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ABSTRACT

A summary of the results of measuring the total emittance of some receiving tube materials is given. The resistance heated strip method described in R59ETR-1 was used.

Major attention is given to carbonized materials, nickel, and converted aluminum-clad iron. The effect of certain processing variables on total emittance was studied. Some measurements of the total emittance of the oxide cathode are included.

TOTAL EMITTANCE OF RECEIVING TUBE MATERIALS

Introduction

During the past few years we have made a rather extensive study of thermal properties of receiving tubes and tube materials. In particular, the thermal radiation property, total emittance (or emissivity), has been determined for a number of materials.

This report summarizes the results of total emittance measurements made at the Receiving Tube Department Chemical & Physics Laboratory. The resistance heated strip method described in R-59ETR-1 was used.

Section I discusses the scope of the problem.

Section II condenses much of the data into a graphical form that should be very useful to tube engineers.

Section III summarizes the results obtained from a number of investigations relating to aluminum-clad iron.

Section IV treats carbon-coated materials.

Section V gives results relating to Grade "A" nickel and the effects of various surface treatments.

Section VI gives some values of oxide cathode emittance as a function of temperature.

SECTION I

Scope of the Work

The purpose of this report is to provide information relating to the total (thermal) emittance of tube materials and the effects of processing variables thereon, which, when considered along with other properties of the material, should enable the tube engineer to use a more scientific approach in the application and testing of materials in electron devices.

The study of thermal properties of tube materials is an integral part of a program of materials research under way at RTD to provide information that is essential to (1) the improvement of standard tube materials through better processing, etc.; (2) the development of new materials; (3) a more enlightened application of materials; and (4) a good quantitative estimate of the physical and chemical activities, e.g., gas evolution, chemical reactions, etc., that occur under conditions of tube operation.

It is hoped (and anticipated) that this type of information will become increasingly helpful in the never ending quest for new electron devices, higher reliability, more electronic functions per unit volume, etc.

The general problem of reducing the rates of chemical and physical reactions that are detrimental to the stability and/or life of an electron tube is quite complex, involving a number of properties of materials. The temperature dependency of these reactions, along with the fact that most heat generated inside a receiving tube must be transferred by thermal radiation, makes it evident that the total emittance of materials is an important factor in determining the equilibrium temperatures of electrodes and other component parts of a tube. The gas content of a material and its sorption characteristics are also very important. (See R-60-ETR-2.)

For example, consider a specific type of polished carbonized nickel that may be obtained from three different suppliers. Each material has a different value of total emittance, and each usually has a different gas content and sorption rate at any stage during its processing and operating history. Unfortunately, in this particular case, the material with the lowest gas content and residual rate of evolution usually has the lowest total emittance. Since the temperature and total emittance of the anode are usually prominent factors in the determination of equilibrium temperatures of other tube elements, including the tube envelope, the problem cannot be isolated from the operating environment of the material of interest. It is therefore essential that each tube type or each family of tubes be treated as a separate problem in applying information relating to thermal properties and gas content of a material. To illustrate an extreme case, even if all other properties of a given material are superior, and the material has the highest emittance, the lowest rate of gas evolution as a function of temperature and time, and the lowest cost, it still may not be the best anode material

to use. It is possible that in a few cases where the bulb temperature is critical, the high emittance (hence lower temperature) of the anode material for a given input power could cause the bulb temperature to rise more than enough to offset the benefit of a lower anode temperature.1

1. See Report R57ETR-9

SECTION II

Summary of Results

A resume of the results of various emittance experiments are given on pages 5 and 6. Figure 1 shows typical emittance versus temperature curves for a variety of tube materials. Figure 2 presents the same information in the form of radiancy; i.e., power radiated in watts/cm^2, as a function of temperature. Power radiated by a source at any temperature T_1 to its surroundings may be calculated by subtracting the appropriate values given in Table 1. The curves in Figure 1 and Figure 2 represent the average values obtained in measuring several samples of each material. All told, a total of about 250 samples has been tested.

The Stefan-Boltzmann Law expresses the thermal energy radiated from a solid body at temperature T_1 to its environment at temperature T_2.

$$P/A = e_1 F_g \sigma (T_1^4 - T_2^4) \qquad (1)$$

Where P = Power radiated, e.g., in watts
A = Surface area
e_1 = Total emittance of source
F_g = Geometrical factor
σ = Stefan-Boltzmann Constant
$= 5.67 \times 10^{-12}$ watts cm^{-2} T^{-4}
T_1 = Source temperature (absolute)
T_2 = Sink temperature (absolute)

If the dimensions of the source are small in comparison to those of the enclosure, F_g in equation (1) may be replaced by unity.

$$P/A = e_1 \sigma T_1^4 - e_1 \sigma T_2^4 \qquad (2)$$

The first right-hand term of equation 2 is the radiancy of the material as given in Figure 2.

Table 1 gives values for the second term with temperature T_2 and emittance e_1 as parameters. The power radiated from a material at temperature T_1 to its environment at temperature T_2 can be obtained by subtracting the appropriate value in Table 1 from the radiancy, which can be obtained from the curves in Figure 2.

The above relation holds only if the source is small in comparison to its surrounding enclosure; otherwise, the geometrical factor, F_g, must be included in the calculations. F_g may be determined for concentric cylinders of infinite length from Figure 3. A good approximation for most irregular objects or enclosures can be obtained by letting $\alpha = 1$.

