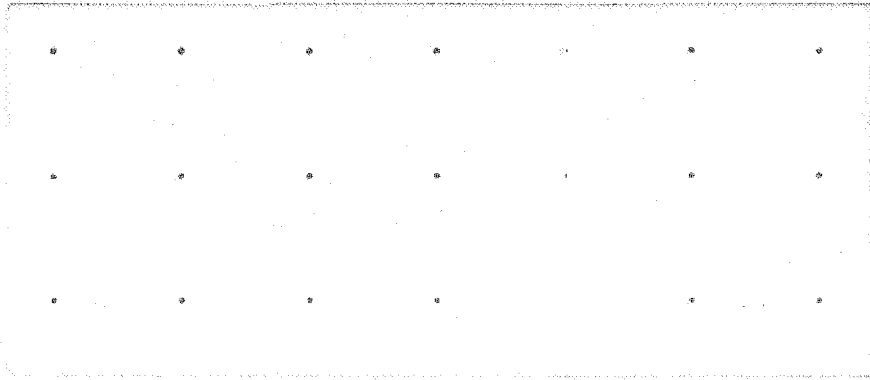


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SIXTH QUARTERLY REPORT
SOLAR THERMIONIC
GENERATOR DEVELOPMENT

June 1967

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SIXTH QUARTERLY REPORT SOLAR THERMIONIC GENERATOR DEVELOPMENT

Summary

This report covers progress for the sixth quarter, corresponding to the period from March 1, 1967, to June 7, 1967.

During this quarter, converter T-206 has been fabricated and tested. The converter was fabricated with particularly flat electrodes and is a good specimen of the T-200 series. The test data revealed a higher output, which has been attributed to the use of a rhenium collector. The data has shown, however, that the output characteristics are sensitive to the type of electron-bombardment filament which is used in the converter heat source. For this reason, Thermo Electron considers that the results presented in this report are of a preliminary nature, and plans have been made to subject T-206 to a new series of tests, which will ascertain accurately the effect of electron-bombardment filament type and give precise performance data.

The data from converter T-206 was sufficiently accurate to allow a detailed evaluation of collector heat transfer. The collector temperatures obtained at selected values of converter output current have been compared with those predicted by the second collector-radiator model previously described in the Fifth Quarterly Report, and it has been found that the actual collector heat transfer exceeds the predicted values by a constant amount. Based on the revised values of collector heat transfer, it has become clear that the T-200 design is so constrained that it cannot be made to operate statically at high current densities without severe collector overheating. For this reason,



Thermo Electron has recommended to JPL that plans be made to incorporate heat pipes in the collector-radiator structures of converters T-208 and T-209. Since the T-200 geometry is still suitable for the evaluation of dynamic performance, and since heat pipes cannot be incorporated immediately, Thermo Electron has recommended to JPL that the fabrication of converter T-207 proceed using the design of converter T-206. JPL and Thermo Electron have agreed to the use of a palladium collector in the fabrication of converter T-207.



1. Fabrication of Converter T-206

Converter T-206 was fabricated with great care to avoid previously encountered difficulties, namely, emitter out-of-flatness and repeated cesium charging due to leaking pinch-offs. The emitter was ground flat, lapped to a mirror-like finish, electroetched for 1 minute at 5 volts in the standard bath composition, and thermally stabilized after welding to the emitter support structure for 2 hours at 2100°C. Final flatness checks showed that the emitter face was flat within 50 millionths of an inch, and that it was square with the axis of symmetry of the support structure within 2.7 minutes of arc. These tolerances are well within the estimated requirements of flatness, within 10% of the nominal interelectrode spacing of 1.8 mils, i. e., within 180 millionths of an inch, and of squareness within 10 minutes of arc.

The converter was fabricated in accordance with the outline shown in Figure 1, which includes an 0.020"-thick rhenium collector pressure-bonded to the collector barrel, and which has a collector radiator structure which exactly duplicates that of the collector-radiator model #2. As described in the Fifth Quarterly Report, this collector-radiator model was fabricated and tested to demonstrate improved heat-transfer characteristics before the fabrication of converter T-206 was begun. Specifically, compared with the design of T-205, converter T-206 had a collector barrel shortened by 0.030 in.; a transition piece, part No. 10, joining the collector barrel to the radiator fins, thickened by 0.070 in.; radiator fins lengthened by 0.3 in., coated with chromium oxide instead of chromium carbide; a redesigned cesium reservoir, partially coated with chromium oxide; a vanadium braze between the rhenium emitter support and the outer niobium seal flange; a more



abundant use of braze material at the root of the radiator fins; and no collector heater.

The fabrication proceeded normally, with the exception of the final braze, where the radiator fins reached their melting point and a small amount of material did melt. The condition may be noticed in Figure 2, which shows a photograph of the finished prototype. The regions of material melted away can be noticed in proximity to the converter support ring. The melting of the fins also caused them to "sink" into the transition piece which supports the fins, and this caused a slight reduction of fin area and, at the same time, a better metallurgical bond of the fins to the collector structure.

The converter was outgassed for 44 hours at an observed emitter temperature of 1750°C. Cesium distillation was conducted for 8 hours at 200°C.

2. Testing of Converter T-206

a. Electron Bombardment Structure

Converter T-206 was tested with two different types of electron-bombardment filaments. All of the data except for the last two data points on sheet 5 was obtained using the regular S-type filament shown in Figure 3. The last two data points on sheet 5 were obtained with the circular filament shown in Figure 4. It is well to discuss the reason for testing with two different filaments and the results obtained before going into more detail regarding the observed characteristics.

One of the persistent difficulties in the T-200 experimental program has been the lack of agreement between the TEECO and the JPL data. After considerable effort at checking the instrumentation,

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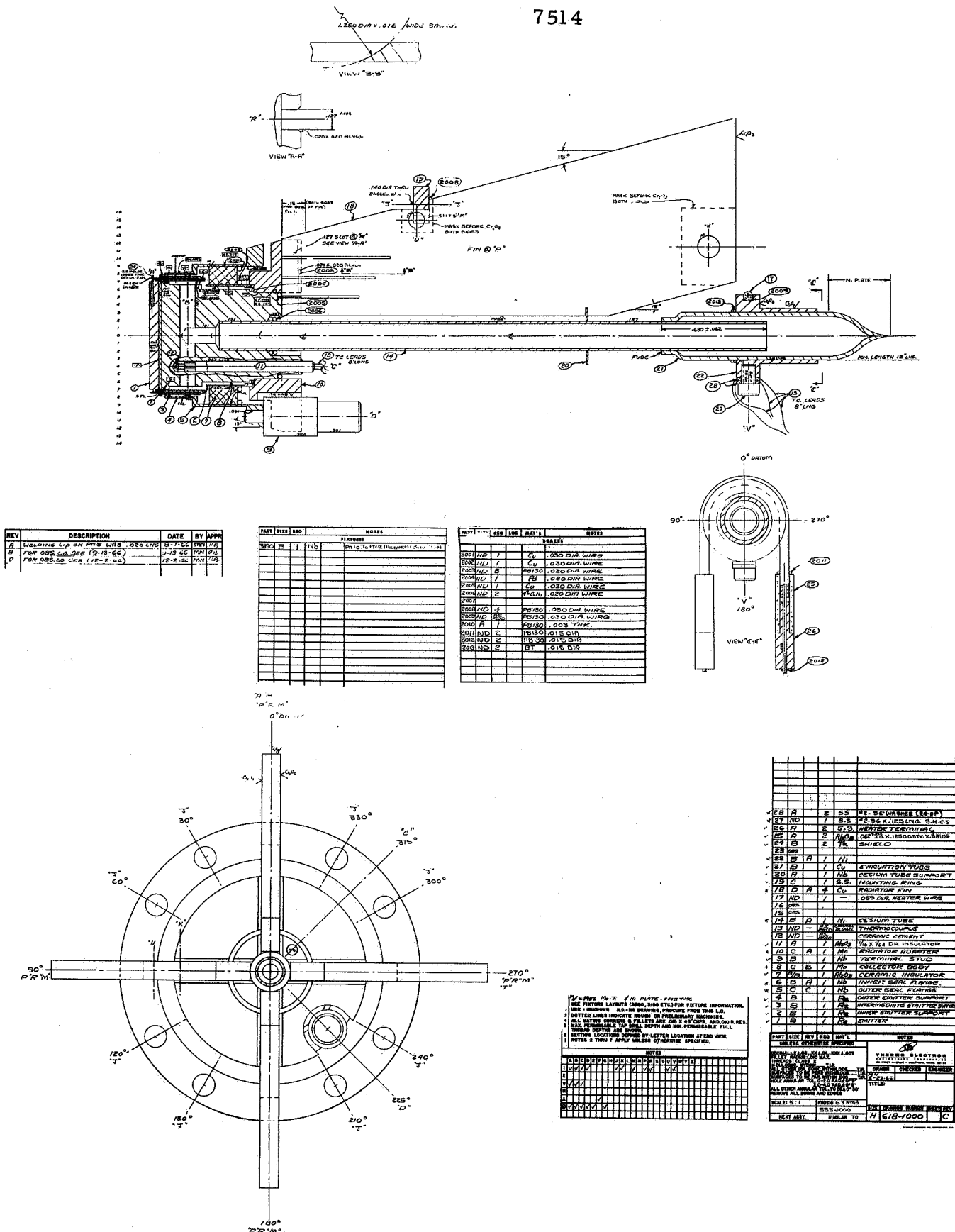


Figure 1

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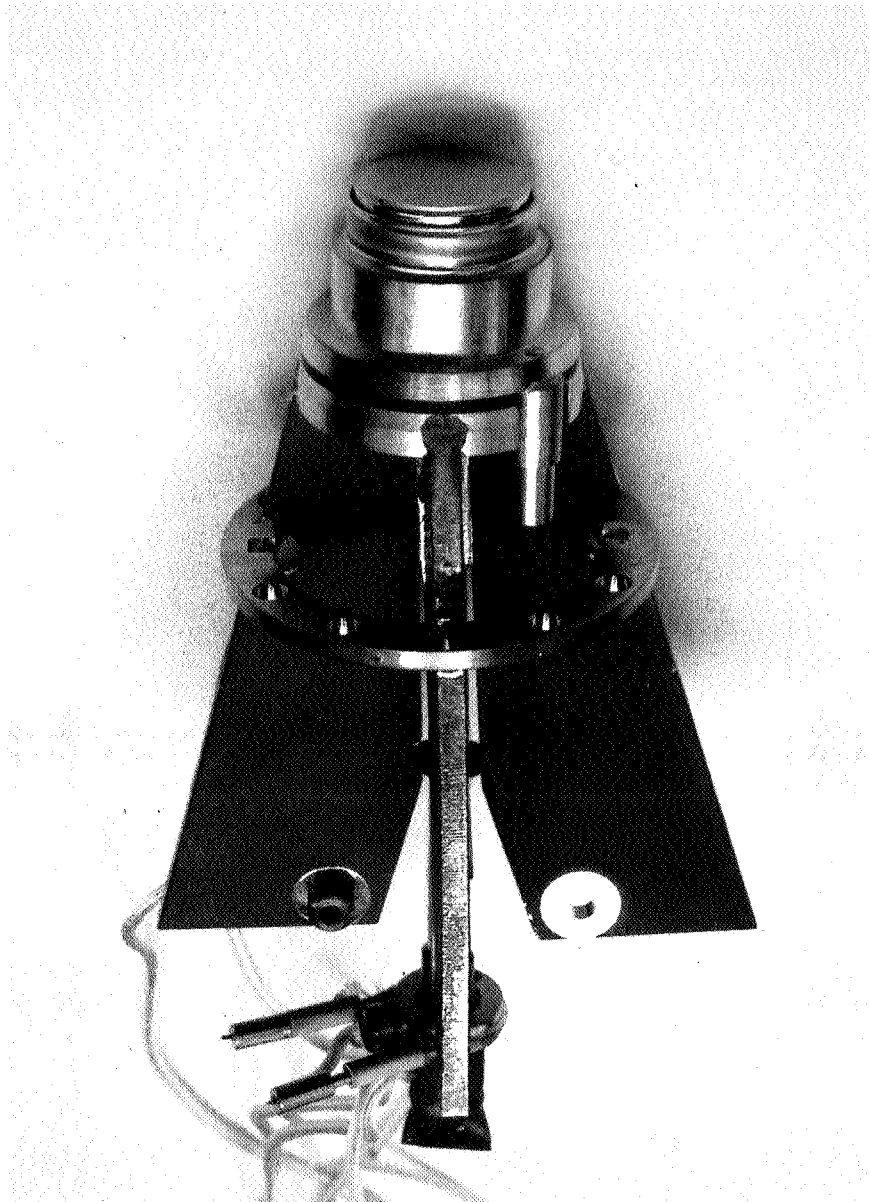


