ORNL-92

This document consists of 11 pages.
Copy 7A

Contract No. W-7405 - Eng. 26

OAK RIDGE NATIONAL LABORATORY

Technical Division

Section II

C. E. Winters - Section Chief

****

Problem Assignment No. TX12-5

THERMAL TESTS OF HANFORD SLUG CARRIER

H. C. Savage

July 12, 1948

[redacted]

DISTRIBUTION:

1. G. T. Felbeck (C&CCC N.Y.-N.Y.)
2. 706-A
3. 706-A
4. 706-A
5. 706-B
6. Biology Library
7. Training School
8. Health Physics Library
9. Central Files
10. Central Files
11. Central Files
12. Central Files
13. Central Files
14. E. J. Murphy
15. A. M. Weinberg
16. E. H. Taylor
17. M. D. Peterson
18. J. S. Felton
19. W. A. Johnson
20. A. Hollaender
21. H. Etherington
22. J. R. Huffman
23. D. G. Reid
24. C. D. Cagle
25. S. R. Sapirie (AEC Townsite)
26. H. M. Roth (AEC Townsite)
27. J. A. Lane
28. L. B. Emlet
29. C. E. Winters
30. E. Witkowski
31. S. McLain
32. H. C. Savage
33. AEC, Oak Ridge National Laboratories
34-35. Atomic Energy Commission, Washington
36-37. General Electric Company
38-44. Hanford Directed Operations
45. Patent Advisor, Washington
46-50. Technical Information Division, ORDO

TABLE OF CONTENTS

1.0 Abstract

The results of an experimental investigation of the thermal efficiency of a carrier designed for hot Hanford slugs are presented in this report.

Eight hours after discharge from the Hanford pile, the hottest Hanford slugs will have a heat evolution of 55 watts per slug (1). This heat output was duplicated in experimental tests on a carrier fabricated per drawing Nos. D3994 - D4000.

The following results and conclusions are presented for the carrier fully loaded with 19 slugs with a total heat evolution of 1045 watts (55 watts per slug).

1. A maximum temperature of 345° F of the slug located in the center of the basket was reached after approximately 12 hours.
2. The temperature at the surface of the carrier was 176° F (ambient air temperature = 86° F).
3. Experimental results are in reasonably close agreement with calculated results on which the design of the carrier was based.
4. The carrier as designed has sufficient thermal cooling capacity for use in the shipment of hot Hanford slugs.

2.0 Introduction

This investigation was conducted to determine whether or not the carrier designed as shown in ORNL drawing Nos. D3994 - D4000 possessed sufficient thermal cooling capacity to be used in shipping hot Hanford slugs. The carrier should be able to lose heat at a rate sufficient to maintain temperatures that would not damage carrier or slugs. A maximum temperature appreciably below the melting point of lead (~620° F) would be satisfactory since lead has a much lower melting point than all other materials in the carrier and slugs.

The design of the carrier was based on recommendations by J. A. Lane (1). He gave a calculated maximum slug temperature of 236° F (neglecting the temperature rise through the basket and across the air gap between slug and basket) when the carrier was loaded with 12 slugs producing 660 watts of heat. This maximum slug temperature is calculated to be 279° F when corrected for the temperature rise through the basket and across the air gap between slug and basket. This would be 12 hottest Hanford slugs 8 hours after discharge from the pile. Since the carrier is designed to hold 19 slugs, the investigation was made using 19 dummy aluminum slugs electrically heated to produce 55 watts per slug (1045 watts, total). Thus calculated results would be increased proportionably and are compared directly with experimental values.

3.0 Calculations

The following calculations of temperature rise in the carrier are those made by J. A. Lane (1) corrected for a carrier loaded with 19 instead of 12 slugs. Total heat evolution is 1045 watts (55 watts per slug) or 3580 Btu/hr.

a) Temperature drop from carrier to air

$$\Delta T_f = \frac{Q}{hA}$$

Q = 3580 Btu/hr (for 19 slugs)

h = 1 Btu/hr $(ft^2)(^oF)$

A = 24 / 18 = 42 ft^2 where surface area of carrier = 24 ft^2 and surface area of cooling holes = 18 ft^2

$$\Delta T_f = \frac{3580}{42 \times 1} = 84^\circ F$$

b) Temperature drop through carrier

$$\Delta T_{pb} = \frac{Q}{4 \pi k} \left(\frac{1}{r_1} - \frac{1}{r_o} \right)$$

k = thermal conductivity of lead = 19 Btu/hr(ft^2) $^oF/ft$

b) Temperature drop through carrier (continued)

r_i = internal radium = 6"

r_o = external radium = 15"

$$\Delta T_{pb} = \frac{3580}{4\pi(19)}\left[\frac{12}{6} - \frac{12}{15}\right] = 18^\circ F$$

(Correction for reduced area at cooling holes = 2° F)

c) Temperature drop across air gap between basket and carrier

$$\Delta T_a = \frac{Ql}{kA}$$

k = 0.016 Btu/hr ft^2 (°F/ft)

