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THERMO ELECTRON

CORPORATION

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Thermo Electron Corporation, 85 First Avenue, Waltham, Massachusetts 02154

FINAL REPORT

DESIGN AND FABRICATION OF ADVANCED THERMIONIC CONVERTERS

Contract No 951263

November 1968

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Prepared for

The Jet Propulsion Laboratory

Pasadena, California

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INTRODUCTION AND SUMMARY

This document constitutes the Final Report of the work performed under Thermo Electron's contract No. 951263 with the Jet Propulsion Laboratory.

This program had two objectives which were to be reached under two task efforts:

I. To develop a converter of the design used under Task II of Contract No. 950671, capable of delivering a power output of 20 watts/cm^2 at 0.8 volt, and at a true hohlraum temperature of 1700°C.

II. To design a multiconverter generator capable of operation in cislunar space with a concentrator 9.5 ft in diameter and which uses the converters developed under Task I.

Task I centered on the iterative construction of 10 engineering models of a solar energy thermionic converter, and Table I describes their main features. The first model was fabricated to duplicate partially the performance of the best converter developed under Task II of Contract No. 950671. The second and third incorporated a modification in the heat transfer path of the collector-radiator structure to improve heat transfer. The fourth and fifth had a convoluted emitter structure made entirely of rhenium. In the sixth and seventh converters the collector material was changed to rhenium and palladium, respectively. In the last three models, the collector-radiator structure of the previous models was replaced by a heat pipe. At the culmination of the effort of Task I, the converter with a heat pipe structure had achieved close to a 70% reduction in weight; however, its performance was the same as that of typical converters with rhenium electrodes, and it did not reach the goal of 20 watts/cm^2 at 0.8 volt, 1700°C.

Task II involved a generator flux analysis to determine the best number of converters to match the converter heat requirements to the available solar energy, the optimum cavity aperture size, the required adjustments of surface emissivity and absorptivity values to insure even flux distribution, and the effects of changes in emitter temperature and heat input on flux distribution within the generator.

Based on this analysis a 16-converter generator, using converters with heat pipe collector-radiators, was designed in detail.

TABLE I

SUMMARY OF DESIGN FEATURES

Feature \ Model	201	202	203	204	205	206	207	208	209	210
Emitter Material	Re	Re	Re	Re	Re	Re	Re	Re	Re	Re
Collector Material	Mo	Mo	Mo	Mo	Mo	Re	Pd	Re	Re	Re
Collector Area, cm^2	2.50	2.50	2.50	2.50	2.52	2.52	2.52	2.16	2.34	2.34
Nominal Spacing, mils	1.0	1.0	1.0	1.8	4.2	1.8	1.8	1.8	1.8	1.8
Emitter Fabrication (1)	B	B	B	M	M	M	M	M	M	M
Emitter Preparation (2)	EP	EP	EP	EE	EE	EE	EE	EE	EE	EE
Emitter Support Material	Ta	Ta	Ta	Re	Re	Re	Re	Re	Re	Re
Collector Preparation (3)	L	C	C	C	G	G	L	L	L	L
Radiator Type - Area, cm^2 (4)	F-113	F-113	F-113	F-113	F-113	F-133	F-133	HP-38	HP-52	HP-52

(1) B = pressure-bonded M = monolithic
(2) EP = electropolished EE = electroetched
(3) L = lapped C = chemically etched G = ground
(4) F = conducting fins HP = heat pipe

TASK I

CONVERTER DEVELOPMENT

1.1 Design of Converters T-201 and T-202

Figures 1 and 2 present four different designs numbered I to IV, which were evolved during the design phase of converters T-201 and T-202. The design selected for converter T-201 was the design I, which included most features and the collector structure in particular of the converter T-100 developed under the preceding contract No. 950671. The design of converter T-202 was the design II, which included a modified collector-radiator structure, with cylindrical braze interface instead of butt braze, and which minimized the effect of braze interfaces on collector temperature distribution.

1.2 Fabrication of Converter T-201

The converter assembly techniques used were the same as those used in the fabrication of converters under JPL contract 950671.

Figures 3, 4, and 5 illustrate some differences in the collector structure which resulted from the T-201 design effort. Figure 3 shows the parts for the collector structure of converter T-201 before assembly, and Figure 4 shows the same parts after brazing with palladium. In the first fabrication attempt, two collector assemblies were brazed and both leaked due to excessive alloying of the braze with the niobium seal flange. Examination of the constitution diagram of the niobium palladium alloys showed that although palladium melts at 1552°C, a eutectic at atomic 50% palladium exists which has a melting point of 1560°C. It was therefore difficult to avoid producing this eutectic during brazing. To solve the problem, it was attempted to plate the palladium with enough copper to form a 10% by weight alloy of copper palladium. The melting point of this alloy would then have been 1454°C or practically 100°C lower than the melting point of palladium. When this was tried, it was found that the copper plating evaporated much too soon to leave any significant amount of copper at the presumed melting point of the copper palladium alloy. The collector of T-201 was finally brazed using pure palladium as a braze material but a tell-tale was used in order to provide a clear visual indication of the instant at which melting of the filler wire occurred. (The procedure could not be repeated successfully for the assembly of converter T-202: small perforations through the niobium sleeve were present as a result of overalloying, and they were closed using copper as a braze filler).

Figures 6 to 11 show the sequence of steps involved in the fabrication of the emitter structure. In the case of converter T-201 a tight fit in the jigs caused a mechanical misalignment. It was found in inspection that the surface of the emitter was out of square with the axis of the support sleeve by a maximum of 4.4 mils. A similar check was made on the collector sleeve structure and it was found that the collector face was out of square by a maximum of 1.5 mils, thus leading to a maximum possible error of 5.9 mils prior to brazing of the seal in the compression jig. Since the compression jig produced a displacement which far exceeded the 5.9 mils, it was expected that the entire amount of the error would disappear during seal braze. Later cesium conduction tests on converter T-201 revealed that the design interelectrode spacing was not achieved, and it was concluded that a misalignment condition such as that encountered should result in rejection of the subassembly.

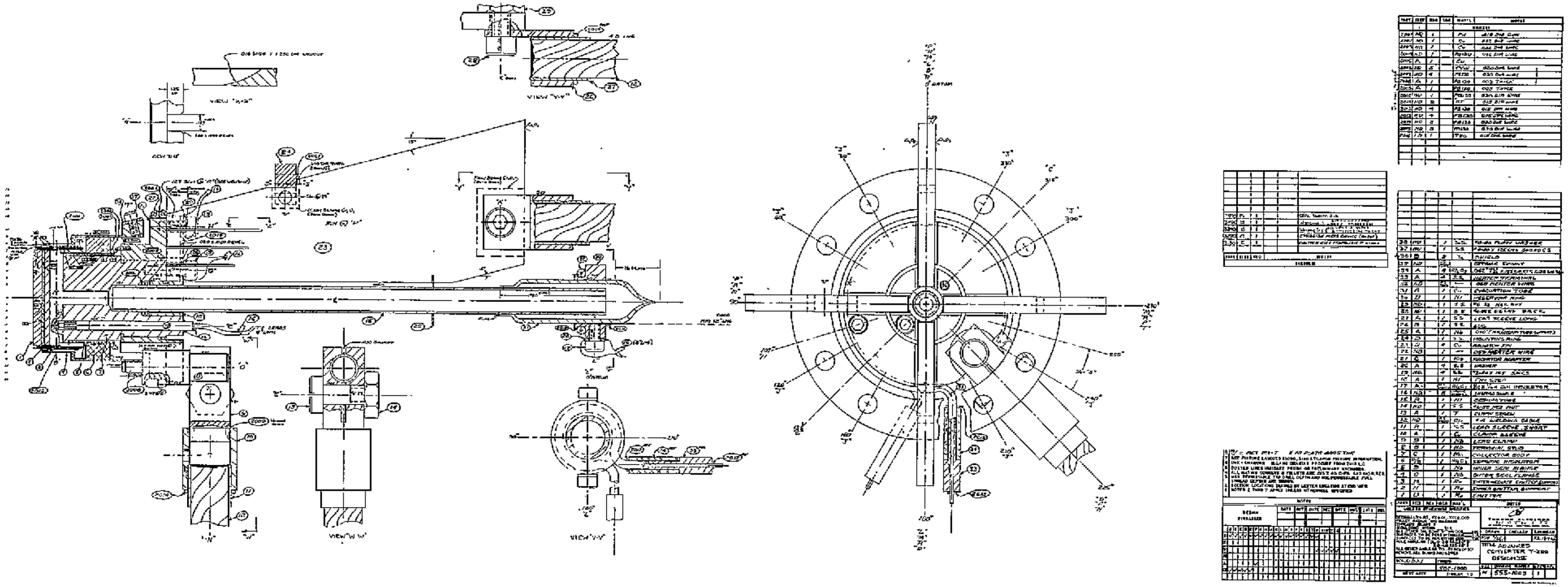

Figure 1.

7/8 - B

7/8 - A

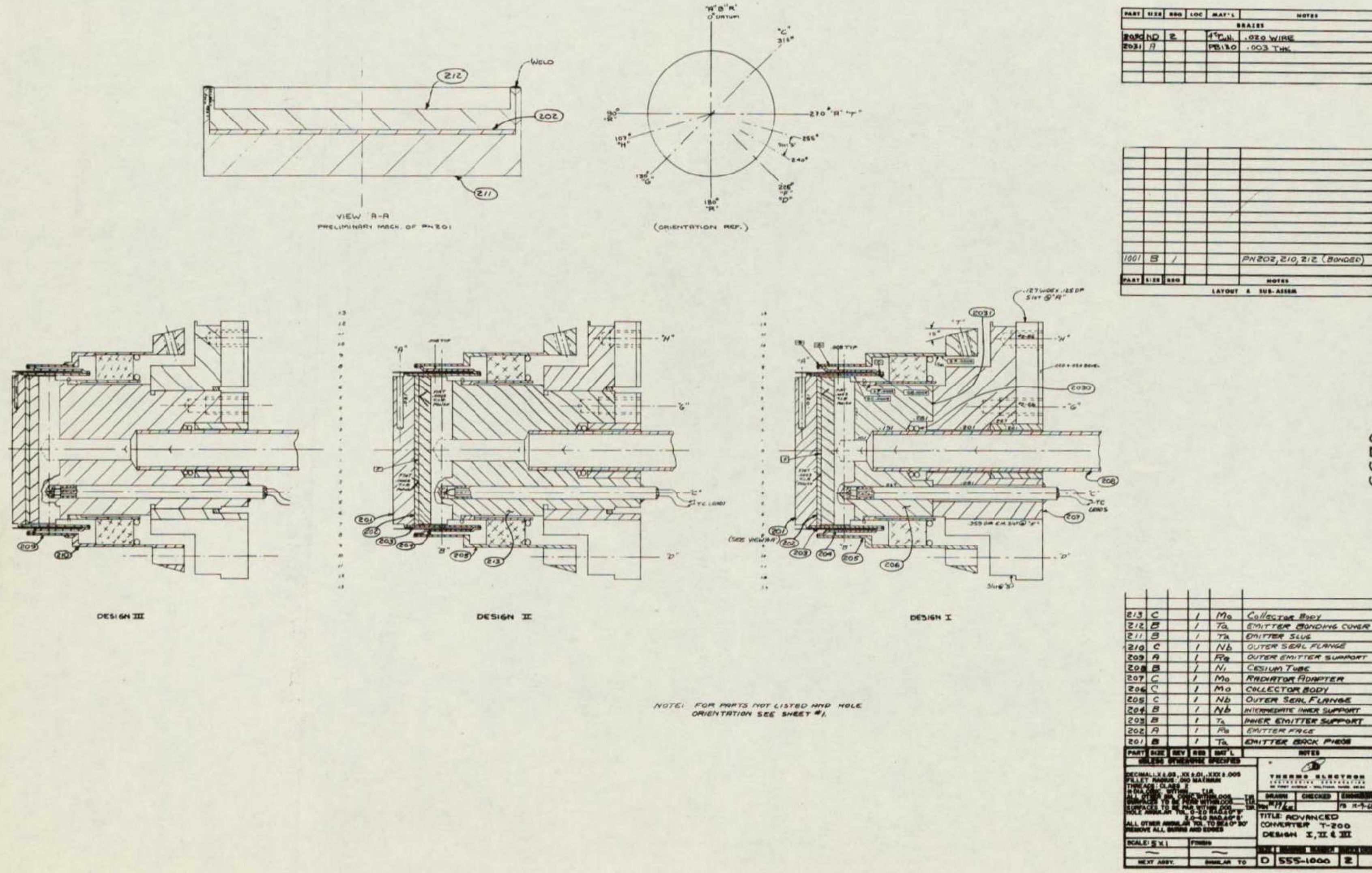

Figure 2. T-200 Layout Detail - Designs I, II and III.

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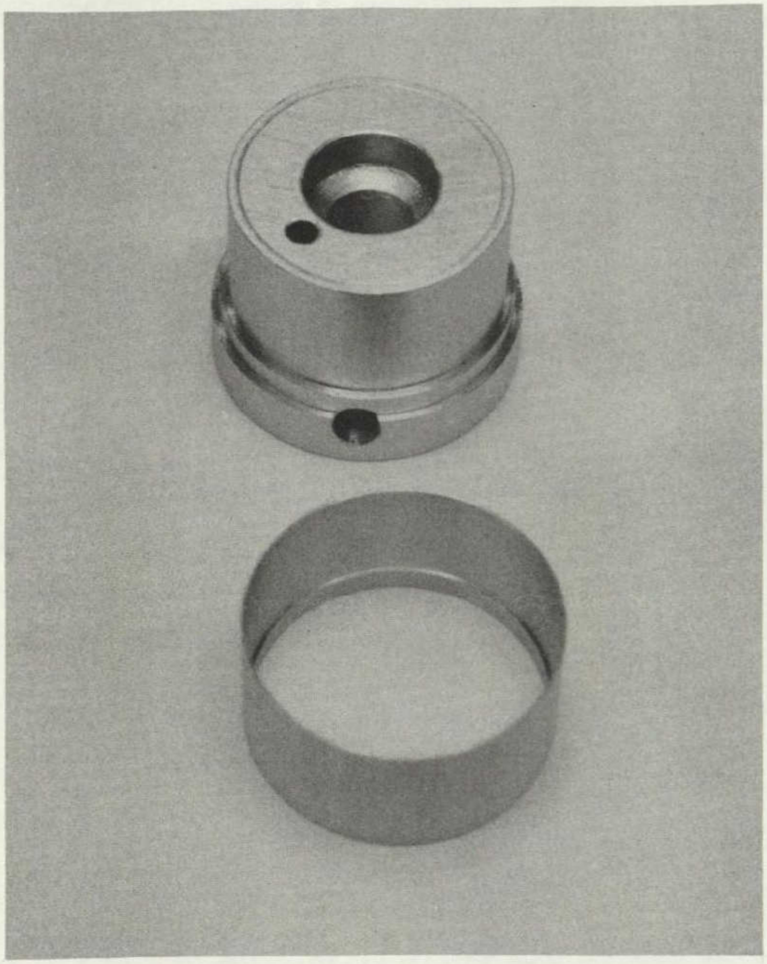

Figure 3. Parts for T-201 Collector Subassembly.

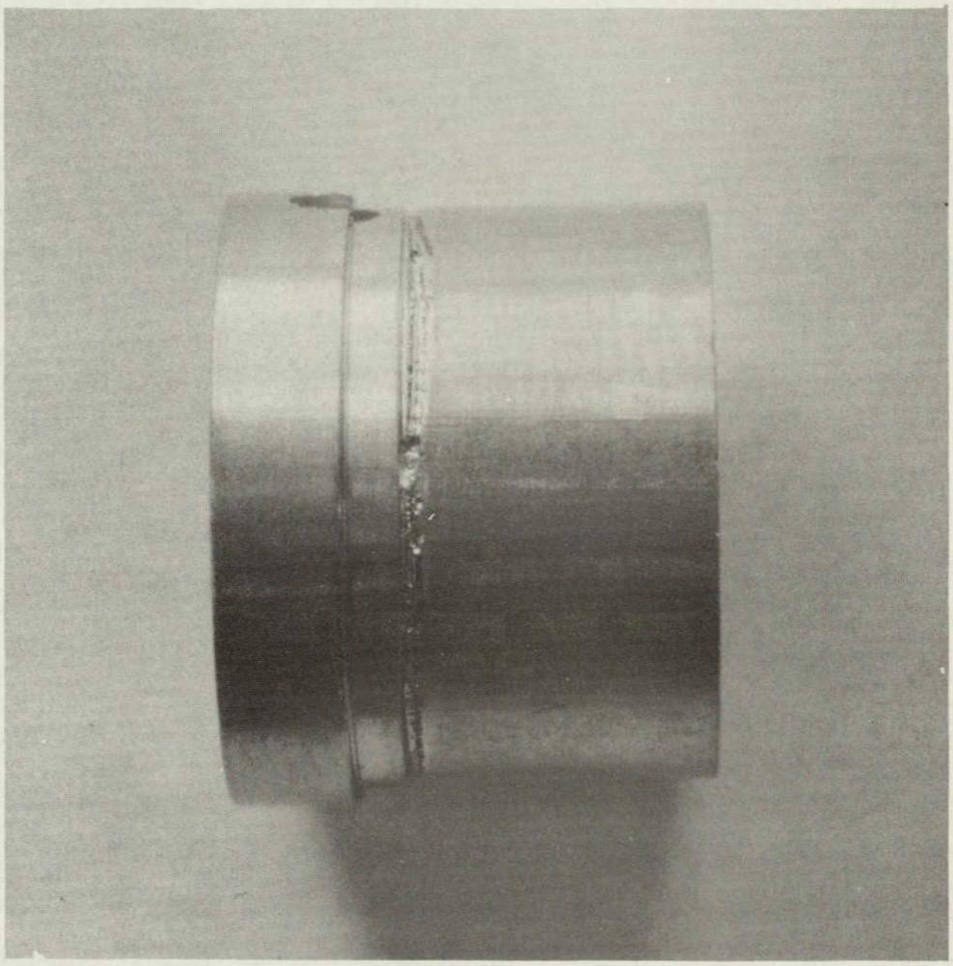

Figure 4. T-201 Collector Subassembly.

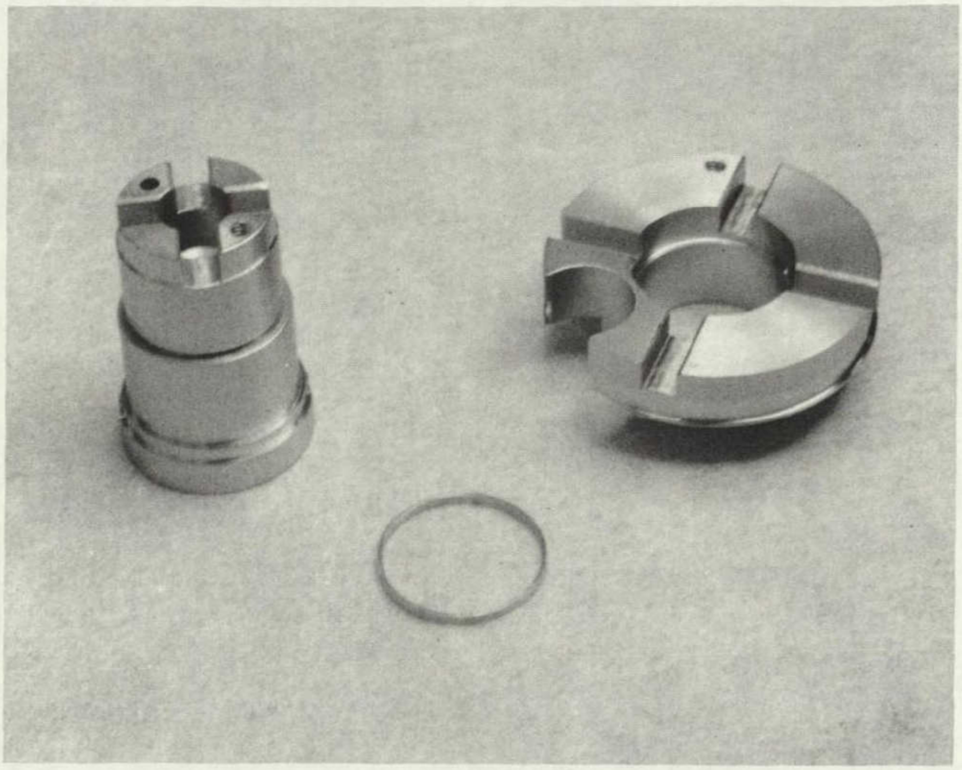

Figure 5. Parts for T-202 Collector Structure.

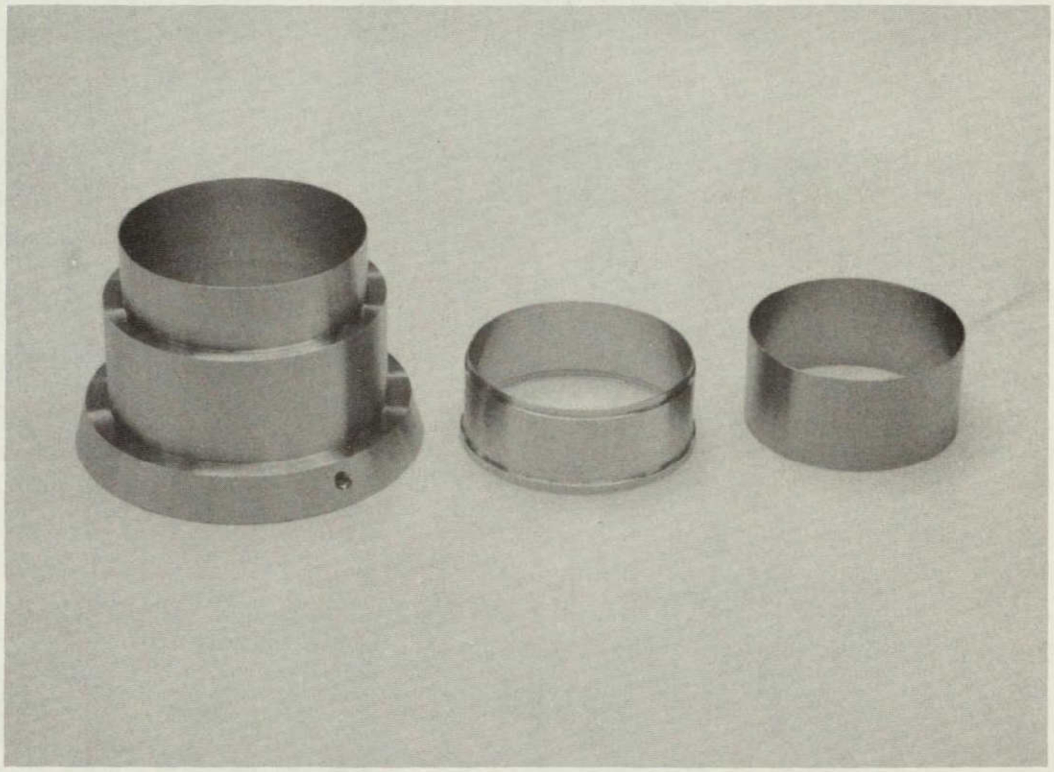

Figure 6. Parts for T-201 Emitter Support Structure.

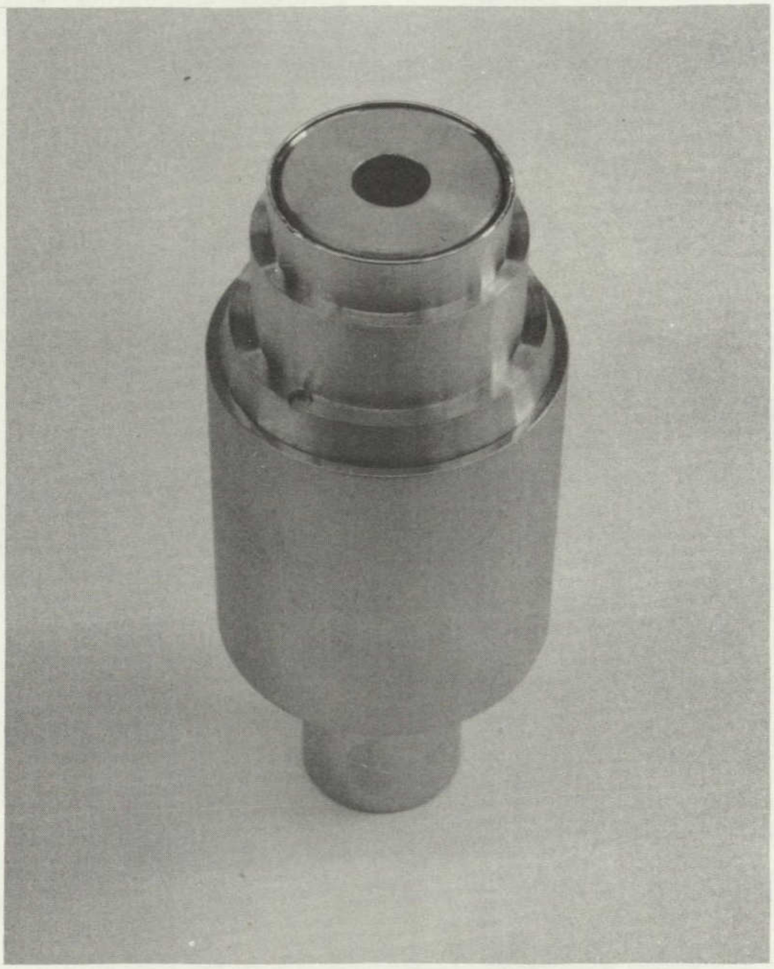

Figure 7. First Weld of Emitter Support Structure.

Figure 8. Second Weld of Emitter Support Structure.

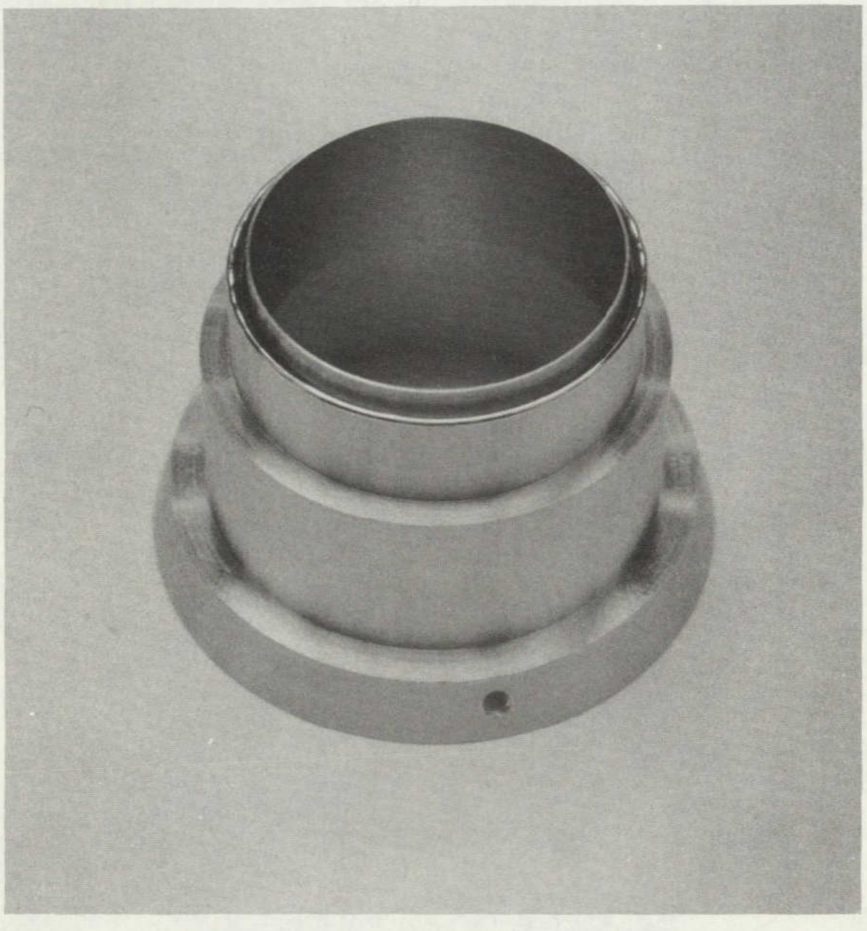

Figure 9. Finished Emitter Support Structure.

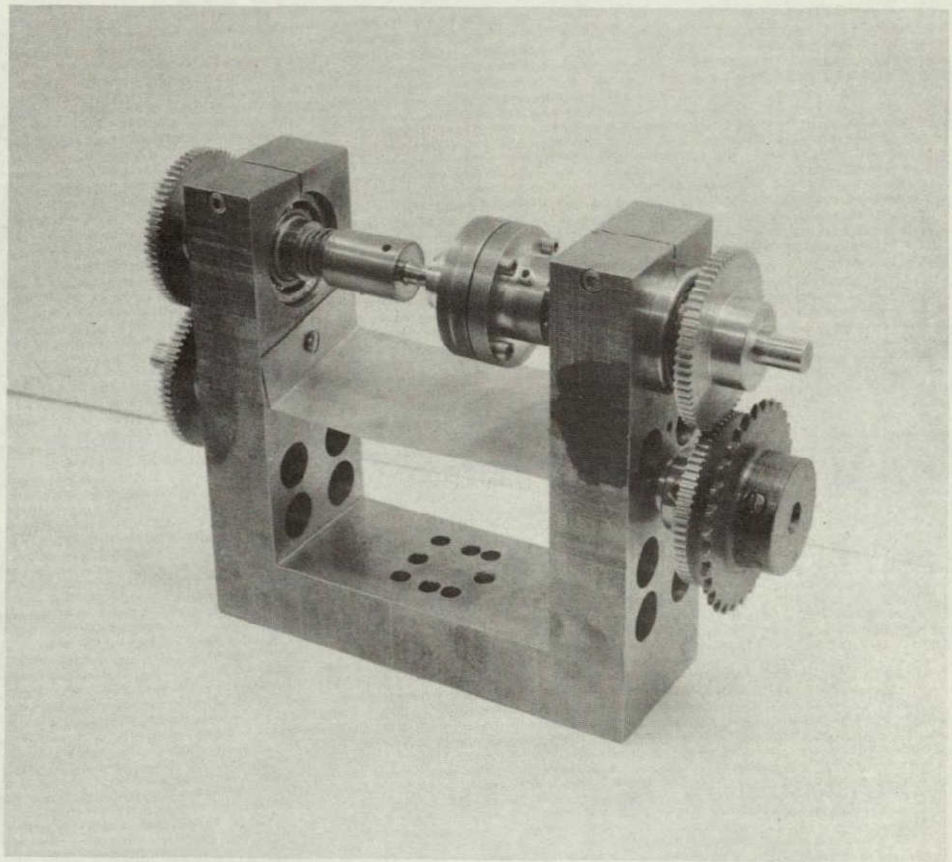

Figure 10. Emitter Assembly Ready for Electron Beam Weld.

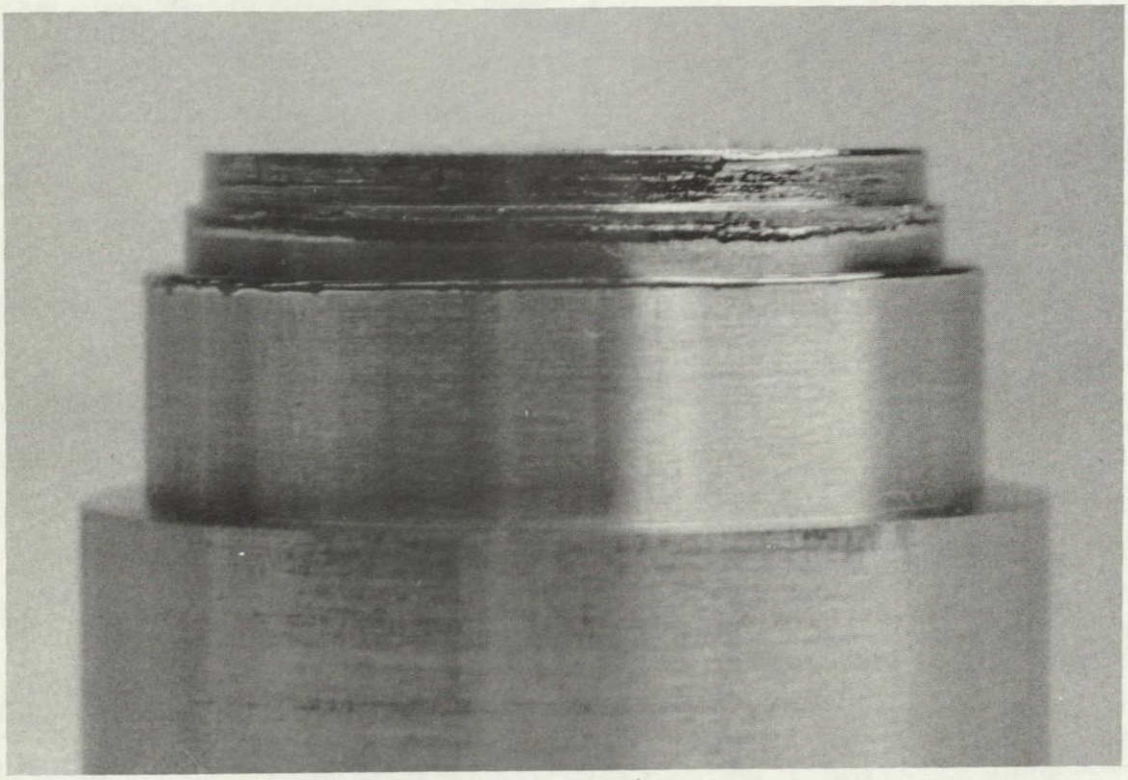

Figure 11. Weld Detail of Emitter Structure.

Figure 12 shows the parts for the seal braze assembled in the compression jig prior to brazing. Figure 13 shows the completed T-201 converter during cesium distillation. Cesium charging was achieved with a 250 mg glass capsule heated to approximately 270°C during converter outgassing, prior to breaking, and then heating the cesium from the broken capsule, by means of two automatically controlled heaters, to 200°C for 5 hours.

The emitter of converter T-201 was electroetched using the fixture shown in Figure 14. The fixture is a plastic structure which completely encloses the emitter piece and its attached current lead, except for the emitter surface which is made co-planar with the streamlined front-surface of the fixture. Thus, the fixture can be agitated in the electroetching solution without inducing cavitation or large scale turbulence which would otherwise interfere with uniform etching action. The time for electropolishing and electroetching was varied slightly to determine the duration that would cause a satisfactory action on the surface yet avoid excessive material removal and consequent departures from flatness. These tests showed that a 10-second electropolish and a 45- to 60-second electroetching should not be exceeded. The final procedure used is described in Appendix 1. The emitter structure was then thermally stabilized for one hour at 1800°C. Figure 15 shows the electroetched emitter, and Figure 16 shows a photomicrograph of the emitter surface after thermal stabilization.

1.3 Testing of Converter T-201

Converter T-201 was tested with a test apparatus essentially the same as that used in the performance of work under Contract 950671.

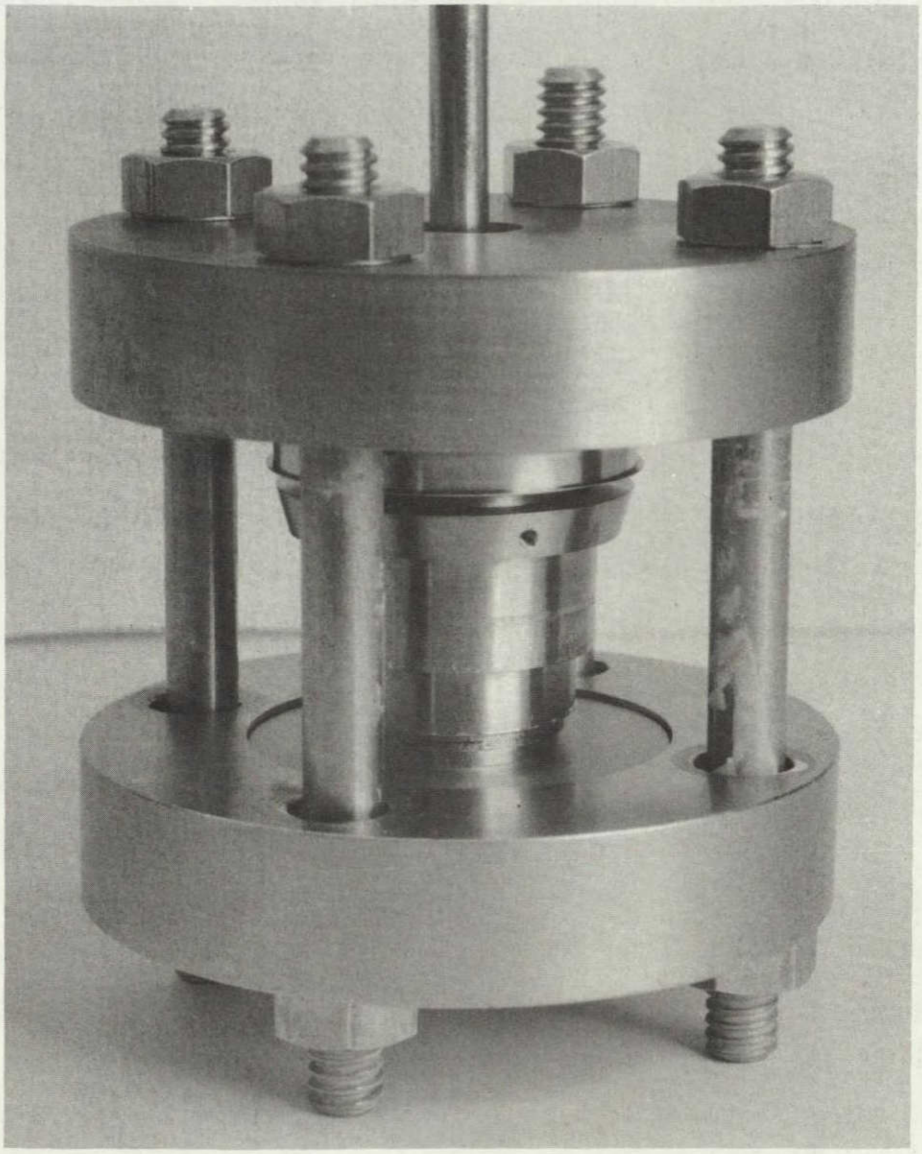

Figure 12. Parts for Seal Braze in Compression Jig.

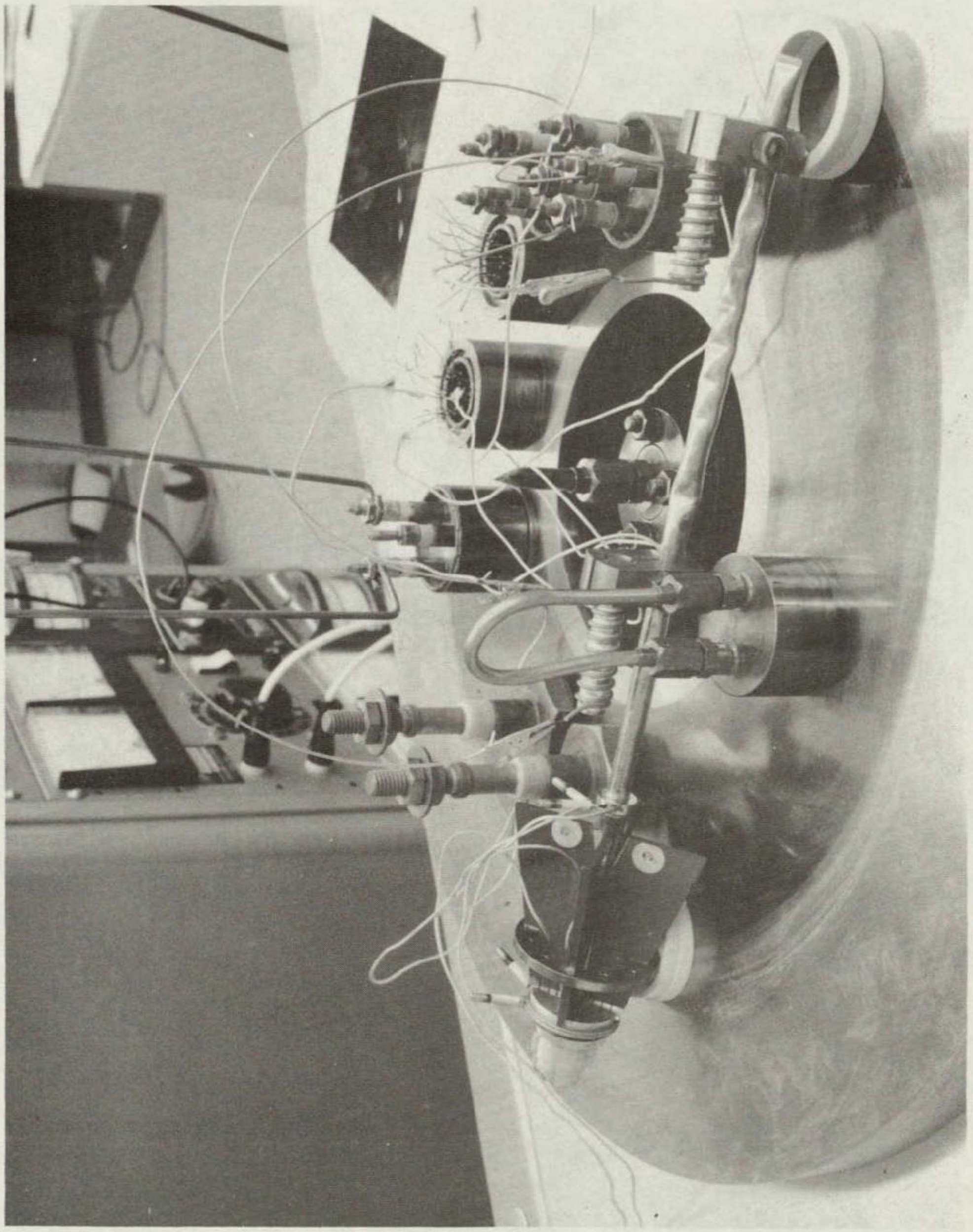

Figure 13. Cesium Distillation.

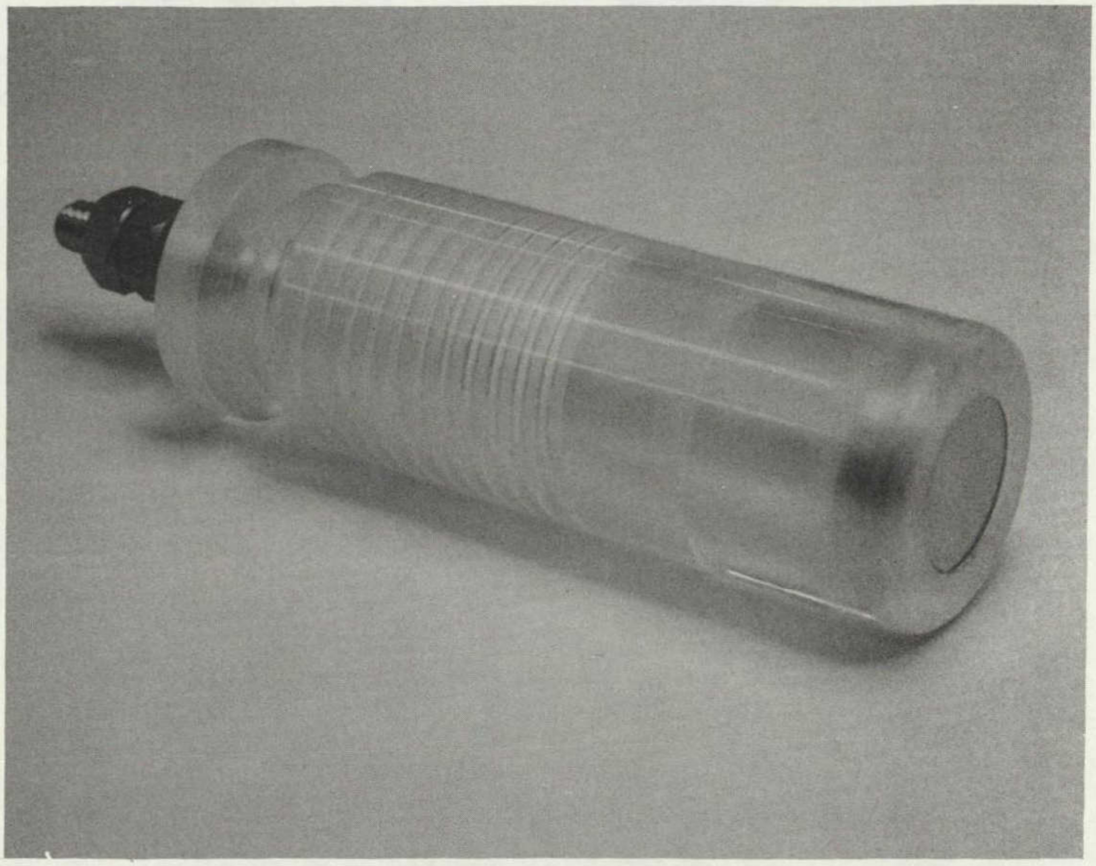

Figure 14. Emitter Electroetching Fixture.

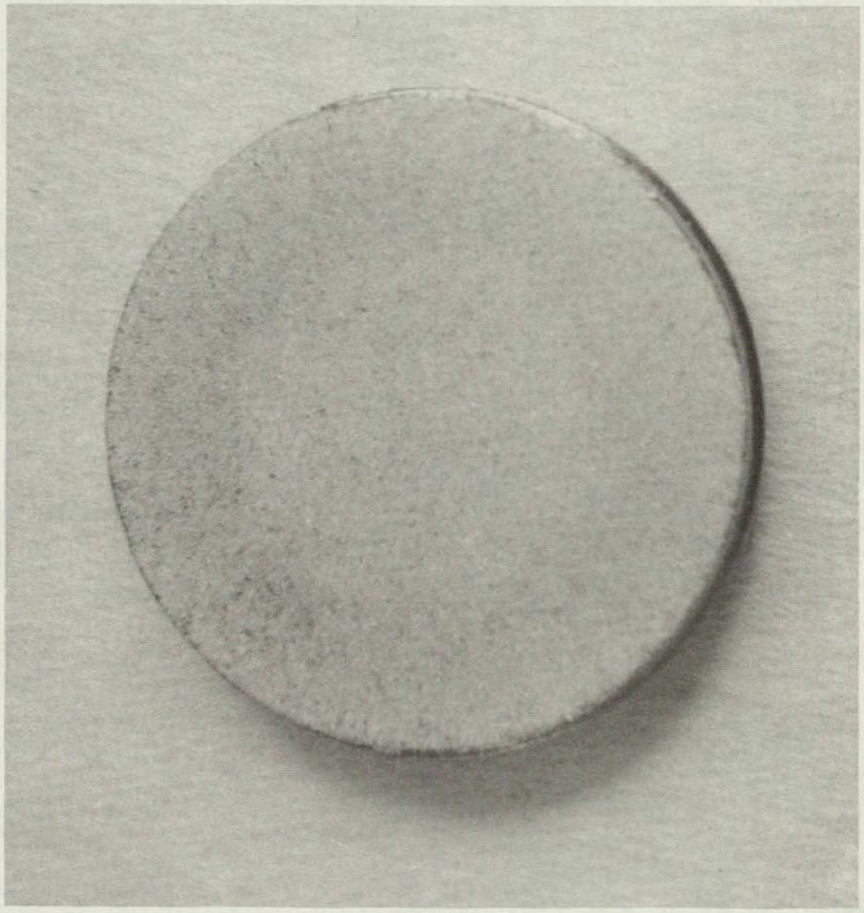

Figure 15. Visual Appearance of Electroetched Emitter.

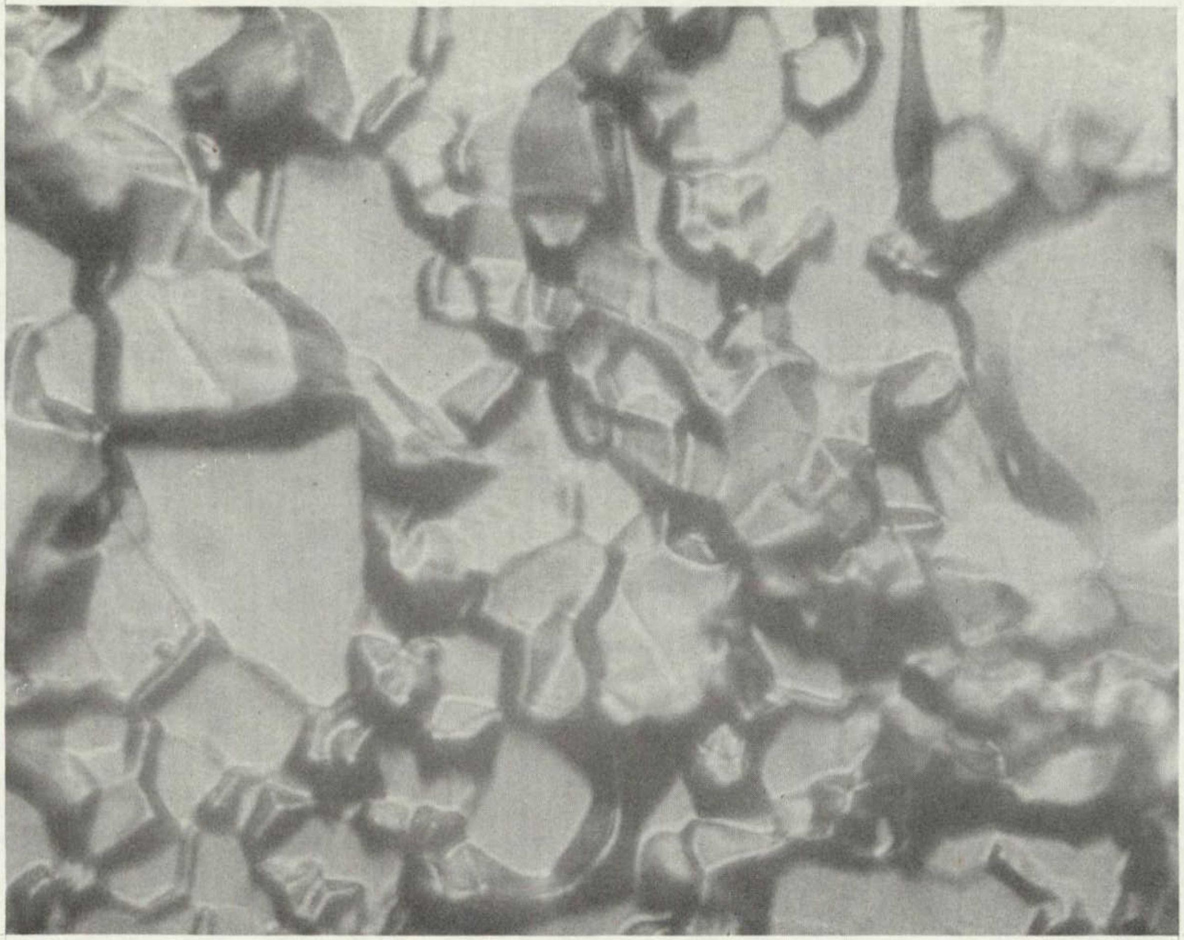

Figure 16. Photomicrograph of T-201 Emitter Surface (after 1800 °C firing).

To broaden the range of temperature control of the cesium reservoir, a water cooled copper strap was clamped to it. The test procedure consisted of first making a relative collector work function measurement and sampling two I-V traces, then running under steady-state at a substantial output current for approximately 150 hours, making a new collector work function measurement, then proceeding to evaluate the other converter characteristics by I-V curve and cesium conduction measurements, and finally testing the converter under steady-state conditions.

In the first four-hour operation period, it was not possible to obtain any output from T-201. The fact that the converter was able to deliver an open circuit voltage and not respond in any appreciable way to changes in reservoir temperature, indicated that the converter had no cesium in it. This was a surprising fact because the portion of the exhaust tubulation that had contained the fragments of the cesium capsule during distillation showed no cesium residues after distillation. The only way in which it appeared possible for the cesium to have escaped was to have dropped from the capsule into the converter exhaust pump right after cracking the capsule at the end of outgassing. This explanation was confirmed when the connections of the exhaust pump were disassembled and cesium residues were found in the pump manifold. Consequently, converter T-201 was opened, and it was further verified that the reservoir did not contain any cesium. The opening of the converter was effected at the pinch-off. The portion of the copper tube that corresponds to this pinch-off was removed to make room for connection of a new copper exhaust tube, and after replacement of the exhaust tube, the converter was outgassed and charged with cesium for a second time. During assembly of the new exhaust tube, the cesium heater was damaged at one of the terminals. It was decided to short this terminal to the cesium reservoir body, and use one of the radiator fins as a substitute electrical terminal.

Appendix 2 gives the data obtained from converter T-201, and Figure 17 summarizes the I-V characteristics observed. The dashed lines represent the envelopes of dynamic measurements made at true emitter temperatures as indicated with optimized collector temperatures, and the solid lines give the steady-state outputs obtained at the true hohlraum temperatures indicated, with the collector allowed to reach its own equilibrium temperature, unaided by the electrical heater provided for collector temperature optimization. A comparison of these characteristics with those obtained from converter T-103 of the previous program shows that the current at large output voltage (above 0.8 volts) has not been reproduced, and is smaller by approximately 30%. In fact, the converter T-201 performance resembles closely that of converter TE-104. This is probably accounted for by spacing variations, converter T-103 having probably had an unusually small spacing.

Cesium conduction experiments on converter T-201 later revealed that the interelectrode spacing was of the order of 1.4 mils as opposed to the 1.05 mils correlated by cesium conduction heat transfer measurements in the previous converters of this design. As mentioned in Section 1.2, it is likely that this deviation was mostly due to the mechanical misalignment which was observed after using tight-fitting jigs. The poor performance of converter T-201 may also be related to the fact that, due to exceptional circumstances, the converter had to be re-opened and recesiated.

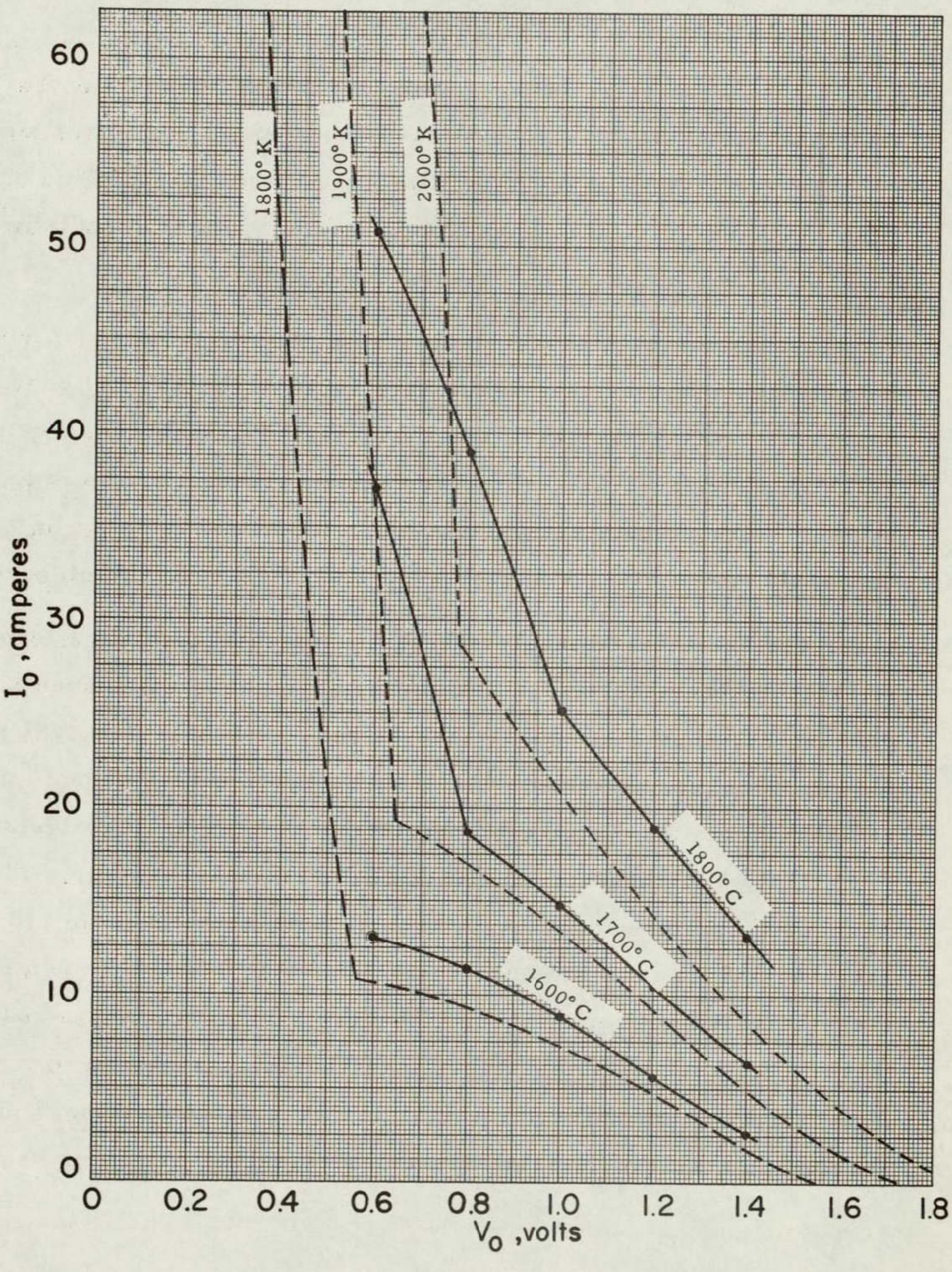

Figure 17. T-201 I-V Characteristics.

2.1 Fabrication of Converter T-202

In order to evaluate the redesigned braze interface in the collector structure for converter T-202, an experimental collector-radiator structure was designed, fabricated and tested. This structure was instrumented to evaluate the heat load that the radiator could dispose of as a function of collector temperature.

Figure 18 is a drawing of the collector-radiator model fabricated. It reproduced the radiator structure of the TE-100 converter built under contract 950671, and it included a collector body with a cylindrical braze (2002) in the area of heat transfer to the radiator support. The completed collector-radiator model is shown in Figure 19, and its radiator fins were coated with chromium carbide.