TOTAL EMITTANCE VS. TEMPERATURE

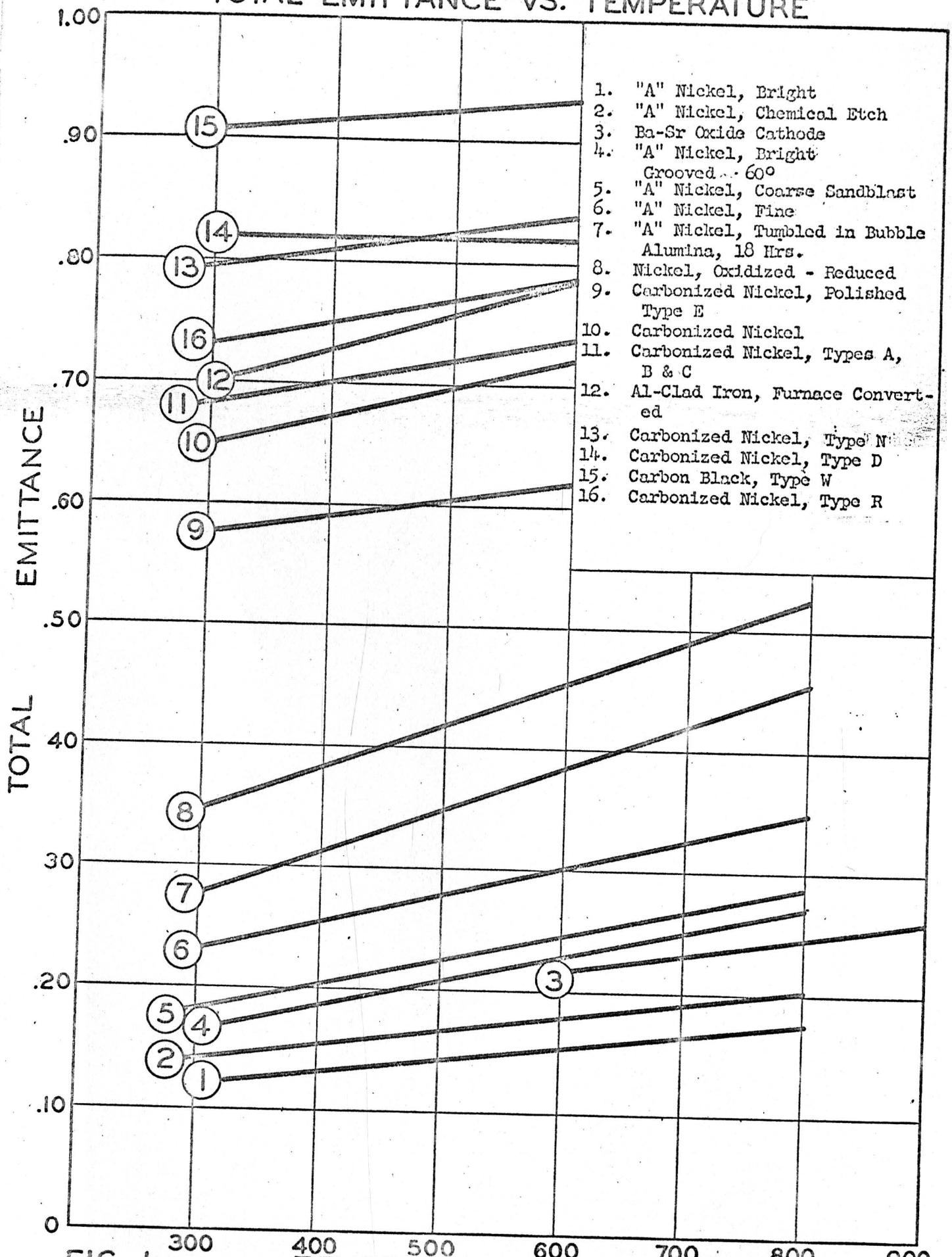


FIG. 1

RADIANCY VS. TEMPERATURE

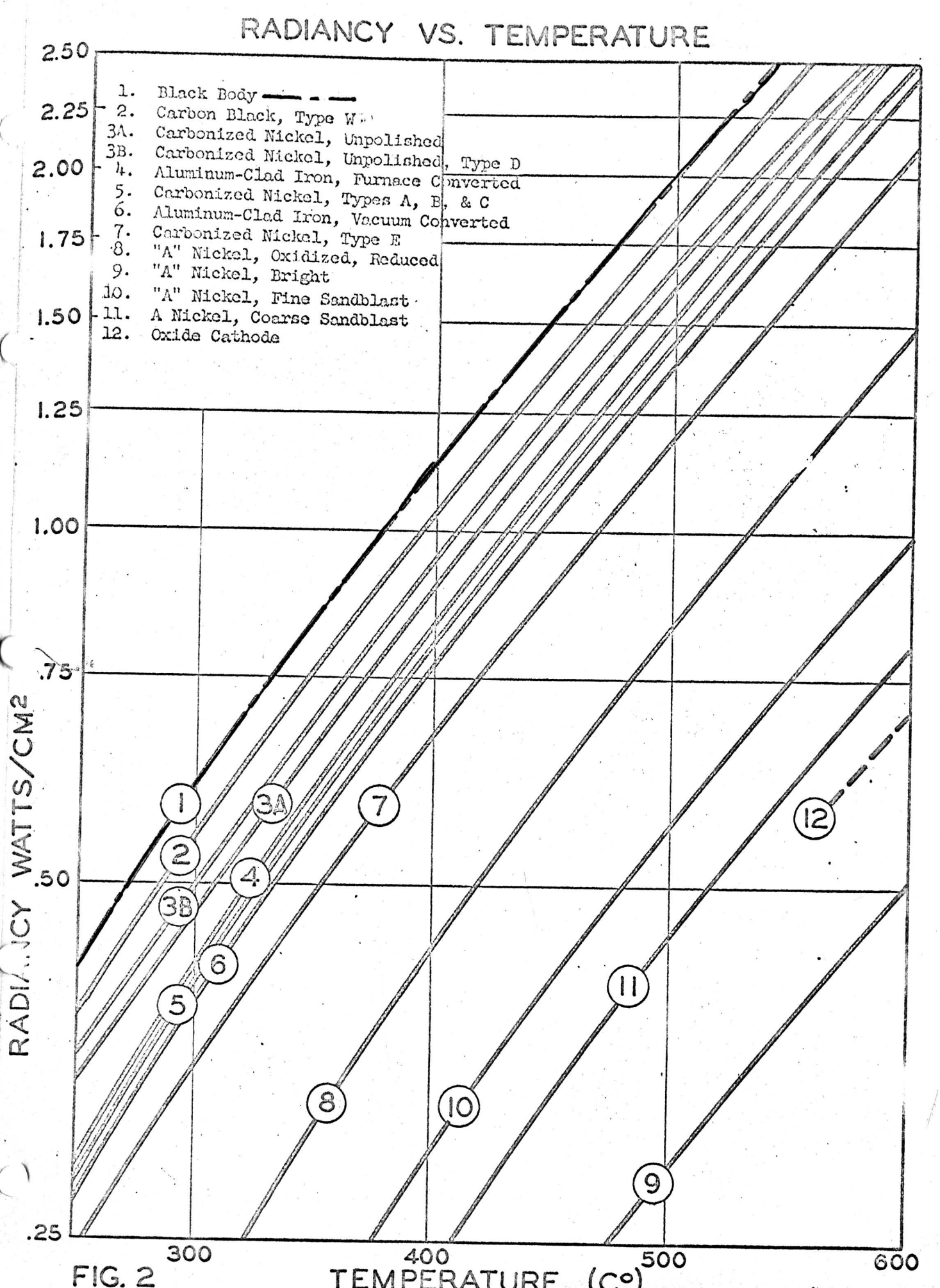


FIG. 2

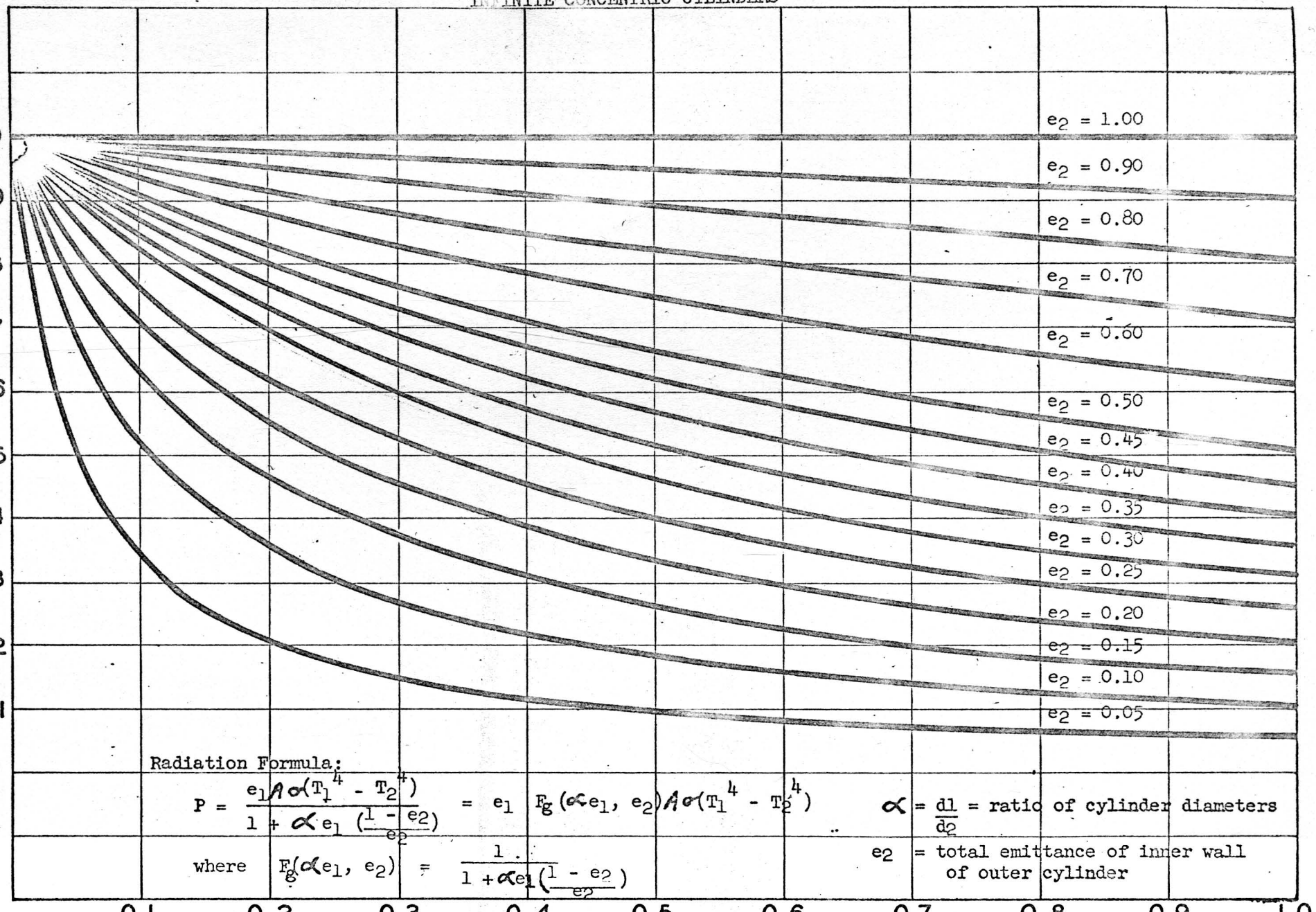
TABLE I

RADIANCY IN WATTS/CM^2

$T^oC \rightarrow$ / e_1	27	100	150	200	250	300	350	400	450	500	550	600
0.10	.005	.011	.018	.028	.042	.061	.085	.116	.155	.203	.260	.329
0.15	.007	.017	.027	.043	.064	.092	.070	.174	.233	.305	.390	.494
0.20	.009	.022	.036	.057	.085	.122	.171	.232	.310	.406	.820	.688
0.25	.012	.028	.046	.071	.106	.153	.214	.290	.388	.508	.650	.823
0.30	.014	.033	.055	.085	.127	.183	.256	.348	.465	.609	.780	0.987
0.35	.016	.039	.064	.099	.148	.214	.299	.406	.543	.711	.910	1.15
0.40	.018	.044	.073	.114	.170	.244	.342	.464	.620	.812	1.04	1.32
0.45	.021	.050	.082	.128	.199	.275	.384	.522	.698	.914	1.17	1.48
0.50	.023	.055	.091	.142	.212	.306	.427	.580	.775	1.02	1.30	1.65
0.55	.025	.061	.100	.156	.233	.336	.470	.638	.853	1.12	1.43	1.81
0.60	.028	.066	.109	.190	.254	.367	.512	.696	.930	1.22	1.56	1.97
0.65	.030	.072	.118	.185	.276	.397	.555	.754	1.01	1.32	1.69	2.14
0.70	.032	.077	.127	.199	.297	.428	.598	.812	1.09	1.42	1.82	2.30
0.75	.035	.083	.137	.213	.318	.458	.641	.870	1.16	1.52	1.95	2.47
0.80	.037	.088	.146	.227	.339	.489	.683	.928	1.24	1.62	2.08	2.63
0.85	.039	.094	.155	.241	.360	.519	.726	.986	1.32	1.73	2.21	2.80
0.90	.041	.099	.164	.256	.382	.550	.769	1.04	1.40	1.83	2.34	2.96
0.95	.044	.105	.173	.270	.403	.580	.811	1.10	1.47	1.93	2.47	3.13
1.00	.046	.110	.182	.284	.424	.611	.854	1.16	1.55	2.03	2.60	3.29

