V. C Campbell

GENERAL ELECTRIC

ELECTRONIC COMPONENTS DIVISION

CRT-705-85 (8-57)

TECHNICAL INFORMATION SERIES

Title Page

AUTHOR	SUBJECT CATEGORY	NO. / DATE
P. P. Coppola	Cathodes - Sprayed Oxide	NO. R 59 ETC-3 DATE 11-2-59

TITLE The Relationship of Cathode Life to Cathode Temperature and Environment in Commercial Cathode Ray Picture Tubes

ABSTRACT

The application of multi-cathode assemblies in individual cathode ray tubes to determine the relationship of cathode operating temperature to life is described. This technique makes it possible to resolve the affects of temperature through the maintenance of similar environmental cathode test conditions.

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CONCLUSIONS

Experimental data have shown that in the test temperature range of 750°C-950°C used optimum life is achieved by cathodes operating at temperatures of 750°C and 800°C. Greatest emission decay with life is shown for cathodes operating at 875°C and 950°C. A temperature of 850°C is borderline. For any of the test temperatures investigated, it is shown that where a relatively poor environmental condition exists, namely in the vicinity of approximately 0.05 gas ratio and greater, a severe limitation is imposed on emission and consequently on tube life.

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For list of contents—drawings, photos, etc., and for distribution see page attached.

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THE RELATIONSHIP OF CATHODE LIFE TO CATHODE TEMPERATURE AND ENVIRONMENT IN COMMERCIAL CATHODE RAY PICTURE TUBES

P. P. Coppola

I. Introduction

Among others, there are two important questions that often arise in respect to increasing the life of oxide cathodes in commercial cathode ray picture tubes, namely (1) what influence does temperature have on cathode life? and (2) what is the most desirable operating cathode temperature? The answer to the second question follows naturally from the investigation of the first.

Cathode life in general denotes the ability of a cathode to maintain stable emission current of sufficiently high density for a maximum period of time. The availability of such an emission current for many hours of cathode ray tube operation implies an ample space charge cathode condition well beyond the requirements necessary to maintain some desirable electron beam characteristics.

Many basic investigations concerning the relationship of oxide cathode life to cathode temperature have been made in past years and are reported in the literature so that some answers in respect to high and low temperature limits are immediately available.

High temperature limits are imposed on a cathode by several deleterious thermal effects on emission. These include the sintering and evaporation of the emitter material; the evaporation of the base metal and its reducing constituents; and the excessive chemical reaction between the emitter material and the reducing constituents in the base metal. Other problems follow such as loss in vacuum and an increase in leakage due to deposition of evaporents on to internal tube components. Below extreme levels, however, a high cathode temperature can provide a very high reserve of space charge emission current, but certainly at the expense of life.

Some of the principle effects which impose a lower limit on a cathode temperature are the loss of space charge; and an adverse shift in the dynamic equilibrium between constituents responsible for electron emitter activity and oxidizing constituents present in the surrounding environment.

As indicated above, physical and chemical principles do govern the temperature extremes within which an oxide cathode can actually function as a satisfactory emitter. But it is very difficult to predict a specific operating temperature for a specific tube type. In respect to cathode ray picture tubes and for many other commerical tubes as well, the difficulty is due in large part to the presence of many pertinent factors which can affect cathode environment. These would include the number and type of tube component materials present, the processing involved, and the operating conditions to which the tube is subjected during life. Since these factors exert a strong influence on cathode emission characteristics through environment, it is often necessary that the final determination of a satisfactory operating temperature be done through the empirical variation of cathode temperature in the tube type under question. Such an empirical approach would imply that the environment surrounding each cathode is guaranteed to be nearly the same for all. Such a condition is not likely to be achieved, however, when single cathodes tested at different temperatures in single tubes are compared since the cathode temperature itself can influence the environment. On the other hand, when several cathodes under test at different temperatures in a single tube are compared, a condition of similar environment for all is approached more closely and thus an internal control is automatically obtained.

Since there appeared to be obvious environmental advantages to be gained in the use of a multi-cathode single tube approach for the determination of a desirable cathode operating temperature, this method was used for all of the experimental work described in this report.

II. Experimental Methods

For our investigation a 17 inch, 70 degree tube type with a 2 inch O.D. neck was used. In such a tube, 3 cathodes mounted in 3 electron guns joined together could be accommodated on a single 14 lead stem. Details of the gun assembly are shown in Figures 1 and 2. Each of the cathodes in a tube can be operated at some test temperature independently of the others. All cathodes in a tube can undergo life testing simultaneously.

Two series of tubes were prepared for life test. Series 1 consisted of 7 tubes and Series 2 consisted of 6 tubes. For Series 1, the 3 cathodes in a tube were adjusted to temperatures of 800°C, 875°C, and 950°C respectively; and for Series 2, the cathodes were adjusted to temperatures of 750°C, 800°C, and 850°C respectively. The 800°C temperature for one cathode in all of the tubes tested provided a base line for the comparison of data between tubes of Series 1 and 2.

Factory cathodes were used for all of the tests. These were of the planar indirectly heated disc type using (Ba, Sr, Ca) CO_3 triple carbonate emission coating sprayed to a thickness range of 0.0025-0.0030 inch on to special 330 nickel. The coating density was approximately 1 gram/cc. Other tube component materials and the procedures used for screening, aluminizing, and inside painting of the bulbs were the same as for current factory production. The exhaust, activation, and aging schedules on the tubes were carried out in the laboratory and differed somewhat from the schedules used in the factory since 3 cathodes instead of one were involved. Life and electrical test conditions followed standard factory practice closely.

On exhaust, the tubes were baked at 400°C for 1/2 hour, and cooled. When the pressure in a tube dropped to below 0.005 micron, the 3 ring channel getters (32 mg barium each) were outgassed by RF at a temperature of 700-800°C optical for 1 to 2 minutes. Next, the grid 1 was outgassed by RF at a temperature of 700-800°C optical for 10 minutes. The RF was turned off before activation of the cathodes was started. The 6.3 volt 600 ma heaters of the 3 cathodes were connected in parallel. The temperature of the heaters was raised gradually so as not to allow the pressure in the tube to exceed 0.04 micron. When the maximum of the heater current range (1.58-2.55 amps) was reached, the heaters were dropped to 1.86 amps, and held until the pressure in the tube dropped to below 0.004 micron. At this point, the heaters were shut off. The tube was tipped off and the 3 ring channel getters were RF flashed simultaneously.

The cathodes in each tube were aged simultaneously. The three heaters were connected in parallel and 11.5 volts were applied for 2 minutes. The heaters were dropped to 9 volts; +4 volts were applied to each grid 1, and +550 volts were applied to each grid 2. These conditions were maintained for 19 minutes. After the aging schedule was completed, each tube was cooled for several hours before proceeding with the initial electrical tests.

The electrical tests were made separately for each cathode operated with 6.3 volts on the heater. The measurement of emission build-up ratio (1), 50 volt emission (2), cut-off voltage (3), and gas ratio (4), were made in proper sequence.

For life test, the heater current of each of the 3 cathodes in a tube was adjusted independently to achieve the desired cathode temperature mentioned previously. The heater current-temperature relationship had been determined previously through thermocouple measurements. A total beam current of 210 microamperes was drawn from the 3 cathodes in each tube. 450 volts were applied to grid 2 and 18,000 volts were applied to the anode of the gun. A full raster was maintained. During life, periodic electrical tests were made after 100, 250, 500 hours, and etc. After each interval, the tube was cooled for at least 3 hours before measurements were made on the first cathode. At least 20 minutes waiting time was allowed before making each of the subsequent measurements on the second and third cathodes. Cathode electrical test sequences were randomized for each tube so as to average out any poisoning effects which might have occurred on the two standby cathodes during the measurement of one.

(1) Emission build-up is a ratio of cathode DC emission measured in the grid 2 circuit with grid 1 zero bias after 30 seconds and after 3 minutes from the time the heater is switched on.

(2) 50 volt emission is a measure of the cathode DC emission for a particular gun configuration and cut-off normalized to a 50 volt cut-off condition.

(3) Cut-off is the amount of grid 1 bias voltage required to decrease cathode DC emission in grid 2 circuit to zero.

(4) Gas ratio is the relation of positive ion current to beam current in grid 2 circuit. It is a relative measurement of residual gas pressure in a tube through the arrangement of its gun electrodes to serve as an ionization gauge. Factory calibration show the ratio to be a factor of about 10 greater than micron gas pressure.

III. Experimental Results

The life testing of tubes in Series 1 was terminated at 2,000 hours since an indication of the emission build-up ratio and 50 volt emission trends was seen well before this time. However, with Series 2 tubes, wherein a lower cathode operating temperature was maintained, the emission trends were not evident early in life especially at relatively low gas ratios. Thus, life testing was continued well beyond 2,000 hours.

At the present time, the initial or 0 hour factory criteria for tube acceptance are a level of 450 microamperes emission in 30 seconds from the time the heater is switched on to 6.3 volts and a 50 volt emission level of 800 microamperes at equilibrium cathode temperature with the heater at 6.3 volts. For tube life, the factory criteria are 100 microamperes emission in 30 seconds and 55 percent of the original 50 volt emission, both at 2,000 hours life. Further tests to determine standards of life beyond 2,000 hours are in progress.

Representative emission and cut-off data obtained from tubes in Series 1 and 2 are listed in Table 1 a, b, c, and d. Emission results from tubes with relatively low and relatively high gas ratios are compared. The emission results for all of the tubes tested are plotted in Figures 3 to 15 inclusive. The figures include the gas ratio data obtained periodically during life.

Examination of the data in Table 1 b and d, and of the data in Figures 7, 8, and 9 of Series 1; and 13, 14, and 15 of Series 2, obtained at relatively high gas ratios, shows clearly that regardless of the cathode operating temperatures used, a high level of gas can adversely influence both emission build-up ratio and 50 volt emission to a great degree. Such evidence points out how very important the surrounding environmental condition are when examining cathode thermal characteristics.

Examination of the data in Table 1 a and b, and of the data in Figures 3, 4, 5, and 6 of Series 1; and 10, 11, and 12 of Series 2 obtained at relatively low gas ratios shows that thermal conditions as affecting cathode emission and life characteristics can be resolved. For example, temperatures of 875°C and 950°C show a definite drop in 50 volt emission with life well in excess of that obtained at lower cathode temperatures; also, the sensitivity of the emission build-up ratio to high cathode temperatures is shown by a pronounced drop very early in life. The serious drop in emission build-up noted particularly for the 875°C and 950°C cathodes temperatures may have resulted from an excessive gas condition localized in the immediate vicinity of the cathode due to increased material evaporation on to and more energetic bombardment of the grid 1 components.

