	Average graphite temperature over cross section above coolant inlet temperature, °F
$\overline{\Delta t}'$ graphite	Average local graphite temperature above local moderator annulus coolant temperature, °F
$\overline{\Delta t}_i$	Reflector graphite block No. 1 average over cross section temperature above coolant inlet temperature, °F
$\overline{\Delta t}$ outer	Average reflector annulus coolant above coolant inlet temperature, °F
Δt unloaded channel	Unloaded channel coolant temperature above coolant inlet temperature, °F

Table 1

MODERATOR
TEMPERATURE DISTRIBUTION

Graphite Block No. 0

Zone 2

Moderator Annulus Flow Rate = 70 lb/hr.

Small Experimental Annulus Flow Rate = 350 lb/hr.

Coolant Inlet Temperature = 510F

	AXIAL POSITION FT.	$\Delta t_{\text{moderator}}$ °F	$\Delta t_{\text{experimental}}$ °F	$\overline{\Delta t}_{\text{graphite}}$ °F	
1	0.25	5.04	10.6	63.4*	88
2	1.25	27.2	25.1	84.1*	108
3	2.25	57.7	43.1	123.8*	152
4	3.25	93.8	64.9	168.3*	200
5	4.25	133.1	90.1	214.4*	248
6	5.25	174.0	118.1	260.0*	296
7	6.25	215.0	148.1	303.7*	341
8	7.25	255.3	179.4	344.4*	381
9	8.25	294.0	210.9	380.9*	417
10	9.25	330.6	241.9	412.2*	446
11	10.25	364.7	271.5	438.7*	470
12	11.25	396.1	298.9	459.7*	486
13	12.25	424.8	323.6	475.8*	497
14	13.25	450.8	345.1	487.4*	503
15	14.25	475.0	363.5	496.4*	505
16	14.50	475.3	378.1	500.0*	510

~~xx Corrected temperatures due to decreased moderator coolant flow rate~~

* Original temperatures obtained using moderator coolant flow rate of 125 lb/hr. Corrected values are based on the final moderator coolant flow rate given at top of table. (See Calculation Sheets 38, 39, 40.)

Table 2

MODERATOR
TEMPERATURE DISTRIBUTION

Graphite Block No. 1

Zone 1

Moderator Annulus Flow Rate = 90 lb/hr
Control Rod Channel Flow Rate = 200 lb/hr
Coolant Inlet Temperature = 510°F

	AXIAL POSITION FT.	$\Delta t_{\text{moderator}}$ °F	$\Delta t_{\text{control rod}}$ °F	$\bar{\Delta t}_{\text{graphite}}$ °F	
1.	0.25	5.29	2.03	90.2*	119
2	1.25	27.6	10.6	113.3*	142
3	2.25	57.8	22.3	162.3*	197
4	3.25	93.9	37.6	217.0*	259
5	4.25	134.1	56.4	273.0*	320
6	5.25	176.4	78.3	327.0*	379
7	6.25	219.4	103.0	379.1*	432
8	7.25	261.9	129.9	425.7*	480
9	8.25	302.9	158.1	465.9*	520
10	9.25	341.5	187.0	499.0*	552
11	10.25	377.2	215.8	525.0*	575
12	11.25	409.7	244.0	543.7*	588
13	12.25	438.9	270.9	555.6*	594
14	13.25	464.9	296.2	561.9*	594
15	14.25	488.4	319.6	565.6*	591
16	14.50	491.7	336.8	568.2*	593

~~* Corrected temperatures due to decreased moderator coolant flow rates~~

* Original temperatures obtained using moderator coolant flow rate of 125 lb/hr. Corrected values are based on the final moderator coolant flow rate given at top of table. (See Calculation Sheets 38, 39, 40.)

Table 3

MODERATOR
TEMPERATURE DISTRIBUTION

Graphite Block No. 2

Zone 1

Moderator Annulus Flow Rate = 90 lb/hr
Control Rod Channel Flow Rate = 200 lb/hr
Coolant Inlet Temperature = 510°F

	AXIAL POSITION FT.	$\Delta t_{\text{moderator}}$ °F	$\Delta t_{\text{control rod}}$ °F	$\bar{\Delta t}_{\text{graphite}}$ °F	
1	0.25	5.19	1.80	83.9*	110
2	1.25	27.2	9.44	106.6*	133
3	2.25	57.2	20.0	153.9*	186
4	3.25	93.3	34.0	207.0*	245
5	4.25	133.6	51.4	261.9*	304
6	5.25	176.2	72.0	315.9*	363
7	6.25	219.6	95.3	366.8*	416
8	7.25	262.7	120.9	413.5*	463
9	8.25	304.2	148.0	454.2*	505
10	9.25	343.4	176.0	488.2*	536
11	10.25	379.8	204.2	515.5*	560
12	11.25	412.9	231.9	535.72*	576
13	12.25	442.7	258.7	549.4*	584
14	13.25	469.2	284.1	557.7*	587
15	14.25	493.3	308.0	563.3*	587
16	14.50	498.2	326.3	567.5*	591