The radiator-collector model was tested at heat input levels of 110, 210, and 310 watts. The temperature levels achieved are given in Appendix 3 and in Figures 20 and 21. Figure 20 gives the temperature rise produced when the only heat input is that of radiation from the electron bombardment of filament. Analysis of this data shows that the filament contribution is 10 watts. Figure 21 gives the temperature levels at total heat input values of 110, 210, and 310 watts. The only abnormal result from this run was the relatively high reservoir temperature. In an attempt to reduce this temperature, a shield was placed along the tubulation to isolate the cesium tube from radiation by the radiator fins. This resulted in a still higher temperature level at the reservoir because,

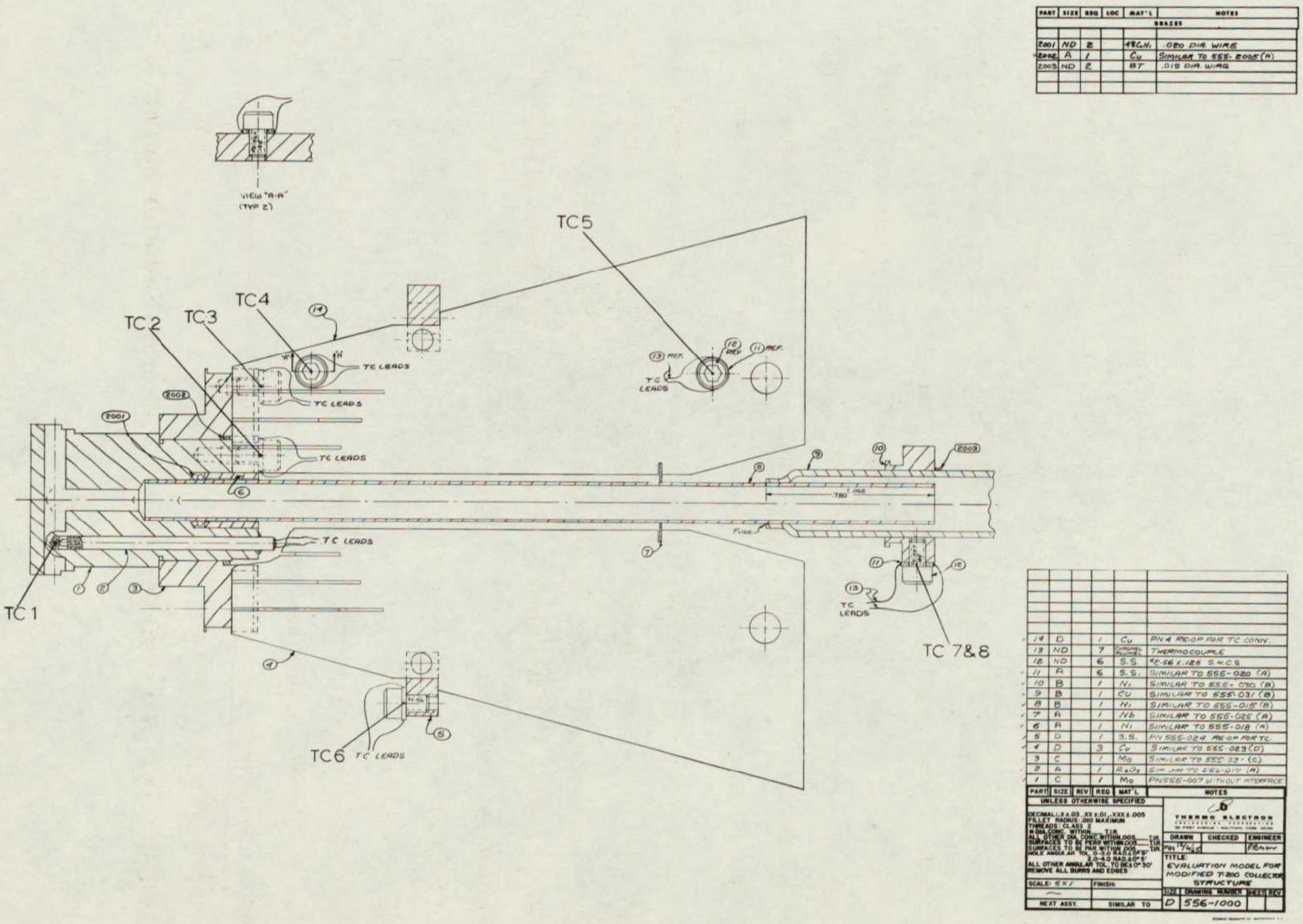

Figure 18. Layout of Collector-Radiator Model.

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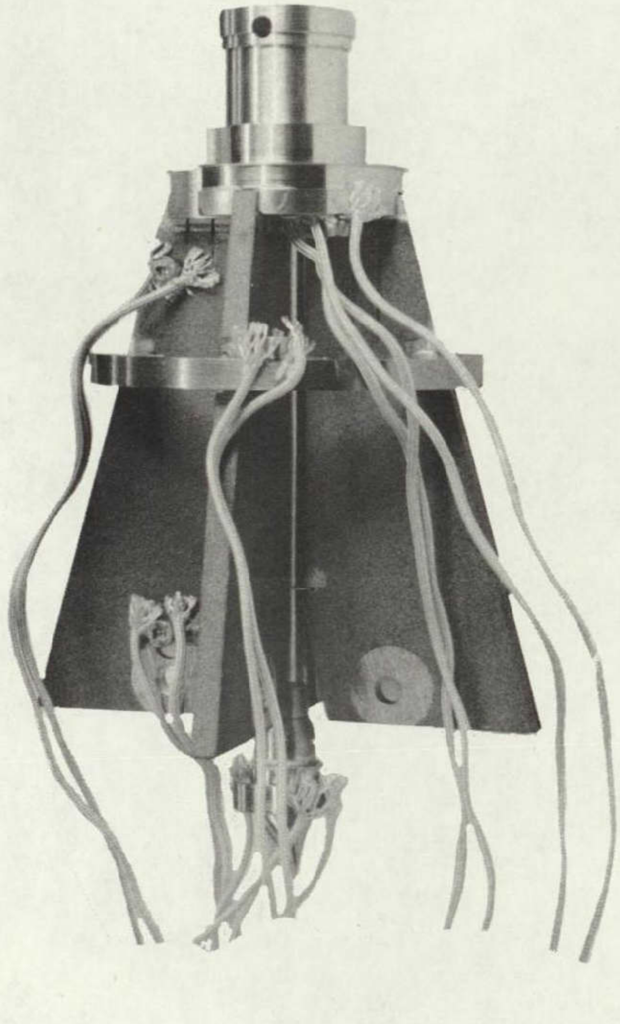

Figure 19. View of Assembled Collector-Radiator Model.

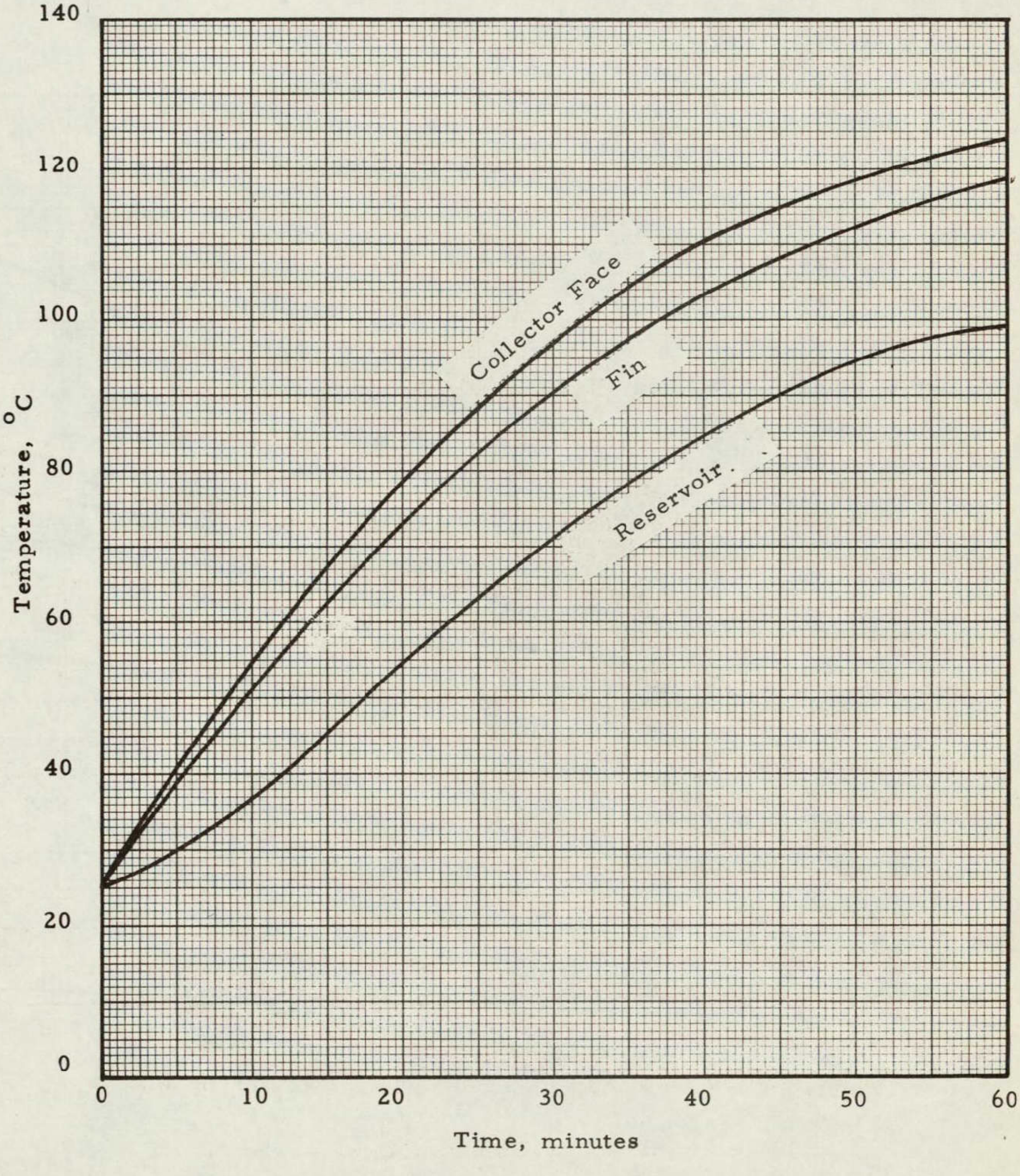

Figure 20. Collector-Radiator Model — Run No. 1.

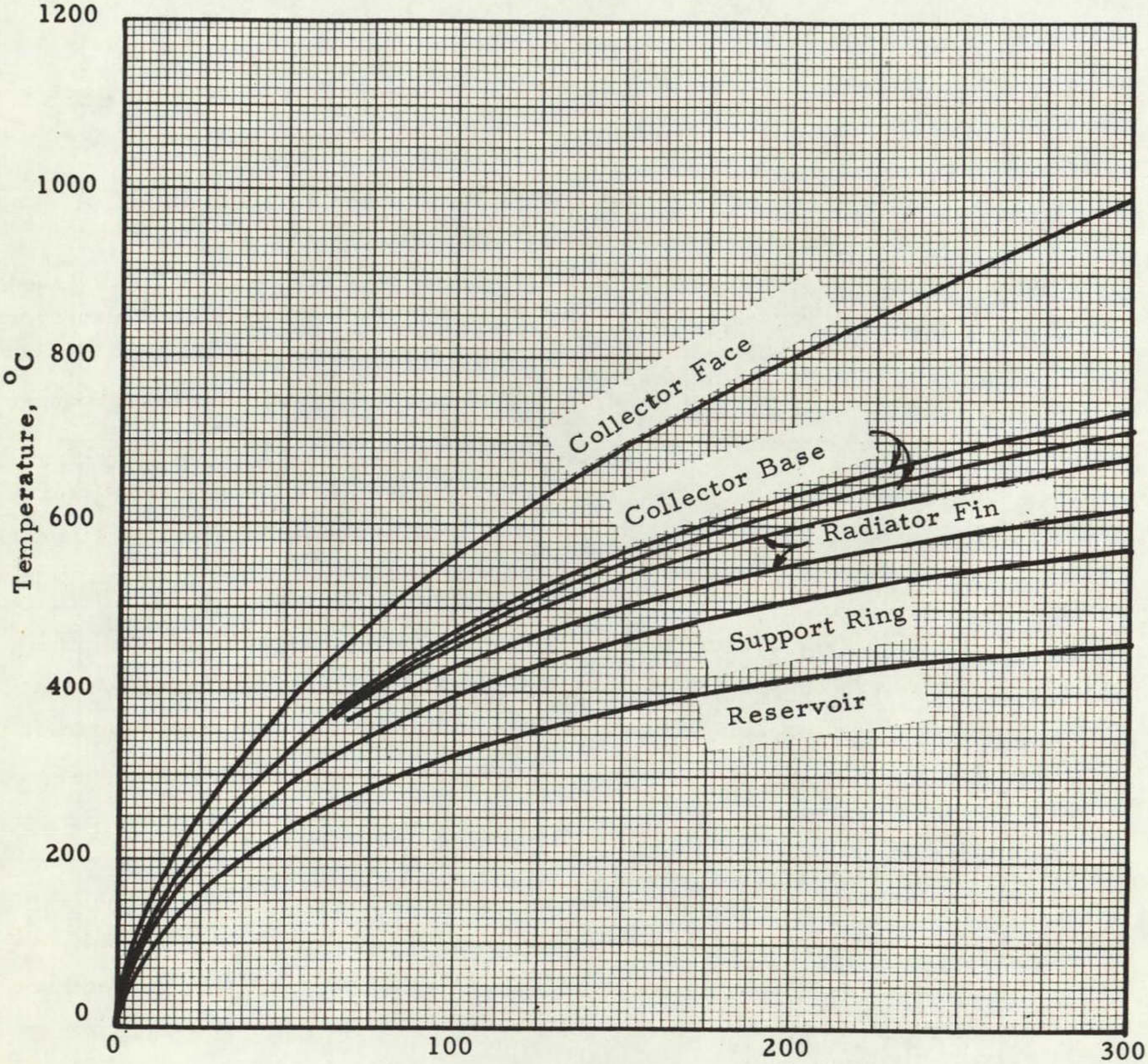

Figure 21. Collector-Radiator Model — Run No. 2.

as it became apparent, the cesium tube loses more heat by its own radiation than it receives from the radiator fins. In another attempt the shield was removed and the copper pinch-off of the reservoir was painted with a black silicone paint. This coating lowered the reservoir temperature by more than 100° C. Such a result indicated that any problem with overheating of the cesium reservoir should be easily overcome by the application of a coating to the reservoir, or by a reduction in the cross-section of the reservoir tubulation.

Figure 21 shows that a heat input of 158.5 watts (interelectrode radiation = 33.5 w, cesium conduction = 24.0 w, electron heating at 20 amp/cm^2 = 86 w, radiation from sleeve = 15 w, the conduction from the emitter support is assumed to be cancelled by radiation from the connecting leads) yielded a collector face temperature of 1013° K, which was in line with the previously observed optimum collector temperature for converter TE-103 of 1015° K at 1 volt. Since it appeared that the radiator size of the model tested was as close to that required for converter T-202 as a collector-radiator model test of the type performed could actually predict, converter T-202 was fabricated with a radiator of that size using the chromium carbide coating on the fins.

In other respects, the fabrication of converter T-202 followed mainly the procedure used for converter T-201. The collector face was chemically etched instead of ground, and the etching procedure used is given in Appendix 4. Figures 22 and 23 show the surface appearance after 5 and 15 minutes of etching time. The emitter was electroetched using the procedure outlined in Appendix 1.

Thermal stabilization was conducted at a substantially higher temperature than for T-201, and it was 2400°C for 1 hour. This treatment resulted in severe alteration of the emitter structure: Figure 24 shows that the tantalum substrate of the emitter developed large grain growth and partial separation along grain boundaries. Figure 25 is a photomicrograph of the heat treated emitter surface.

2.2 Testing of Converter T-202

Converter T-202 was tested according to the same procedure used for T-201. Appendix 5 gives the data obtained, and Figure 26 gives the I-V characteristics from converter T-202. The dashed lines represent the envelopes of dynamic measurements made at true emitter temperatures as indicated, with optimized collector temperatures, and the solid lines give the steady-state outputs obtained at the true hohlraum temperatures indicated, with the collector allowed to reach its own equilibrium temperature, unaided by the electrical heater provided for collector temperature optimization. As may be seen, the spacing between the branches corresponding to ignited operation is not uniform; it is narrower between 1900 and 2000°K than it is between 1800 and 1900°K. This is because it had been initially assumed that optimum collector temperatures would be obtained at 1.75 times the reservoir temperature and the 2000°K curves were run making this assumption. Further testing showed that a ratio of 1.60 gave a nearer-to-optimum condition and this ratio was adopted for the 1900°K and 1800°K runs.

Of particular interest in Figure 26 is the point obtained in steady state, with no collector heat applied, at 1800°C and 0.8 volt output. The collector temperature achieved there was 1073°K at an output current

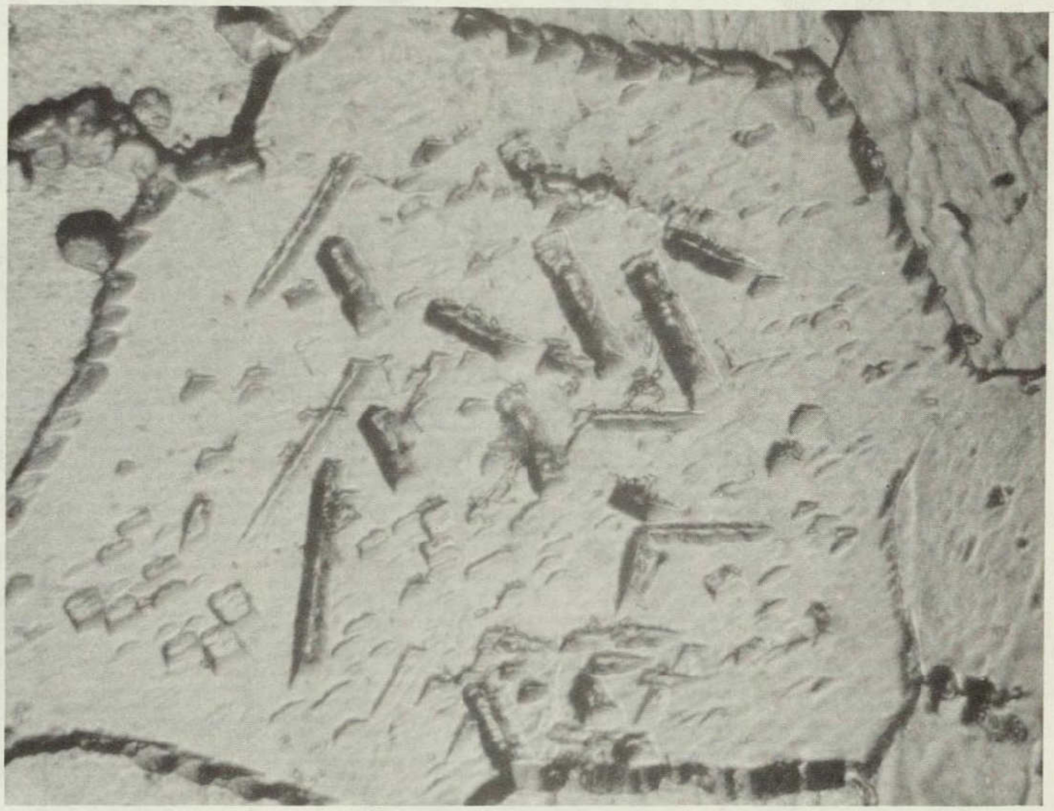

Figure 22. Photomicrograph of T-202 Collector Face (after 5 min. etch).

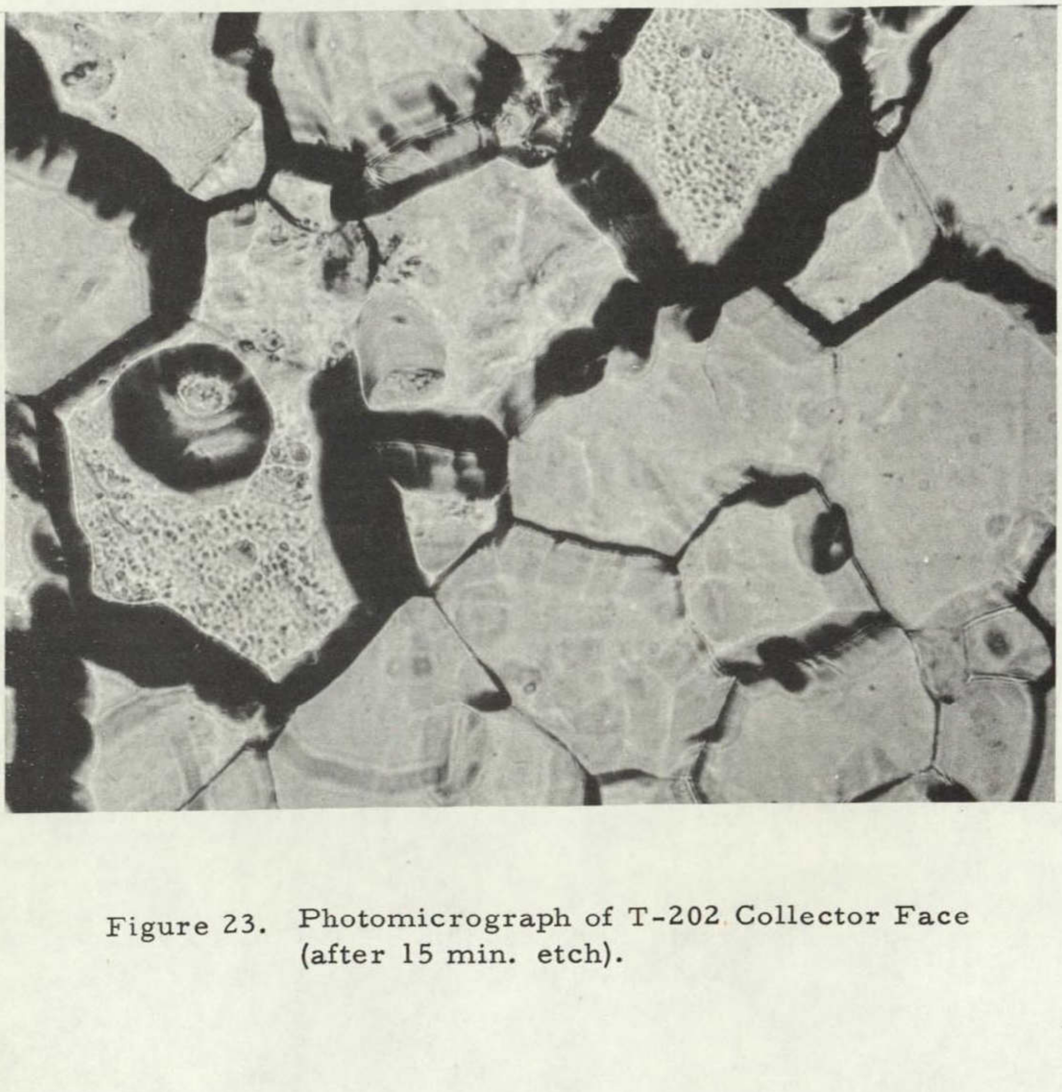

Figure 23. Photomicrograph of T-202 Collector Face (after 15 min. etch).

Figure 24. Visual Appearance of T-202 Emitter Structure.

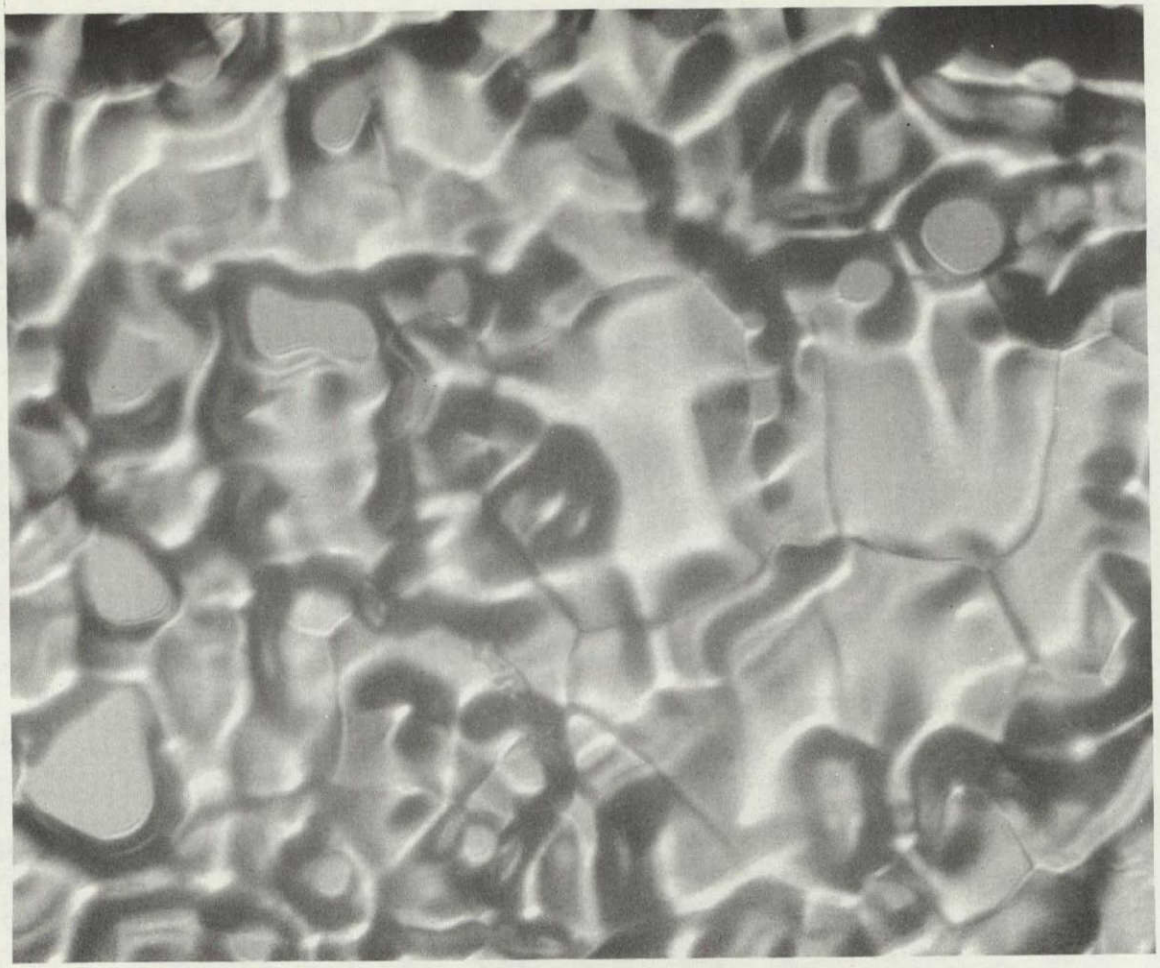

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Figure 25. Photomicrograph of T-202 Emitter Surface (after 2400°C firing).

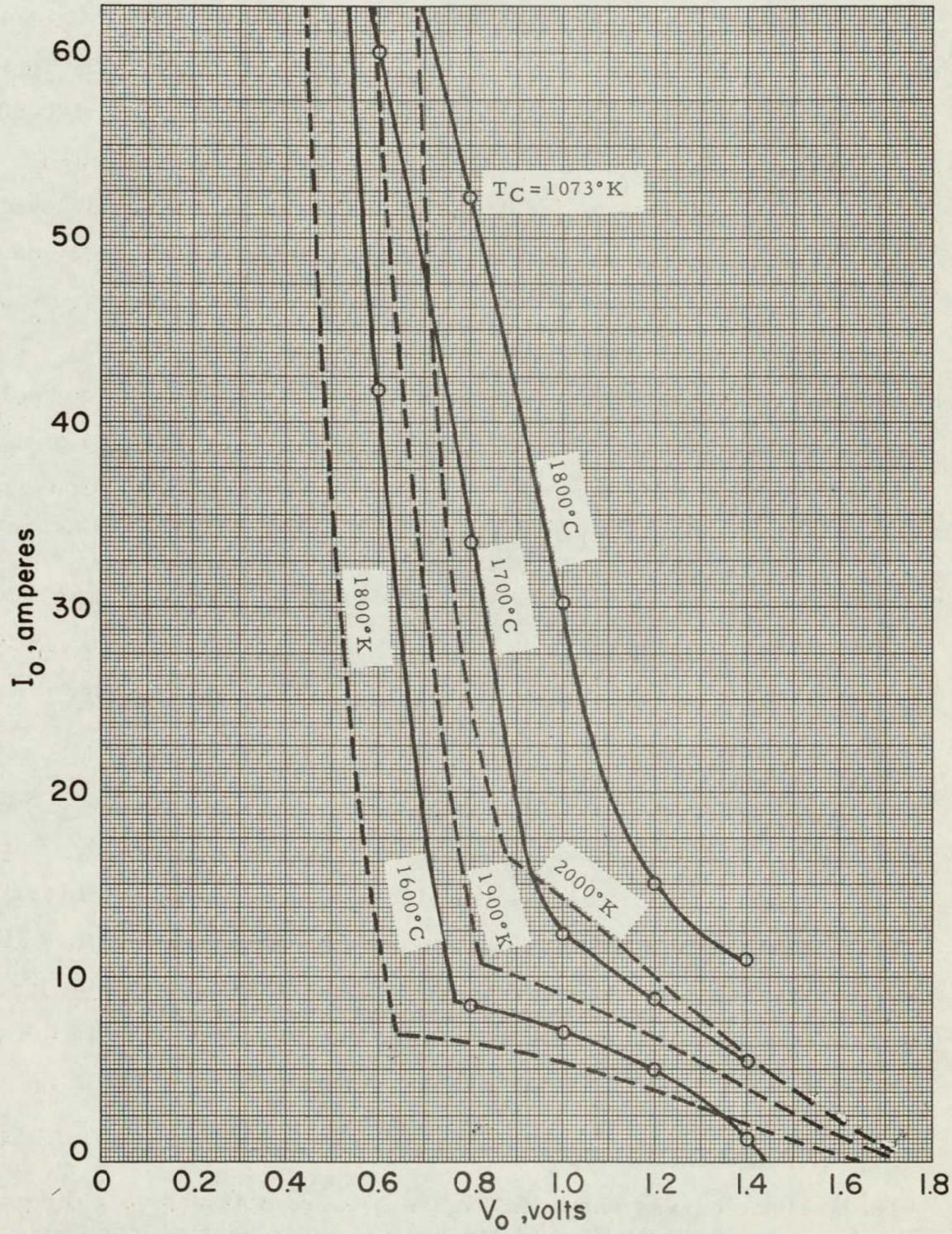

Figure 26. T-202 I-V Characteristics

of 52.3 amperes, and it compared favorably with the desired goal of 1015° K at 50.0 amperes.

Figure 27 compares the T-202 performance with that of converter T-201, and also gives T-103 results previously obtained. The figure reveals that, in the ignited mode, the performance of T-201 and T-202 is similar except that in steady-state, T-201 was not able to reach a sufficiently high collector temperature to attain the performance level predicted by the dynamic curve. In the unignited mode, the performance of T-201 is superior to that of T-202, and this result would indicate that the interelectrode spacing of T-202 was larger than that of T-201. This is not surprising, for T-202 was noticed to have a collector face convex by .0004" in addition to a convex emitter. The departure from flatness of the collector was the result of the 15-minute chemical etch on the face. Converter T-201 had a ground collector which was flat within .0001 inch.

Figure 28 gives the variation in heat transfer obtained as a function of reservoir temperature with T-201 and T-202,* which tends to verify that T-202 must have had a larger average interelectrode spacing.

As a result of these findings, it was recommended to JPL that the etching time for the collector of converter T-203 be reduced to 5 minutes, and that the T-202 collector radiator geometry be preserved. Furthermore, it was recommended to reduce the side-emission area to 1 cm^2 from the 2 cm^2 used previously for T-201 and T-202. This area had had a value of 1.3 cm^2 in T-103 and 0.5 cm^2 in all other T-100 converters. It was increased in T-201 and T-202 to 2 cm^2 to enhance output contribution to the lateral area of the collector. Since there was a large discrepancy in the

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*The analytic curves shown in Figure 28 were obtained with the experimental correlation of Kitrilakis and Meeker, given in Section 6.6e.

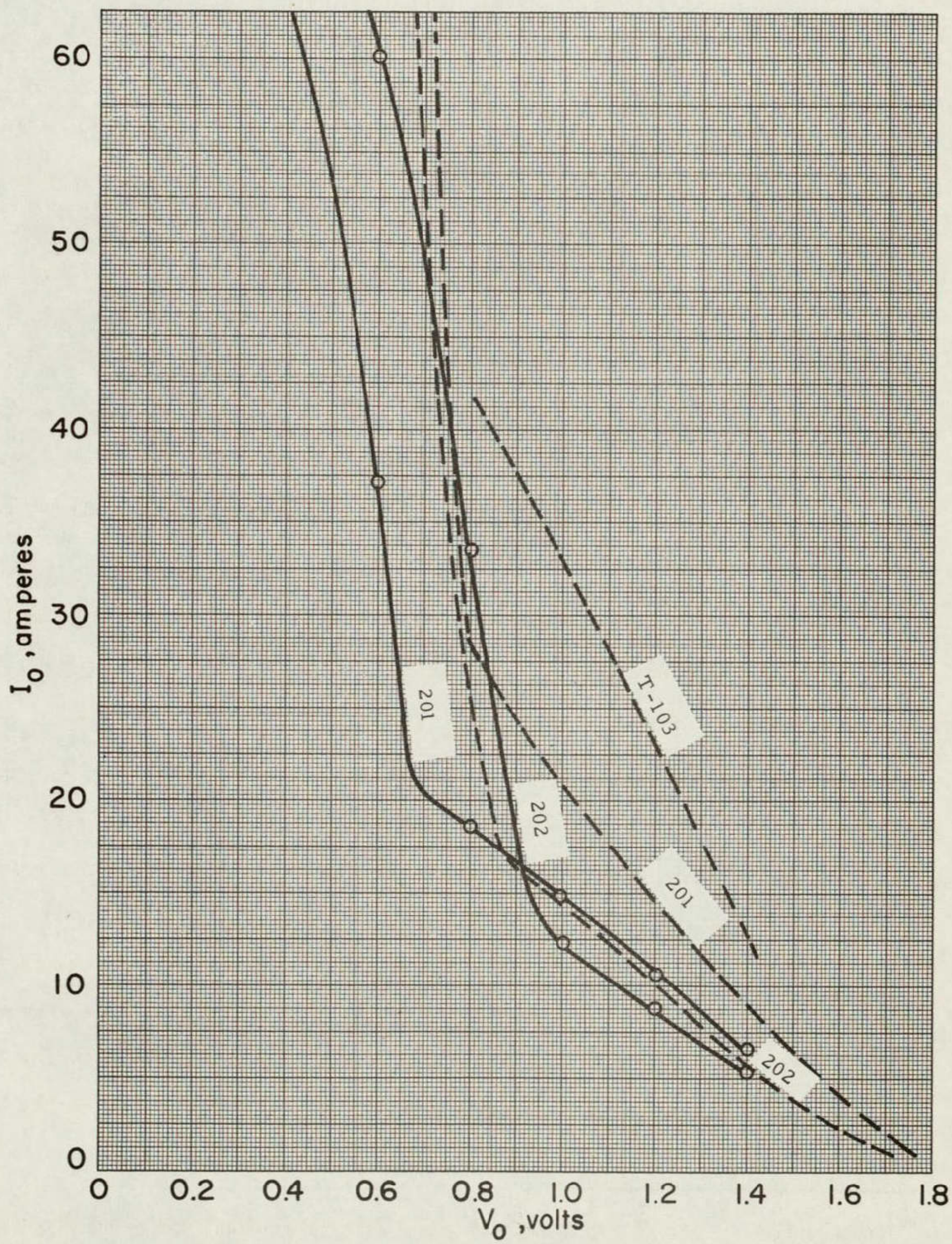

Figure 27. Comparison of T-201 and T-202 I-V Characteristics at 1700°C and 2000°K (------).

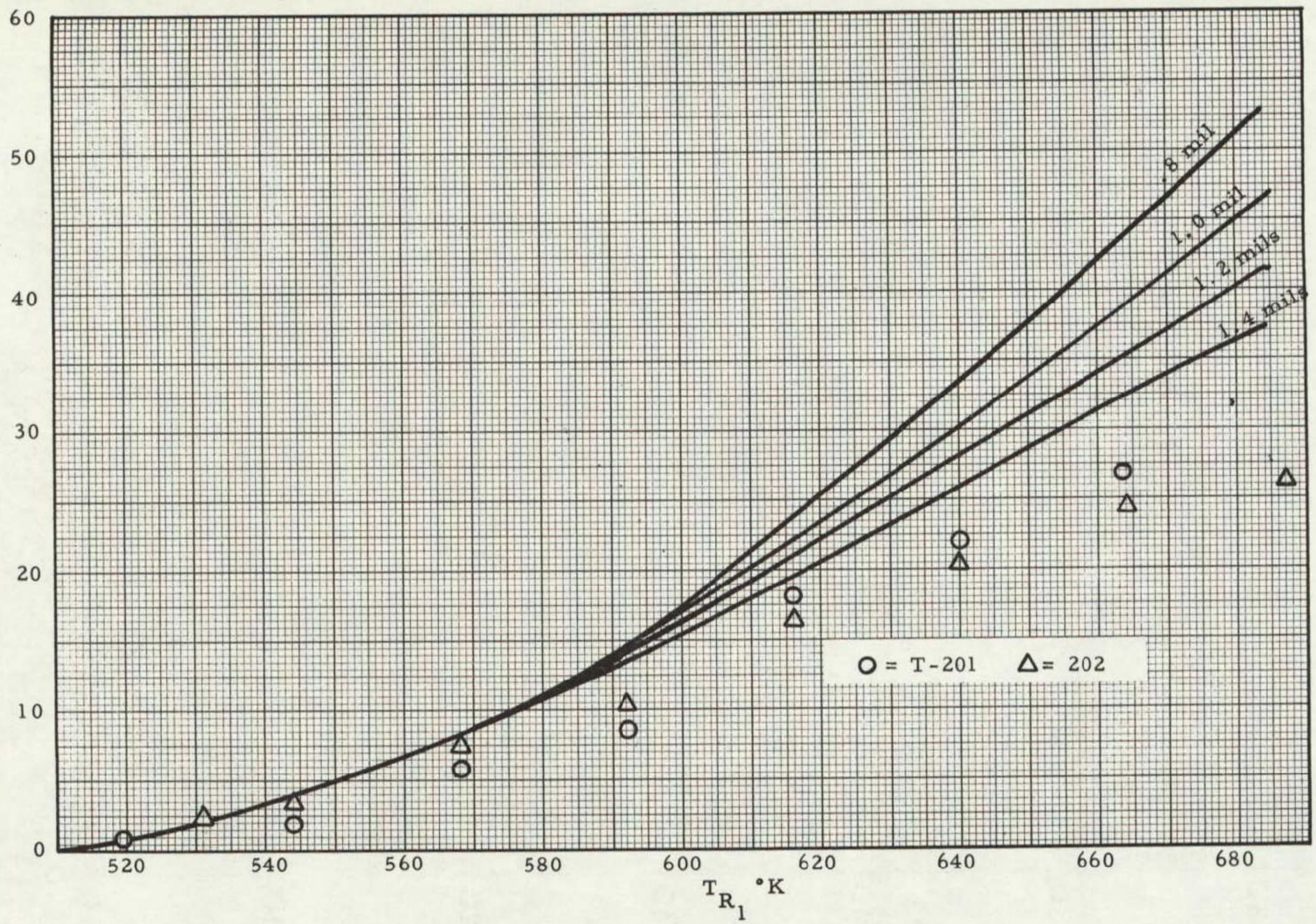

Figure 28. Cesium Conduction

output of converters T-202 and T-103 in the extinguished mode, it was felt that some effort at exploring the influence of lateral collector area should be made.

To evaluate the design of the cesium reservoir of converter T-202, an additional test was performed, and the data is presented in sheet 7 of the data which is also plotted in Figure 29. This data shows the equilibrium reservoir temperatures achieved as a function of reservoir heater current, for a collector temperature of 854°K. As it may be seen, the reservoir had a tendency to overheat (when not connected to a water-cooled strap) even at the relatively low collector temperature of 854°K. A desirable equilibrium reservoir temperature is approximately 623°K for optimum output at 50 amperes. Further effort on improving the cesium reservoir design was made in subsequent T-200 models.

3.1 Fabrication of Converters T-203 and T-203A

The fabrication of two converters, T-203 and T-203A, could not be completed successfully. These converters were fabricated following the T-201 procedures except for a change in the outgassing specification. Prior to T-203, the converters were outgassed with a collector temperature generally in the vicinity of 700°C. Although the performance characteristics had not revealed a need for a higher collector outgassing temperature, it was felt that it should be increased to 800°C because during testing the collector temperature often reached that level. Consequently, both T-203 and T-203A were outgassed maintaining the collector temperature at 800°C for a period of 64 hours for T-203, and 24 hours for T-203A. At the end of outgassing, converter T-203 showed immediate signs of having developed a leak; when

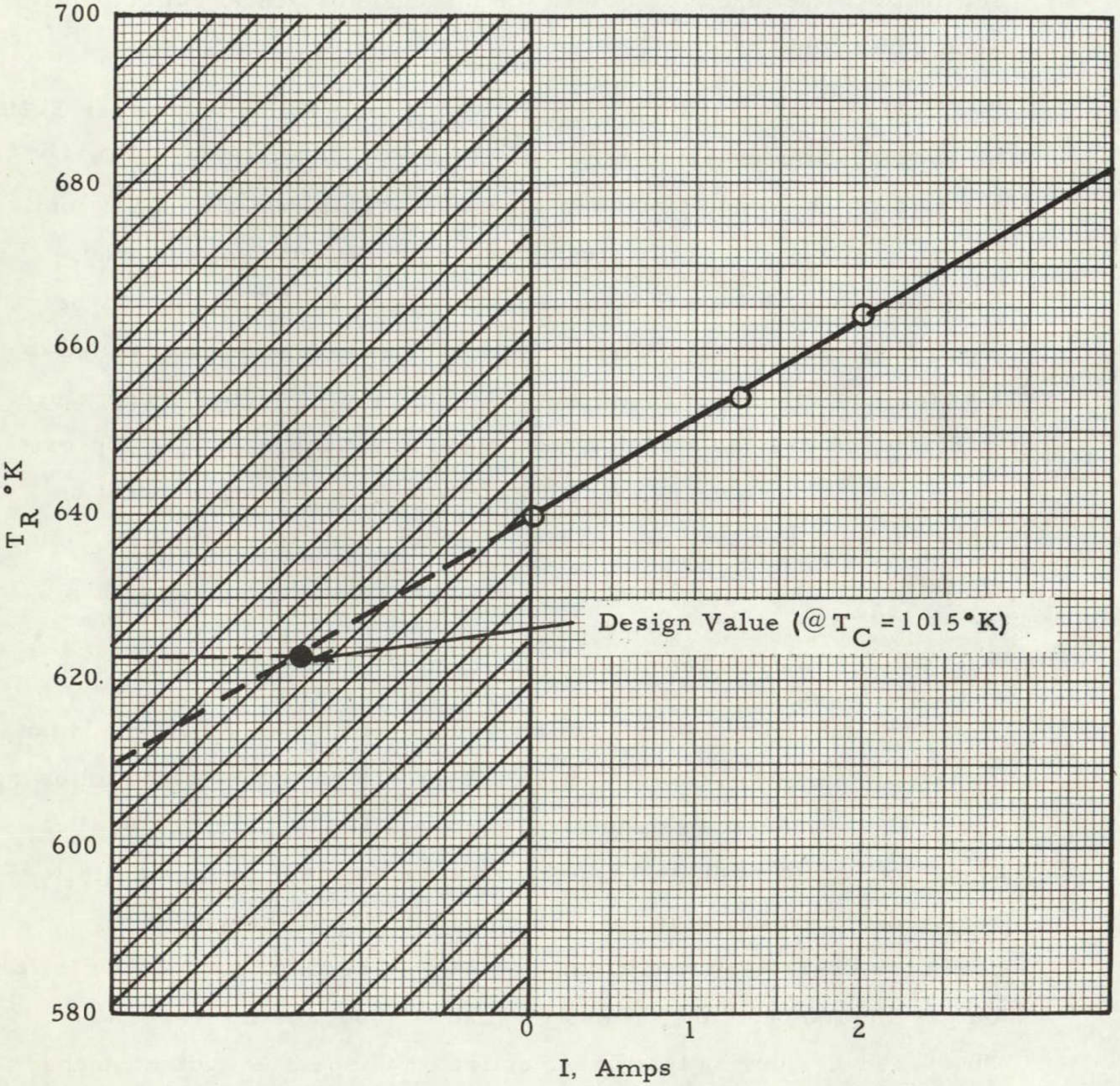

Figure 29. Thermal Characteristics of T-202 Reservoir (T_C = 854°K)

air was released in the external vacuum system, the exhaust vac-ion pumping system connected to the vacuum envelope of the converter showed a rapid rise in pressure. Subsequent leak checking indicated that the failure had occurred either at the palladium braze between the niobium seal flange and the collector stem, or at the ceramic seal. Since no such failure had been encountered before, it was assumed that its nature was accidental.

Converter T-203A did not show the signs of difficulty at the end of outgassing as did T-203, and it was charged with cesium and instrumented for test. However, it developed no output, and it was then decided to open the reservoir, and connect a new tubulation to leak check the unit. A leak was found in the general area of the seal, and to pinpoint its location, the converter was sectioned so that the seal area could be exposed without damaging it. A new tubulation was brazed to facilitate connection to the leak detector, and the leak was found at the palladium braze. The emitter structure was cut out to allow direct visual and mechanical inspection of the braze. This examination revealed that at some places the bond to the molybdenum had occurred over areas only 0.020" wide which were easily broken by the application of relatively low forces. The fracture observed was along intergranular surfaces in the molybdenum material adjacent to the braze.

The emitter of converter T-203A was obtained from a new pressure bonded assembly etched for 1 minute and thermally stabilized for 1 hour at 2100°C. The firing temperature corresponded to the average of the values used for the previous two emitters for converters T-201 and T-202. After firing, the flatness check showed that the emitter was convex at the center by .0003" which was the minimum value that it had been found possible to achieve. Figure 30 shows a photomicrograph of an emitter treated according to the above procedure.

3.2 Fabrication of Converter T-203B

The emitter structure of T-203A, consisting of the pressure-bonded electropolished and electro-etched rhenium sheet and its tantalum substrate, was salvaged, checked for flatness and used in the fabrication of T-203B. The collector was chemically etched with a room-temperature solution of 50 parts H_2O, 20 parts HNO_3 and 30 parts H_2SO_4. The radiator fins were coated with chromium carbide. To avoid a repetition of the previous two failures, converter T-203B was assembled with a carefully selected collector subassembly with good braze flow, and its outgassing was performed with a collector temperature of 660°C instead of 800°C. The outgassing time was approximately 24 hours and the vac-ion reading at the end of outgassing was 8×10^{-7} torr, hot, and 1×10^{-7} torr, cold. After the converter was charged with cesium, initial tests showed that it had a leak located at the final pinch-off. The converter was then opened at the location of the leak and placed in a vacuum furnace for 2 hours at 500°C to remove any traces of possible cesium compounds. A new tubulation was attached for outgassing, and the final outgassing was performed for 16 hours with a collector temperature of 627°C. The final pressure readings were 16 and 8×10^{-7} torr in the hot and cold conditions. The cesium distillation followed the usual schedule of 5 hours at 200°C.

4.1 Design of Converter T-204

The design of converter T-204 included an all-rhenium emitter structure and a number of modifications aimed primarily at simplifying the converter structure and its assembly procedure; it is shown in Figure 31. One of the principal changes was a reversal of the inner seal flange so that the flange reached to the rear of the collector barrel rather than forward. This change allowed a much more favorable configuration for the palladium braze of the flange to the collector. It also resulted in a larger interelectrode spacing which was estimated as follows:

Expansion of the 0.220" Re emitter support structure to an average temperature of 1200°C:	1.85 mils
Add expansion of the 0.400" Nb seal structure to an average temperature of 700°C:	2.20 mils
	4.05 mils
Subtract expansion of the 0.620" Mo collector structure to an average temperature of 640°C:	-2.30 mils
	1.75 mils

Assuming zero spacing at room temperature, the operating spacing calculated was 1.75 mils. Other changes were the elimination of the thermocouples at the collector base, the omission of grooves in the collector barrel to fit the radiator fins, and a simplified cesium reservoir structure.

4.2 Fabrication of Converter T-204

The fabrication of converter T-204 started with the development of electron-beam welds for the all-rhenium emitter structure. The first weld attempts produced the structure shown in Figure 32. These welds were difficult to make by electron-beam welding because of the extreme care required by the end-weld of concentric thin-walled rhenium tubes. To avoid this difficulty, it was decided to experiment with heliarc welding, and the next weld of the inner emitter support to the intermediate emitter support, on the same assemblies, was made by heliarc welding. The weld failed because of misalignment of parts due to improper dimensional specification of the parts. As can be seen in Figure 33, "scalloping" occurred, because the edge of one of the rhenium tubes was located higher than that of the other, and the edge of that tube had to be completely melted away before the weld to the other tube could take place. The localized collection of beads of molten metal was so pronounced that the molten rhenium made contact at several points with the niobium of the outer seal flange, and alloyed with it. Therefore, the final assemblies were unusable.

Consequently, new parts were made with modifications to avoid the above problems, and one assembly including an electropolished rhenium emitter was successfully completed. Figures 34 and 35 show the details of the various welds. As can be noted, a slight "scalloping" was still apparent on the weld of the inner to the intermediate emitter supports. The only defect of this assembly was a slight depression of 0.0002" in the center of the emitter caused by pressure from the jig used to retain this piece during electron-beam welding. The jig pressure was reduced later on and the defect was avoided.

The completed structure shown in Figure 33 was thermally cycled by raising the hohlraum quickly ten times to 1780°C. The niobium flange temperature was monitored with a chromel-alumel thermocouple, and it varied over the range from 500°C to 900°C in each cycle. The warm-up time was 1 minute 10 seconds, and the

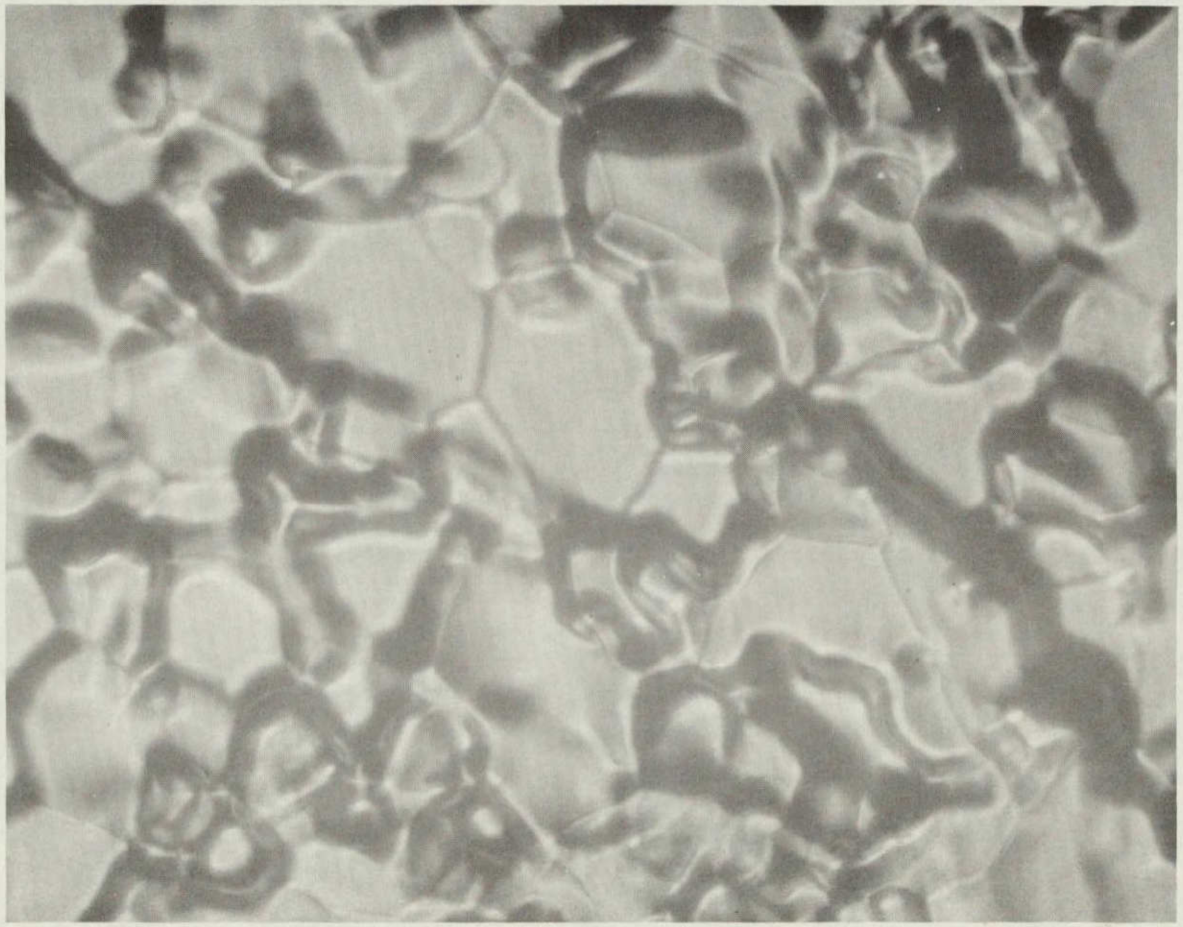

Figure 30. Photomicrograph of T-203 Emitter Surface (after 2100 °C firing).

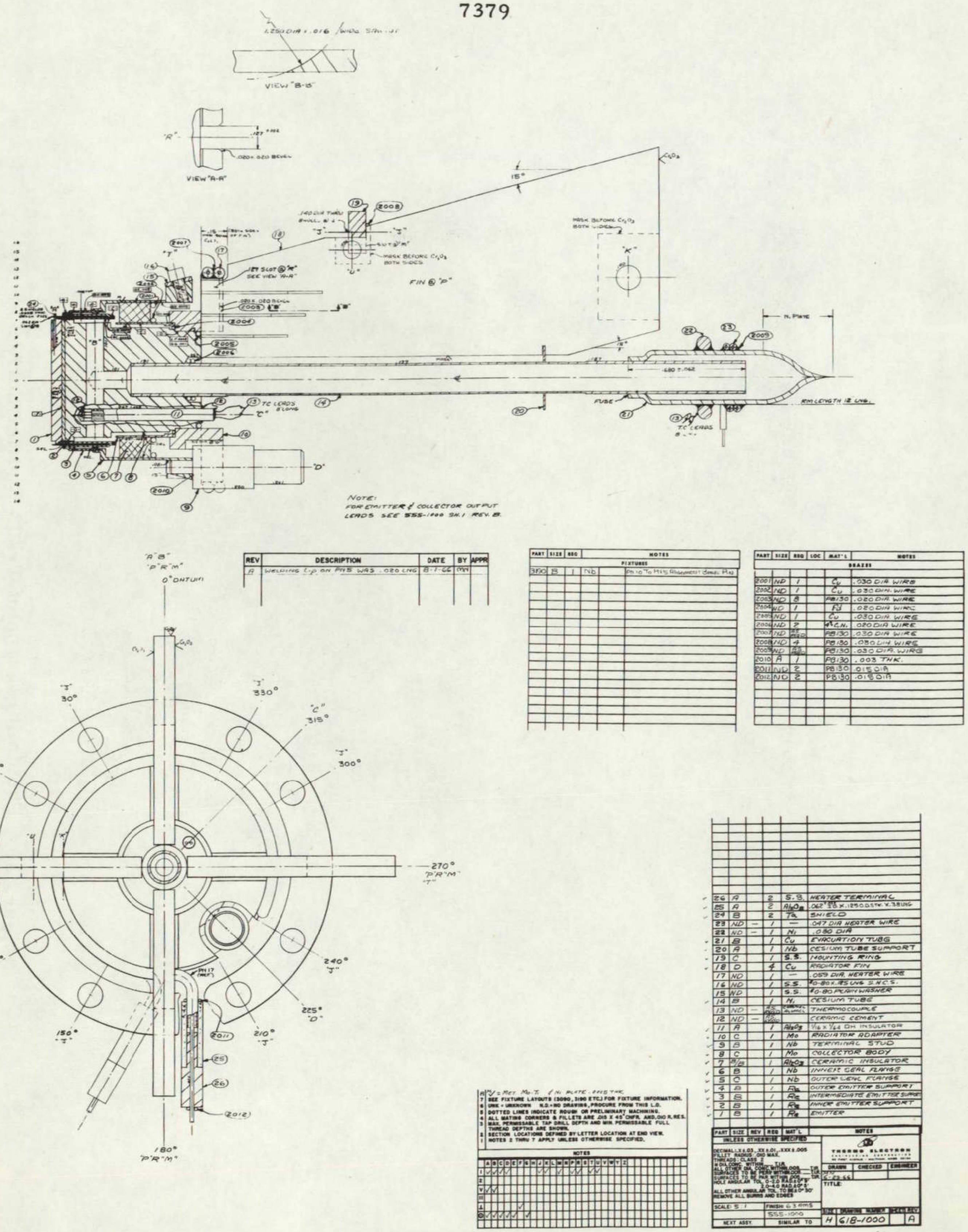
VIEW "B-B"
VIEW "A-A"
.020 x .020 BEVEL
MASK BEFORE Cr_2O_3 BOTH SIDES
"K"
FIN @ "P"
TC LEADS
FUSE
NOTE: FOR EMITTER & COLLECTOR OUTPUT LEADS SEE 555-1000 SH.1 REV. B.
REV | DESCRIPTION | DATE | BY | APPR
A | WELDING LIP ON P115 WAS .020 LNG | 8-1-66
PART | SIZE | REQ | NOTES
FIXTURES
PART | SIZE | REQ | LOC | MAT'L | NOTES
BRAZES
2001 | ND | 1 | Cu | .030 DIA WIRE
2002 | ND | 1 | Cu | .030 DIA. WIRE
2003 | ND | 8 | PB130 | .020 DIA WIRE
2004 | ND | 1 | Pd | .020 DIA WIRE
2005 | ND | 1 | Cu | .030 DIA WIRE
2006 | ND | 2 | 4% C.N. | .020 DIA WIRE
2007 | ND | AS REQD | PB130 | .030 DIA WIRE
2008 | ND | 4 | PB130 | .030 DIA WIRE
2009 | ND | AS REQD | PB130 | .030 DIA. WIRE
2010 | A | 1 | PB130 | .003 THK.
2011 | ND | 2 | PB130 | .015 DIA
2012 | ND | 2 | PB130 | .015 DIA
0° DATUM
90° "P"R"M"
270° "P"R"M"
180° "P"R"M"
"J" 30°
"J" 330°
"C" 315°
"J" 60°
"J" 300°
120° "J"
240° "J"
225° "D"
150° "J"
210° "J"
26 | A | 2 | S.S. | HEATER TERMINAL
25 | A | 2 | Al_2O_3 | .062 x .1250 DSTK x .38 LNG
24 | B | 2 | Ta | SHIELD
23 | ND | — | 1 | — | .047 DIA HEATER WIRE
22 | ND | — | 1 | Ni | .030 DIA
21 | B | 1 | Cu | EVACUATION TUBE
20 | A | 1 | Nb | CESIUM TUBE SUPPORT
19 | C | 1 | S.S. | MOUNTING RING
18 | D | 4 | Cu | RADIATOR FIN
17 | ND | 1 | — | .059 DIA. HEATER WIRE
16 | ND | 1 | S.S. | #0-80 x .25 LNG S.H.C.S.
15 | ND | 1 | S.S. | #0-80 PLAIN WASHER
14 | B | 1 | Ni | CESIUM TUBE
13 | ND | — | AS REQD | THERMOCOUPLE
12 | ND | — | AS REQD | CERAMIC CEMENT
11 | A | 1 | Al_2O_3 | 1/16 x 1/64 DH INSULATOR
10 | C | 1 | Mo | RADIATOR ADAPTER
9 | B | 1 | Nb | TERMINAL STUD
8 | C | 1 | Mo | COLLECTOR BODY
7 | A/B | 1 | Al_2O_3 | CERAMIC INSULATOR
6 | B | 1 | Nb | INNER SEAL FLANGE
5 | C | 1 | Nb | OUTER SEAL FLANGE
4 | B | 1 | Re | OUTER EMITTER SUPPORT
3 | B | 1 | Re | INTERMEDIATE EMITTER SUPPORT
2 | B | 1 | Re | INNER EMITTER SUPPORT
1 | B | 1 | Re | EMITTER
PART | SIZE | REV | REQ | MAT'L | NOTES
UNLESS OTHERWISE SPECIFIED
THERMO ELECTRON ENGINEERING CORPORATION
DRAWN | CHECKED | ENGINEER
6-23-66
TITLE:
SCALE: 5:1
FINISH: 63 RMS
555-1000
NEXT ASSY. | SIMILAR TO
H | 618-1000 | A
SEE FIXTURE LAYOUTS (3090, 3190 ETC) FOR FIXTURE INFORMATION.
UNK = UNKNOWN N.D. = NO DRAWING, PROCURE FROM THIS I.D.
DOTTED LINES INDICATE ROUGH OR PRELIMINARY MACHINING.
SECTION LOCATIONS DEFINED BY LETTER LOCATION AT END VIEW.
NOTES 2 THRU 7 APPLY UNLESS OTHERWISE SPECIFIED.
NOTES

Figure 31.