Figure 2

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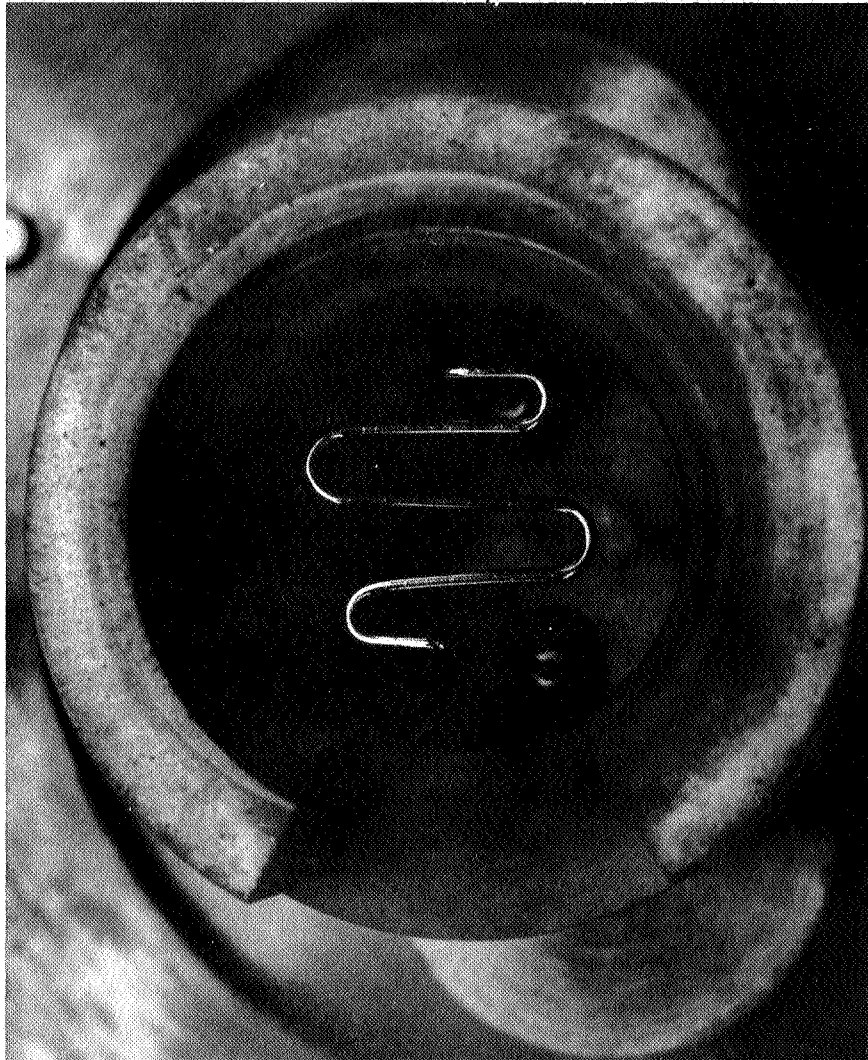


Figure 3

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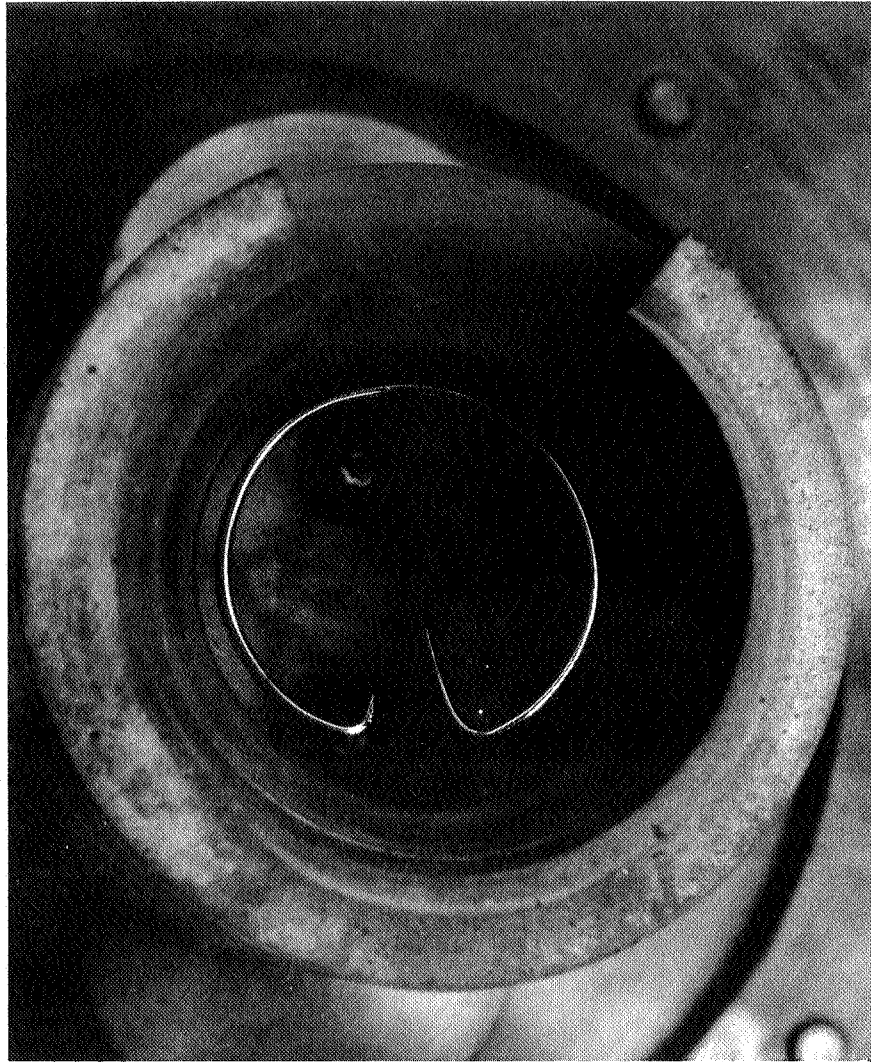


Figure 4



particularly the pyrometers used for emitter temperature measurement, it was suspected that the discrepancies might be due to the configuration of the device used for heating the converter. The JPL electron-bombardment unit is different from that used at Thermo Electron in that it uses a 1500-volt accelerating voltage instead of 1000, and a filament requiring nearly 50 amperes of heating current instead of 20. Although normally such differences would not be expected to cause significant variations in the data, the T-200 converter design may be more susceptible to performance discrepancies because it has a thinner emitter structure. With a thin emitter structure, the actual temperature distribution over the emitter surface and the brightness of the hohlraum will depend to a greater extent on the energy and distribution of the bombarding electrons on the heated side.

The experiment performed with the two types of filaments confirmed that very large differences in performance can be observed with different electron-bombardment sources. The two data points #9 and #10 given in sheet 5 were selected to attempt reproducing the data point #5 of sheet 4. In the first attempt the observed temperature of the emitter was the same, 1700°C, but the observed output at 0.8 volt was 32.1 amperes instead of 41.2 amperes, a decrease of 22%, and the required power input was 305.7 watts instead of 344.8, a decrease of 11.3%. In the second attempt the power input of 345 watts was reproduced, and the output current observed at 0.8 volt was practically the same: 40.9 amperes compared with the previous value of 41.2. The observed emitter temperature was considerably higher, however: 1742°C true hohlraum temperature instead of 1700°C.



It is felt that this test shows quite conclusively what is apt to be the greatest source of discrepancy between the JPL and TEECO experiments. Furthermore, the test shows that the power input is a more reliable and reproducible measurement, particularly when different electron-bombardment structures are used, than the observed hohlraum temperature. The most likely cause of hohlraum temperature variation is the development of a hot spot along the hohlraum inside wall due to concentrated electron bombardment on the heated side; it must be borne in mind that the wall thickness between the hohlraum and the heated side is only 0.010 in. in the T-200 converter (except those with pressure-bonded emitters). Thus an electron-bombardment structure with a U-type filament such as shown in Figure 5, where care is taken to avoid placing any portion of the bombardment filament directly on top of the hohlraum, should allow the reliable measurement of emitter temperature. Any other structures should be avoided. Thermo Electron considers that the data presented in this report should be collected again, using the U-type filament, and plans have been made with JPL to repeat the test of T-206. The data in this report is preliminary, and the next Quarterly Report will present the results obtained with the modified filament structure.

b. Collector Thermal Performance

As already mentioned, converter T-206 had exactly the same collector radiator structure as that which had been tested independently in the collector-radiator model #2 to assess the capability of this structure to achieve near-optimum collector temperatures. It is of interest here to attempt some comparisons in thermal performance between the collector-radiator model #2 and the corresponding structure

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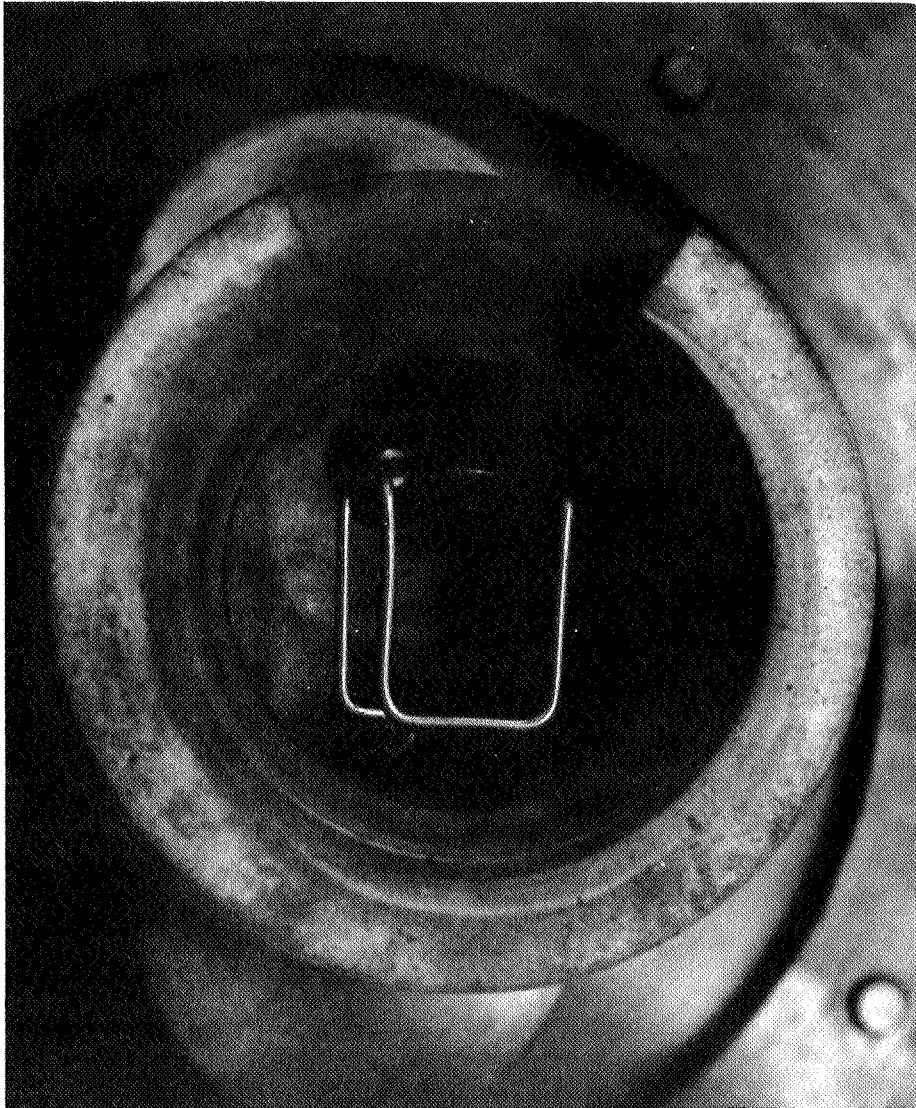


Figure 5



of converter T-206 to see how closely the heat transfer conditions in an operating converter can be predicted.