~~*Corrected temperatures due to decreased moderator coolant flow rate.~~

* Original temperatures obtained using moderator coolant flow rate of 125 lb/hr. Corrected values are based on the final moderator coolant flow rate given at top of table. (See Calculation Sheets 38, 39, 40.)

MODERATOR TEMPERATURE DISTRIBUTION

Zone 2

Moderator Annulus Flow Rate = 70 lb/hr
Control Rod Channel Flow Rate = 200 lb/hr
Coolant Inlet Temperature = 510F

	AXIAL POSITION FT.	$\Delta t_{\text{moderator}}$ °F	$\Delta t_{\text{control rod}}$ °F	$\Delta \bar{t}_{\text{graphite}}$ °F	
1	0.25	5.25	1.41	67.0*	93
2	1.25	27.7	7.53	89.8*	115
3	2.25	58.9	16.4	134.2*	165
4	3.25	96.3	28.6	184.6*	221
5	4.25	137.5	44.1	236.8*	278
6	5.25	180.5	62.9	288.3*	333
7	6.25	223.8	84.4	337.2*	384
8	7.25	266.3	108.2	382.3*	431
9	8.25	307.0	133.7	422.1*	470
10	9.25	345.2	160.2	456.0*	502
11	10.25	380.6	187.1	484.2*	527
12	11.25	413.1	213.9	506.5*	545
13	12.25	442.6	240.0	523.3*	556
14	13.25	469.3	265.1	535.6*	563
15	14.25	494.1	289.1	545.9*	567
16	14.50	498.6	308.8	550.0*	571

~~XXXXXXXXXXXXX
XXXXXXXXXXXX~~

* Original temperatures obtained using moderator coolant flow rate of 125 lb/hr. Corrected values are based on the final moderator coolant flow rate given at top of table. (See Calculation Sheets 38, 39, 40.)

Table 5

MODERATOR
TEMPERATURE DISTRIBUTION

Graphite Block No. 5

Zone 1

Moderator Annulus Flow Rate = 90 lb/hr
Control Rod Channel Flow Rate = 200 lb/hr
Coolant Inlet Temperature = 510°F

	AXIAL POSITION FT.	$\Delta t_{\text{moderator}}$ °F	$\Delta t_{\text{control rod}}$ °F	$\Delta t_{\text{graphite}}$ °F	
1	0.25	4.63	1.70	81.9*	107
2	1.25	24.4	8.92	100.0*	125
3	2.25	51.7	18.8	141.7*	172
4	3.25	84.6	31.7	188.2*	223
5	4.25	121.3	47.7	236.0*	275
6	5.25	160.0	66.6	283.0*	325
7	6.25	199.5	87.8	327.0*	370
8	7.25	238.8	111.1	367.4*	410
9	8.25	276.8	135.7	402.6*	444
10	9.25	312.9	161.0	431.9*	472
11	10.25	346.8	186.5	455.5*	493
12	11.25	378.0	211.7	473.0*	503
13	12.25	406.5	235.9	485.0*	510
14	13.25	432.4	259.0	492.4*	512
15	14.25	456.3	280.7	497.8*	513
16	14.50	456.7	297.3	500.2*	514

~~XX~~
~~XX~~

* Original temperatures obtained using moderator coolant flow rate of 125 lb/hr. Corrected values are based on the final moderator coolant flow rate given at top of table. (See Calculation Sheets 38, 39, 40.)

Table 6

MODERATOR
TEMPERATURE DISTRIBUTION

Graphite Block No. 6

Zone 2

Moderator Annulus Flow Rate = 70 lb/hr

Control Rod Channel Flow Rate = 200 lb/hr

Coolant Inlet Temperature = 510F

	AXIAL POSITION FT,	$\Delta t_{\text{moderator}}$ °F	$\Delta t_{\text{control rod}}$ °F	$\overline{\Delta t}_{\text{graphite}}$ °F	
1	0.25	5.49	1.64	73.8*	102
2	1.25	28.8	8.68	97.6*	127
3	2.25	60.7	18.7	144.2*	180
4	3.25	98.4	32.2	196.4*	237
5	4.25	139.6	49.2	250.1*	295
6	5.25	182.5	69.4	302.6*	352
7	6.25	225.4	92.4	352.0*	404
8	7.25	267.4	117.5	397.0*	451
9	8.25	307.5	144.2	436.4*	490
10	9.25	345.0	171.6	469.3*	521
11	10.25	379.8	199.3	496.2*	545
12	11.25	411.4	226.5	516.6*	560
13	12.25	440.1	252.8	531.3*	570
14	13.25	466.0	277.8	541.3*	573
15	14.25	490.0	301.4	549.4*	574
16	14.50	492.3	319.9	551.2*	576