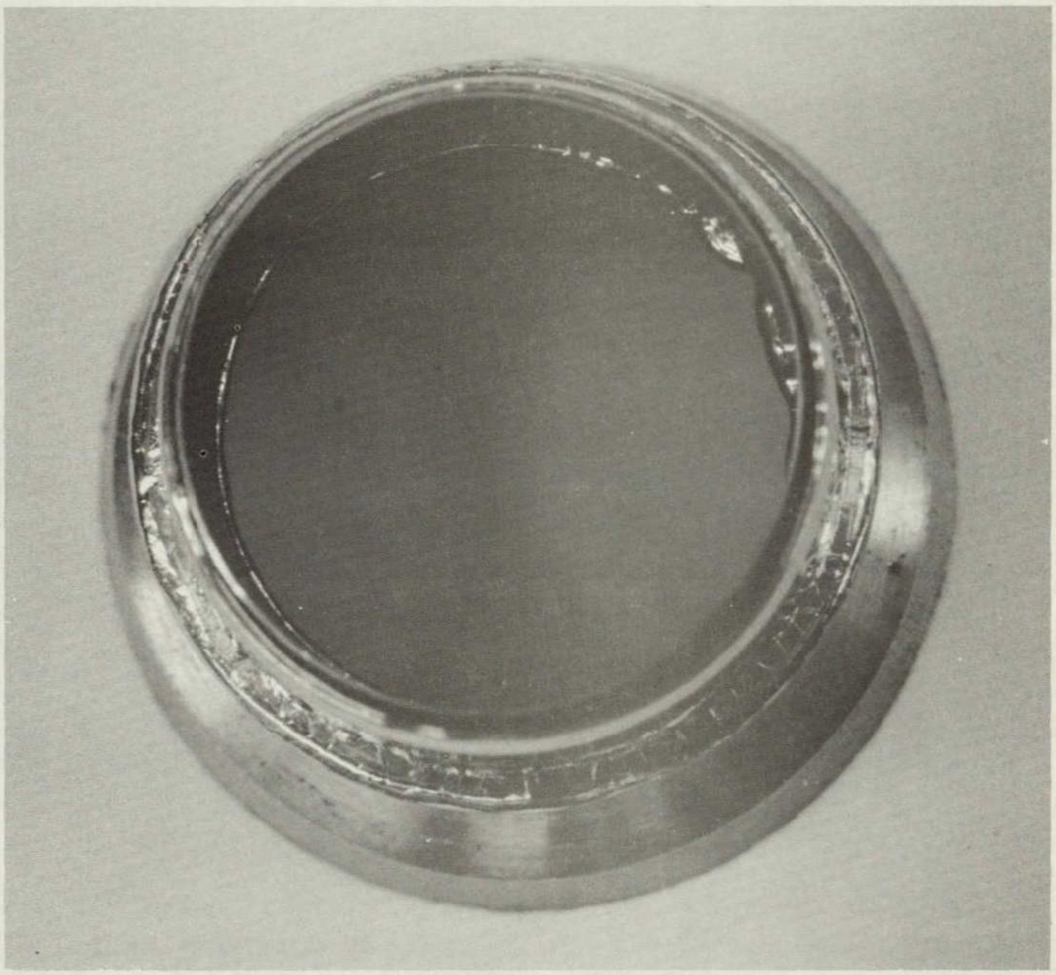

Figure 32.

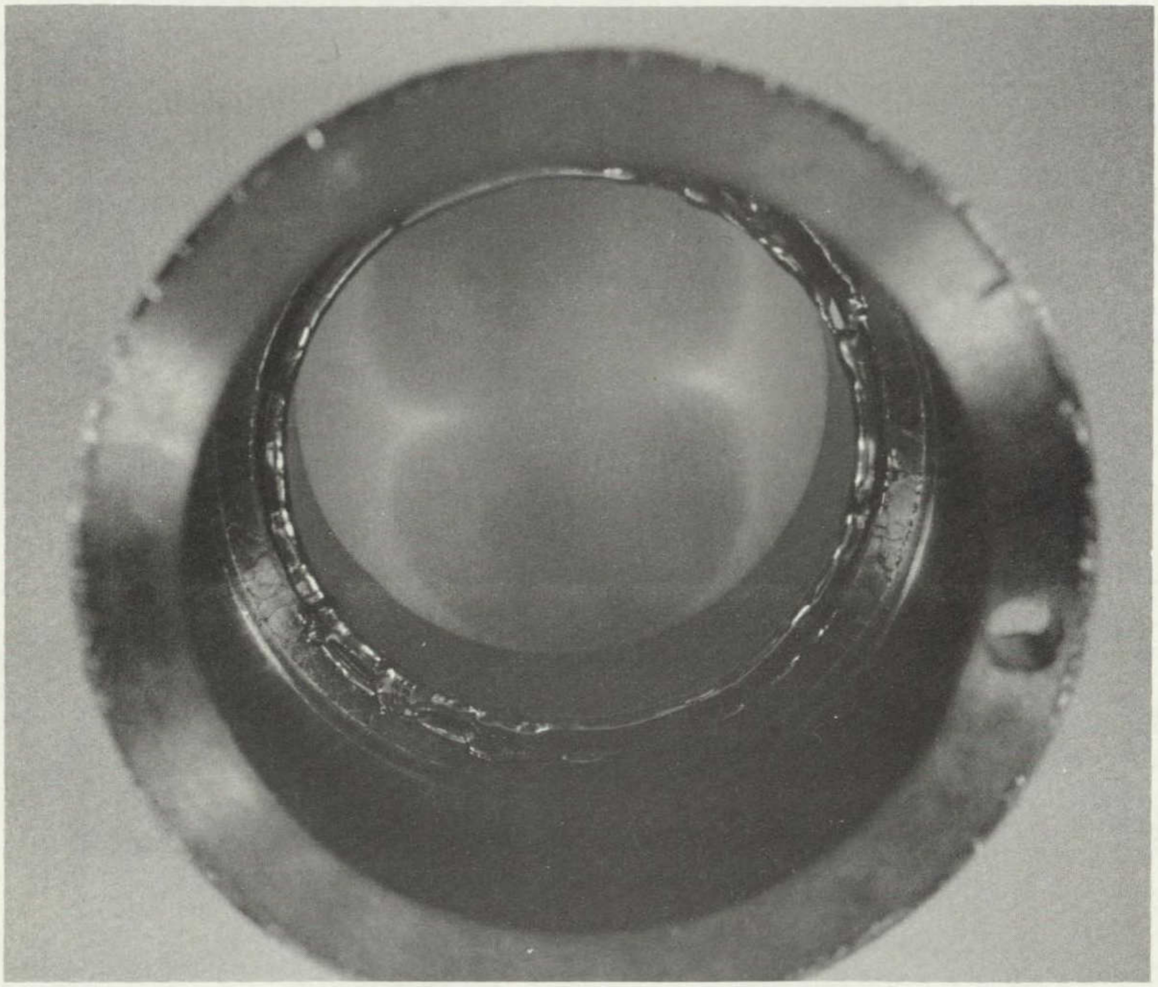

Figure 33.

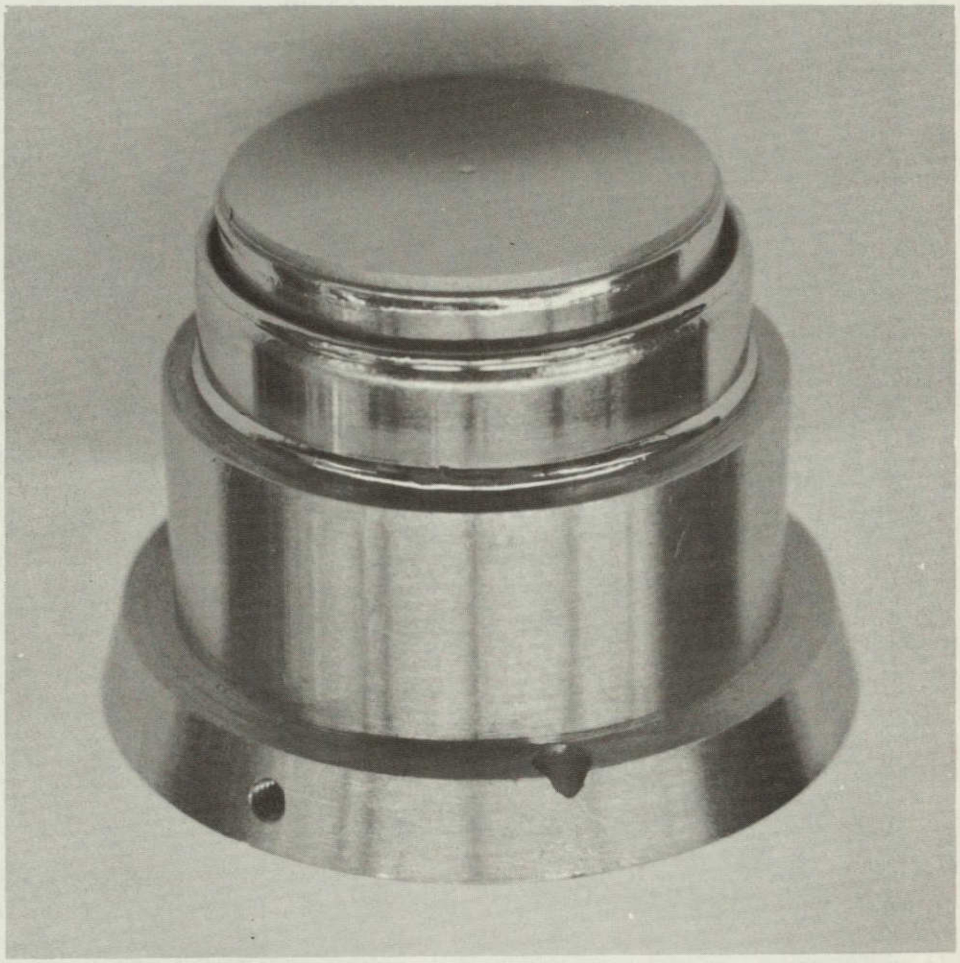

Figure 34.

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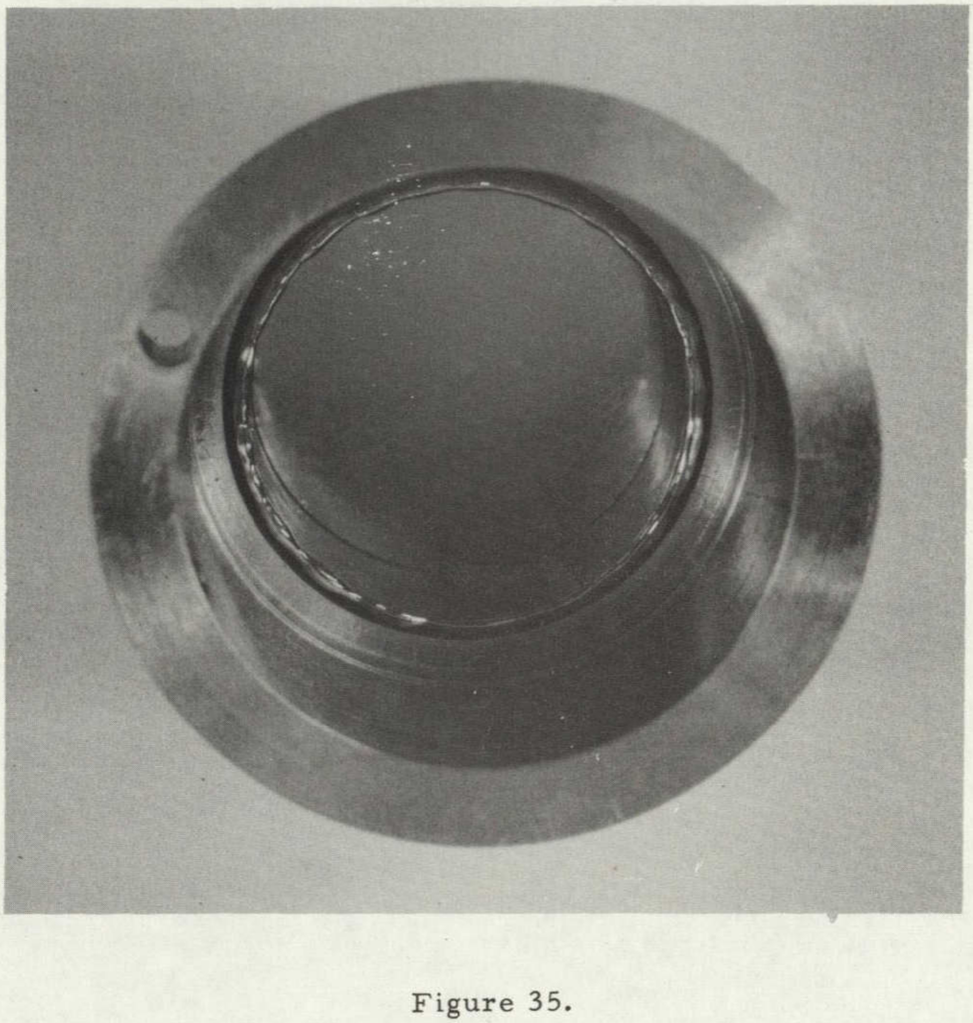

Figure 35.

cool-down time 3 minutes 30 seconds. After the thermal cycles were completed the structure was leak-tight and had maintained flatness with no visual evidence of deterioration.

A subassembly of the palladium niobium-to-molybdenum braze of the new configuration is shown in Figure 36. As can be seen, excellent braze flow was obtained, and three such subassemblies were made without any difficulty. The emitter of T-204 was electropolished for 10 seconds at an applied potential of 23 volts and a current of 3.5 amperes. It was then thermally stabilized at 2040°C observed hohlraum temperature for 2.2 hours in a vacuum of 2×10^{-6} torr. The collector was chemically etched using the same procedure as for T-203B. The coating used on the radiator fins was chromium carbide, and the cesium reservoir modifications of Figure 31 were not implemented. The converter was outgassed for 17 hours at an observed hohlraum temperature of 1750°C, and a collector temperature of 696°C. The final internal pressures were 1.0 and 0.6×10^{-6} torr in the hot and cold conditions.

4.3 Testing of Converters T-203B and T-204

The data sheets for these two converters are presented in Appendices 6 and 7, respectively.

In the optimized 144-hour run, the performance observed for the first four converters was as follows:

	T-201	T-202	T-203B	T-204
Emitter Temperature, °K	2000	2000	2000	1974
Output Voltage, V	0.60	0.80	0.80	0.77
Output Current, amperes	38.0	43.4	39.3	41.4
Reservoir Temperature, °K	623	621	614	618
Collector Temperature, °K	1030	1006	979	1074
Power Input, watts	302	297	299	323
Collector temperature drop, °C	223	213	177	260

As may be noted in the above table, the collector temperature of converter T-204 was considerably higher than previously achieved, and it was, in fact, not optimum. Part of the increase in collector temperature was due to the larger amount of heat received by the converter (which was partly the result of increased radiation heat transfer due to chemical etching of the collector surface), and part was due to a lack of direct heat transfer from the collector barrel to the radiator fins as a result of the design change of the collector barrel described in Section 4.1. Fully optimized performance was obtained in converter T-204 by connecting a water-cooled strap to one of the radiator fins. The fully optimized I-V curves at 2000°K showed the following differences in converter output current (amperes):

	T-201	T-202	T-203B	T-204
0.8 V	28.3	43.5	40.0	45.3
1.0 V	20.8	14.2	23.2	26.0
1.2 V	14.6	10.0	18.1	18.5

7384

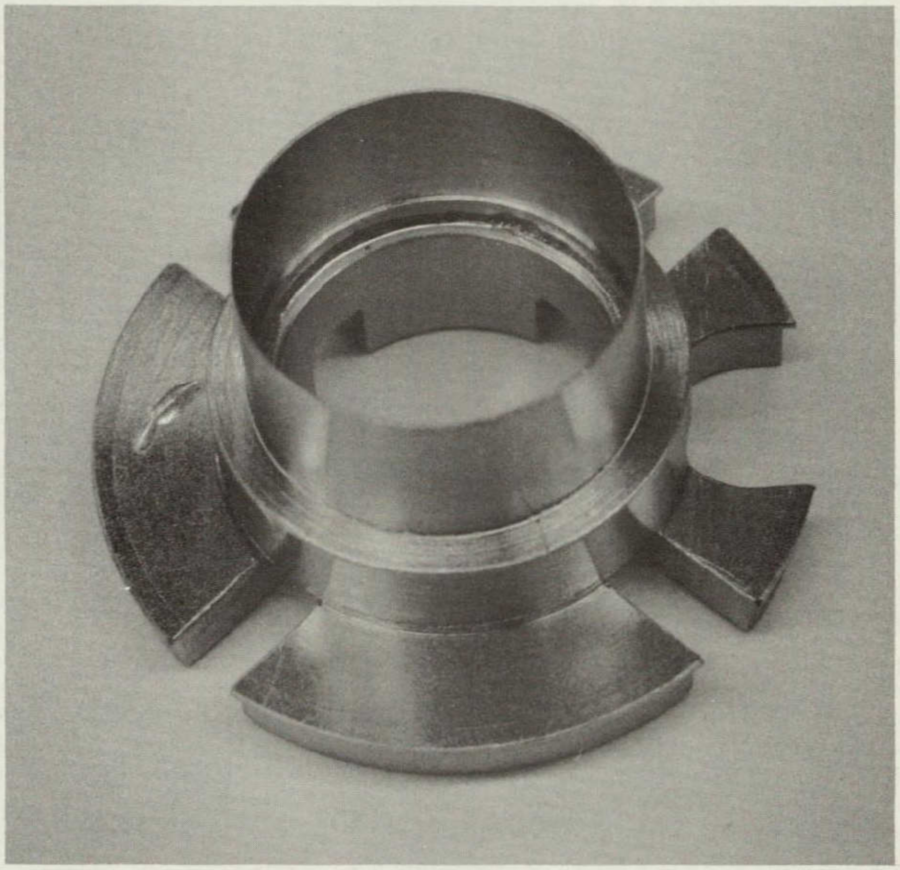

Figure 36.

The steady-state performance achieved with the various prototypes at an output voltage of 1 volt, with no heat applied to control collector temperature, was as follows:

Prototype:	TE-103	T-201	T-202	T-203B	T-204
Hohlraum Temperature, °C	1723	1700	1700	1700	1724
Output Current, amperes	32.5	14.8	12.3	17.6	29.0
Reservoir Temperature, °K	614	602	592	614	614
Collector Temperature, °K	1015	886	852	865	1002
Radiator Temperature, °K	–	737	720	739	802
Collector Temperature Drop, °C	–	149	132	126	200
Power Input, watts	282	220	202	226	292
Overall Efficiency, %	11.5	6.7	6.1	7.8	9.9

The cesium conduction heat transfer of prototypes T-203B and T-204 was measured to infer interelectrode spacing. The measurements were made at varying cesium pressures, at an emitter temperature of 2000°K and a collector temperature of 900°K. Assuming an effective area for cesium conduction 10% in excess of the 2.50 cm^2 interelectrode area,* the computed variation of cesium conduction with cesium reservoir temperature is given in Figure 37 for various interelectrode spacings. The data plotted in this figure, obtained from the two converters, shows that the interelectrode spacing of converter T-203B was approximately 1.25 mils, and that of converter T-204 was 1.65 mils. This latter value agreed well with the calculated T-204 interelectrode spacing of 1.75 mils.

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*The assumed effective area attempts to correct for cesium conduction from components other than the electrodes.

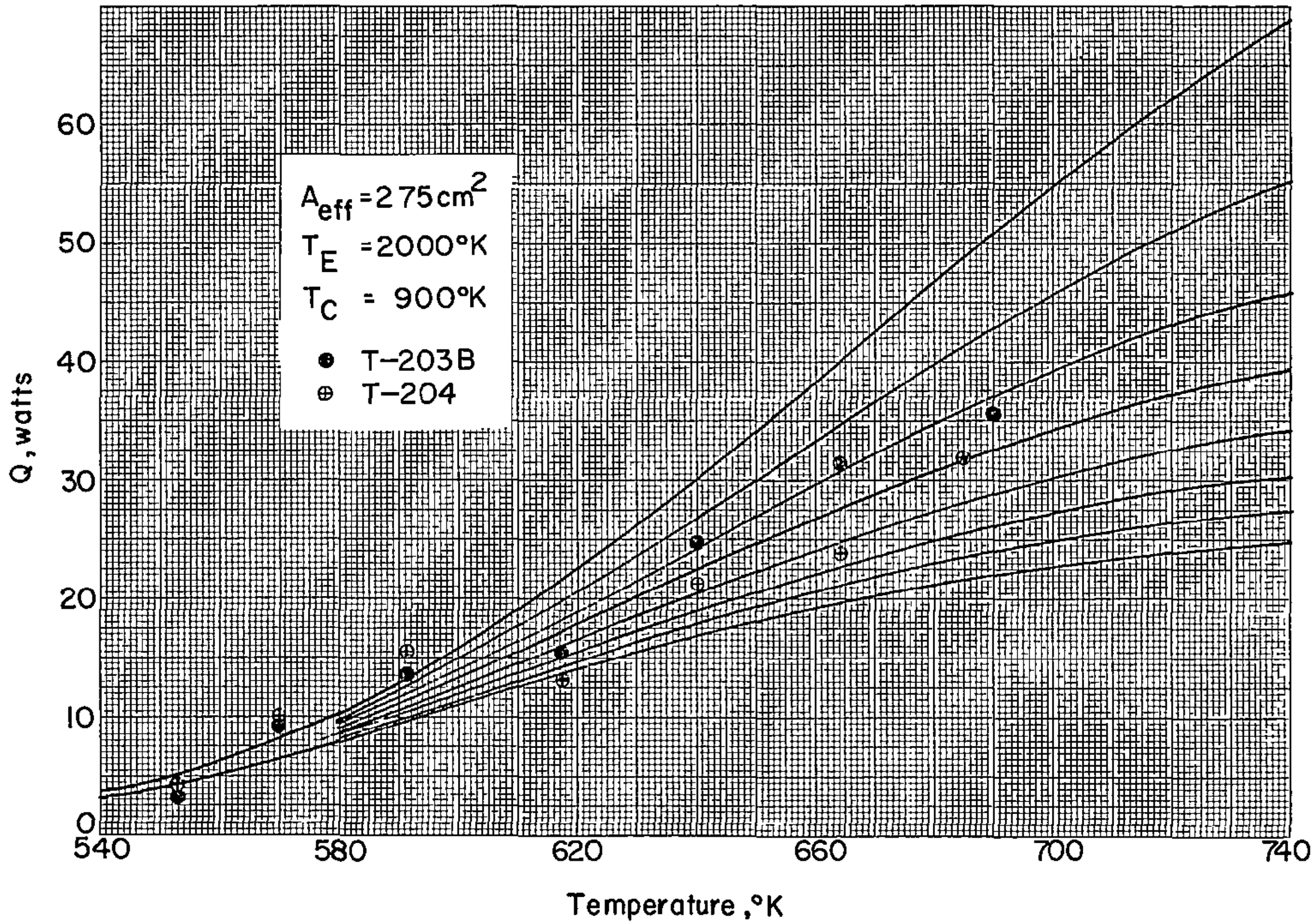

Figure 37.

7431

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5.1 Design of Converter T-205

As explained in Section 4.3, Converter T-204 had a collector temperature drop considerably higher than that previously achieved. Part of this increase in collector temperature was traced to the lack of direct heat transfer from the collector barrel to the radiator fins, and the collector barrel of Converter T-205 was designed to incorporate slotted sections with effective radiator fin contact.

Two other important design changes were effected in the structure of Converter T-205. The first change was to increase the inter-electrode spacing of the converter by 2 to 3 mils to a value approximately equal to 4.25 mils. The increase was to be accomplished by machining the face of the collector so as to leave a raised edge around the collector face 12.5 mils wide and 2 to 3 mils high. The second change was a very slight increase in the collector face diameter, so that the spacing between the cylindrical edge of the collector and the sleeve supporting the emitter would be of approximately the same magnitude as the interelectrode spacing (that is, approximately 4 mils), and it would therefore be more nearly possible to optimize the operating conditions in the interelectrode spacing and at the collector periphery simultaneously.

5.2 Fabrication of Converter T-205

In order to preserve the dimensional tolerances of the raised edge on the collector face of Converter T-205, the collector surface was not chemically etched, as had been those of Converters T-203B and T-204. As in Converter T-204, the emitter of Converter T-205 was a slab of rhenium 0.060" thick, and it was found to be concave by 0.0007". The slightly larger deviation from flatness of the emitter was not serious, however, because of the much larger interelectrode spacing. The deviation from flatness may have resulted from the thermal relief of the grinding stresses locked in the relatively thin rhenium slab.

In all other respects, Converter T-205 was nearly identical to Converter T-204, and it included radiator fins coated with chromium carbide.

The first outgassing of Converter T-205 was applied for 65 hours. The converter was then cesiated according to normal procedures and set up for testing. When the converter was first warmed up for test, it became immediately apparent that there was an air leak, and testing was stopped. A leak check quickly showed that the converter had a leak at the pinch-off. Further investigation to determine the cause of this leak revealed that the copper tubing used for exhausting the converter had been polished with emery cloth in the machine shop as a final polishing operation. Normally, a copper tubing is not given this polishing but is used with the as-received finish of the outside surface. A microscopic examination of the copper material near the pinch-off showed that emery particles had remained embedded in the copper and very likely had interfered with the pinch-off operation. To clean the converter from whatever contamination may have resulted from the air leak, it was placed overnight in a furnace at 600° to 700°C after removal of the defective pinch-off. A new copper tubulation was brazed, and the converter was set up for a second outgassing. The outgassing was performed for a total outgassing time of 68 hours. It was then pinched off and cesiated. When attempts were made to test the converter, it was again discovered that an air leak had developed. The leak was found at the same location, namely, at the pinch-off of the cesium reservoir. To diagnose the cause of this leak, an examination was made of the portion of copper tubing that had contained the cesium capsule from which cesium was distilled into the converter. The inside wall of this tubing was found to be completely blackened. A portion of the tubing was then cut and rf-heated in an open bucket in vacuum at gradually increasing temperatures to observe the behavior of this black coating with increasing temperature in vacuum. It was suspected that this coating was cupric oxide, and, indeed, at about 600°C it turned to the characteristic reddish color of cuprous oxide and pure copper. It was subsequently reasoned that this copper oxide had formed during the second outgassing, when more oxygen was released by the converter while the outgassing tubulation was relatively cold and in the temperature range which would readily cause oxidation. With an oxidized inside wall, it was then impossible to perform a successful pinch-off. This then implied that the heating of the converter in vacuum in a furnace at 600 to 700°C overnight had not been sufficient to remove the oxygen within the converter. To improve upon this procedure the converter structure was then set up in its outgassing stand rather than the vacuum at typical outgassing conditions with the pinch-off removed, so that all oxygen could then be released from the surfaces heated at their normal operating conditions. After this treatment a new tubulation was brazed in place, the converter was given a further outgassing of one hour, and it was cesiated for two hours with the cesium ampoule at 200°C. Subsequent attempts to test the converter showed that the repair had been successful.

5.3 Testing of Converter T-205

The T-205 converter data is presented in Appendix 8. Converter T-205 had a tendency to operate at high collector temperature, and its radiator surface was increased by means of four additional fins mechanically fastened to the converter radiator. These additional fins were used when obtaining the I-V characteristics but were removed before the final steady-state run at 1.0 V.

The fully optimized I-V curves at 2000°K showed the following differences in converter output current (amperes):

	T-201	T-202	T-203B	T-204	T-205
0.8V	28.3*	43.5	40.0	45.3	41.0
1.0V	20.8*	14.2*	23.2	26.0	22.1
1.2V	14.6*	10.0*	18.1	18.5	12.8

The steady-state performance achieved with the various prototypes at an output voltage of 1 volt, with no heat applied to control collector temperature, and with optimized reservoir temperature, were as follows:

Prototype:	TE-103	T-201	T-202	T-203B	T-204	T-205
Hohlraum temperature, °C	1723	1700	1700	1700	1724	1720
Output current, amperes	32.5	14.8	12.3	17.6	29.0	17.1
Reservoir temperature, °K	614	602	592	614	614	590
Collector temperature, °K	1015	886	852	865	1002	928
Radiator temperature, °K	–	737	720	739	802	758
Collector temperature drop, °C	–	149	132	126	200	170
Power input, watts	282	220	202	226	292	257
Overall efficiency, %	11.5	6.7	6.1	7.8	9.9	6.6

*The collector temperature of these runs was too high (1.75 times the reservoir temperature instead of 1.60).

Figure 38 shows the cesium conduction data obtained from prototype T-205, compared with that from prototypes T-203B and T-204. The data for T-205 was corrected so as to correspond to an effective heat transfer area of 3.50 sq cm. As can be seen, it indicates that the interelectrode spacing of converter T-205 was of the order of 2.60 mils, as compared with the design value of 4.20 mils. The reason for the difference between the measured and calculated values of spacing could be that the interelectrode spacing of converter T-205 was greater than 2.60 mils, somewhere between 2.60 and 4.20 mils, and therefore the effective area for cesium heat transfer may have been greater than 3.50 sq. cm.

The calculation of the temperature drop between the hohlraum and the emitter surface of the converter was calculated as follows: For the solid rhenium emitter, the distance from the hohlraum to the emitter face is approximately 0.045 in. or 0.114 cm. The converter heat transfer is approximately* (34.6 + 1.09 I) watts/cm^2 in the vicinity of 2000°K emitter temperature. At 2000°K, the thermal conductivity of rhenium is** 0.48 watt/cm-°K. The calculated emitter temperature drop for the solid rhenium emitter was then

$$\Delta T = \frac{q \times 0.114}{0.48} = 10 + 0.25\, I, \ ^\circ C$$

where I is the output current of the converter in amperes. The above expression gave just about the temperature drop previously observed in pressure-bonded structures of tantalum and rhenium.

---

*$q = q_{radiation} + q_{cs} + q_e = 33.5 + 1.1 + (2.72/2.50)\, I$

**"Thermal Conductivity of Ta, W, Re, Ta-10W, T-111, T-222, W-25 Re in the Temperature Range 1500°K - 2800°K," by C.K. Gun and M. Koch, University of Cincinnati, Cincinnati, Ohio.

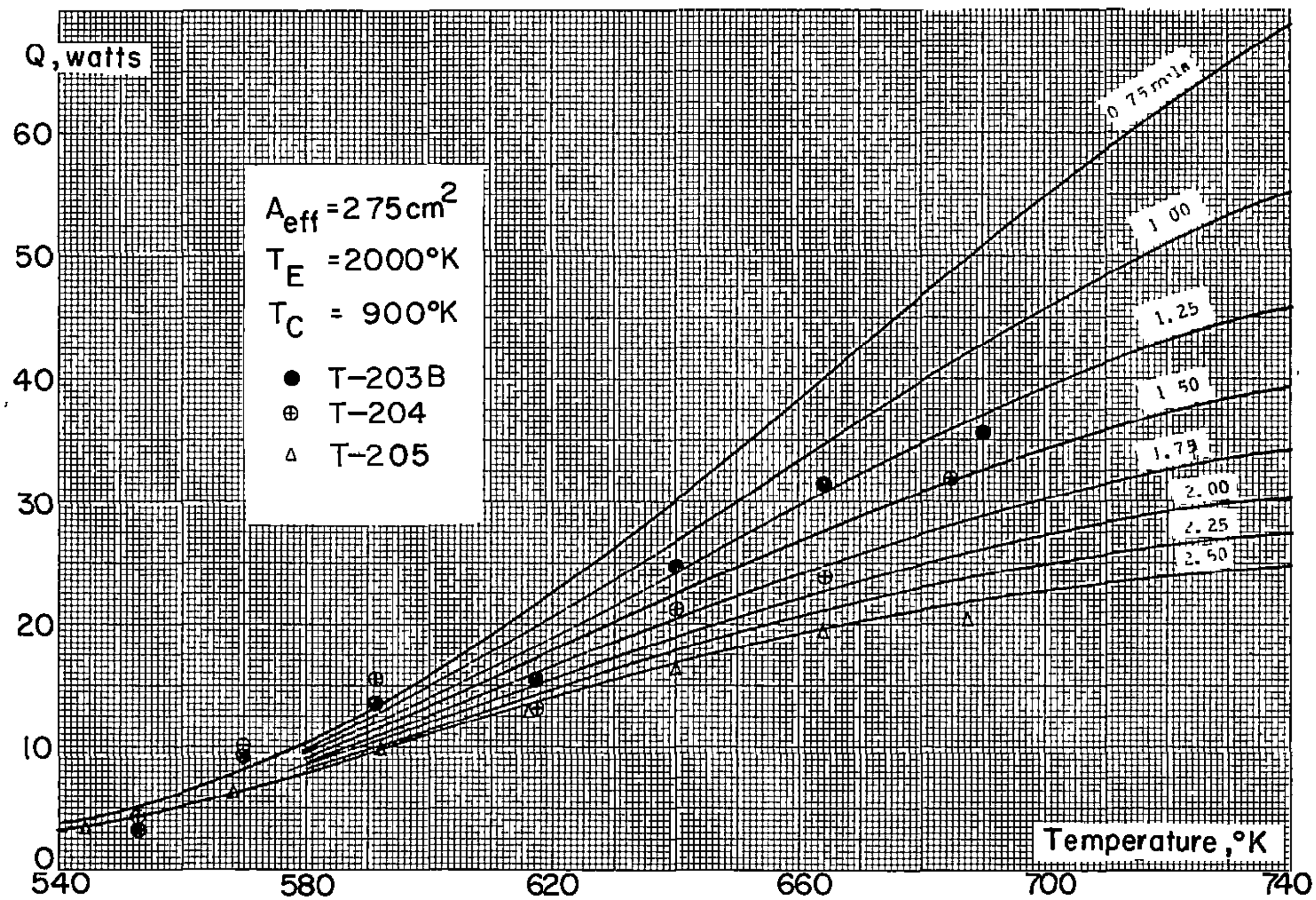
Q, watts
60
50
40
30
20
10
0
540
580
620
660
700
740
Temperature, °K
A_{eff} = 275 cm^2
T_E = 2000°K
T_C = 900°K
T-203B
T-204
T-205
0.75 mils
1.00
1.25
1.50
1.75
2.00
2.25
2.50

Figure 38.

6.1 Design of Converter T-206

The design of converter T-206, shown in Figure 39, involved several modifications to that of converter T-205, aimed at reducing the collector temperature. The collector barrel was shortened by 0.030 in., and the transition piece, part No. 10, joining the collector barrel to the radiator fins, was thickened by 0.070 in. To accommodate these two changes, part No. 5 was made shorter by 0 020 in Furthermore, the area of the radiator fins was increased by adding 0 3 in. to their length, which yielded a total radiator area of 133 sq cm, and the fins were coated with chromium oxide Finally, the design included a new cesium reservoir, partially coated with chromium oxide, capable of increased radiation heat loss and, therefore, lower operating temperatures Because of the capability of the reservoir to dissipate more heat, the cesium tube, part No. 14, was changed to stock dimensions and therefore no longer required thinning down of the wall over a portion of its length.

To demonstrate the ability of the design changes to effect a suitable reduction in collector temperature before proceeding with the fabrication of converter T-206, it was decided to fabricate and test a new collector-radiator structure that would reflect all the design features proposed for converter T-206

6.2 Fabrication of the Collector-Radiator Model

Figure 40 shows the assembled collector-radiator model. The unit was instrumented with a brazed thermocouple 0 080 in underneath the collector face, two thermocouples at the root of one fin, one thermocouple at the end of another fin, and one thermocouple on

7514

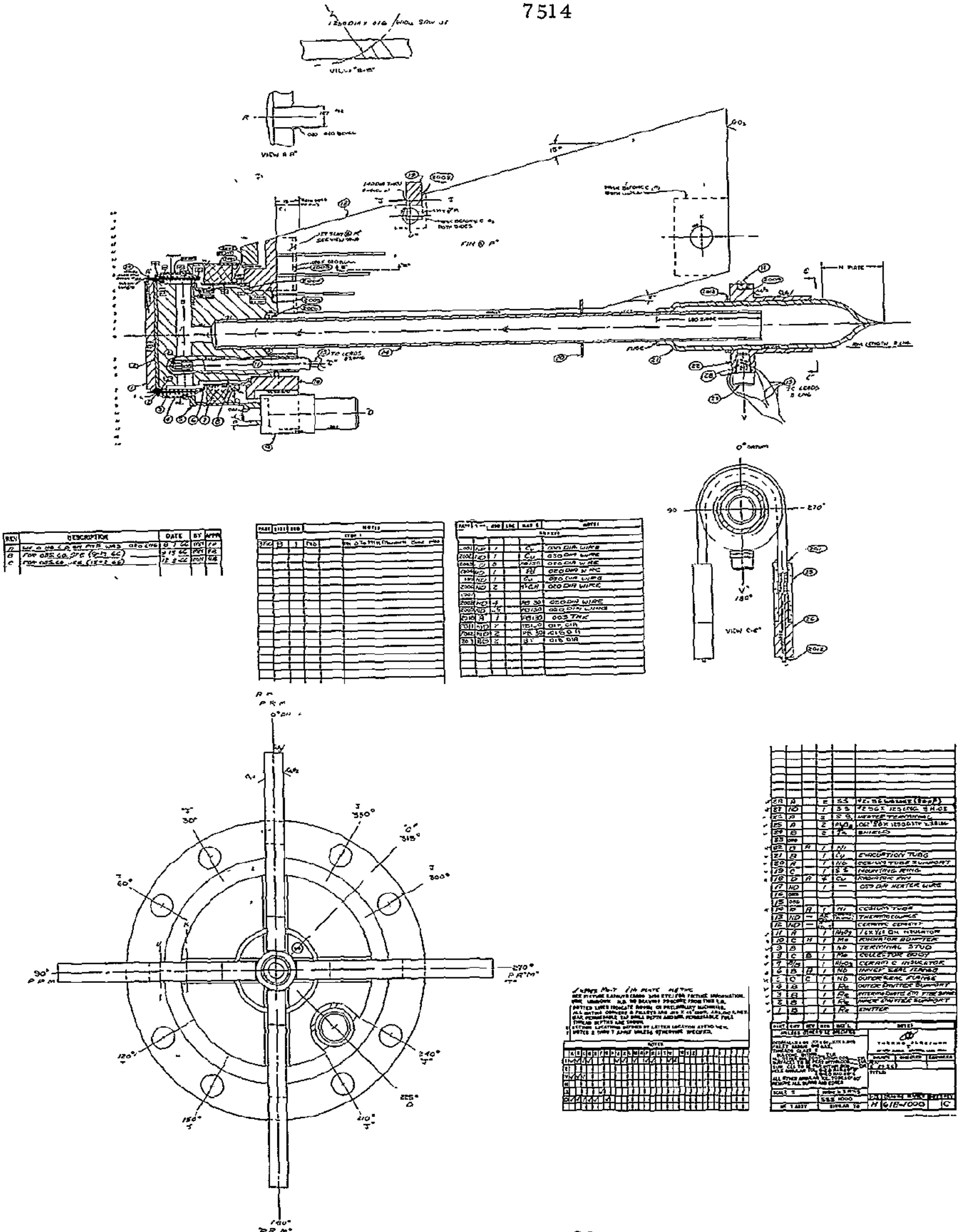

Figure 39.

the cesium reservoir. No heater was brazed to the cesium reservoir In order to ensure good contact between the radiator fins and the molybdenum base into which they were brazed, the fin braze was performed so that braze material could be added before the second braze operation. The resulting assembly showed one defect: The space between the inner seal flange, part No. 6, and the collector body, part No. 8, was partially filled with copper braze material that overflowed from the braze between the radiator adapter, part No. 10, and the collector body. Although the amount of braze was much too small to have caused any significant error in the heat transfer data, it could cause the failure of the ceramic seal in a fully assembled converter because it defeats the expansion isolation function of the seal flange. The possibility of this occurrence during converter fabrication can be minimized by reducing the amount of braze material used between the collector body and the radiator adapter.

6 3 Test of the Collector-Radiator Model

The Collector-Radiator #2 data is presented in Appendix 9. It gives the temperature measurements obtained on the collector-radiator model at various heat inputs, and the measurements are interpreted in Figure 41 The first step in the test procedure was to obtain the temperature distribution caused by filament heating alone, so that the magnitude of this heat input could be ascertained. The initial set of readings was obtained for a filament current of 17 5 amperes, which proved to be too low For that reason, this measurement was repeated at the end of testing for a filament current of 22 8 amperes. The remainder of the test consisted of measuring the temperature distribution achieved at these discrete

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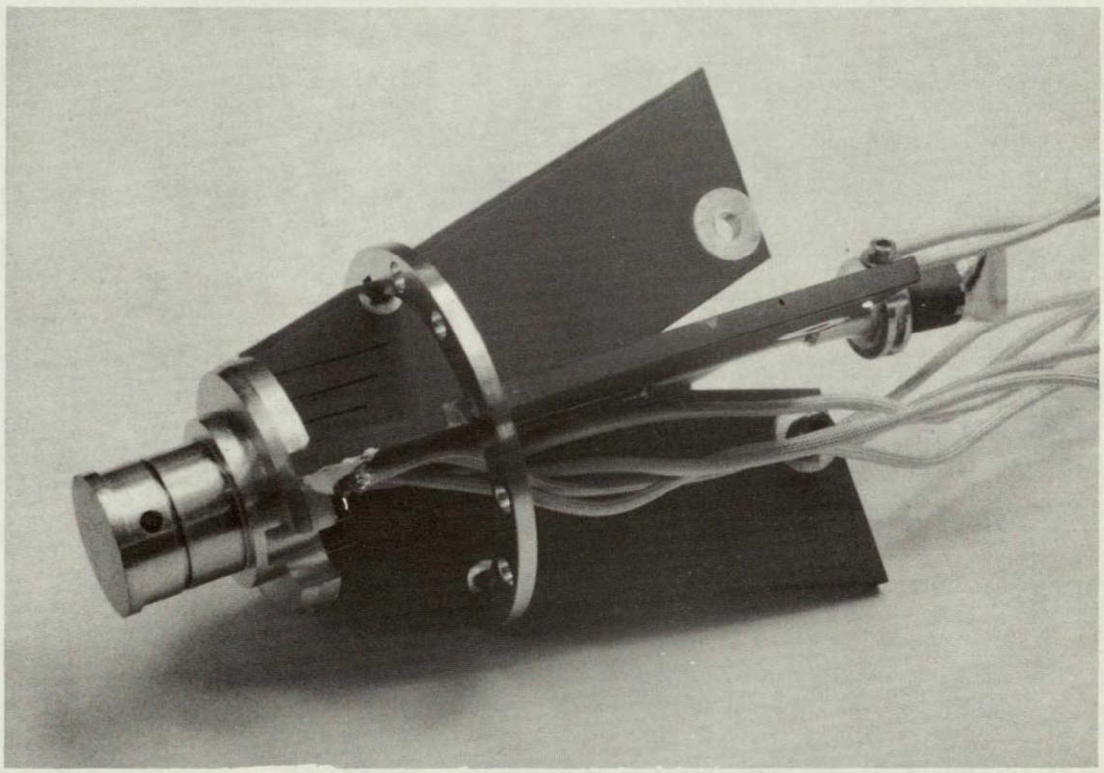

Figure 40.

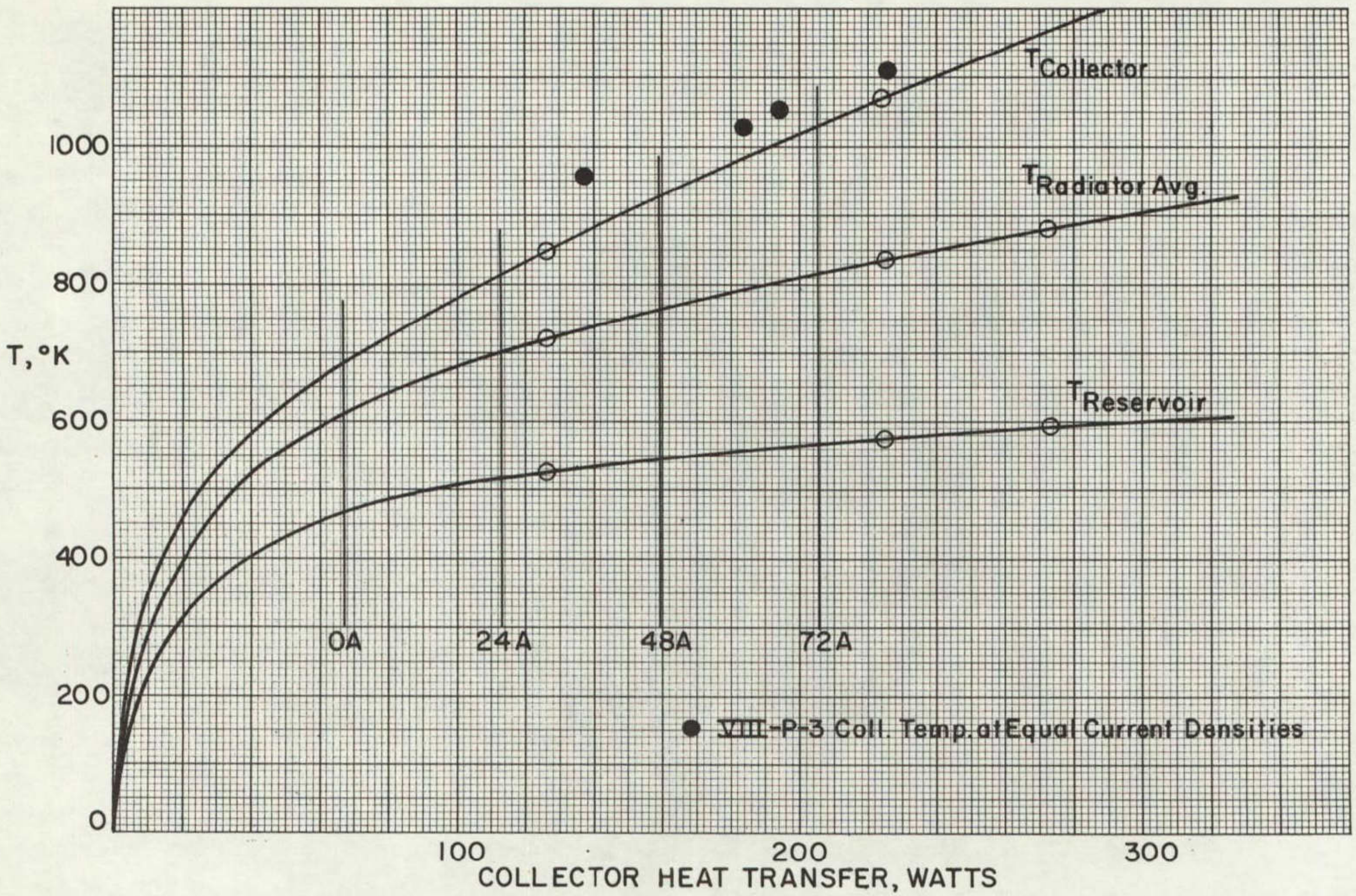
T, °K
0
200
400
600
800
1000
100
200
300
COLLECTOR HEAT TRANSFER, WATTS
$T_{Collector}$
$T_{Radiator\ Avg.}$
$T_{Reservoir}$
0A
24A
48A
72A
VIII-P-3 Coll. Temp. at Equal Current Densities

Figure 41.

and carefully controlled values of electron-bombardment heat input. To avoid transient effects, the heat input was maintained constant at least 45 minutes before each reading of temperatures. The collector face was exposed to an electron-bombardment structure that operated at a temperature very closely equal to the collector temperature, so that the collector face was in radiation heat transfer equilibrium with the bombardment structure (excluding the filament), and its radiation heat losses could be neglected. From a comparison of the average radiator temperature achieved with filament heating alone with that achieved with filament heating plus electron bombardment, it is shown in Appendix 9 that at 22.8 amperes of filament current, the filament heat input was 29.2 watts. Assuming that this input was proportional to the product of filament voltage and current, the following tabulation summarizes the heat transfer conditions obtained:

Data Point No.	2	3	4
Collector temperature, °K	843	1073	–
$V_F \times I_F$, watts	104	113	119
Filament heat into collector, watts	25.5	27.8	29.2
Electron bombardment power, watts	100.7	197.0	244.0
Total power input, watts	126.2	224.8	273.2
Average radiator temperature, °C	446	560	604
°K	719	833	877
Reservoir temperature, °K	525	569	587

Figure 41 shows the plots of collector temperature, average radiator temperature and cesium reservoir temperature vs collector heat transfer. As can be seen, no data was recorded for collector temperature at the highest value of heat transfer. This is because the temperature reading at the thermocouple decreased abruptly as the heat input was raised between data points 3 and 4. Examination of the collector-radiator structure at the end of testing revealed that the collector thermocouple braze connection had melted and the thermocouple was no longer bonded to the place of measurement on the collector; therefore, its readings were inaccurate after loss of bond. The temperature at which loss of bond occurred, that is, above 800°C, was consistent with the softening point of the braze material used, T50, which is 779°C. High-melting-point braze materials were not used because they may dissolve the chromel alumel thermocouple material or alter its emf characteristics.

6.4 Discussion of Collector-Radiator Model Test Results

In order to interpret the collector-radiator model test results, it was necessary to calculate the output current values that correspond to various values of collector heat transfer. This was done using the following assumptions, which are documented in Appendix 9:

Cesium conduction loss	16.0 watts
Interelectrode radiation	34.4 watts
Additional internal radiation	2.0 watts

Furthermore, it was assumed that the emitter support radiates 15 watts to the collector body (out of its total loss of 58 watts, see Appendix III of the Task II Final Report, JPL 950671), and that this heat input all takes place at the collector face (a conservative assumption). Electron cooling losses were assumed to equal 2.72 watts/ampere, which, at output voltages of the order of 0.8 volt, corresponds to a collector electron heating of 1.92 watts/ampere. Adding these heat quantities,

Output current, amperes	Collector heat transfer, watts
0	67.4
24	113.4
48	159.4
72	205.4

The additional heat input to the radiator by conduction through the seal was assumed to be exactly offset by the cooling effect of the output leads. The collector-radiator model incorporated neither a heat-conducting seal nor output leads, and therefore its radiator heat transfer was expected to have simulated that of an operating converter quite closely.

Figure 41 includes lines which correspond to the heat transfer values at 0, 24, 48 and 72 amperes of output current. As can be seen, collector and reservoir temperatures of 1030°K and 565°K, respectively, corresponded to the highest output current value of 72 amperes. To ascertain that satisfactory converter operation could be achieved with these values of temperature, the temperatures were compared with those observed in converter VIII-P-3 of JPL 950671, Task I, which were believed to be representative of a well-optimized design. Since this converter had 20% less emitter area, the output current value corresponding to 72 amperes was 57.6 amperes. All available data showed that VIII-P-3 reached this output at an optimum reservoir temperature exceeding 317°C, i.e., 590°K. The observed reservoir temperature of 565°K in the collector-radiator model was therefore low enough to allow ample opportunity to optimize reservoir temperature with the electrical heater on the reservoir. The original data on converter VIII-P-3 also showed that at an output current of about 57.6 amperes the collector temperature, without collector heating, stabilized to the following values:

Data Sheet	Data Point	I_o, amperes	T_{coll}, °C	T_o, °C	P_{eb}, watts
11	10	56.0	809	1677	385
14	3	62.0	838	1677	400
21	8	57.5	823	1700	420
23	8	68.5	861	1700	430

The converter was then handled to install thermocouples on the seal and the emitter output lead, and the following data was obtained:

Data Sheet	Data Point	I_o, amperes	T_{coll}, °C	T_o, °C	P_{eb}, watts
29	5	55.0	759	1700	410
30	7	55.5	767	1700	410

This last data shows that a substantial drop in collector temperature (of the order of 50°C) had occurred, and it was suspected that the bond of the collector thermocouple of VIII-P-3 must have failed in a manner similar to that of the collector-radiator model. This was likely because the same braze material was used in both devices. The test data at JPL offered further evidence of such a failure because the 1700°C data showed that, at an output of 54.0 amperes and with a power input of 350 watts, the observed collector temperature was only 700°C. Thus it seemed reasonable to conclude that the collector temperature of VIII-P-3 for the output of 57.6 amperes was in excess of 809°C or 1082°K. Then the collector temperature of 1030°K achieved by the collector-radiator model at the equivalent output current of 72 amperes was more than 50°C below the desired value, and consequently the design of the new collector-radiator structure was considered adequate for converter T-206.

6.5 Fabrication of Converter T-206

The fabrication of converter T-206 was preceded by three concurrent development efforts which were the improvement of the niobium rhenium joint in the rhenium emitter structure, the evaluation of brazing procedures for the radiator fins, and the fabrication of electron beam welded rhenium tubing.

One of the difficult joints to perform in the fabrication of T-200 converters was that of the re-entrant rhenium emitter structure to the niobium seal flange. This joint was achieved by a low-penetration electron-beam melting of the niobium around the rhenium. The joint was difficult to make because it is critically important to avoid melting the rhenium. Otherwise a brittle intermetallic results, and the structure will not be leaktight. To avoid these problems, the use of vanadium brazing was evaluated for the joint. Figure 42 shows the braze obtained with an 0.015"-dia wire. Tear tests on the joint showed that the joint is sound and that both the rhenium and the niobium remain ductile. This technique was therefore adapted for the fabrication of T-206.

Another weak area found in previous T-200 converters was the braze of the copper fins to the molybdenum radiator adaptor. The weakness lies in that quite often the amount of braze material used, a nickel-gold eutectic alloy, is not sufficient to establish a metallurgical bond over the entire contact area available between the copper and molybdenum pieces. If more braze material is used, experience had shown that an overflow of braze alloy occurs at undesired locations without necessarily improving the copper-molybdenum bond obtained. Thus it appeared that the only method available to improve this bond was to subject the assembly to a repeat braze with either the same or a different braze alloy. A different braze alloy offered the potential advantage that it might have a lower melting point, and therefore permit lowering the temperature to which the assembly had to be heated in the second braze operation, so that a more reliable fabrication could be achieved. It was necessary, however, for this second braze alloy to possess good flow characteristics; otherwise a good thermal bond would not be obtained in those areas where addition of braze material is attempted. Figure 43 shows the results of a test conducted to compare the strength of the bond obtained using the conventional nickel-gold eutectic with that obtained with an alloy containing 10% palladium, 58% silver, and 32% copper. This alloy was commercially available under the trade name Engaloy 491, and it has a solidus-liquidus temperature range of 825 to 852°C. In the test one pair of diametrically opposed fins were brazed with nickel-gold eutectic, and a second pair was brazed in a second braze with Engaloy 491. After the unit was completed it was visually inspected, and it appeared that the Engaloy 491 had not wetted the molybdenum as well as the nickel-gold eutectic. A subsequent mechanical-pull test showed, as shown on the left of Figure 43, that Engaloy does not adhere to molybdenum. One of the fins brazed with the nickel-gold eutectic was pulled, and the assembly broke right through the molybdenum bulk in preference to separating at the brazed interface as shown on the right in Figure 43.