CYLINDRICAL RADIATION TRANSFER

INFINITE CONCENTRIC CYLINDERS



Radiation Formula:

$$P = \frac{e_1 A \sigma (T_1^4 - T_2^4)}{1 + \alpha e_1 \left(\frac{1 - e_2}{e_2}\right)} = e_1 F_g(\alpha e_1, e_2) A \sigma (T_1^4 - T_2^4)$$

where $$F_g(\alpha e_1, e_2) = \frac{1}{1 + \alpha e_1 \left(\frac{1 - e_2}{e_2}\right)}$$

$\alpha = \frac{d1}{d2}$ = ratio of cylinder diameters

e_2 = total emittance of inner wall of outer cylinder

FIG. 3

SECTION III

Aluminum-Clad Iron (Steel)

Measurements of the total emittance of aluminum-clad iron and studies of the effects of a number of processing variables have been made. A brief summary of the pertinent results and observations are given below.

Summary

1. Converted aluminum-clad iron has a total emittance that usually occurs between 0.7 and 0.8 within the 300°C-600°C temperature range.

2. In a study involving hydrogen, dissociated ammonia, and air furnace atmospheres, the total emittance of converted aluminum-clad iron was found to be affected very little by the composition of the furnace atmosphere during the alloying period or thereafter.

3. Vacuum conversion of aluminum-clad iron produces a total emittance 5 to 10 percent lower than atmosphere conversion, unless the process is carried out extremely slowly.

4. The brushing process used by the manufacturers of strip materials to remove oxide films, etc., does not normally change the total emittance of the converted material. Samples of bright brushed, bright unbrushed, stained brushed, and stained unbrushed, were used in making this study.

5. The rate of formation of the aluminum-iron alloy during conversion in vacuum produces distinct differences in the surface roughness, porosity, and total emittance of the material. A rapid traversing of the eutectic temperature produces a material that possesses a much lower total emittance.

6. Experimental samples of nickel-plated aluminum-clad iron were found to have total emittances ranging from that of aluminum-clad iron to about 10% lower, although the material was darker in appearance after conversion.

7. Experimental samples of iron-clad aluminum-clad iron possessed a total emittance 10 to 15 percent higher than regular aluminum-clad iron.

8. Darkening the appearance of converted aluminum-clad iron by tumbling in refractory granules does not change its total emittance much, if at all.

9. It was discovered that a vacuum converted sample of aluminum-clad iron will turn almost black upon subsequent firing at 800°C in dissociated ammonia; whereas, one that has been previously converted in dissociated ammonia changes very little in appearance during a second firing. The darkening of the vacuum converted sample did not change its total emittance by more than 2 or 3 percent, however.

10. The new 5-ply copper-cored aluminum-clad iron, C50B1, was found to have about the same total emittance as regular aluminum-clad iron.

11. After conversion, a cycling of an aluminum-clad iron sample strip between room temperature and 1000°C in vacuum does not appreciably affect the total emittance.

12. Samples fired in a furnace usually have a more porous surface than their counterparts fired in vacuum.

13. X-ray diffraction patterns of the converted aluminum-clad iron vary somewhat with the processing schedule. However, it is difficult to determine whether the differences are due to lattice distortions or to a difference in composition of the alloy.

14. When samples of aluminum-clad iron strip material are held together during the conversion process in a hydrogen or dissociated ammonia furnace atmosphere, their adjacent surfaces appeared darker, more olive drab in color, than the characteristic gray or blue-gray color normally obtained.

15. Two samples of converted aluminum-clad nickel that had a dark blue-black appearance were found to have a much lower total emittance (~ 0.5) than aluminum-clad iron. The surface aluminum-nickel alloy films may have been too thin to achieve the maximum total emissivity. Further work will be necessary to settle the question.

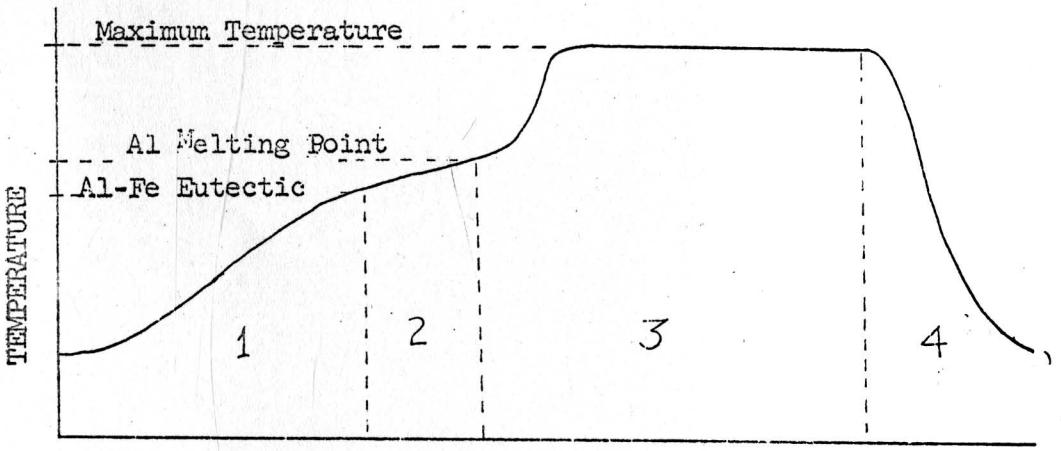
16. Experimental samples of aluminum-iron and copper cored aluminum-iron strips prepared by powder metallurgy techniques were found to have about the same total emittance as the standard material.

Comments and Recommendations

The general problem of processing anode materials must include considerations of several other physical and chemical properties in addition to that of total emittance. In terms of controlled variables, the optimum processing schedule of a material that is used to perform a specific function in a specific tube type can be defined in terms of its environment and of its own temperature versus time processing function, which henceforth will be called the T-P function. For a given application there exists an optimum T-P function and a family of acceptable functions which lie within the process limits (which may or may not as yet be adequately determined).

The results given in this report serve to indicate that the T-P function is very important in controlling the emittance and macrostructure of the aluminum-iron alloy. The effects of varying the T-P function upon the properties of the material, e.g., structure, porosity, and surface geometry of the aluminum-iron alloy, gas absorption and evolution properties, total sublimation from the surface, etc., are not too well known in a quantitative manner.

If further study of the processing of anode materials is warranted, it is suggested that the T-P curve be divided into four segments as shown below, and used for the purpose of obtaining a superior empirical T-P processing function.



Illustrative Example - T-P Curve

Section (1) is that portion of the curve prior to reaching the Al-Fe eutectic temperature, i.e., the lowest melting point of the Al-Fe alloy system. Section (2) is that portion which lies between the eutectic point and the melting point of aluminum. Section (3) includes the maximum temperature reached, whereas section (4) is the cool-down or annealing portion of the curve.

The slope of segment #2 portion of the curve and the peak magnitude and time duration of segment #3 are of considerable interest in the processing schedule. Other portions of the curve may also be important.

Experimental T-P curves could be generated in a regular gas-filled furnace by attaching a thermocouple to the material to be processed, and moving the material in and out of the hot zone of the furnace at a controlled rate. If experiments revealed any significant improvements in the material, the automatic programming of the T-P curve could be set up without undue difficulty.