The results of 50 volt emission at 2,000 hours life taken from Figures 3, 4, 5, 6, 10, 11, and 12 are summarized in Figure 16. It will be noticed in this figure that slightly lower values of 50 volt emission are obtained from cathodes operating at 800°C in series 1 tubes than are obtained from cathodes operating at the same temperature in series 2 tubes. This difference may be a coincidence, however, it is suspected that a slight adverse shift in cathode equilibrium may have occurred in series 1 tubes due to change in the total environmental condition contributed to by the cathodes operating at considerably higher temperatures. During the planning period of the complete experimental program described in this report, it was believed that just such an effect might occur and thus a base line cathode temperature of 800°C was included as a control in both series of tubes.

The comparison of both the 50 volt emission and emission build-up data collected from all tubes tested under relatively low gas ratios shows that 750°C and 800°C cathode operating temperatures give consistently better results in peak emission for optimum life. A cathode temperature of 850°C is borderline. Temperatures of 875°C and especially 950°C are obviously too high for long life.

Even under the most ideal environmental conditions, it should be expected that an oxide cathode operating temperature of 950°C will give a relatively shorter life when compared to lower temperatures simply through increased evaporation of barium oxide emitter material. Table 2 lists the evaporation of barium oxide in gram per square centimeter area per hour as a function of cathode temperature from a (Ba Sr Ca) O triple oxide emitter coating on passive nickel. These figures were obtained from instantaneous barium oxide evaporation rate data[5].

It should be pointed out that the actual evaporation of barium oxide from a coating of finite thickness decreases with time, so that its total loss over some period will be smaller than the product of instantaneous evaporation vs. hours time shown in Table 2. However, the instantaneous evaporation rate data do show that a considerably greater loss of barium oxide (a factor of 1,000) can occur at 950°C when compared to 750°C.

In spite of the greater loss factor of the emitter constituent that can result from higher cathode operating temperatures, the experimental test data described in this report show that non-ideal environmental conditions can impose even greater limitations on cathode life than can be due to evaporation as such.

IV. Conclusion

Experimental data have shown that in the test temperature range of 750°C-950°C used, optimum life is achieved by cathodes operating at temperatures of 750°C and 800°C. Greatest emission decay with life is shown for cathodes operating at 875°C and 950°C. A temperature of 850°C is borderline. For any of the test temperatures investigated, it is shown that where a relatively poor environmental condition exists, namely in the vicinity of approximately 0.05 gas ratio and greater, a severe limitation is imposed on emission and consequently on tube life.

Acknowledgment

The writer wishes to express his thanks to all of the laboratory personnel whose contributions helped toward the successful completion of this work.

(5) M.D. Gibbons "Evaporation Rate of Oxide Cathodes by X-Ray Emission Spectrometry" paper M-7 of the American Physical Society Summer Meeting in the East, Ithaca, N. Y., June 1958.

TABLE 1

Series #	Part	Tube #	Hours Life	Emission Build-up Ratio 800°	875°	950°	50 Volt Emission Microamperes 800°	875°	950°	% Original 50 Volt Emission 800°	875°	950°	Gas Ratio	
1	a	I15I1B	0	.895	.615	.485	1080	1110	1160	100	100	100	.0005	Relatively low
			170	.905	.625	.125	1090	1060	1090	101	95.6	94.0	.0025	
			540	.935	.635	.066	1100	1040	900	102	93.5	77.3	.004	
			1019	.880	.145	.029	1040	980	580	96.5	88.4	50.0	.003	
			1571	.835	.093	.024	1030	760	550	95.6	69.5	47.5	.003	
			2000	.770	.089	.025	1000	630	470	92.6	56.7	40.1	.002	
1	b	L03H1B	0	.920	.840	.906	1235	1350	1270	100	100	100	.0025	Relatively high
			49	.955	.925	.900	1290	1305	1200	104	97.0	94.5	.002	
			113	.955	.900	.670	1290	1330	1200	104	98.6	94.5	.002	
			255	.971	.878	.540	1290	1230	1130	104	91.2	89.0	.0018	
			494	.965	.576	.300	1270	1220	1190	103	88.4	93.6	.002	
			750	.848	.000	.000	1225	1110	1120	99.0	82.4	88.3	.057	
			1056	.383	.000	.000	1190	970	1070	96.8	71.6	84.2	.10	
			1420	.119	.000	.000	750	530	280	60.5	39.3	22.0	.10	
			1683	.063	.000	.000	560	370	80	45.3	27.4	6.3	.10	
			1981	.010	.000	.000	70	50	30	5.7	3.7	2.4	.14	
				750°	800°	850°	750°	800°	850°	750°	800°	850°		
2	c	A28J1B	0	.930	.769	.920	1320	1190	1360	100	100	100	.001	Relatively low
			158	.894	.963	.915	1250	1150	1170	94.8	96.7	86.2	.001	
			251	.917	.933	.763	1250	1180	1160	94.8	99.2	85.5	.0018	
			499	.905	.981	.820	1270	1200	1170	96.5	100.1	86.2	.002	
			994	.918	.943	.819	1250	1150	1170	94.8	96.7	86.2	.0025	
			1503	.905	.950	.692	1280	1160	1160	97.2	97.2	85.5	.0025	
			1974	.838	.872	.312	1130	1150	1040	85.6	96.7	76.6	.002	
			2478	.725	.830	.324	1050	1110	920	79.6	93.4	67.5	.003	
			2716	.770	.795	.500	1010	1130	920	76.6	95.2	67.5	.003	
			3100	.780	.850	.480	920	1060	905	69.6	89.2	66.5	.0028	
			4249	.710	.800	.810	720	1230	620	54.6	103.3	45.5	.0025	
			4620	.510	.815	.250	720	1000	720	54.6	85.9	52.8	.0028	
			5108	.355	.660	.000	396	850	0	30.0	71.5	0	.0028	
2	d	B26J1B	0	.889	.625	.733	1200	1200	1170	100	100	100	.0038	Relatively high
			150	.911	.703	.818	1300	1230	1170	108.3	102.5	100	.0042	
			238	.879	.647	.720	1300	1240	1120	108.3	103.5	96.1	.005	
			495	.719	.240	.269	1190	1020	960	99.3	85.0	82.0	.15	
			982	.361	.333	.100	810	460	620	67.4	38.2	53.0	.18	
			1507	.195	.080	0	420	160	210	35.0	13.3	17.9	.10	
			2011	.233	.10	0	267	100	130	22.3	8.3	11.1	.15	
			2503	.215	0	0	147	65	55	12.2	5.4	4.7	.18	

T A B L E 2

Coating Temperature ^{o}C	Ba O Evaporation Rate Gram/cm^2/hour
750°C	1.8×10^{-9}
800°	1.1×10^{-8}
850°	7.2×10^{-8}
875°	1.8×10^{-7}
950°	1.8×10^{-6}

ENGINEER P. P. Coppola

GLASS GUNS

COMPLETE BEST MOUNTS

CATHODE INFORMATION

GUNSEAL LENGTH

SPRINGS

GUNSEAL LENGTH

GUN OVERALL LENGTH

PAINT LENGTH

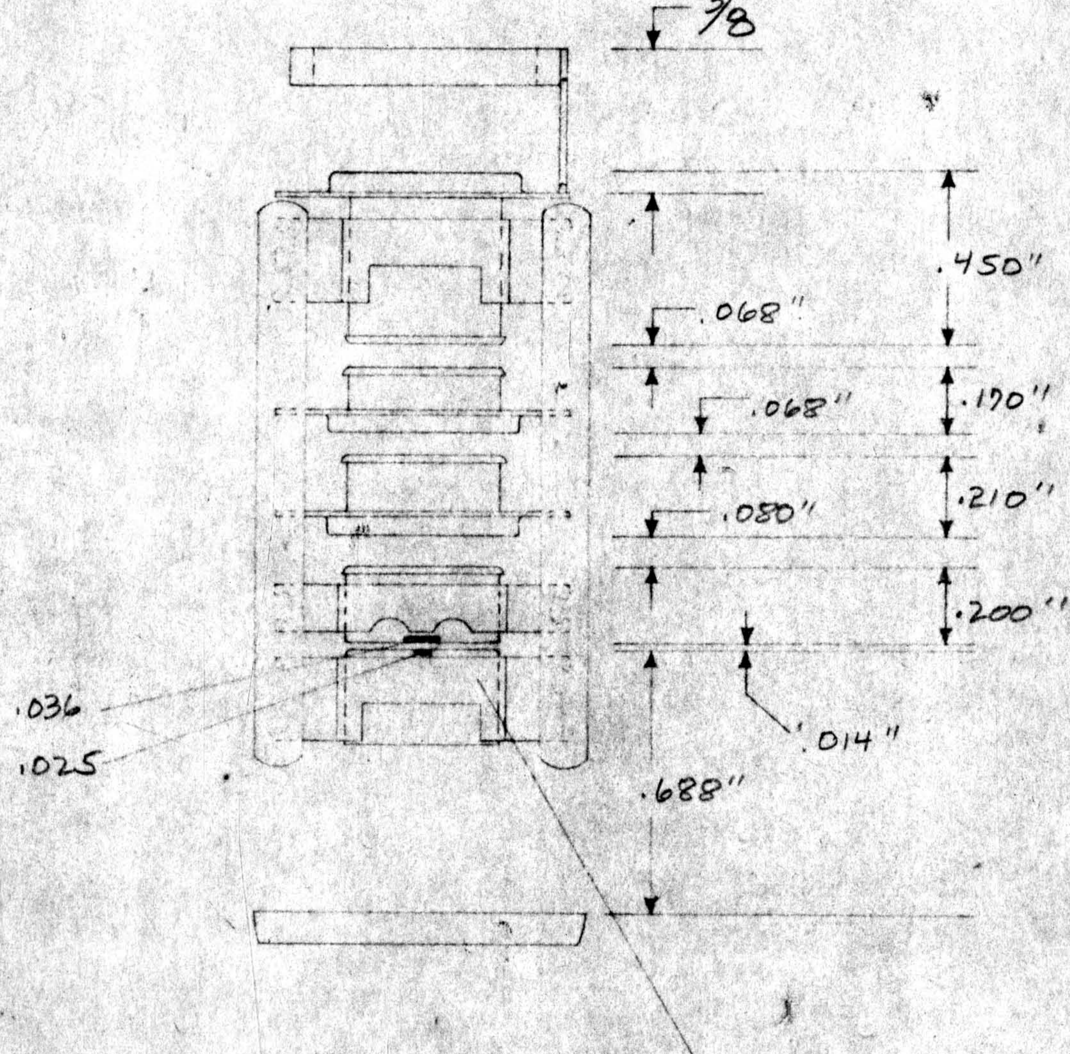
GUNS E. T. I.