Finally, an in-house effort for the fabrication of electron beam welded rhenium tubing was conducted because the supplier of rhenium tubing, the rhenium division of the Chase Brass Company, had relocated from Waterbury, Connecticut, to Solon, Ohio, and as a result of this relocation, the Chase Brass Company was no longer in a position to

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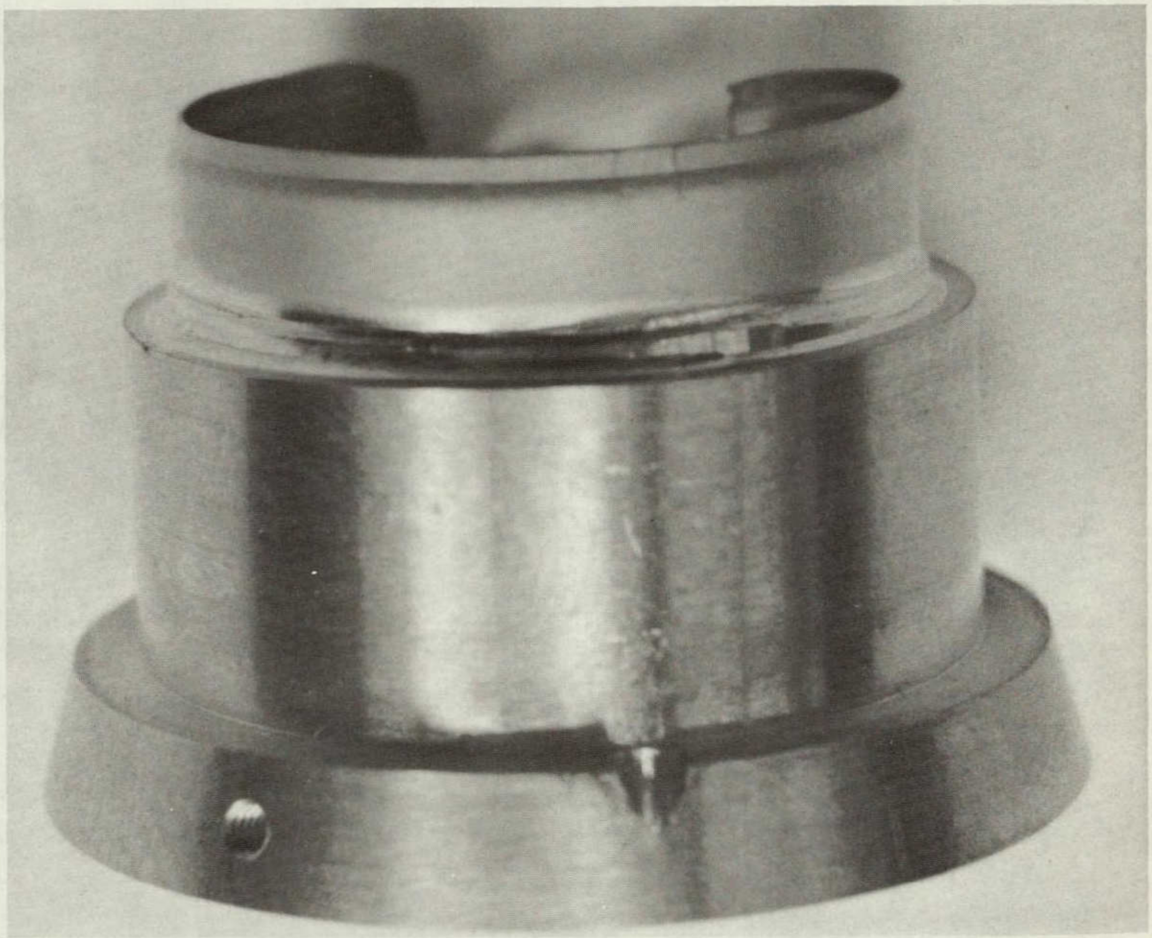

Figure 42.

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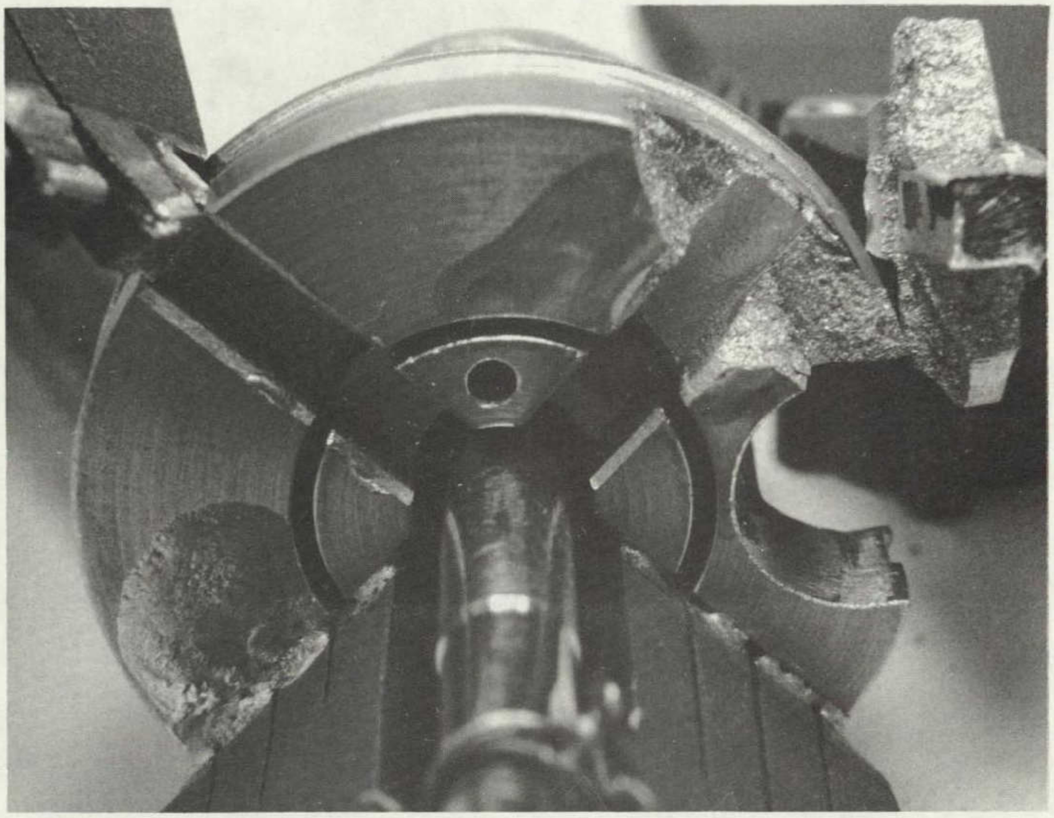

Figure 43.

fabricate rhenium tubing to custom dimensions. An insufficient amount of rhenium tubing was on hand to fabricate the last five prototypes under this program, and the in-house fabrication of rhenium tubing had to be pursued very actively. Also, the available rhenium tubing was often of marginal quality and in a few instances had developed leaks in the region of the seam weld. Figure 44 shows one such sleeve, where it may be observed that the arc-welded seam is not uniformly melted on both sides of the seam. The material on only one side has been melted, and then it has resolidified against the unmelted abutting edge at the seam. Although the resulting weld is leak-tight, work under other programs at Thermo Electron had shown that the weld can fail after a few thermal cycles to normal operating conditions.

The effort to fabricate rhenium tubing consisted of ordering flat rhenium stock 0.020" thick, cutting it to the necessary dimensions, rolling it and electron-beam welding it. Both the rolling and electron-beam welding operations were performed by outside vendors. Figure 45 shows the three sizes required for prototype fabrication after the beam-welding operation. The tubes were then ground to final dimensions.

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

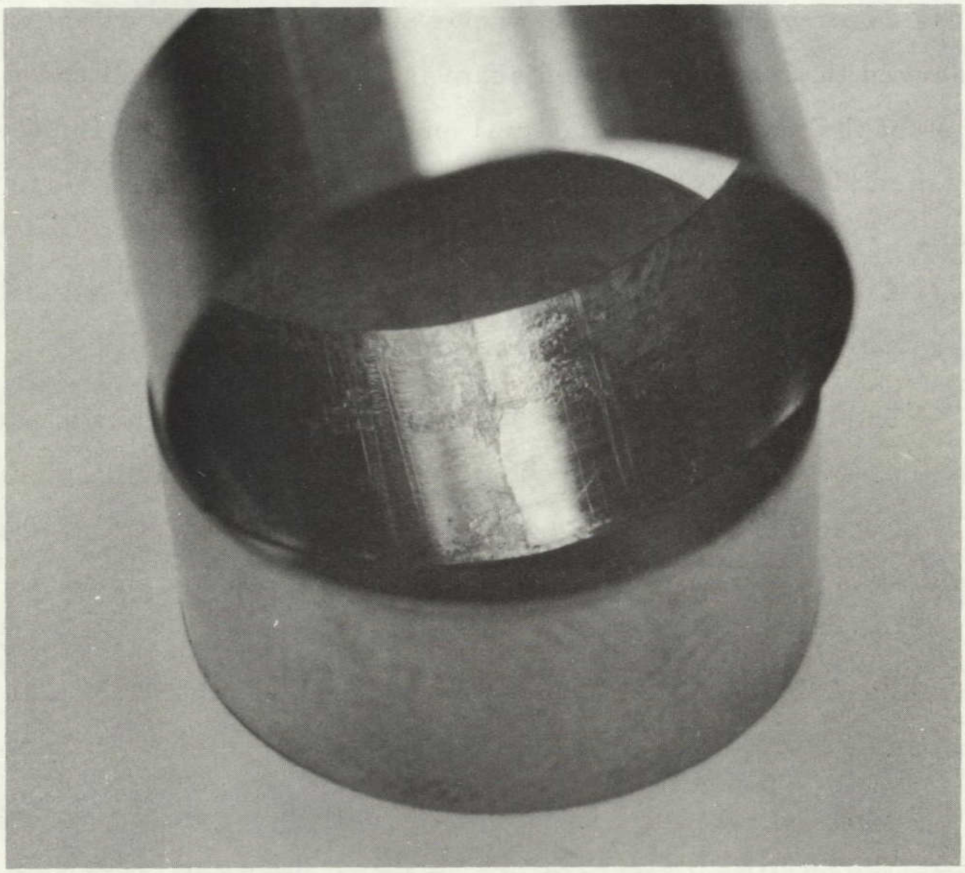

Figure 44.

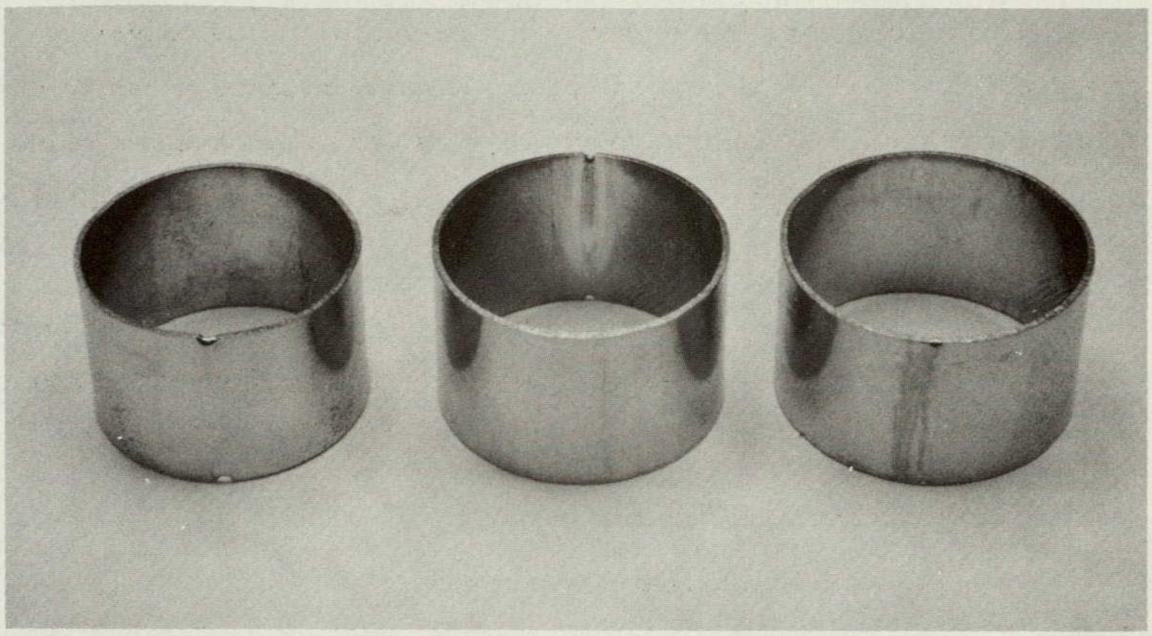

Figure 45.

structure within 2.7 minutes of arc. These tolerances were 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 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 46 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.

6.6 Testing of Converter T-206

a. Electron Bombardment Structure:

Converter T-206 was tested with three different types of electron-bombardment filaments. All of the data presented in Appendix 10 except for the last two data points on sheet 5 was obtained using the regular S-type filament shown in Figure 47. The last two data points on sheet 5 were obtained with the circular filament shown in Figure 48, and the data presented in Run No. 8 was collected using the U-type filament shown in Figure 49.

The reason for the use of these different heat sources is that one of the persistent difficulties in the T-200 experimental program had been the lack of agreement between the TECO and the JPL data. After considerable effort at checking the instrumentation, 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 was different from that used at Thermo Electron in that it used 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 have been expected to cause significant variations in the data, the T-200 converter design was thought to be more susceptible to performance discrepancies because of its thinner emitter structure. With a thin emitter structure, the actual temperature distribution over the emitter surface and the brightness of the hohlraum could depend to a greater extent on the energy and distribution of the bombarding electrons on the heated side.

The experiment performed with the three types of filaments confirmed that differences in performance can be observed with different electron-bombardment sources. The two data points with the circular filament, #9 and #10 given in sheet 5, were selected to attempt reproducing the data point #5 of sheet 4, obtained with the S-filament. 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

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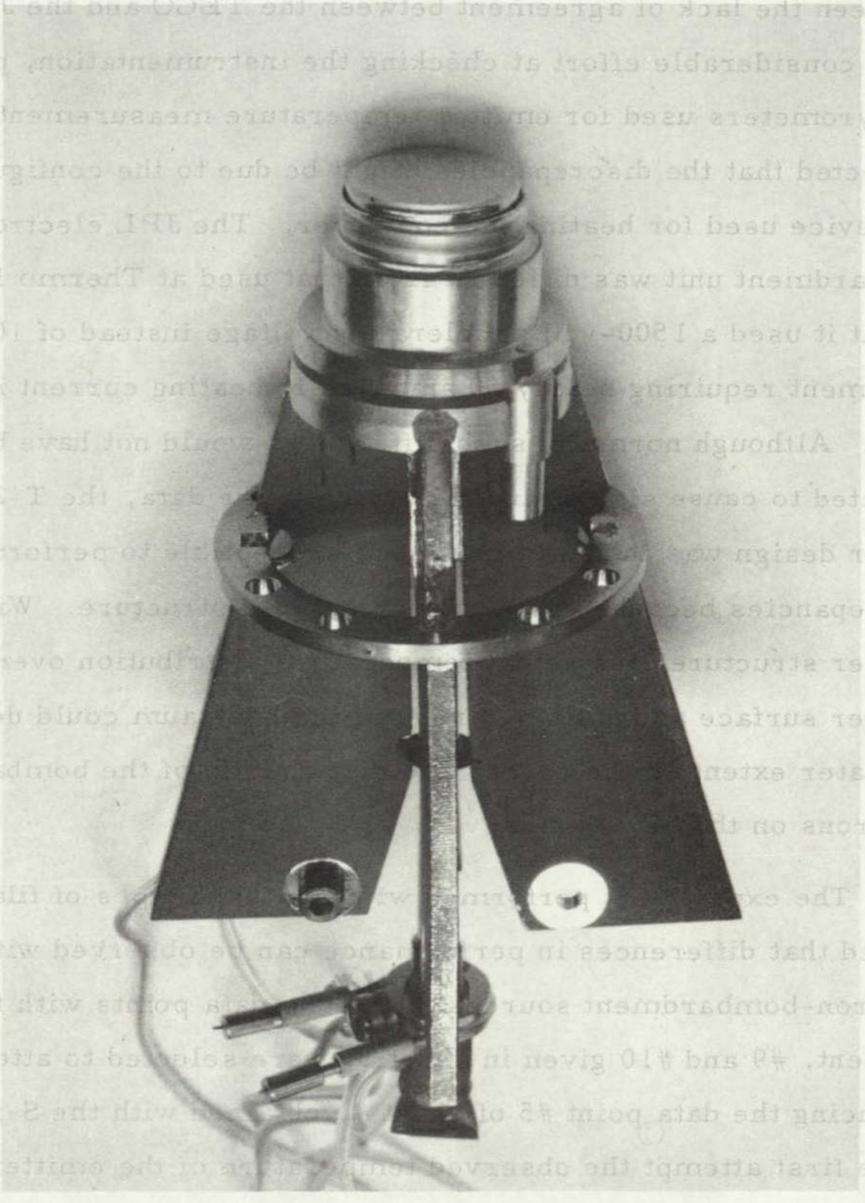

Figure 46.

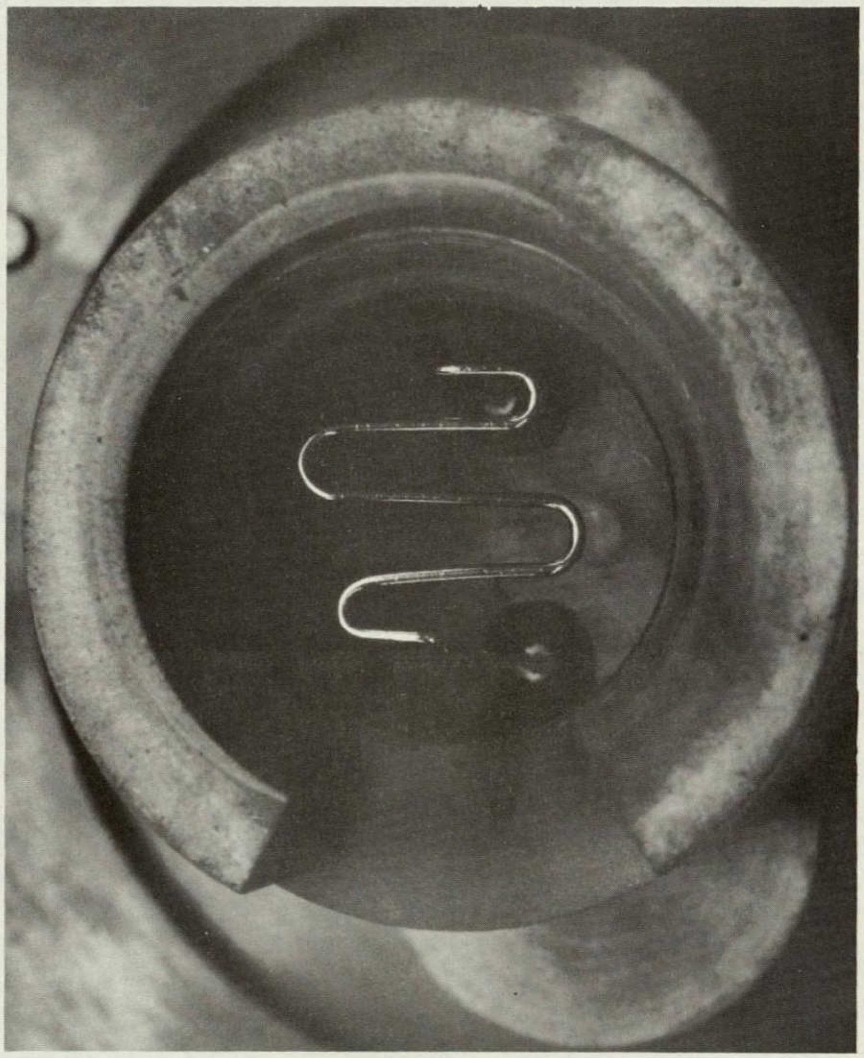

Figure 47.

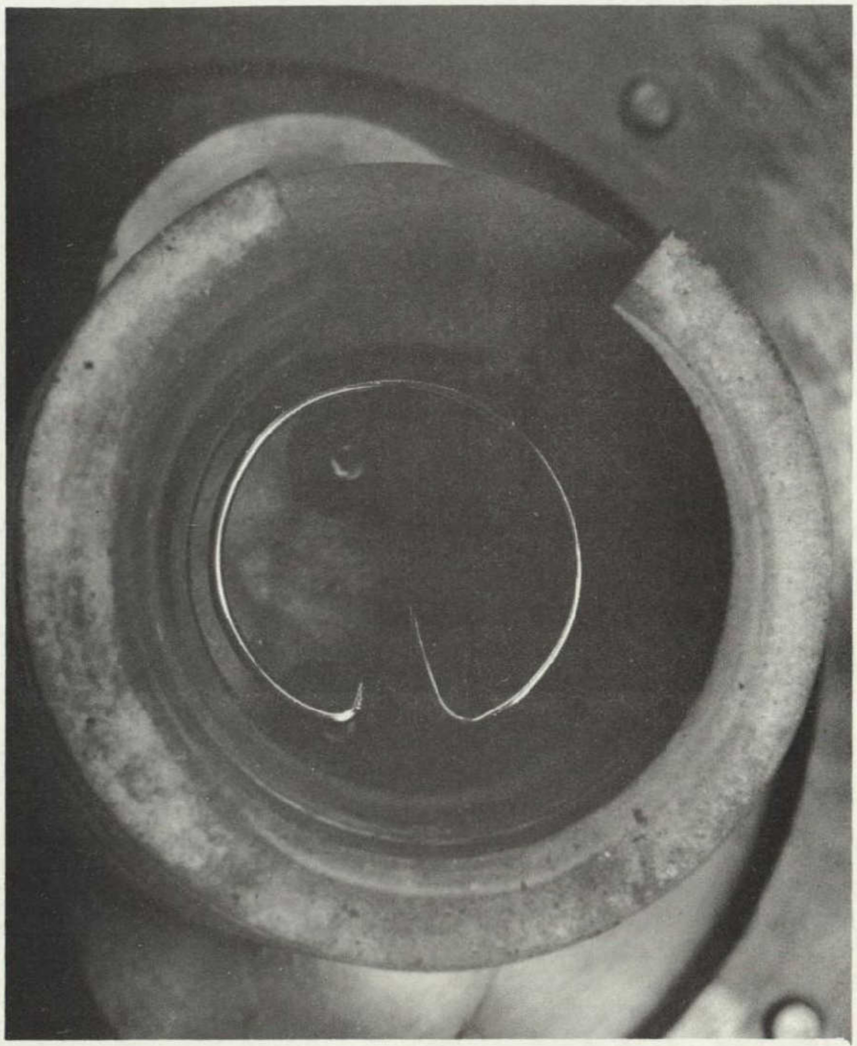

Figure 48.

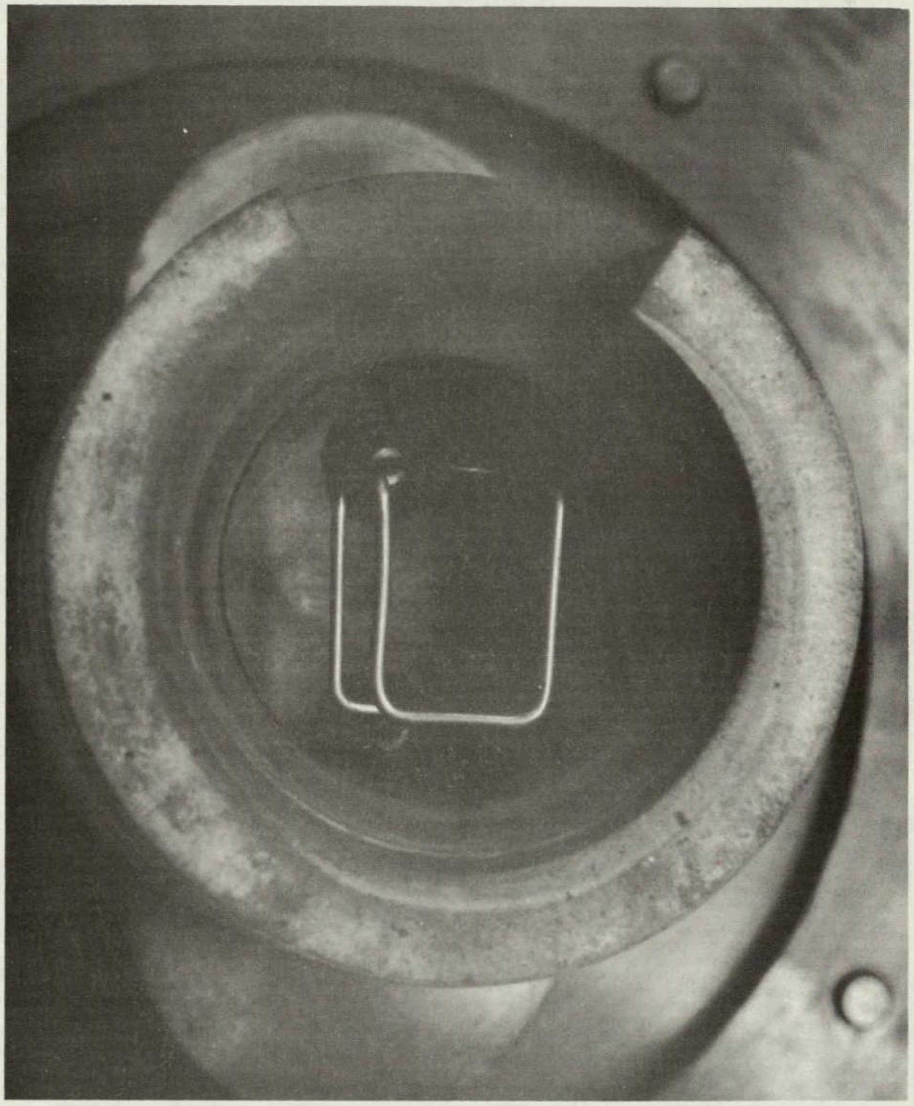

Figure 49.

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.

The U-type filament was designed to avoid electron bombardment of any portion of the emitter structure close to the hohlraum. The electron-bombardment filament projections onto the emitter structure were approximately 0.160 in. from the hohlraum. The data sheet for Run No. 8 shows the results obtained with the filament. The tests conducted with this filament were intended to reproduce two conditions in particular: The outputs at 1 volt and 0.8 volt with electron-bombardment power inputs of 292.4 and 344.8 watts, respectively, observed with the S-filament. Sheet 4 of the data gives recorded output currents of 23.3 and 41.2 amperes, respectively. With the U-type filament, the values obtained were 21.6 and 40.9 amperes, and the observed emitter temperatures were 15°C higher. The higher emitter temperature readings obtained with the U-filament were surprising because avoiding bombardment of the hohlraum was expected to reduce hohlraum temperature. It was felt that the discrepancy of 7% observed at 1 volt could be due to experimental error because of the output sensitivity to power input in the 1-volt region, and that the results tended to confirm, in general, that the observed emitter temperature is affected by the type of electron-bombardment filament used, and that the converter output observed is a sole function of the electron-bombardment power input.

Since the results obtained with the S- and U-type filaments were in close agreement, and since an S-type filament had been used for all previous tests and was capable of more uniform heating of the emitter face, it was recommended to JPL that the use of the S-type filament be continued for all further converter tests.

b. Thermal Performance of Collector-Radiator Structure:

Another aspect of the T-206 converter test was the comparison of the thermal performance of its collector-radiator structure with that of the model described under paragraph 6.4.

Figure 41 gives the thermal performance observed in the collector-radiator model, and the vertical lines superimposed on the performance curves identify the collector heat transfer values that were predicted at the labeled values of converter output current. Thus the data of this figure can be tabulated as follows:

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

and solid-line curves for these values are plotted in Figure 50. 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 temperatures somewhat higher than predicted 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 had 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 was 684-612 = 72°K at a heat transfer value of 67.4 watts, according to the solid curves of Figure 41. The value which was actually measured in converter T-206 is given by data point 1 of sheet 4: 525-412 = 113°C. To a first approximation, then, the actual collector heat transfer at zero current was 67.4 x 113/72 = 105.7 watts, or 38.3 watts more than expected. This value agreed well with the observed shift corresponding to approximately 40 watts. Furthermore, the heat transfer ratio 105.7/67.4 had to be approximately equal to the fourth power of the ratio of observed to predicted average radiator temperatures. These were 412 + 273 = 685°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 compared very well with the value of 1.569 for the ratio 105.7/67.4.

In conclusion, then, it was demonstrated that the collector heat transfer in converter T-206 had been underestimated by 38.3 watts, resulting in collector temperatures higher by 120°C than predicted, and which were higher than the VIII-P-3 collector temperatures, shown in Figure 50, by approximately 65°C.

One of the causes for this discrepancy was the increase in interelectrode heat transfer due to the use of a rhenium instead of molybdenum collector. The previous calculation of interelectrode radiation

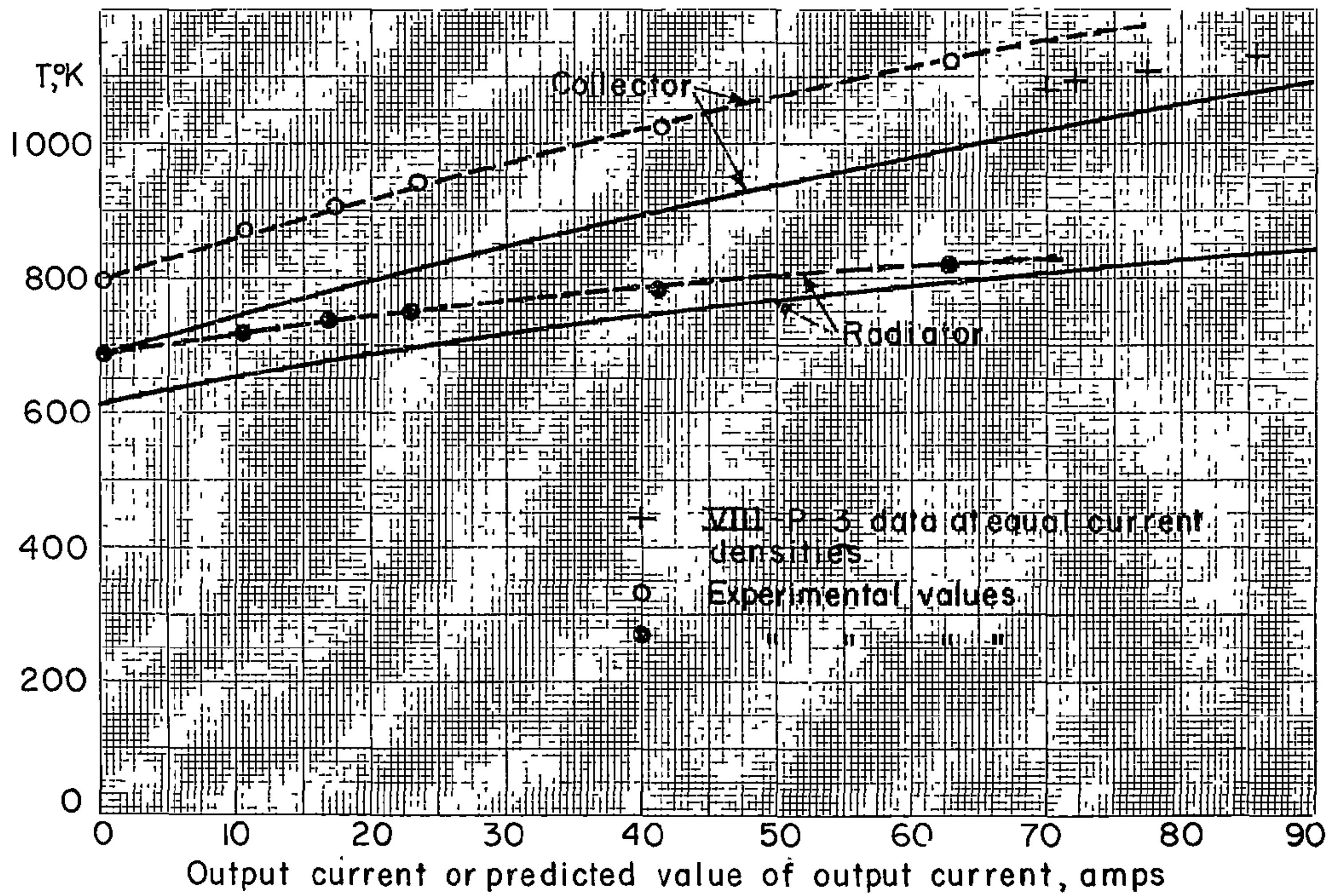

Figure 50.

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had been based on the assumption of emitter and collector emissivities of 0.28 at corresponding temperatures of 2000°K and 1040°K, and had yielded a value of 34.4 watts. The collector emissivity value 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 $\sqrt{2000 \times 1040} = 1450$°K is approximately 0.15 The assumed value allowed then for an addition of 0.13 to the theoretical value. Figure 51 gives the emittance data for rhenium 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 of 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 rhenium. Using these values, the interelectrode radiation calculated at emitter and collector temperatures of 2000°K and 1040°K was (90.86 - 6.64)/ (1/0 35 + 1/0.374 - 1) = 18.6 watts/cm^2. For an emitter area of 2.5 cm^2, the loss is then 46.5 watts, which was 12.1 watts larger than the value previously assumed. The remainder of the difference in collector heat transfer could not be accounted for by simple additional corrections to the basic converter heat transfer model.

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

	T-205		T-206	
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

It was obvious from this table 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 achieved 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 50 showed that these improvements were insufficient.

c. Converter Thermal Performance:

Since doubts existed about the accuracy of the emitter temperature measurements, it was also of interest to compare the optimized characteristics of all the converters tested, 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 52 and 53 gave this information for the T-100 series of converters at 0.8 volt and 1.0 volt, respectively Figures 54 and 55 are corresponding figures for the T-200 series of converters It was seen, on the basis of these figures, that the best T-100 converter was converter T-103, and the best T-200

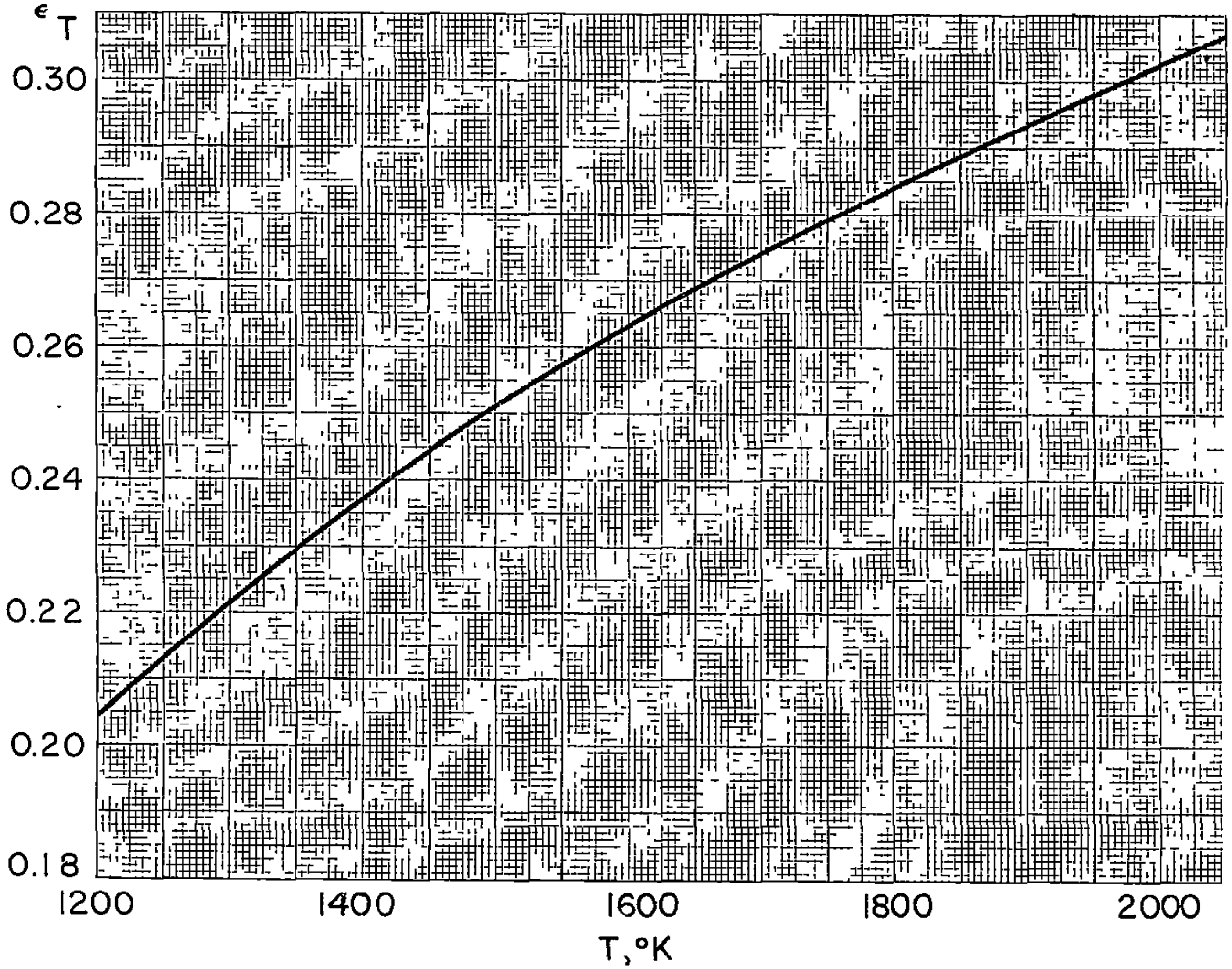

Figure 51.

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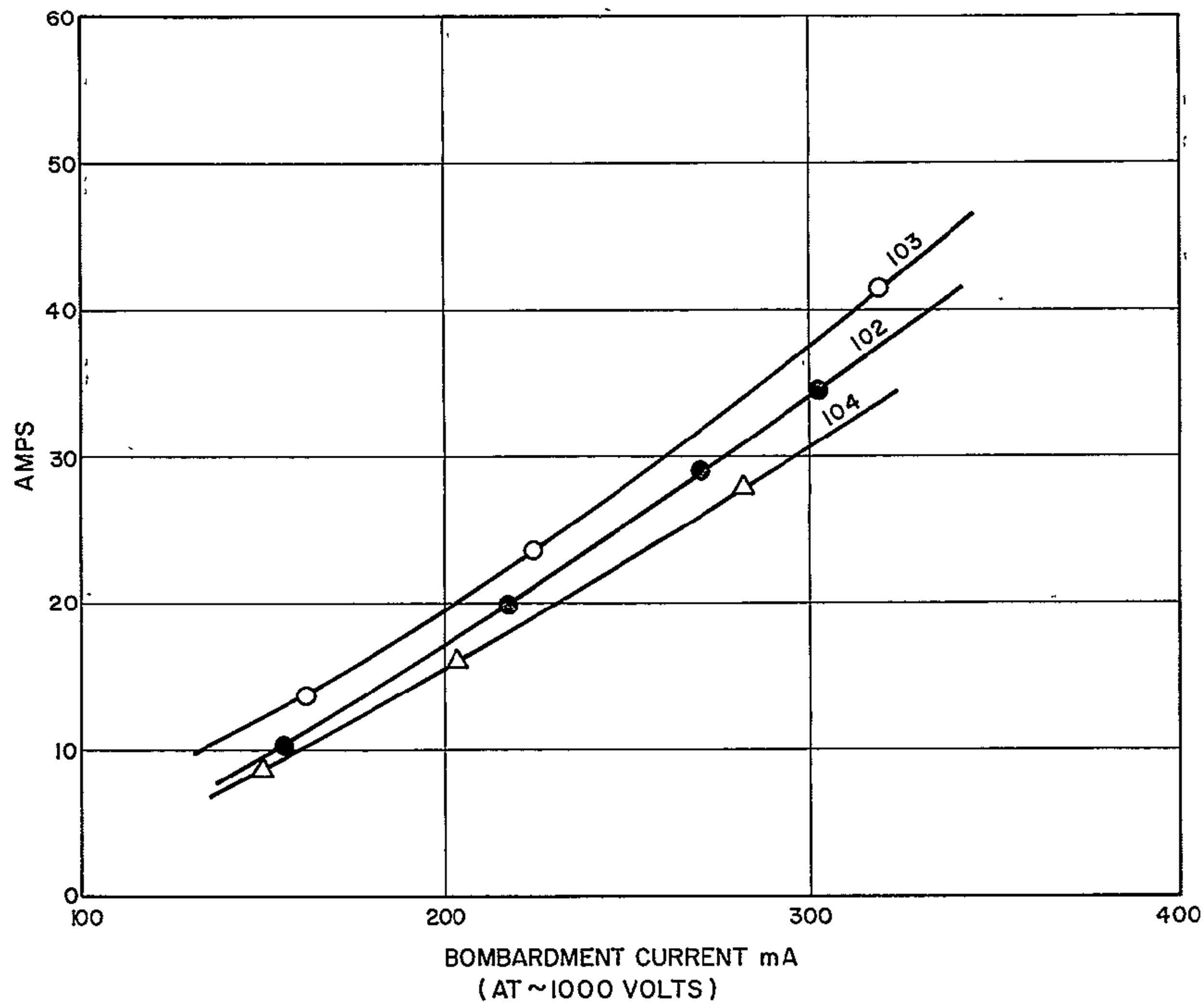

Figure 52.

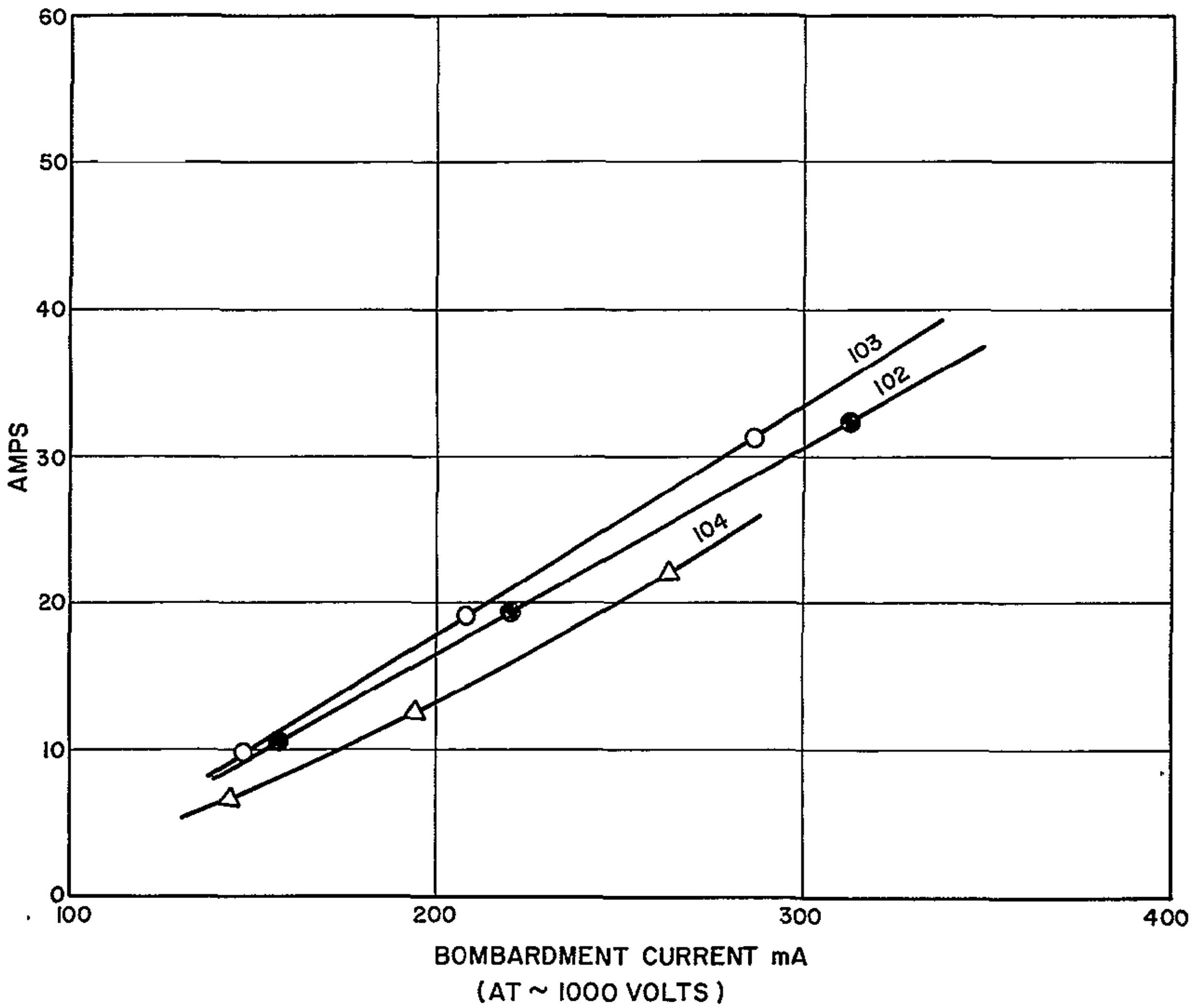
60
50
40
30
20
10
0
AMPS
100
200
300
400
BOMBARDMENT CURRENT mA
(AT ~ 1000 VOLTS)
103
102
104

Figure 53.

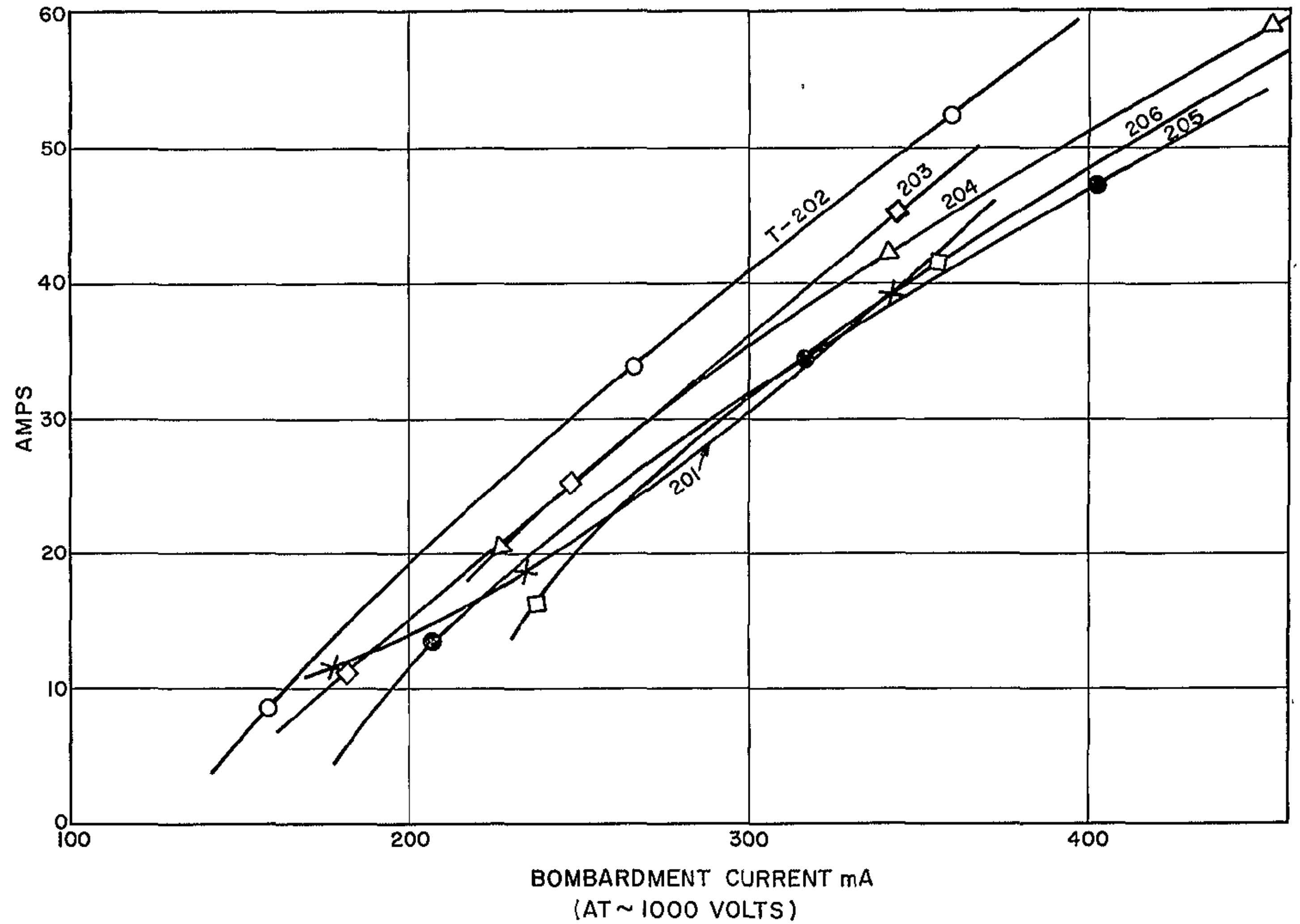
AMPS
60
50
40
30
20
10
0
100
200
300
400
T-202
203
204
206
205
201
BOMBARDMENT CURRENT mA
(AT ~ 1000 VOLTS)

Figure 54.

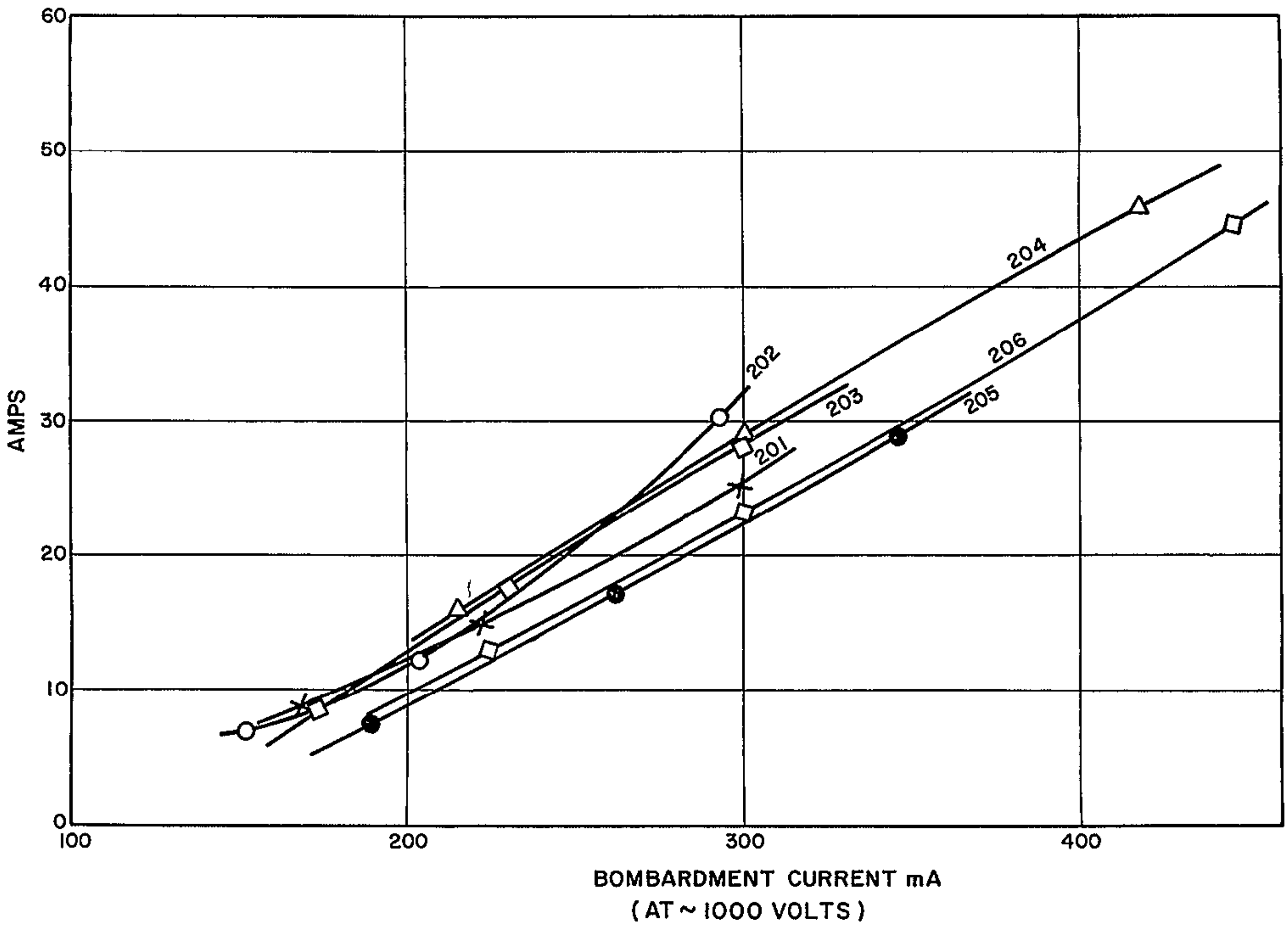

Figure 55.

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converter was T-202 with the exception of the low temperature range. Converters T-205 and T-206 were among the poorest, T-205 because of its lower output, and T-206 because of its higher heat losses. It was 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 have affected the efficiency, and because it had the tantalum emitter support structure which has lower radiation and conduction losses. Since this emitter structure could not be used without the use of pressure-bonding, which was considered unreliable for long life, the best converter choice available was converter T-204, which was the same as converter T-206 except that it had a molybdenum collector.

In summary, then, the changes required to reduce the T-200 converter to a fully qualified item of hardware 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 had 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 had 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 had made it necessary to use a longer emitter support and collector barrel, and as a result severe heat transfer problems were encountered in the collector, which prevented the achievement of optimum collector temperatures. A solution to this problem could probably only be found with the application of heat pipe structures to dissipate collector heat. The use of an integral rhenium emitter had been adopted to avoid pressure-bonding and its attendant problems due to diffusion at the bonded boundary: formation of brittle intermetallics and Kierkendall porosity. The disadvantage of the integral rhenium emitter was that it increased external radiation losses in proportion to the ratio of the emissivities of rhenium and tantalum at 2000°K: 0.302/0.234 = 1.29. The use of heavy rhenium emitter support could not be avoided because thin rhenium tubing of reliable quality was not available.

d. Relative Collector Work Function:

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 was 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, was 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 for all T-200 converters were:

	201	202	203	204	205	206
V_{40A} 645°K	0.76	0.67	0.67	0.79	0.76	0.91

These showed that the collector work function achieved with the rhenium collector of converter T-206 was 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 showed 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 were as follows:

	201	202	203	204	205	206
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 collector temperatures were optimum because testing experience had consistently indicated that the optimum collector temperature was closely equal to 1.6 times the corresponding reservoir temperature, and this was nearly the case for the above data.

e. Interelectrode Spacing:

The procedure used to find the T-206 interelectrode spacing was 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 was differentiated implicitly with respect to pressure to yield:

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

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 56 gives the values of Q which were 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°K and T_C = 810°K, the effective heat transfer area calculated was 2.52 cm^2 Then, using the values at p = 13 mm Hg to calculate d, the spacing of converter T-206 correlated to about 2.5 mils.

6.7 Required Collector-Radiator Modifications

As mentioned in Section 6.6b, 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 into agreement with the experimental observations, it was necessary to modify the calculations, presented in section 6.4, by the addition of the discrepancy of 38.3 watts. The resulting revised table of collector heat transfer values was·

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

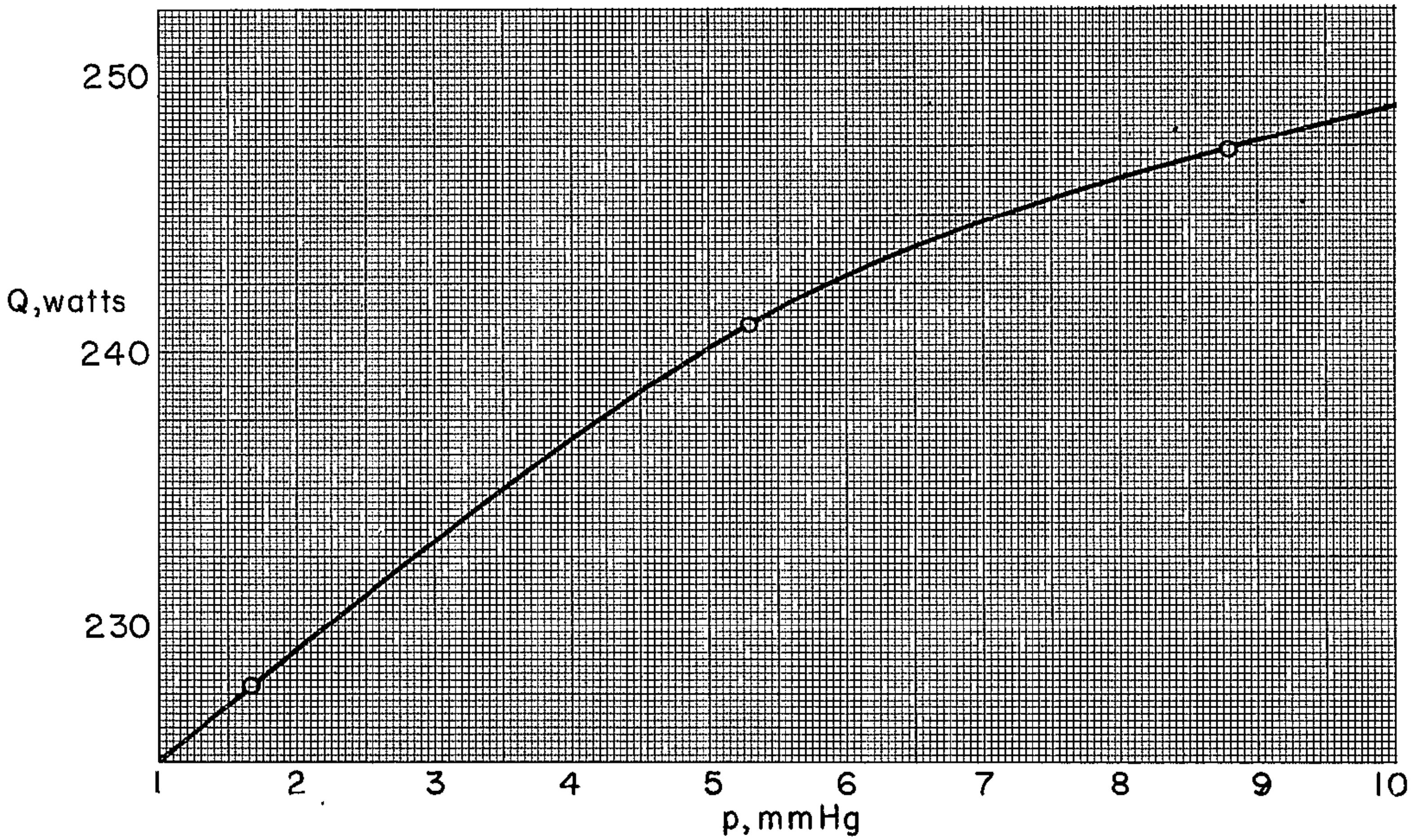

Figure 56.

which could be expressed in terms of the linear equation

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

where I_o is the output current in amperes.