ALUMINUM-CLAD IRON
EMITTANCE VS TEMPERATURE

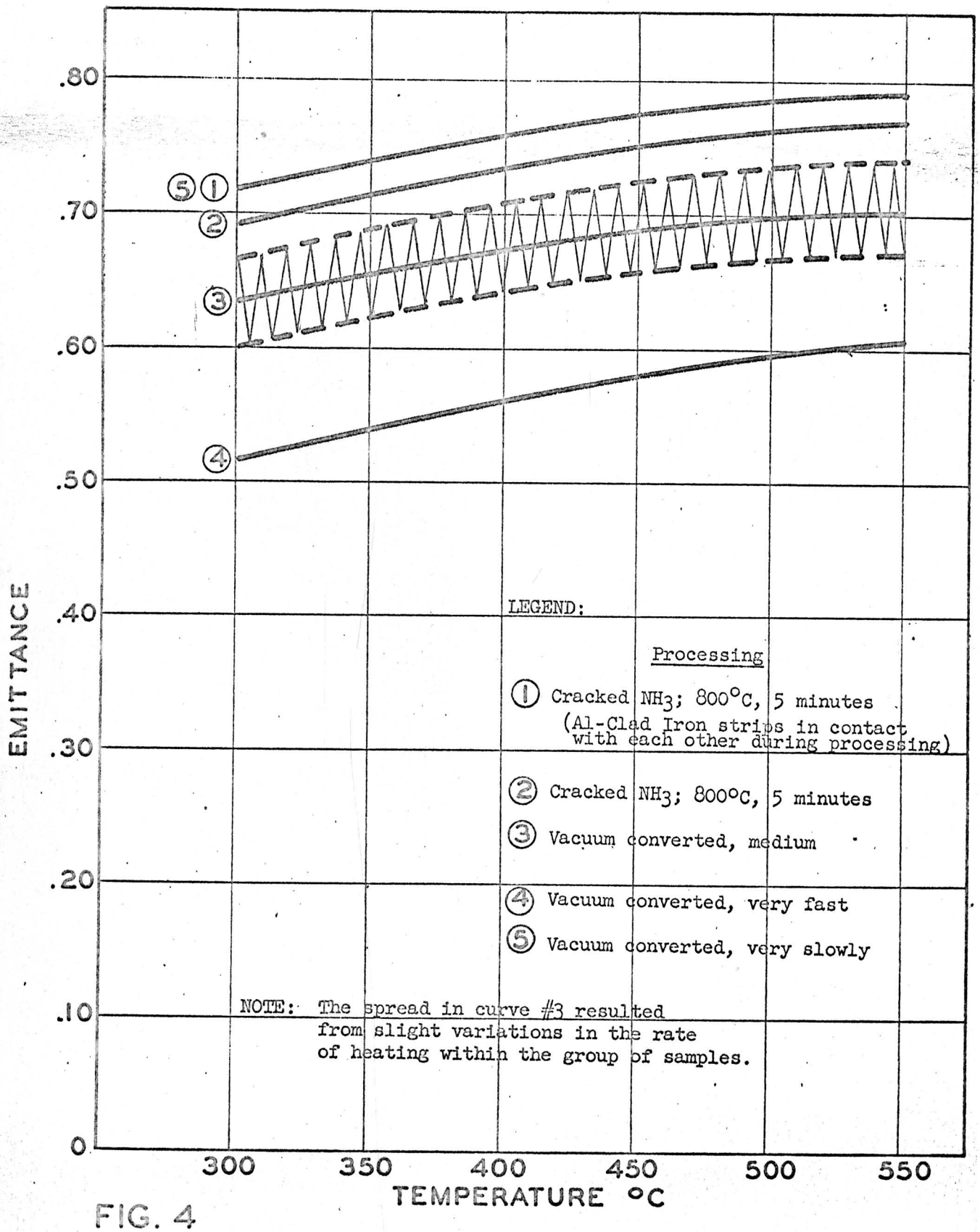


FIG. 4

RADIANCY OF ALUMINUM-CLAD IRON

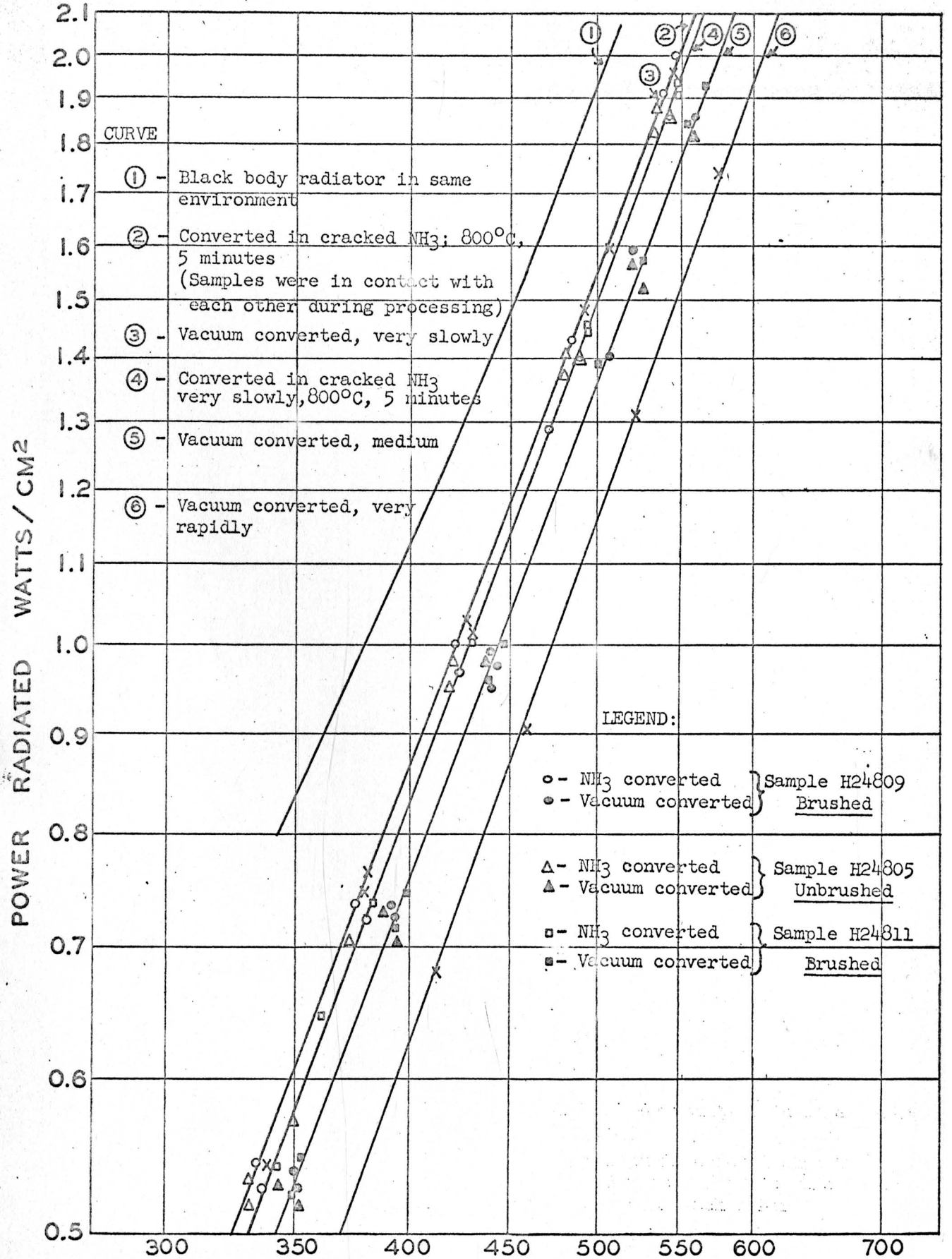


FIG. 5

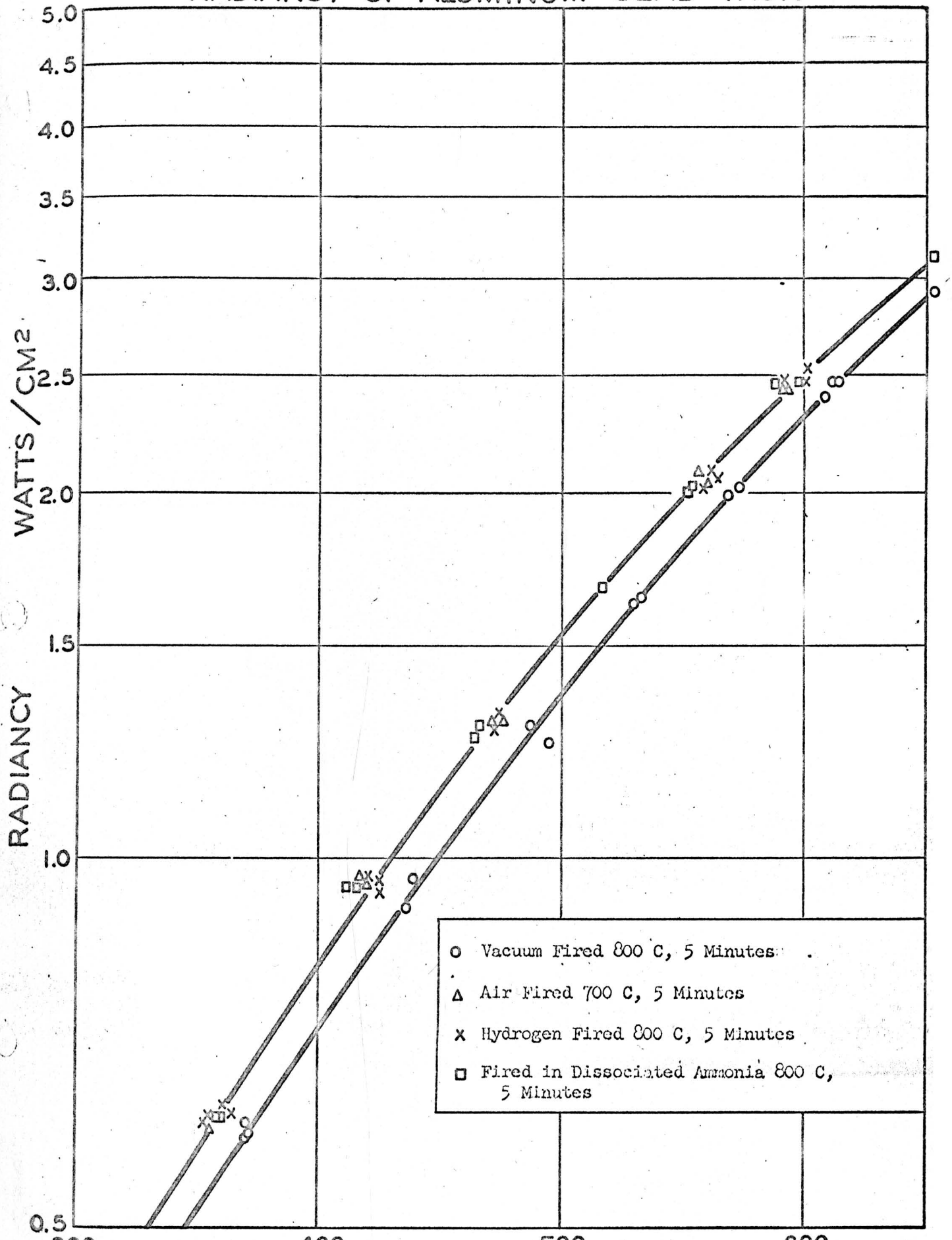

RADIANCY OF ALUMINUM CLAD IRON
RADIANCY
WATTS / CM2
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
300
400
500
600
TEMPERATURE °C
o Vacuum Fired 800 C, 5 Minutes
Δ Air Fired 700 C, 5 Minutes
x Hydrogen Fired 800 C, 5 Minutes
□ Fired in Dissociated Ammonia 800 C, 5 Minutes

FIG. 6

SECTION IV

Carbonized Nickel

A number of carbonized nickel materials have been tested to study their total emittance characteristics. While the information is not as complete as that for aluminum-clad iron materials, the following facts have been fairly well established.