Figure 6 gives the thermal performance observed in the collector-radiator model, and the vertical lines superimposed on the performance curves identify the predicted collector heat transfer values at the labeled values of converter output current. Thus the data of this figure can be tabulated as follows:

<u>Output Current, Amperes</u>	<u>Predicted T_c, °K</u>	<u>Predicted T_{rad}, °K</u>
0	684	612
24	814	702
48	928	764
72	1030	816

and solid-line curves for these values are plotted in Figure 7. All the static data points obtained for converter T-206 in the temperature range of 1700°C are shown on the figure along the dashed lines. As can be seen, somewhat higher than predicted values of temperature were actually achieved. The curves indicate a horizontal shift of 20 to 25 amperes, which corresponds to underestimating the heat transfer by approximately 40 watts. The value of the shift increases with current, because at higher currents the output voltage is lower and the corresponding value of electron heating per ampere is higher. The amount by which the collector heat transfer has been underestimated can also be calculated from the measured and predicted values of the temperature difference between the collector and the radiator at zero output current. The value of this difference predicted by the collector-radiator model is $684-612 = 72^\circ\text{K}$ at a heat transfer value of 67.4 watts,

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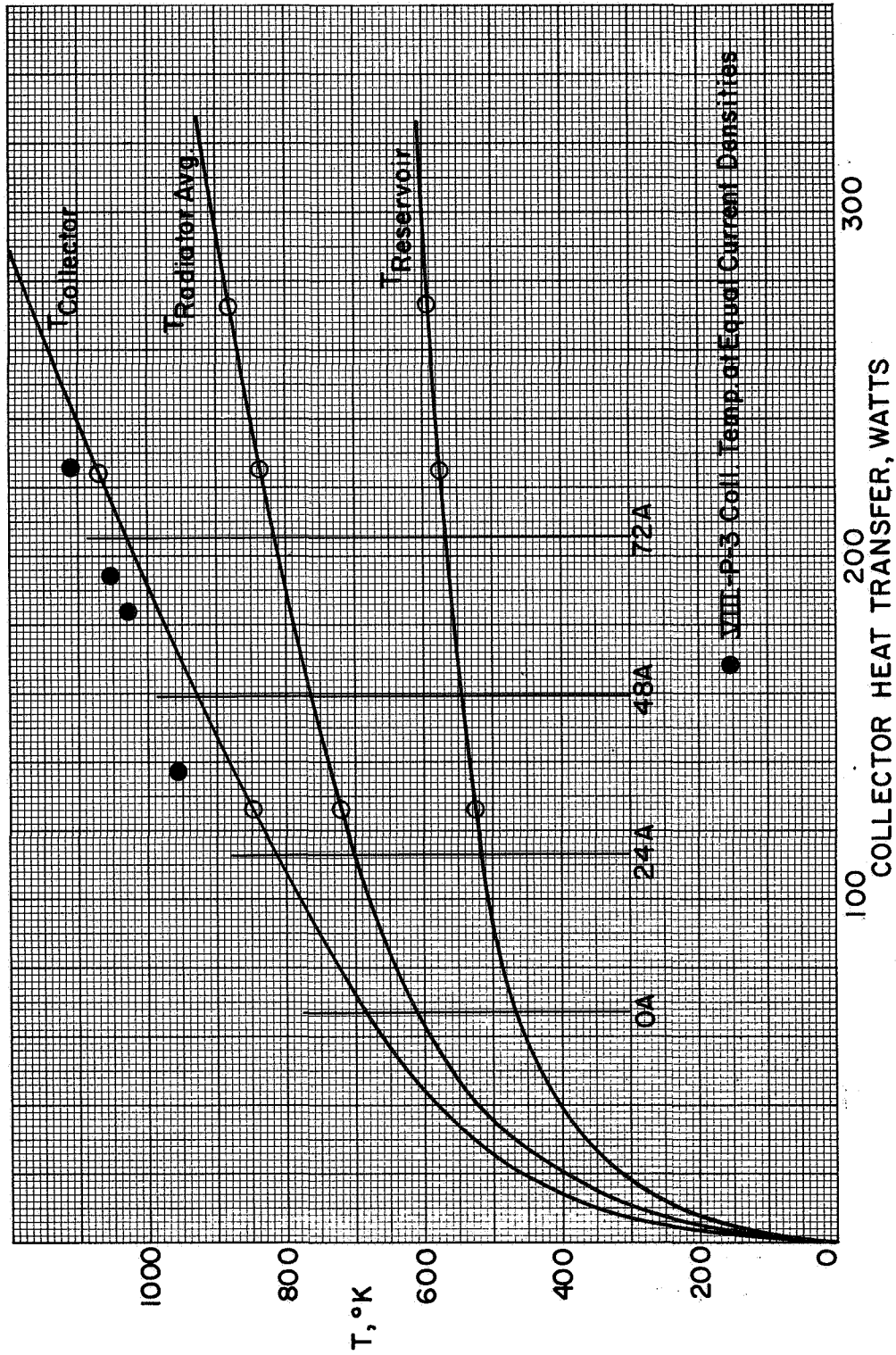


Figure 6

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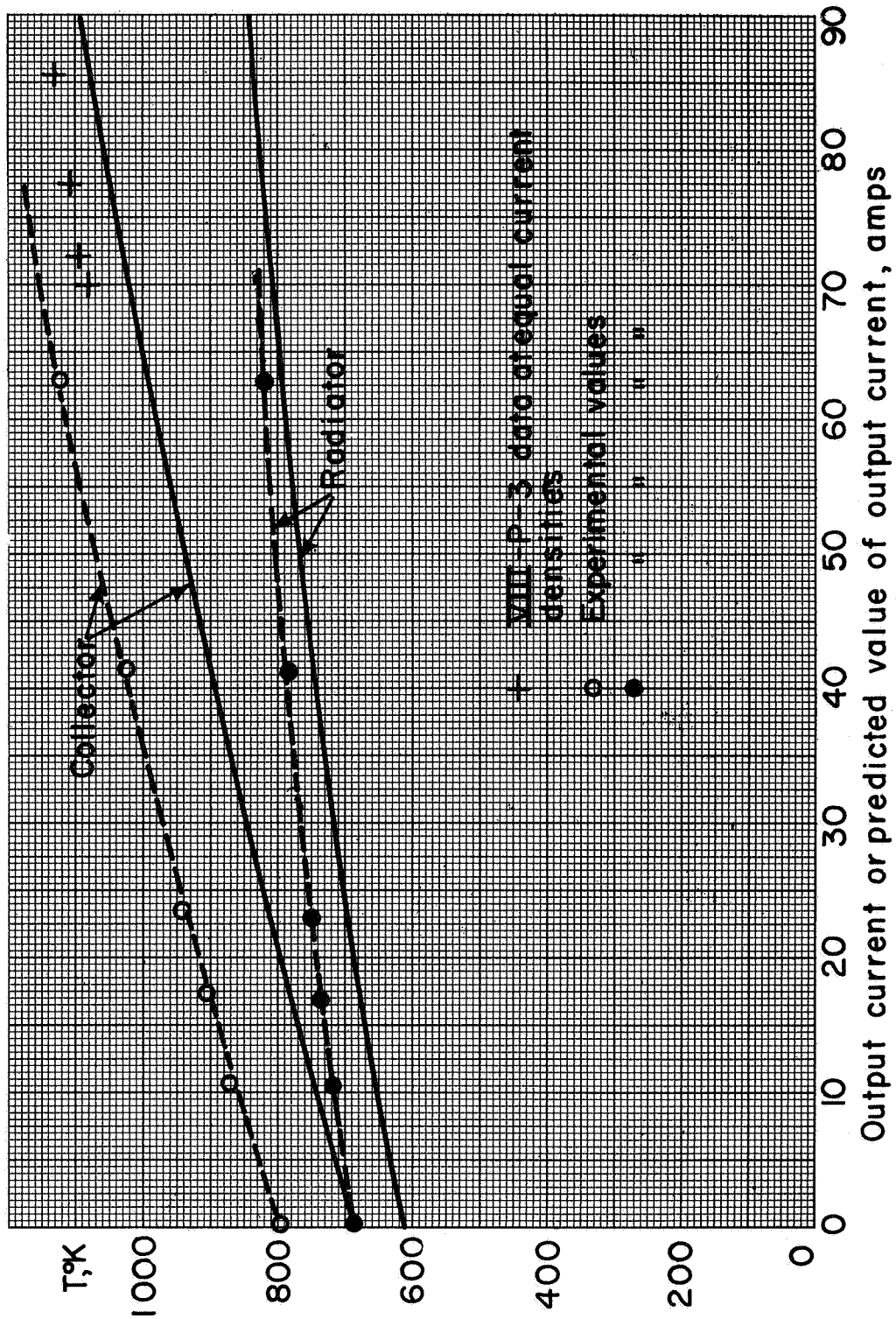


Figure 7



according to the solid curves of Figure 6. The value actually measured in converter T-206 is given by data point 1 of sheet 4: $525 - 412 = 113^{\circ}\text{C}$. To a first approximation, then, the actual collector heat transfer was $67.4 \times 113/72 = 105.7$ watts, or 38.3 watts more than expected. This value agrees well with the observed shift corresponding to approximately 40 watts. Furthermore, the heat transfer ratio $105.7/67.4$ should be approximately equal to the fourth power of the ratio of observed to predicted average radiator temperatures. These are $412 + 273 = 685^{\circ}\text{K}$ for converter T-206, and 612°K for the collector-radiator model. The fourth power of the ratio $685/612$ is 1.565, which compares very well with the value of 1.569 for the ratio $105.7/67.4$.

In conclusion, then, it is demonstrated that the collector heat transfer in converter T-206 has been underestimated by 38.3 watts, resulting in collector temperatures higher by 120°C than predicted, and which are higher than the VIII-P-3 collector temperatures, shown in Figure 7, by approximately 65°C . One of the causes for this discrepancy is the increase in interelectrode heat transfer due to the use of a rhenium instead of a molybdenum collector. The previous calculation of interelectrode radiation had been based on the assumption of emitter and collector emissivity of 0.28 at corresponding temperatures of 2000°K and 1040°K , and had yielded a value of 34.4 watts. The value for collector emissivity of 0.28 had been made deliberately large to compensate for the experimentally measured surface deterioration that is normally encountered in operation. The actual value of total emissivity for molybdenum at the effective temperature of $\sqrt{2000 \times 1040} = 1450^{\circ}\text{K}$ is approximately 0.15. The assumed value allowed for an increment of 0.13 to the theoretical value. Figure 8 gives the emittance data for



rhenum measured by G. B. Gaines of Battelle Memorial Institute and C. T. Sims of General Electric Company in the Journal of Applied Physics, 34, 2922. It can be seen here that the emittance of the emitter at 2000°K is actually at least 0.30, and probably a value of 0.35 should be assumed to account for the effect of electroetching the surface. The emissivity at 1450°K is 0.244. If allowance for deterioration by the addition of 0.13 to the emittance is made, as in the case of molybdenum collectors, the collector emissivity assumed should be 0.374 for rhenum. Using these values, the interelectrode radiation calculated at emitter and collector temperatures of 2000°K and 1040°K is $(90.86 - 6.64)/(1/0.35 + 1/0.374 - 1) = 18.6 \text{ watts/cm}^2$. For an emitter area of 2.5 cm^2 , the loss is then 46.5 watts, which is 12.1 watts larger than the value previously assumed. The remainder of the difference in collector heat transfer cannot be accounted for by simple additional corrections to the basic converter heat transfer model, and this should be taken into account when calculating the collector heat transfer of thermionic converters.

As far as the overall effect of the collector-radiator modifications is concerned, it is of interest to compare the steady-state performance of T-206 with that of T-205. The optimized conditions compare as follows:

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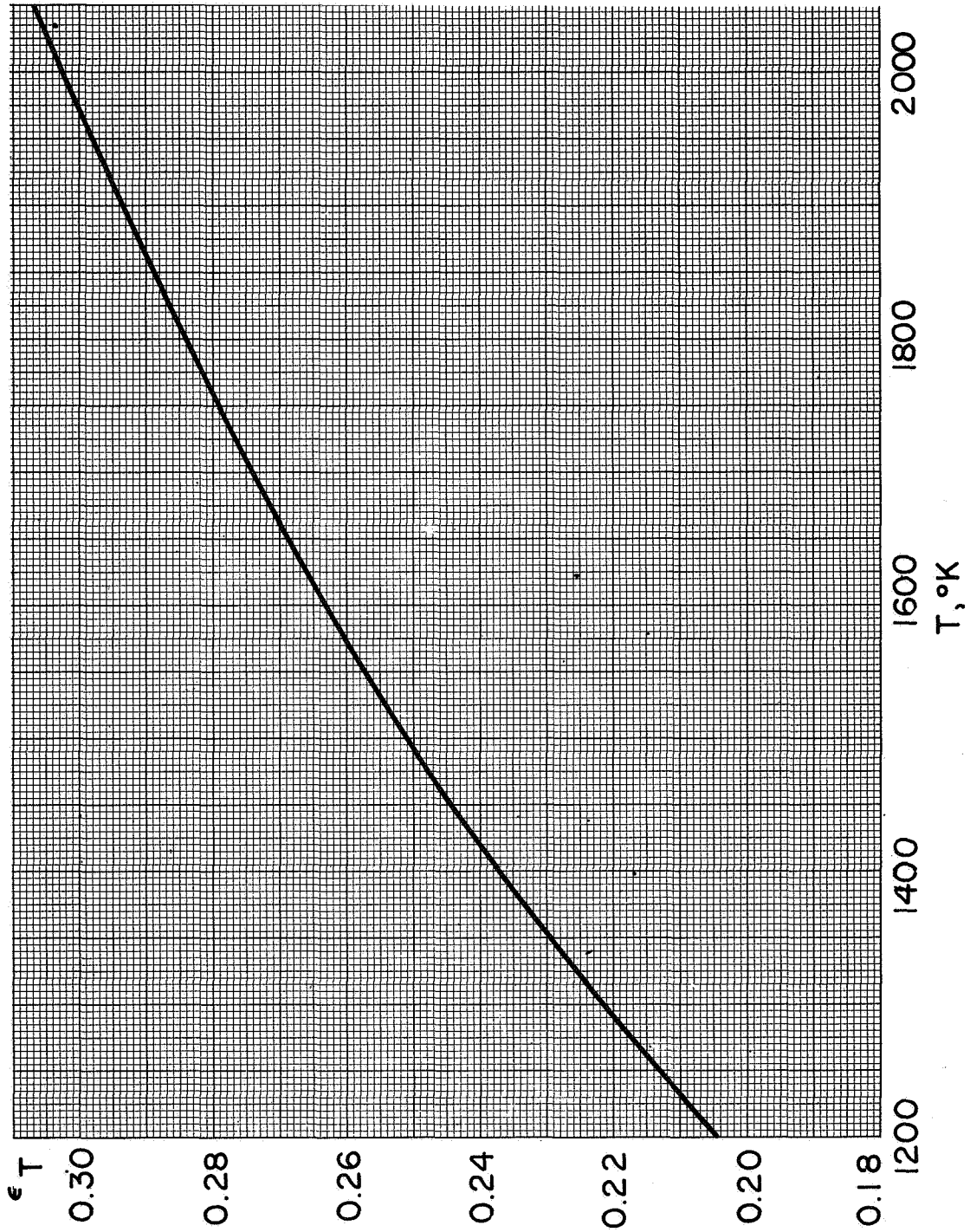