The effect of the underestimation of collector heat transfer had been to continue to exceed optimum collector temperatures by a significant margin. Figure 57 shows the collector and radiator temperatures which were achieved in converter T-206, at a hohlraum temperature of 1700°C, versus output current. The figure also shows the expected optimum value of collector temperature according to the empirical equation:

$$\text{Optimum } T_C = 1.6 \times \text{Optimum } T_R$$

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

Although Figure 50 showed, 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 was overheated by about 70°C, Figure 57 shows that the actual amount of overheat above optimum collector temperature was 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 were so drastic that the resulting hardware would no longer be practical for use in a practical energy-conversion system. The requirement that the converter envelope be contained within a 30° envelope established a basic limit on the thermal conductance of the structure between the

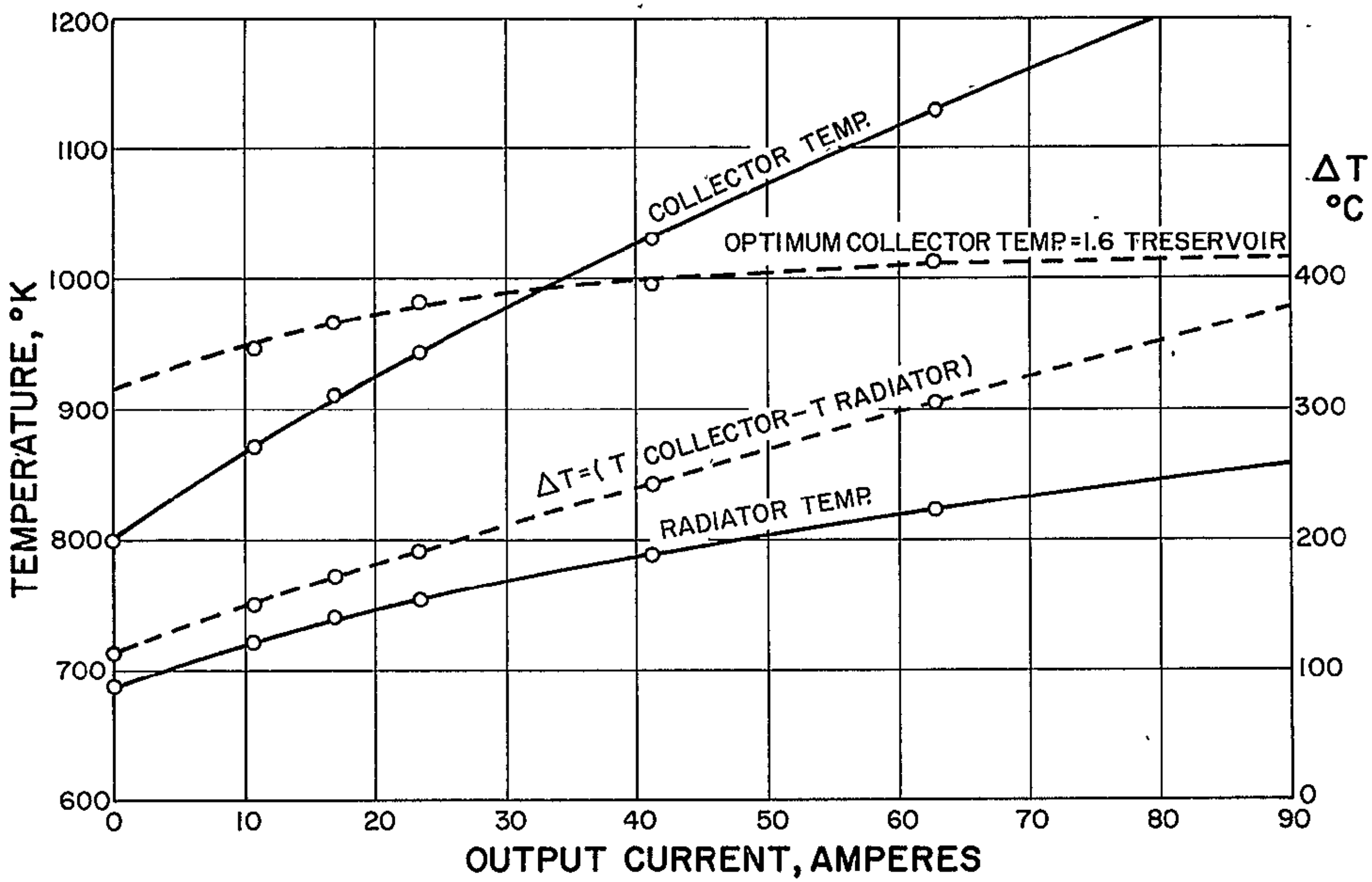
TEMPERATURE, °K
1200
1100
1000
900
800
700
600
ΔT °C
400
300
200
100
0
COLLECTOR TEMP.
OPTIMUM COLLECTOR TEMP.=1.6 TRESERVOIR
ΔT=(T COLLECTOR−T RADIATOR)
RADIATOR TEMP.
0
10
20
30
40
50
60
70
80
90
OUTPUT CURRENT, AMPERES

Figure 57.

collector and the radiator, and this limit had been approached very closely with the modifications incorporated in the structure of T-206. Thus, since the collector heat transfer could not be reduced, the collector-to-radiator temperature drop could not be reduced either The conclusion arrived at was that reductions in the collector temperature of the T-200 structure could be achieved only by reductions in radiator temperature. These reductions were very difficult to achieve because they implied 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 57 would have required increasing the radiator area by a factor of $(832/732)^4$, or 1.67. The radiator length of 2.8 inches would have had to be increased to about 4 inches, and the converter would undoubtedly have become too bulky and heavy

A much more attractive way to modify the structure of the T-200 converter was to replace its collector-radiator structure by a heat pipe of the design used for the T-200 converter being developed under JPL Contract 951465. The heat pipe characteristics were presented in the Third Quarterly Report of that program, and are summarized here in Figure 58. This figure repeats the T-206 collector temperature data of Figure 57 and the optimum collector temperature curve, and it gives the collector temperature which was expected with a heat pipe collector-radiator structure. It can be seen that the overheating point was shifted from 33 amperes to 54 amperes with the heat pipe. Furthermore, the heat pipe could follow the optimum collector-temperature characteristic quite closely, and a comparison with Figure 50 showed that, even at an output current of 90 amperes, the collector temperature would be below that achieved by converter VIII-P-3 at an equivalent output current of 70 amperes.

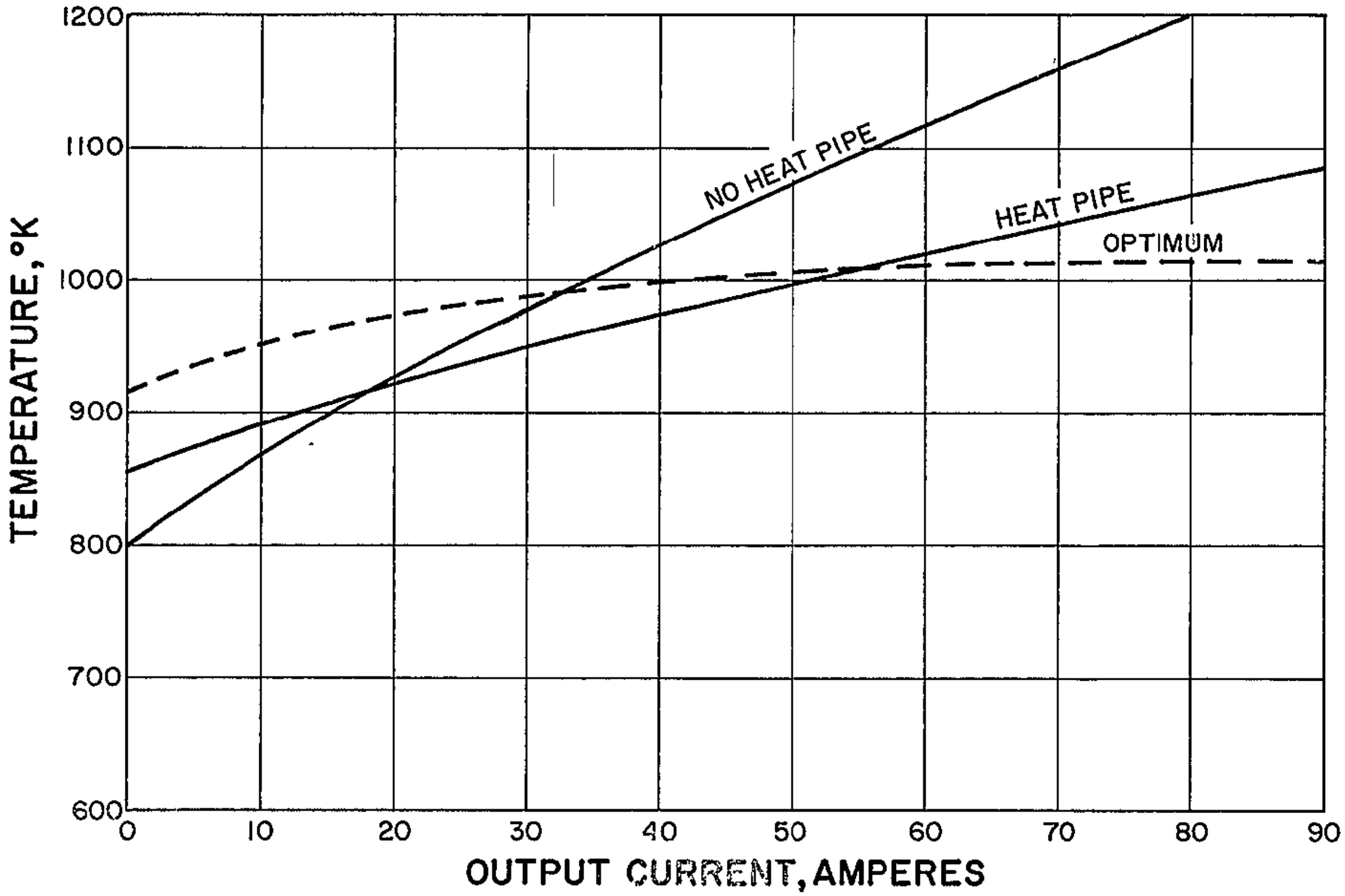
NO HEAT PIPE
HEAT PIPE
OPTIMUM
TEMPERATURE, °K
1200
1100
1000
900
800
700
600
0
10
20
30
40
50
60
70
80
90
OUTPUT CURRENT, AMPERES

Figure 58.

6.8 Recommendations to JPL

In view of the practical impossibility of avoiding excessive collector temperatures in the T-200 design, Thermo Electron made the recommendation to JPL that heat pipe technology be incorporated in the fabrication of prototypes T-208, T-209 and T-210. Since this technology could not be applied immediately, the next prototype, T-207, was fabricated using the T-206 design, and it incorporated a palladium collector.

7.1 Fabrication of Converter T-207

Converter T-207 was fabricated with care to produce a structure which, except for the collector material, would reproduce as accurately as possible that of converter T-206.

The emitter used for the fabrication of T-207 was prepared at the same time as that used for T-206. Both emitters were lapped to a mirror finish and electroetched at 5 volts, 1 ampere for 1 minute. Both emitters were thermally stabilized for 2 hours; the temperature for T-206 was 2100°C, and that for T-207 2000°C. The lower temperature for T-207 was due to space charge in the electron-bombardment heat source used for thermal treatment, which limited the maximum power input. According to the experience gained in this program, the effect of the lower heat-treating temperature should have been negligibly small. The space-charge limitation was due to excessive filament-to-target distance and the smaller filament area of the filament used for thermal stabilization of the T-207 emitter, which was of the U-type rather than the S-type. This change in filament may also have been responsible for some distortion of the T-207 emitter because of less symmetrical distribution of heat. Final flatness checks for T-206 and T-207 compared as follows, in inches:

	T-206	T-207
Emitter quadrant I	0 00005	0.0004
II	0.00000	0.0000
III	0.00005	0.0004
IV	0.00000	0.0000
Emitter center	0.00000	0.0000
Seal flange quandrant I	0.0005	-0.0025
II	-0.0002	-0.0030
III	0.0000	0.0020
IV	0.0006	0 0014

As can be observed, the emitter of T-207 after thermal treatment had eight times more distortion than that of T-206. The actual amount of distortion of the T-207 emitter was about 20% of the interelectrode spacing and should not have produced a noticeable change in converter performance, although it exceeded the estimated flatness requirement of a maximum allowable distortion of 10% of the interelectrode spacing. Converter T-207 also had a greater deviation from squareness of the seal flange. The values given above correspond to a misalignment of 15 minutes of arc, which was reasonably close to the desired value of 10 minutes of arc.

Converter T-207 was fabricated using a pressure-bonded palladium collector, and the surface preparation of the collector consisted only of a surface grinding and polishing operation. The rest of the collector-radiator structure of converter T-207 was identical to that of T-206.

The final assembly of T-207 was defective in one respect: the stainless steel support ring, part No. 19 in Figure 39, was not brazed to the copper fins. This defect was due to an excessive rate of warm-up of the assembly during final brazing; the support ring was considerably hotter than the radiator fins when the brazing material at the joint melted, and the braze flowed only on the support ring. The final assembly is shown in Figure 59.

Converter T-207 was outgassed for 65 hours at an observed emitter temperature of 1675°C. Cesium distillation was conducted for 5 hours at 200°C.

7.2 Test of Converter T-207

Converter T-207 was tested using the S-type filament as the electron-bombardment source, which was adopted as the standard source to be used in all converter tests under this program after tests with the S- and U-type filaments had shown little difference in the observed performance of converter T-206.

The converter test of T-207 duplicated that of converter T-206, so as to facilitate the comparison of experimental observations The tests included the dynamic measurement of I-V characteristics at 2000, 1900 and 1800°K, cesium conduction measurement, and static measurement of performance at hohlraum temperatures of 1700, 1600 and 1800°C. There was a thermal runaway while the equipment was being adjusted before the static measurement of performance, and as a result, the collector thermocouple became unbrazed. The collector temperature readings for these runs are therefore incorrect, as noted on pages 4 and 5 of the data presented in Appendix 11.

The envelopes of the dynamic characteristics, and the static I-V data, are plotted in Figure 60. The static I-V points correspond to an emitter temperature approximately 40°C above the adjacent dynamic curves immediately below them. As can be seen, the static curves intersected the dynamic characteristics at high output currents, and this was a direct consequence of collector overheating, which was to be solved by the incorporation of a heat-pipe collector-radiator in the converter structure of subsequent converters.

7.3 Interpretation of the T-207 Data

Converter T-207 was identical to converter T-206 except for the collector material, which was palladium in T-207 and rhenium in T-206. A comparison of the I-V characteristics for T-207 with those for T-206, presented in Appendix 10, showed a marked shift of the I-V characteristics along the voltage axis. The shift could be interpreted as a difference entirely due to collector material. However, when the static data was plotted in terms of current at specified voltages as a function of input power, it appeared that important emitter temperature errors existed in the data. The output current observed at 0.8 and 1.0 volt in the two converters was plotted as a function of bombardment power in Figure 61. The data in the range of 330 watts input corresponded to emitter temperatures in the vicinity of 2000°K. Since the two converters tested had practically identical emitter structures, they were expected to achieve the same emitter temperature when they were heated with the same bombardment power and made to deliver the same output current. Yet, in open circuit, converters T-206 and T-207 required substantially different amounts of bombardment power to reach the same observed temperatures. The values were as follows:

7834

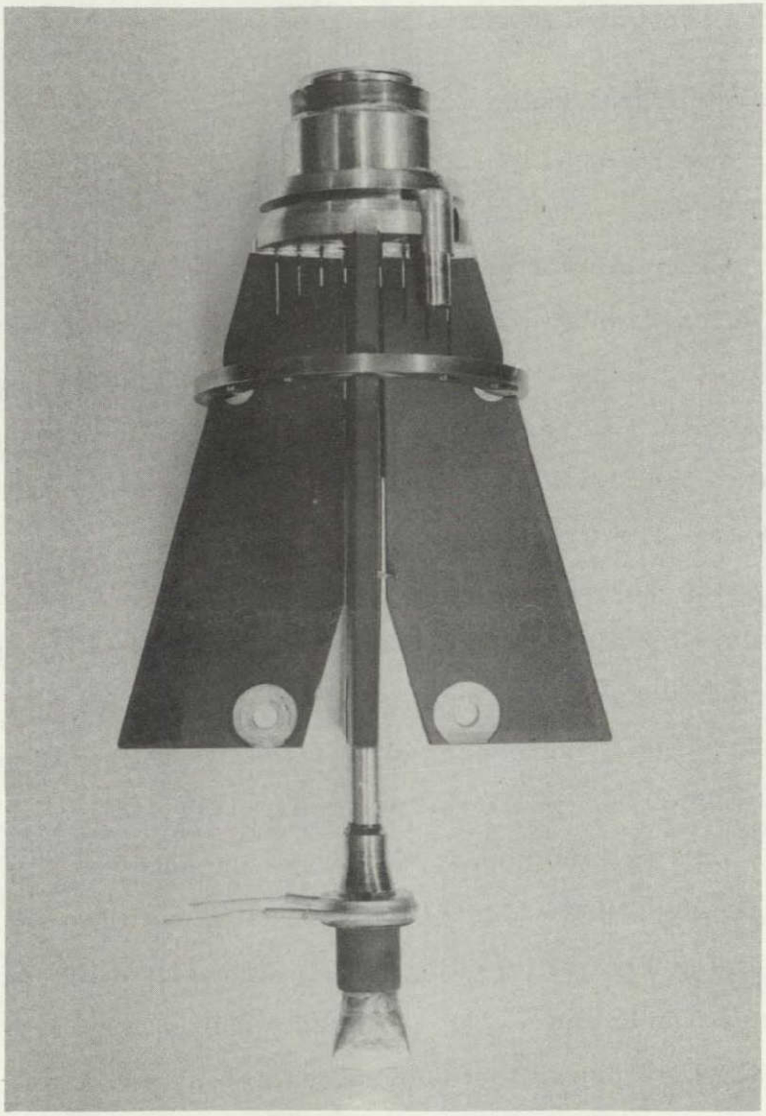

Figure 59

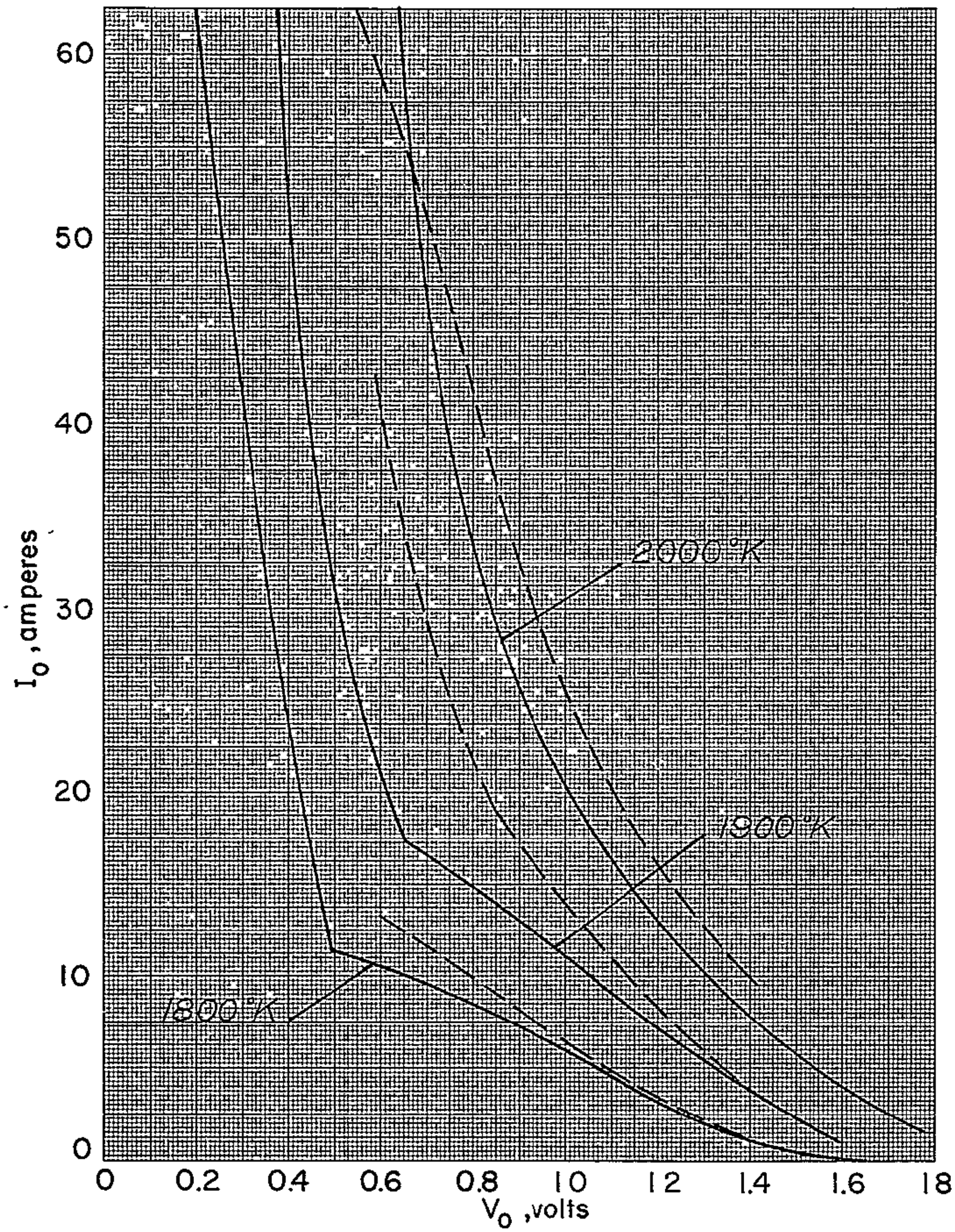
60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts
2000°K
1900°K
1800°K

Figure 60.

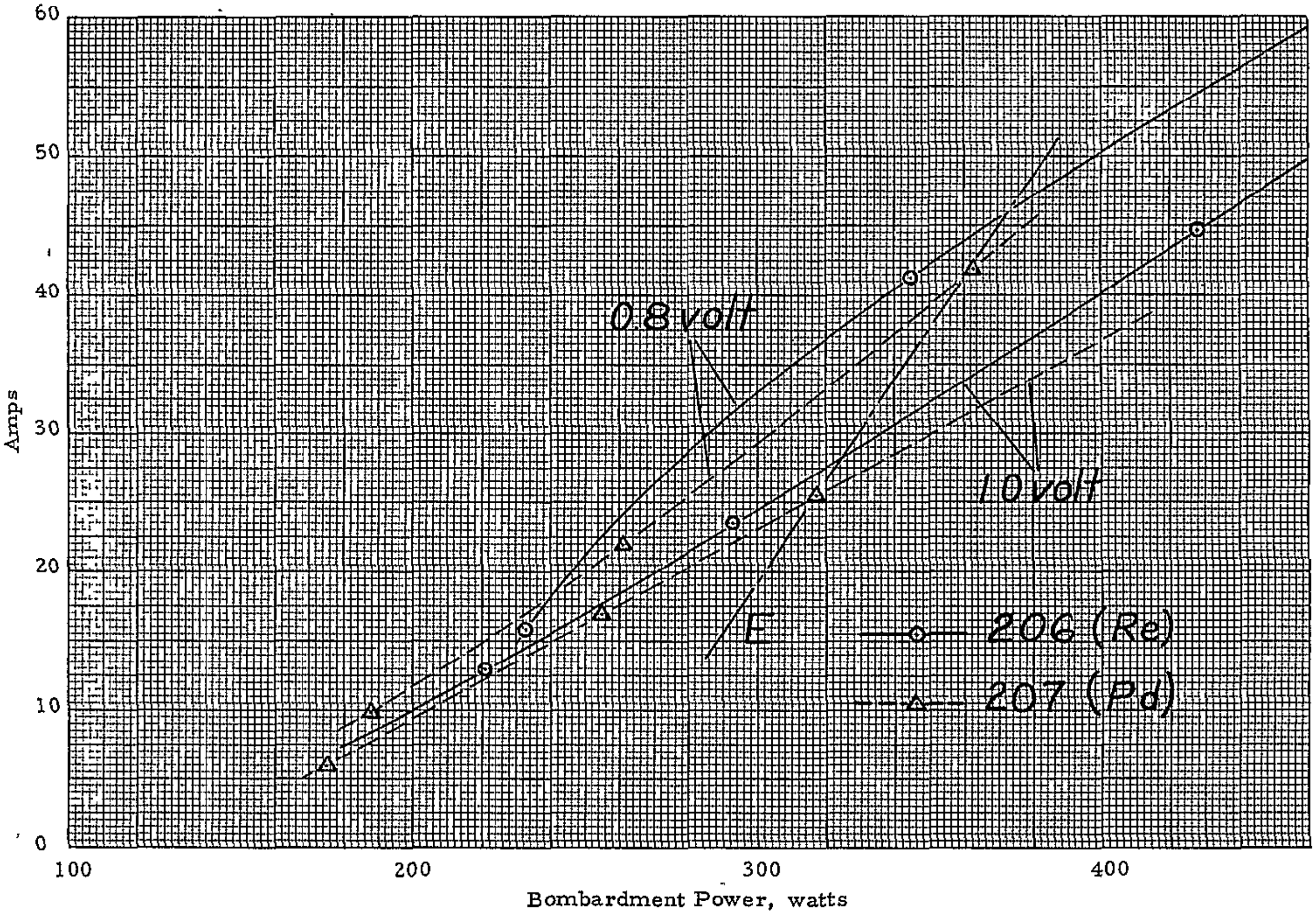
60
50
40
30
20
10
0
Amps
100
200
300
400
Bombardment Power, watts
0.8 volt
1.0 volt
E
206 (Re)
207 (Pd)

Figure 61.

Emitter Temperature °K	Q_{206} watts	Q_{207} watts	Q_{206}/Q_{207}
1863	174.5	151.8	1.149
1963	211.8	191.9	1.103
2063	263.0	227.4	1.156

As may be noted, converter T-206 required from +10.3 to +15.6% more power than converter T-207. Based on the difference in emissivity between rhenium and palladium, interelectrode radiation could only account for a difference of +2.0% in bombardment power. The major source of the inconsistency was believed to be a temperature measurement error, because all other variables were measured with good accuracy on the same equipment each time. The emitters of both converters were manufactured simultaneously from the same strip of rhenium sheet, and electroetched with the same procedure. The emitter support structures had the same dimensions, and welding of the emitters to their emitter supports was performed by the same operator and equipment. Thus it was reasonable to expect a high degree of reproducibility in the thermal characteristics of the two converters.

The cesium conduction data for converters T-206 and T-207 is plotted in Figure 62. The electron-bombardment power required to maintain an emitter temperature of approximately 2000°K is shown as a function of cesium vapor pressure. As can be seen, the curves are very similar and may be taken to have the same slope at a pressure of 13 torr Using the calculation procedure outlined in section 6.6e, the corresponding value of interelectrode spacing for both converters was found to be 2.54 mils

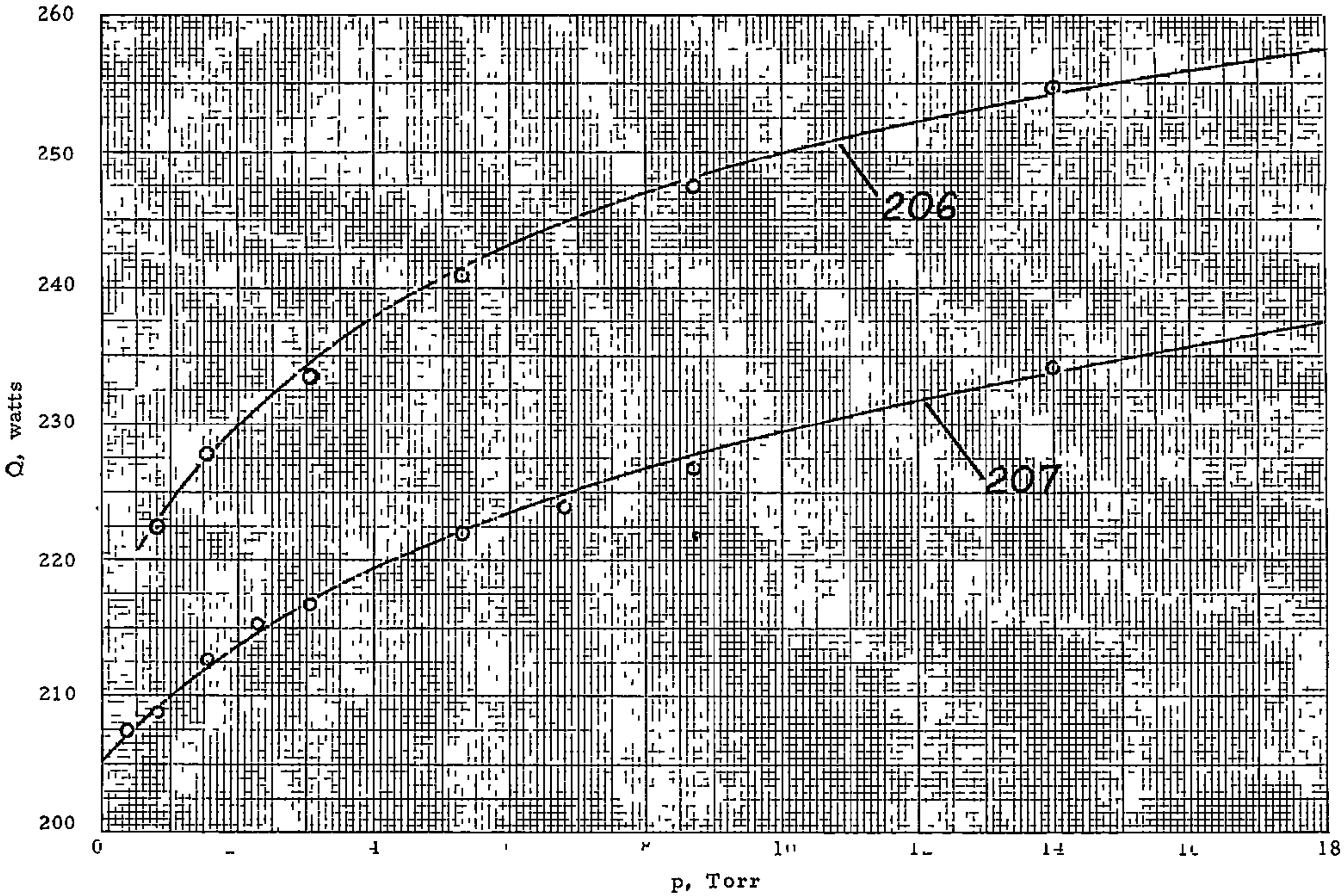

Figure 62

Although the pyrometer instrument used could reproduce readings within 2°C, and was carefully calibrated on an NBS lamp before each test, including the transmission losses through the observation area of the vacuum bell jar, an emitter temperature error could have resulted from variations in the configuration of the black-body hole used for these measurements. The black-body hole was 0.015 in. in diameter and 0.120 in. long, and was machined by electrical discharge in the emitter. Because of the small thickness of the emitter, the black-body hole lay very close, and not necessarily parallel, to the heated surface of the converter The thickness of the material between the heater surface and the pyrometer hole could be expected to vary between 1 and 10 mils This lack of control was a direct result of the constraints imposed by the need for the emitter to be thin to minimize heat losses, temperature drop and weight. When the black-body hole is positioned very close to the heated surface, the thin wall separating it from the heated surface can overheat and raise the apparent temperature of the emitter. No measurements had been made, however, to confirm that the resulting error could be as high as 80°C, which was the magnitude required to account for the observed thermal input discrepancies.

Assuming that the thermal conduction and external radiation characteristics of the emitter structure were identical for all three converters, it was possible to use the measured converter thermal data and estimate the difference in performance between the two collector materials. The calculation of the quantitative difference between these converter materials could only be as accurate as the assumption about identical thermal characteristics; therefore, the values given here are tentative

The interpretation of the thermal data was based on the further assumption that the electron cooling for these converters was 2.72 watts per ampere. This value had been verified repeatedly, particularly at emitter temperatures near 2000°K. For instance, in Figure 61, an intersecting line labeled "E", has been drawn through a pair of data points. The data points were obtained on the same converter at the same observed emitter temperature, and the inverse slope of the "E" line is found to confirm the value of 2.72 watts per ampere. By using two "E" lines shifted by 4 watts, which was the difference in the interelectrode radiation losses between a converter with a rhenium collector and one with a palladium collector, it was possible to predict the amount by which the current outputs of the two converters would actually differ at any one emitter temperature and output voltage. Following this procedure, it was found that, at the same emitter temperature, converter T-207 produced 6.1 amperes less current at 0.8 volt, and 3.9 amperes less current at 1.0 volt, than converter T-206.* The differences in output current at a fixed voltage could be translated into output voltage differences at a fixed current from a knowledge of the slopes of the I-V characteristics. Taking the output of T-206 as a guide, the slope of the I-V characteristic at 24 A/cm^2 is 80 A/cm^2-volt, and that at 18 A/cm^2 is 36 A/cm^2-volt. For the current differences of 6.1 and 3.9 amperes, the corresponding voltage shifts were 0.030 and 0.044 volt. Thus the I-V characteristics of converter T-207 were shifted to a lower output voltage than those of converter T-206 by an average value of 0.037 volt. The tentative conclusion was then that the effect of using palladium in place of rhenium as a collector material is equivalent to a collector work function increase of 0.037 eV.

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*Brosens, P. J., "Advanced Converter Development," Thermionic Specialist Conference, Palo Alto, 1967.

7.4 Heat Balance of Converter T-207:

Since a substantial error in emitter temperature seemed to exist in some of the converter tests, it was of interest to calculate what the emitter temperature ought to be as a function of power input, and to determine, for instance, in which converter test the observed emitter temperatures were closest to the true values

Using the total hemispherical thermal emissivity values presented in Figure 51, the interelectrode radiation of a rhenium-emitter, rhenium-collector converter with 2.50 cm^2 of electrode area is as follows:

Emitter Temperature °K	ϵ_E	ϵ_C	Q_r watts
1860	0.290	0.231	22.97
1960	0.298	0 236	32.27
2060	0.307	0.242	37.79

The external radiation area of the converter emitter structure was assumed to be that of an 0 725-in. diameter disc with a height of 0.060 in., which is 3.545 cm^2. The corresponding values of external radiation were:

Emitter Temperature °K	ϵ_E	$Q_{r\ ext}$, watts
1860	0.290	69.91
1960	0.298	96.03
2060	0.307	111.33

The cesium conduction loss was taken to be that which occurs at a reservoir temperature of 560°K (cesium pressure of 1 torr), which, according to Figure 62, is 5 watts.

The lead conduction was estimated to equal 150% of that which would occur in the lead if the effects of thermal radiation on temperature gradient were absent. The developed length of the emitter support was 1.7 cm, and the average cross-sectional area of the lead was 0.109 cm^2, with an average thermal conductivity of 0.55 watt/cm°C The calculated lead conduction was then as follows:

T_E, °K	T_C, °K	ΔT, °C	Q_ℓ, watts
1860	750	1110	58.6
1960	800	1160	61.3
2060	850	1210	63.9

Finally, the total estimated heat input required to bring the emitter to temperature in the absence of output (open-circuit) could be tabulated by adding the above component losses, and the values could be compared with those experimentally observed in converter T-206. The result was:

Converter T-206

T_E, °K	$Q_{calculated}$, watts	Q_{actual}, watts
1860	156.5	174.5
1960	194.6	211.8
2060	218.0	263.0

For converter T-207 the predicted heat input values were 4 watts lower, to account for the lower emissivity of palladium (.193* as compared to .237 for rhenium,** at an effective temperature of 1400°K, see p. 89) and the corresponding tabulation was:

Converter T-207

T_E, °K	$Q_{calculated}$, watts	Q_{actual}, watts
1860	152.5	151.8
1960	190.6	191.9
2060	214.0	227.4

As can be seen, the experimentally observed conditions were in much better agreement with the calculated conditions for converter T-207. It is difficult to conclude that the T-207 measurements were more accurate from this evidence, because accurate calorimeter measurements have not been made on the T-200 converter to verify the accuracy of the heat loss calculation.

8.1 Design of Converter T-208

The design of converter T-208 is presented in Figure 63. As can be seen, this converter rejects heat with the help of a heat pipe collector-radiator structure of the design developed under JPL Contract 951465. The sequence of converter assembly is:

1. Fabricate the heat pipe structure.
2. Braze the emitter and seal structures to the heat pipe.
3. Outgas and charge the heat pipe with sodium.
4. Connect the cesium reservoir, and outgas and charge the converter with cesium.

*Handbook of Thermophysical Properties of Materials, Volume 1, Armour Research Foundation, Pergamon Press, 1960.

**From Figure 51

8.2 Fabrication of Converter T-208A:

Figure 67 illustrates the components and various subassemblies of the heat pipe structure. The assembly of T-208A was begun by first welding the sodium fill tube to the heat-pipe radiator, as shown in the far left of Figure 64; the joint was made by inert-gas welding in argon. Then the collector subassembly was made by first welding the inner heat-pipe tube to the cesium tube, as shown in Figure 63, and then brazing the joined tubes to the collector. The tubes were welded together by melting the end of the outermost, which was made of niobium, onto the outside of the innermost, which was made of tantalum to avoid its melting during the welding operation. The collector face was made of a rhenium sheet bonded to the niobium collector base by vanadium brazing. Initially it had been sought to effect this bond by isostatic pressure-bonding, but the pressure-bonding facility which had been used previously was unavailable for a period of several months. The braze of the welded tubes to the collector was made with palladium, and a typical subassembly is shown at the left center of Figure 64.

The heat-pipe radiator and collector subassemblies were then joined together by first inserting the converter support and ceramic insulator on the collector end of the heat-pipe radiator, and then positioning the collector subassembly and welding it to the end of the heat-pipe radiator by electron-beam welding. The corresponding parts and final subassembly are shown at the left bottom and top corners, respectively, of Figure 64.

The heat-pipe structure assembly was then completed by inserting the capillary elements shown in the remainder of Figure 64, with the exception of the central capillary, part No. 17, which was omitted because work under Contract 951465 had shown that this part is not essential. To do this, the perforated-sheet capillary screen

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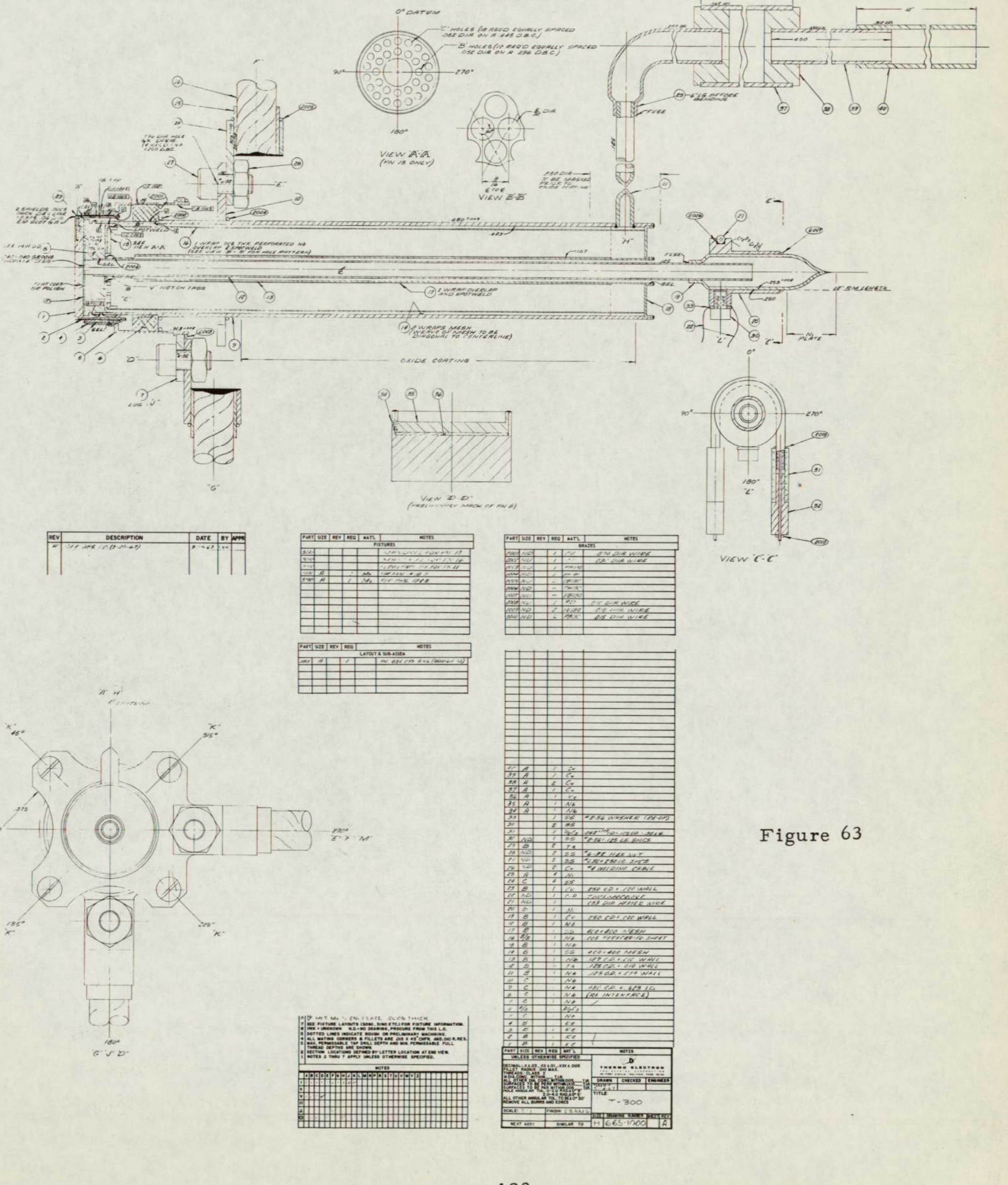

Figure 63

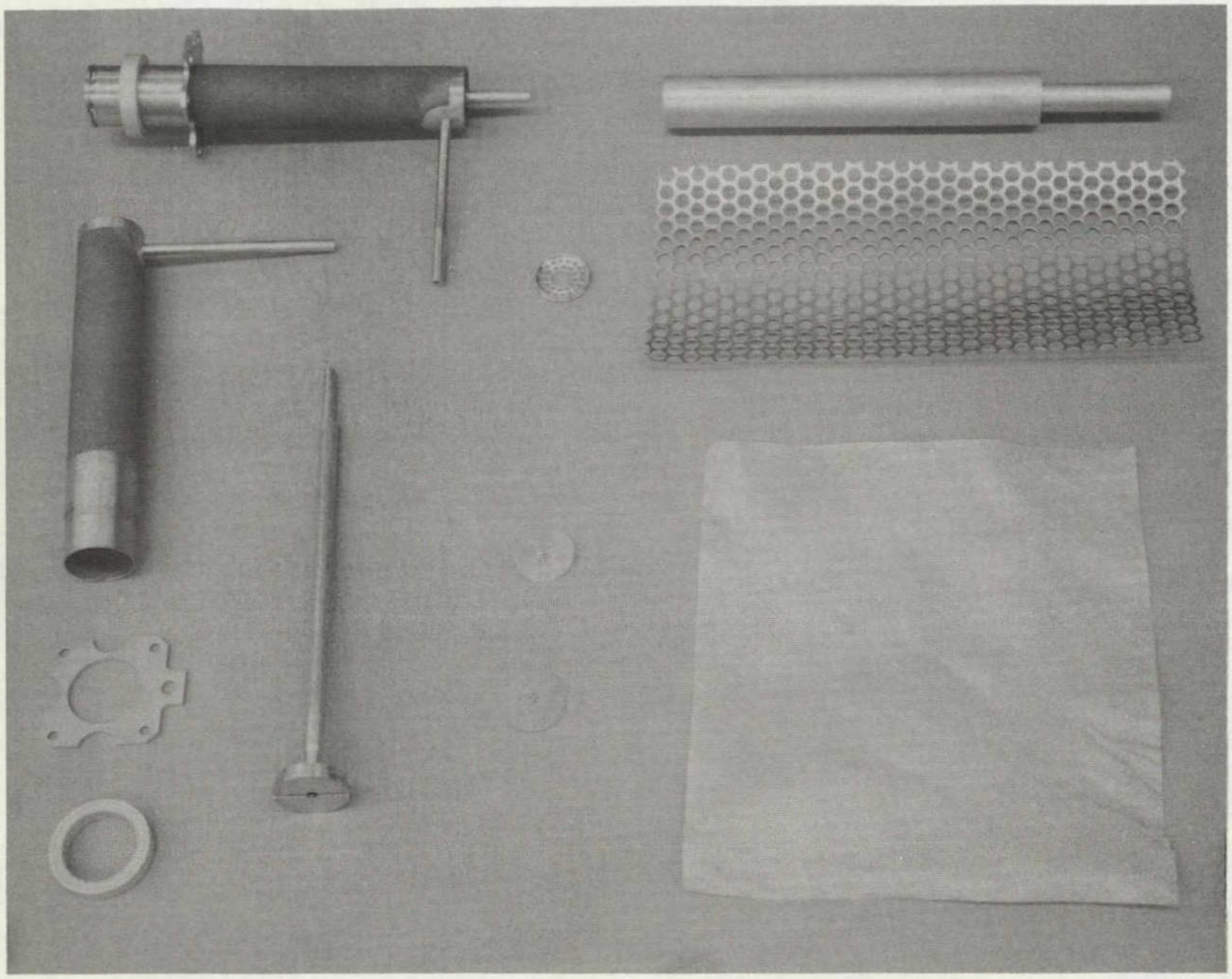

Figure 64

support was wrapped and spot-welded around the mandrel shown at the top right corner of Figure 64, and the collector capillary support piece was positioned as shown in Figure 65; then the mesh screen elements were wrapped around the capillary support, and spot-welded at the end only, as shown in Figure 66. The end capillary consisted of one disc of mesh screen, the end folds of the cylindrical mesh screens, and one inner disc; therefore, the end consisted of essentially three layers of mesh screen, spot-welded together and supported by a perforated niobium plate. Two wraps of mesh screen were used around the cylindrical screen support.

The capillary assembly was slid into the heat pipe, and the mandrel was removed by pulling it out while retaining the capillary support. The exposed end of the capillary was trimmed and bent, as shown in Figure 67, so that it would rest against the end cover of the heat pipe, and so that it would not block the sodium fill tube. Finally, the end cover was arc-welded in argon, using a 5-mil tungsten wire coiled between the center tubes to maintain the concentricity of the cesium tube during welding of the inner lip of the end cover. This wire was left in place after welding, and the assembly after welding is shown in Figure 68.

The heat pipe structure was then ready for converter assembly. This was done by first fabricating the emitter subassembly; it consisted of three concentric sleeves of rhenium arc-welded together to form the convoluted emitter support, vanadium-brazed to a niobium outer seal flange, and electron-beam welded to an electro-etched rhenium emitter in the same manner as previously used for the assembly of converter T-207. Normally, the emitter was heated by electron bombardment

7865

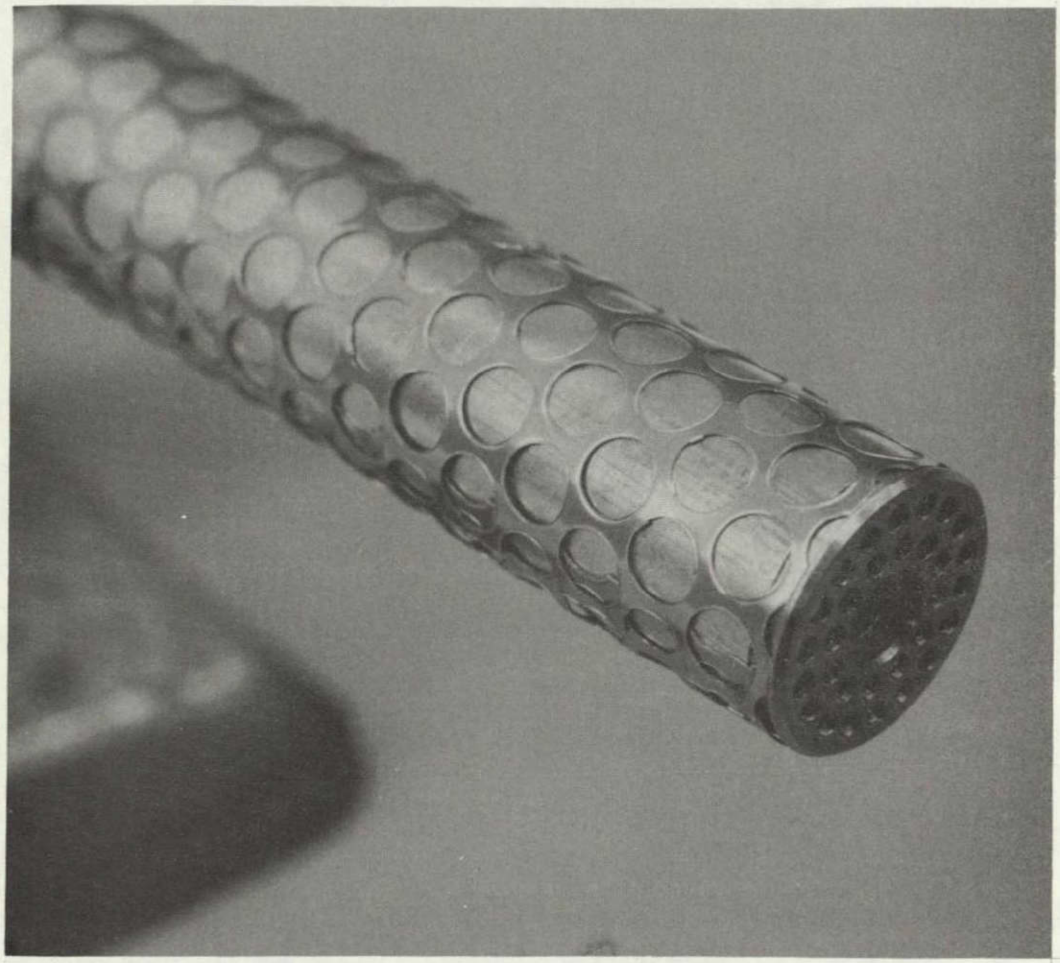

Figure 65

7864

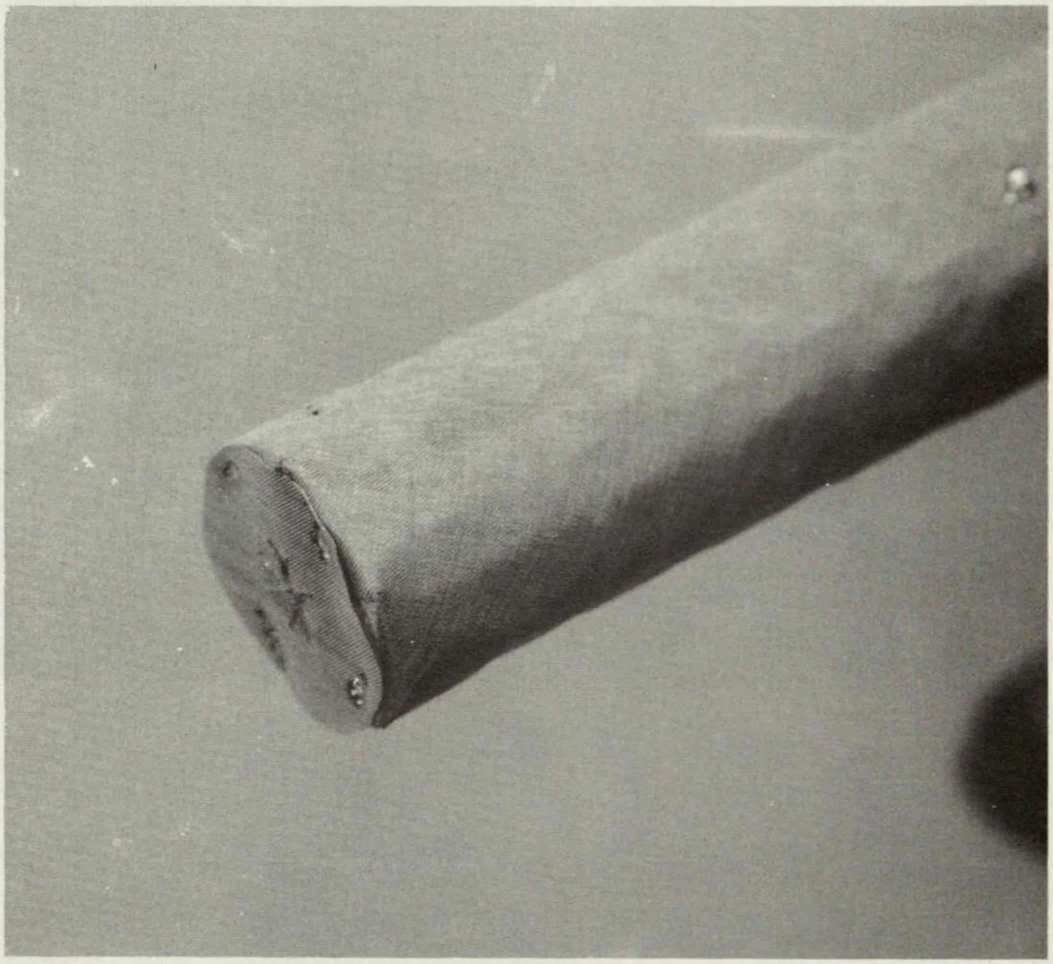

Figure 66

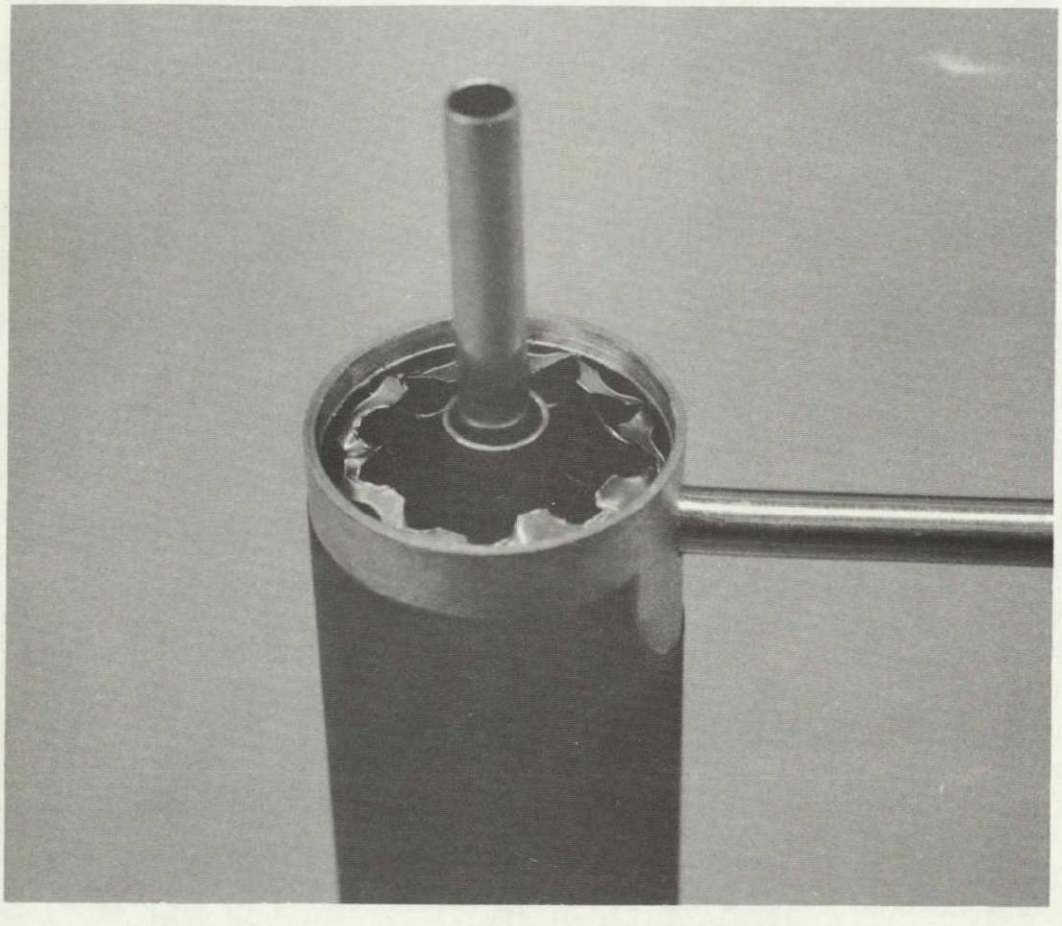

Figure 67

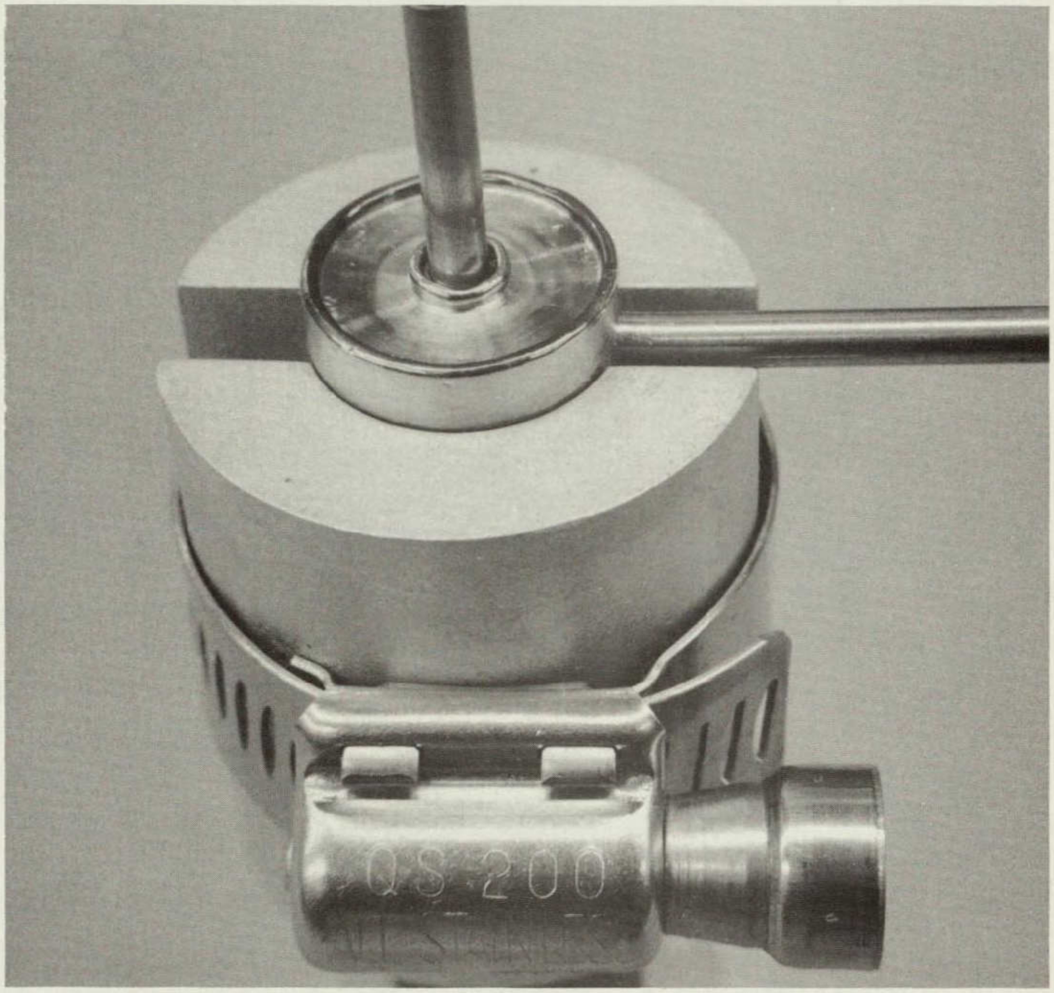

Figure 68

after it was welded to thermally stabilize its surface, but in the case of converter T-208A this step was omitted inadvertently. Converter assembly proceeded by inserting the emitter structure around the loose ceramic insulator, placing the emitter terminal piece in position around the outer seal flange, and brazing all parts with copper.

The converter was outgassed and charged with sodium in the same manner as previous heat pipe models: A sodium ampoule manifold was fuse-brazed to the sodium fill tube, and connected to a Vac-Ion pump; the heat pipe was then heated to 500°C by a resistance heater wound around it, and the sodium ampoule manifold was heated to approximately 375°C for a period of 48 hours. The sodium ampoule was cracked, and the sodium was made to flow by gravity into the heat pipe; finally, the niobium fill tube was pinched and cut off by electron bombardment.