~~* Corrected temperatures due to decreased moderator
moderator flow rate~~

* Original temperatures obtained using moderator coolant flow rate of 125 lb/hr. Corrected values are based on the final moderator coolant flow rate given at top of table. (See Calculation Sheets 38, 39, 40.)

Table 7

MODERATOR
TEMPERATURE DISTRIBUTION

Graphite Block No. 7

Zone 3

Moderator Annulus Flow Rate = 50 lb/hr
Control Rod Channel Flow Rate = 200 lb/hr
Coolant Inlet Temperature = 510°F

	AXIAL POSITION FT.	$\Delta t_{\text{moderator}}$ °F	$\Delta t_{\text{control rod}}$ °F	$\Delta t_{\text{graphite}}$ °F	
1	0.25	5.72	1.22	56.5*	86
2	1.25	30.2	6.61	80.9*	111
3	2.25	64.2	14.8	125.3*	161
4	3.25	103.6	26.5	175.0*	217
5	4.25	145.5	41.6	225.7*	273
6	5.25	188.0	60.0	275.0*	326
7	6.25	229.9	81.0	321.3*	375
8	7.25	270.3	104.2	363.7*	419
9	8.25	308.7	128.9	401.3*	455
10	9.25	344.6	154.5	433.7*	487
11	10.25	378.1	180.6	461.2*	519
12	11.25	409.1	206.5	483.7*	528
13	12.25	437.7	231.9	501.9*	539
14	13.25	464.2	256.5	516.5*	547
15	14.25	489.5	280.1	529.8*	553
16	14.50	489.9	300.0	530.3*	554

~~* Corrected temperatures due to decreased moderator
coolant flow rates~~

* Original temperatures obtained using moderator coolant flow rate of 125 lb/hr. Corrected values are based on the final moderator coolant flow rate given at top of table. (See Calculation Sheets 38, 39, 40.)

Table 8

MODERATOR
TEMPERATURE DISTRIBUTION

Graphite Block No. 8

Zone 3

Moderator Annulus Flow Rate = 50 lb/hr

Large Experimental Annulus Flow Rate = 430 lb/hr

Coolant Inlet Temperature = 510F

	AXIAL POSITION FT.	$\Delta t_{\text{moderator}}$ °F	$\Delta t_{\text{experimental}}$ °F	$\bar{\Delta t}_{\text{graphite}}$ °F	
1	0.25	5.04	10.4	47.0*	72
2	1.25	27.6	26.4	69.0*	93
3	2.25	60.2	46.8	108.6*	137
4	3.25	98.4	72.1	153.5*	186
5	4.25	139.4	101.9	200.4*	236
6	5.25	181.3	135.4	247.1*	286
7	6.25	223.0	171.5	292.0*	333
8	7.25	263.7	209.1	334.5*	376
9	8.25	302.8	246.9	373.4*	415
10	9.25	339.9	284.0	408.1*	448
11	10.25	374.8	319.2	438.5*	476
12	11.25	407.4	351.9	464.6*	498
13	12.25	437.8	381.3	486.6*	514
14	13.25	466.2	407.0	505.0*	527
15	14.25	493.1	429.2	521.4*	538
16	14.50	497.4	445.8	527.5*	545

~~* Corrected temperatures due to decreased moderator moderator flow rate.~~

* Original temperatures obtained using moderator coolant flow rate of 125 lb/hr. Corrected values are based on the final moderator coolant flow rate given at top of table. (See Calculation Sheets 38, 39, 40.)