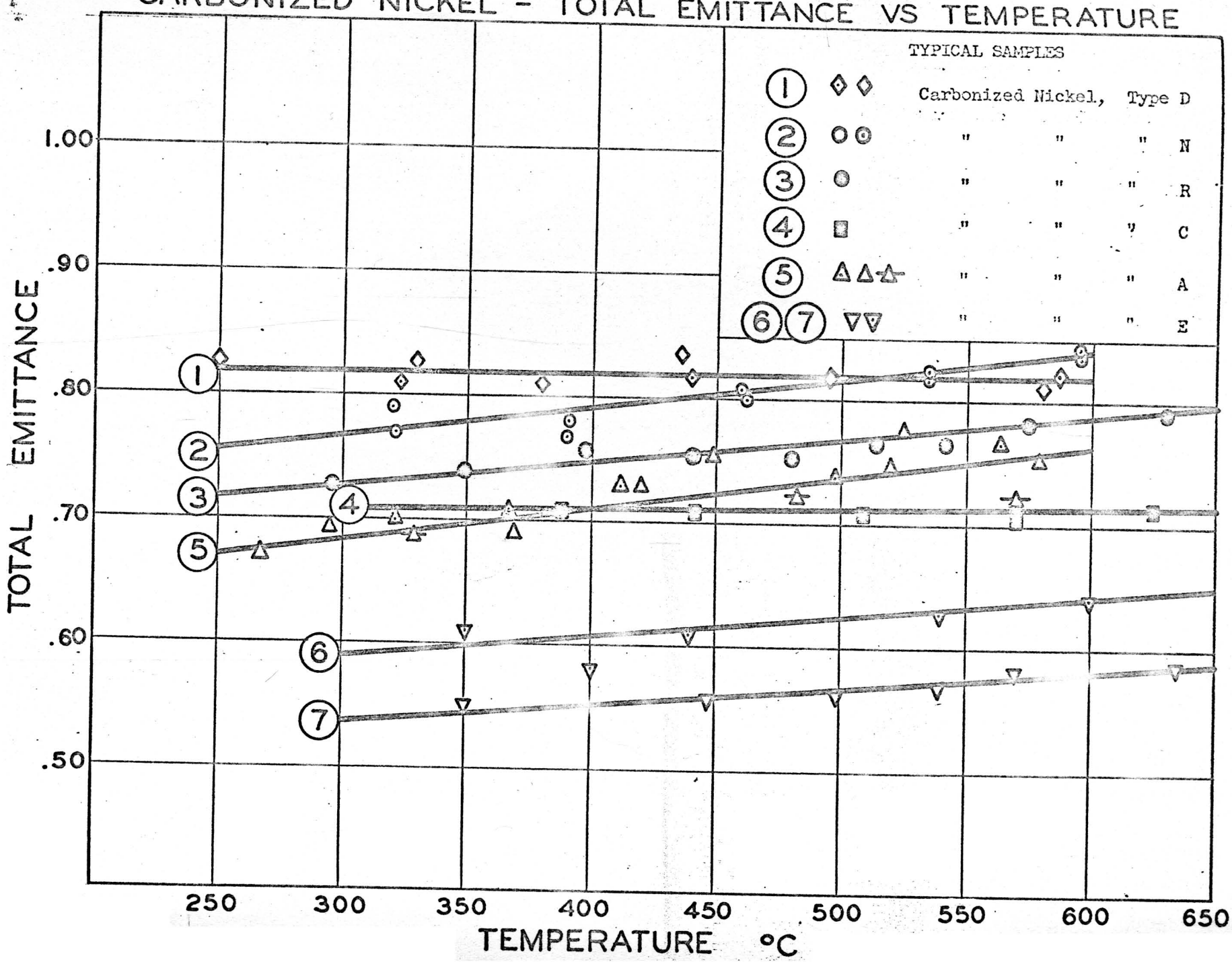
1. Unpolished carbonized materials usually have a higher total emittance than polished carbonized samples. At 400°C the emittance values for different types of unpolished samples ranged from 0.70 to 0.92; whereas, the various polished materials ranged from 0.55 to 0.75.

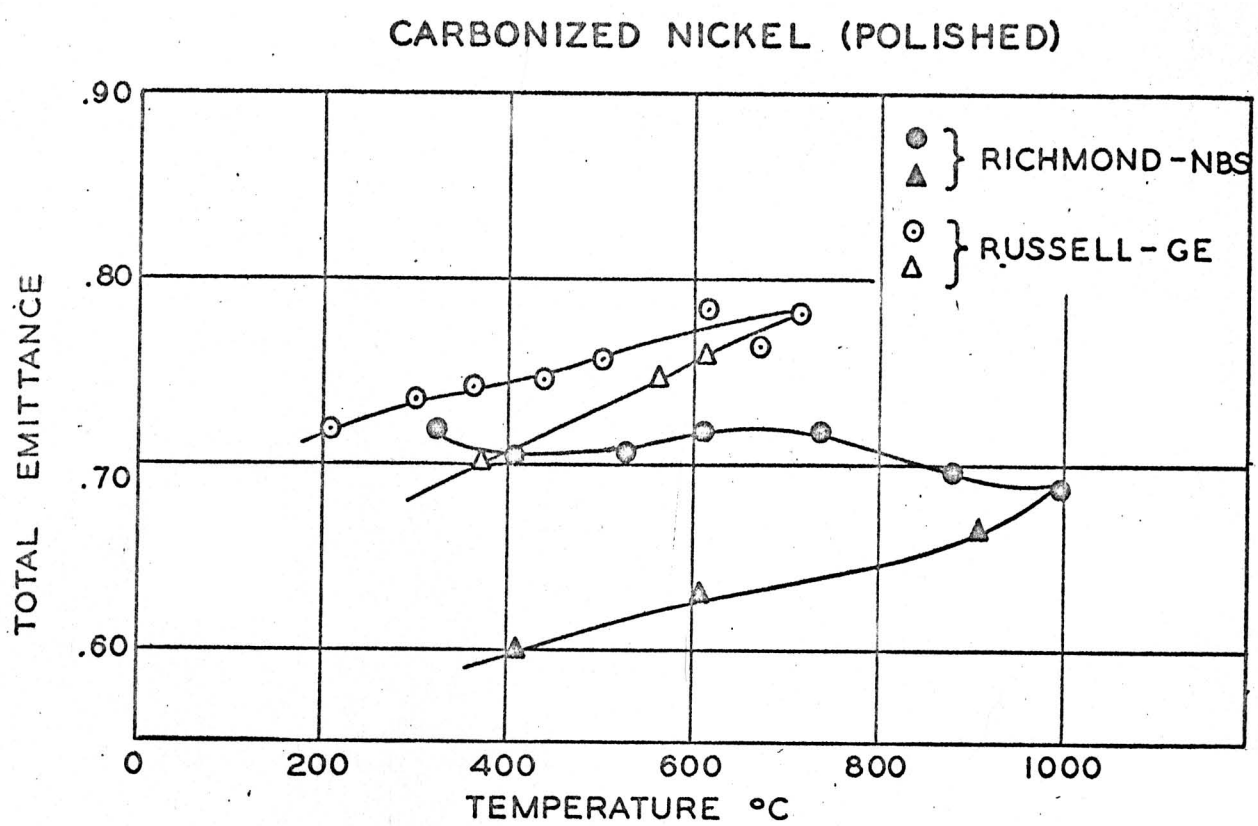
   As a general rule, unpolished carbonized nickel has a total emittance equal to or greater than gas converted aluminum-clad iron, and polished carbonized nickel has a total emittance less than or equal to aluminum-clad iron in the temperature range of 300°C to 600°C.

