UNCLASSIFIED

CF-55-10-19

OAK RIDGE NATIONAL LABORATORY

Operated By

UNION CARBIDE NUCLEAR COMPANY

POST OFFICE BOX P
OAK RIDGE, TENNESSEE ORNL
CENTRAL FILES NUMBER

CF-55-10-19

DATE: October 14, 1955

SUBJECT: TEMPERATURE DISTRIBUTION IN THE ORR CORE HOUSING

TO: Distribution

FROM: F. T. Binford

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither 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 liabilities 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.

Photostat Price \$ 6.30Microfilm Price \$ 3.00

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

UNCLASSIFIED

1

2501

573-1

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.

TEMPERATURE DISTRIBUTION IN THE ORR CORE HOUSING

1. MODEL USED:

Since only a conservative estimate of the metal temperatures attained in the core housing is required, the calculations below have been restricted to the consideration of one dimensional heat flow. For the purpose of these estimates the various structural members have been considered as semi-infinite plates in which heat is generated at a constant rate S_0 . The plates are cooled, or insulated at the faces as the case may be and no heat is considered to flow parallel to the faces.

Several of the plates are provided with internal cooling by means of 3/16" diameter holes drilled parallel to the plate faces. These holes are arranged so that the total heat transfer area available because of them is just equal to the area of one of the faces. This internal cooling is taken into account by considering these cooling channels to be in the form of a semi-infinite slot and by assuming at this slot the existence of an overall heat transfer coefficient equal to one half that actually present at the surface of the drilled holes.

Calculations have been made covering a substantial range of heat transfer coefficients and the results particularized for those values of this parameter which apply to the ORR.

2. CALCULATIONS:

A. Plate of thickness W cooled by forced convection on one side and insulated on the other:

The equations which describe the temperature distribution in this case are;

$$T(r) = \frac{S_o W^2}{2K} \left\{ (1-r^2) + \frac{1}{\beta} \right\} \quad 0 \leq r \leq 1$$

$$T_{max} = T(0) = \frac{S_o W^2}{2K} \left(1 + \frac{1}{\beta} \right) \quad T_{min} = T(1) = \frac{S_o W^2}{2K} \cdot \frac{1}{\beta}$$

$$\Delta T = \frac{S_o W^2}{2K}$$

where here

Note: The ambient water temperature is here taken as zero for simplicity

W = plate thickness (ft)

S_o = heat generation rate (BTU/ft³ hr)

K = thermal conductivity (BTU/ft hr °F)

$x=rw$ = distance from insulated face (ft)

β = Biot's number = $Wh/2K$

h = overall heat transfer coefficient (BTU/ft² hr °F)

$T(r)$ = temperature in °F at a distance $x=rw$ from the insulated surface

T_{max} = maximum temperature °F

T_{min} = minimum temperature °F

ΔT = maximum temperature spread °F.

B. Plate of thickness W cooled equally on both sides by forced convections.

The equations governing this situation are;

$$T(r) = \frac{S_o W^2}{2K} \left\{ \frac{1-r^2}{4} + \frac{1}{2\beta} \right\} \quad -1 \leq r \leq 1$$

$$T_{max} = T(0) = \frac{S_o W^2}{2K} \left\{ \frac{1}{4} + \frac{1}{2\beta} \right\} \quad T_{min} = T(1) = \frac{S_o W^2}{2K} \cdot \frac{1}{2\beta}$$

$$\Delta T = \frac{S_o W^2}{8K}$$

where here $Wr = 2x$ and the other symbols have the same meaning as before

C. Plate of thickness W cooled unequally on both sides;

The equations are;

$$T(r) = \frac{S_o W^2}{2K} \left\{ \frac{2(1+\beta)}{(1+\eta) + 2\eta\beta} (\eta r + \frac{1}{2}\beta) - r^2 \right\} \quad 0 \leq r \leq 1$$