The converter was then ready for the assembly of the cesium reservoir tubulation. This was the final assembly operation prior to converter outgassing and cesium charging. The reservoir tubulation was to be fuse-brazed to the tantalum tube, part No. 12, in Figure 63. To facilitate wetting by the molten copper, and to strengthen the metallurgical bond between the copper and the tantalum, the tantalum tube was given a very thin nickel electroplate prior to fuse-brazing. In the first two attempts at fuse-brazing the tubulation on converter T-208A a leak-tight bond could not be obtained; consequently, the fuse-brazed tubulation was removed, and the tantalum tube was given a new and thicker nickel electroplate. When a new reservoir tubulation was slipped over the tantalum tube for another fuse-braze attempt, the tantalum tube broke. It was found that the tube had embrittled, apparently during the second fuse-braze, when a high temperature was used, and when the nickel electroplate alloyed with the tantalum. The embrittlement was severe, and it extended along the length of the tantalum tube all the way to the inner weld bead of the end cap of the heat pipe, part No. 18.

The tube could not be replaced without completely dismantling the converter; therefore, a repair was attempted, which consisted of brazing an extension piece to the broken end of the tantalum tube. The extension piece was made of tantalum, and brazed with palladium using an inert-gas arc as the heat source; it had a length of 3/4 in., 3/16 in. of which was machined to slide into the broken end of the converter tube, and it had an inside diameter of 0.065 in.

An attempt to repeat the fuse-braze on this extension failed, and it was concluded that the difficulty in making a successful fuse-braze was caused by the large difference in the diameters of the two tubes being joined; to avoid this difficulty, it was decided to use an intermediate tubular insert, made of niobium, with a diameter of 3/16 in. This insert was made and joined to the tantalum tube in the exact same manner as the inner heat-pipe tube, part No. 13, and its length was 7/8 in.

This intermediate piece was welded in place, and the first fuse-braze attempt failed, in part because the niobium tube had not been plated, and in part because the wall thickness of the fuse and of the copper tube was not small enough. A new fuse-braze attempt was made, and it was successful. Upon leak-checking the assembly, however, it was found that the area of the tantalum cesium tube, which had been repaired by means of a palladium braze, had developed a leak. It was subsequently determined that during heliarc-welding of the niobium intermediate tube to the end of the tantalum cesium tube, the area of the tantalum tube which was palladium-brazed overheated to the extent that an alloying reaction between palladium and tantalum occurred and formed a brittle intermetallic. During handling of the assembly to effect the fuse-braze this embrittled area developed a crack and leaked.

The failed assembly could still be repaired by using the internal heat pipe tube, part No. 13 in Figure 63, as the tube to transport the cesium vapor from the cesium reservoir. To accomplish this, the length of the normal cesium tube which protruded beyond the end of the heat pipe was cut off, and a niobium extension piece was copper-brazed to the end of the internal heat pipe tube, part No. 13. A leak-tight assembly was obtained, and a copper tube was fuse-brazed to the niobium extension to serve as the cesium reservoir and outgassing tubulation. Model T-208A was then set up for outgassing, and at the end of a few hours it was evident that sodium was leaking from the heat pipe. Upon examination, it was found that the end cap, part No. 18, had developed a crack midway between the inner and outer welds. At this point further attempts to salvage the assembly 208A were abandoned because no technique was available for discharging the sodium from a leaking heat pipe, which is a prerequisite to any repair attempt on heat pipe envelopes.

8.3 Fabrication of Converter T-208B:

The fabrication of model T-208B proceeded without incident up to the point of cesium reservoir assembly. This reservoir was being constructed by welding an intermediate niobium piece to the end of the tantalum cesium tube, part No. 12, to facilitate fuse-brazing of the copper tubulation, part No. 19. Unfortunately, due to operator error, air was admitted into the welding chamber before the weld was performed, and the joint was completely brittle. The brittle portion of this weld area was removed by cutting the tantalum tube, and an extension piece of tantalum was palladium-brazed to the tantalum tube to continue construction of model 208B. The model was then finally brazed to an emitter structure and prepared for outgassing prior to sodium charging. It was then found that the outer weld of the end cap, part No. 18, was cracked and leaked. Attempts to seal this area by re-welding were not successful, and it was decided to remove the end cap, part No. 18, by machining. Upon removal of the end cap, it was found that the capillary structure was oxidized, and the pattern of this oxidation suggested strongly that it had been caused by a seepage of the nickel electroplating solution which was used to plate the sodium fill tube prior to fuse-brazing it to the heat pipe outgassing and sodium charging tubulation.

8.4 Fabrication of Converter T-208C:

The assembly of a third model, designated T-208C, ran into complications during the electron-beam weld of the collector to the heat pipe radiator. To provide better positioning of the collector face with respect to the heat pipe radiator tube, part No. 9, during electron-beam welding of these two parts, a stainless steel tie rod was inserted through the center of the tantalum cesium tube, part No. 12. The heat developed during electron-beam welding was sufficient to cause melting of the tie rod, however, and the molten metal alloyed with the collector, causing irreparable damage.

8.5 Fabrication of Converter T-208D:

The assembly of the fourth model, designated T-208D, was successful. It was accomplished with a new set of parts, and in accordance with the layout of Figure 63, with the following exceptions: The cesium tube, part No. 12, was made of niobium, with an 0.025-in. wall thickness, to avoid using the relatively fragile 0.010-in wall tantalum tube used in the previous heat pipe converter models. As in previous models, the central capillary, part No. 17, was omitted. A thicker end cap, part No. 18, was used to avoid crack leaks due to possible exposure to embrittling atmospheres or processes. An extension of 3/16-in.-dia niobium tubing was used to connect the cesium tube, part No. 12, to the cesium reservoir tube, part No. 19, as described in the assembly of model T-208A, and for the purpose of reducing the dissimilarity in tube diameters that would occur at the joint of parts Nos. 12 and 19. The rhenium collector face was vanadium-brazed to the niobium substrate because of the unavailability of the pressure-bonding facility which would otherwise have been used. Nickel plating of the ends of both tubes, Nos. 12 and 11, was performed using a pair of small rubber plugs to avoid seepage of plating solution inside the tubes. A 3/16-in.-dia niobium tubing extension was used to connect the sodium fill tube, part No. 11, to the sodium reservoir discharge tube, part No. 23. Also, to avoid joining tubes which differ excessively in diameter, this extension was first fuse-brazed to the sodium discharge tube, and then it was electron-bombardment brazed to the sodium fill tube using two rings of nickel-plated 0.020-in.-dia copper.

The electroetched emitter was thermally stabilized at approximately 2050°C for 2 hours, at a vacuum of 10^{-5} torr. The maximum deviation from flatness measured after thermal stabilization was 0.0004 in.

The assembled model was then connected to a vacuum station to outgas the heat pipe portion of the envelope. The heat pipe was maintained at an average temperature of 490°C with resistance heaters for a period of 16 hours.* At the end of this time the sodium ampoule was broken by crushing the walls of the copper manifold where it was located, the argon of the ampoule was pumped out, and the assembly was pinched off. It was then placed in an oven at 150°C for 2 hours to melt the sodium, and the sodium was then transferred into the heat pipe. Following this operation the sodium manifold was pinched off, and the niobium fill tube was cut and sealed with an electron beam.

The next assembly operation consisted of connecting the cesium reservoir with a fuse-braze. That assembly was then connected to the same vacuum station to outgas the converter envelope and proceed with cesium charging. During outgassing of the converter envelope, a radiation shield was wrapped around the heat pipe radiator to help maintain high collector temperatures. The heat pipe was at 800°C, and the radiator temperature was uniform. Converter outgassing was performed for a period of 26 hours with the emitter at an observed temperature of 1700°C. The cesium was then distilled at 200°C for 4 hours.

8.6 Test of Converter T-208

The test of converter T-208 consisted of 7 runs as follows: Runs 1 to 3 to map the output under dynamic conditions at 2000, 1900 and 1800°K, Run 4 to measure interelectrode spacing via cesium conduction, and Runs 5 to 7 to map the output under static conditions at 1700, 1600 and 1800°C. Appendix 12 presents the data collected during test.

*The outgassing temperature was limited to 490°C to avoid the reaction of the sodium with the glass ampoule, which otherwise occurs.

During these tests it was found that the cesium reservoir tended to run hotter than in previous heat pipe models owing to the heavier 0.025-in. wall of the cesium tube. Since the previous models had shown that there is no problem in achieving lower reservoir temperatures with an 0.010-in.-wall tube, it was clear that the cesium reservoir temperature could be lowered later with little difficulty.

Figure 69 presents a summary of the optimized I-V characteristics; the solid lines are the characteristics obtained by dynamic test, and the dashed ones were obtained statically.

Figure 70 presents the cesium conduction data.

8.7 Interpretation of Converter T-208 Test Results

Converter T-208 had rhenium electrodes, and it was therefore of interest to compare its performance with that of converter T-206, which also had rhenium electrodes. Converter T-207, fabricated in the interim, had a palladium collector.

Other differences in structure were as follows: Converter T-206 had a finned radiator and was assembled using well-developed procedures; in addition, it had a collector diameter of 0.705 in., corresponding to a collector electrode area of 2.52 cm^2. Converter T-208 used a heat pipe radiator structure for the first time in this program, which was assembled according to untried procedures; furthermore, its collector diameter had to be decreased to 0.680 in. because of reduced tolerance control in the heat pipe structure assembly. This diameter corresponded to an area of 2.34 cm^2, which was further reduced by the slot used for outgassing purposes, shown in Figure 63, and the reduction was 0.18 cm^2, leaving a net electrode area of 2.16 cm^2. The effective electrode area

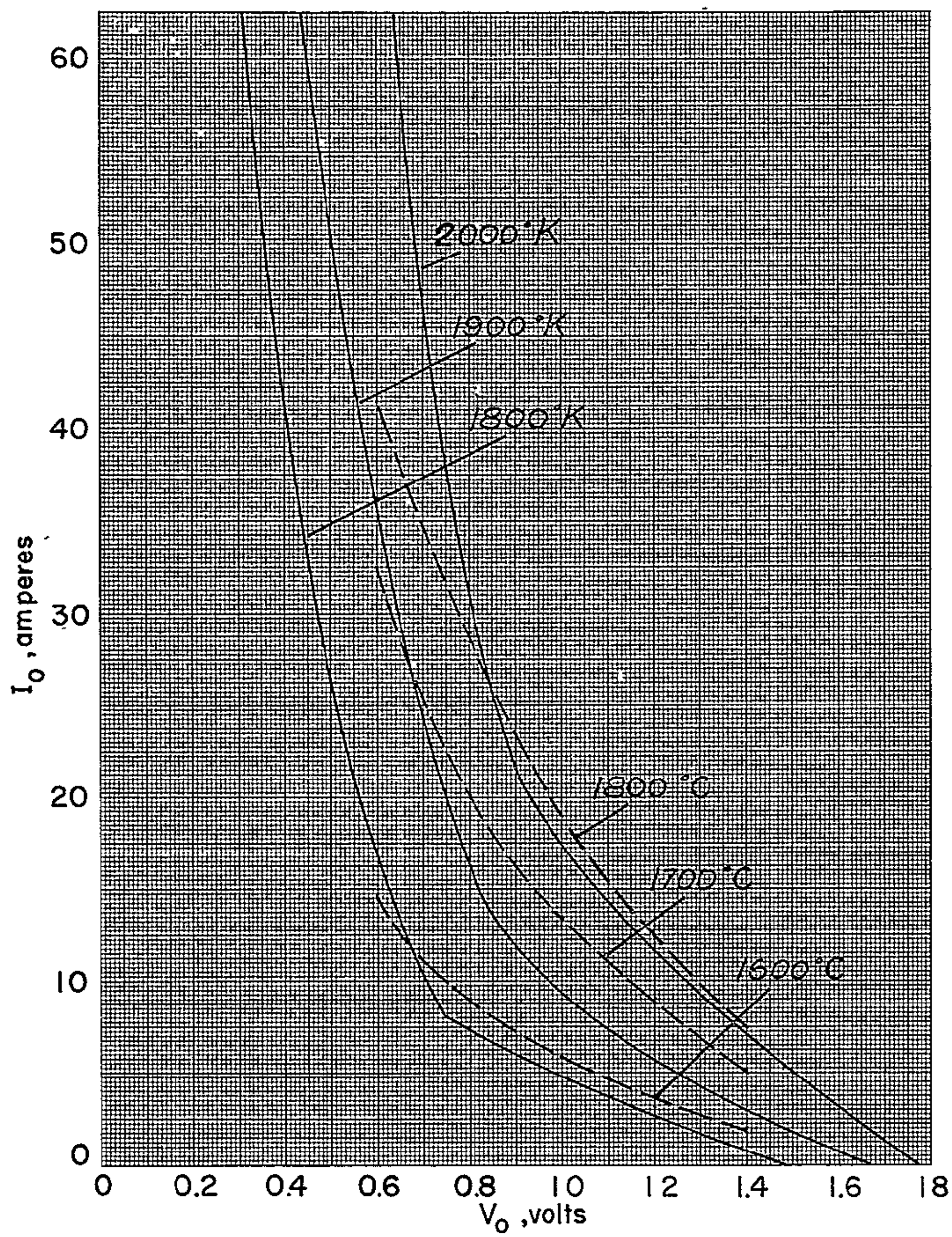
60
50
40
30
20
10
0
I_o ,amperes
0
0.2
0.4
0.6
0.8
10
12
1.4
1.6
18
V_o ,volts
2000°K
1900°K
1800°K
1800°C
1700°C
1600°C

Figure 69

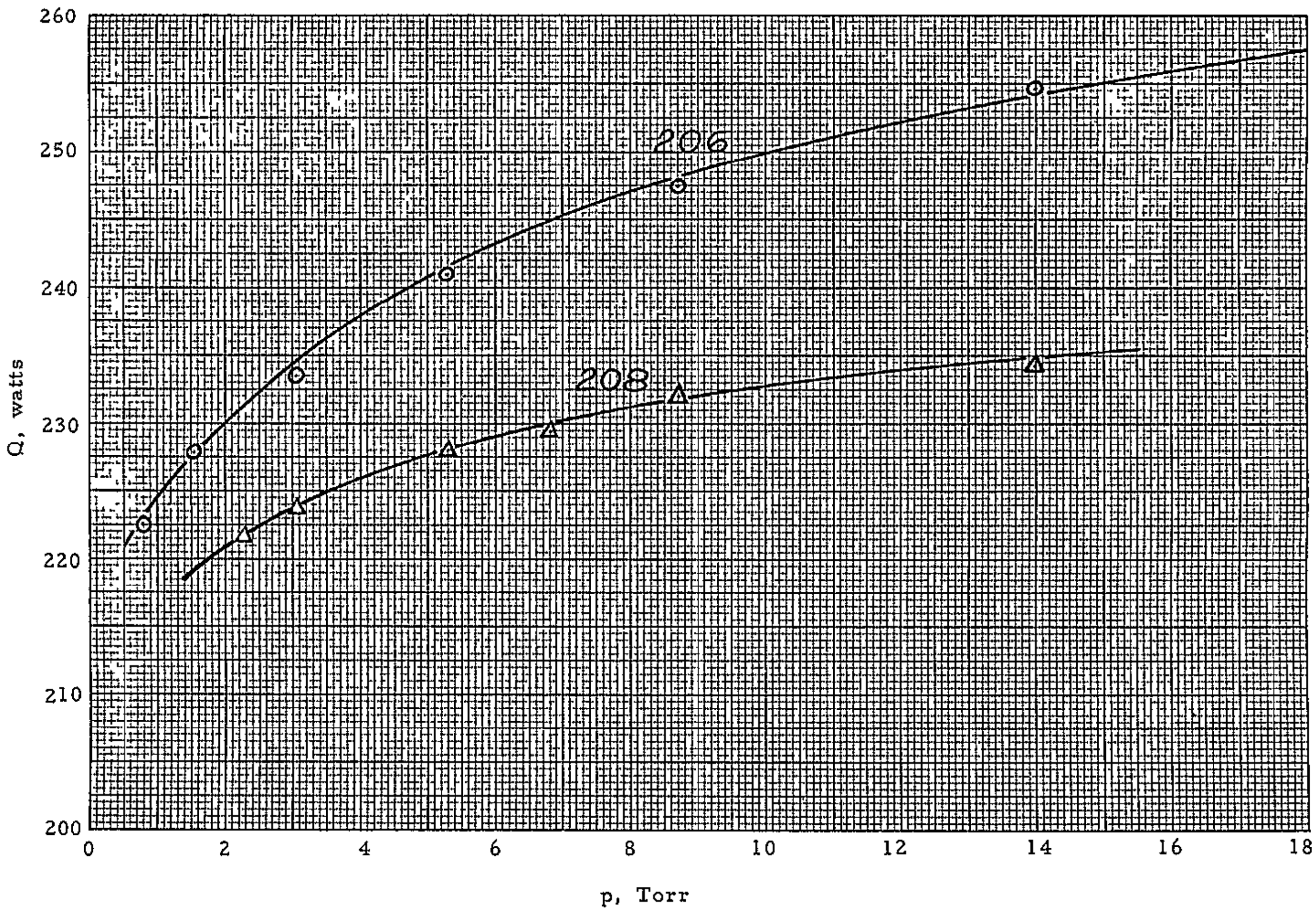

Figure 70

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of converter T-208 was then 2.16/2.52 = 0.86 times the electrode area of converter T-206

Figures 71, 72 and 73 give the comparison of the dynamic characteristics of converters T-206 and T-208, at emitter temperatures of 1800, 1900, and 2000°K, respectively. In order to subtract the effect of the 14% reduction in collector area of converter T-208, the figures show, in dashed lines, the effect of reducing the output current values of converter T-206 by 14%. As can be seen, converter T-206 was able to produce a consistently higher output voltage In the ignited mode, the increment in output voltage increased with emitter temperature; thus at 1800°K it was approximately 60 mV, at 1900°K it was approximately 120 mV, and at 2000°K it was approximately 160 mV.

The lower performance of T-208 was not the only problem observed in this converter: Figure 69 shows that the dynamic data could not be reproduced statically at high output currents. This was a typical indication of collector overheating Figure 74 shows a comparison of the electron-bombardment power required to develop a given output current at output voltages of 0.8 and 1.0 volt for both converters T-206 and T-208. At low currents (below 15 amperes) both converters are similar, but at higher input powers the additional input power in converter T-208 was used to overcome the high emitter temperatures that resulted from the inability to produce more output current This was additional evidence of collector overheating, which was traced to an excessive restriction in the vapor channel in the heat pipe, as is explained in the following section.

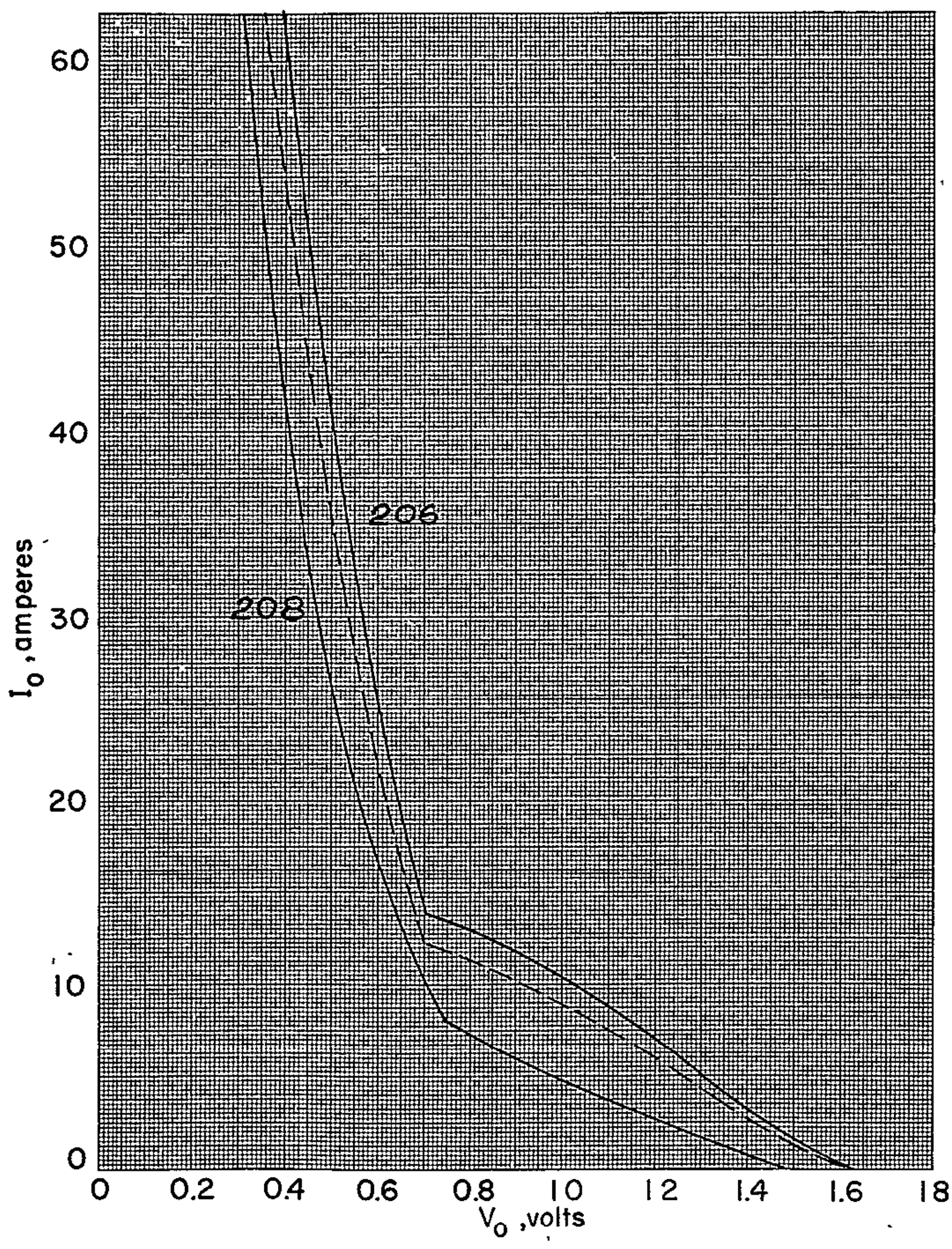
60
50
40
30
20
10
0
I_o, amperes
206
208
0
0.2
0.4
0.6
0.8
10
12
1.4
1.6
18
V_o, volts

Figure 71

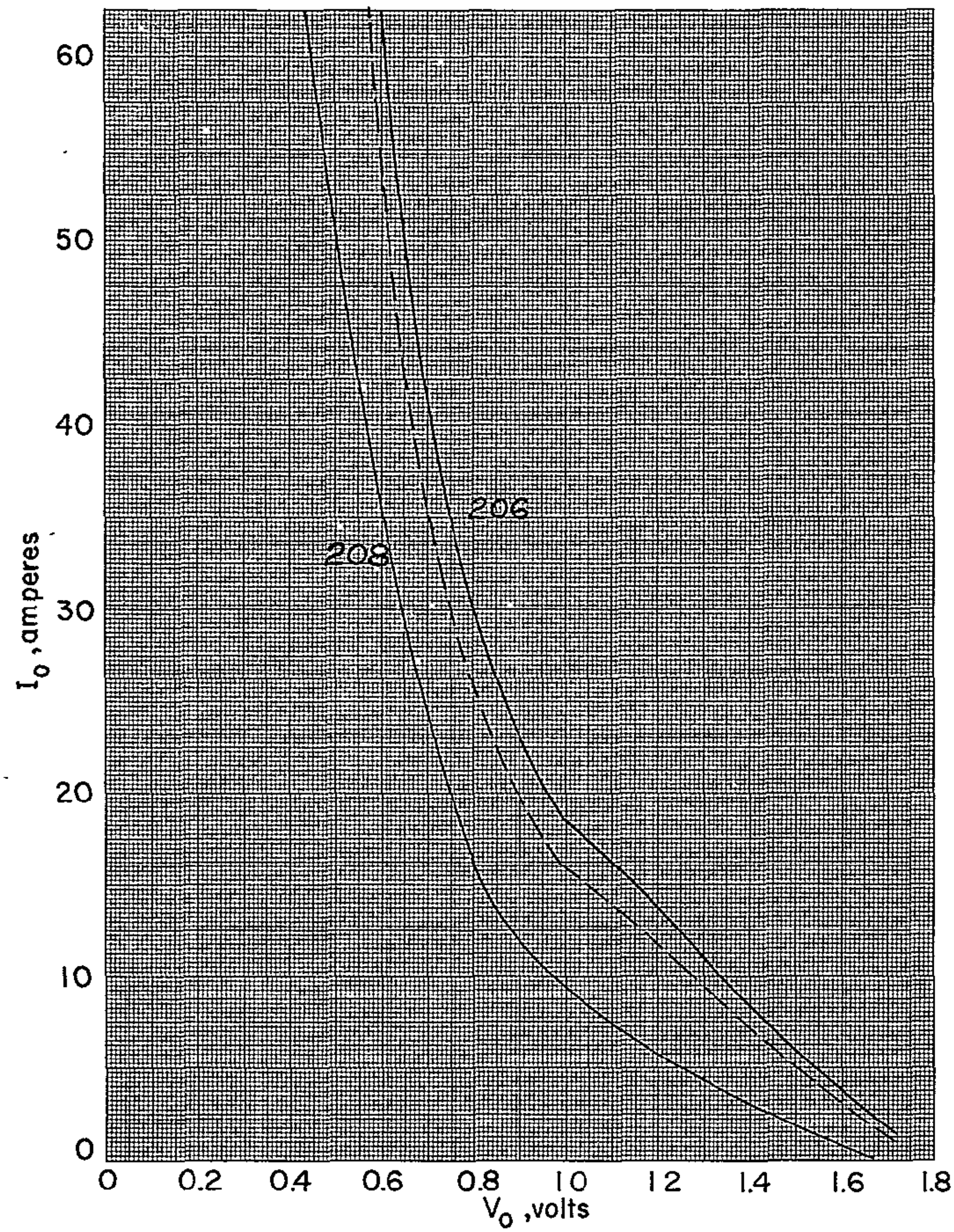
60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts
206
208

Figure 72

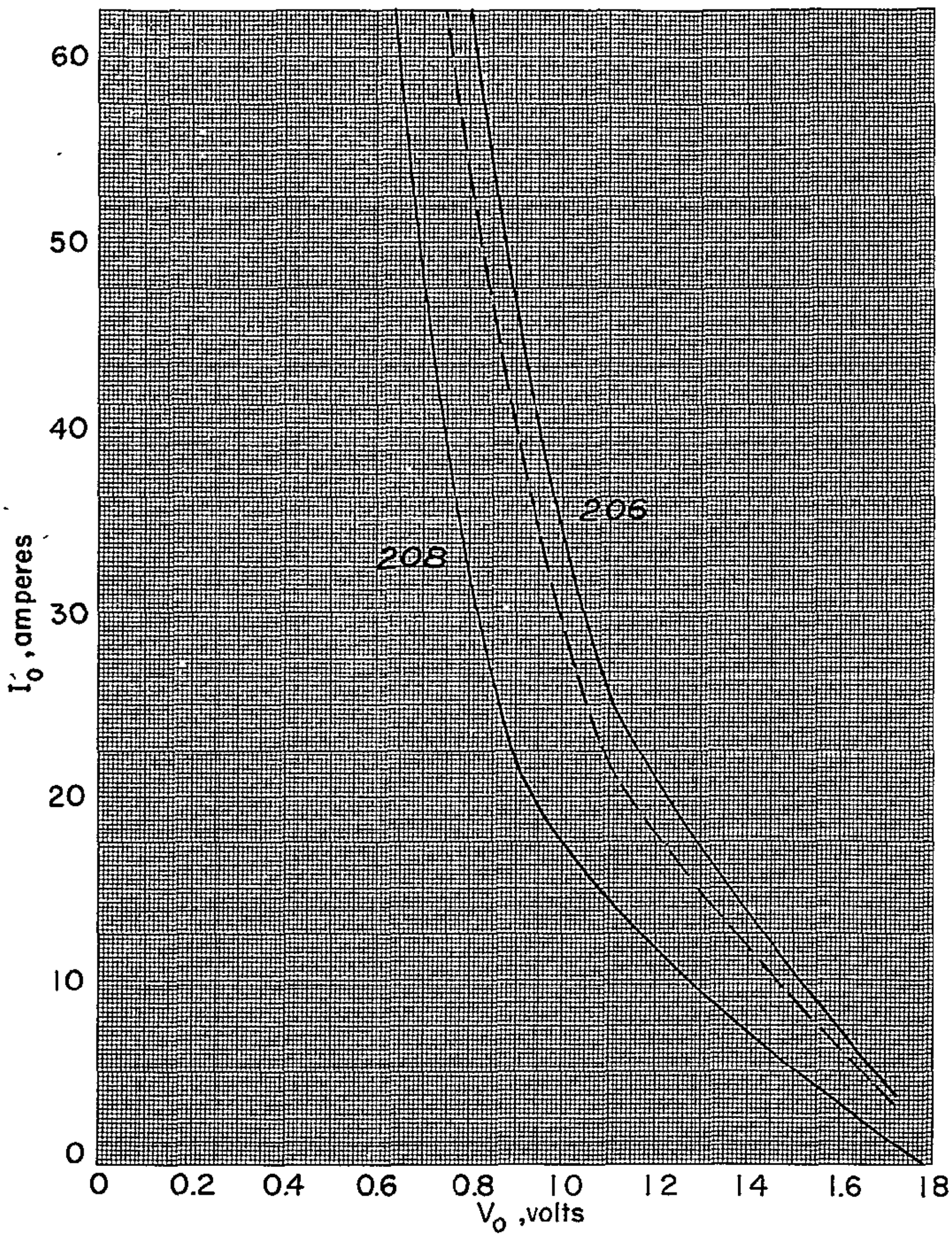
60
50
40
30
20
10
0
I'o , amperes
206
208
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
Vo ,volts

Figure 73

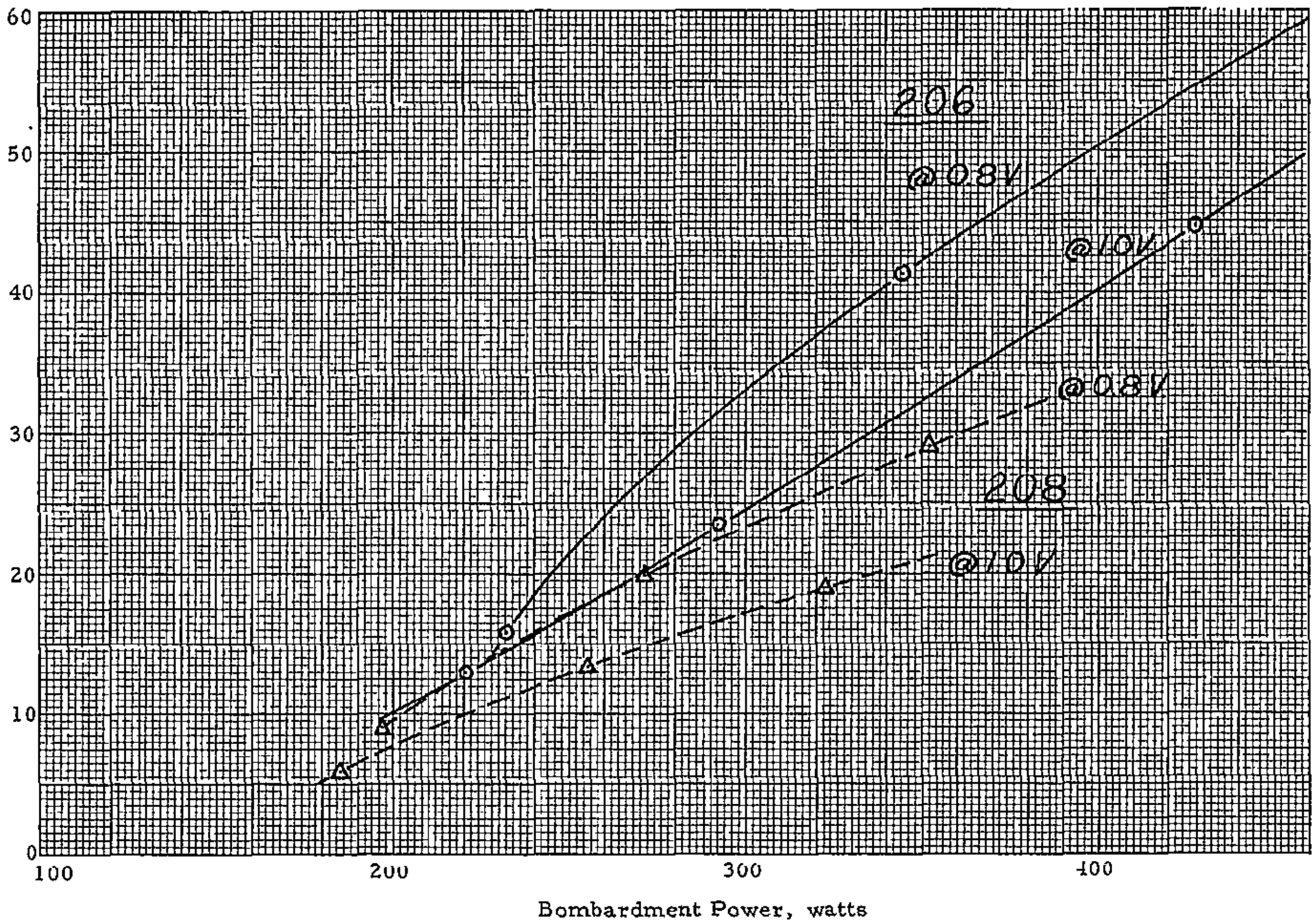
206
@08V
@10V
208
@08V
@10V
0
10
20
30
40
50
60
100
200
300
400
Bombardment Power, watts

Figure 74

8.8 Heat Pipe Temperature Drop

The particular area of the heat pipe which is of interest in this discussion is the capillary structure at the heat-receiving end. In most heat pipes the heat input is distributed over a cylindrical surface of relatively unobstructed construction; as a result the heat transfer flux densities are sufficiently small to justify the assumption that liquid evaporation occurs with no significant temperature drop. In the T-200 heat pipe design, the evaporating conditions were more severe, and as a result the temperature drop for evaporation reached a value of about 80°C, which raised the collector temperature excessively.

A temperature drop occurs at the liquid-vapor interface because evaporation at a finite rate can occur only when the atom rate of evaporation of the liquid exceeds the atom arrival rate from the vapor. From kinetic theory, the corresponding heat flux in the one-dimensional case (evaporation from a plane surface) is given by:

$$q\ (\text{watts/cm}^2) = 7.66 \times 10^{-4}\, \Delta H \left[\frac{p_1}{\sqrt{mT_1}} - \frac{p_2}{\sqrt{mT_2}} \right]$$

where

where	ΔH	is the heat of evaporation in cal/gm-mole
	p_1, p_2	are the saturation processes in dynes/cm^2
	T_1, T_2	are the corresponding temperatures in °K
	m	is the molecular weight in grams

This relationship is plotted in Figure 75, assuming $p_2 = 0$. The curve corresponds to the rate of evaporation when the surface is exposed to a vacuum. The dashed line represents the evaporation rate that would correspond to sonic vapor velocity at p_1, T_1.

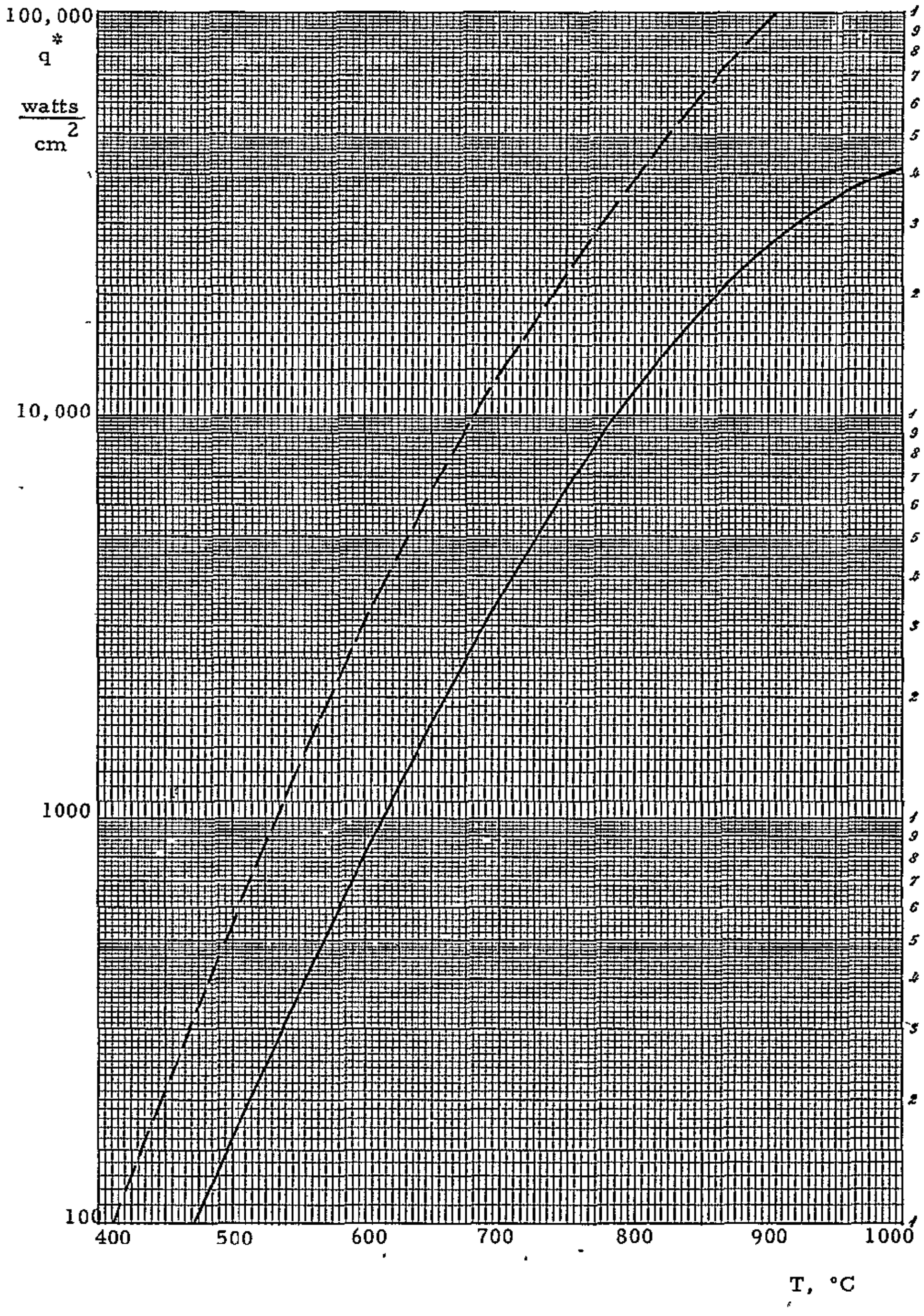
100,000
q*
watts/cm2
10,000
1000
100
400
500
600
700
800
900
1000
T, °C

Figure 75

In converter T-208, the heat transfer rate was given in section 6.7 at an emitter temperature of 2000°K by the equation:

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

At an output current of 83 amperes, the collector heat transfer would be 265.7 watts. The projected area of the heat pipe evaporator to handle this heat transfer was a circle approximately 0.590 in. in diameter, or 1.77 cm^2. The design heat transfer rate was then 265.7/1.77 = 150 watts/cm^2. Figure 75 shows that this rate, at a collector temperature (temperature of the liquid) of 700°C, would require a vapor temperature of 697°C, for then the heat transfer of 3500 W/cm^2 corresponding to liquid evaporation would exceed the rate of arrival of atoms from the vapor by the desired 150 W/cm^2. In that case, the temperature drop across the liquid-vapor interface would be negligible. However, not all of the projected area of the heat pipe evaporator was used to develop a liquid-vapor interface in converter T-208. To begin with, the capillary screen had an open area of only approximately 25%, so that the evaporation rate from the liquid occurred at a heat transfer rate of 150/0.25 = 600 W/sq cm; furthermore, the perforated plate, part No. 15, which was placed against the back of the screen as a support, also obstructed a large portion of the available liquid-vapor interface. The holes in the plate represented an open area of 0.413 cm^2, which was 23.4% of the projected area. The actual heat-transfer flux at which the sodium would evaporate in the T-208 converter heat pipe was then 600/0.234 = 2560 w/cm^2. Figure 75 shows that, at a vapor saturation temperature of 700°C, the evaporating liquid would have to be at 785°C, or an increase of 85°C.

If the holes in part No. 15 are replaced by a webbed support with 90% open area, the heat flux need only be 600/0.9 = 666 W/cm^2, and the liquid temperature corresponding to a 700°C vapor saturation temperature would then be 725°C, a reduction of 60°C in the collector temperature of T-208.

These temperature drops were difficult to detect in models of the heat pipe because they occur between the collector face and the heat pipe, and thermocouple instruments could not be mounted readily on the heated face of the collector, which was exposed to electron bombardment during heating.

9.1 Design of Converter T-209

The design approved by JPL for the fabrication of converter T-209 is shown in Figure 76. The differences between this design and that of the previous model T-208, shown in Figure 63, were as follows:

a. The heat pipe was longer by one inch, increasing the radiator area by 36%, from 38.3 to 52.0 sq cm. The reason for this increase was to augment the heat rejection capability of the heat pipe as much as possible without exceeding the capillary liquid column height where difficulty might be experienced when operating the device "against gravity."

b. The outgassing groove on the collector face was eliminated, yielding a collector area of 2.34 sq cm.

c. The capillary support at the back of the collector had a webbed design, shown in view A-A of Figure 76, instead of the perforated plate, shown in view A-A of Figure 63, which allowed a much larger flow cross section for the heat pipe vapor, and which was intended to avoid the large temperature drop at the liquid-vapor interface found in converter T-208 discussed in Section 8. 8.

d. The capillary mesh screen was made of niobium instead of stainless steel, and the mesh number was 100 instead of 400 because of the unavailability of niobium wire smaller than 0. 0035 in in diameter. Both the T-208 and T-209 designs used 2 wraps of mesh material. Appendix 13 presents the mesh design calculations for 100-mesh material.

e. The rhenium collector face was attached to the niobium substrate by pressure-bonding instead of vanadium brazing.

It had also been suggested to JPL to fabricate T-209 with an 0. 200-in.-thick emitter structure so as to explore the effect of emitter thickness on emitter temperature measurement accuracy, but JPL expressed a preference to retain the thin emitter configuration (0. 060 in. thick) because it minimizes the temperature drop across the thickness of the emitter piece

9.2 Fabrication of Converter T-209

The fabrication of the converter encountered no significant difficulties. As in T-208D, the cesium tube was made of 0. 025-in -wall niobium instead of 0. 010-in. -wall tantalum. It was found that the

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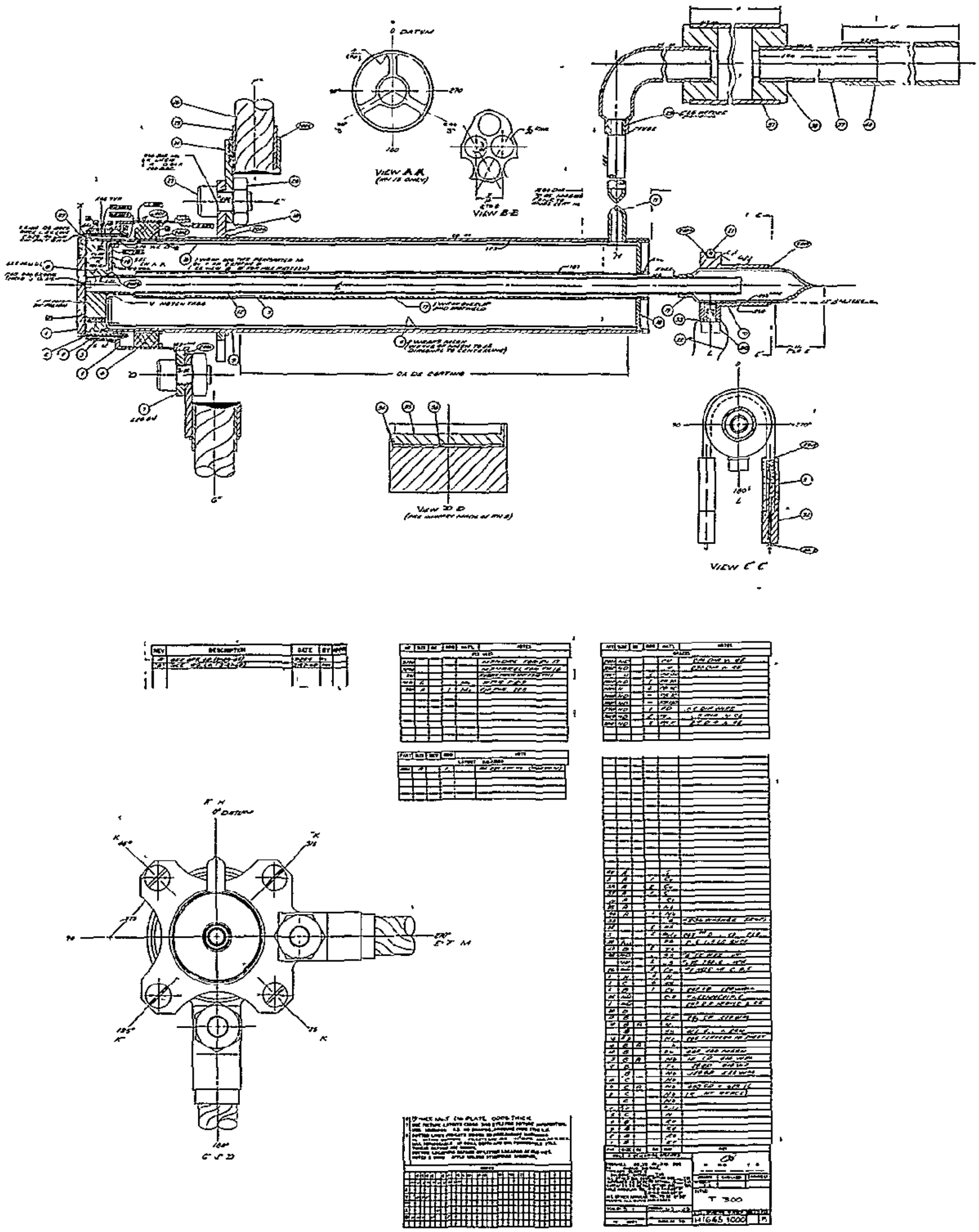


Figure 76

weld of the inner heat pipe tube to this tube required careful control; otherwise, the cesium tube could melt. The use of a thin (0.020-in. - dia) thoriated tungsten electrode was found to be particularly helpful

Initial fabrication efforts included exploring the problems of electron-beam welding a thick (0.200-in.) emitter to the emitter support assembly, and it was found difficult to produce a leak-tight weld because of the dissimilarity in cross-section of the parts joined. Attempts to obtain a leak-tight weld were not pursued.

The standard emitter (0.060 in. thick) used for the fabrication of T-209 was electroetched with the same procedure used for T-208 (1 minute at 5 volts). It was then thermally stabilized for 2 hours at 1990°C observed (approximately 2020°C true temperature) The emitter flatness was checked after thermal stabilization and the maximum deviation measured was 0.0006 in.

The capillary structure insertion required an 0.006-in. reduction in the diameter of the capillary support mandrel in order to accommodate a double wrap of the thicker 100-mesh niobium capillary screen.

It was deemed prudent to insure that the collector would be in intimate contact with the emitter surface during the final braze operation of converter T-209, and this was accomplished with the use of a small molybdenum weight.

The heat pipe portion of the envelope was outgassed for 8 hours at an average temperature of 500°C. The remainder of the sodium-fill operation was performed in the same manner as used for T-208D.

Converter outgassing was performed with care so as not to expose the converter envelope to elevated temperature conditions before the internal gases were pumped out through the small interelectrode gap. Cesium distillation was carried out at 200°C for 4 hours.

The completed model is shown in Figure 77, and as indicated there, its weight was 110 grams.

9.3 Test of Converter T-209

Converter T-209 was tested with a special double-spiral electron-bombardment filament shown in Figure 78. This filament shape was recommended by JPL to achieve a more uniform heating of the emitter piece.

The converter test consisted of 8 runs as follows: Runs 1 to 3 to map the output under dynamic conditions at 2000, 1900 and 1800°K; Run 4 to measure cesium conduction for interelectrode spacing determination; Runs 5 to 7 to map the output under static conditions at 1700, 1600 and 1800°C, and Run 8 to ascertain the magnitude of a suspected change in collector work function. Appendix 14 presents the data and I-V traces collected during test.

In converter T-208 it had been found that with the use of the heavier 0.025-in.-wall cesium tube, the cesium reservoir had a tendency to overheat. In T-209, it was found that the lengthening of the heat pipe had lowered the general level of temperatures in the converter, to the extent that the reservoir overheating problem was solved.

Figure 79 shows the optimized I-V characteristics; the solid lines were obtained under dynamic testing, and the dashed lines were obtained under static load.

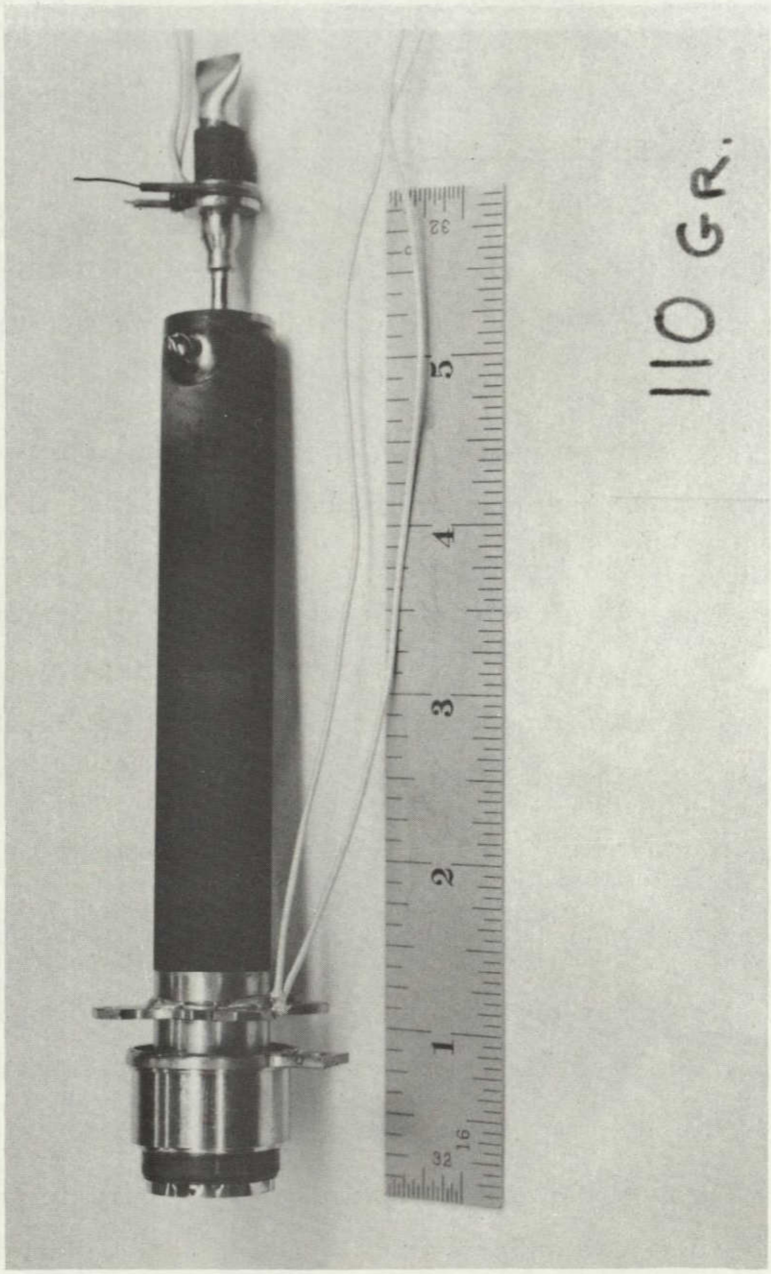


Figure 77

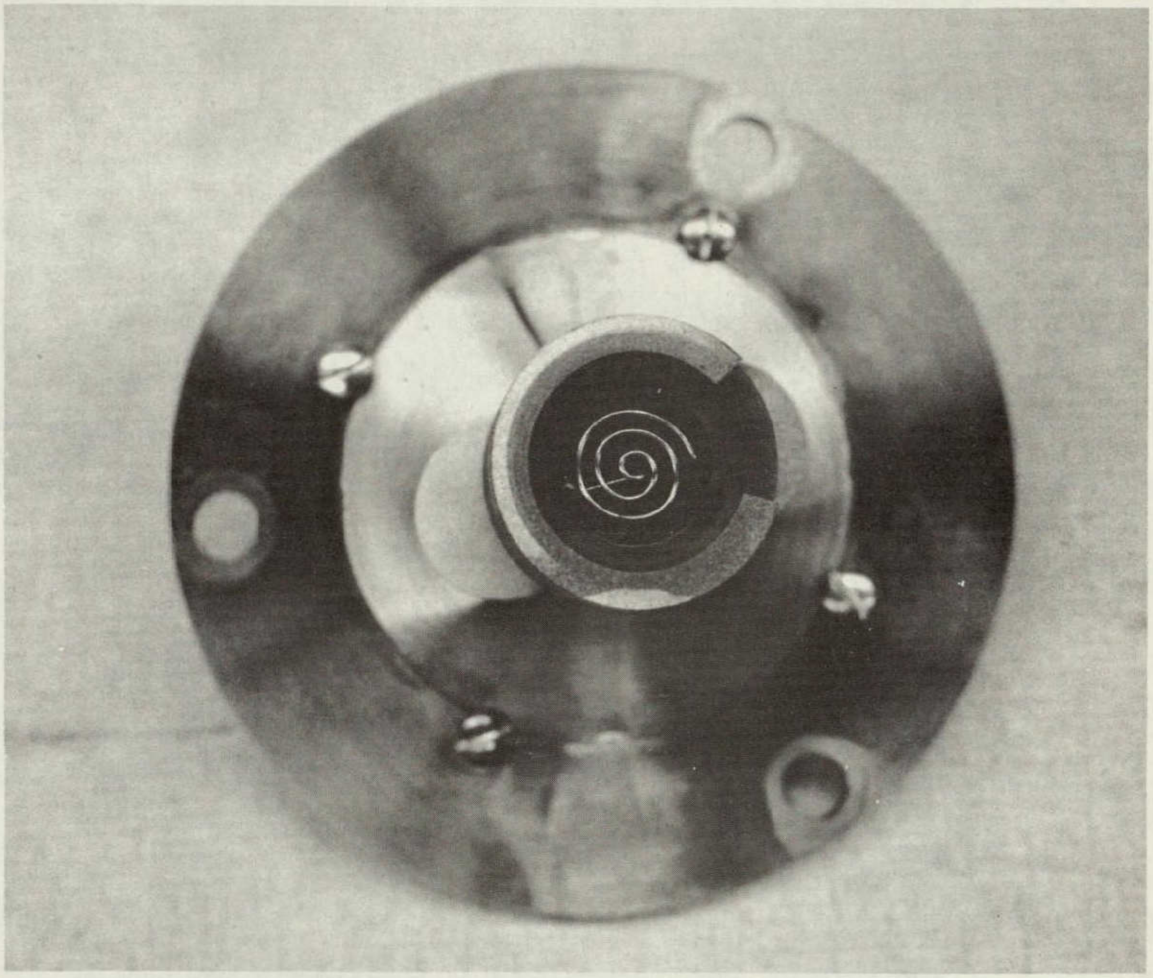


Figure 78

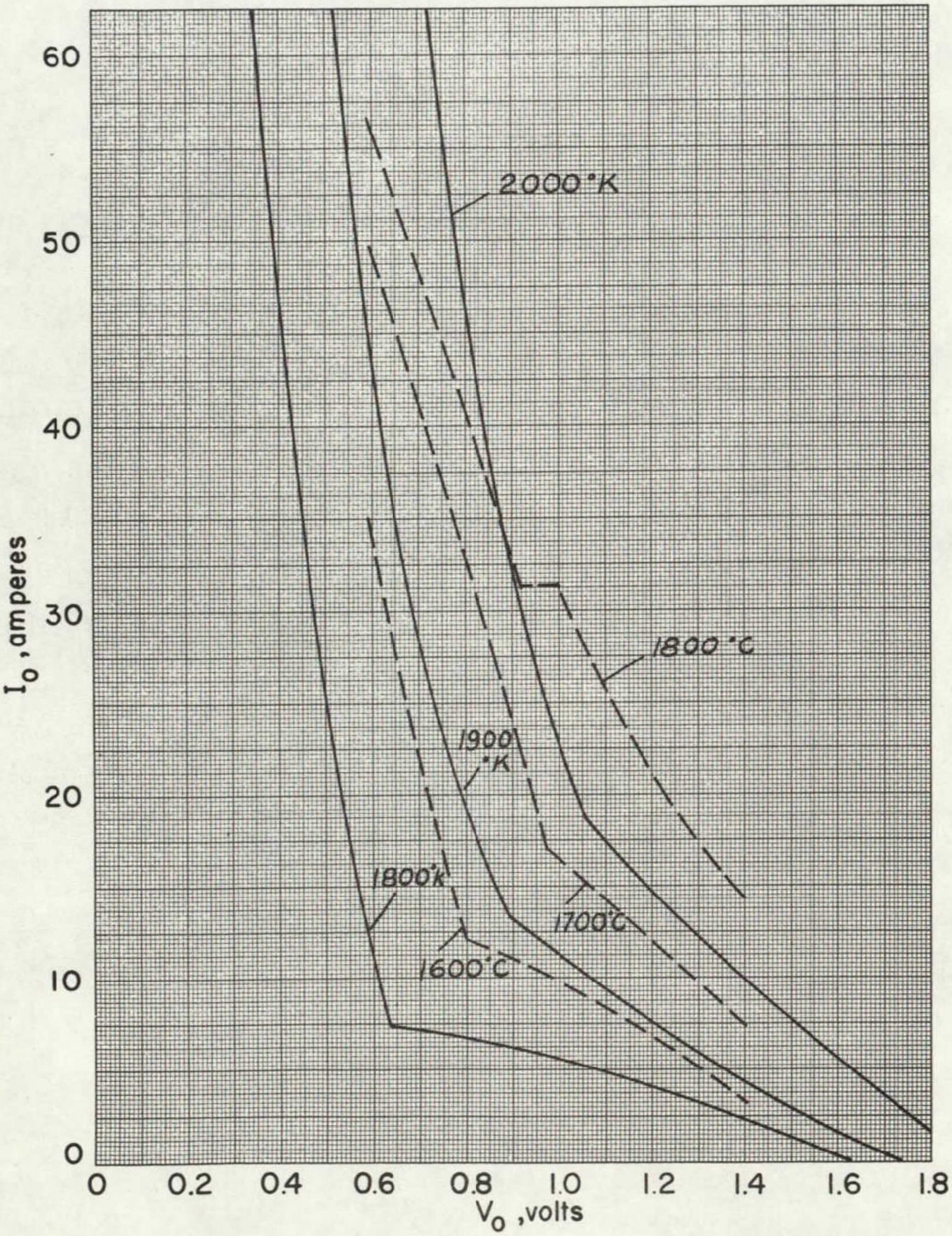

60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts
2000°K
1800°C
1900 °K
1800°K
1700°C
1600°C

Figure 79

Figure 80 is a plot of the cesium conduction data, which is compared with that of T-206 and T-208

9.4 Interpretation of Converter T-209 Test Results

As in the case of converter T-208, it was of interest to compare the performance of T-209 with that of T-206, because both converters had rhenium electrodes. In making the comparison, however, the difference in collector areas of these two converters, which were 2.34 sq cm and 2.52 sq cm, respectively, was accounted for. Figure 81 gives the optimized I-V traces at 2000°K for T-206, T-208 and T-209, where both the T-208 and T-209 traces have been scaled up by the respective collector area ratios of 2.52/2.16 and 2.52/2.34. On the basis of this figure, converter T-206 appeared to have better performance than T-209. Since such comparisons had often been found to be misleading because they included unreliable emitter temperature measurements, performances were compared on a thermal input basis, and this was done with Figure 82. The comparison of T-208 with T-206 on this type of plot, shown in Figure 74, had proven that Converter T-208 had a definitely lower output than T-206. Figure 82 showed that this was not the case for T-209, which had the same output as, or slightly higher output than, converter T-206. Thus, within the current capability to measure converter performance, it appeared that converter T-209 was as good as converter T-206.