2. The temperature coefficient of emittance, α_ϵ, i.e., the slope of the emittance versus temperature curve varies somewhat from sample to sample of the same type of material. It varies more however among the different types of material (see Figure 7). A specific study of the statistical distribution of the temperature coefficient, α_ϵ, was not included as a part of the experiments. Therefore, the possibility that the variations may be due to systematic errors cannot be ignored. However, since the range of α_ϵ's of other materials studied, such as aluminum-clad iron and nickel, was much smaller. I suspect that at least a part of the measured variations of α_ϵ is real.

3. Samples of the same type of polished carbonized material acquired from different suppliers had different values of total emittance. (See Figure 7.)

4. The firing of carbonized nickel to temperatures above 800°C sometimes causes a decrease in total emittance of the sample (e.g., see Figures 7 & 8). Obviously, if enough carbon is removed to partly expose the metal surface, the effective emittance will be lowered. The effect of film thickness upon the total emittance of carbonized materials has not been well established, however.


CARBONIZED NICKEL - TOTAL EMITTANCE VS TEMPERATURE
TYPICAL SAMPLES
1 Carbonized Nickel, Type D
2 " " " N
3 " " " R
4 " " " C
5 " " " A
6 7 " " " E
TOTAL EMITTANCE
1.00
.90
.80
.70
.60
.50
250
300
350
400
450
500
550
600
650
TEMPERATURE °C


CARBONIZED NICKEL (POLISHED)
TOTAL EMITTANCE
.90
.80
.70
.60
0
200
400
600
800
1000
TEMPERATURE °C
RICHMOND - NBS
RUSSELL - GE