Figure 8



	<u>T-205</u>		<u>T-206</u>	
Hohlraum Temperature, °C	1720		1700	
Output Voltage, volts	0.8	1.0	0.8	1.2
Output Current, amperes	34.2	17.1	41.2	16.9
Reservoir Temperature, °K	609	590	621	604
Collector Temperature, °K	1029	928	1027	910
Radiator Temperature, °K	802	758	786	739
Collector Temperature Drop, °C	227	170	241	171
Power Input, watts	308	257	345	281
Overall Efficiency, %	8.9	6.6	9.6	7.2

In the above table it is obvious that, in spite of the higher interelectrode radiation losses due to the use of a rhenium collector, and in spite of the higher values of input power, converter T-206 achieves lower collector and radiator temperatures at higher or equal output currents. Thus an improvement in collector heat transfer was achieved, but the VIII-P-3 values plotted in Figure 7 show that further improvements are needed.

c. Converter Thermal Performance

Since doubts exist about the accuracy of the emitter temperature measurements, it is of interest to compare the optimized characteristics of all converters developed to date, based on optimized output current for prescribed values of output voltage and heat input, which is a direct measure of efficiency vs heat input. Figures 9 and 10 give this information for the T-100 series of converters at 0.8 volt and 1.0 volt, respectively. Figures 11 and 12 are corresponding figures for the T-200 series of converters. It can be seen, on the basis of these figures, that the best T-100 converter is converter T-103, and the best T-200 converter is T-202 with the exception of

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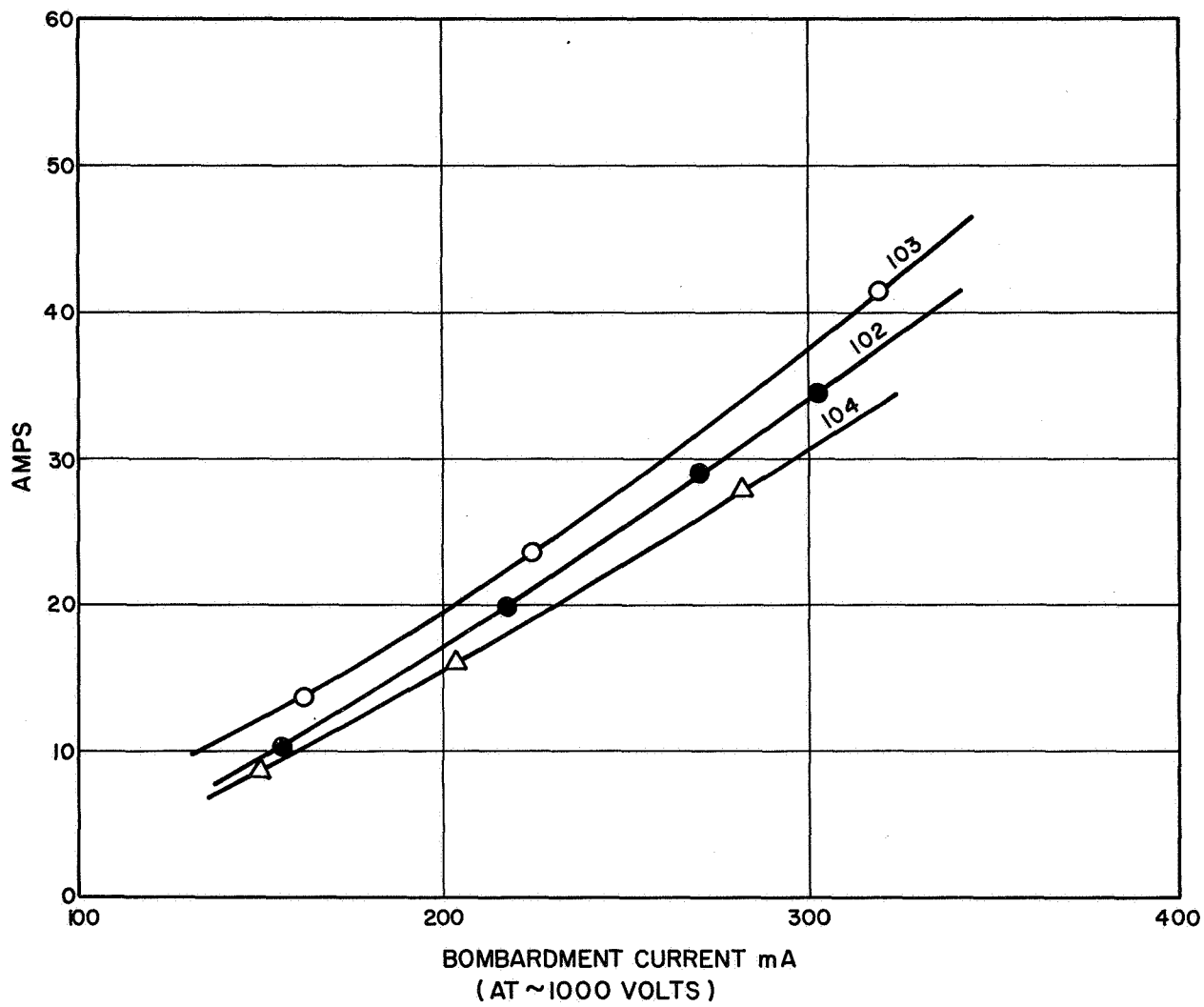


Figure 9

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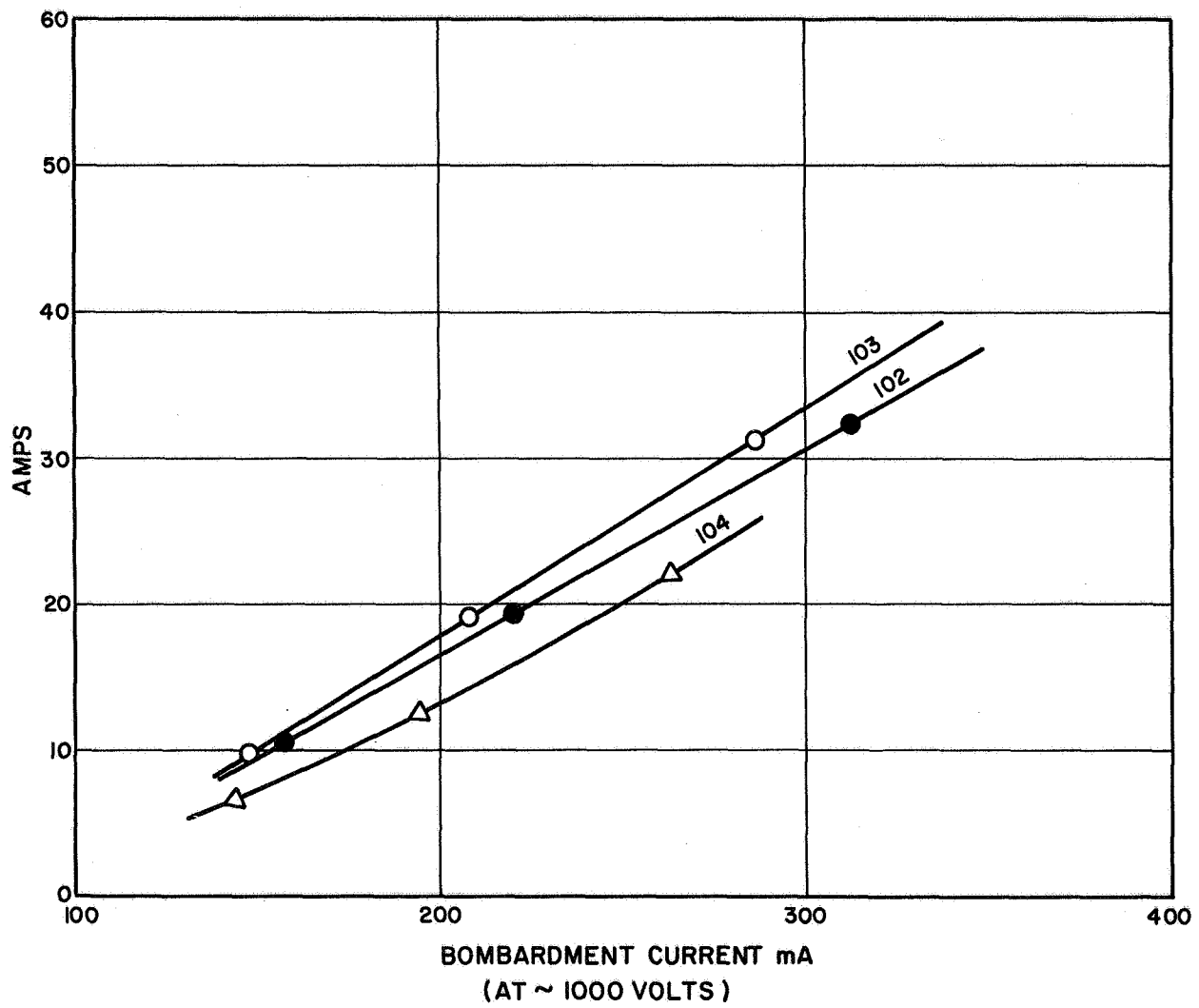


Figure 10

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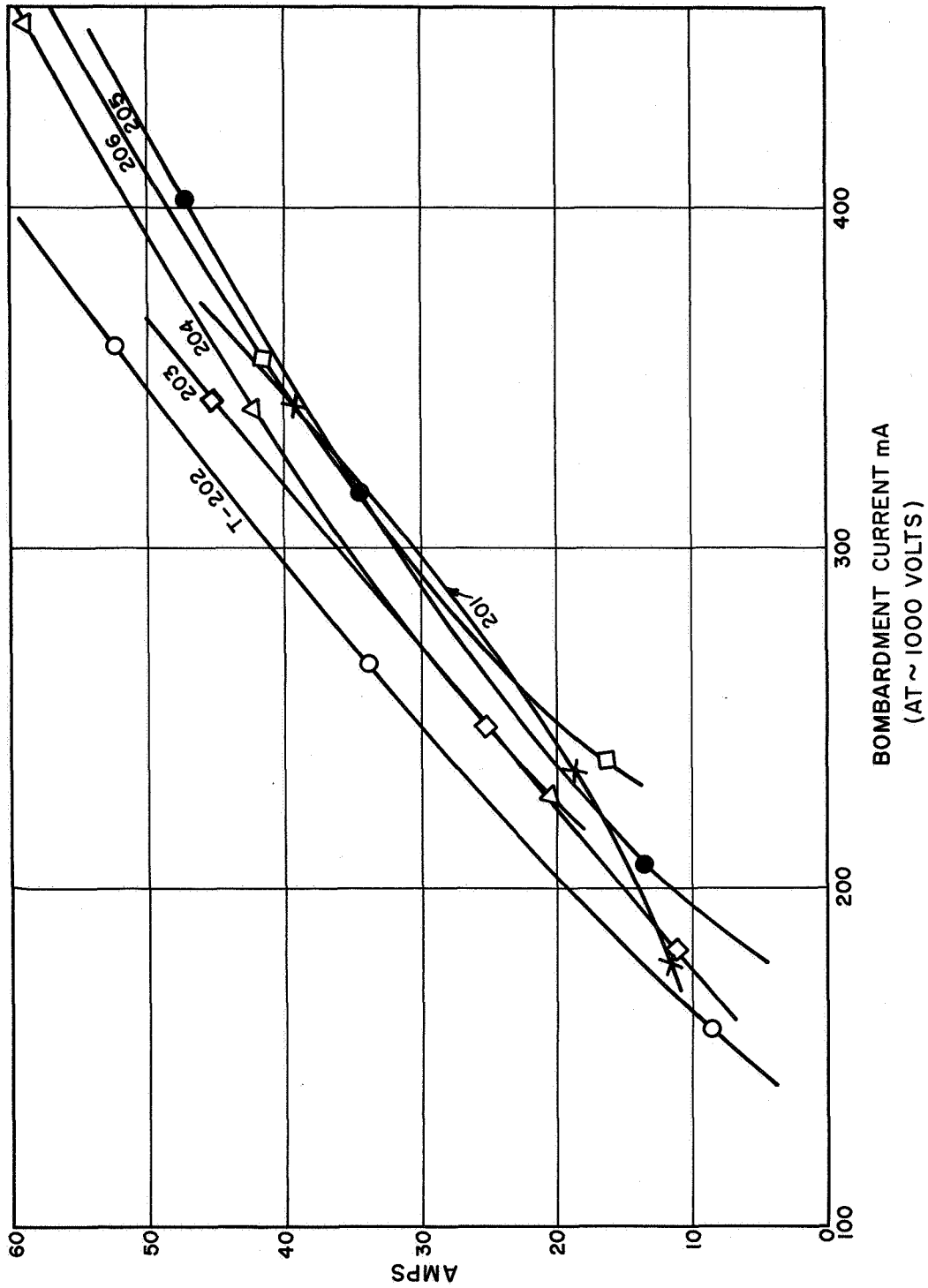


