NATIONAL BUREAU OF STANDARDS REPORT

2795

INDUSTRIAL RADIANT HEATER CORPORATION

ELECTRIC MAP HEATER

by

O. N. McDorman
P. R. Achenbach

Report to

ARMY MAP SERVICE
CORPS OF ENGINEERS
DEPARTMENT OF THE ARMY

NBS

U. S. DEPARTMENT OF COMMERCE
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Building Technology Division

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INDUSTRIAL RADIANT HEATER CORPORATION
ELECTRIC MAP HEATER

O. N. McDorman & P. R. Achenbach

ABSTRACT

Tests were made of an electric map-heater submitted by the Army Map Service, Corps of Engineers, U. S. Army to determine uniformity of heater temperature, the portion of the energy transmitted to the map by radiation, and the wave length of the energy emitted by the heated surface. The results showed that the heater, when operating on a 220-volt source, had a surface temperature of 720°F ± 12°. The measurements showed that the percentage of heat transmitted to the map by radiation would exceed 90 percent of the total heat transfer. Nearly all of the energy emitted from the heater was determined to have a wave length between 1.2μ to 6μ. The radiant energy would not be appreciably refracted or bent in travelling through the short path of air encountered in normal use of the map heater.

I. INTRODUCTION

In accordance with a request dated June 9, 1953 of the Army Map Service, Corps of Engineers, U. S. Army, measurements were made of the operating temperatures and radiation characteristics of an electric map-heater submitted by Mr. Gurtowski of the Army Map Service.

The following five operating characteristics of the heater were investigated, as agreed upon with the representative of the Army Map Service.

1. Heater surface temperature when operated on a 220-volt source.

2. Uniformity of temperature over the full heater surface.

3. The percentage of the heat absorbed by the map that was transmitted from the heater by radiation.

4. The wave length of the radiant energy.

5. The possibility of the radiation bending.

II. TEST SPECIMEN

The outside dimensions of the map-heater were approximately 43 5/8-inches long x 31 1/2-inches wide x 5 3/4-inches

high. An area of about 36-inches x 24-inches of the heater surface was heated electrically by elements underneath the surface material. A nameplate attached to the heater contained the following information:

Industrial Radiant Heat Corp.
Gladstone, New Jersey
220 AC Volts 6820 Watts 31 Amps
Model 24 x 36 Serial No. CF 446

Fig. 1 is a side view of the specimen tested and Fig. 2 is a view of the under side of the heater showing the woven glass cloth which comprised the heat-emitting surface.

III. TEST APPARATUS AND PROCEDURE

A test apparatus was constructed which simulated the horizontal track arrangement employed at the Army Map Service in making maps with such heaters. Calorimetric methods were used to measure the heat emission of the heater and to evaluate the significance of radiation in the transfer of energy. A heat receiver was constructed of an aluminum plate 36 inches x 24 inches x 7/8 inch. In the transfer of energy tests the heater was placed horizontally with the glass cloth 2 inches above the receiver surface simulating conditions of use by the Army Map Service. Fig. 1 shows the heater and receiver in position.

Two separate series of tests were made to determine the amount of heat which reached the receiver and the portion of this heat which was radiant in nature. For the first condition the aluminum surface of the heat absorber was cleaned. For the second condition the surface of the aluminum plate which was adjacent to the heater surface was painted with two coats of semi-gloss white enamel to materially change its emissivity without appreciably changing conduction and convection heat transfer. The heater was energized and allowed to reach a steady temperature before placing it over the aluminum receiver. At a chosen time the heater was quickly moved over the receiver on the horizontal track, allowed to remain over the receiver for exactly 10 minutes, then disconnected from the power source and moved away from the receiver. Heater surface and plate temperatures were observed at one-minute intervals during the 10-minute heating period and at regular intervals for a period of 90 minutes.

The temperatures on the heater surface were measured by means of 6 butt-welded chromel-alumel thermocouples, one junction being located in each of the 6 square feet of heated area.

Fig. 2 shows the thermocouple placement. An exploratory thermocouple capable of being placed at any surface point was

also constructed to measure temperatures in between the permanently attached thermocouples. The rise in receiver plate temperature was ascertained by the temperatures observed with 8 surface-type copper-constantan shielded thermocouples, four being secured to the upper surface of the receiver and four on the lower surface. When the receiver was used in its initial state the thermocouple junctions on the upper surface were covered with a reflective tape. This tape was painted the same color as the plate for the second series of tests.