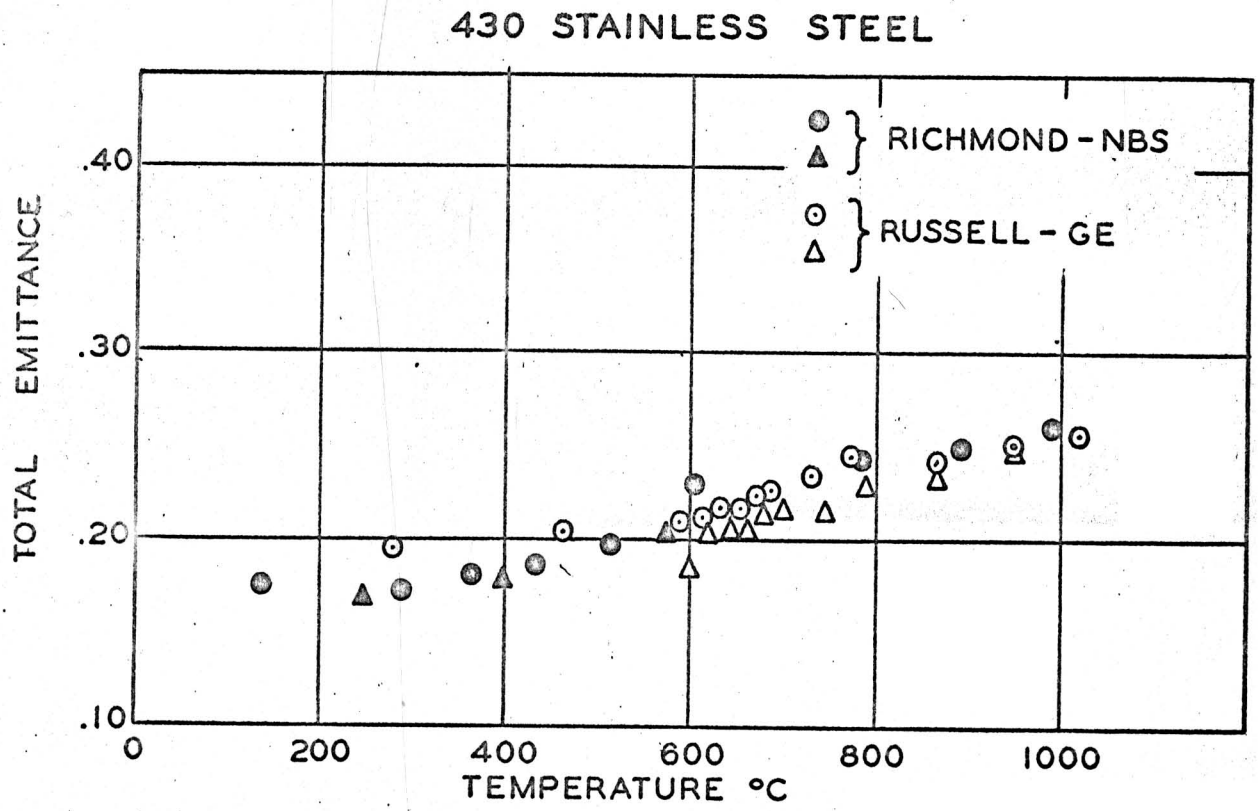

430 STAINLESS STEEL
TOTAL EMITTANCE
.40
.30
.20
.10
0
200
400
600
800
1000
TEMPERATURE °C
RICHMOND - NBS
RUSSELL - GE

FIG. 8

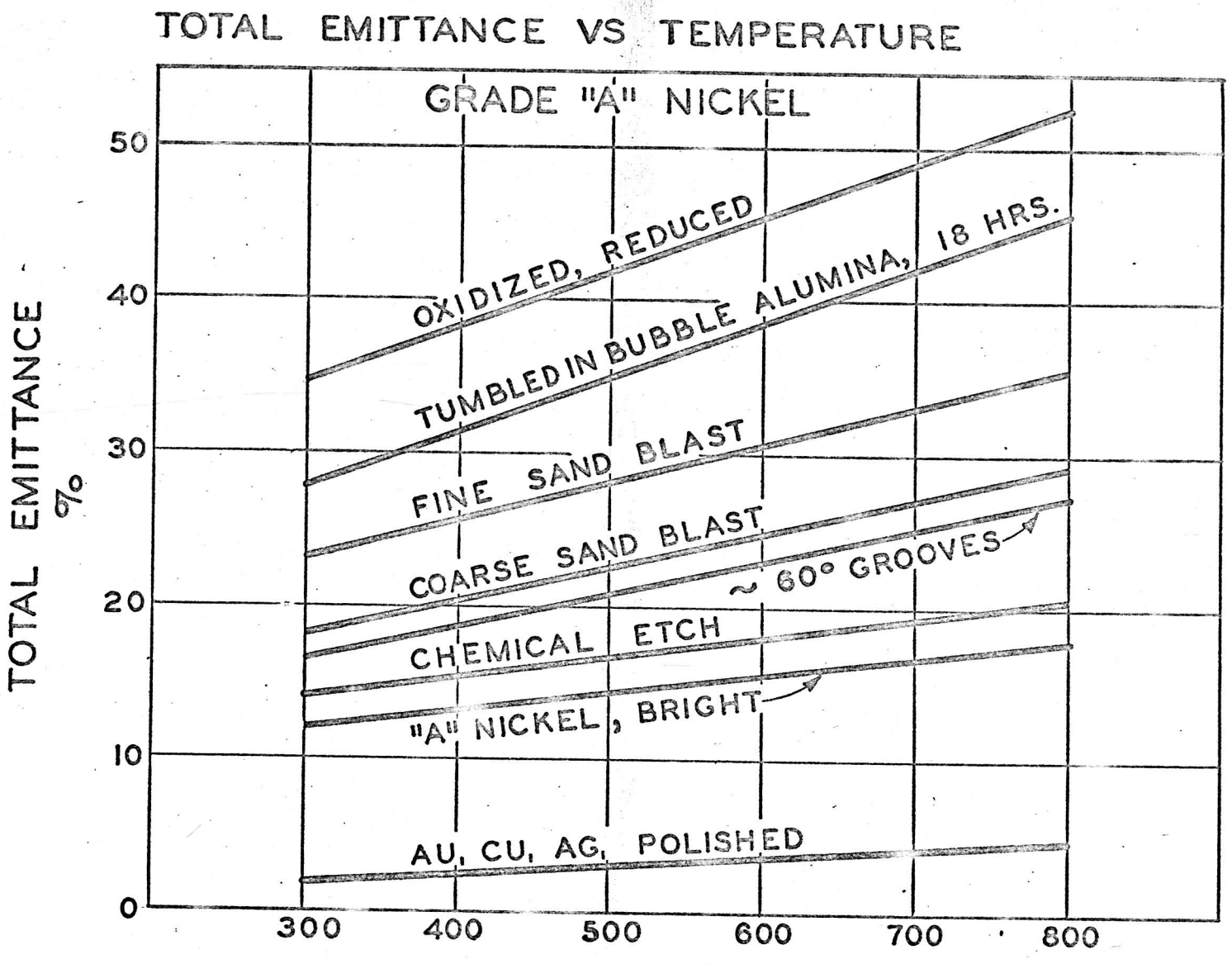
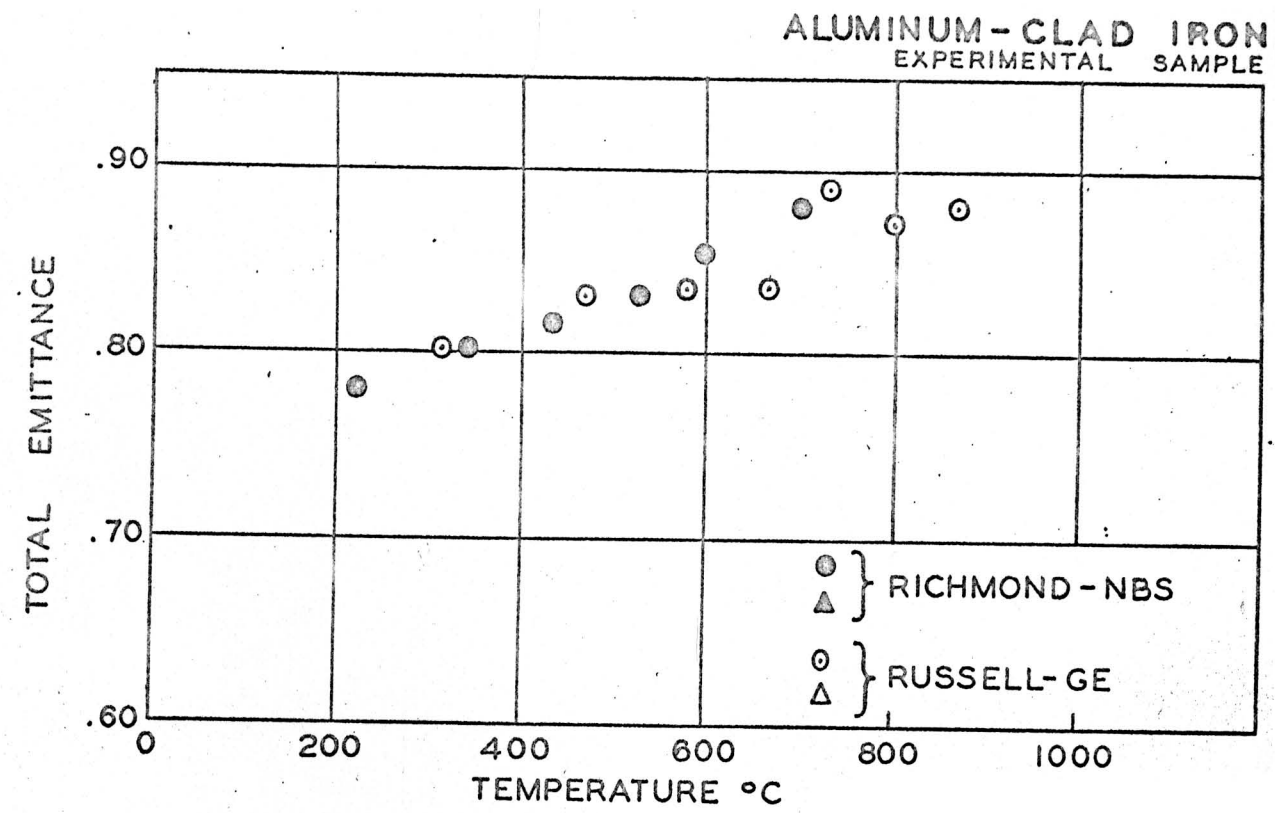

TOTAL EMITTANCE VS TEMPERATURE
GRADE "A" NICKEL
TOTAL EMITTANCE %
50
40
30
20
10
0
OXIDIZED, REDUCED
TUMBLED IN BUBBLE ALUMINA, 18 HRS.
FINE SAND BLAST
COARSE SAND BLAST
~ 60° GROOVES
CHEMICAL ETCH
"A" NICKEL, BRIGHT
AU, CU, AG, POLISHED
300
400
500
600
700
800
TEMPERATURE (°C)

FIG. 8A


ALUMINUM-CLAD IRON
EXPERIMENTAL SAMPLE
TOTAL EMITTANCE
.90
.80
.70
.60
0
200
400
600
800
1000
TEMPERATURE °C
RICHMOND-NBS
RUSSELL-GE

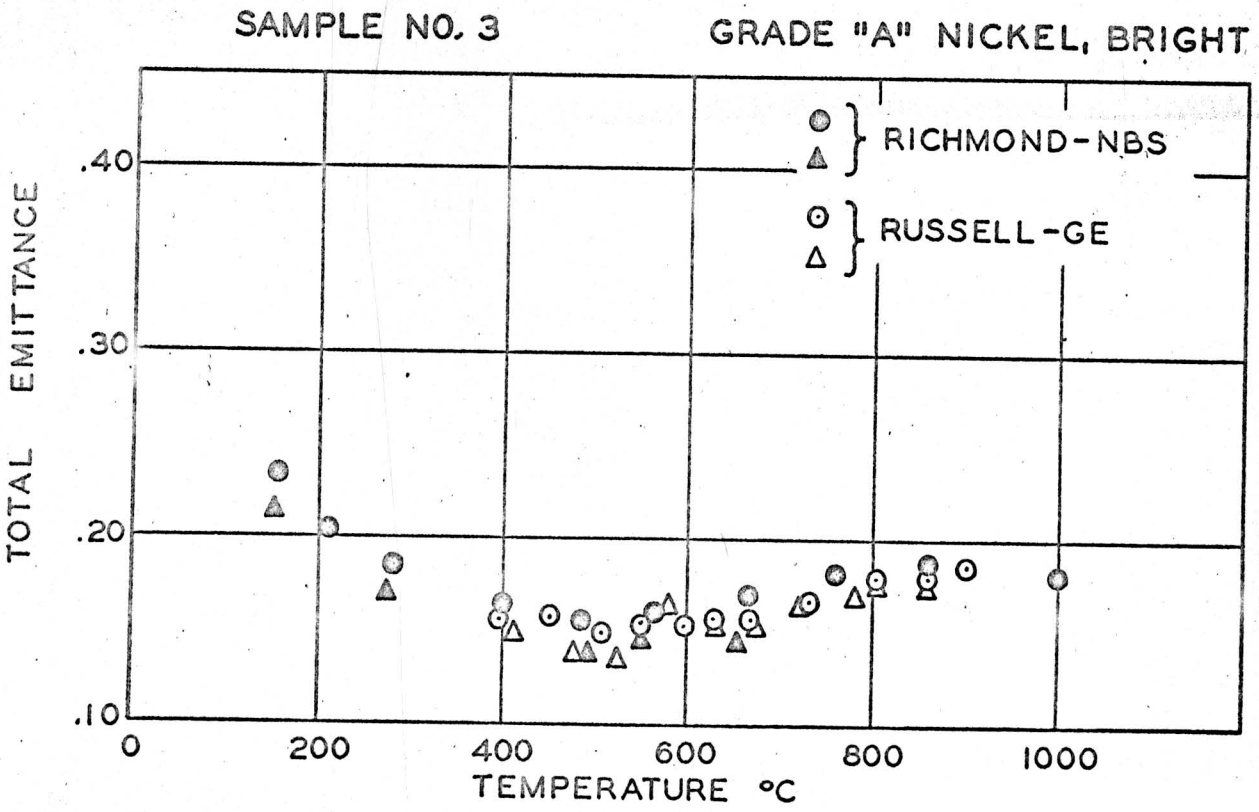

SAMPLE NO. 3
GRADE "A" NICKEL, BRIGHT
TOTAL EMITTANCE
.40
.30
.20
.10
0
200
400
600
800
1000
TEMPERATURE °C
RICHMOND-NBS
RUSSELL-GE

FIG. 9

SECTION VI

Total Emittance of the Oxide Cathode

The total emittance of certain oxide cathodes was determined within the general range of 700°C to 1000°C.