ACCUMLATED

COMPLETED

USE PIN

N16063 - Mount Type



G,K .0085"

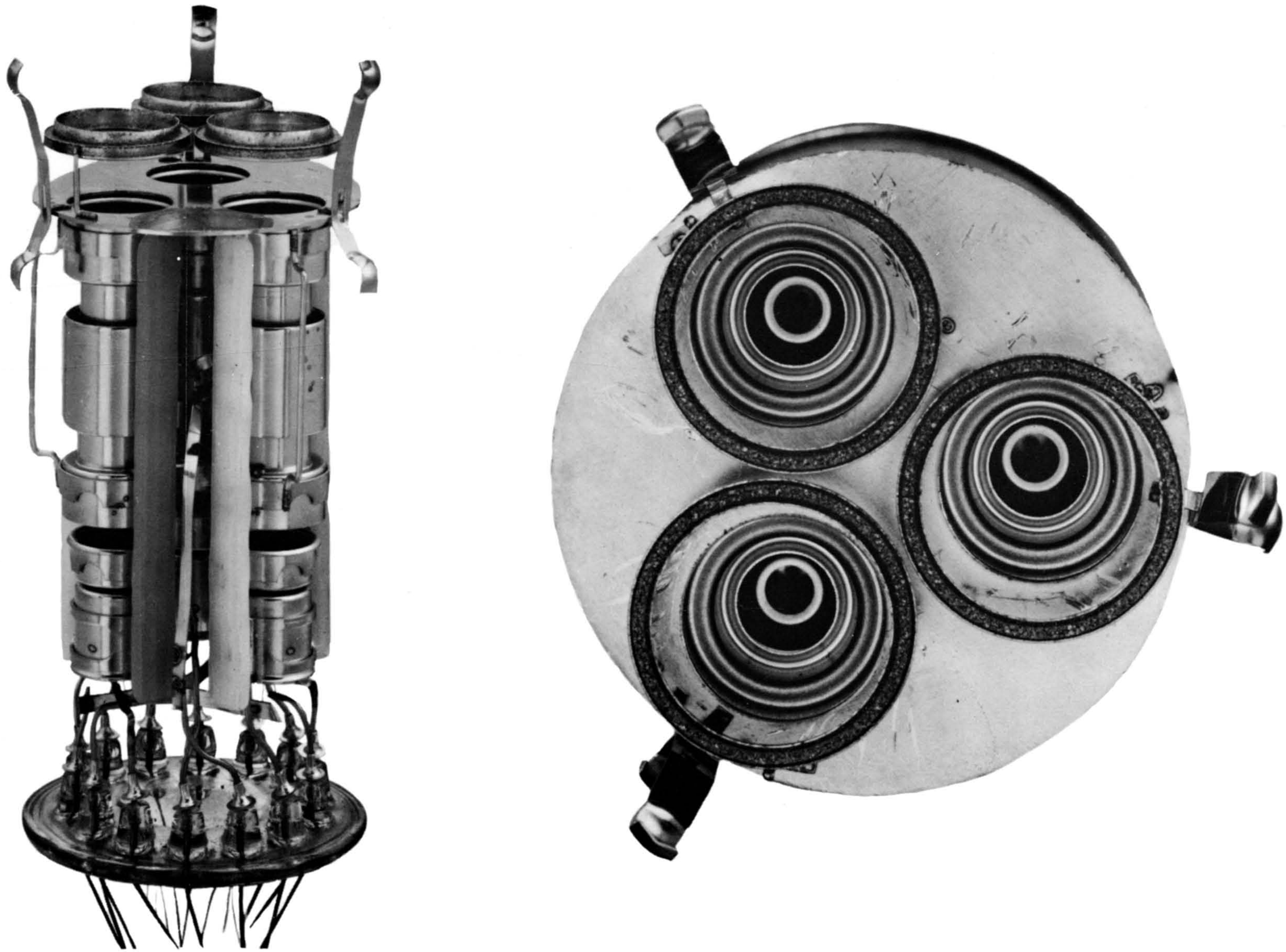
GUN NUMBERS

G, DESCRIPTION

COINED AVG. TOP THICKNESS

RECEIVED

FIGURE 1



GUN ASSEMBLY
FIGURE NO. 2

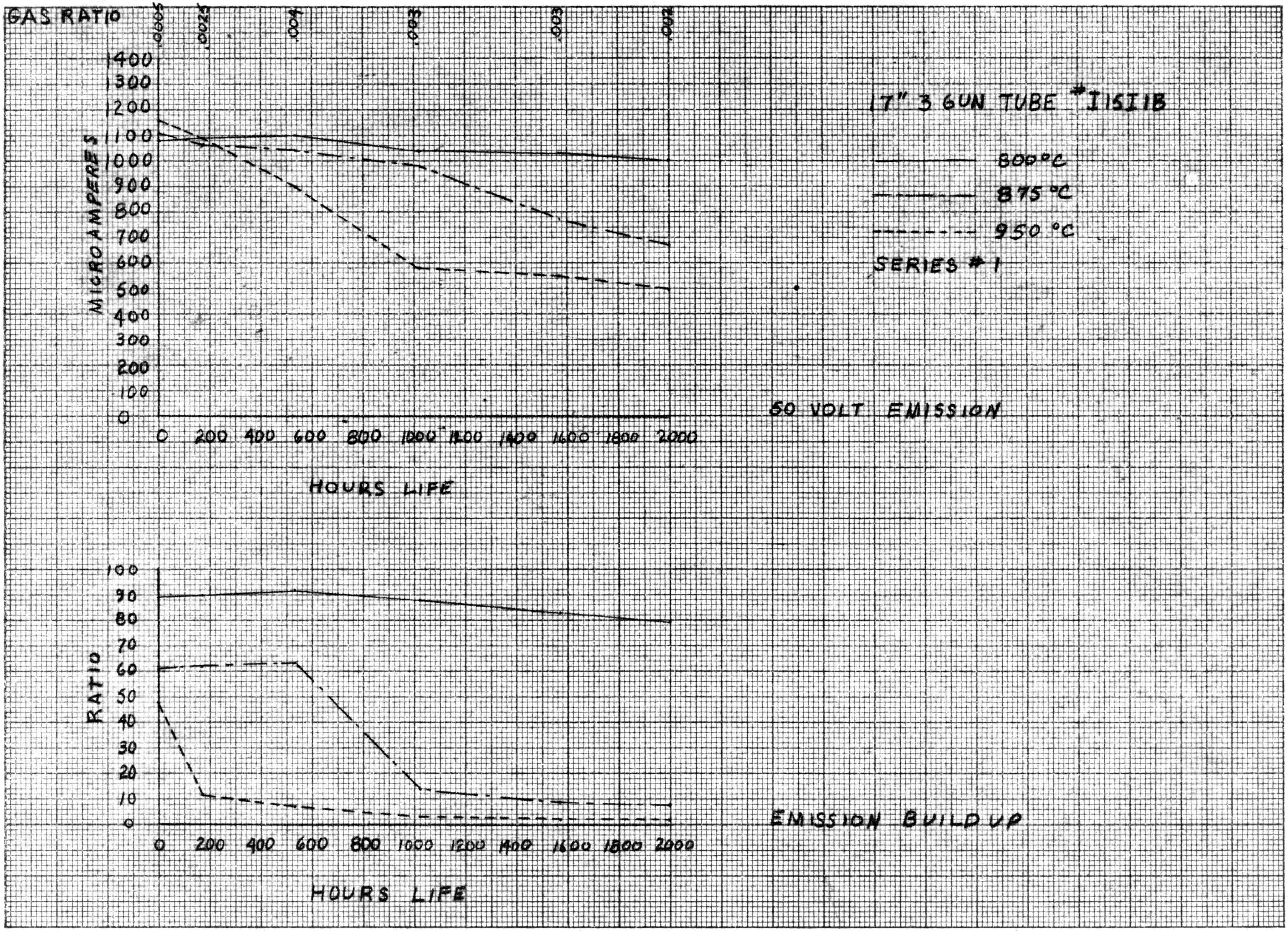
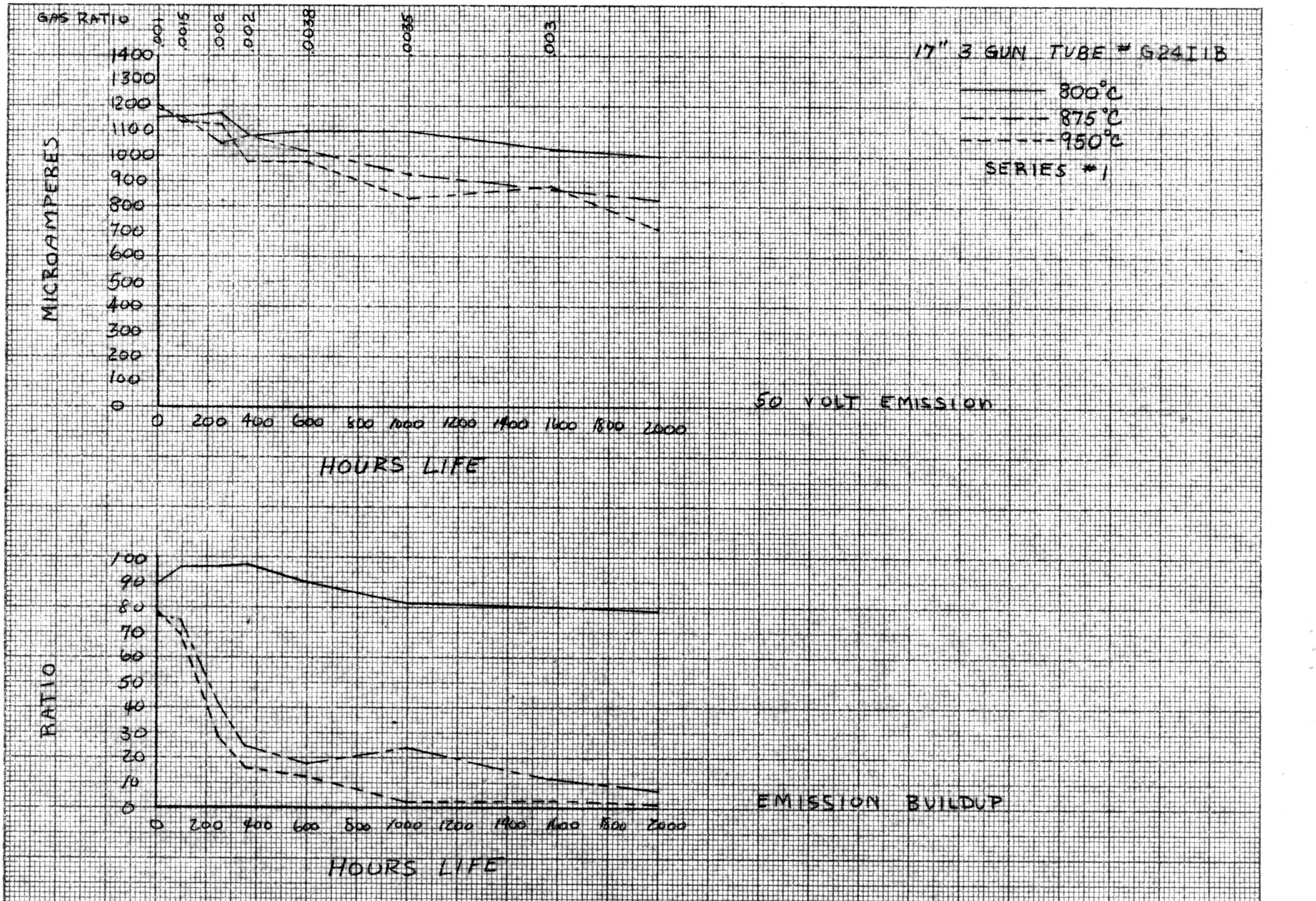