Emissivity measurements were made at the temperature of boiling water on selected areas of different colors of a typical map and of the white paint used to cover the aluminum receiver.

IV. TEST RESULTS

Heater Surface Temperature and Uniformity

The permanently-attached and the exploratory thermocouples showed that the temperature of the glass cloth surface of the map heater ranged from 708°F to 732°F at an applied voltage of 220. The heater current was 27.2 amperes at this line voltage and the watthour meter readings indicated a unity power factor. The observed current and voltage readings corresponded to a power consumption of 5980 watts.

Emissivity of Map and Painted Surface

Emissivity measurements made of the white paint used to cover the aluminum receiver and of a typical map specimen furnished by the Army Map Service showed almost equal values. The average of five observations of the emissivity of the white paint was 0.920 whereas the average of four readings taken on different parts of the map was 0.926. These results which were obtained at boiling temperature of water are summarized in Table 1. The literature indicates that there would be only small changes in emissivity of these materials for the temperature range from 100°F to 212°F.

Table 1
EMISSIVITIES OF WHITE PAINT AND OF PLASTIC MAP

Test	White Paint	Map	Color of Map Area
1	0.910	--	
2	0.933	0.935	gray
3	0.914	0.916	gray
4	0.919	0.929	green
5	0.924	0.926	white border
Avg.	0.920	0.926	

Wave Length and Bending

The map heater was mounted in front of an infrared spectrometer and operated on 208 volts. After the current had been on for 30 minutes the spectral energy distribution of the emitted energy was measured. The energy spectrum was found to be continuous from 1.2μ to 6μ. The energy emitted outside this spectral region was very small in amount. The energy increased gradually from 1.2μ to 4μ where it remained constant for a small region of the spectrum and then decreased gradually to 6μ. A globar source was measured on the same instrument with similar conditions and was found to have a spectral energy distribution approximately that of the map heater when the globar source was at about 700°F. This indicates that the map heater has a spectral energy distribution which is similar to that of many heated surfaces whose emissivity is 0.8 or greater.

The infrared radiation travelling through short paths of air is not appreciably refracted or bent. The index of refraction of air is nearly unity (1.00027) and the coefficient of temperature change of the refractive index is about 0.000001 per degree centigrade. The change in direction of the radiation when passing through air at different temperatures would be very small. There would be a considerable change in direction of transmitted radiation within the plastic map when radiation fell on the surface at an angle other than perpendicular to the surface.

The transmission of the plastic map material was measured. It was found to be opaque except from 3.5μ to 7μ. The percent transmittance was low in this region and it reached its greatest value at 5.2 microns where it was 9 percent.

Radiant Heat Transfer

If the heat transmitted from the heater surface to the heat absorber were transmitted solely by conduction and convection, then covering the aluminum surface of the heat receiver with paint would not alter significantly the amount of heat received and retained by it with identical heater surface temperatures and the same ambient temperature conditions. If a portion of this transmitted heat were radiant, altering the receiver surface emissivity would influence the amount of heat received and retained by the plate. Furthermore, if the emissivity factor of the receiver and the heater surface is known, the percentage of radiant heat can be computed by the Stefan-Boltzmann equation.

A fundamental concept of heat transfer by convection is the movement of a fluid across the heated surface to convey the heat from one place to another and a further essential concept of convective heat transfer is that the heat flow is in the same direction as the fluid flow. The air flow pattern between the aluminum absorber plate and the heater surface was observed while the heater was energized and located over the absorber to reveal

the direction of air flow and heat flow.

Fig. 3 shows the air flow pattern which was observed when smoke was introduced between the heater and receiver surfaces. Air entered from the outside edge and passed toward the center over the absorber surface, rose toward the heater surface, and then reversed its direction and flowed over the heater surface toward the edge. This pattern indicated that there was probably no heat transferred by convection from the heater to the absorber.

The heat transferred from the heater surface to the absorber plate by conduction for a still air condition would be expressed by the equation:

$$H_c = \frac{KA\,\Delta Tt}{d} \quad \text{where}$$

K is the thermal conductivity of air = approx. 0.20 Btu/hr(sq ft)(°F/in)

A is the area of the absorber, sq ft

ΔT is the average temperature difference between heater and plate, °F

t is the length of the heating period, hr

d is the distance between the heater and absorber, in.