Table 9

MODERATOR
TEMPERATURE DISTRIBUTION

Graphite Block No. 9

Zone 4

Moderator Annulus Flow Rate = 30 lb/hr

Large Experimental Annulus Flow Rate = 430 lb/hr

Coolant Inlet Temperature = 510F

	AXIAL POSITION FT.	$\Delta t_{\text{moderator}}$ °F	$\Delta t_{\text{experimental}}$ °F	$\overline{\Delta t}_{\text{graphite}}$ °F	
1	0.25	5.34	9.92	39.9*	68
2	1.25	30.4	24.0	62.1*	88
3	2.25	66.8	42.3	100.4*	128
4	3.25	106.1	65.3	142.2*	172
5	4.25	145.9	92.5	184.6*	216
6	5.25	185.6	123.0	226.6*	261
7	6.25	224.7	155.7	267.3*	302
8	7.25	262.9	189.8	306.2*	341
9	8.25	299.8	224.2	342.3*	377
10	9.25	335.3	258.0	375.3*	408
11	10.25	369.4	290.4	405.2*	434
12	11.25	401.8	320.7	431.6*	456
13	12.25	432.8	348.2	454.8*	473
14	13.25	462.3	372.8	475.2*	485
15	14.25	491.3	394.4	494.0*	496
16	14.50	489.0	412.1	497.5*	505

~~* Corrected temperatures due to decreased moderator coolant flow rate~~

* Original temperatures obtained using moderator coolant flow rate of 125 lb/hr. Corrected values are based on the final moderator coolant flow rate given at top of table. (See Calculation Sheets 28, 39, 40.)

Table 10

MODERATOR
TEMPERATURE DISTRIBUTION

Graphite Block No. 1

Zone 1

For the Case of Fuel Unloading In
One Channel

Moderator Annulus Flow Rate = 90 lb/hr

Unloaded Channel Flow Rate = 3,500 lb/hr

Coolant Inlet Temperature = 510F

	AXIAL POSITION FT.	$\Delta t_{\text{moderator}}$ °F	$\Delta t_{\text{unloaded}}$ channel °F	$\bar{\Delta t}_{\text{graphite}}$ °F
1	0.25	4.58	.22	85.2
2	1.25	24.1	1.14	99.7
3	2.25	51.2	2.32	136.6
4	3.25	83.9	3.79	177.0
5	4.25	120.3	5.54	217.4
6	5.25	158.7	7.54	255.8
7	6.25	197.6	9.76	290.4
8	7.25	236.0	12.1	320.6
9	8.25	273.0	14.6	345.1
10	9.25	307.9	17.2	363.5
11	10.25	340.2	19.7	376.5
12	11.25	369.7	22.2	382.6
13	12.25	396.3	24.7	383.4
14	13.25	420.2	27.0	391.0
15	14.25	442.0	29.1	376.5
16	14.50	438.1	30.7	373.0

A

B

C

TABLE 11. GRAPHITE BLOCK CROSS-SECTION TEMPERATURE DISTRIBUTION
FOR THE CASE OF FUEL UNLOADING IN ONE CHANNEL
GRAPHITE BLOCK NO. 1

COOLANT TEMPERATURE DIFFERENCE BETWEEN LOADED AND UNLOADED CHANNELS = 0.0°F
ANNULUS COOLANT TEMPERATURE = 510°F AXIAL POSITION = 0.0 FT
(ACTIVE CORE)

NOTE: ALL POINT TEMPERATURE REFERENCE TO MODERATOR
ANNULUS COOLANT TEMPERATURE

TABLE 11

A-C STUDY 226

SIMILAR TO

DR'N F.C. 2/27/60

CH'D

APP'D

SCALE

= 12

SHEET

OF

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

A

B

A-C MFG. CO., MILWAUKEE, WIS. FORM NO. 6833-3

TABLE 12. GRAPHITE BLOCK CROSS-SECTION TEMPERATURE DISTRIBUTION
FOR THE CASE OF FUEL UNLOADING IN ONE CHANNEL
GRAPHITE BLOCK NO 1

COOLANT TEMPERATURE DIFFERENCE BETWEEN LOADED AND UNLOADED CHANNELS = 115 F
ANNULUS COOLANT TEMPERATURE = 630 F
AXIAL POSITION = 4.25 FT (ACTIVE CORE)

NOTE : ALL POINT TEMPERATURE REFERENCE TO MODERATOR
ANNULUS COOLANT TEMPERATURE

TABLE 12

A-C STUDY 226

DR'N F.C. 2/27/60	CH'D	APP'D	SCALE = 12	SIMILAR TO	SHEET OF	ISSUE
ALLIS-CHALMERS MFG. CO. DEPT.						

TABLE 13. GRAPHITE BLOCK CROSS-SECTION TEMPERATURE DISTRIBUTION
FOR THE CASE OF FUEL UNLOADING IN ONE CHANNEL
GRAPHITE BLOCK NO. 1

COOLANT TEMPERATURE DIFFERENCE BETWEEN LOADED AND UNLOADED CHANNELS $\cong 320^{\circ}\text{F}$
ANNULUS COOLANT TEMPERATURE = 850°F AXIAL POSITION $\cong 10.25\text{ FT}$
(ACTIVE CORE)

NOTE: ALL POINT TEMPERATURE REFERENCE TO MODERATOR
ANNULUS COOLANT TEMPERATURE

TABLE 13

A-C STUDY 226

SIMILAR TO

DR'N F.C. 2/29/61 CH'D

APP'D

SCALE = 12

SHEET OF

ISSUE

ALLIS-CHALMERS MFG. CO. DEPT.