GAS RATIO
.0005
.0025
.004
.003
.003
.002
MICROAMPERES
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
17" 3 GUN TUBE #I151B
800°C
875°C
950°C
SERIES # 1
50 VOLT EMISSION
0 200 400 600 800 1000 1200 1400 1600 1800 2000
HOURS LIFE
RATIO
100
90
80
70
60
50
40
30
20
10
0
EMISSION BUILDUP
0 200 400 600 800 1000 1200 1400 1600 1800 2000
HOURS LIFE

FIGURE 3



GAS RATIO
.001
.0015
.002
.002
.0038
.0035
.003
17" 3 GUN TUBE # G24IIB
800°C
875°C
950°C
SERIES #1
MICROAMPERES
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0 200 400 600 800 1000 1200 1400 1600 1800 2000
HOURS LIFE
50 VOLT EMISSION
RATIO
100
90
80
70
60
50
40
30
20
10
0
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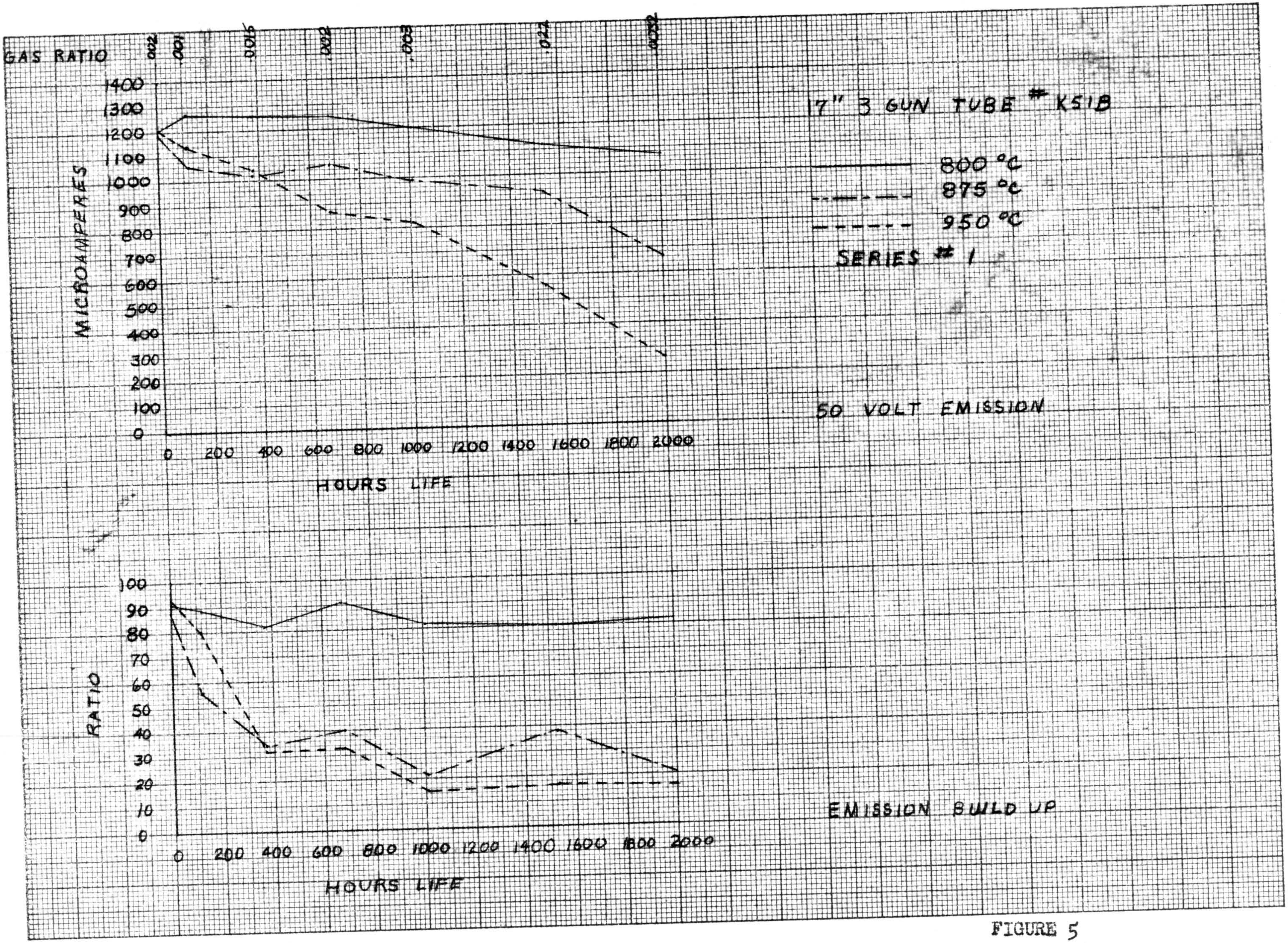
HOURS LIFE
EMISSION BUILDUP

FIGURE 4


GAS RATIO
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.001
.0015
.002
.003
.022
.0032
MICROAMPERES
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0 200 400 600 800 1000 1200 1400 1600 1800 2000
HOURS LIFE
17" 3 GUN TUBE # K51B
800 °C
875 °C
950 °C
SERIES # 1
50 VOLT EMISSION
RATIO
100
90
80
70
60
50
40
30
20
10
0
0 200 400 600 800 1000 1200 1400 1600 1800 2000
HOURS LIFE
EMISSION BUILD UP

FIGURE 5

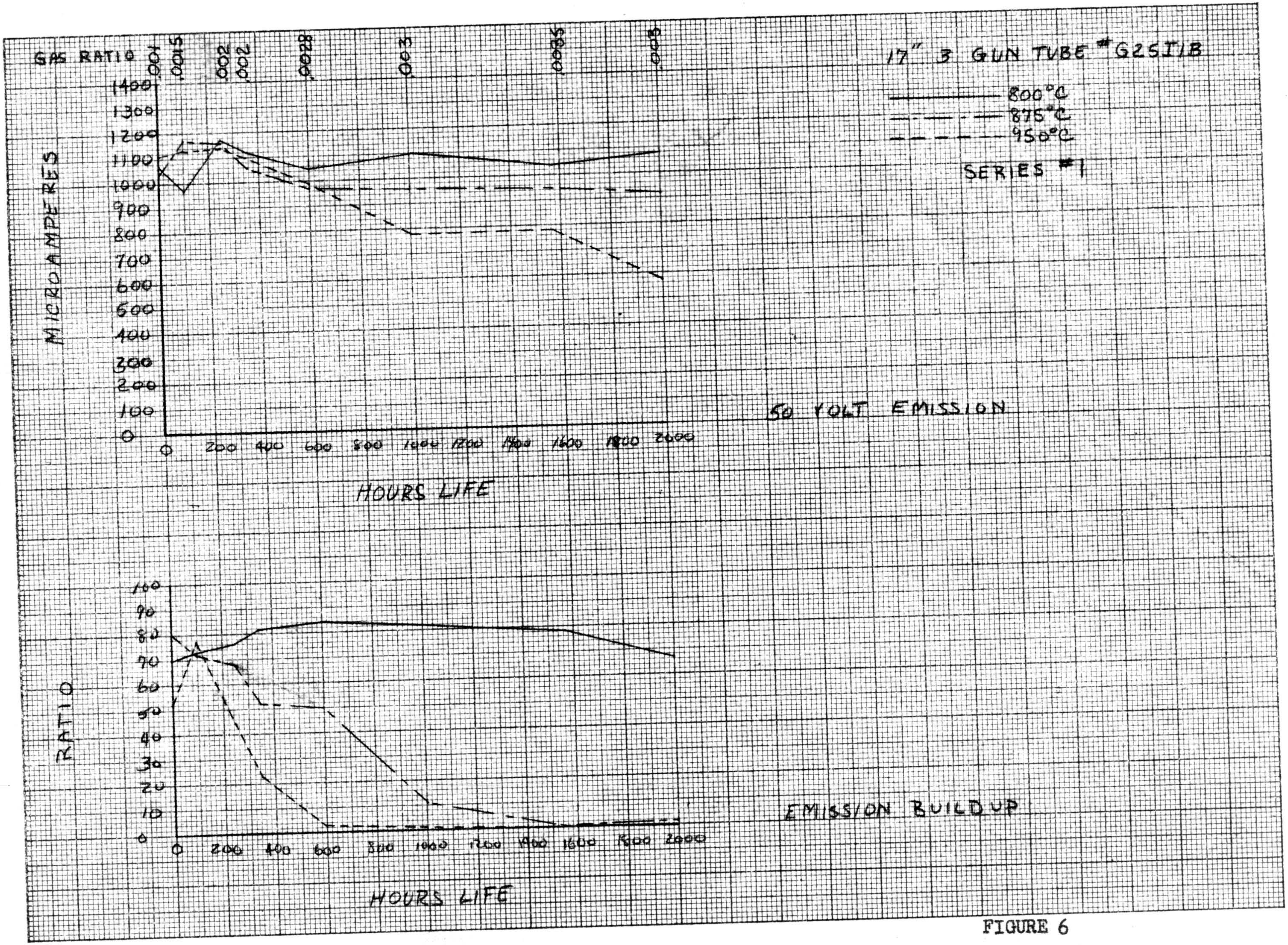

17" 3 GUN TUBE # G25I1B
800°C
875°C
950°C
SERIES #1
GAS RATIO
.001 .0015 .002 .002 .0028 .003 .0035 .003
MICROAMPERES
1400 1300 1200 1100 1000 900 800 700 600 500 400 300 200 100 0
0 200 400 600 800 1000 1200 1400 1600 1800 2000
HOURS LIFE
50 VOLT EMISSION
RATIO
100 90 80 70 60 50 40 30 20 10 0
0 200 400 600 800 1000 1200 1400 1600 1800 2000
HOURS LIFE
EMISSION BUILDUP