For a separation of 2 inches between the heater and absorber and a heating period of 10 minutes the heat transmitted by conduction would be 0.1 times the average temperature difference between heater and absorber provided the air was still. However, the air flow was observed to have a counterflow relationship to the direction of heat conduction. Hence the air between the heater and absorber was constantly being replaced by cool ambient air so the heat conduction would be considerably less than the values computed for still air conditions.

Three measurements were made of the heat transferred to the bare aluminum plate for a range of applied voltage from 138 to 198 corresponding to average heater surface temperatures ranging from 637°F to 870°F. Two measurements were made of the heat transferred to the painted aluminum plate for applied voltages of 198 and 227 corresponding to average heater surface temperatures of 638°F and 695°F, respectively. The results of these tests are summarized in Table 2. Since the plate was heated above ambient air temperature during each test, there was some loss of heat from the plate by convection to the ambient air and by radiation downward during each test. These corrections are shown in Table 2 in determining the total heat absorbed by the aluminum plate during each test.

The results in Table 2 for tests 3 and 5 show that with identical heater surface temperatures of 637.5°F ± 0.5°F the

aluminum plate retained 7.7 times as much heat when coated with paint as when bare. The heater surface temperatures during these tests were adjusted by regulating the supply voltage.

Several methods were used to compute what percentage of the total heat absorbed by the receiver was transferred by radiation. One approach was to use the data in Table 2 together with the measured emissivity of the paint and the map and the results described under the wave length measurements in the Stefan-Boltzmann equation of transfer of energy by radiation. This analysis resulted in a value of 89.9 percent heat transfer by radiation as being the minimum possible. Other methods indicated that the more probable percentage of heat transfer by radiation was above 97 percent. These computations are shown in the appendix.

TABLE 2
ARMY MAP HEATER
SUMMARY OF RESULTS

		BARE ALUMINUM PLATE				PAINTED ALUMINUM PLATE		
TEST NO.		1	2	3	Avg.	4	5	Avg.
HEATER DATA								
Avg. Temp.	°F	870	752	637		695	638	
Applied Voltage		198	166	138		227	198	
Current	Amp.	24.3	20.6	17.2		28.3	24.8	
ABSORBER PLATE DATA								
Initial Temp.	°F	84	86	76		82	85	
Final Temp.	°F	115	104	89		209	185	
Rise in Temp.	°F	31	18	13		127	100	
Avg. Temp.	°F	99.5	95.0	82.5		146	135	
HEAT TRANSFER								
Heat Stored in Absorber Plate	Btu	518	306	217		2124	1672	
Computed Convection Loss, Plate to Room	Btu	16	9	7		100	70	
Computed Radiation Downward from Plate	Btu	2	1	1		8	7	
Total Heat Transferred to Plate	Btu	536	316	225		2232	1749	
Computed Radiant Heat Exchange for Unity Emissivity Factor	Btu	5220	3554	2339		2864	2286	
COMPUTED EMISSIVITY FACTOR [a]		0.103	0.089	0.096	0.096	0.780	0.766	0.773

[a] Based on the assumption that the heat transferred from heater to absorber by conduction and convection was zero.

APPENDIX

Computations to determine the percentage of the heat absorbed by the receiver that was transferred by radiation.

Heat stored in the absorber plate during any test, H_s,

H_s = Spec. heat x weight x temp. rise
Weight of aluminum absorber, 74 lb
Specific heat of aluminum, 0.226 Btu/lb (°F)

$H_s = 74 \times 0.226 \times \Delta T = 16.72$ Btu/°F temp. rise

Consider Test 5 in Table 2
Rise in absorber temp. = 100°F
Therefore $H_s = 16.72 \times 100 = 1672$ Btu

Heat loss of plate to ambient air by convection during test.
Using the formula for free convection from a flat plate in the ASHVE Guide (See page 94, 1953 Guide)

$$H_{c_1} = 0.478\left(\frac{P}{P_o}\right)^{0.5}\left(\frac{\Delta T}{L}\right)^{0.25} \Delta T \text{ for upper surface}$$

$$H_{c_2} = 0.239\left(\frac{P}{P_o}\right)^{0.5}\left(\frac{\Delta T}{L}\right)^{0.25} \Delta T \text{ for lower surface}$$

or

$$H_c = 0.717\left(\frac{P}{P_o}\right)^{0.5}\left(\frac{\Delta T}{L}\right)^{0.25} \Delta T \text{ for both surfaces}$$

where $\frac{P}{P_o}$ is the ratio of the air pressure during the test to atmospheric pressure