As a primary objective, a comparison was made between our most widely used cathode coating and the experimental coating, type F. The strip resistance heating method described in T.I.S. Report No. R-59-ETR-1 was used to obtain the data. Results are given on pages 23 and 24.

The experiment was performed using 8" x 1/2" x 0.005" type 499 nickel as a base material for the coatings.

The deposition of carbon upon the surface of the oxide coating in the 600°C to 900°C range, caused by the residual hydrocarbon gases in a bell jar coating unit, proved to be a major problem. The difficulty was circumvented enough to obtain good data only after carefully cleaning and baking the system, and by using liquid nitrogen cold trap between the oil diffusion pump and the bell jar.

Results indicate that the total emittance of the experimental coating is 25 to 30 percent greater than that of the regular H1-IN coating.

The experience gained in this work has enabled us to develop what should prove to be a very reliable method of investigating the dependence of total emittance upon coating thickness, coating composition, coating density, base material, processing, etc. A statistically designed experiment has been worked out for that purpose, and further work has been planned.

OXIDE CATHODE

TOTAL EMITTANCE VS TEMPERATURE

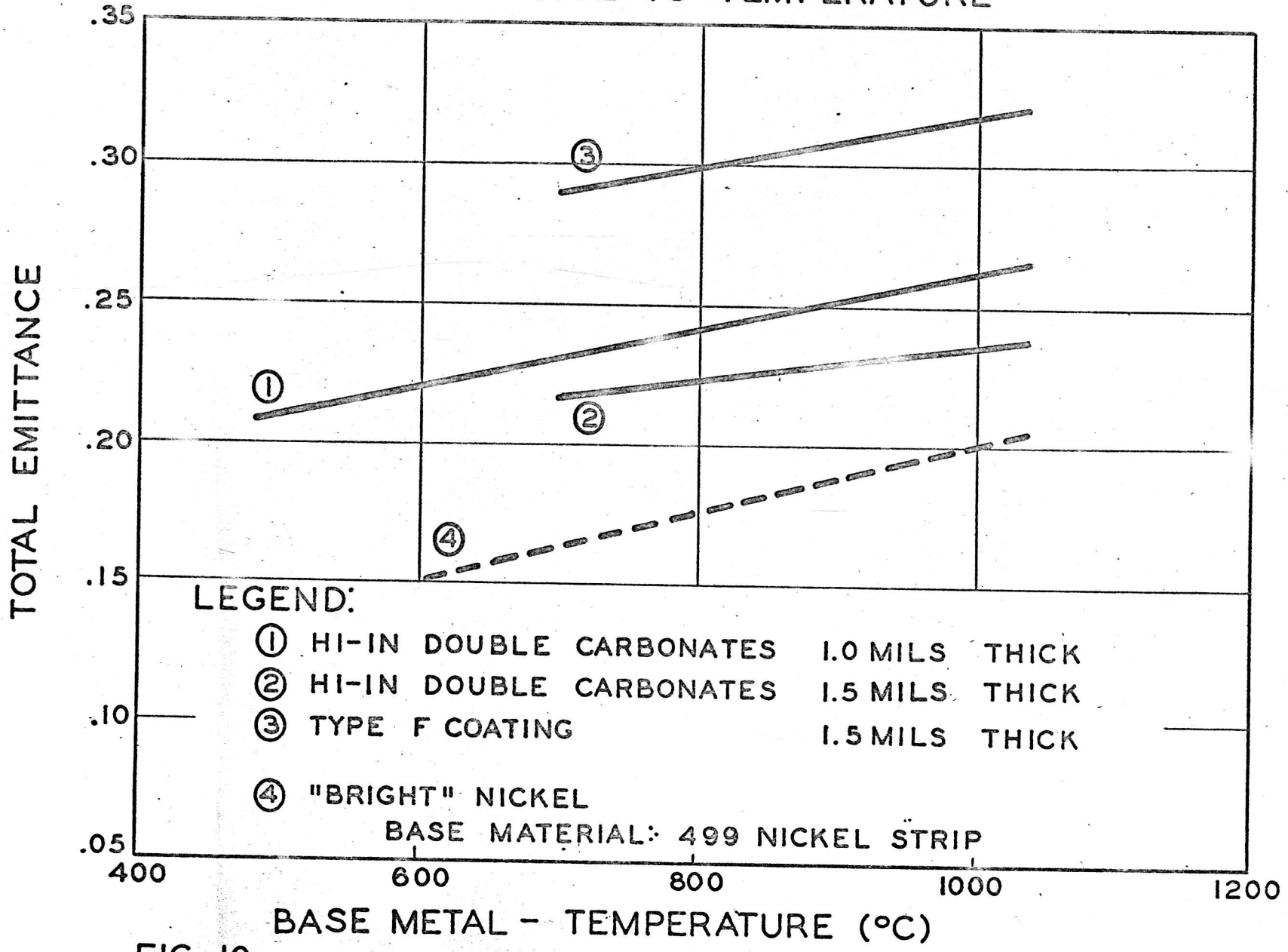


FIG. 10

OXIDE CATHODE

* RADIANCY VS TEMPERATURE

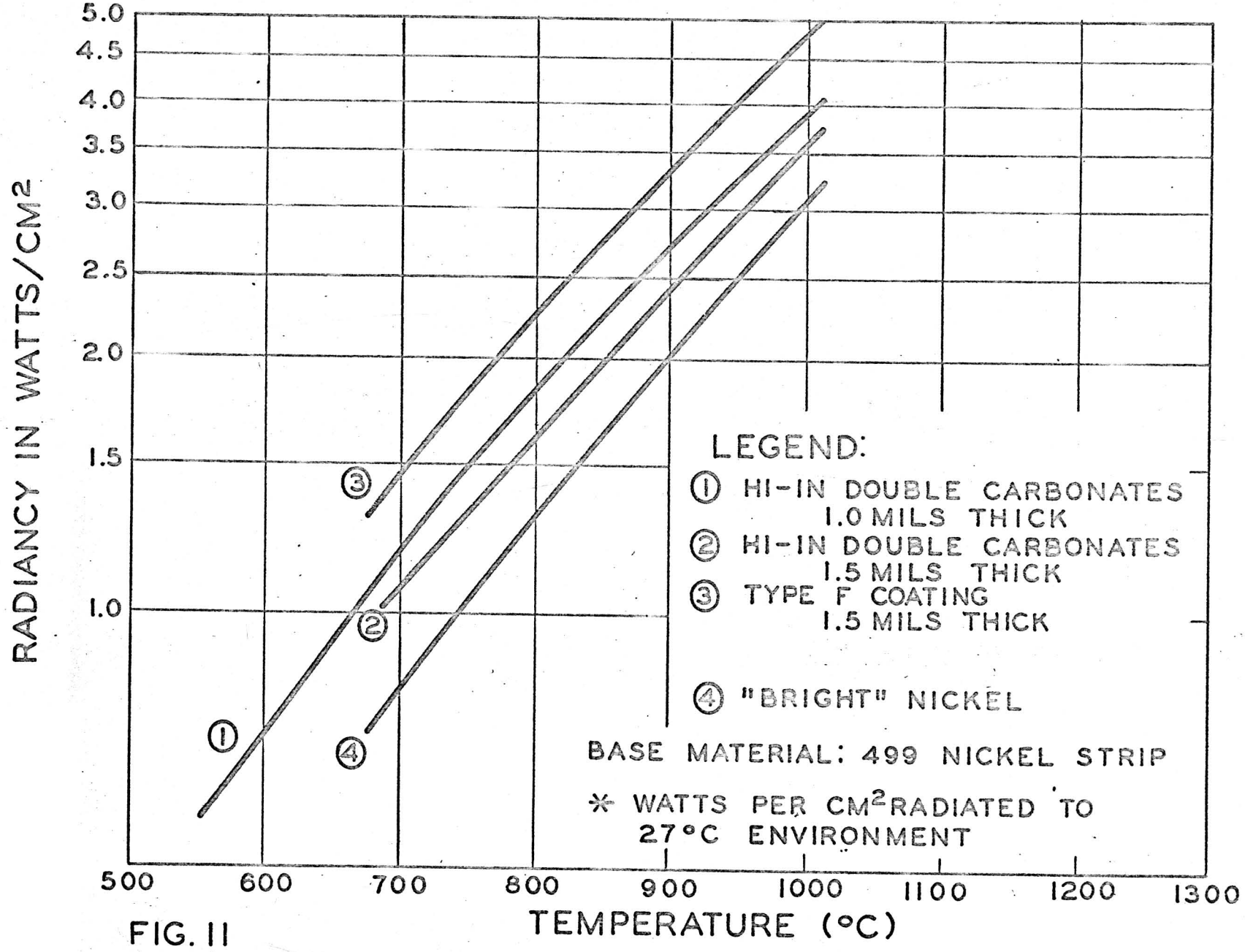


FIG. 11

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3. Russell, M.W., "An Accurate Method of Measuring Total Emittance," R59-ETR-1, 1-31-59.

4. American Institute of Physics, "Temperature, Its Measurement and Control in Science and Industry," Rheinhold Publishing Company, 1941.