FIGURE 6

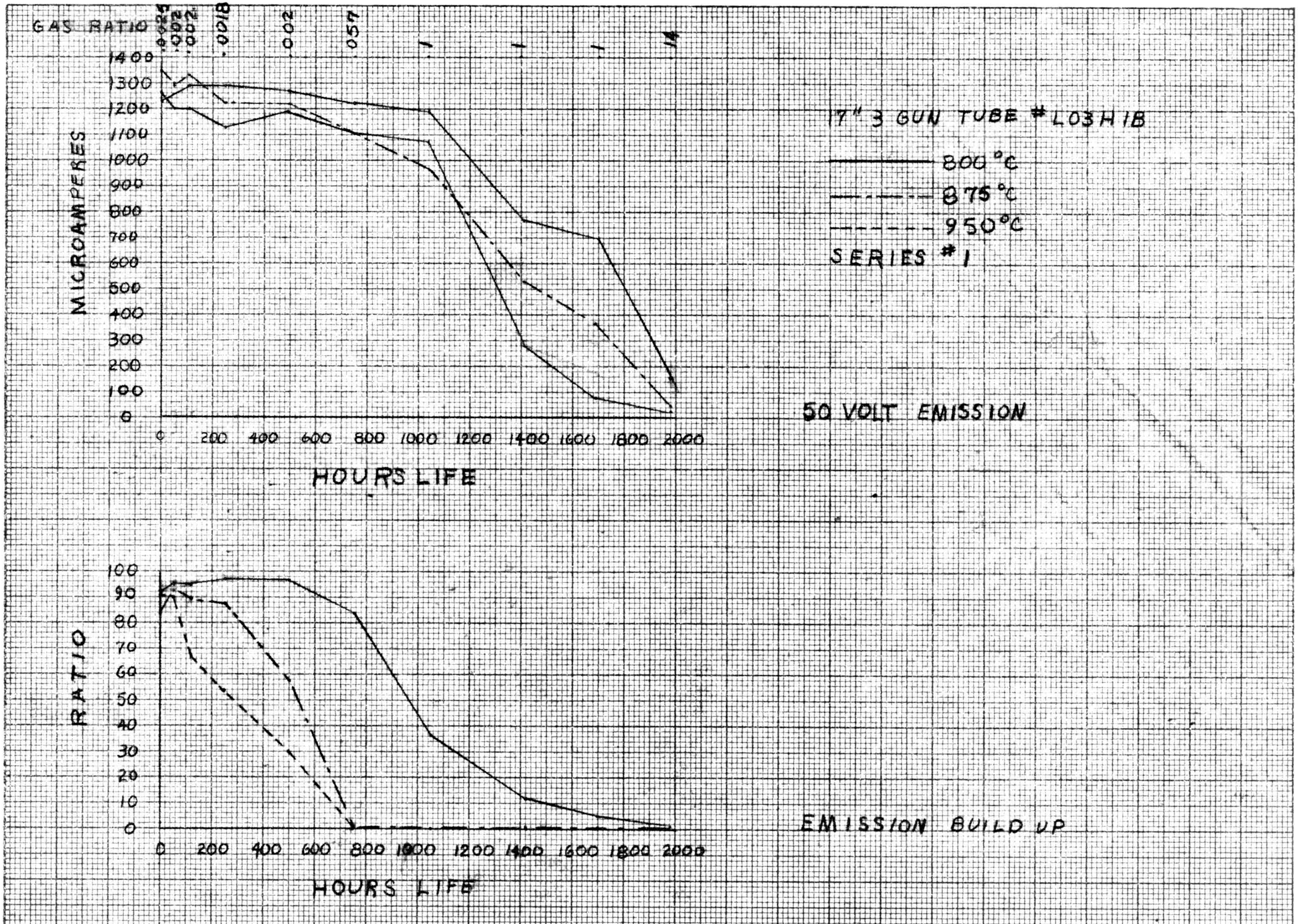

GAS RATIO
.0024
.002
.002
.0018
.002
.057
1
1
1
14
MICROAMPERES
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0 200 400 600 800 1000 1200 1400 1600 1800 2000
HOURS LIFE
17" 3 GUN TUBE # L03H1B
800°C
875°C
950°C
SERIES # 1
50 VOLT EMISSION
RATIO
100
90
80
70
60
50
40
30
20
10
0
0 200 400 600 800 1000 1200 1400 1600 1800 2000
HOURS LIFE
EMISSION BUILD UP

FIGURE 7

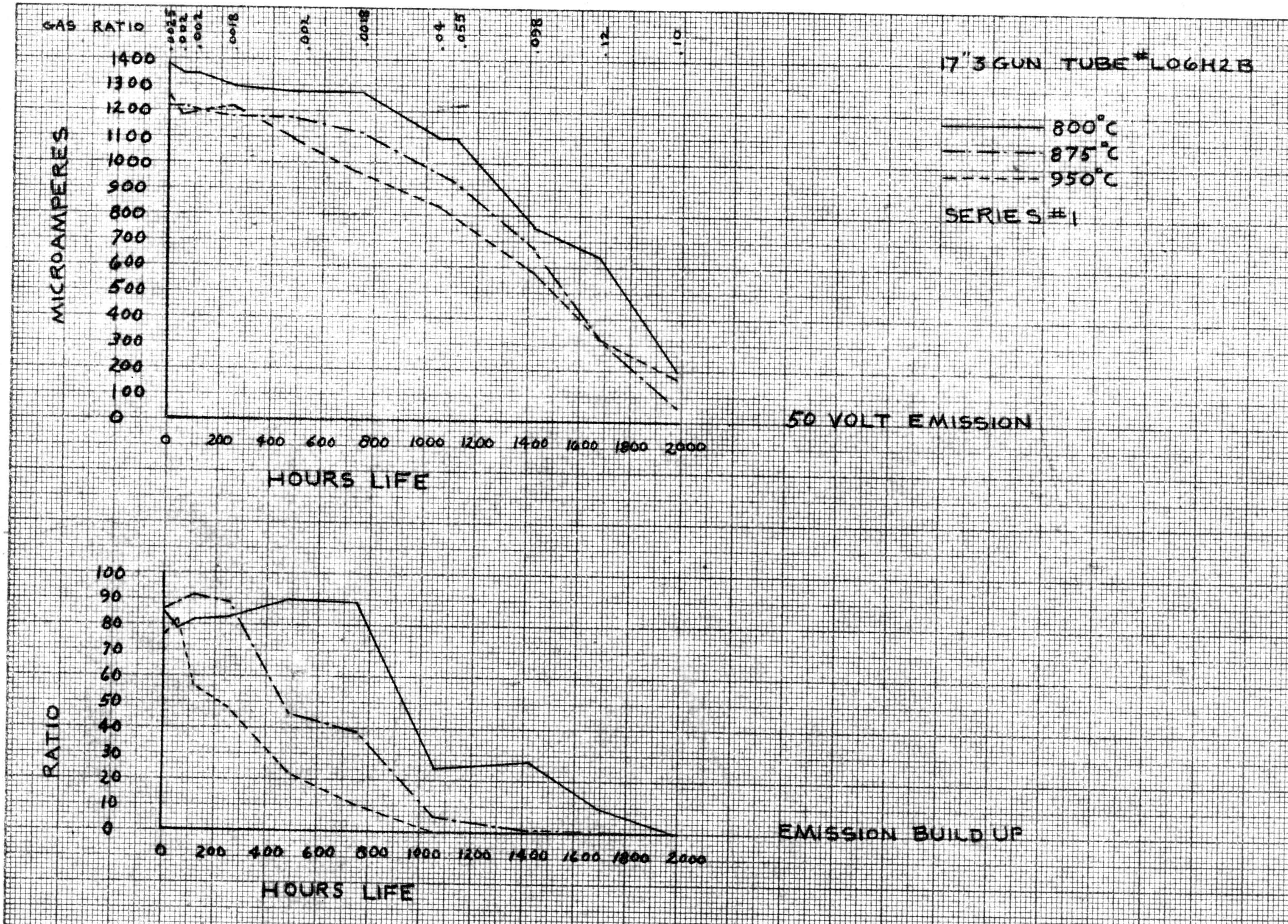

GAS RATIO
.0025
.002
.0002
.0018
.002
.0018
.04
.053
.098
.12
.10
MICROAMPERES
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0 200 400 600 800 1000 1200 1400 1600 1800 2000
HOURS LIFE
17" 3 GUN TUBE # L06H2B
800°C
875°C
950°C
SERIES #1
50 VOLT EMISSION
RATIO
100
90
80
70
60
50
40
30
20
10
0
0 200 400 600 800 1000 1200 1400 1600 1800 2000
HOURS LIFE
EMISSION BUILD UP