ΔT is the average temperature difference between the plate and ambient air, °F

L is the average width of the plate, ft

For Test 5 in Table 2

$$H_c = 0.717 \times (1)^{0.5}\left(\frac{47}{2.5}\right)^{0.25} 47 = 70.2 \text{ Btu/hr (sq ft)}$$

H_c = 70 Btu during a 10 min test for the entire plate.

The actual convection loss was probably less than that computed by the above equation because it applies to a plate to which the air has free access above and below. These conditions did not exist during the test.

Heat radiated from the bottom of the plate to the supporting table during the test can be approximated using the Stefan-Boltzmann equation with a combined emissivity factor of 0.1

H_r = 7 Btu for Test 5 in Table 2

Total heat transmitted to the painted absorber plate during Test 5, Q_p,

$$Q_p = H_s + H_c + H_r = 1672 + 70 + 7 = 1749 \text{ Btu}$$

Using the same procedure for Test 3, made with the absorber plate unpainted,

$$Q_A = 225 \text{ Btu}$$

Then $$\frac{Q_p}{Q_A} = \frac{1749}{225} = 7.78 \qquad (1)$$

Considering the three methods of heat transfer from the heater to the absorber plate the total transfer can be expressed as follows:

$$Q_p = c + E_p \sigma (T_1^4 - T_2^4) \quad \text{for the painted plate}$$

$$Q_A = c + E_A \sigma (T_1^4 - T_2^4) \quad \text{for the bare plate}$$

where c is the total heat transfer from the heater to absorber by convection and conduction. c would be equal for the painted and unpainted plate for practical purposes.

E_p is the combined emissivity factor of heater surface and painted plate

E_A is the combined emissivity factor of heater surface and unpainted plate

T_1 is the average absolute temperature of the heater

T_2 is the average absolute temperature of the absorber

Using the observed temperatures in Tests 3 and 5

$$Q_p = c + 2298\, E_p \qquad (2)$$

$$Q_A = c + 2358\, E_A \qquad (3)$$

Combining equations (1), (2) and (3)

$$c + 2298\, E_p = 7.78\, (c + 2358\, E_A)$$

$$6.78c = 2298\, E_p - 18345\, E_A$$

$$c = 339\, E_p - 2707\, E_A \qquad (4)$$

Using the formula for combined emissivity of two large parallel surfaces

$$E = \frac{e_1 e_2}{(e_1 + e_2) - e_1 e_2}$$

and e_p = emissivity of painted absorber = 0.92 (from experimental data)

e_h = emissivity of heater surface, > 0.8 (from experimental data)

e_a = emissivity of aluminum plate

The maximum possible value of $E_p = 0.92$ taking $e_h = 1.0$

The minimum possible value of $E_A = 0.0494$ taking $e_a = 0.05$ and $e_h = 0.8$

Then, the maximum possible value of heat transfer by convection and conduction would be from equation (4)

$$c = 339 \times 0.92 - 2707 \times .0494 = 178 \text{ Btu}$$

But the total heat transferred was determined to be 1749 Btu

Minimum transfer by radiation $= \frac{1749 - 178}{1749} = 89.9\%$

More probable values of e_a and e_h taken from the literature are 0.07 and 0.90, respectively. Based on these values the minimum transfer by radiation would be 94.5% of the total transfer.

A Second Method for Determining Radiant Heat Transfer

$e_h > 0.8$ (experimental data)

$e_p = 0.92$ (experimental data)

$E_p > 0.748$

The radiant heat transfer for Test 5 by the Stefan-Boltzmann equation would be

$$H_R = E_p \sigma (T_1^4 - T_2^4)$$

$$H_R > 0.748 \times 0.173 \times 10^4 \times (1.098^4 - .595^4)$$

$$H_R > 1720 \text{ Btu}$$

Percent Radiation $> \frac{1720}{1749}$

" " $> 98\%$

A Third Analysis of Radiant Heat Transfer

From the convection currents observed with smoke around the absorber and heater, it is probable that the convection heat transfer from heater to absorber was negligible.