$$T(0) = \frac{S_o W^2}{2K} \left\{ \frac{1+\beta}{(1+\eta)\beta + 2\eta\beta^2} \right\} \quad T(1) = \frac{S_o W^2}{2K} \left\{ \frac{1+\eta\beta}{\beta(1+\eta) + 2\eta\beta^2} \right\}$$

$$T_{max} \text{ occurs at } r_{max} = \frac{(1+\beta)\eta}{(1+\eta) + 2\eta\beta}$$

$$T_{max} = \frac{S_o W^2}{2K} \left\{ \frac{(1+\beta)}{\beta} \cdot \frac{\beta\eta^2(1+\beta) + (1+\eta + 2\eta\beta)}{(1+\eta + 2\eta\beta)^2} \right\}$$

Where here η is a parameter specifying the heat transfer coefficient on one side as a function of the heat transfer coefficient on the other. For the particular choice $0 \leq \eta \leq 1$

$$\Delta T = \frac{S_o W^2}{2K} \left\{ \frac{1+\eta\beta}{1+\eta + 2\eta\beta} \right\}^2$$

D. Plate of thickness W cooled on one side and cooled internally by a slot;

Here ψ is a parameter which specifies the location of the cooling slot. This can be treated as a combination of cases (A) and (C).

3. APPLICATION TO THE ORR:

The basic constants employed are $K = 80$ BTU/ft hr $^{\circ}$ F for the aluminum used in fabrication, and a heat generation of one watt per gram i.e., 2.61×10^5 BTU/ft³ hr.

Thus in every case

$$S_0 W^2 / 2K = 1,631 W^2; \quad \beta = 0.00625 W h$$

A. POOLSIDE FACILITY: This face consists of a 1" thick plate pierced by cooling holes located 0.25" from the outer (uncooled) surface. Forced convection cooling on the inner surface is characterized by an overall heat transfer coefficient h and as outlined above η is taken to be $1/2$. Curves showing the surface and maximum temperature for various values of h are given in figure 1.

B. LARGE FACILITIES: These consist of $7/8$ " thick plates similar to the pool-side plate. The cooling holes are located 0.219" from the insulated surface. Curves showing the surface and maximum temperature as a function of h are given in figure 2.

C. BEAM HOLE FACE: The core housing at this face is $5/8$ " thick but is reduced to $1/2$ " inside the beam hole ends. Cooling is supplied to the $1/2$ " thick portions only on the inner face. The $5/8$ " thick portions are cooled

on the inner face by forced convection and on the outer face by natural convection. Figure 3 gives the surface temperatures of the 1/2" portion as a function of h while figure 4 gives the surface and maximum temperatures of the 5/8" face as a function of h , the overall heat transfer coefficient for the forced convection cooling and h_o , the overall heat transfer coefficient for natural convection.

D. TANK WALL ADJACENT TO POOLSIDE FACILITY: The straight section of the tank wall immediately adjacent to the poolside face consists of a 1 3/4" plate which is cooled internally by forced convection and externally on both faces by natural convection. The surface temperature of this plate as a function of h the forced convection heat transfer coefficient and h_o , the natural convection heat transfer coefficient is given in figure 5. The maximum temperature in this case differs little from the surface temperature.

The curved section of the tank wall adjacent to the poolside facility is also 1 3/4" thick and is cooled on both faces by natural convection. The surface and maximum temperatures are given as a function of h_o , the heat transfer coefficient, in figure 6.

4. OPERATING CONDITIONS:

The restriction placed on the metal temperature in the ORR is that the surface temperature shall nowhere exceed the boiling point, i.e., 240°F at the operating pressure. Sanders* has calculated the value of the heat generation term at various locations in the structure. In what follows the ambient water temperature is taken to be 125°F and h , the overall heat transfer coefficient at those surfaces where forced convection cooling is employed is taken to be 2000 BTU/ft² hr °F.

* Sanders, J. P., CF-55-7-134.