Figure 11

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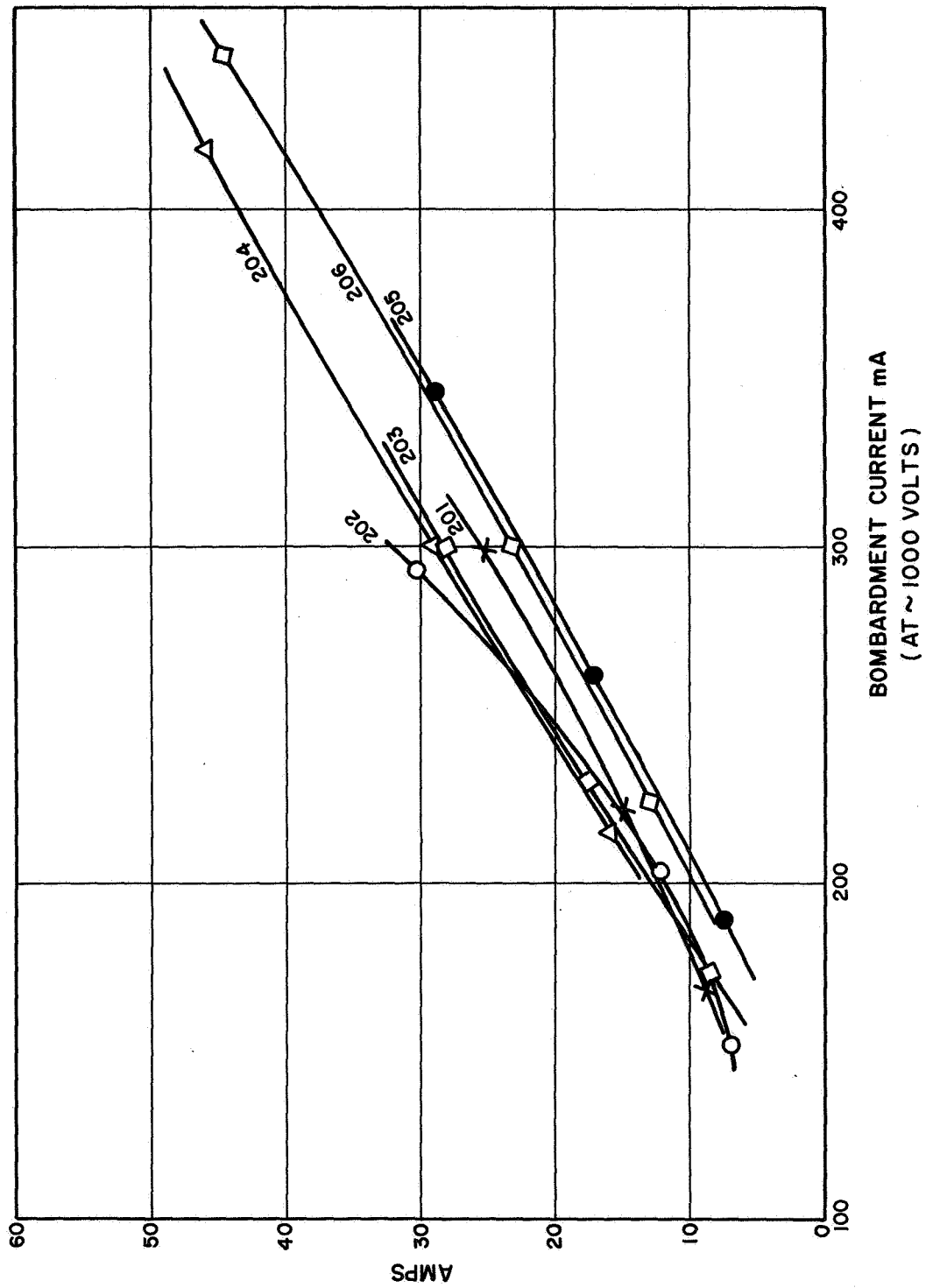


Figure 12



the low temperature range. Converters T-205 and T-206 are among the poorest, T-205 because of its lower output, and T-206 because of its higher heat losses. It is reasonable to expect that T-202 should have the highest efficiency in the T-200 series because it closely reproduced converter T-103, except for the modified collector barrel which should not affect the efficiency, and it had the tantalum emitter support structure with lower radiation and conduction losses. Since this emitter structure cannot be used without the use of pressure-bonding, which is considered unreliable for long life, the best choice available is converter T-204, which is the same as converter T-206 except that it has a molybdenum collector.

In summary, then, the procedures required to reduce the T-200 converter to a fully qualified item of space hardware have tended to reduce slightly the overall converter performance which had been obtained with the converters of the experimental Series VIII and T-100. These changes have been:

- (1) Increasing the T-100 spacing of 1 mil to 1.75 mils.
- (2) Use of an integral rhenium emitter.
- (3) Use of a heavy rhenium emitter support.

The increase in spacing to 1.75 mils has been made principally to ensure the achievement of long operating life, which would otherwise have been in doubt with spacings of 1 mil. This increase has made it necessary to use a longer collector barrel, and as a result severe heat transfer problems have been encountered which prevent the achievement of optimum collector temperatures. A solution to this problem will probably be found only when heat pipe structures are used to dissipate collector heat. The use of an integral rhenium emitter



has been adopted to avoid pressure-bonding and its attendant problems due to diffusion at the bonded boundary: formation of brittle inter-metallics and porosity by the Kirkendall effect. The disadvantage of the integral rhenium emitter is that it increases external radiation losses. The increase is in proportion to the ratio of the emissivities of rhenium and tantalum at 2000°K: $0.302/0.234 = 1.29$. Making allowance for the smaller lateral area of the T-200 converter, it is found that the external heat loss of 84.5 watts of the T-100 series becomes 95.0 watts. The use of a heavy rhenium emitter support cannot be avoided because thin rhenium tubing of reliable quality is not yet available.

d. Relative Collector Work Function

The measurements to obtain relative collector work function could not be conducted readily with converter T-206 because of the absence of a collector heater. The best available measurement is that provided by comparing the optimum output voltage at which an output of 40 amperes was obtained during converter mapping at 2000°K, at the highest reservoir temperature of 645°K, and with a near optimum value of collector temperature which, at a reservoir temperature of 645°K, is nearly 1030°K. The higher this voltage, the lower the collector work function. This relative indication is dependent on emitter temperature at the rate of 1.5 mV/°C at a reservoir temperature of 645°K. The values recorded to date are:

	<u>201</u>	<u>202</u>	<u>203</u>	<u>204</u>	<u>205</u>	<u>206</u>
V _{40A}	0.76	0.67	0.67	0.79	0.76	0.91
645°K						



These show that the collector work function achieved with the rhenium collector of converter T-206 is at least a tenth of a volt lower than that of the molybdenum collectors of the other converters. Converter T-206 was not able to demonstrate the benefits of the lower collector work function under static testing because of collector overheating, but the dynamic characteristics show substantial improvement in performance. The optimum outputs obtained in dynamic testing at 0.8 and 1.0 volt and at 2000°K for the various converters are as follows:

	<u>201</u>	<u>202</u>	<u>203</u>	<u>204</u>	<u>205</u>	<u>206</u>
Output current at 0.8 volt, A	28.8	26.0	35.5	45.0	41.0	63.0
Output current at 1.0 volt, A	21.0	14.0	22.7	26.0	22.0	34.7
Collector temperature, °K	1065	1052	973	1017	990	1002

The output values for converter T-206, as already explained, must be considered tentative data, to be confirmed by further tests with the U-type filament. The collector temperatures given should be optimum because testing experience has consistently indicated that the optimum collector temperature is closely equal to 1.6 times the corresponding reservoir temperature, and this is nearly the case for the above data.

e. Interelectrode Spacing

The procedure used to find interelectrode spacing is based on the formula for cesium conduction of Kitrilakis and Meeker:

$$Q = 0.0615 A (T_e - T_c) / [2.5 d + 0.015 (T_e + T_c) / p]$$

where A is the area in sq cm, d the spacing in mils, and p the cesium pressure in mm Hg. The formula can be differentiated implicitly with respect to pressure to yield:



$$\partial Q/\partial p = 0.00092 A (T_E^2 - T_C^2) / [2.5 p d + 0.015 (T_E + T_C)]^2$$

and solved for spacing:

$$d = \{ [0.0001475 A (T_E^2 - T_C^2) / \partial Q/\partial p]^{0.5} - 0.006 (T_E + T_C) \} / p$$

At very small pressures, the slope of the curve is given by

$$\partial Q/\partial p = 4.10 A (T_E - T_C) / (T_E + T_C)$$

and the effective heat transfer area can be calculated:

$$A = (\partial Q/\partial p)_{p \approx 0} (T_E + T_C) / 4.10 (T_E - T_C).$$

Figure 13 gives the values of Q observed as a function of reservoir pressure. The slope of the curve at very small pressures is 4.35 watts/mm Hg, and for the values of $T_E = 1990^\circ\text{K}$ and $T_C = 810^\circ\text{K}$, the effective heat transfer area calculated is 2.52 cm^2 . Then, using the values at $p = 7 \text{ mm Hg}$ to calculate d , we obtain:

$$\partial Q/\partial p = 1.72 \text{ watts/mm Hg}$$

$$T_E = 1990^\circ\text{K}$$

$$T_C = 860^\circ\text{K}$$

and $d = 1.33 \text{ mils}$. A similar calculation at $p = 10 \text{ mm Hg}$ yields $d = 1.58 \text{ mils}$. Thus the spacing of converter T-206 correlates to about 1.5 mils.

3. Required Collector-Radiator Modifications

As mentioned in Section 2b, the model used to calculate the heat transfer in the collector-radiator structure of converter T-206 underestimated the heat transfer by 38.3 watts. To bring the predictions

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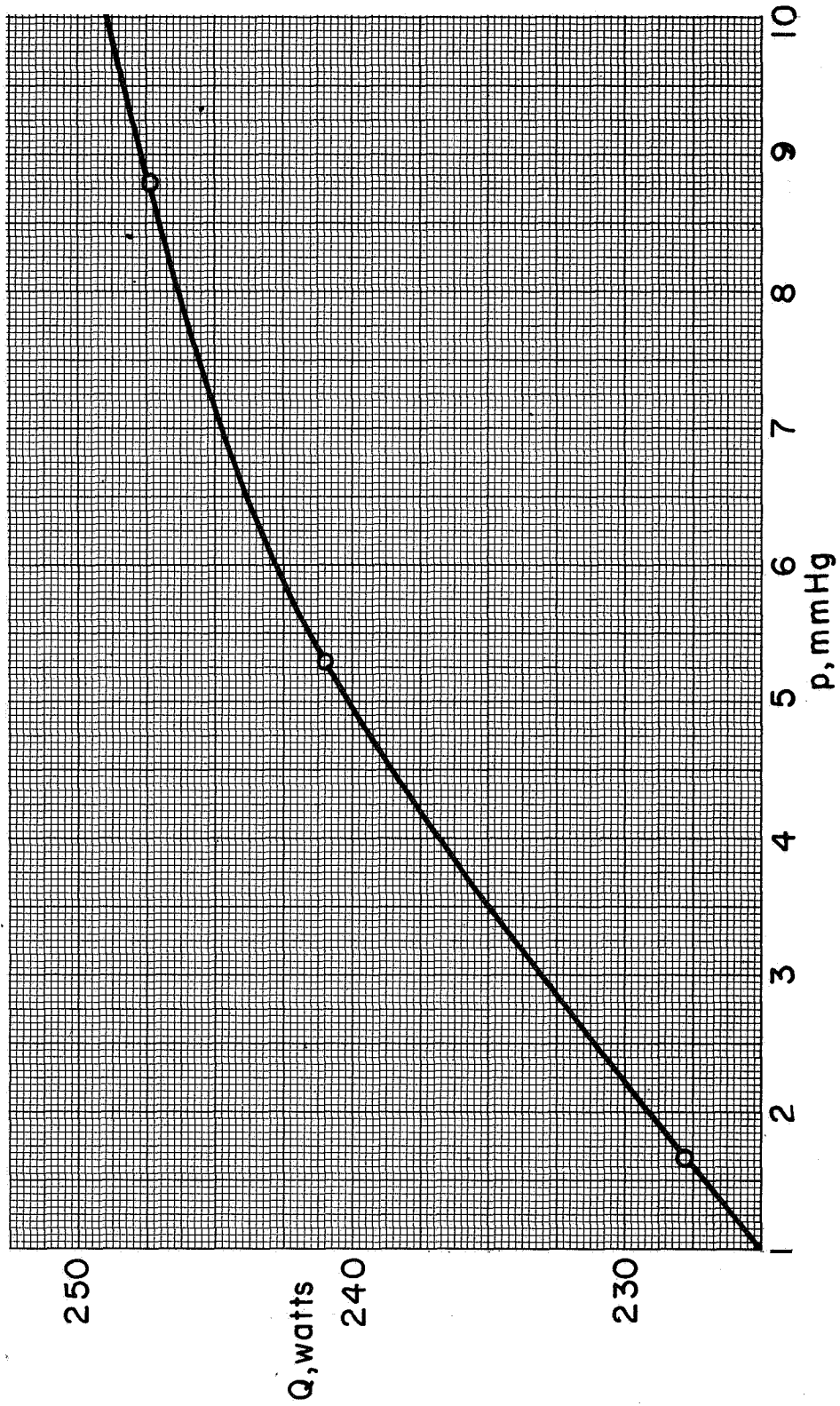


Figure 13



into agreement with the experimental observations, it is necessary to modify the calculations, presented on pages 3 and 9 of the Fifth Quarterly Report, by the addition of the discrepancy of 38.3 watts. The resulting revised table of collector heat transfer values is:

<u>Output Current, Amperes</u>	<u>Collector Heat Transfer, Watts</u>
0	105.7
24	151.7
48	197.7
72	243.7

which can be expressed in terms of the linear equation

$$Q_{\text{collector}} = 105.7 + 1.92 I_o$$

where I_o is the output current in amperes.