A = 2.2 ft^2

l = clearance = 0.005 inches

$$\Delta T_a = \left(\frac{3580}{2.2}\right)\frac{0.005"}{12(.016)} = 43^\circ F$$

d) Temperature drop across basket

	$\frac{k}{19}$
Volume of Pb = 0.107 ft^3	
Volume of U = 0.133 ft^3	12
Volume of air = 0.003 ft^3	.016

The average value of k = 15 Btu/hr ft^2 (°F/ft)

$$\Delta T_b = \frac{q_o r^2}{4k} = \frac{3Q}{16\pi rk}$$

where q_o = heat generated per unit volume

Q = total heat generated

r = radius from center of basket to outer slug = 4"

$$\Delta T_b = \frac{(3580)(3)}{16}\frac{12}{(4)}\frac{}{15} = 42^\circ F$$

e) Temperature drop across air gap from slug to basket

$$\Delta T_s = \frac{q\,l}{A\,k}$$

A = surface area of slug = 0.246 ft^2

e) Temperature drop across air gap from slug to basket (continued)

q = heat generated per slug = 55 watts = 188 Btu/hr

k = 0.018 Btu/hr ft^2 (°F/ft)

l = air gap = 0.007 inches

$$\Delta T_s = \frac{188\ (0.007)}{0.246\ (12)\ 0.018} = 25^\circ F$$

The temperature of the center slug then becomes

$$T_a + \Delta T_f + \Delta T_{pb} + \Delta T_a + \Delta T_b + \Delta T_s$$

For an air temperature (T_a) of 86° F the calculated center slug temperature is 300° F.

Calculation of time required for carrier to reach equilibrium.

Since the carrier increases in temperature about 100° F at equilibrium, the total heat capacity of the carrier is = $W C_p \Delta T$ where

W = weight of carrier = 6350 lbs.

C_p = heat capacity of lead = 0.0315 Btu/lb °F

ΔT = average temperature rise = 100° F

Total heat capacity = (6350)(.0315)100

= 20,000 Btu

The average heat loss to air = $hA \Delta T_{ave}$

where h = 1 Btu/hr ft^2 °F

A = surface area of carrier and cooling holes = 42 ft^2

$$\Delta T_{ave} = \frac{0 + 85}{2} = 42.5^\circ F$$

heat loss = 1 (42) 42.5 = 1760 Btu/hr

heat generated = 3580 Btu/hr

Time to reach equilibrium = $\frac{20{,}000}{3580 - 1760}$ = 11 hrs.

4.0 Description of Apparatus and Procedure

Test work was conducted on the carrier fabricated per drawing Nos. D3994 - D4000. The clearance between the slug basket and the carrier was a maximum of 0.005" as measured with feeler gages.

The carrier was fully loaded with nineteen (19) electrically heated "dummy" aluminum slugs machined to dimensions of the Hanford slug as given on page 115, Section A of the Hanford Technical Manual. The diameter was held to 1.440 ± 0.002 inches. All slugs fitted snugly but easily into the holes in the basket. The average clearance between the slugs and holes was 0.007 inch.

The slugs were connected in series and the total power input adjusted to any desired value by means of a variac and watt meter. A total of 23 chromel-alumel thermocouples were located at various points in the slugs and the carrier for temperature measurements. A small (3/8") hole drilled thru the carrier plug was used for electrical and thermocouple connections. Figure 1 is a cross section of the carrier showing thermocouple locations.

For the initial test the power was adjusted to 950 watts (50 watts per slug) and temperature measurements made at regular intervals of time. The small plugs around the top and bottom of the carrier were removed to allow air circulation thru the cooling tubes. When equilibrium temperatures were reached, these plugs were replaced to determine the affect on temperature.

After 30 hours of operation the power was increased to 1045 watts (55 watts per slug) and the test continued for an additional 18 hours.

Testing was discontinued after 48 hours of continuous operation.