The maximum heat generation rate in the core housing has been estimated to be 12.5 watts per gram thus the maximum temperatures to be expected in the poolside and large facility faces are

	INNER SURFACE	OUTER SURFACE	MAXIMUM
POOLSIDE FACE	188°F	201°F	218°F
LARGE FACILITY FACE	180°F	191°F	203°F

For the beam hole face we have in the interior of the beam hole ends

	INNER SURFACE	OUTER SURFACE (MAX.)
BEAM HOLE FACE (INT.)	193°F	229°F

The face exterior to the beam holes will remain below 240°F provided that a heat transfer coefficient greater than 200 characterizes the cooling by natural convection at this face. Assuming $h_o = 200$ we have

	INNER SURFACE	OUTER SURFACE	MAXIMUM
BEAM HOLE FACE (EXT.)	198°F	239°F	239°F

For the case of the straight portion of the tank adjacent to the poolside facility the maximum heat generation is found to be 4.7 watts per gram, thus h_o must exceed 560 if the temperature is to be kept below boiling. Under this assumption we have

	SURFACE	MAXIMUM
STRAIGHT PORTION	239°F	256°F

If 50% more internal cooling were provided then an external heat transfer coefficient of 200 would result in

	SURFACE	MAXIMUM
STRAIGHT PORTION	239°F	240°F

For the case of the curved section of the tank wall the maximum heat generation rate is 2.2 watts per gram whence a heat transfer coefficient of about 400 would prevent boiling. Under this assumption.

	SURFACE	MAXIMUM
CURVED PORTION	230°F	249°F

573-7

CONCLUSION: It seems clear from these calculations that surface temperatures in the ORR core housing will not exceed the boiling point provided overall heat transfer coefficients for forced convection and for natural convection can be maintained above $2000 \text{ BTU/ft}^2 \text{ hr } ^\circ\text{F}$ and $200 \text{ BTU/ft}^2 \text{ hr } ^\circ\text{F}$ respectively. Difficulties arise, however, in cooling the heavy portions of the core tank which are located near the poolside face since it is questionable whether natural convection will provide sufficient cooling at these points.

For convenience, there is appended a drawing of the core housing giving the temperature distribution in this region under the assumption $h = 2000$, $h = 200$. These temperatures are based on the work by Sanders previously cited.

8

TEMPERATURE DISTRIBUTION IN 1" THICK
POOLSIDE FACE AS A FUNCTION OF THE
OVERALL HEAT TRANSFER COEFFICIENT

FIG. 1

573-9

9

TEMPERATURE DISTRIBUTION IN $\frac{7}{8}$ " THICK
LARGE FACILITY AS A FUNCTION OF THE
OVERALL HEAT TRANSFER COEFFICIENT

FIG. 2

TEMPERATURE (DEGREES F ABOVE AMBIENT PER WATT/CM)

12
10
8
6
4
2
0

400

800

1200

1600

2000

2400

2800

3200

HEAT TRANSFER COEFFICIENT (BTU/FT²IN °F)

MAXIMUM
OUTER SURFACE
INNER SURFACE

ORN-IR-DWG. 9480
UNCLASSIFIED

9

573-10

10

TEMPERATURE DISTRIBUTION IN $\frac{1}{2}$ " THICK
SECTION OF BEAM HOLE FACE AS
A FUNCTION OF THE OVERALL HEAT
TRANSFER COEFFICIENT

FIG. 3

ORNL-IR-DWG.-9461
UNCLASSIFIED

573-11

FIG 4 (a)
TEMPERATURE OF OUTER SURFACE
OF $\frac{5}{8}$ " BEAM HOLE FACE AS A
FUNCTION OF h AND h_0

FIG 4(6)

TEMPERATURE OF INNER SURFACE
OF $\frac{5}{8}$ " BEAM HOLE FACE AS A
FUNCTION OF h AND h_o

573-13

FIG 4(c)

MAXIMUM METAL TEMPERATURE
OF $\frac{5}{16}$ " BEAM HOLE FACE AS A
FUNCTION OF h_i AND h_o

573-14

Fig 5

SURFACE TEMPERATURE IN
INTERIALLY COOLED $1\frac{3}{4}$ " PLATE
AS A FUNCTION OF h_i AND h_o

FIG 6

TEMPERATURE DISTRIBUTION
IN $1\frac{3}{4}$ " PLATE COOLED ONLY
AT THE SURFACE AS A FUNCTION
OF THE OVERALL HEAT TRANSFER
COEFFICIENT