From the analysis in the text the conduction heat transfer, $H_k < 0.1 \times$ Avg Temp Diff.

For Test 5

$H_k < 0.1\ (638 - 135)$

$H_k < 50.3$ Btu

Therefore Percent Radiation $> \frac{1749 - 50}{1749}$

" " $> 97.2\%$

It is considered probable that the percent radiant heat transfer to the painted absorber (and therefore to a map of equal emissivity) was nearer to the values obtained by the second and third methods of analysis shown above than to the minimum value computed by the first method.

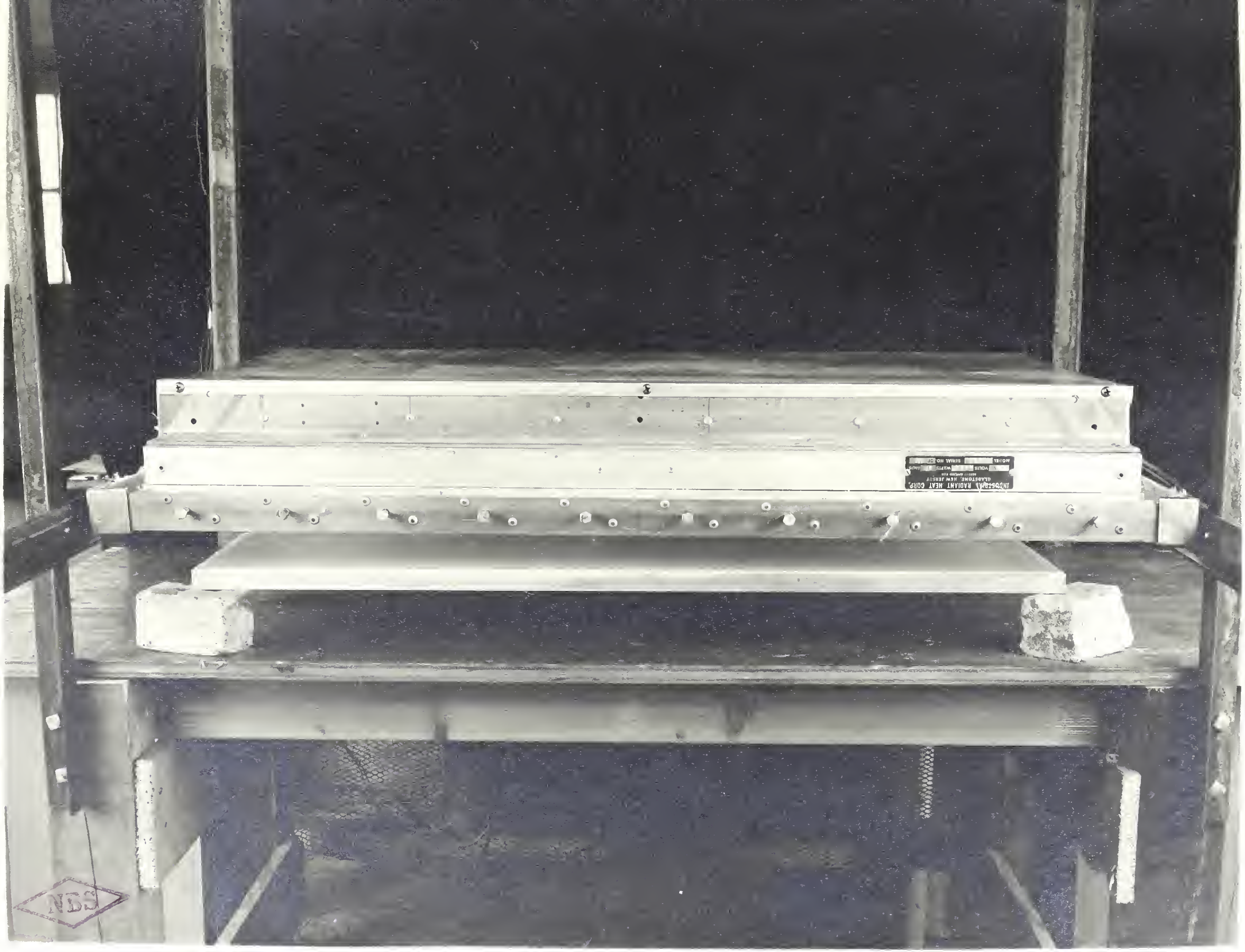
INDUSTRIAL RADIANT HEAT CORP.
GLADSTONE, NEW JERSEY
MODEL
VOLTS
WATTS
SERIAL NO.
NBS

