APR 4 1960

ATOMICS INTERNATIONAL
A Division of North American Aviation, Inc.

MASTER

Do not remove
this sheet

NAA-SR-MEMO -4914

This document contains 8 pages

This is copy _____ of _____ series _____

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, expressed 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, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

UNCLASSIFIED

Security Classification

*NAA-SR-MEMOs are working papers and may be expanded,
modified, or withdrawn at any time,
and are intended for internal use only.*

This report may not be published without the approval of the Patent Branch, AEC.

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 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.

WRITTEN BY H. H. Cappel		ATOMICS INTERNATIONAL A Division of North American Aviation, Inc.	TDR NO.	4914
SECTION Sodium Reactors			GO	7519
GROUP Engineering			LEDGER ACCT.	3621
UNIT Reactor Technology			SUB-ACCT.	4448
APPROVED BY: (SUPERVISOR)		PROGRAM ASGR	TWR	
OTHER		PROJECT	DATE February 22, 1960	
		Sodium Heat Transfer Studies	PAGE 1	OF 8

TO: **R. C. Moyes***

COPIES TO: **C. Baroczy, R. J. Beeley*, W. P. Corcoran*, R. W. Dickinson, J. Droher, J. Hagel, G. L. Reed***

SUBJECT:

Radial Temperature Profile of Sodium Pool Boiling Heater Assembly

CONTENTS:

- I STATEMENT OF PROBLEM PAGE 1
- II SUMMARY OF RESULTS AND RECOMMENDATIONS PAGE
- III METHOD USED, DESCRIPTION OF EQUIPMENT, SAMPLE CALCULATIONS . . . PAGE
- IV REFERENCES AND APPENDICES PAGE

I STATEMENT OF PROBLEM

- A. Determine the accuracy, with which the thermocouple in the well of the heater assembly, will predict the heater surface temperature.
- B. Determine the temperature distribution around the thermocouple well of the heater assembly, for a steady state heat flux of $.5 \times 10^6$ Btu/hr-ft² with boiling in water.

II SUMMARY OF RESULTS

Some means must be found, to bond the thermocouple to the molybdenum sleeve. Without bonding, the thermocouple temperatures may differ from that of the heater surface by as much as 650°F.

A rectangular two-dimensional model of the heater cross section, was found by the method of conformal mapping. The model, when analyzed by the Tiger II as well as by the IHM-709 steady state code, appears to represent the physical system correctly. Temperature profiles which were calculated for two conditions of radial steady state heat transfer, agree with values obtained by analytical methods (Figure 3) as well as experimental measurements (Reference 1).

ATOMICS INTERNATIONAL

A Division of North American Aviation, Inc.

NO. 4914
DATE February 22, 1960
PAGE 2 OF 8

The temperature distribution around the thermocouple well for a heat flux of 5×10^5 Btu/hr-ft², shows a radial temperature drop across the center of the well of about 680°F, (Figure 3) or an average temperature difference to the bulk coolant of 330°F. This is within 6% of the actual value, which was found by experiment. (Reference 1)

The temperature drop across the .001" helium gap between the heater and the heater sleeve, at all angular distances sufficiently away from the thermocouple well to minimize its heat transfer perturbations, was found to be 656°F. Since this drop is not significantly smaller than the temperature drop across the well, it appears that the latter is primarily dependent upon the thickness of the helium gap. Or in other words, the thickness of the helium gap determines the well temperature drop. This large temperature drop however, will result in an equally large variation in thermocouple reading, depending on where in the well the end of the thermocouple is located. To minimize this variation and find a dependable correlation for true sleeve wall temperature measurements, the thermocouple will have to be bonded to the sleeve.

III METHOD USED

A. Description of Heater Assembly

The heater consist of a solid molybdenum rod, covered with alternate layers of alumina and molybdenum. (Figure 1 and 2) The actual heating surface is a layer of molybdenum .01 in. thick, sandwiched between two layers of alumina. The heating rod fits into a molybdenum sleeve, (Figure 2) containing a uniform slot or well, along part of its length. This well will contain the thermocouple during actual operation. The clearance between heating rod and sleeve is approximately .001 inches; this gap, as well as the slot for the thermocouple, is filled with gas at essentially atmospheric pressure*. The radial dimensions of the heater assembly used in this analysis are given in Table 1. The dimensions of the thermocouple well are shown in Figure 2.

TABLE 1

<u>Material</u>	<u>OD (in)</u>	<u>Thickness (in)</u>
Molybdenum	.205	
Alumina	.225	.01
Molybdenum	.245	.01
Alumina	.265	.01
Molybdenum	.281	.008
Helium	.283	.001
Molybdenum	.381	.049

* The gas in this space depends on the history of the heating element. When initially fabricated, the gas is air. Due to diffusion, it is replaced by nitrogen or helium during operation. For these calculations helium was assumed to occupy the gap. In the experience referred to, air occupied the gap.