31

32

T_{MAX}	T_{AVG}	T_O	T_I
203	195	191	180
203	195	191	180
202	194	190	179
201	193	189	178
199	191	187	177
196	189	185	175
193	186	183	173
190	183	180	171
187	180	177	169
183	177	174	166
177	172	169	162
171	166	164	158
165	161	159	153

35

LEGEND

T_{MAX} = Maximum metal temperature
 T_{AVG} = Average metal temperature
 T_O = Outer surface temperature
 T_I = Inner surface temperature
All temperatures in °F.

30

NO.	REVISIONS	DATE	APPR.	APPR.
DRAWING NO. D-				
DRAWN	DATE	CHECKED	DATE	APPROVED
DESIGNED	DATE	SUBMITTED	DATE	APPROVED
HEALTH PHYSICS	MEDICAL	OPERATIONS	SAFETY	
FIRE PROTECTION	RESEARCH SHOP	MAINTENANCE		

33

34

MATERIALS LIST

ITEM NO.	DWG. NO.	QTY.	NAME	SIZE	MATERIAL
----------	----------	------	------	------	----------

36

REFERENCE DRAWINGS	DWG. NO.
--------------------	----------

MACHINE FINISH SPECIFICATIONS:

1. Finish symbols are in accordance with ASA Standard B46.1 - 1947.
2. Roughness height values are the maximum arithmetical average deviation from the mean surface, expressed in microinches.
3. For surfaces not otherwise indicated, roughness height shall not exceed $\sqrt{\quad}$.

THIS DRAWING CLASSIFIED
AS <i>OFFICIAL USE ONLY</i>
PER <i>H. P. Smith</i>
LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED
FRACTIONS: $\pm$
DECIMALS: $\pm$
ANGLES: $\pm$
SCALE: $\frac{1}{2}'' = 1''$

OENL RESEARCH REACTOR BLDG. 3042	
TEMPERATURE DISTRIBUTION IN LARGE FACILITY PLATE	
OAK RIDGE NATIONAL LABORATORY	
OPERATED BY	
CARBIDE AND CARBON CHEMICALS COMPANY	
A DIVISION OF UNION CARBIDE AND CARBON CORPORATION	
OAK RIDGE, TENNESSEE	
SUBMITTED	ACCEPTED
APPROVED	REV
D-16873	

573-19

27

573-v8

MATERIALS LIST				
ITEM NO.	DWG. NO.	QTY.	NAME	SIZE
				MATERIAL

LEGEND

T_{MAX} = Maximum metal temperature
T_{AVG} = Average metal temperature
T₀ = Outer surface temperature
T_I = Inner surface temperature

All temperatures in °F.

NO.	REVISIONS				DATE	APPR.	APPR.
DRAWING NO. D-							
DRAWN	DATE	CHECKED	DATE	APPROVED	DATE		
<i>W. J. Little</i>	<i>10/1/63</i>						
DESIGNED	DATE	SUBMITTED	DATE	APPROVED	DATE		
HEALTH PHYSICS		MEDICAL	OPERATIONS		SAFETY		
FIRE PROTECTION		RESEARCH SHOP	MAINTENANCE				

THIS DRAWING
CLASSIFIED
AS OFFICIAL USE ONLY
PER *A. J. Datta*
SCALE: 1/2" = 1"

REFERENCE DRAWINGS		DWG. NO.
OONL Research Reactor Bldg 3042		
TEMPERATURE DISTRIBUTION IN BEAM HOLE PLATE		
OAK RIDGE NATIONAL LABORATORY OPERATED BY CARBIDE AND CARBON CHEMICALS COMPANY A DIVISION OF UNION CARBIDE AND CARBON CORPORATION OAK RIDGE, TENNESSEE		
SUBMITTED	ACCEPTED	APPROVED
		REV
		D-15955