SECRET

Drawing # 5900

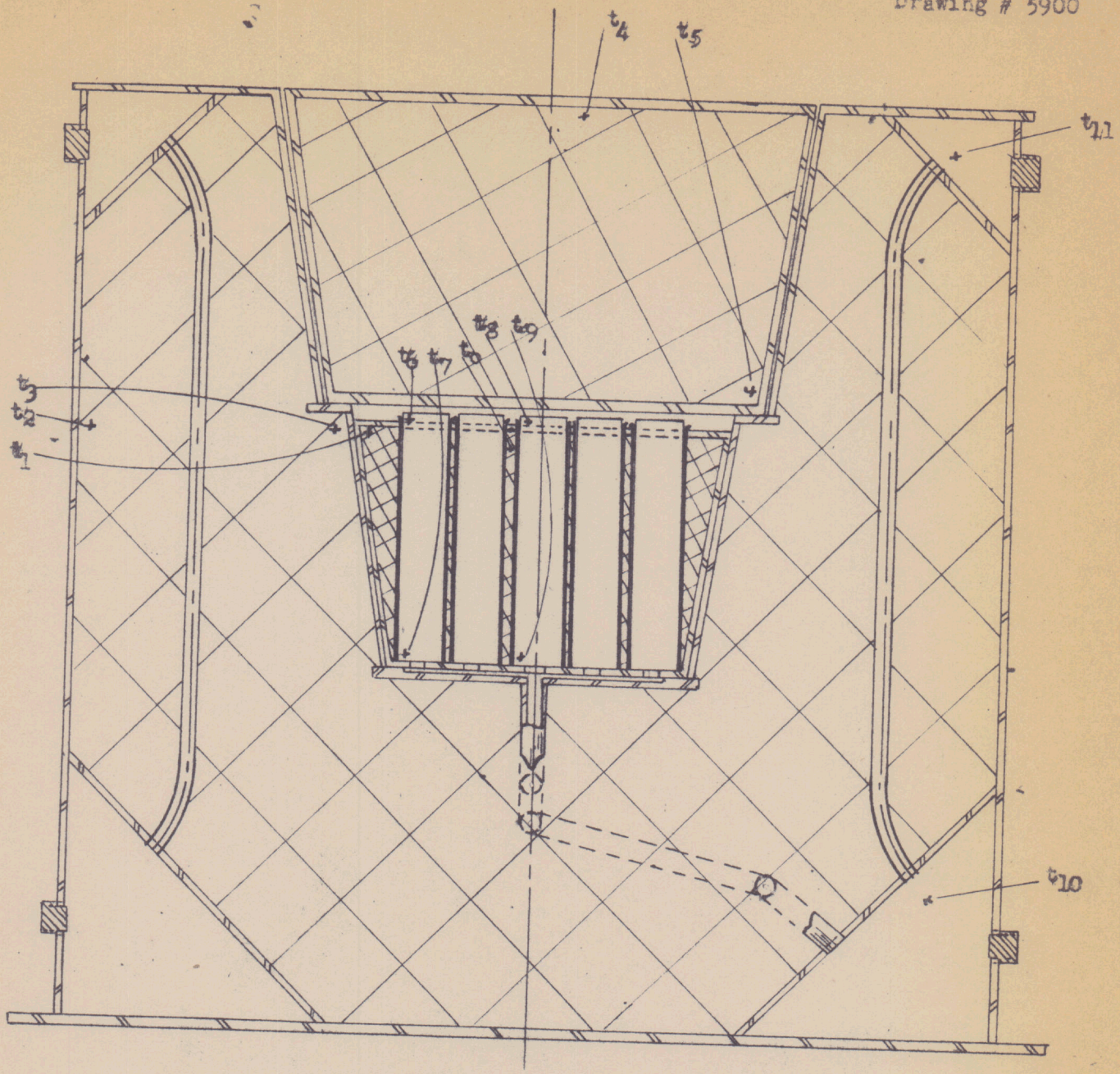

FIGURE I - CROSS SECTION OF CARRIER SHOWING THERMOCOUPLE LOCATION

SECRET

5.0 Results

The temperatures and temperature gradients obtained in the carrier fabricated per drawing Nos. D3994 - D4000 are shown in tables 1 and 2. The slug temperature given in Table 1 is the maximum obtained of five (5) slugs. The average temperature of the five slugs was 331° F. None of the individual temperatures varied more than 13° F from the average. The maximum slug temperature of 345° F was observed on the center slug while the minimum slug temperature of 320° F was obtained on a slug nearest the outer edge of the basket. The values reported are for a total slug heat evolution of 1045 watts (55 watts per slug). Equilibrium temperatures were reached after 12 hours of heating. This is in good agreement with a calculated time of 11 hours.

Table I

Location	Temperature °F	
	Calculated	Experimental
Outer surface of carrier (ambient air = 86° F)	170	176
Inner surface of carrier	190	196
Outer surface of slug basket	233	279
Center of slug basket	275	320
Slug	300	345

Table II

Location	Temperature Gradients, °F	
	Calculated	Experimental
Across air film at carrier surface	84	90
Thru lead carrier	20	20
Across air gap between slug basket and carrier	43	83*
From edge to center of slug basket	42	41
Across air gap between slug and slug basket	25	25

*This rise does not necessarily represent the true air gap gradient since the thermocouples were not directly in line across the gap.

Temperature measurements were also made at the bottom and top of the cooling tubes (thermocouples 10 and 11, Figure 1). With the plugs around top and bottom of the carrier removed, the bottom temperature (t_{10}) was 125° F and the temperature at the top (t_{11}) was 154° F (ambient air = 75° F).

During the first part of the carrier heating the plugs around the top and bottom of the sides were removed. However, after equilibrium temperatures were reached, these plugs were replaced. No appreciable temperature increase in carrier temperatures was observed with the exception of the air at top and bottom of the cooling tubes. The air at the bottom increased from 125° F to 142° F while the air at the top decreased from 154° F to 150° F.

The results presented in Tables 1 [redacted] 2 clearly indicate that the carrier is satisfactory for use in shipping hot Hanford slugs. The maximum temperature of 345° F is well within safe operating limits of the materials involved. Actually the experimental temperatures carry a slight additional factor of safety since no allowance was made for slug decay beyond the eight hour period.

6.0 References

(1) Carrier for Hanford Slugs, memorandum from J. A. Lane to L. B. Emlet, February 13, 1948.