FIGURE 8

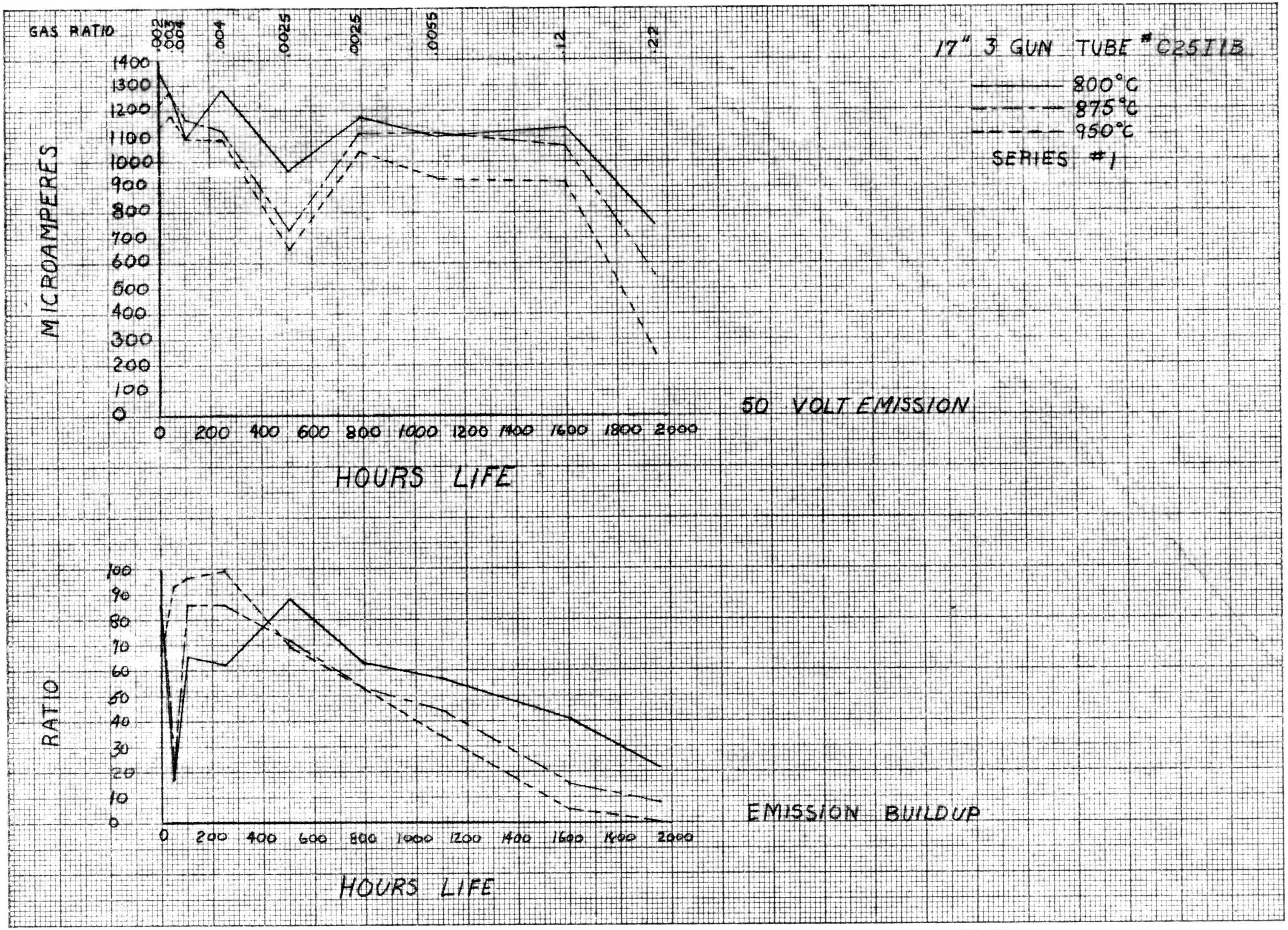
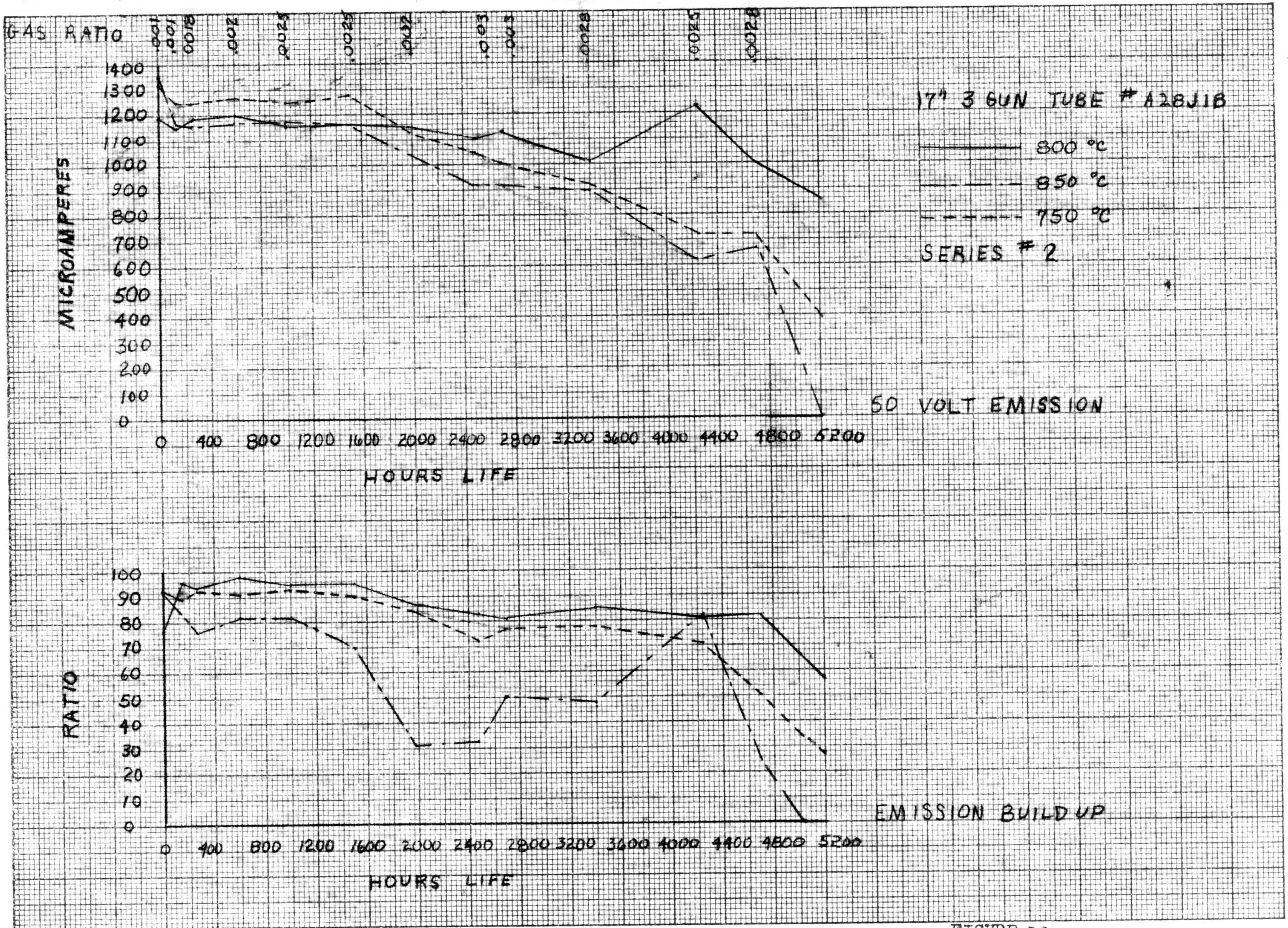

GAS RATIO
.002
.004
.006
.004
.0025
.0025
.0055
.12
.22
17" 3 GUN TUBE # C25T1B
800°C
875°C
950°C
SERIES #1
MICROAMPERES
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0 200 400 600 800 1000 1200 1400 1600 1800 2000
HOURS LIFE
50 VOLT EMISSION
RATIO
100
90
80
70
60
50
40
30
20
10
0
0 200 400 600 800 1000 1200 1400 1600 1800 2000
HOURS LIFE
EMISSION BUILDUP

FIGURE 9



GAS RATIO
.001 .001 .0018 .002 .0025 .0025 .0032 .003 .003 .0028 .0025 .0028
MICROAMPERES
1400 1300 1200 1100 1000 900 800 700 600 500 400 300 200 100 0
0 400 800 1200 1600 2000 2400 2800 3200 3600 4000 4400 4800 5200
HOURS LIFE
17" 3 GUN TUBE # A28J1B
800 °C
850 °C
750 °C
SERIES # 2
50 VOLT EMISSION
RATIO
100 90 80 70 60 50 40 30 20 10 0
0 400 800 1200 1600 2000 2400 2800 3200 3600 4000 4400 4800 5200
HOURS LIFE
EMISSION BUILD UP

FIGURE 10

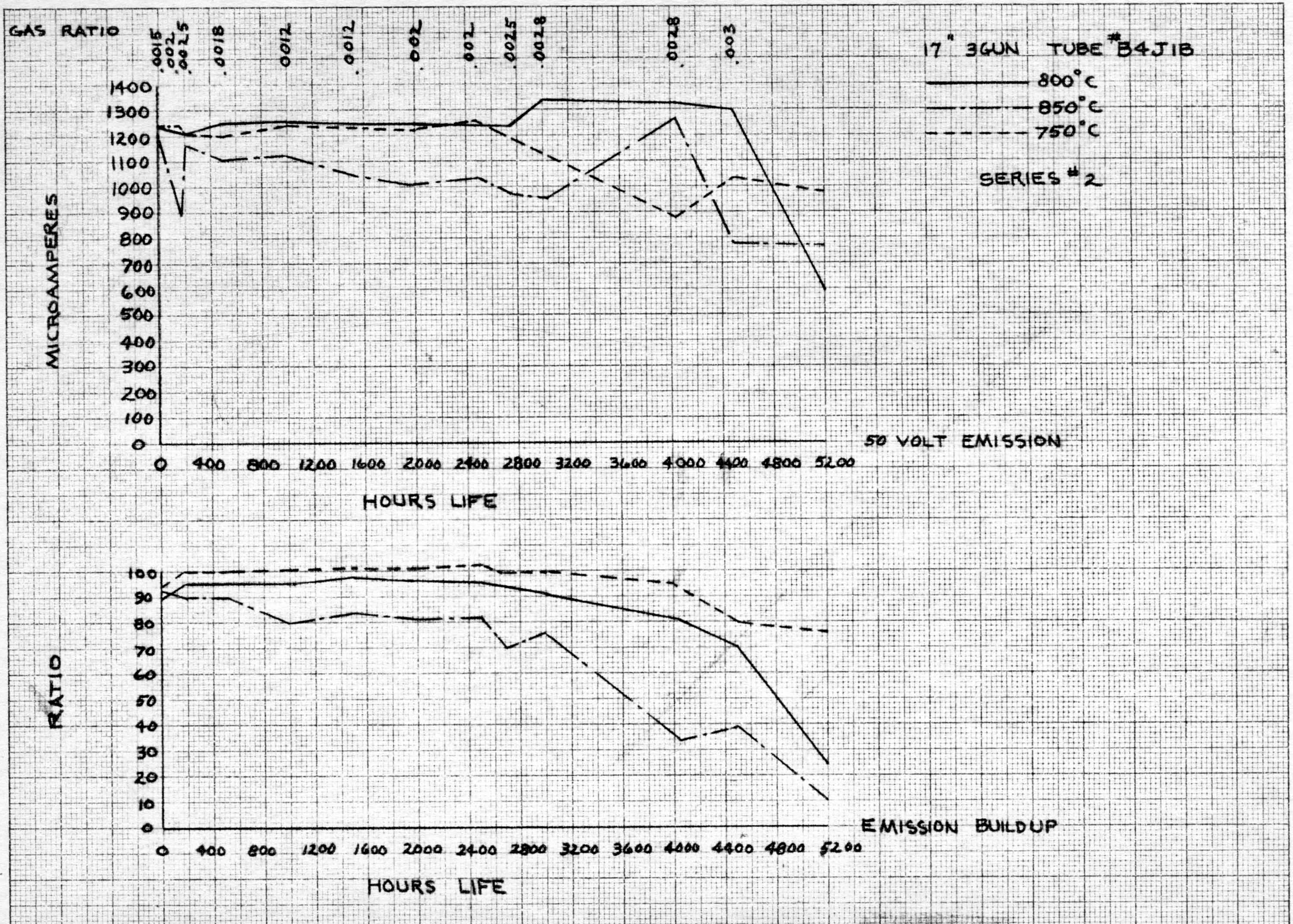
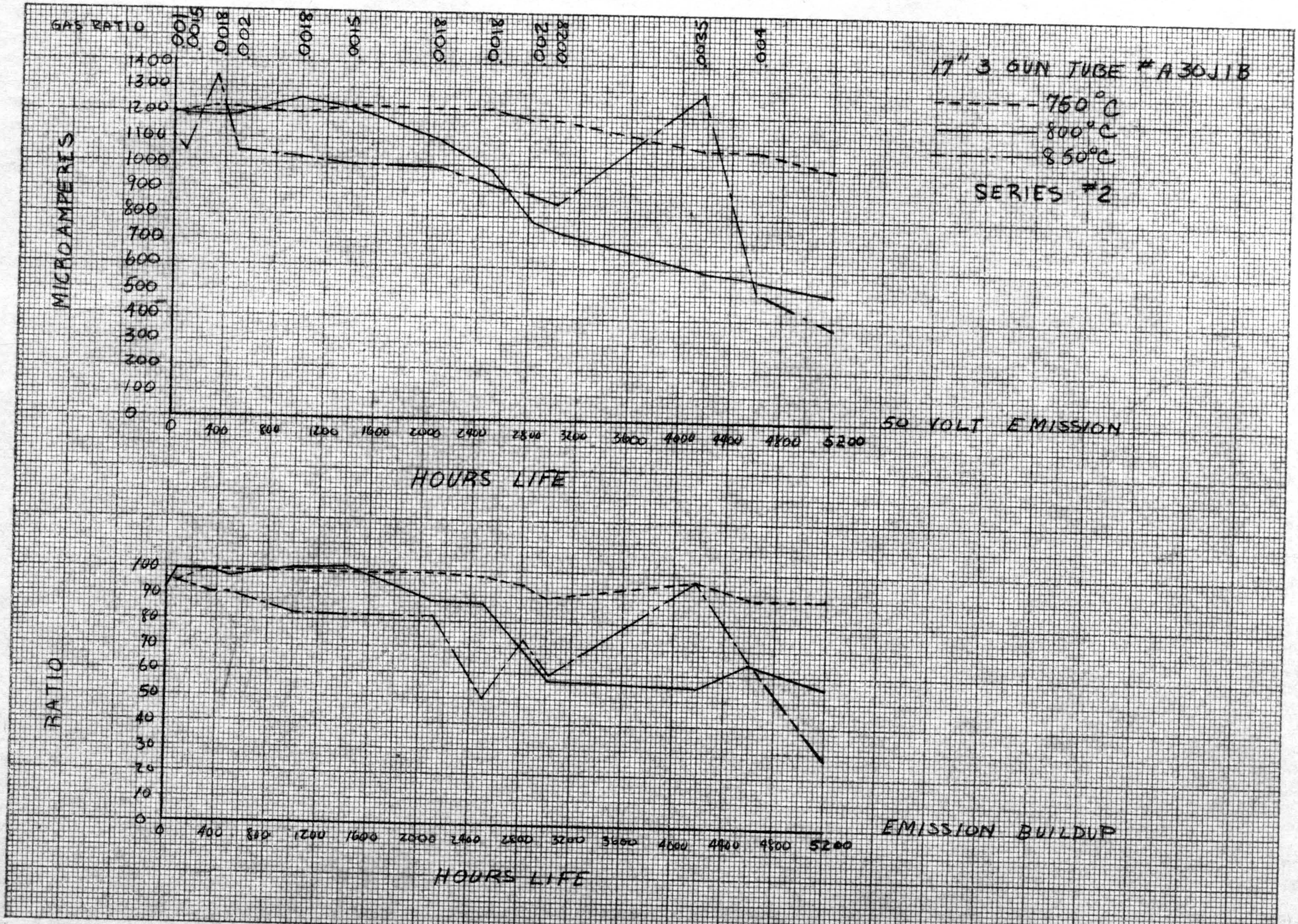