A

B

A-C MFG. CO., MILWAUKEE, WIS. FORM NO. 6833-3

TABLE 14 GRAPHITE BLOCK CROSS-SECTION TEMPERATURE DISTRIBUTION
FOR THE CASE OF FUEL UNLOADING IN ONE CHANNEL
GRAPHITE BLOCK NO. 1

COOLANT TEMPERATURE DIFFERENCE BETWEEN LOADED AND UNLOADED CHANNELS = 393F
ANNULUS COOLANT TEMPERATURE = 930F AXIAL POSITION $\approx$ 13.25 FT
(ACTIVE CORE)

NOTE: ALL POINT TEMPERATURE REFERENCE TO MODERATOR
ANNULUS COOLANT TEMPERATURE

TABLE 14

A-C STUDY 226

DR'N F.C. 2/29/60	CH'D	APP'D	SCALE = 12	SIMILAR TO
ALLIS-CHALMERS MFG. CO. DEPT.				ISSUE

DRN

F.C. 3/29/60

CH'D

APP'D

SCALE

= 12

SHEET

OF

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

A

B

A-C MFG. CO., MILWAUKEE, WIS. FORM NO. 6833-3

Table 15 Reflector Temperature Distribution
A-C Study 226

SIMILAR TO

TABLE 15

REFLECTOR TEMPERATURE DISTRIBUTION

Assumption: Adiabatic Outer Surface

Ratio of Individual ΔT_i to Whole Octant ΔT_{graph} $\frac{\Delta T_i}{\Delta T_{\text{graph}}}$																	
Reflector Graphite Block Number																	
Axial Position	Q'	ΔT_{MOD}	θ	ΔT_{outer}	ΔT_{graph}	ΔT_{graph}	ΔT_i	ΔT_i	ΔT_i	ΔT_i	ΔT_i	ΔT_i	ΔT_i	ΔT_i	ΔT_i	ΔT_i	ΔT_i
1	0.25 FT	5030	7 °F	-46 °F	53	46	53	52	53	52	53	39	37	62	58	45	
2	1.25	5130	28	-47	75	47	75	74	75	73	75	61	59	83	80	67	
3	2.25	6300	58	-58	116	58	116	114	116	111	116	99	96	126	122	106	
4	3.25	7450	93	-68	161	68	161	159	161	158	161	141	137	173	168	149	
5	4.25	8480	130	-77	207	77	207	205	207	203	207	184	180	220	215	194	
6	5.25	9300	170	-86	256	86	256	253	256	252	256	230	226	271	265	241	
7	6.25	9850	209	-91	300	91	300	297	300	295	300	273	268	315	309	285	
8	7.25	10130	248	-93	341	93	341	338	341	336	341	313	308	357	350	325	
9	8.25	10130	285	-93	378	93	378	375	378	373	378	344	344	394	387	362	
10	9.25	9850	321	-91	412	91	412	409	412	407	412	385	386	427	421	397	
11	10.25	9300	355	-86	441	86	441	438	441	437	441	415	411	456	450	426	
12	11.25	8480	386	-77	463	77	463	461	463	459	463	440	436	476	471	450	
13	12.25	7450	405	-68	473	68	473	471	473	470	473	453	449	485	486	461	
14	13.25	6300	442	-58	500	58	500	498	500	497	500	483	486	516	506	496	
15	14.25	5130	468	-47	515	47	515	514	515	513	515	501	499	523	526	507	
16	14.50	5030	473	-46	520	46	520	518	520	517	520	505	503	527	524	511	

 $\theta = T_{\text{CHANNEL}} - T_{\text{OUTER SURFACE}}$ $\Delta T_{\text{graph}} = \text{Average Graphite Temperature Rise}$ $\Delta T_{\text{graph}} = \text{LOCAL AVERAGE GRAPHITE TEMPERATURE EXCESS ABOVE CHANNEL COOLANT}$

TABLE 16

REFLECTOR TEMPERATURE DISTRIBUTION

Assumption: Maximum Outer Surface Coolant Temperature $\approx 533^{\circ}\text{F}$