The effect of the underestimation of collector heat transfer has been to continue to exceed optimum collector temperatures by a significant margin. Figure 14 shows the collector and radiator temperatures achieved in converter T-206, at a hohlraum temperature of 1700°C, versus output current. The figure also shows the optimum value of collector temperature according to the empirical equation:

$$\text{Optimum } T_c = 1.6 \times \text{Optimum } T_r$$

which has been derived from the test experience with the T-200 converter design. As can be seen, the figure predicts that for any output above 33 amperes, the collector temperature will exceed its optimum value by an amount which increases rapidly with current.

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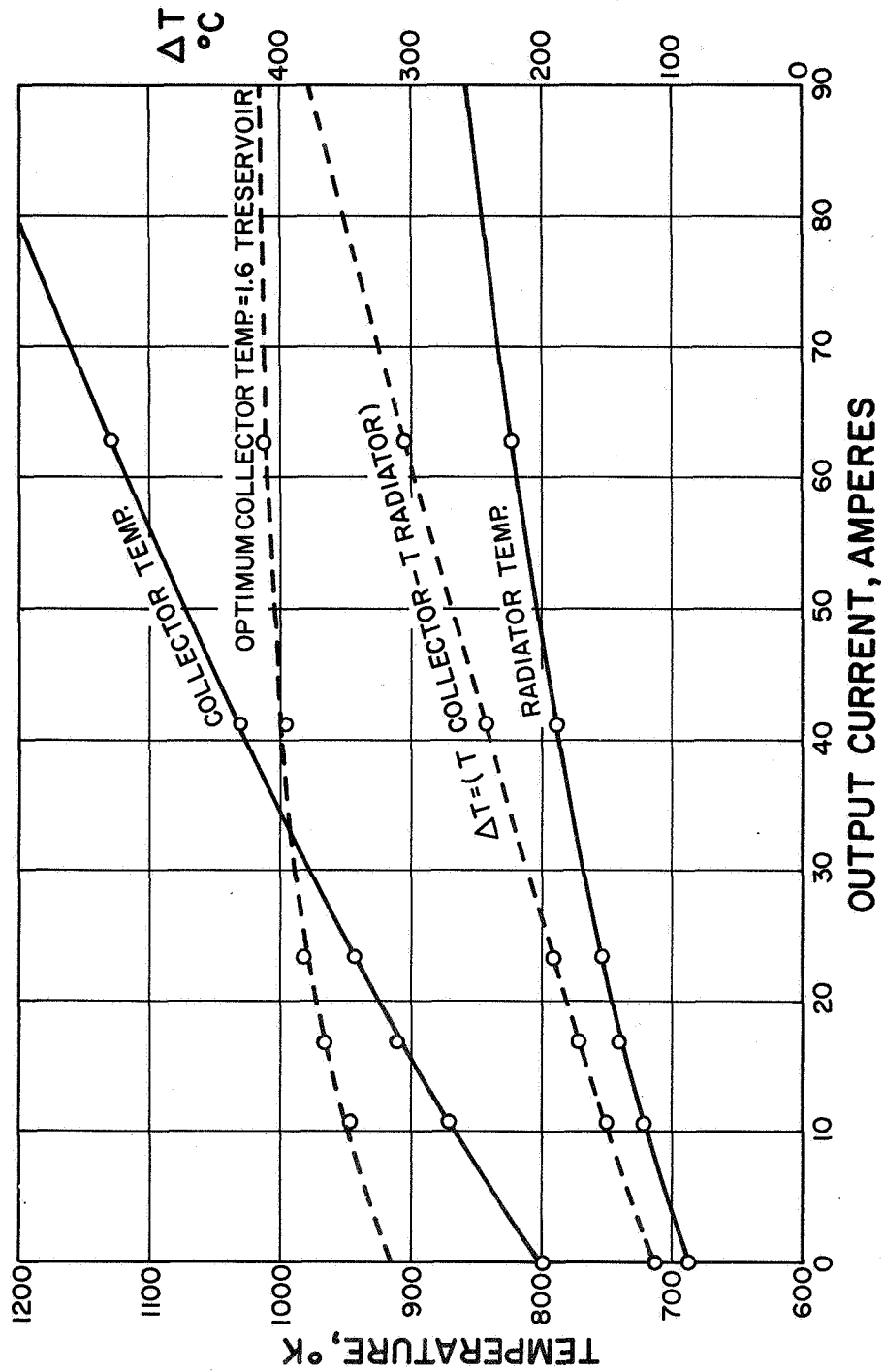


Figure 14



Although Figure 7 shows, in the comparison of the T-206 collector temperature data with that for converter VIII-P-3, that at 70 amperes the collector of converter T-206 is overheated by about 70°C, Figure 14 shows that the actual amount of overheat above optimum collector temperature is nearly 144°C.

The design changes required in the T-200 type of structure to further reduce collector temperature by as much as 100°C are so drastic that the resulting hardware would no longer have the features that make it attractive for use in a practical energy-conversion system. The requirement that the converter envelope be contained within a 30° envelope establishes a basic limit on the thermal conductance of the structure between the collector and the radiator, and this limit has been approached very closely with the modifications incorporated in the structure of T-206. Thus, since the collector heat transfer cannot be reduced, the collector-to-radiator temperature drop cannot be reduced either. The conclusion arrived at is that reductions in the collector temperature of the T-200 structure can be achieved only by reductions in radiator temperature. These reductions are very difficult to achieve because they imply large increases in radiator area. In the case of T-206 at 70 amperes, a reduction of only 100°C to the radiator temperature of 832°K given by Figure 14 would require increasing the radiator area by a factor of $(832/732)^4$, or 1.67. The radiator length of 2.8 inches would have to be increased to about 4 inches, and the converter would undoubtedly become too bulky and heavy.

A much more attractive way to modify the structure of the T-200 converter is to replace its collector-radiator structure by a heat pipe



of the design used for the T-300 converter being developed under JPL Contract 951465. The heat pipe characteristics are presented in the Third Quarterly Report of that program, and are summarized here in Figure 15. This figure repeats the T-206 collector temperature data of Figure 14 and the optimum collector temperature curve, and it gives the collector temperature expected with a heat pipe collector-radiator structure. It can be seen that the overheating point is shifted from 33 amperes to 54 amperes with the heat pipe. Furthermore, the heat pipe follows the optimum collector temperature characteristic quite closely, and a comparison with Figure 7 shows that, even at an output current of 90 amperes, the collector temperature will be below that achieved by converter VIII-P-3 at an equivalent output current of 70 amperes.

4. Recommendations to JPL

In view of the practical impossibility of avoiding excessive collector temperatures in the T-200 design, Thermo Electron has made the recommendation to JPL that heat pipe technology be incorporated in the fabrication of prototypes T-208 and T-209. Since this technology cannot be applied immediately, the next prototype, T-207, will be fabricated using the T-206 design. It will incorporate a palladium collector. Both converters, T-206 and T-207, will be tested using the U-type electron-bombardment filament described in Figure 5.

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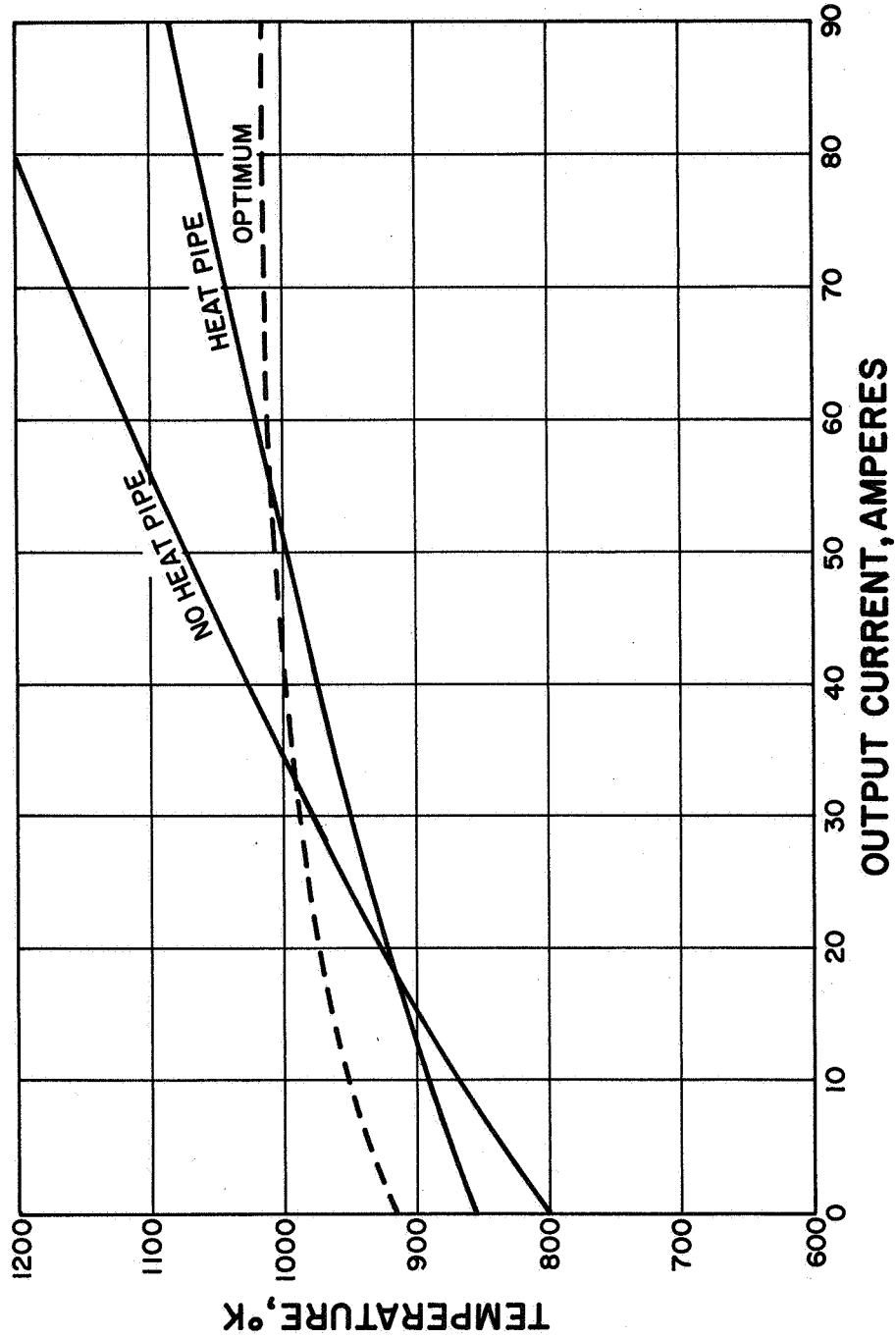