GAS RATIO
.0015 .002 .0025 .0018 .0012 .0012 .002 .002 .0025 .0028 .0028 .003
17" 3GUN TUBE # B4J1B
800°C
850°C
750°C
SERIES # 2
MICROAMPERES
1400 1300 1200 1100 1000 900 800 700 600 500 400 300 200 100 0
0 400 800 1200 1600 2000 2400 2800 3200 3600 4000 4400 4800 5200
HOURS LIFE
50 VOLT EMISSION
RATIO
100 90 80 70 60 50 40 30 20 10 0
0 400 800 1200 1600 2000 2400 2800 3200 3600 4000 4400 4800 5200
HOURS LIFE
EMISSION BUILDUP

FIGURE 11



GAS RATIO
.001
.0015
.0018
.002
.0018
.0015
.0018
.0018
.002
.0028
.0035
.004
MICROAMPERES
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
17" 3 GUN TUBE #A30J1B
750°C
800°C
850°C
SERIES #2
50 VOLT EMISSION
HOURS LIFE
RATIO
EMISSION BUILDUP
HOURS LIFE

FIGURE 12

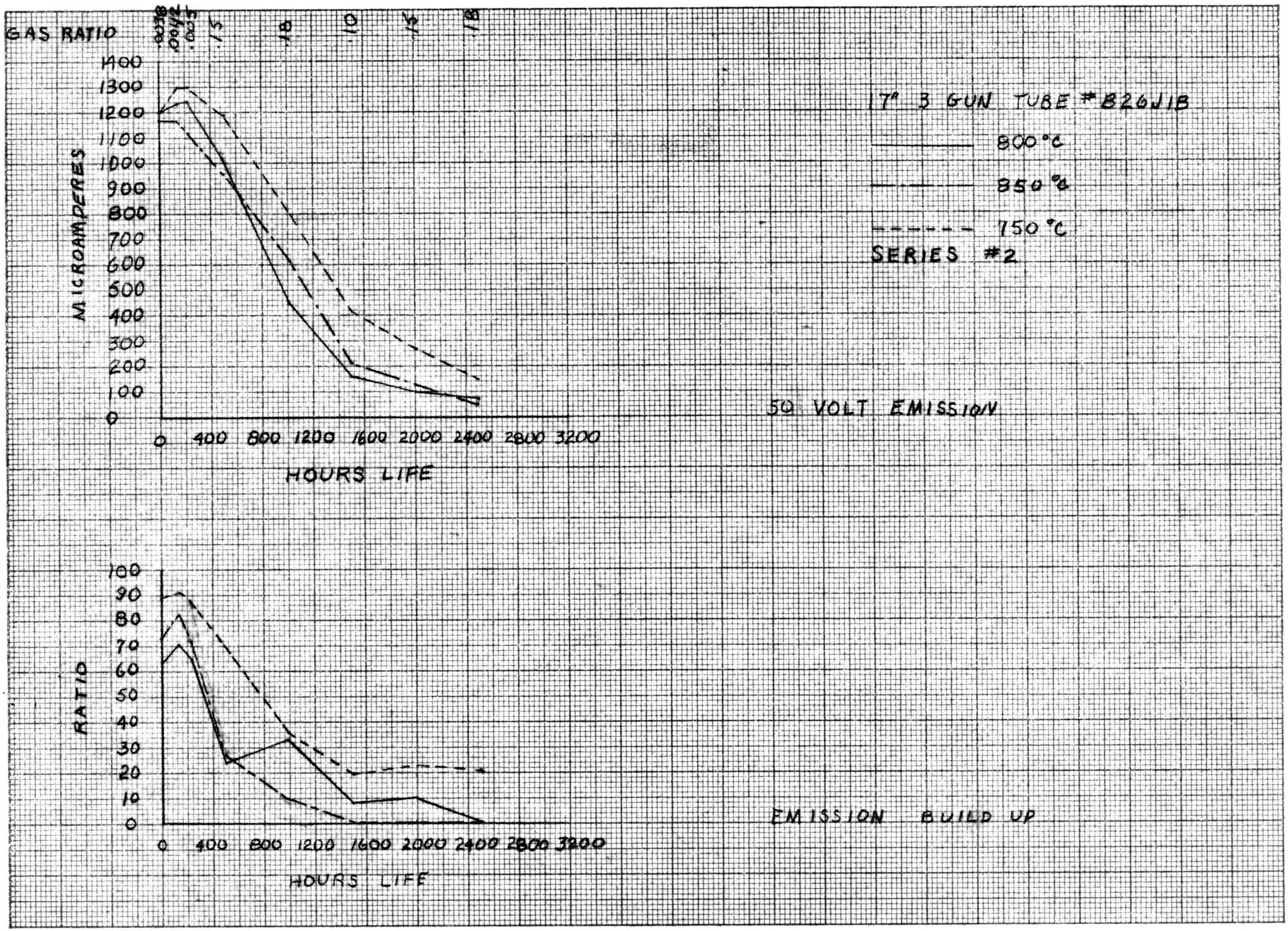

GAS RATIO
.0038 .0042 .003 .15 .18 .10 .15 .18
MICROAMPERES
1400 1300 1200 1100 1000 900 800 700 600 500 400 300 200 100 0
0 400 800 1200 1600 2000 2400 2800 3200
HOURS LIFE
17" 3 GUN TUBE # B26J1B
800 °C
850 °C
750 °C
SERIES #2
50 VOLT EMISSION
RATIO
100 90 80 70 60 50 40 30 20 10 0
0 400 800 1200 1600 2000 2400 2800 3200
HOURS LIFE
EMISSION BUILD UP