Ratio of Individual ΔT_i To Whole Section ΔT_{graph} , $\frac{\Delta T_i}{\Delta T_{\text{graph}}}$		Reflector Graphite Block Number		0.62	1.10	0.98	1.05	0.63	0.60	1.05	1.05	0.75
Reflector Graphite Block Number		10	12	14	16	15	4	11	13	9		
AXIAL POSITION	Q'	ΔT_{MOD}	θ	ΔT_{OUTER}	ΔT_{graph}	ΔT_{graph}	ΔT_i	ΔT_i	ΔT_i	ΔT_i	ΔT_i	ΔT_i
1	0.25 FT	5030	7°F - 60°F	67°F	50°F	57°F	38°F	62°F	56°F	60°F	40°F	37°F
2	1.25	5130	28 - 62	90	51	79	60	84	78	82	61	58
3	2.25	6300	58 - 76	134	63	121	97	127	120	124	99	96
4	3.25	7450	93 - 90	183	75	168	146	176	167	172	142	138
5	4.25	8480	130 - 102	232	85	215	183	224	213	219	185	181
6	5.25	9300	170 - 112	282	93	263	228	273	261	269	230	226
7	6.25	9850	209 - 118	327	99	308	270	318	306	313	273	332
8	7.25	10130	248 - 122	376	101	349	311	359	347	354	314	309
9	8.25	9850 10130	285 - 122	407	101	386	348	396	384	391	351	345
10	9.25	9850	321 - 118	439	99	420	382	430	418	425	385	380
11	10.25	9300	355 - 112	467	93	448	413	457	446	453	415	411
12	11.25	8480	386 - 102	488	85	471	439	480	469	475	441	437
13	12.25	7450	405 - 90	495	75	480	452	488	479	484	454	450
14	13.25	6300	442 - 76	518	63	505	481	511	504	508	483	480
15	14.25	6730	468 - 62	530	51	519	495 500	524	518	522	501	498
16	14.50	5030	473 - 60	533	50	523	504	528	522	526	506	503

Note: $\theta = T_{\text{CHANNEL}} - T_{\text{OUTER SURFACE}}$ $\Delta T_{\text{graphite}}$ = AVERAGE GRAPHITE TEMPERATURE RISE $\Delta T'_{\text{graphite}}$ = LOCAL AVERAGE GRAPHITE TEMPERATURE EXCESS ABOVE CHANNEL COOLANT TEMPERATURE

DRN

FC 2/29/65 CHD

APPD

ALLIS-CHALMERS MFG. CO. DEPT.

SCALE

= 12

SHEET

OF

ISSUE

SIMILAR TO

Table 16 Reflector Temperature Distribution

A-C Study 226

A

B

TABLE 17

REFLECTOR TEMPERATURE DISTRIBUTION

Assumption: Channel Coolant Temperature = Outer Surface Coolant Temperature

Ratio ΔT_i (of Individual) to Whole Section ΔT_{graph} $\frac{\Delta T_i}{\Delta T_{\text{graph}}}$								0.766	0.928	0.919	0.795	0.766	0.772	1.37	1.157	1.074
Reflector Graphite Block Number								10	12	14	16	15	4	11	13	9
	AXIAL POSITION	Q'	ΔT_{MOD}	θ	ΔT_{OUTER}	ΔT_{GRAPH}	ΔT_{GRAPH}	ΔT_i	ΔT_i	ΔT_i	ΔT_i	ΔT_i	ΔT_i	ΔT_i	ΔT_i	ΔT_i
1	0.25 FT	5830	7°F	0.0	7°F	32°F	39°F	32	37	36	33	32	32	51	44	41
2	1.25 FT	5130	28	6.0	28	32	60	53	58	57	54	53	53	72	65	62
3	2.25	6300	58		58	46	98	88	94	94	89	88	88	111	103	100
4	3.35 FT	7450	93		93	47	140	129	137	136	130	129	129	157	147	143
5	4.25	8480	130		130	53	183	171	179	179	172	171	171	203	191	187
6	5.25	9300	170		170	58	228	211	221	220	213	211	211	245	237	232
7	6.25	9850	209		209	61	270	256	266	265	257	256	256	293	280	275
8	7.25	10130	248		248	63	311	296	307	306	298	296	291	334	321	316
9	8.25	10130	285		285	63	348	333	344	343	335	333	333	371	358	353
10	9.25	9850	321		321	61	382	368	378	377	369	368	368	405	392	387
11	10.25	9300	355		355	58	413	399	409	408	401	399	399	434	422	417
12	11.25	8480	386		386	53	439	427	435	435	428	427	427	459	447	443
13	12.25	7450	405		405	47	452	441	449	448	442	441	441	469	459	455
14	13.25	6300	442		442	39	481	472	478	478	472	472	472	495	488	485
15	14.25	5130	468		468	32	500	495	506	499	496	495	495	512	505	502
16	14.50	5030	473		473	32	505	497	502	501	498	497	497	517	510	507

Table 17 Reflector Temperature Distribution

A-C Study 226

SIMILAR TO

SHEET OF

ISSUE

DR.N

F.C. 2/29/60

APPD

ALLIS-CHALMERS MFG. CO. DEPT.