Figure 15



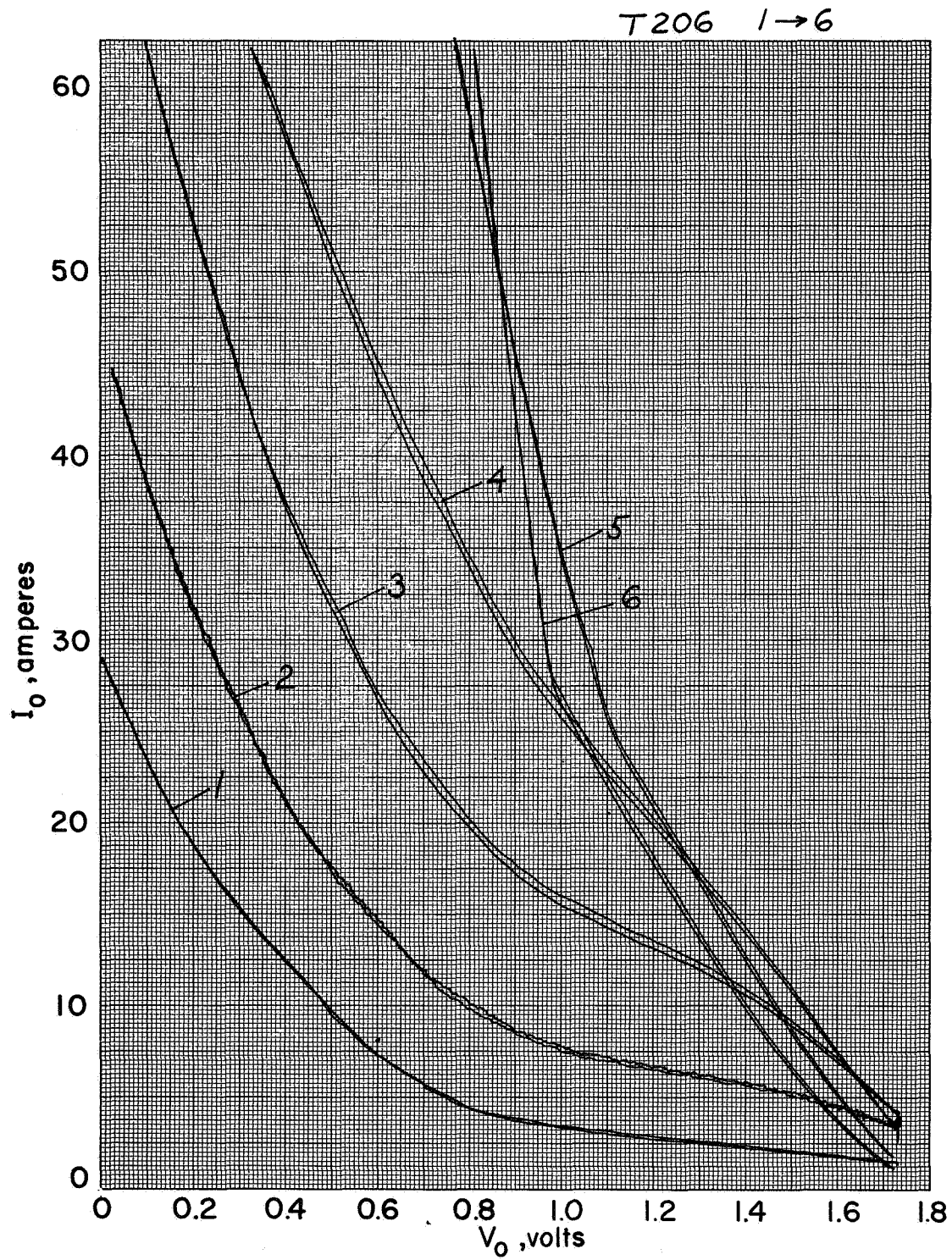
THERMO ELECTRON
ENGINEERING CORPORATION

APPENDIX

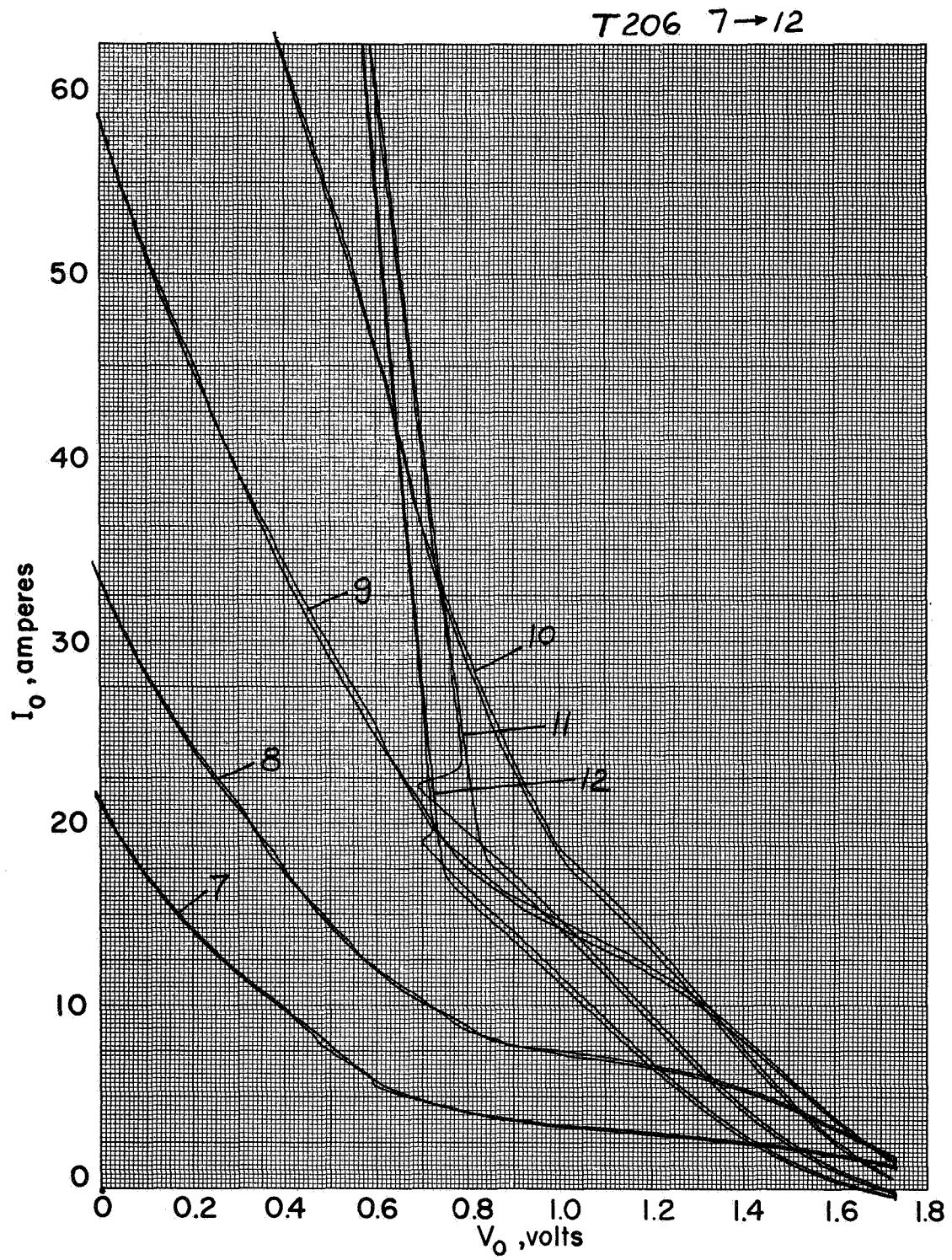
T-206 DATA



7691

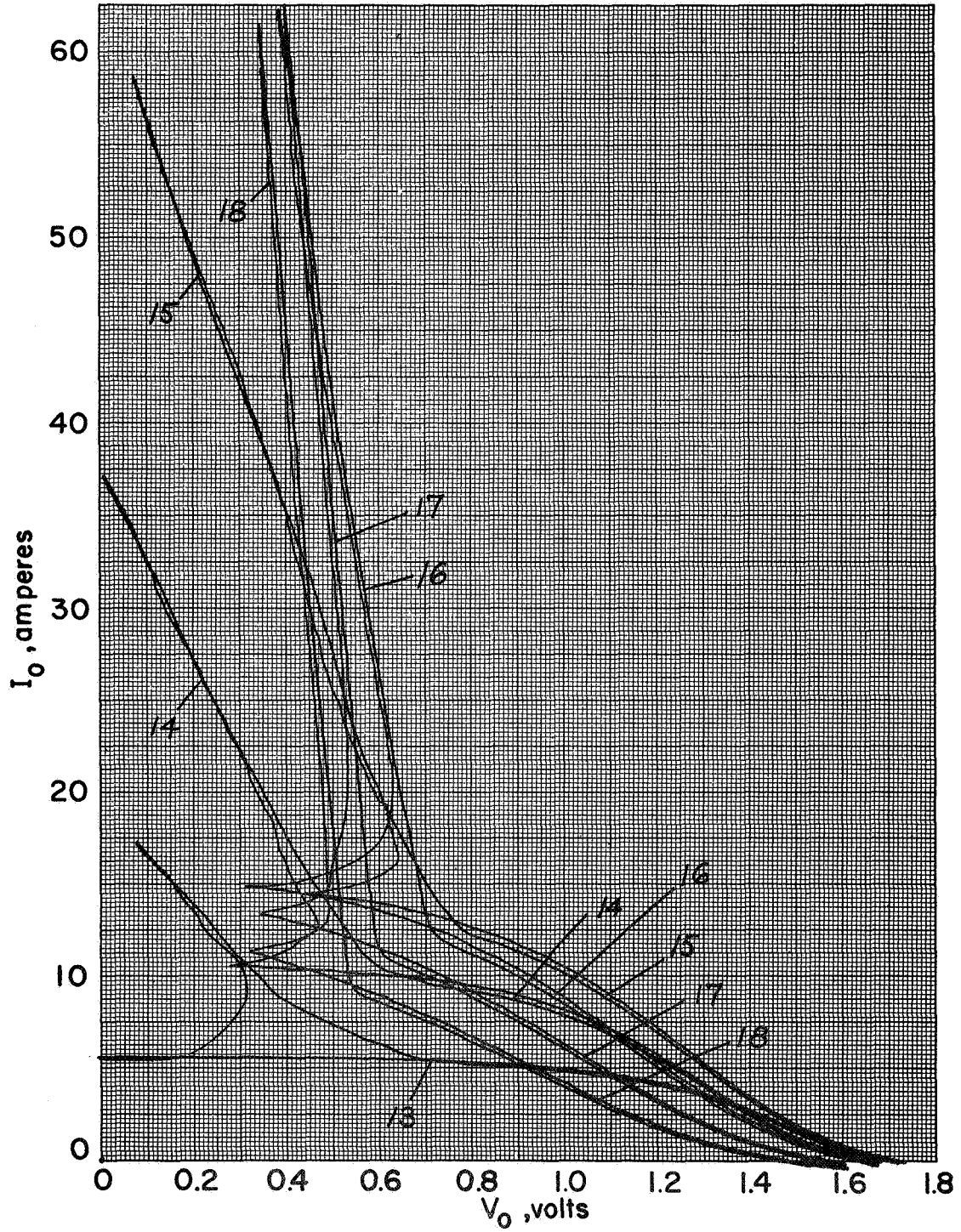


7693



7692

T206 13→18





Converter No. T-206

Run No. 1 & 2

Observer P. Broser

VARIABLE	1	2	3	4	5	6	7	8	9	10
Date <u>1967</u>	3-30	3-30	3-30	3-30	3-31	3-31	3-31	3-31	3-31	3-31
Time	11:51	15:45	16:14	17:34	9:12	9:25	9:36	10:30	10:40	11:10
Elapsed Time, Hours	0	3.9	4.4	5.7	21.4	21.6	21.7	22.7	23.0	23.3
T_0 , °C	1731	1720	1722	1730	1728	1728	1730	1624	1624	1630
T_0 Corrected, °C	1741	1730	1732	1740	1738	1738	1740	1633	1633	1639
$\Delta T_{\text{Bell Jar}}$, °C (1)	14	14	14	14	14	14	14	12	12	12
T_H , °C	1755	1744	1746	1754	1752	1752	1754	1645	1645	1651
ΔT_E , °C	29	20	16	25	25	25	25	15	18	24
T_E , °K	1999	1997	2003	2002	2000	2000	2002	1903	1900	1900
V_0 , volts (2)	.912	—	—	—	—	—	—	—	—	—
I_0 , amps	37.7	20	12	30	31	30	29	10	15	28
P_0 , watts	—	—	—	—	—	—	—	—	—	—
I-V Trace No. (3)	—	2	1	3	4	5	6	7	8	9
T_R	mv	14.5	11.8	11.0	12.6	13.4	14.3	15.2	11.0	11.8
	°C	355	290	271	309	329	350	372	271	290
	°K	628	563	544	582	602	623	645	544	563
T_C	mv	31.8	26.5	24.4	29.3	30.1	30.3	30.4	22.7	24.3
	°C	764	637	588	704	723	728	730	548	586
	°K	1037	910	861	977	996	1001	1003	821	859
T_C base inner	mv									
	°C									
T_C base outer	mv									
	°C									
T_{Radiator}	mv	21.4	19.1	18.2	20.2	20.7	20.8	20.8	17.4	18.1
	°C	518	464	443	489	501	504	504	424	440
V_{eb} , volts	965	973	977	970	966	966	966	980	977	974
I_{eb} , mA	375	281	253	322	342	348	349	213	233	271
E_{Filament} , volts	5	4.8	4.7	4.8	4.8	4.9	4.9	4.6	4.6	4.7
I_{Filament} , amps	21	20	20	20	21	21	21	20	20	20
$I_{\text{Coll. Heater}}$, amps	—	—	—	—	—	—	—	—	—	—
$I_{\text{Res. Heater}}$, amps	1	1	0	1	1	1	1	0	1 (4)	1.77
Vacuum, 10^{-6} mm Hg	3.0	3.4	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Measured Efficiency, % $\frac{E_B}{\text{POWER}}$	362	273	247	312	330	336	337	209	228	264