The cesium conduction data given in Figure 80 was analyzed with the slope method previously outlined in section 6.6e, and it was found that the interelectrode spacing of converter T-209 was essentially the same as that of T-208. The calculations were as follows:

Converter	208		209	
p, torr	8	12	8	12
A, cm^2	2.16		2.34	
T_E, °K	2000°K		2000°K	
T_C, °K	880	885	800	800
$\partial Q/\partial p$, $\frac{watts}{torr}$	0.090	0.50	1.13	0.58
d, mils	2.06	2.33	1.90	2.32
Average d, mils	2.19		2.11	

As is evident in the data (sheet 5), in Figure 79 at 1800°C, 1.0 volt, and in Figure 82 at 366 watts, the output of converter T-209 was found to degrade during the high heat-transfer tests at 1800°C. This was the first instance of converter degradation experienced under this program To help diagnose the degradation, additional dynamic I-V characteristics were obtained for comparison with those recorded at the beginning of converter testing Figure 83 shows the curves which were obtained at a reservoir temperature of 623°K, with a power input of 308 watts, and after 3.5 and 30.6 hours of testing, respectively. The curves showed a shift along the voltage axis which was characteristic of an increase in collector work function. The amount of the shift was about 0.17 volt. There was no evidence to indicate that all degradation due to occur had in fact occurred at the end of the 30.6 hours.

Because the converter was still operative at the end of these tests, it was delivered to JPL rather than dismantled for detailed

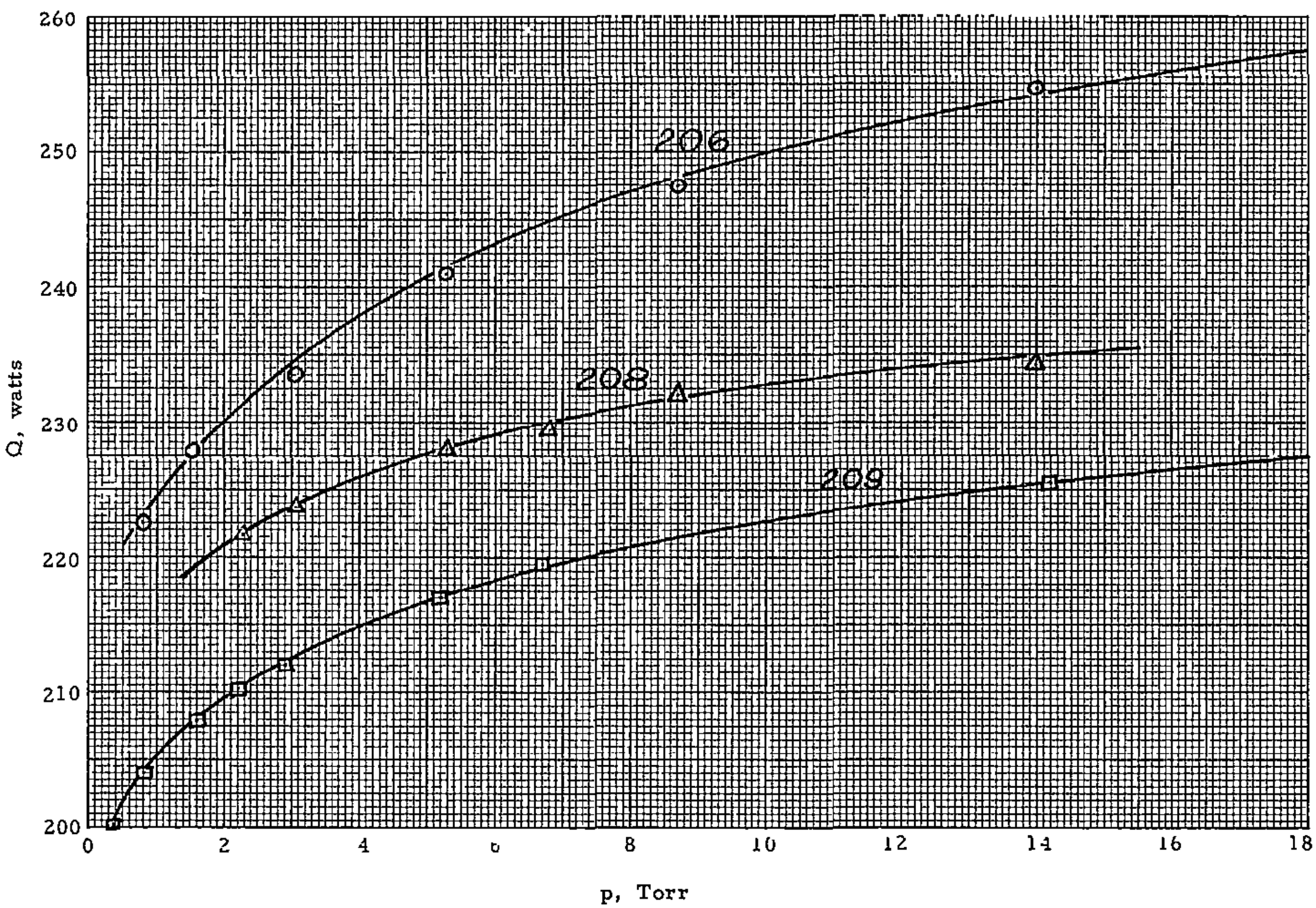

Q, watts
260
250
240
230
220
210
200
0
2
4
8
10
12
14
16
18
p, Torr
206
208
209

Figure 80

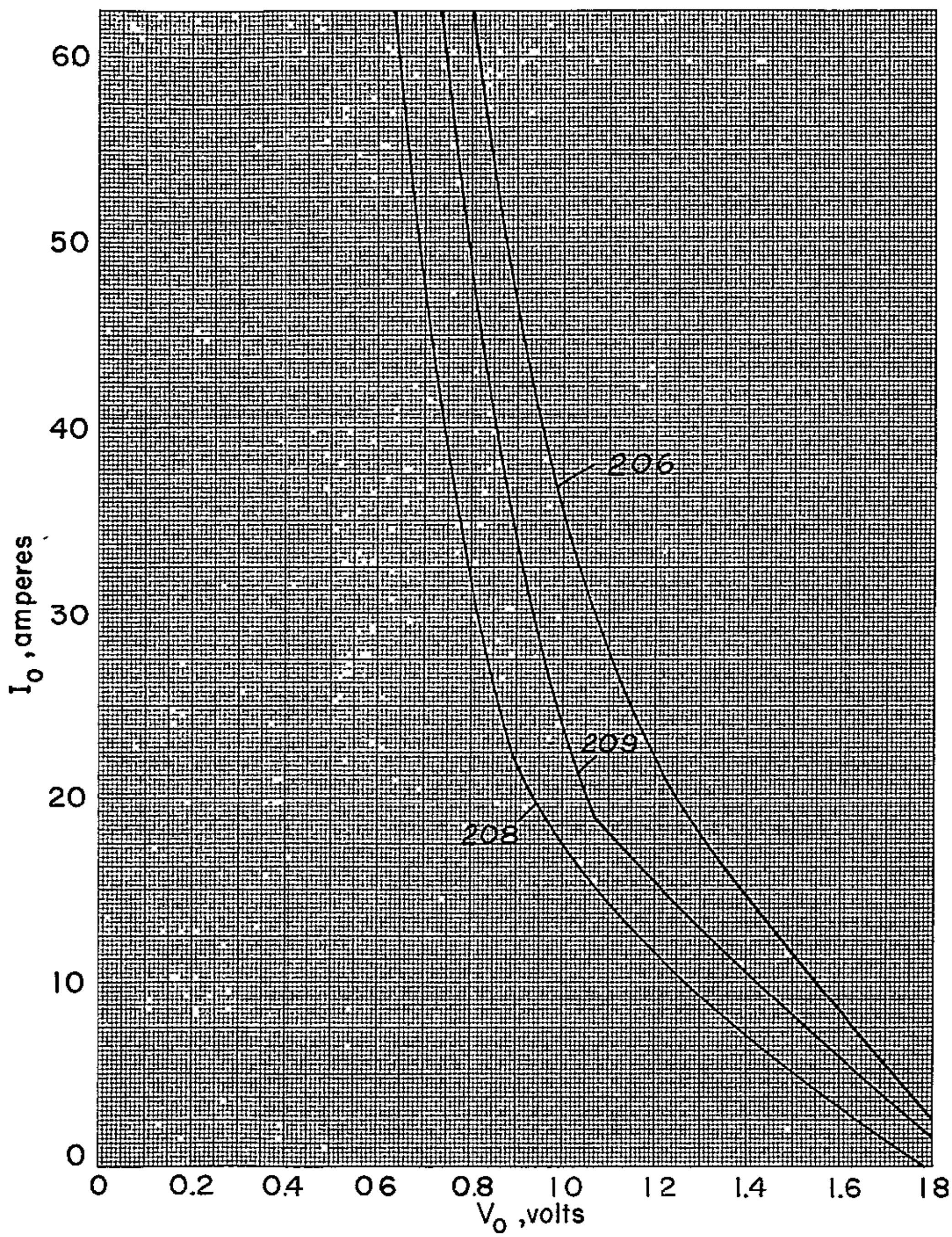

60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts
206
209
208

Figure 81

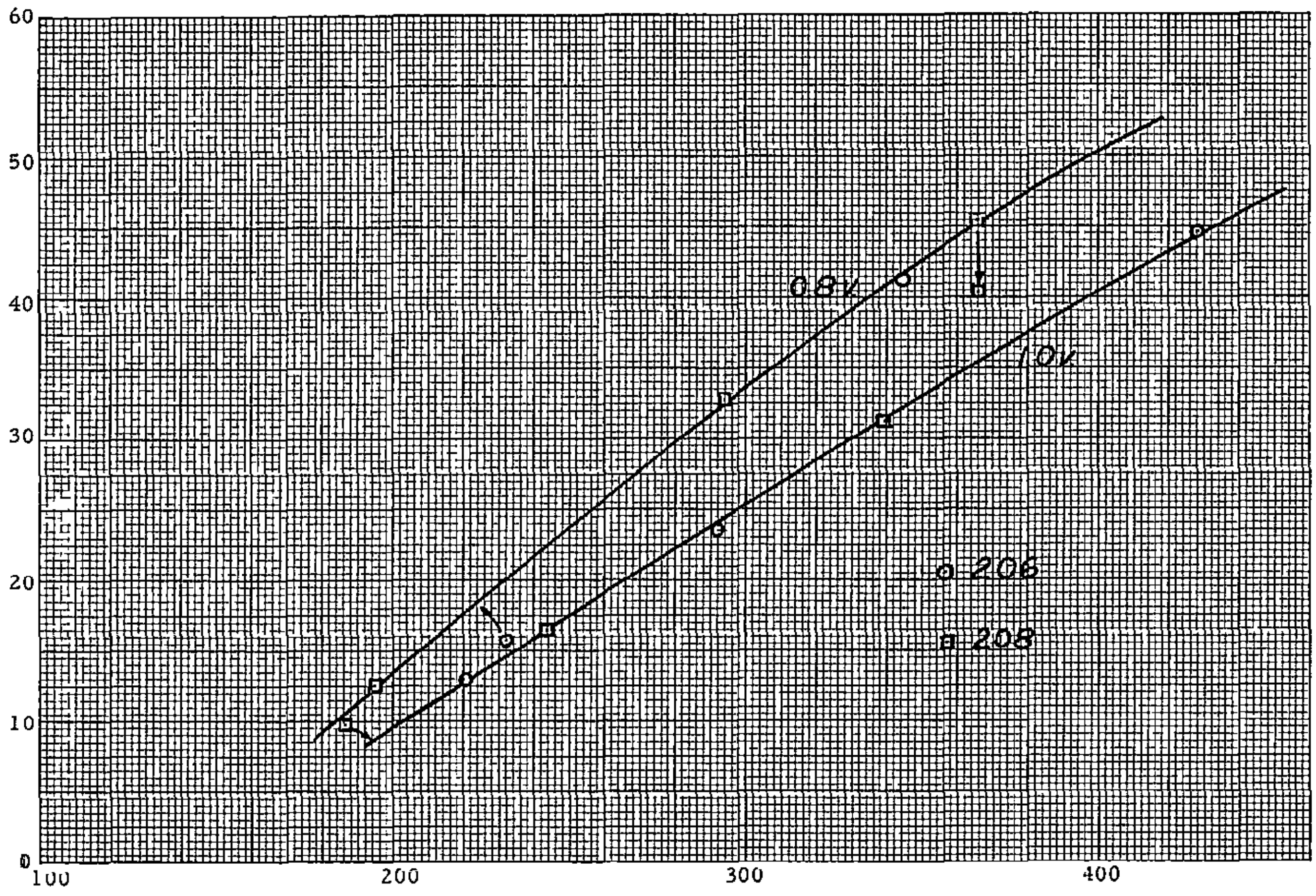


Figure 82

8382

THERMO ELECTRON CORPORATION

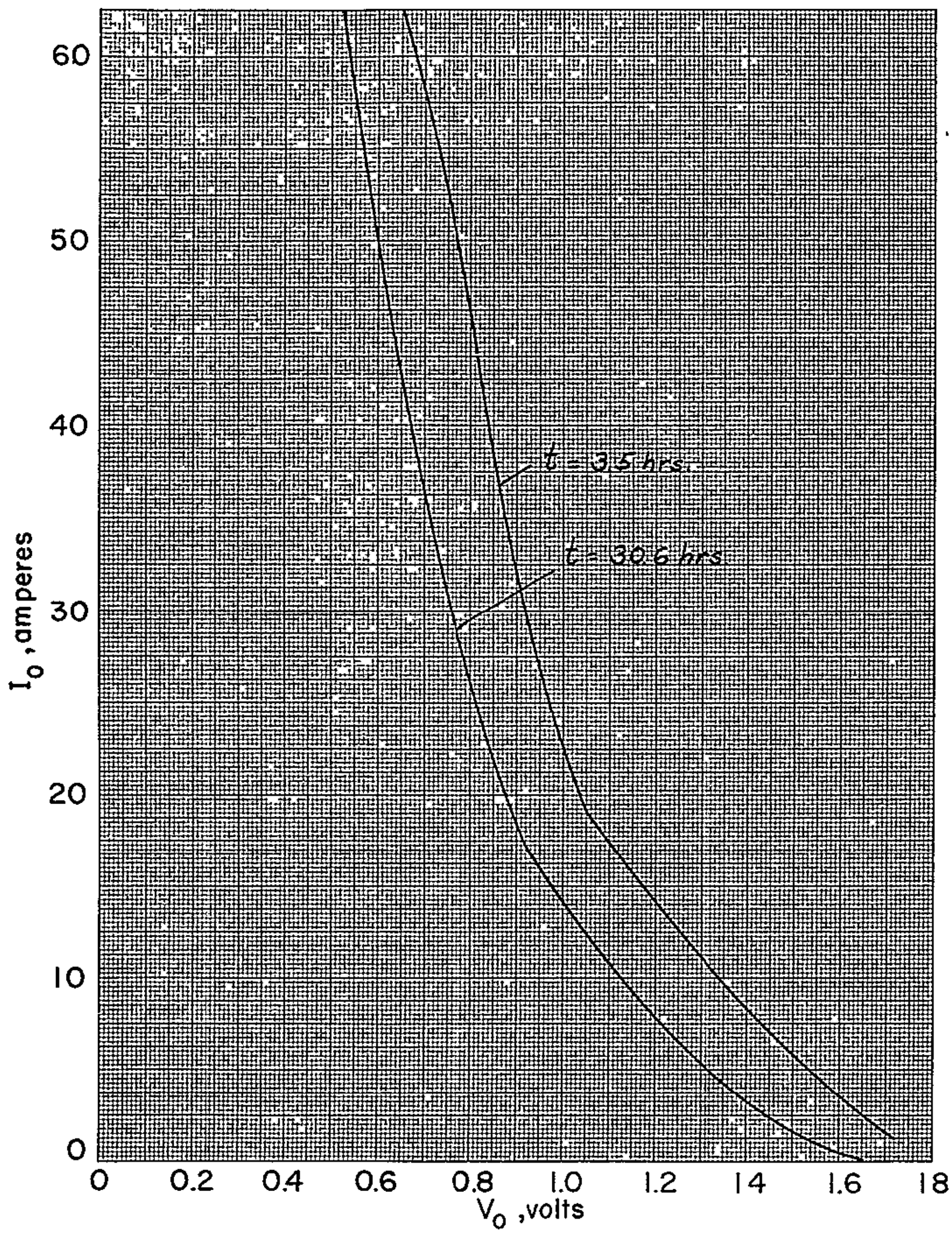

60
50
40
30
20
10
0
I_o, amperes
t = 3.5 hrs.
t = 30.6 hrs
0
0.2
0.4
0.6
0.8
1.0
1.2
14
1.6
18
V_o, volts

Figure 83

examination. It was judged extremely likely, however, that when such an examination would be conducted, it would reveal the presence of a sodium vapor leak from the heat pipe section into the converter envelope Sodium has a thermionic work function of approximately 2.28 eV as compared with a value of 1.81 eV for cesium. Thus the shift of 0.17 eV could easily have been the result of such a leak.

10 1 Fabrication of Converter T-210A

The design of the converter T-210 approved by JPL was identical to that of the T-209 converter. In particular, it included the longer collector heat pipe of T-209, which was selected to allow operation of the converter at high output currents without collector overheating.

The first T-210 fabrication effort was made using the emitter structure, including the re-entrant emitter support, of converter T-208B. This structure was vanadium-brazed to a new niobium seal flange and thermally stabilized for 1-3/4 hours at 2050°C.

The collector heat pipe assembly proceeded without difficulty. The converter was final-brazed and set up for outgassing. At the conclusion of heat-pipe outgassing, the pressure at the pump used to maintain vacuum within the heat pipe increased drastically when the vacuum surrounding the heat pipe was released. This was a clear indication of the existence of a leak, which must have formed during outgassing, because the entire assembly was leak-checked on both the cesium and sodium sides just prior to outgassing. A new leak check showed that the leak was at or close to the joint of the cesium tube to the inner heat pipe tube; unfortunately, this location is inaccessible and a repair of the leak could not be attempted. As an alternate remedy, the circular gap between these two tubes was closed at the end of the heat pipe by electron beam welding, but the closure was not leak-tight.

10.2 Fabrication of Converter T-210B

A review of the observations made during the assembly of T-210A indicated that the palladium braze between parts No 12 and 18 could result in a joint which is considerably out of square, so as to make it necessary to bend the tubes to the proper position, thereby stressing the joint and its vicinity, in order to proceed with prototype assembly. Consequently, special care was used to support the parts in proper alignment during the assembly of converter T-210B

The emitter structure used for this prototype was salvaged from converter T-208A, including the re-entrant support. It was thermally stabilized for 2-3/4 hours at 2050°C., and flatness measurements made after thermal stabilization showed that the emitter was flat within 0.0008 inch.

Special care was used in the construction of the capillary assembly to insure that no gaps would be present at the collector end, which could lead to a collapse of capillary force, and which could have occurred in T-209, since that converter still exhibited a lack of consistency between static and dynamic tests

During the final braze operation, PB130 braze material was used instead of nickel-plated copper wire by error. Since the final braze operation is performed slightly above the melting point of copper (which exceeds substantially that of PB 130), considerable braze flow occurred over the neighboring areas of the converter structure; fortunately, no damage resulted.

The heat pipe was outgassed at 500°C, while keeping the sodium ampoule at 350°C, for 7 hours The sodium was then melted by placing the heat pipe and reservoir in an oven at 150°C for 2 hours; the ampoule was then broken, and the sodium caused to flow into the heat pipe.

The converter outgassing was performed with a shield around the heat pipe radiator to insure that the collector could reach normal operating temperatures and to bring the emitter to temperature during outgassing despite the relatively low heat inputs applied. The emitter temperature was maintained at 1700°C, and the collector at 800°C, for 24 hours.

Cesium distillation was carried out at 200°C for 3 hours.

10.3 Testing of Converter T-210B

Converter T-210B was tested using the same procedure as for converter T-209, including the spiral filament. The data is presented in Appendix 15. Figure 84 shows the optimized I-V characteristics, the solid lines representing data obtained under dynamic loading, and the dashed ones corresponding to static loading. Figure 85 gives the cesium conduction data, and compares it with that obtained from converter T-209. During the testing of T-210, the converter showed no signs of a tendency to degrade in output as had been observed near the end of testing of converter T-209.

10.4 Interpretation of Converter T-210 Test Data:

Since converter T-210 was a duplicate of converter T-209, and since converter T-209 had in turn duplicated well the results obtained with the previous T-206 which had had rhenium electrodes, it was of particular interest to compare the performance of T-210 with that of T-209. Figure 86 compares the optimum envelopes of these two converters at 2000°K. As can be seen, they had nearly identical performance at low voltages and high currents; at voltages above 1.1 volt, however, converter T-209 produced more output, and it was concluded that this difference was due to a difference in interelectrode spacing: T-210 was found to have a larger spacing, as discussed below, and the output level obtained supported the general observation that, at spacings of the order of 2 mils and at 2000°K, spacing has a strong effect at the higher voltage end of the I-V characteristics, and practically none at the lower end.

From the point of view of thermal performance, Figure 87 shows that T-209 and T-210 were essentially identical.

The performance of converter T-210 was also compared with that of state-of-the-art converters tested by JPL. In particular, the JPL data indicated that a typical converter with a collector area of 1.88 cm^2 had the following output characteristics:

Hohlraum Temperature, °C	1735	1735
Output Voltage, volt	0 7	0.8
Output Current, A	50 7	35.6
Power Input, watts	376	339
Cesium Reservoir Temp , °K	612	602

In attempting to duplicate these points in converter T-210, a method was sought such that it would not require an accurate emitter temperature measurement; this was done to avoid the inconsistency problem which had been faced throughout the program of the T-200 emitter temperature measurements The method

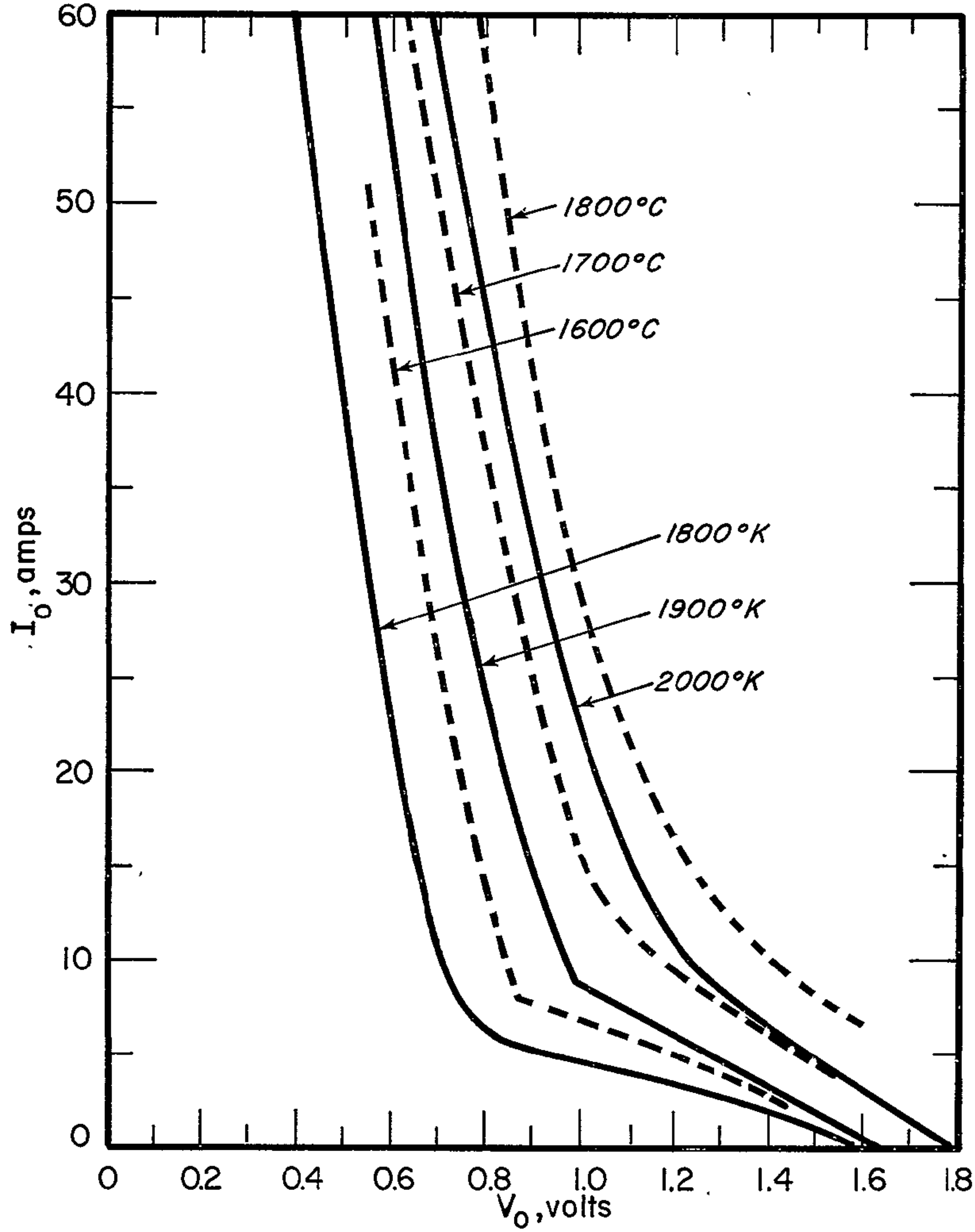
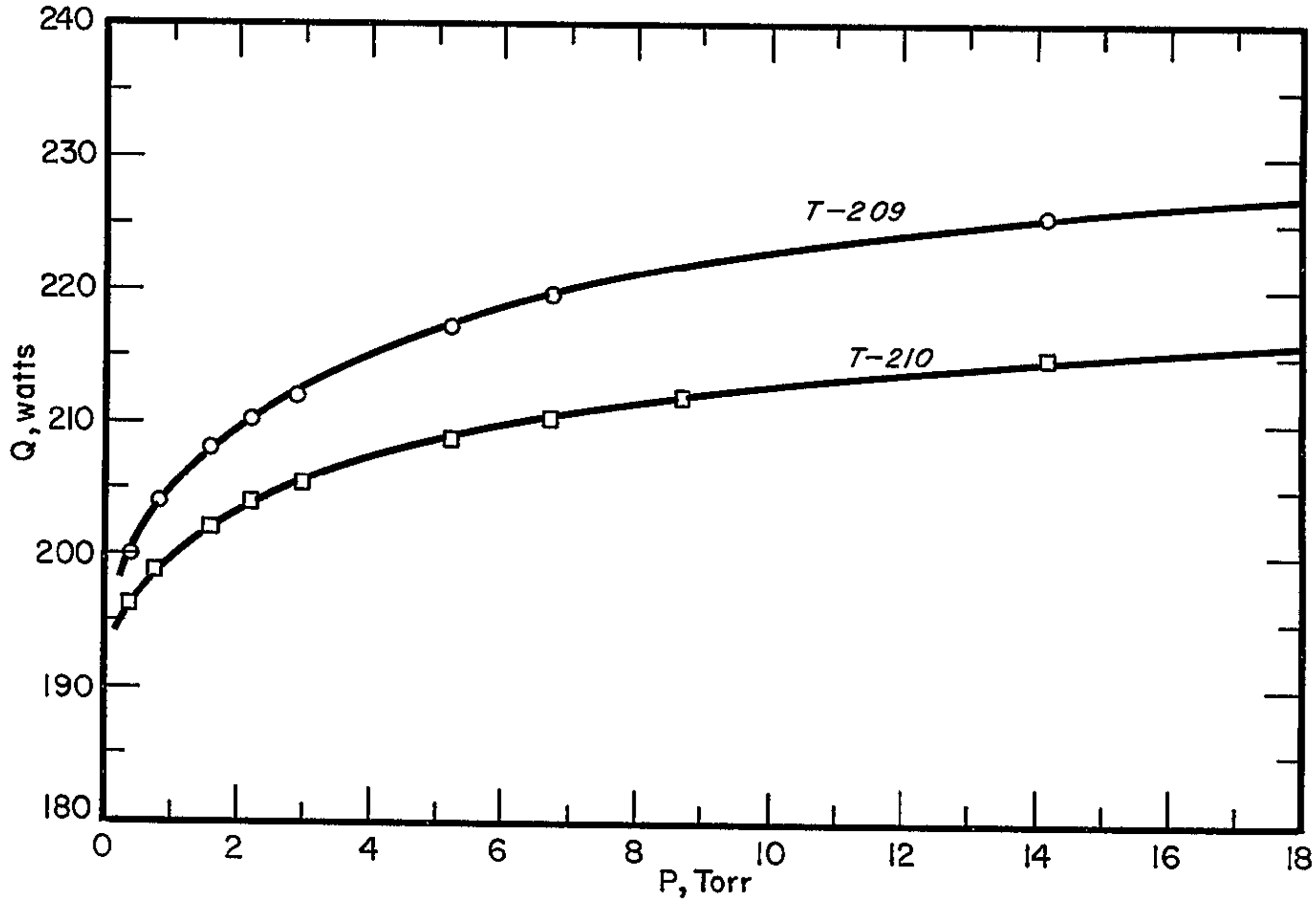

60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
I₀, amps
V₀, volts
1800°C
1700°C
1600°C
1800°K
1900°K
2000°K

Figure 84.



240
230
220
210
200
190
180
Q, watts
0
2
4
6
8
10
12
14
16
18
P, Torr
T-209
T-210

Figure 85.

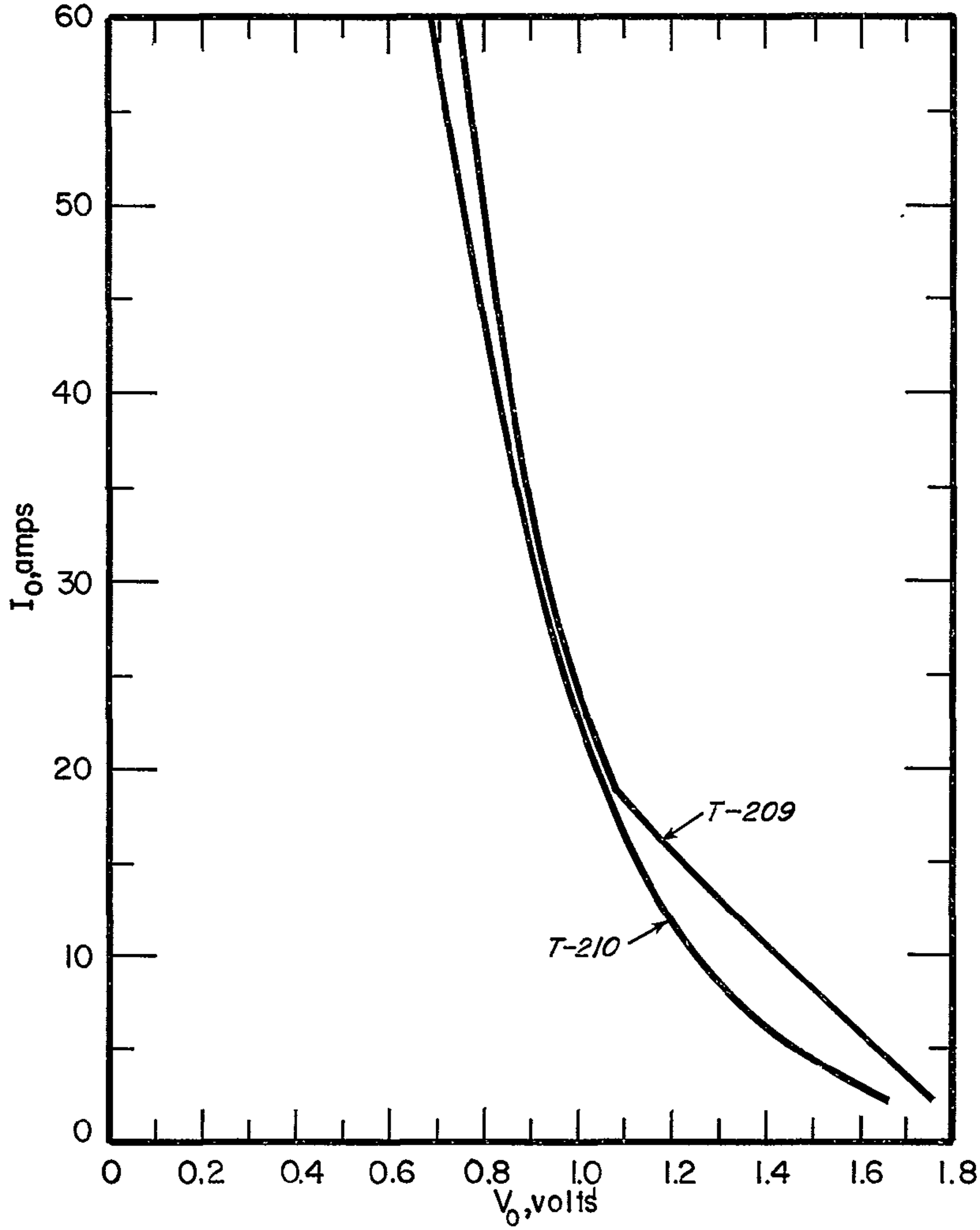

60
50
40
30
20
10
0
I_0,amps
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_0,volts
T-209
T-210

Figure 86.

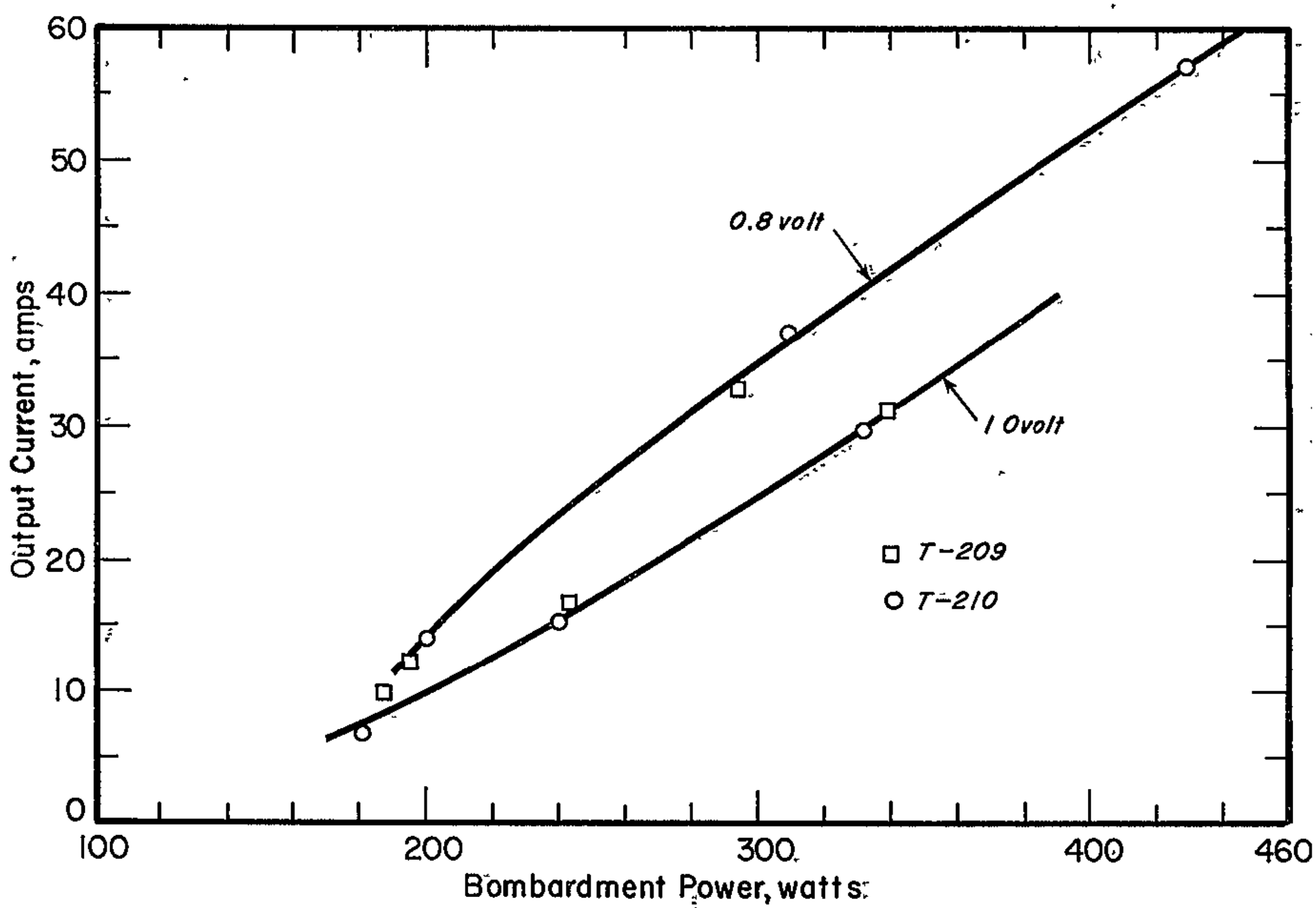

60
50
40
30
20
10
0
Output Current, amps
100
200
300
400
460
Bombardment Power, watts
0.8 volt
1.0 volt
T-209
T-210

Figure 87.

adopted was based on defining an equivalent power input: If T-210 were to have the same output current density as the JPL converter, its output current would be larger because of its larger collector area of 2.34 cm^2; then it would also require more input power in proportion to the additional output current, and the typical electron cooling power of 2.67 watts per ampere was used to compute this additional current. The predicted T-210 output was then:

Hohlraum Temperature, °C	1735	1735
Output Voltage, volt	0 7	0.8
Output Current, A	63 1	44.3
Power Input, Watts	409	362
Cesium Reservoir Temp., °K	612	602

When the test conditions of T-210 were adjusted for output voltages of 0.7 and 0.8 volt at 409 and 376 power input, respectively, the actual values of the other variables were found to be (Sheet 5, data points 7 and 8):

Hohlraum Temperature, °C	1733	1738
Output Voltage, volt	0.7	0.8
Output Current, A	61.1	44.5
Power Input, Watts	408	362
Cesium Reservoir Temp., °K	642	630

which, except for the reservoir temperatures, showed excellent agreement with the JPL data No attempt was made to resolve the 30°C discrepancy in reservoir temperatures, but it is known that instrumentation errors of this magnitude can easily occur when a thermocouple lead makes contact at a cooler point in the vicinity of the instrumented point.

TASK II

MULTICONVERTER GENERATOR DESIGN

1. Introduction

The design of the multiconverter generator was aimed at producing a generator configuration that would accommodate a large number of converters, so as to be able to generate a large amount of power from a single solar concentrator, and to allow the possibility of a moderate number of series-parallel connections for greater power network reliability.

This task consisted of a thermal analysis of the generator solar cavity, a calculation of net flux available to the converters and of the electrical power that could then be generated, and a design of the generator.

2 Thermal Analysis

2.1 Cavity Geometry

For the purpose of conducting a flux distribution analysis, the generator cavity geometry was simplified so that a moderate number of parameters could describe it. The simplified geometry is shown in Figure 88, and it approached closely the actual cavity configuration. The major differences were:

1. Cavity interstitial spaces were lumped with cavity areas and treated analytically as sharing common average absorptivity and emissivity properties. Thus, the values of emissivity and absorptivity which were specifically assumed for the various cavity surfaces had to take into account the fact that they included the properties of these interstitial spaces.

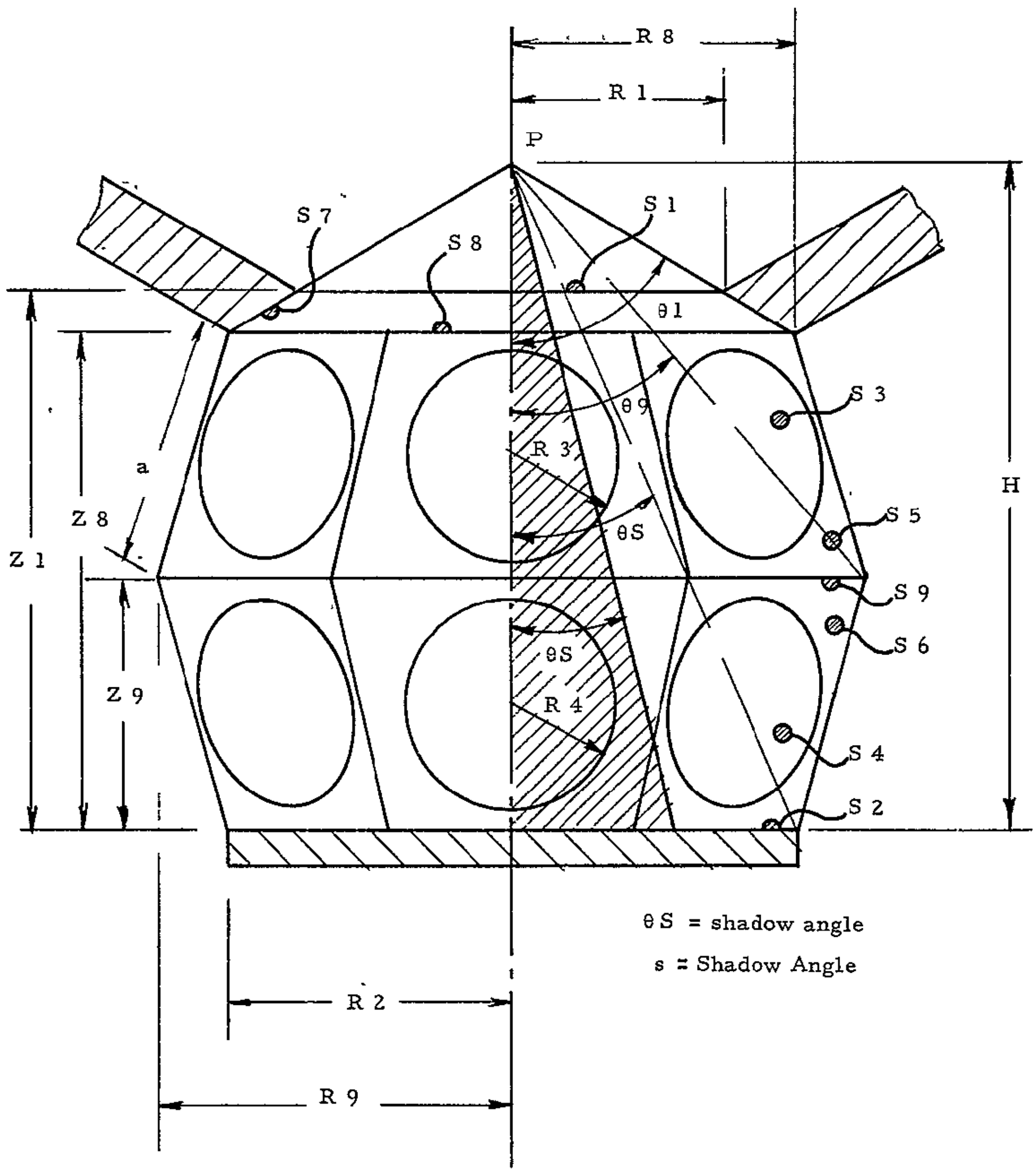


Figure 88 Cavity Nomenclature.

a shadow angle θ_s produced by the generator and its test chamber on the solar concentrator.

Although the intensity produced by an ideal paraboloid increased slightly with θ, the fact that profile errors also increased with θ in actual concentrators had led to the assumption in this analysis that the solar flux was spread spherically with uniform intensity between the angles θ_s and θ_1. In all cases, θ_s was assumed to equal 10°.

The reflection of both the solar flux and the cavity thermal radiation within the cavity was assumed to be diffuse The view factors Fij between all seven areas Si of the cavity were calculated for each combination of number of converters and cavity aperture. Defining Ei and Ai as the thermal emissivity and solar absorptivity of surface Si, respectively, each cavity surface i receives directly a solar input Wi, the fraction Fi of the total solar input W:

$$Wi = Fi*W$$

and it thermally radiates a flux per unit area:

$$Ei * Pi$$

where: Pi = SIGMA * Ti ** 4

Ti is the temperature of cavity surface i

and: SIGMA = 5.679 E - 12 (E = exponentiation)

Denoting by Vi and Hi the total thermal and solar fluxes arriving at each area i, the following matrix equations describe the cavity heat balance:

$$[Eij] * [Hi] = [Pii]$$

and $$[Aij] * [Vi] = [Wi]$$

where $$[Pii] = [Fij] * [Ei * Pi * Si]$$

$$Eij = -Fij * (1. - Ei) \text{ for } i \neq j$$

$$Eij = 1 - (1. - Ei) * Fii \text{ for } i = j$$

and Aij was obtained using the expressions for Eij and substituting Ai for Ei.

The net heat input at each surface was then:

$$Qi = Ei * (Hi - Si * Pi) + Ai * Vi$$

As it should be evident, the above calculations could be performed once the solar flux input was defined and the cavity temperatures were known. In all cases, the rear cavity surface temperature was assumed to equal the selected converter emitter temperature, and the cone piece temperature was arbitrarily assigned the value T7 = 1000°K. To describe the temperature distribution of the converter shoe pieces, these were assigned a single finite value of temperature which was found by computer iteration so that the temperature value would simultaneously satisfy the cavity flux distribution equations and the conduction heat transfer characteristics of the shoe piece.

2.3 Computer Program

Figure 89 shows the flow diagram of the computer program used to solve the flux distribution problem, and Appendix 18 gives the program listing. The program was arranged so that the input data consisted of the cavity aperture diameter, the solar flux input, the number of converters, the selected emitter temperature, and the emissivity and absorptivity of each surface element of the cavity The computer then calculated the heat reradiated by the cavity, the equivalent cavity emissivity, the heat absorbed by the rear cavity piece, the front cone piece and by each of the converters of each family, and the temperature reached by the shoe piece of each converter.

2.4 Concentrator Performance

As explained above, one of the required computer program inputs was the solar flux input corresponding to each value of cavity aperture. Two heat sources were considered: an 11.5 ft. dia. concentrator operated on Earth ground in conjunction with a protective pyrex window, and a 9.5 ft. dia. concentrator operated in cislunar space. In order to determine the net heat flux delivered to the cavity for these two cases, it was assumed that the relative flux intensity at the focal plane as a function of the ratio of position to theoretical solar image size would equal the values achieved in 5-foot concentrators. In addition, it was assumed that the concentrator reflectivity for the Earth case was 88%, and for the cislunar case, 89%; corresponding shadow losses assumed were 5% and 2%. A window loss of 11% was included in the Earth case. Appendix 19 presents the pertinent calculations, and the resulting curves of cavity input flux vs. cavity aperture diameter are given in Figure 90.

2 5 Predicted Thermal Performance of Generator Cavity

The flux distribution in the generator cavity was computed for 137 different conditions. Appendix 20 gives the computer outputs

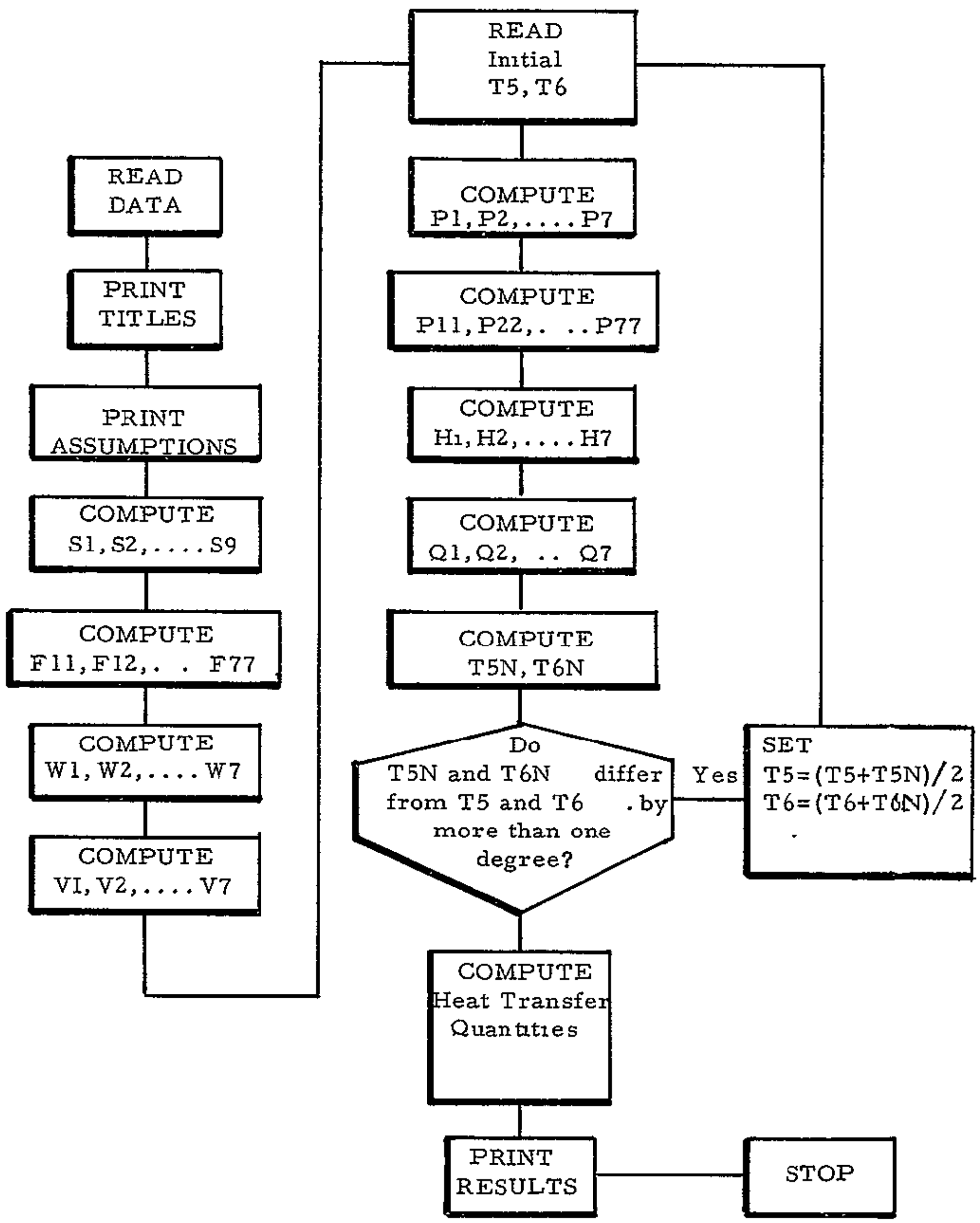


Figure 89 Computer Program Flow Chart.

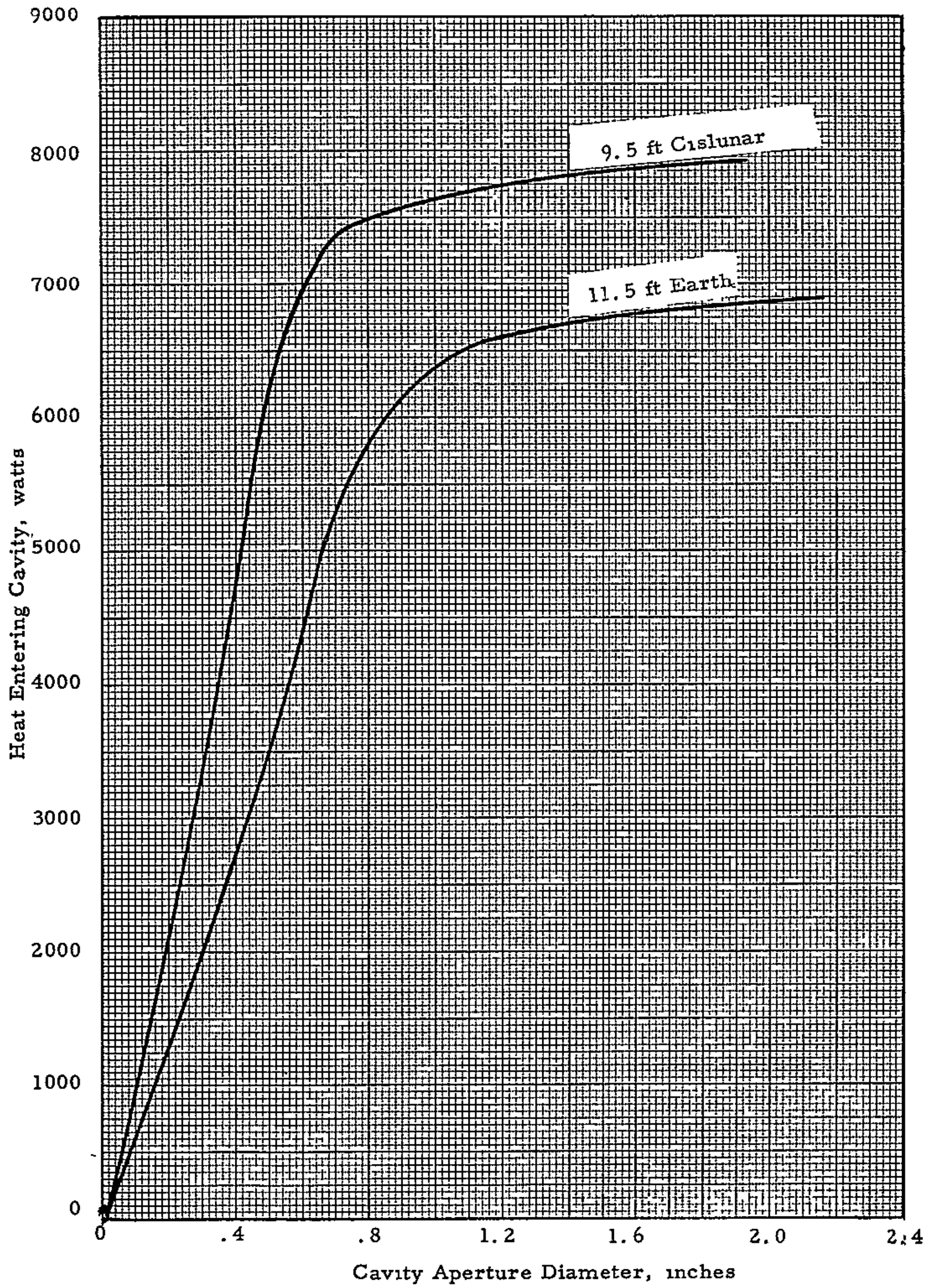

9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Heat Entering Cavity, watts
9.5 ft Cislunar
11.5 ft Earth
0
.4
.8
1.2
1.6
2.0
2.4
Cavity Aperture Diameter, inches

Figure 90

obtained. In the first nine runs, the calculations performed aimed at evaluating the required emissivity on the heated faces of the converters to produce a balanced distribution of heat between the two families of converters. It was assumed that the emissivity of the heated face would be adjusted by grooving or etching the largest circle that could be inscribed on the heated face of each shoe piece, and that an increase in emissivity would be accompanied by a corresponding increase in solar absorptivity as predicted by the equations of radiation from v-grooves with diffuse surfaces. In the first nine runs, the chosen values of emissivity were 0.250, 0.400 and 0 563, and the corresponding values of solar absorptivity were 0.500, 0.750 and 0.875. All nine possible combinations of these three values were assigned to the two families of converters in a generator with 14 converters, a cavity aperture diameter of 1.400 inches, with the solar input corresponding to operation on Earth ground. The difference in the net heat transfer to the emitter structure of the converters of each family was then calculated, and it is plotted in Figure 91. The figure shows by extrapolation that, for the selected generator conditions, thermal balance was achieved for the values of E4 of 0.250, 0.400 and 0.563, provided the corresponding values of E3 were 0.145, 0.285 and 0.345 respectively Since polished rhenium had an emissivity of approximately 0.250, the lowest possible value of E3 was 0.250, and Figure 91 shows by interpolation that the corresponding value of E4 for thermal balance was 0.365 to which corresponded a value of A4 of 0.700. Conversely, it was assumed that the highest value of A4 that could be achieved was 0.875 (corresponding to three reflections within the hit surface at a base absorptivity of 0.500) to which corresponded E4 = 0.563. The corresponding value of E3 at thermal balance predicted by Figure 91 was E3 = 0.310, and the corresponding absorptivity was A3 = 0.605.

In the next 64 runs, these two extremes of emissivity combinations were used to compute the thermal performance of generators with 10, 12, 14 and 16 converters, operated at 2000°K on Earth and in cislunar space, at four different values of cavity apertures The results are plotted in Figures 92 to 95. It can be noticed in these figures that the large difference in emissivity conditions resulted in minor differences of thermal performance, and it was therefore possible to consider the use of the lower emissivity values which required the surface treatment of only one family of converters.

To determine the effect of changes in cavity temperature, 64 more runs were computed for 14 and 16 converter generators with the lower emissivity values (E3 = 0.250, E4 = 0.365, A3 = 0.500, A4 = 0.700), and operated both on Earth and in cislunar space with the converters at 1900, 2000, 2100 and 2200°K, at various cavity aperture diameters. The results of these runs are given in Figures 96 and 97. One of the most remarkable indications given by these two figures was that the 14-converter generator, which had been thermally balanced at Earth flux and for a cavity aperture of 1.4 inch, remained thermally balanced at the cislunar flux, at all emitter temperatures, and even over a wide range of aperture diameter variations. Although the 16-converter generator was not as closely balanced for the emissivity values selected, it should be noted that in the case of greatest imbalance, the heat QC3 received by the front converters exceeded that received by the rear converters by less than 10%.