SCALE

= 12

A

B

Study No. II-226
EGCR

X. FIGURES

FIGURE 1

CORE OCTANT SHOWING GRAPHITE
BLOCKS BY NUMBERS AND FUEL CHANNELS
BY ZONE NUMBERS

FIGURE 1

A-C STUDY 226

DR'N F.C. 2/25/60

CH'D

APP'D

SCALE

=12

SIMILAR TO

SHEET OF

ISSUE

ALLIS-CHALMERS MFG. CO.

DEPT.

A-C MFG. CO., MILWAUKEE, WIS. FORM NO. 6833-3

FIGURE 2 GRAPHITE COLUMN AXIAL TEMPERATURE DISTRIBUTIONS

ASSUMPTIONS:

1. Thermal Conductivity of Graphite = $15 \frac{\text{BTU}}{\text{HR-FT}^2-\text{F}}$
2. Moderator Coolant Flows as Specified in II-A
3. Control Rod and Experimental Tube Flows as Specified in Study 179-1
4. Maximum Coolant Temperature Outside of Reflector = 1043°F
5. No Leakage Flow Between Blocks.

FIGURE 3 TEMPERATURE DISTRIBUTION - BLOCK NO. 0

$\frac{Q}{Q_0}$

FRACTION OF HEAT DISSIPATED INTO 2 CHANNEL

FIGURE 4. TEMPERATURE DISTRIBUTION

BLOCKS NO. 1, 6 AND 7

FIGURE 5 TEMPERATURE DISTRIBUTION
BLOCK NO. 2 & NO. 3

FIGURE 16 TEMPERATURE DISTRIBUTION, BLUEN NO. 12

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. 47. 48. 49. 50. 51. 52. 53. 54. 55. 56. 57. 58. 59. 60. 61. 62. 63. 64. 65. 66. 67. 68. 69. 70. 71. 72. 73. 74. 75. 76. 77. 78. 79. 80. 81. 82. 83. 84. 85. 86. 87. 88. 89. 90. 91. 92. 93. 94. 95. 96. 97. 98. 99. 100. 101. 102. 103. 104. 105. 106. 107. 108. 109. 110. 111. 112. 113. 114. 115. 116. 117. 118. 119. 120. 121. 122. 123. 124. 125. 126. 127. 128. 129. 130. 131. 132. 133. 134. 135. 136. 137. 138. 139. 140. 141. 142. 143. 144. 145. 146. 147. 148. 149. 150. 151. 152. 153. 154. 155. 156. 157. 158. 159. 160. 161. 162. 163. 164. 165. 166. 167. 168. 169. 170. 171. 172. 173. 174. 175. 176. 177. 178. 179. 180. 181. 182. 183. 184. 185. 186. 187. 188. 189. 190. 191. 192. 193. 194. 195. 196. 197. 198. 199. 200. 201. 202. 203. 204. 205. 206. 207. 208. 209. 210. 211. 212. 213. 214. 215. 216. 217. 218. 219. 220. 221. 222. 223. 224. 225. 226. 227. 228. 229. 230. 231. 232. 233. 234. 235. 236. 237. 238. 239. 240. 241. 242. 243. 244. 245. 246. 247. 248. 249. 250. 251. 252. 253. 254. 255. 256. 257. 258. 259. 260. 261. 262. 263. 264. 265. 266. 267. 268. 269. 270. 271. 272. 273. 274. 275. 276. 277. 278. 279. 280. 281. 282. 283. 284. 285. 286. 287. 288. 289. 290. 291. 292. 293. 294. 295. 296. 297. 298. 299. 300. 301. 302. 303. 304. 305. 306. 307. 308. 309. 310. 311. 312. 313. 314. 315. 316. 317. 318. 319. 320. 321. 322. 323. 324. 325. 326. 327. 328. 329. 330. 331. 332. 333. 334. 335. 336. 337. 338. 339. 340. 341. 342. 343. 344. 345. 346. 347. 348. 349. 350. 351. 352. 353. 354. 355. 356. 357. 358. 359. 360. 361. 362. 363. 364. 365. 366. 367. 368. 369. 370. 371. 372. 373. 374. 375. 376. 377. 378. 379. 380. 381. 382. 383. 384. 385. 386. 387. 388. 389. 390. 391. 392. 393. 394. 395. 396. 397. 398. 399. 400. 401. 402. 403. 404. 405. 406. 407. 408. 409. 410. 411. 412. 413. 