108 003

FIG. 1

HEATER ASSEMBLY

HORIZONTAL SCALE: 2X FULL, VERTICAL SCALE: 4X FULL

FINISH GRIND OD OF
(-3) CORE FOR $\pm .0002$ TO $\pm .0001$
SHRINK FIT TO (-1) SLEEVE

(-5) FLANGE - MAT'L: MOLYBDENUM
SCALE: 2X FULL

FLAME-SPRAY SEQUENCE FOR -3 CORE
FULL SCALE

468 004

RCNOYES 9/3/59

FIG. 2
HEATER DETAILS

TDR. No. 4914
PAGE 4 OF 8

DRILL $\frac{17}{32}$ DIA X $4\frac{13}{16}$ DEEP (FLAT BOTTOM)

REAM $.281 \pm .0005$ DIA X $4\frac{13}{16}$ DEEP AFTER ASSY TO -5 FLANGE (1) SLEEVE - MAT'L - MOLYBDENUM $\frac{1}{2}$ " BAR
SCALE - 2X FULL

SANDBLAST (3) WITH #40 GRIT
AFTER MACH. TO SIZE

(3) CORE - MAT'L - MOLYBDENUM $\frac{1}{4}$ " BAR
SCALE - 2X FULL

FIGURE 3.
RADIAL TEMPERATURE DISTRIBUTION
OF HEATER ASSEMBLY AND NODE
CENTER TEMPERATURES FOR
11 RADIAL NODES

ATOMICS INTERNATIONAL

A Division of North American Aviation, Inc.

NO. 4914
DATE February 22, 1960
PAGE 6 OF 8

B. Description of Rectangular Model and Code Used

Only a radial heat transfer analysis was made for this assembly, since it is assumed that variations in longitudinal heat conduction due to the presence of the thermocouple well are negligible. It is assumed furthermore, that the temperature distribution is symmetrical around a line bisecting the cross section through the center of the thermocouple well.

By plotting the angular distance in radians from the bisector at the well to any arbitrary angle less than π radians, versus the natural logarithm of the radial distance, a rectangular model is formed, in which the rings of the various materials are transformed into parallel strips of equal length, or expressed in coordinates of the mathematical model.

$$x = \ln \frac{r}{a}$$

$$y = \theta$$

where

a - constant

r - radial distance

θ - angle in radians

By sub-dividing now the x and y coordinates of the model into an arbitrary number of sections, a rectangular grid is formed in which each rectangle can be made to correspond to a node in a two-dimensional relaxation method analysis. Care has to be taken however, to express the heat generation rate in that part of the model which corresponds to the cross section of the heating layer, in the units of the grid. The difficulty of employing a small number of nodes, without sacrifice to the required accuracy in the region of high temperature disorderliness, can be resolved by dividing the transformed radial distance into a large number of small intervals and the transformed angular distance into small intervals near the well and into large ones at large angular distances.

The code used in the determination of the temperature profile for a heat flux of 5×10^5 Btu/hr-ft², was the IBM-709 code in which the matrix of heat balance equations is solved by the Gauss-Siedel method of iteration. The constants used are given in Table 2.

768 007

ATOMICS INTERNATIONAL

A Division of North American Aviation, Inc.

NO. 4914
DATE February 22, 1960
PAGE 7 OF

TABLE 2 (Reference 2 & 3)

Material	K(Btu/Hr-Ft°F)	C _p (Btu/Lb°F)	ρ(Lb/In ³)
Molybdenum	75	.069	.37
Alumina	3	.02	.087
Helium	.121	1.21	.10

The value for the density of helium is fictitious and has been chosen for reasons of convergence speed. Letting K be equal to the product ρC_p will for a steady state problem decrease the total machine time without affecting the answer.

The bulk temperature of the boiling water was chosen to be 250°F, corresponding to a saturation pressure of 30 psia. The heat generation rate is as follows:

Total heat generation of heater assembly

$$q = 5 \times 10^5 \text{ Btu/hr-ft}^2$$

Heat generation rate per unit volume of heating layer of model

$$Q = q \frac{\text{heater surface area}}{\text{Volume of heating surface of model}}$$

$$= q \frac{\pi D}{\theta_0 \ln \frac{r_1}{r_0}}$$

Where

D = heater outside diameter

$\theta_0 = 2 \pi$ (radians)

r_0 = inside radius of heating layer

r_1 = outside radius of heating layer

Q is found to be

$$Q = 8819$$

The units are Btu per hour, inches, radians.

ATOMICS INTERNATIONAL

A Division of North American Aviation, Inc.

NO 4914
DATE February 22, 1960
PAGE 8 OF 8

The total number of nodes chosen in this analysis was 122, 1 boundary, 11 radial and 11 angular nodes.

Figure 3 is a plot of the radial temperature distribution of the heater assembly with superimposed node center temperatures for 3 different radii as found by the computer analysis. The temperature distribution was calculated (ignoring the thermocouple well) by the following formulas:

$$T_1 = T_o + \frac{q^*}{2\pi k} \ln \frac{r_o}{r_1}$$

for all sections without internal heat generation, and

$$T_1 = T_o + \frac{q^*}{4\pi k} \left[1 - \frac{r_1^2}{r_o^2 - r_1^2} \ln \frac{r_o}{r_1} \right]$$

for the heating layer.

Where

r_1 - inside radius of particular layer

r_o - outside radius of particular layer

T_1 - inside surface temperature of layer

T_o - outside surface temperature of layer

q^* - heat generation rate per unit length of heater

In this calculation, because of the large film coefficient, it was assumed that the heater sleeve temperature is at 250°F.

IV REFERENCES

1. R. C. Noyes personal conversation
2. "Selected Values of the Physical Properties of Various Material" by F. T. Tebo ANL-5914 September 1958.
3. "Thermal Conductivity of Helium and Hydrogen at High Temperatures" by T. B. Mann LA 2316 September 1959.

768 009