NOTES: (1) p-12 FOURTH QUARTERLY $\Delta T = 10 \pm 0.25 I$
 (2) VOLTAGE TAP AT EMITTER LEAD CLAMP
 (3) X-Y RECORDER SETTINGS X: 50 mV/DIV. VAR - Y: .2 V/DIV. VAR -
 (4) CONNECTED RESERVOIR TO DC POWER SUPPLY



Converter No. T-206

Run No. 2 & 3

Observer P. Brose

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		3-31	3-31	3-31	3-31	3-31	3-31	3-31	3-31	3-31	
Time		11:20	11:30	11:40	14:23	14:31	14:42	14:48	14:55	15:15	
Elapsed Time, Hours		23.5	23.7	23.8	26.5	26.7	26.8	27.0	27.1	27.4	
T_0 , °C		1630	1630	1630	1521	1524	1531	1531	1532	1532	
T_0 Corrected, °C		1639	1639	1639	1529	1532	1539	1539	1540	1540	
$\Delta T_{\text{Bell Jar}}$, °C		12	12	12	10	10	10	10	10	10	
T_H , °C		1651	1651	1651	1539	1542	1549	1549	1550	1550	
ΔT_E , °C		25	23	23	12	17	22	23	23	23	
T_E , °K		1899	1901	1901	1800	1798	1800	1799	1800	1800	
V_0 , volts		—	—	—	—	—	—	—	—	—	
I_0 , amps		$\overline{29}$	$\overline{27}$	$\overline{26}$	$\overline{5}$	$\overline{15}$	$\overline{24}$	$\overline{26}$	$\overline{26}$	$\overline{25}$	
P_0 , watts		—	—	—	—	—	—	—	—	—	
I-V Trace No.		10	11	12	13	14	15	16	17	18	
T_R	mv	13.4	14.3	15.2	11.0	11.8	12.6	13.4	14.3	15.2	
	°C	329	350	372	271	290	309	329	350	372	
	°K	602	623	645	544	563	582	602	623	645	
T_C	mv	28.8	28.1	28.4	20.1	22.3	25.6	26.2	26.5	26.7	
	°C	692	675	682	487	539	616	630	637	642	
	°K	965	948	955	760	812	889	903	910	915	
T_C base inner	mv										
	°C										
T_C base outer	mv										
	°C										
T_{Radiator}	mv	19.9	19.8	20.0	15.8	16.9	18.5	18.9	19.0	19.2	
	°C	483	480	485	386	412	450	459	461	466	
V_{eb} , volts		972	973	973	987	984	979	978	978	979	
I_{eb} , mA		291	286	287	171	190	229	239	239	235	
E_{Filament} , volts		4.8	4.8	4.8	4.5	4.6	4.7	4.7	4.7	4.7	
I_{Filament} , amps		20	20	20	20	20	20	20	20	20	
$I_{\text{Coll. Heater}}$, amps		—	—	—	—	—	—	—	—	—	
$I_{\text{Res. Heater}}$, amps		2.28	2.96	3.42	1.75	2.22	2.12	2.68	3.42	3.49	
Vacuum, 10^{-6} mm Hg		2.0	2.0	2.0	1.8	1.8	1.8	1.8	1.8	1.8	
Measured Efficiency, % $\frac{EB}{\text{POWER}}$		283	278	279	169	187	224	234	234	230	

NOTES:



Converter No. T-206

Run No. 4

Observer P. Brosen

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		3-31	—	—	—	—	—	3-31			
Time		15:37	—	—	—	—	—	16:07			
Elapsed Time, Hours		27.8	—	—	—	—	—	28.3			
T_0 , °C	(1)	1703	—	—	—	—	—	1703			
T_0 Corrected, °C		1713	—	—	—	—	—	1713			
$\Delta T_{\text{Bell Jar}}$, °C		14	—	—	—	—	—	14			
T_H , °C		1727	—	—	—	—	—	1727			
ΔT_E , °C		10	—	—	—	—	—	10			
T_E , °K		1990	—	—	—	—	—	1990			
V_0 , volts		2.46	2.45	2.44	2.41	2.39	2.35	2.30			
I_0 , amps		0	0	0	0	0	0	0			
P_0 , watts											
I-V Trace No.											
T_R	mv	11.0	12.0	13.0	14.0	15.0	16.0	17.0			
	°C	271	295	319	343	367	391	414			
	°K	544	568	592	616	640	664	687			
T_C	mv	21.9	22.4	22.9	23.8	24.4	25.0	25.6			
	°C	529	541	553	574	588	602	616			
	°K	802	814	826	847	861	875	889			
T_C base inner	mv										
	°C										
T_C base outer	mv										
	°C										
T_{Radiator}	mv	16.9	—	—	—	—	—	18.8			
	°C	412	—	—	—	—	—	457			
V_{eb} , volts		986	986	985	984	983	982	981			
I_{eb} , mA		225.6	230.9	237.1	244.9	251.7	259.4	264.4			
E_{Filament} , volts		4.6	—	—	—	—	—	4.7			
I_{Filament} , amps		20	—	—	—	—	—	20			
$I_{\text{Coll. Heater}}$, amps		—	—	—	—	—	—	—			
$I_{\text{Res. Heater}}$, amps		1.52	2.32	2.31	3.14	3.72	4.19	4.63			
Vacuum, 10^{-6} mm Hg		2.0	—	—	—	—	—	2.0			
Measured Efficiency, % $\frac{E_B}{\text{POWER}}$		222.4	227.7	233.5	241.0	247.4	254.7	259.4			

NOTES: (1) TEMPERATURE AUTOMATICALLY CONTROLLED BY PHOTOELECTRIC CIRCUIT AND MONITORED BY MICRO-OPTICAL PYROMETER.



Converter No. T-206

Run No. 5 & 6

Observer P. Brosens

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		3-31	3-31	3-31	4-3	4-3	4-3	4-3	4-3	4-3	4-3
Time		16:25	16:55	17:22	11:00	11:50	12:03	15:18	15:30	15:37	15:58
Elapsed Time, Hours		28.5	29.0	29.5	30.8	31.7	31.9	35.2	35.4	35.5	35.8
$T_0, ^\circ\text{C}$		1676	1676	1676	1676	1676	1676	1579	1579	1579	1579
T_0 Corrected, $^\circ\text{C}$		1686	1686	1686	1686	1686	1686	1588	1588	1588	1588
$\Delta T_{\text{Bell Jar}}, ^\circ\text{C}$		14	14	14	14	14	14	12	12	12	12
$T_H, ^\circ\text{C}$		1700	1700	1700	1700	1700	1700	1600	1600	1600	1600
$\Delta T_E, ^\circ\text{C}$		10	15	18	22	31	41	10	12	14	16
$T_E, ^\circ\text{K}$		1963	1958	1955	1951	1942	1932	1863	1861	1859	1857
V_0 , volts		2.42	1.4	1.2	1.0	0.8	0.6	2.17	1.4	1.2	1.0
I_0 , amps		0	10.6	16.9	23.3	41.2	62.7	0	4.3	8.0	12.9
P_0 , watts											
I-V Trace No.		—	—	(1)	—	—	—	—	—	—	—
T_R	mv	11.0	13.0	13.5	13.8	14.2	14.7	11.0	11.9	12.2	12.7
	$^\circ\text{C}$	271	319	331	338	348	360	271	292	300	312
	$^\circ\text{K}$	544	592	604	611	621	633	544	565	573	585
T_C	mv	21.7	24.8	26.5	27.8	31.4	35.4	19.6	20.9	21.9	23.4
	$^\circ\text{C}$	525	597	637	668	754	852	476	506	529	564
	$^\circ\text{K}$	798	870	910	941	1027	1125	749	779	802	837
T_C base inner	mv										
	$^\circ\text{C}$										
T_C base outer	mv										
	$^\circ\text{C}$										
T_{Radiator}	mv	16.9	18.4	19.2	19.7	21.2	22.7	15.8	16.4	16.9	17.7
	$^\circ\text{C}$	412	447	466	478	513	548	386	400	412	431
V_{eb} , volts		988	979	975	974	968	962	992	987	984	982
I_{eb} , mA		214.4	262.4	288.0	300.2	356.2	420	175.9	193.6	208.2	224.4
E_{Filament} , volts		4.6	4.7	4.8	4.8	5.0	5.1	4.5	4.6	4.6	4.6
I_{Filament} , amps		20	20	20	20	21	21	19	20	20	20
$I_{\text{Coll. Heater}}$, amps		—	—	—	—	—	—	—	—	—	—
$I_{\text{Res. Heater}}$, amps		0.96	2.46	2.58	2.63	2.59	2.66	1.69	2.19	2.54	2.41
Vacuum, 10^{-6} mm Hg		2.0	2.0	2.0	2.0	2.0	2.0	1.8	1.8	1.8	1.8
Measured Efficiency, % $\frac{EB}{\text{POWER}}$		211.8	257.0	280.8	292.4	344.8	404.0	174.5	191.1	204.9	220.4

NOTES: (1) SHUT OFF OVER WEEK-END. DATA POINT #3 WAS REPRODUCED 4-3 BEFORE PROCEEDING WITH TEST.



Converter No. T-206

Run No. 6 E 7

Observer P. Brosnan

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		4-3	4-3	4-3	4-3	4-3	4-3	4-4		4-4	4-4
Time		16:11	16:23	16:34	16:49	17:13	17:39	11:27		16:46	17:52
Elapsed Time, Hours		36.0	36.2	36.4	36.7	37.1	37.5	40.1		42.2	43.3
T_0 , °C		1579	1579	1773	1773	1773	1773	1773	1773	1676	1718
T_0 Corrected, °C		1588	1588	1784	1784	1784	1784	1784	1784	1686	1728
$\Delta T_{\text{Bell Jar}}$, °C		12	12	16	16	16	16	16	16	14	14
T_H , °C		1600	1600	1800	1800	1800	1800	1800	1800	1700	1742
ΔT_E , °C		18	29	10	19	24	32	41		26	30
T_E , °K		1855	1844	2063	2054	2049	2041	2032		1947	1985
V_0 , volts		0.8	0.6	2.44	1.4	1.2	1.0	0.8	0.6	0.8	0.8
I_0 , amps		16.0	37.9	0	18.1	29.3	44.6	62.7		32.1	40.9
P_0 , watts											
I-V Trace No.		—	—	—	—	—	—	(1)	(2)	(3)	(4)
T_R	mv	13.1	13.6	12.0	13.7	14.2	14.7	15.5		14.0	14.3
	°C	321	333	295	336	348	360	379		343	350
	°K	594	606	568	609	621	633	652		616	623
T_C	mv	24.5	28.7	24.0	28.1	30.7	33.7	37.7		29.2	31.2
	°C	590	690	579	675	737	810	908		702	749
	°K	863	963	852	948	1010	1083	1181		975	1022
T_C base inner	mv										
	°C										
T_C base outer	mv										
	°C										
T_{Radiator}	mv	18.3	20.1	18.2	19.9	21.0	22.2	23.8		20.5	21.2
	°C	445	487	443	483	508	537	574		497	513
V_{eb} , volts		981	974	982	971	966	960	951		972	968
I_{eb} , mA		236.6	290.2	267.8	348.4	390.6	446.0	507.8		314.5	357.1
E_{Filament} , volts		4.7	4.8	4.7	4.8	4.9	5.1	5.3			5.2
I_{Filament} , amps		20	20	20	20	21	21	22			22
$I_{\text{Coll. Heater}}$, amps		—	—	—	—	—	—	—	—	—	—
$I_{\text{Res. Heater}}$, amps		2.57	2.46	1.47	2.54	2.63	2.63	2.64		2.59	2.59
Vacuum, 10^{-6} mm Hg		1.8	1.8	1.8	1.8	1.9	1.9	2.2	—	2.6	2.3
Measured Efficiency, % $\frac{EB}{POWER}$		232.1	282.6	263.0	338.3	377.3	428.2	482.9		305.7	345.7

NOTES: (1) SHUT OFF PRECEEDING NIGHT

(2) CONVERTER WAS NOT RUN AT 0.6V FOR FEAR OF EXCEEDING SAFE
LIMIT OF COLLECTOR TEMPERATURE. CONVERTER SHUT OFF. WILL

CHANGE EB FILAMENT TO DIFFERENT SIZE.

(3) CIRCULAR FILAMENT - SAME OBSERVED TEMP AS SHEET 4 POINT 5

(4) " " " " BOMB CURRENT " " -

END OF TEST.