FIGURE 13

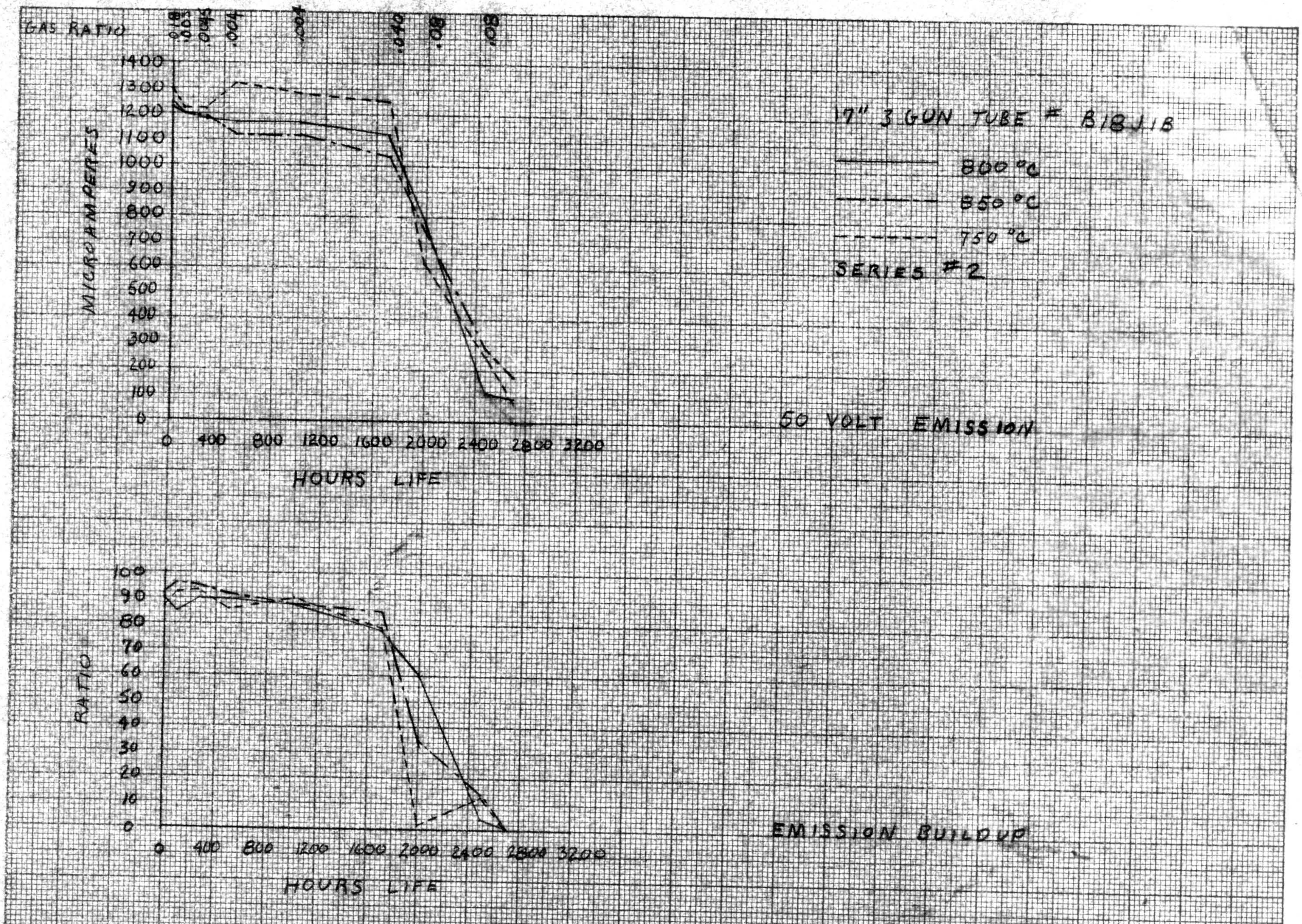

GAS RATIO
.018
.003
.045
.004
.004
.040
.08
.08
MICROAMPERES
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0 400 800 1200 1600 2000 2400 2800 3200
HOURS LIFE
17" 3 GUN TUBE # B18J1B
800 °C
850 °C
750 °C
SERIES #2
50 VOLT EMISSION
RATIO
100
90
80
70
60
50
40
30
20
10
0
0 400 800 1200 1600 2000 2400 2800 3200
HOURS LIFE
EMISSION BUILDUP

FIGURE 14

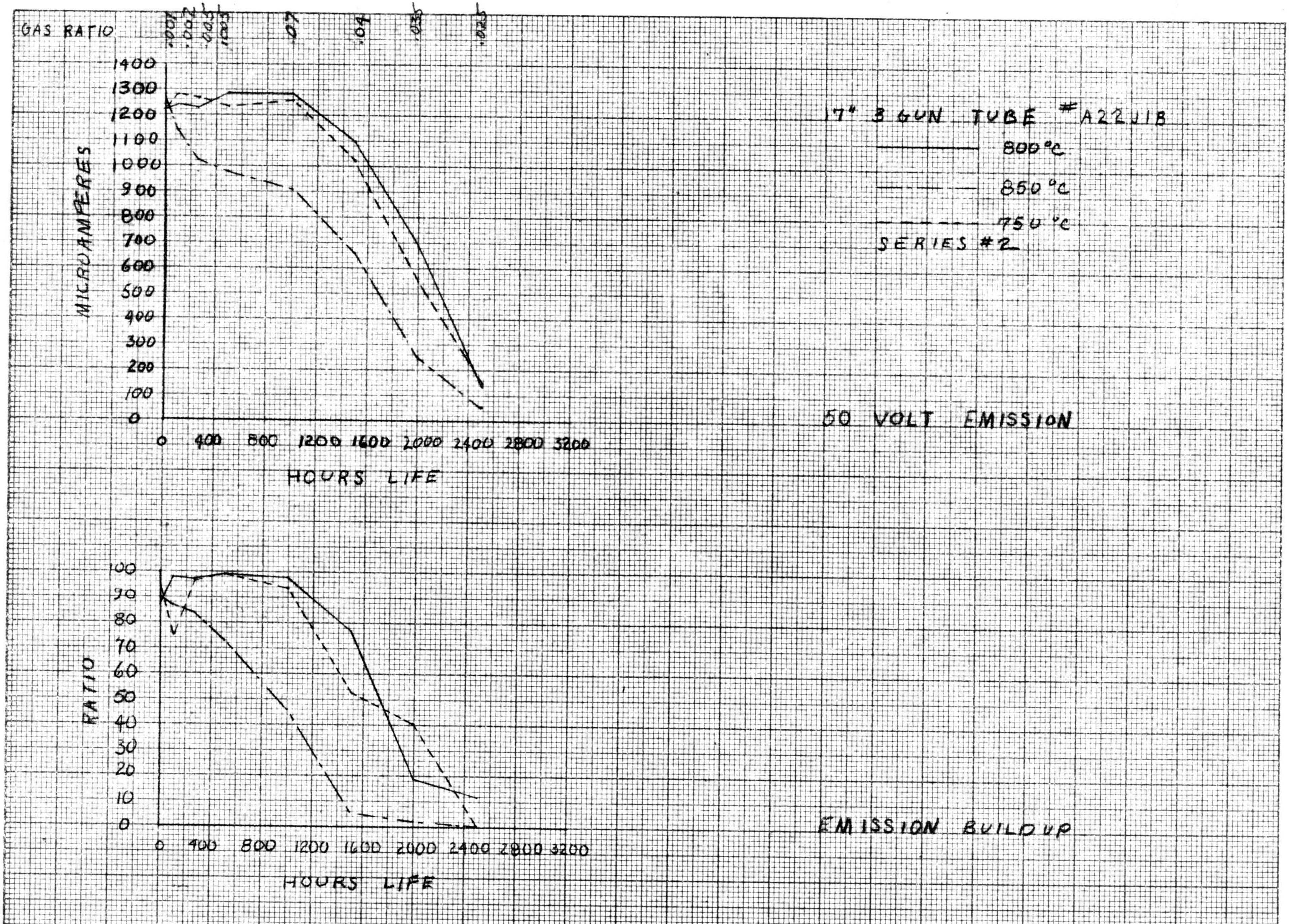

GAS RATIO
MICROAMPERES
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0 400 800 1200 1600 2000 2400 2800 3200
HOURS LIFE
17" 3 GUN TUBE #A22J1B
800 °C
850 °C
750 °C
SERIES #2
50 VOLT EMISSION
RATIO
100
90
80
70
60
50
40
30
20
10
0
0 400 800 1200 1600 2000 2400 2800 3200
HOURS LIFE
EMISSION BUILDUP

FIGURE 15

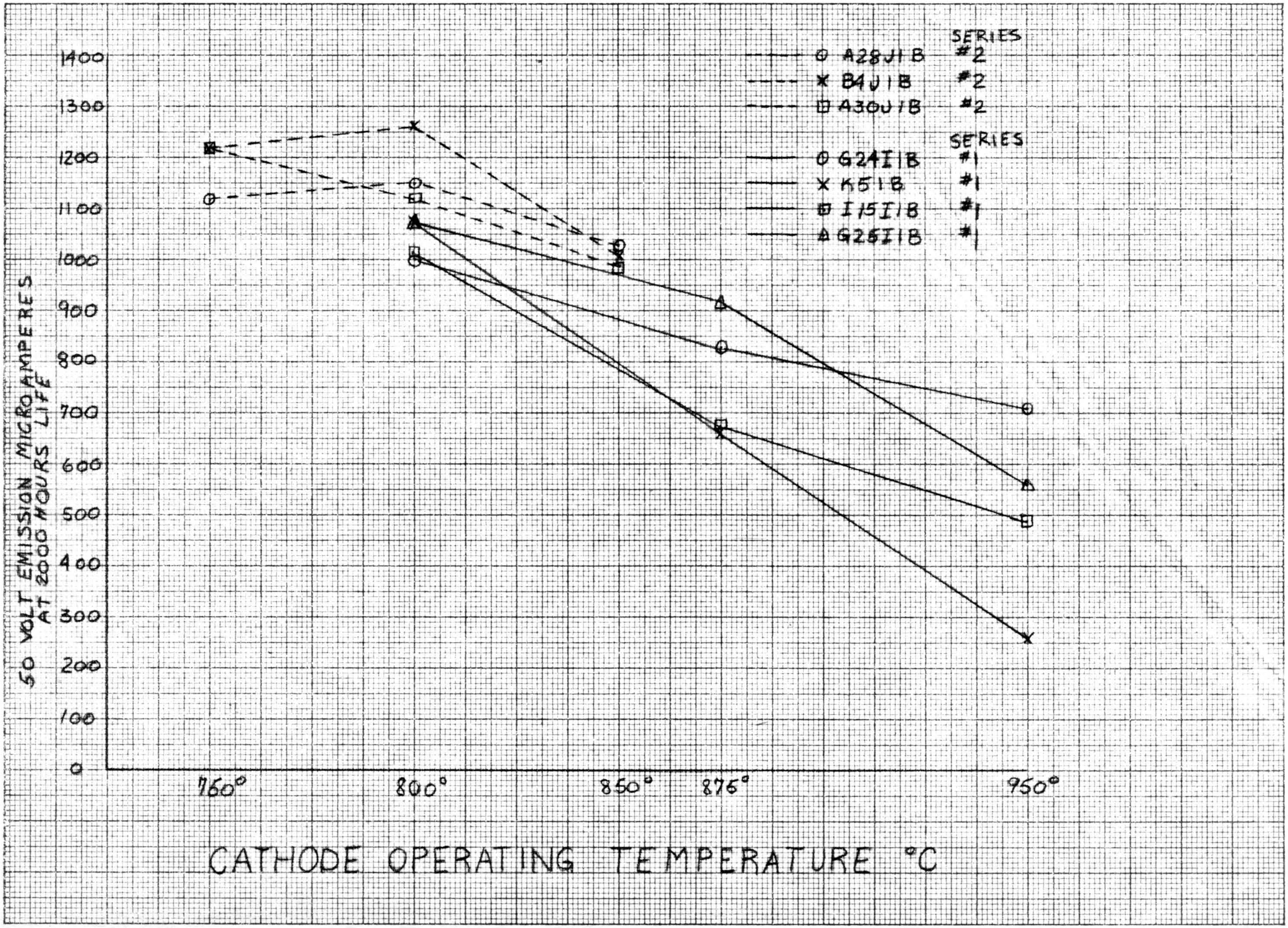

50 VOLT EMISSION MICROAMPERES AT 2000 HOURS LIFE
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
760°
800°
850°
876°
950°
CATHODE OPERATING TEMPERATURE °C
SERIES
A28J1B #2
B4J1B #2
A30J1B #2
SERIES
G24I1B #1
K51B #1
I15I1B #1
G25I1B #1

FIGURE 16