414. 415. 416. 417. 418. 419. 420. 421. 422. 423. 424. 425. 426. 427. 428. 429. 430. 431. 432. 433. 434. 435. 436. 437. 438. 439. 440. 441. 442. 443. 444. 445. 446. 447. 448. 449. 450. 451. 452. 453. 454. 455. 456. 457. 458. 459. 460. 461. 462. 463. 464. 465. 466. 467. 468. 469. 470. 471. 472. 473. 474. 475. 476. 477. 478. 479. 480. 481. 482. 483. 484. 485. 486. 487. 488. 489. 490. 491. 492. 493. 494. 495. 496. 497. 498. 499. 500. 501. 502. 503. 504. 505. 506. 507. 508. 509. 510. 511. 512. 513. 514. 515. 516. 517. 518. 519. 520. 521. 522. 523. 524. 525. 526. 527. 528. 529. 530. 531. 532. 533. 534. 535. 536. 537. 538. 539. 540. 541. 542. 543. 544. 545. 546. 547. 548. 549. 550. 551. 552. 553. 554. 555. 556. 557. 558. 559. 560. 561. 562. 563. 564. 565. 566. 567. 568. 569. 570. 571. 572. 573. 574. 575. 576. 577. 578. 579. 580. 581. 582. 583. 584. 585. 586. 587. 588. 589. 590. 591. 592. 593. 594. 595. 596. 597. 598. 599. 600. 601. 602. 603. 604. 605. 606. 607. 608. 609. 610. 611. 612. 613. 614. 615. 616. 617. 618. 619. 620. 621. 622. 623. 624. 625. 626. 627. 628. 629. 630. 631. 632. 633. 634. 635. 636. 637. 638. 639. 640. 641. 642. 643. 644. 645. 646. 647. 648. 649. 650. 651. 652. 653. 654. 655. 656. 657. 658. 659. 660. 661. 662. 663. 664. 665. 666. 667. 668. 669. 670. 671. 672. 673. 674. 675. 676. 677. 678. 679. 680. 681. 682. 683. 684. 685. 686. 687. 688. 689. 690. 691. 692. 693. 694. 695. 696. 697. 698. 699. 700. 701. 702. 703. 704. 705. 706. 707. 708. 709. 710. 711. 712. 713. 714. 715. 716. 717. 718. 719. 720. 721. 722. 723. 724. 725. 726. 727. 728. 729. 730. 731. 732. 733. 734. 735. 736. 737. 738. 739. 740. 741. 742. 743. 744. 745. 746. 747. 748. 749. 750. 751. 752. 753. 754. 755. 756. 757. 758. 759. 760. 761. 762. 763. 764. 765. 766. 767. 768. 769. 770. 771. 772. 773. 774. 775. 776. 777. 778. 779. 780. 781. 782. 783. 784. 785. 786. 787. 788. 789. 790. 791. 792. 793. 794. 795. 796. 797. 798. 799. 800. 801. 802. 803. 804. 805. 806. 807. 808. 809. 810. 811. 812. 813. 814. 815. 816. 817. 818. 819. 820. 821. 822. 823. 824. 825. 826. 827. 828. 829. 830. 831. 832. 833. 834. 835. 836. 837. 838. 839. 840.

FIGURE 8 TEMPERATURE DISTRIBUTION BLOCK NO. 8

FIGURE 9

TEMPERATURE DISTRIBUTION

BLOCK NO. 9

FIGURE 10

TEMPERATURE DISTRIBUTION FOR THE CASE OF FUEL UNLOADING
IN ONE CHANNEL -- BLOCK NO. 1

FIGURE 11

HEAT DISSIPATION OF FUEL
ELEMENT SLEEVES

FIGURE 12 REFLECTOR TEMPERATURE DISTRIBUTION

$\dot{Q} = 7950 \frac{\text{Btu}}{\text{hr-ft}}$

TEMPERATURE DIFFERENCE BETWEEN CHANNEL AND OUTER SURFACE OF REFLECTOR

COOLANT TEMPERATURE DIFFERENCES BETWEEN CHANNEL AND OUTER SURFACE OF REFLECTOR

FRACTION OF HEAT DISEMINATED INTO CHANNELS FOR EACH SURFACE

0.2

FIGURE 13 RATIO OF INDIVIDUAL BLOCK SURFACE TEMPERATURE DROP TO OVERALL AVERAGE TEMPERATURE DROP IN REFLECTOR