Fig. 1

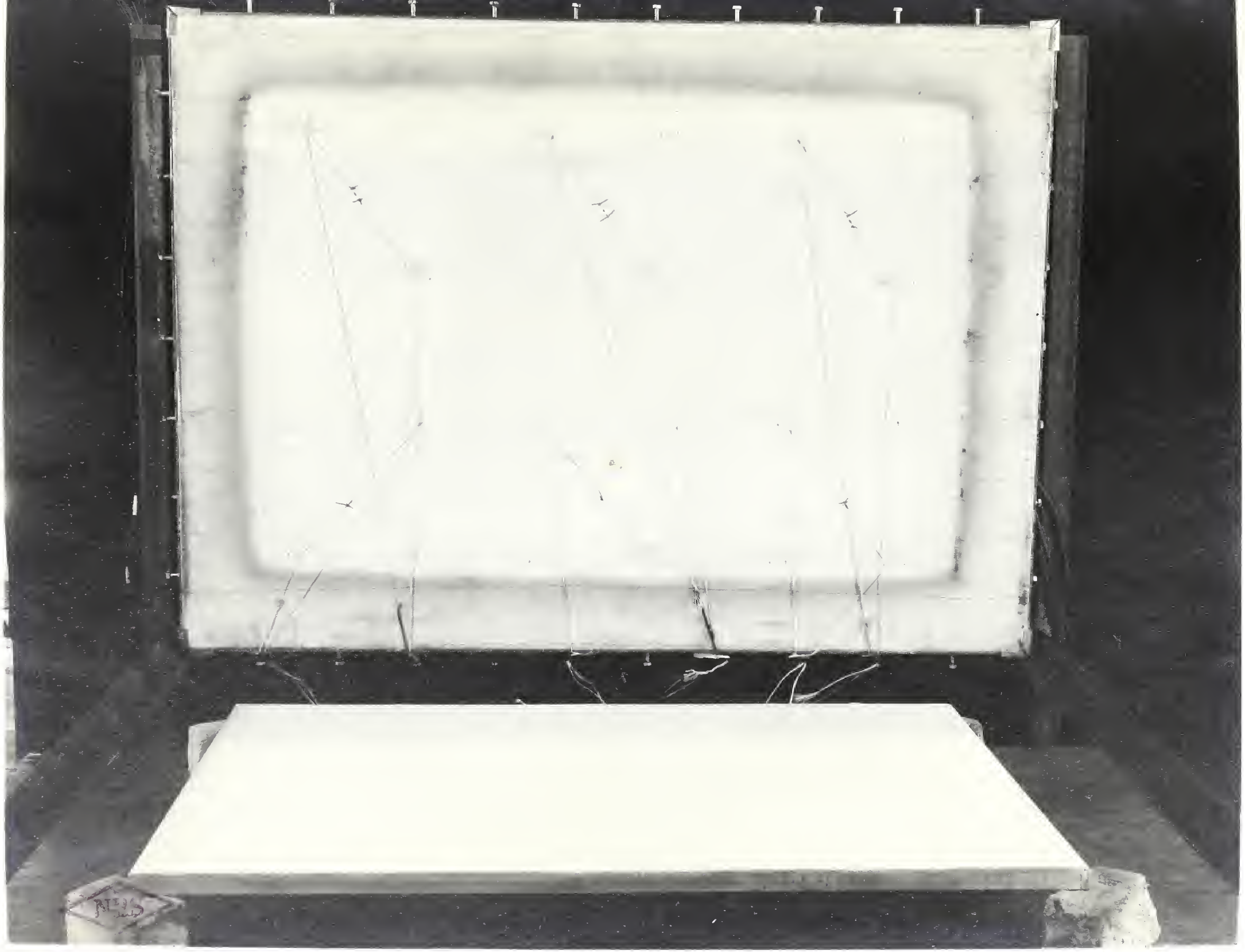

Fig. 8

Fig. 3

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