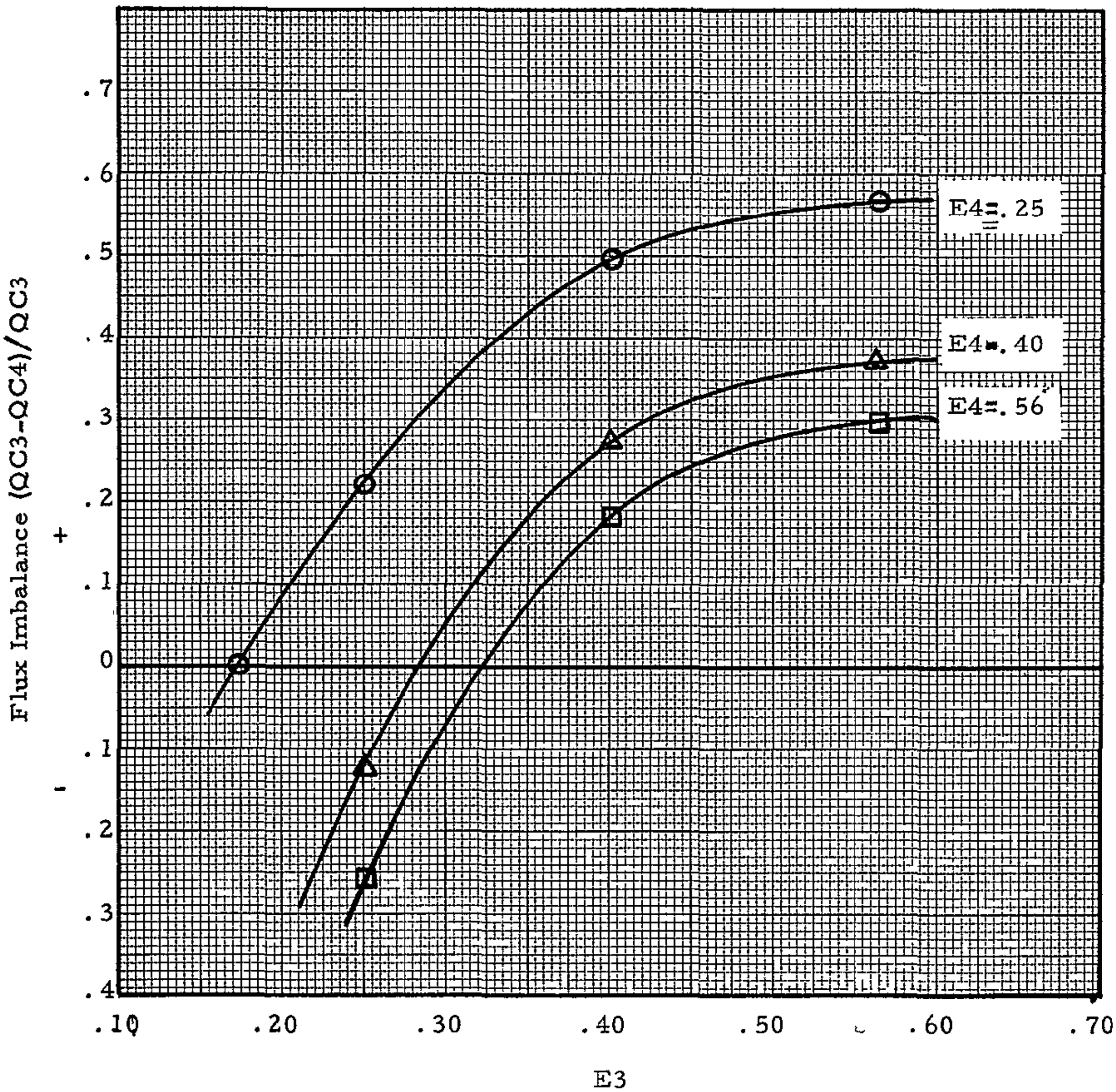


Figure 91 Effect of Surface Treatment on Flux Distribution.

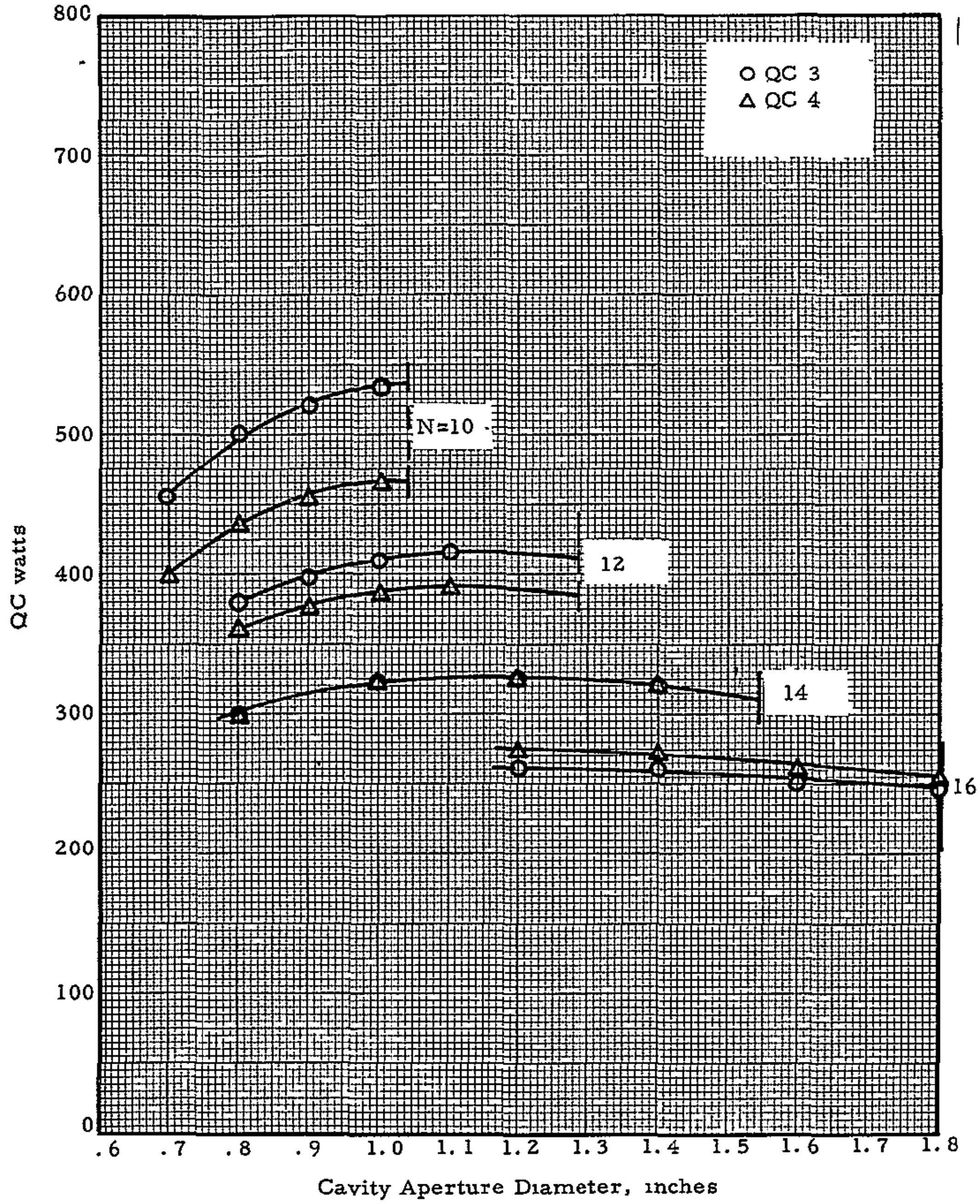

800
700
600
500
400
300
200
100
0
QC watts
O QC 3
Δ QC 4
N=10
12
14
16
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
Cavity Aperture Diameter, inches

Figure 92

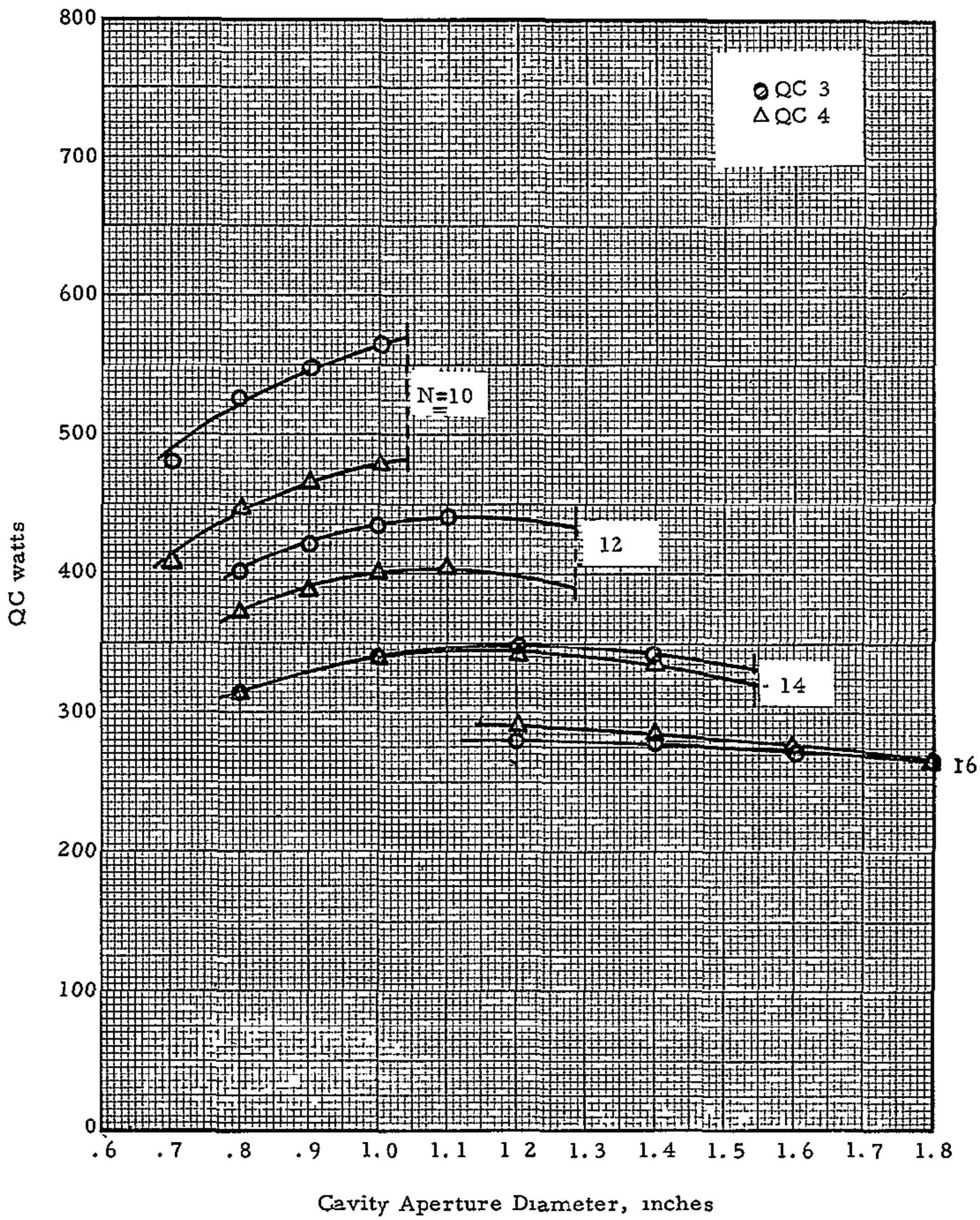


Figure 93 Predicted Cavity Performance at High Emissivity - Earth Case.

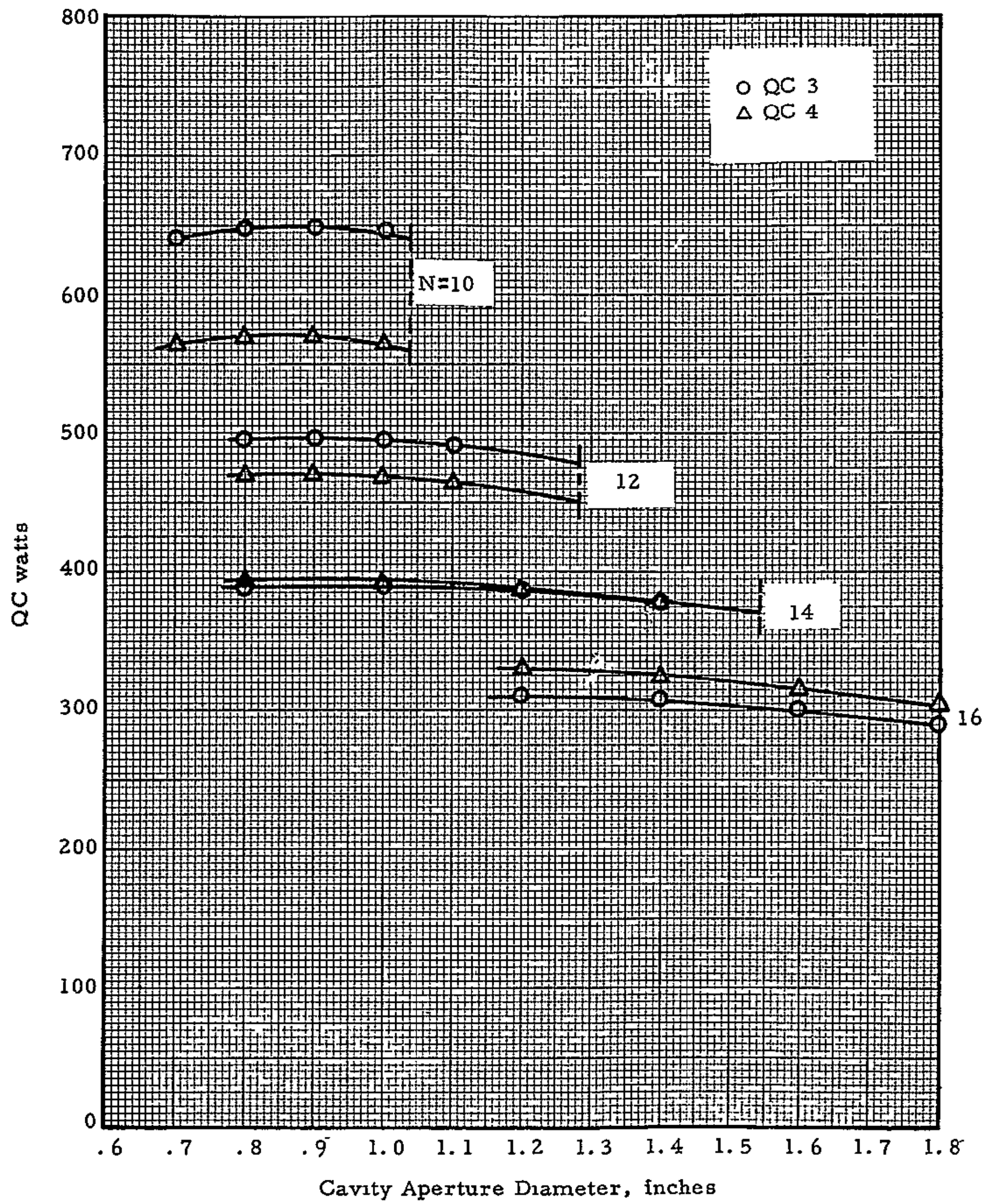


Figure 94 Predicted Cavity Performance at Low Emissivity - Cis lunar Case.

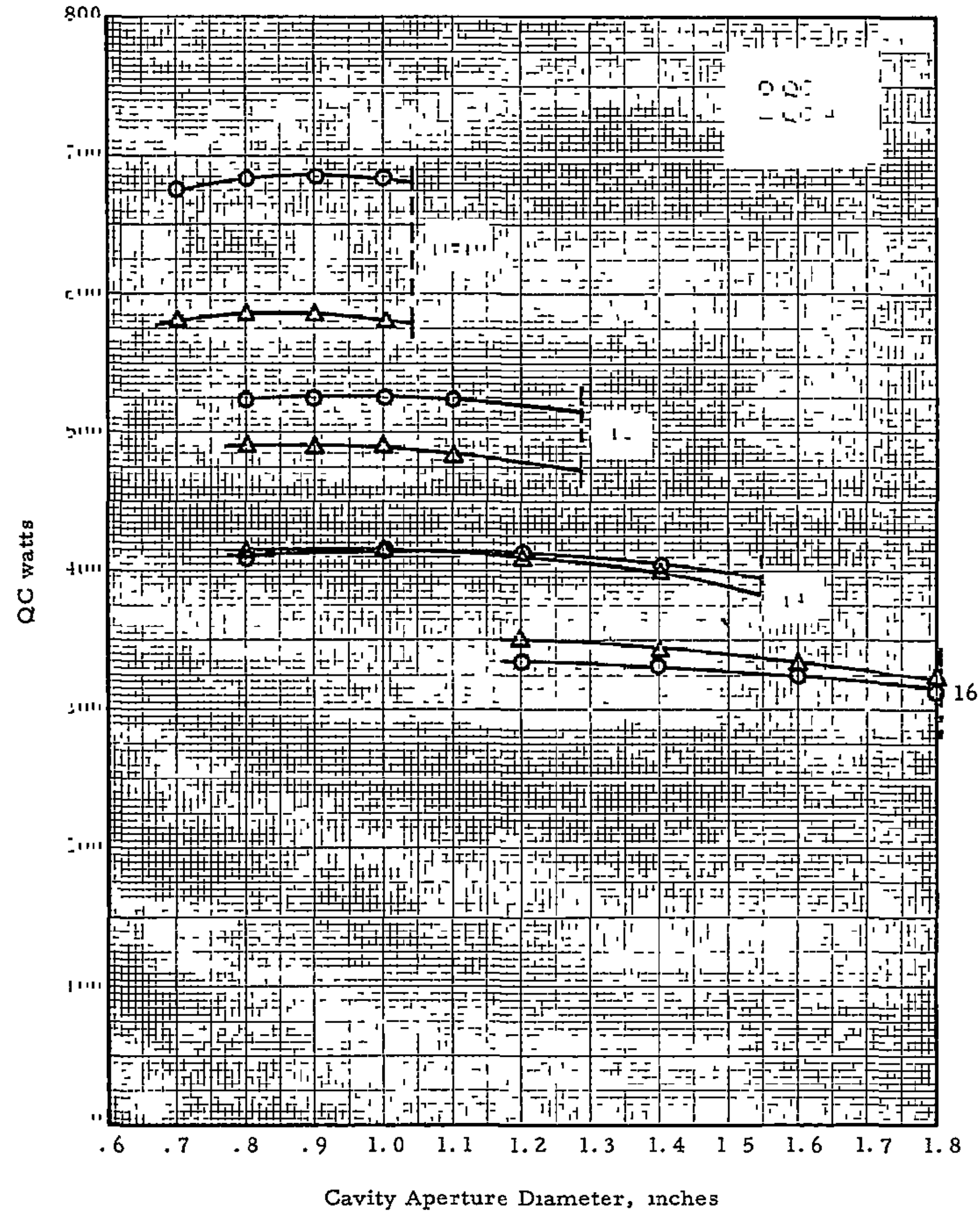


Figure 95 Predicted Cavity Performance at High Emissivity - Cis lunar Case.

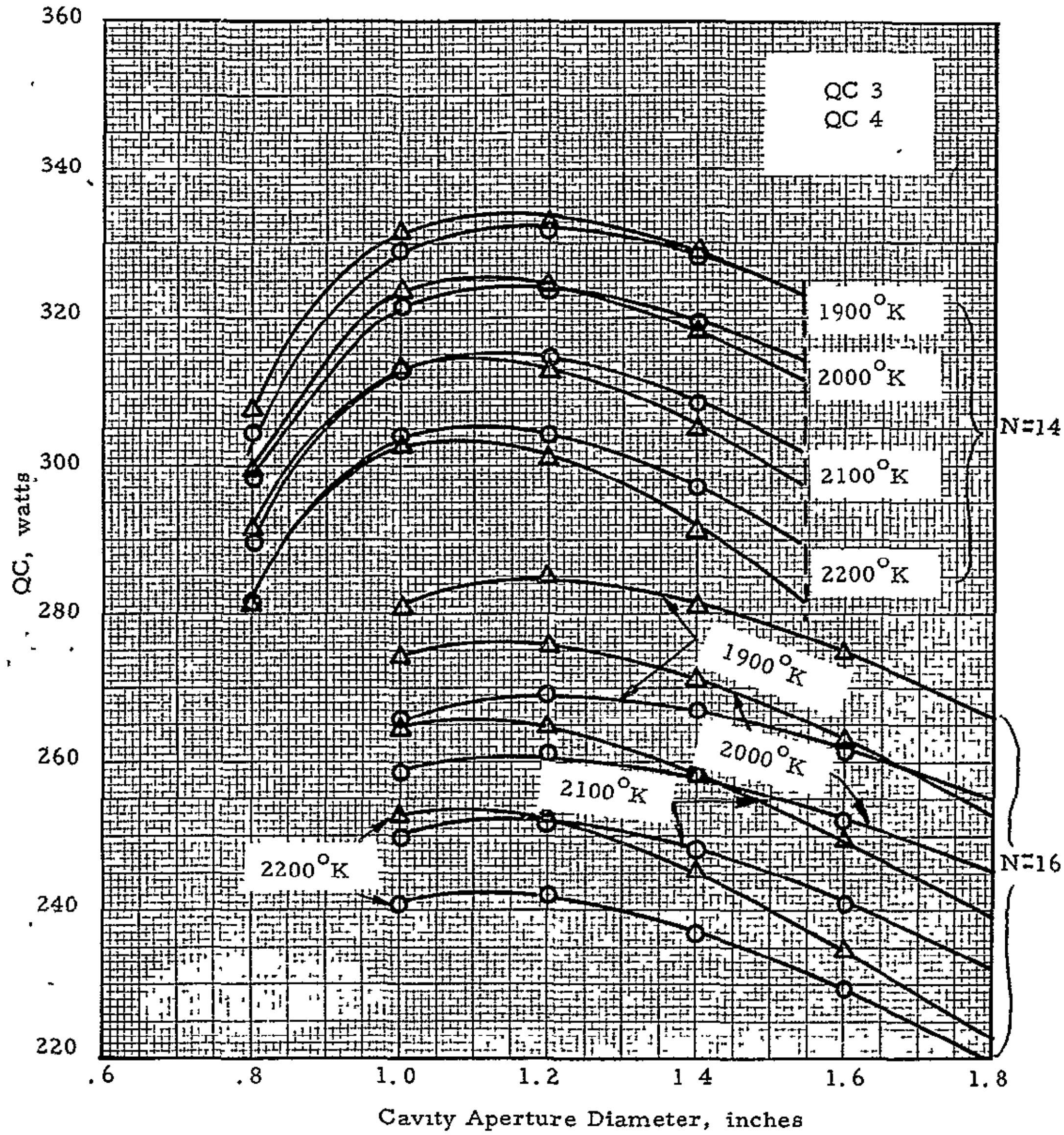


Figure 96 Effect of Cavity Temperature - Earth Case.

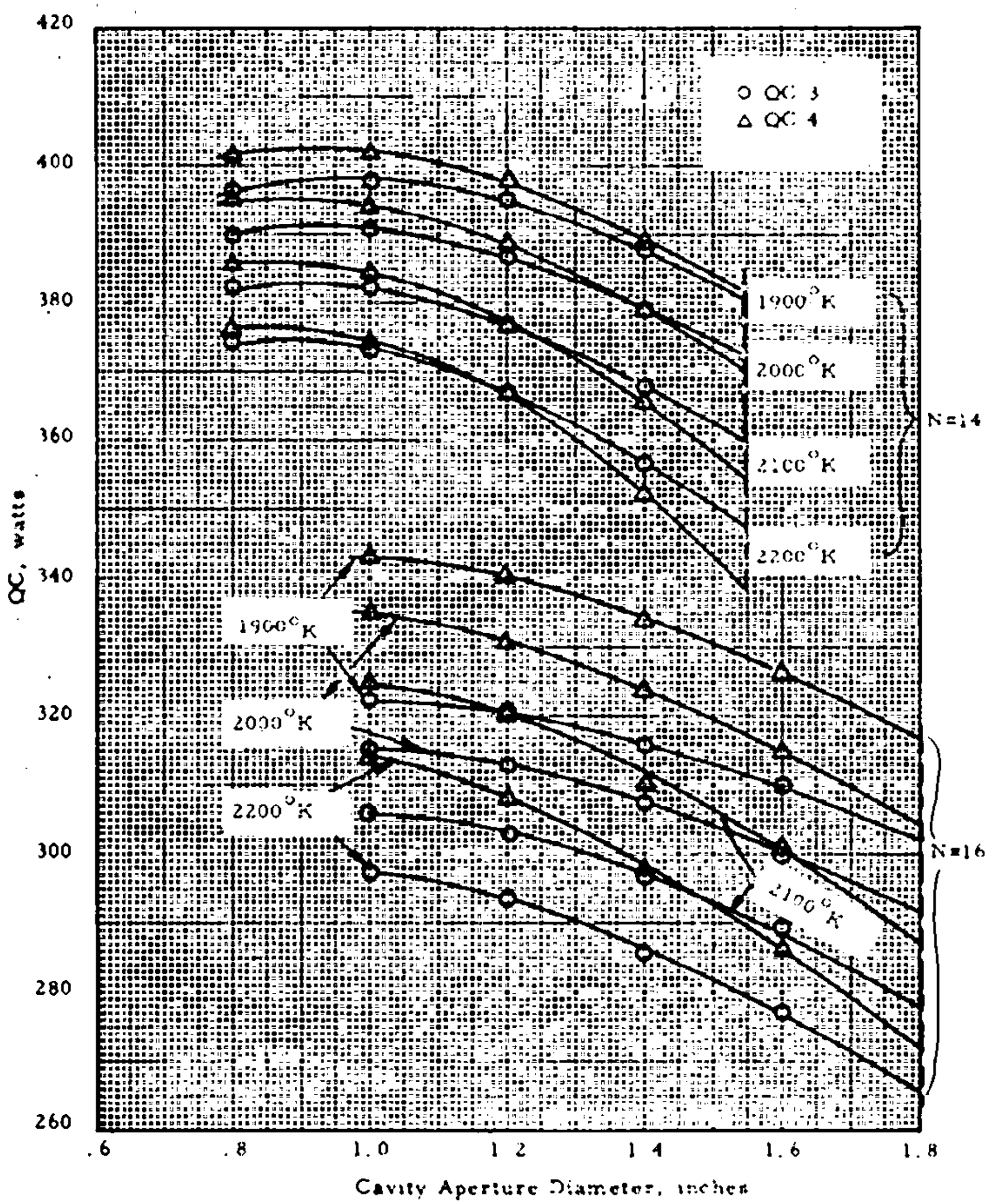


Figure 97 Effect of Cavity Temperature - Cislunar Case.

2.6 Predicted Electrical Performance of Generator

JPL recommended that the predicted output of converter T-210, 70 amperes at 0.80 volt, be used to predict the performance and power output of the generator, and that the generator be designed so as to be compatible with operation of the converters at an output current of 70 amperes. Figure 98 gives the optimized performance which was predicted for converter T-210, which will be referred to as the reference converter.

Figures 92 and 94 gave the net heat available to the two families of homologous converters in the generator as a function of cavity aperture diameter and the number of converters in the generator. The converters identified by the nomenclature QC3 were those which lay closest to the cavity aperture, and those labeled QC4 were those nearest the bottom of the cavity. The calculations for these figures included the determination of the thermal emissivity of the converter cavity surfaces required for thermal balance, and Figures 92 and 94 assumed one compatible set of values where the converters lying close to the cavity aperture had a cavity surface thermal emissivity of 0.25 and the others 0.365.

Experience with 5-ft-diameter concentrators had shown that, although these concentrators had an optimum cavity aperture of 0 5 inch, the aperture often had to be enlarged by as much as 40% in order to obtain optimum performance in actual solar tests of thermionic generators. As Figures 92 and 94 indicate, there was a maximum possible cavity aperture for each generator design, which was governed by the average cavity diameter, which in turn was a function of the number of converters clustered around the generator

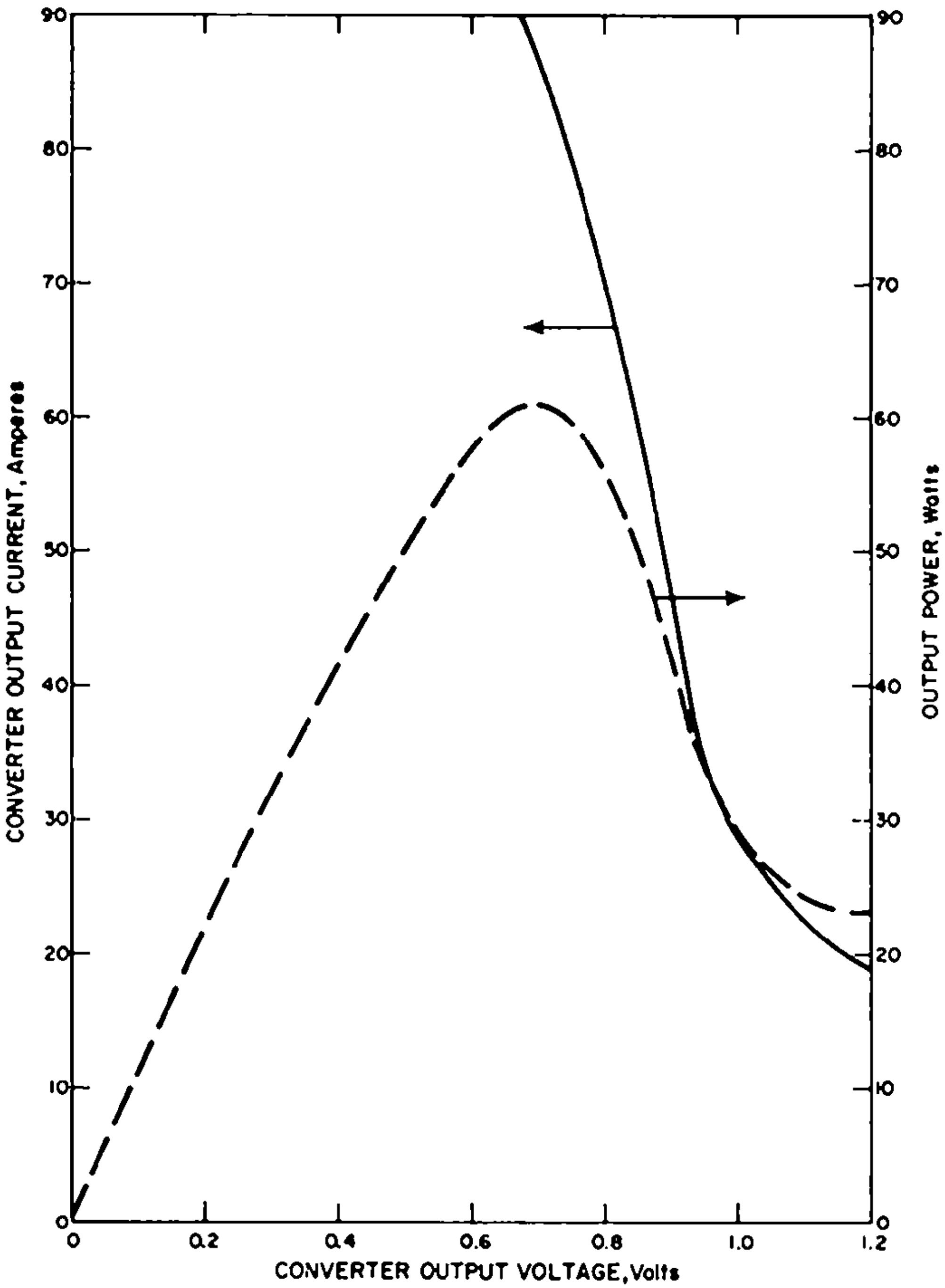

CONVERTER OUTPUT CURRENT, Amperes
OUTPUT POWER, Watts
CONVERTER OUTPUT VOLTAGE, Volts
0
0.2
0.4
0.6
0.8
1.0
1.2
10
20
30
40
50
60
70
80
90

Figure 98

cavity. For design purposes it was assumed that the maximum practical cavity apertures corresponding to generators having 10, 12, 14, and 16 converters were 1.0, 1.25, 1.50 and 1.75 inches. To the 0.5-inch optimum cavity aperture diameter for a 5-ft. dia. concentrator there corresponded a 1.15-inch optimum aperture for an 11.5-ft. dia. concentrator and an 0.95-inch optimum for a 9.5-ft. dia. concentrator. When these latter cavity apertures were increased by 40%, it was found that a cavity aperture diameter of up to 1.61 inches might be desired. This figure could have been still larger if the geometrical accuracy of the large-diameter concentrators was substantially worse than that of 5-ft. concentrators. Thus it appeared that only 14-converter and 16-converter generators were large enough to operate with an 11.5-ft. concentrator, and that the 14-converter generator size was marginally satisfactory. For this reason, the generator with 16 converters was regarded as the optimum configuration.

Next, the maximum efficiency and maximum power that could be expected from the 16-converter generator when operated in ground test and in cislunar space with converters having the output characteristic given in Figure 98 were calculated. The assumed cavity apertures for the 11.5-ft. dia. and 9.5-ft. dia. concentrators were 1.61 and 1.33 inches, respectively. With these assumptions, Figures 92 and 94 showed that the net heat received by the converters was 255 watts in ground test, and 315 watts in cislunar operation. Converter output current at these values of power input and 2000°K could be easily estimated: The heat input had to equal the sum of the electrical output, the emitter support conduction, and the collector heat transfer. The electrical output was the current times the voltage output, the emitter support conduction had been calculated to be 58 watts* (Final Report, Task II, Contract 950671, Table 7, page 105), the collector heat transfer had been measured from the calorimetric data of converter T-206 (see page 100), and the correlating equation was

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

Thus the total converter heat transfer could be expressed as

$$Q_{in} = 105.7 + 58 + (1.92 + V_o)\, I_o$$

$$= 163.7 + (1.92 + V_o)\, I_o$$

This equation could then be used to determine what output currents could be sustained with the 255 and 315 watts of input available in ground test and in cislunar space, respectively; for this calculation, the output voltage was determined from the assumed reference converter characteristic presented in Figure 98. The required heat input so calculated for the reference converter is given in Figure 99. As can be seen, with power inputs of 255 and 315 watts, the converter output currents that could be achieved were 31.0 and 54.5 amperes, respectively; Figure 98 shows that these currents could be achieved at output voltages of 0.98 and 0.87 volt, and output powers of 30.3 and 47.5 watts, respectively. Thus the predicted output power of the generator in ground test was 30.3 x 16 = 485 watts, and in cislunar operation it was 47.5 x 16 = 760 watts. The corresponding solar inputs for the assumed cavity apertures of 1.61 and 1.33 inches are given by Figure 90, and they were equal to 6,770 and 7,800 watts, respectively. Thus, the 16-converter generator performance could be summarized as follows:

---

*Based on tantalum, with a thermal conductivity of 0.79 watts/cm°C at 1416°C. The value is conservative because the thermal conductivity of rhenium at the same temperature is 0.49 watts/cm-°C.

8068

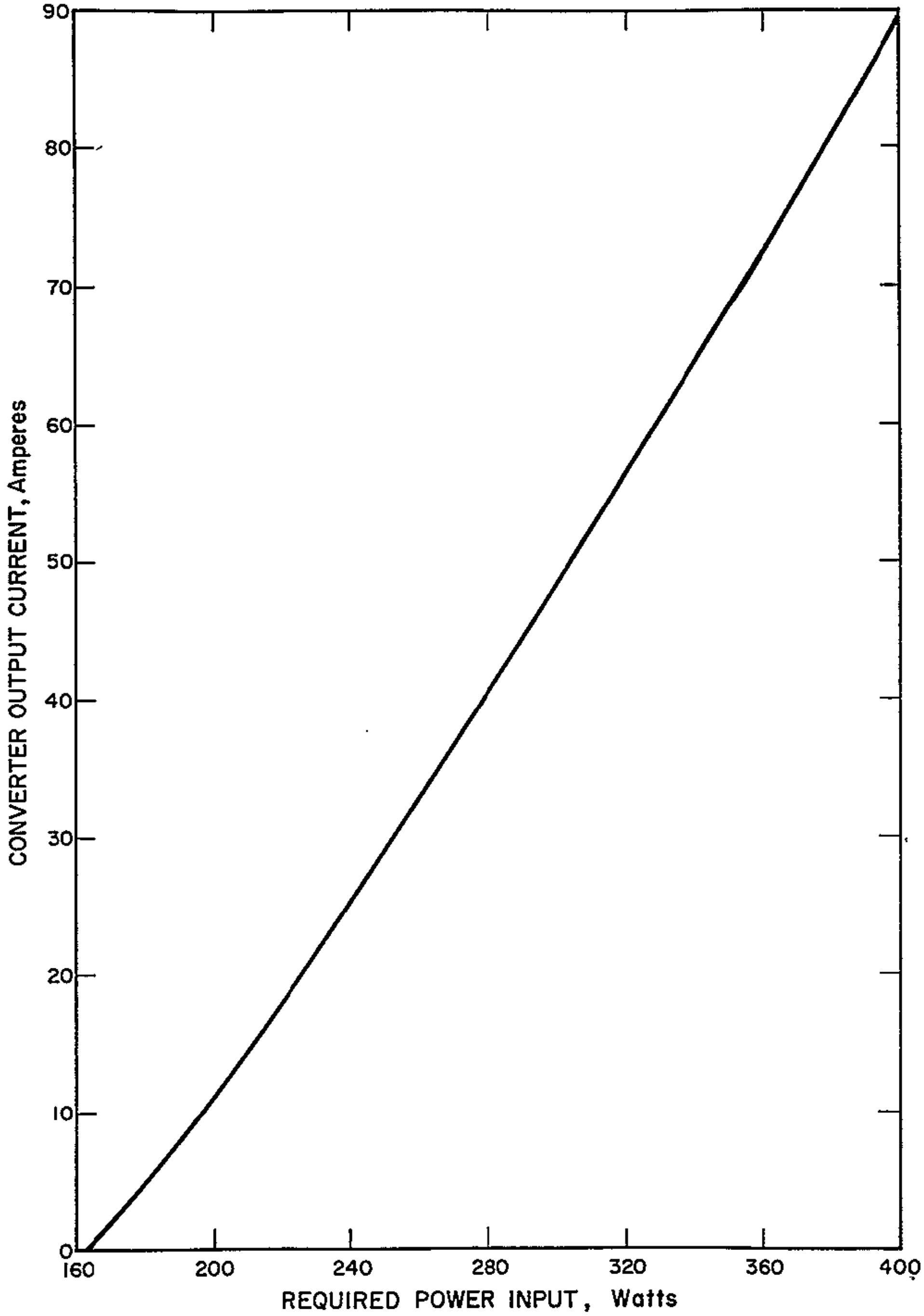


Figure 99

Generator Performance, Solar-Heated

	Ground Test	Cislunar Performance
Cavity aperture dia., in.	1 61	1.33
Cavity input, watts	6770	7800
Available converter input, watts	255	315
Converter output current, amperes	31.0	54.5
Converter output voltage, volts	0.98	0.87
Converter output power, watts	30.3	47.5
Generator output power, watts	485	760
Absorber-generator efficiency, %	7.2	9.7

Since the cavity heat losses were fixed by the fixed cavity temperature of 2000°K, the above represented both the maximum-power and maximum-efficiency performance which could be obtained with solar heating.

The above calculation was repeated for the case of electric heating to determine the maximum power and efficiency which could be obtained in laboratory testing of the generator. Assuming a cavity aperture of 1.33 inches (cislunar case), and that the cavity losses were the same under solar and electric heating, the input power to drive the converters at maximum power was equal to 7,800 watts (see the table above) plus the additional converter heat input required to reach maximum output power from the 315-watt input condition for the cislunar case given above. At maximum power, the converter output was 61 watts at 87 amperes (Figure 98). The required heat input (Figure 99) was 394 watts, which represented an increase of 79 watts from the input for the cislunar case; for

16 converters, this totalled to an increase of 1270 watts. Thus the corresponding generator power input was 7800 + 1270 = 9070 watts, and the generator would produce an output of 61 x 16 = 975 watts at an efficiency of 10.7%.

The point of maximum generator efficiency could be found by repeating the above procedure for various converter power inputs. The results were:

Converter Power Input, watts	Generator Power Input, watts	Generator Power Output, watts	Generator Efficiency, %
390	9000	975	10 82
380	8840	960	10.85
370	8680	940	10.82
360	8520	919	10.78

It is clear that maximum efficiency was obtained in the vicinity of a converter power input of 380 watts. The results for electrical testing were then:

Generator Performance, Electrically Heated

	Maximum Power	Maximum Efficiency
Cavity aperture dia., in.	1.33	1.33
Cavity input, watts	9070	8680
Available converter input, watts	394	380
Converter output current, amperes	87.0	81.2
Converter output voltage, volts	0.70	0.74
Converter output power, watts	61.0	60.0
Generator output power, watts	975	960
Generator efficiency, %	10.7	10.8

2 7 Sixteen-Converter Generator Design

The layout of the generator design is shown in Figures 100 to 103. Figure 100 is a view in the direction of the solar rays entering the cavity; Figure 101 is a sectional view along a cutting plane which contains the optical axis; Figure 102 is a rear view; and Figure 103 gives the list of parts and materials.

The generator assembly consists of eight two-converter modules, having a front and a rear converter oriented at a common angle around the optical axis. These two converters are assembled by riveting or spot-welding them to a bent plate support, part No. 31, which electrically shorts their collector structures; thus, the converters in each module are wired in parallel. Each module is supported with electrically insulated attachments, so that the modules can be wired in series or in parallel at will. In the particular design presented, all modules are connected in series

One advantage of this generator design is that the gap between the emitter pieces of the converters of a module can be closed since contact will not cause electrical shorting of converter output. By not insulating every converter, a substantial amount of insulating hardware is avoided, and a simpler, more compact and stronger structure is obtained. The nominal spacing between the surfaces of the cavity at different electrical potentials is 0.020 inch.

The modules are supported by front and rear one-piece metal rings, so that the complete assembly of modules and support rings forms a rigid frame. The design also provides for the simple removal of a converter module without the necessity of disassembling the entire generator. The front ring supports an entrance cone for the cavity, which helps to guide the solar energy into the cavity. Part No. 32 is an extension of the entrance cone, and its function is to protect the converters from concentrated sunlight in the event of accidental misorientation The rear ring supports a cavity back-piece, made of tungsten, and shaped to reflect the sunlight striking it towards the heated faces of the converters. The rear ring is also attached to the generator support, which is a webbed conical structure, part No. 1.

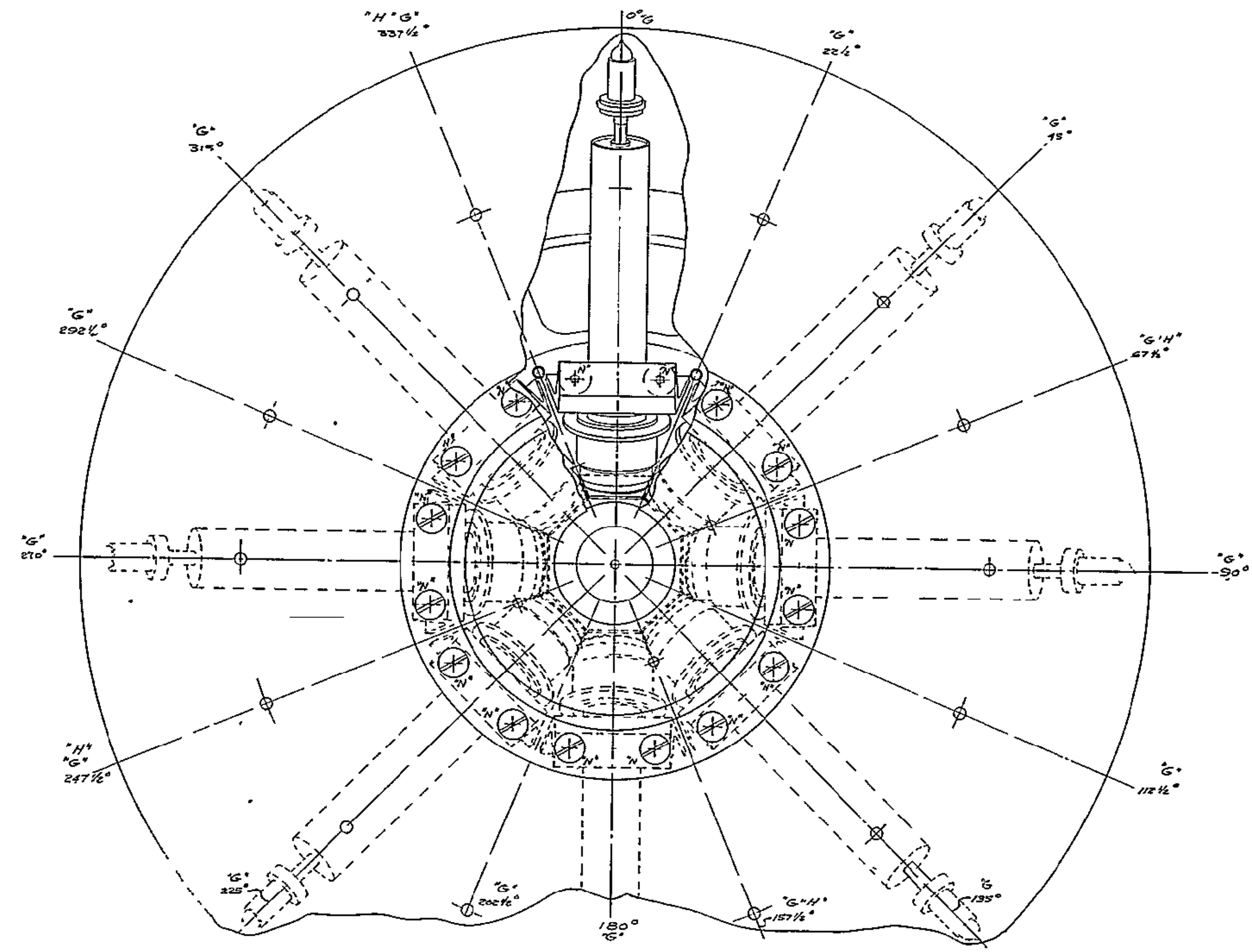


Figure 100

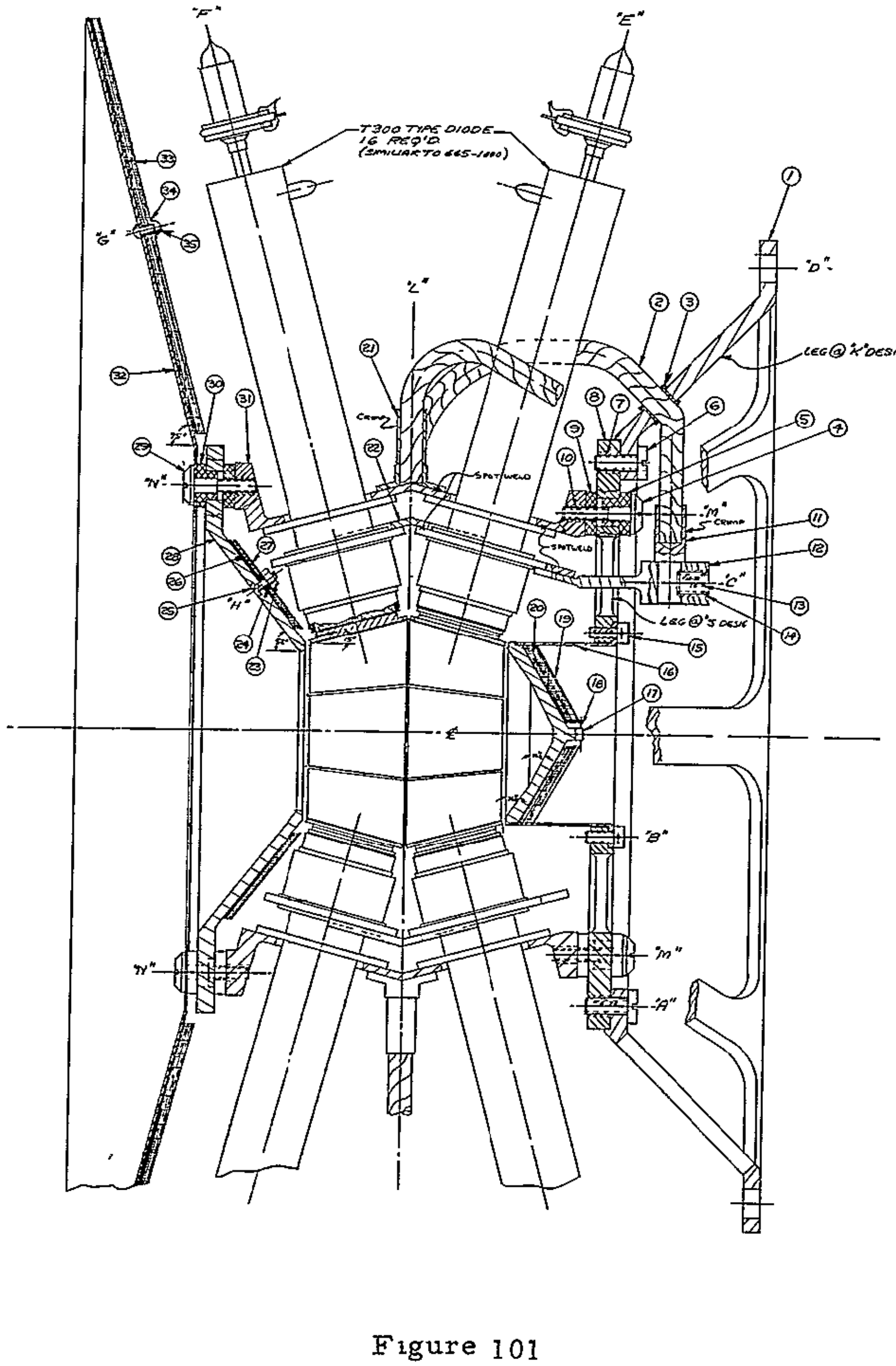

"F"
"E"
T300 TYPE DIODE
16 REQ'D.
(SIMILAR TO 665-1000)
"L"
LEG @ "K" DESIG
"D"
"G"
"N"
"M"
CRIMP
SPOTWELD
"C"
LEG @ "S" DESIG
"H"
"B"
"A"

Figure 101

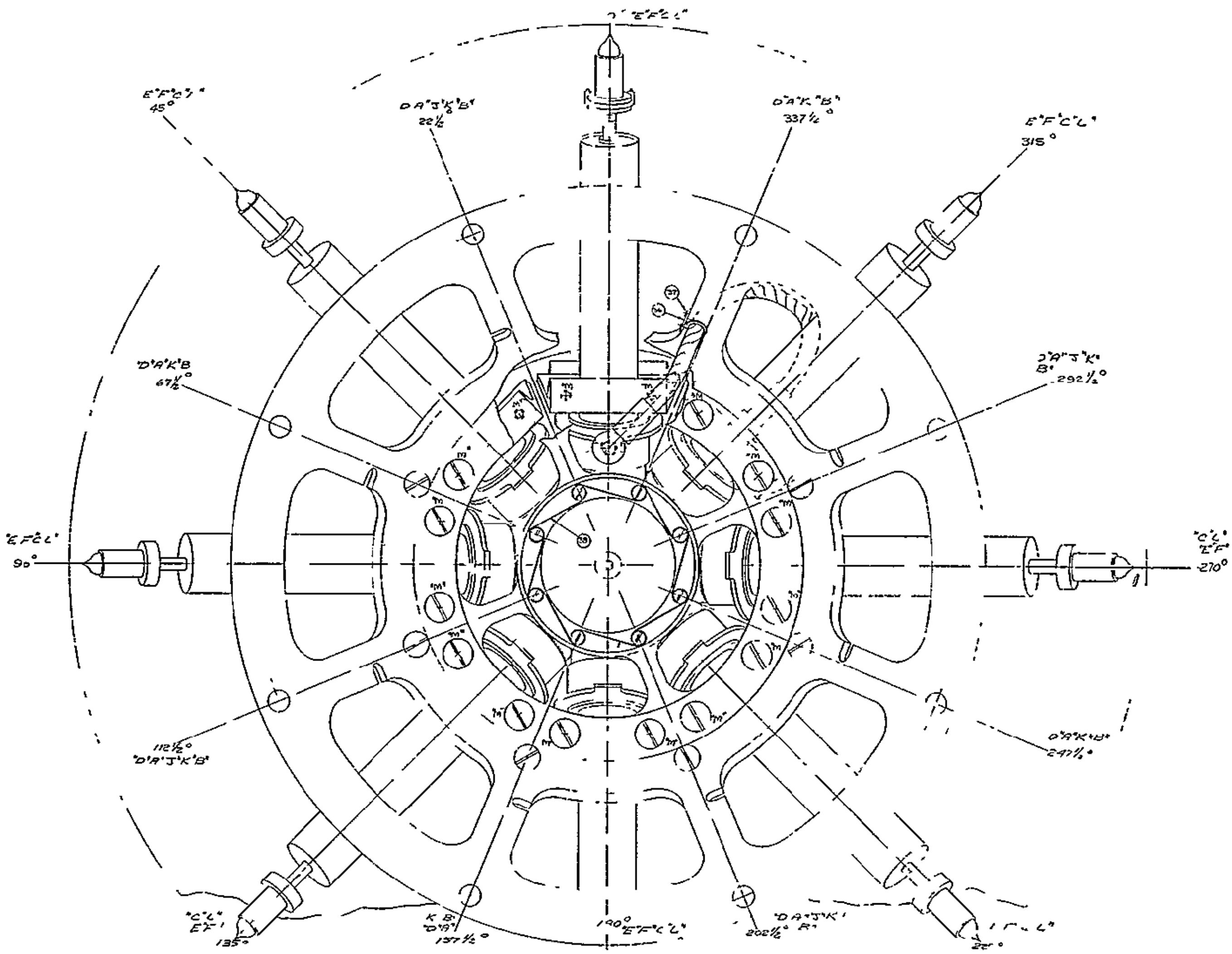


Figure 102

THERMO ELECTRON CORPORATION

8347

PART	SIZE	REV	REQ	NOTES	
LAYOUT & SUB-ASSEM					
1000				SHT 1	
1001				SHT 2	S-1 LAYOUT OF CAVITY & EMITTER

7	SEE FIXTURE LAYOUTS (3090, 3190 ETC.) FOR FIXTURE INFORMATION
6	UNK = UNKNOWN N D = NO DRAWING, PROCURE FROM THIS L O
5	DOTTED LINES INDICATE ROUGH OR PRELIMINARY MACHINING
4	ALL MATING CORNERS & FILLETS ARE .015 X 45° CHFR. AND 010 R. RES
3	MAX. PERMISSABLE TAP DRILL DEPTH AND MIN PERMISSABLE FULL THREAD DEPTHS ARE SHOWN.
2	SECTION LOCATIONS DEFINED BY LETTER LOCATION AT END VIEW
1	NOTES 2 THRU 7 APPLY UNLESS OTHERWISE SPECIFIED

NOTES

	A	B	C	D	E	F	G	H	J	K	L	M	N	P	R	S	T	U	V	W	Y	Z
1		)		/	/	/	)		V		/		/									
2																						
V																						
II																						
I																						
O																						

PART	SIZE	REV	REQ	MAT'L	NOTES
38	ND		AS REQ'D	Mo	.030 DIA WIRE
37			16	SS	#0-80 X 125 LNG SHCS.
36			8	SS	
35			16	Ta	
34			16	Ta	
33			5	Ta	
32			1	Ta	
31			8	Nb	
30			16	Al_2O_3	
29			16	Ta 10% W	
28			1	W	
27			1	Ta	
26			4	Ta	
25			4	Ta-10% W	
24			4	Ta	
23			4	Ta 10% W	
22			8	Nb	
21			8	Nb	
20			10	W	
19			1	Ta	
18			1	Ta	
17			1	W	
16			1	W	
15			8	Ta 10% W	
14	ND		8	SS	HELI COIL INSERT #3591-3CN-0190
13	ND		8	SS	#10-32 X 250 S.H SET SCR
12			8	Nb	
11			8	Nb	
10	ND		32	SS	HELICOIL INSERT #3585-04CN-0168
9			32	Al_2O_3	
8			1	Nb	
7	ND		8	SS	HELI COIL INSERT #3585-06CN 2.0
6			8	Ta-10% W	
5			16	Al_2O_3	
4			16	Ta 10% W	
3			8	Al_2O_3	
2	ND		8	Cu	
1			1	Mo	

UNLESS OTHERWISE SPECIFIED

DECIMAL: .X ± 03, .XX ± 01, .XXX ± 005
FILLET RADIUS .010 MAX
THREADS CLASS 2
* DIA. CONC WITHIN ___ T.I.R.
ALL OTHER DIA. CONC. WITHIN .005 ___ T.I.R.
SURFACES TO BE PERP. WITHIN .005 ___ T.I.R.
SURFACES TO BE PAR WITHIN .005 ___ T.I.R.
HOLE ANGULAR TOL. 0-2.0 RAD. ± 0° 9'
2.0-4.0 RAD. ± 0° 5'
ALL OTHER ANGULAR TOL. TO BE ± 0° 30'
REMOVE ALL BURRS AND EDGES

THERMO ELECTRON ENGINEERING CORPORATION, 85 FIRST AVENUE WALTHAM, MASS. 02154

DRAWN	CHECKED	ENGINEER
MN 2-26-68		

TITLE.

SCALE	FINISH
2 / 1	63 RMS
NEXT ASSY	SIMILAR TO

SIZE	DRAWING NUMBER	SHEET	REV
H	711-1000	1	

Figure 103

CONCLUSIONS

TASK I

This task attempted to improve both converter structure and converter performance. Converter structure was improved in many respects: An all-rhenium emitter structure was successfully developed, and it offered the advantages of greater high-temperature strength, elimination of emitter contamination by diffusion and migration of materials from the emitter support, and relative inertness to operation in environments with traces of oxygen, nitrogen and carbon. Vanadium brazing was shown to be an ideal technique for joining this structure to the cylindrical seal flange of the converter. Pressure bonding was applied as a technique for joining the collector to the collector support. Considerable know-how in the use of palladium as a braze material for niobium and molybdenum was generated Similarly, the relative advantages of inert gas welding and electron-beam welding were explored for application to small joints of rhenium and niobium The technology of sodium-filled niobium heat pipes was advanced with the use of low-flow-resistance evaporators and niobium as a capillary fabrication material; also, the application of this technology solved a major problem of collector heat transfer which had been caused by the excessive geometrical and heat transfer constraints imposed on the converter, and greatly reduced converter weight. The stability of the interelectrode spacing was enhanced by increasing the spacing from 1 mil to 2 mils, which produced greater shock resistance, and decreased the probability of electrode shorting due to deformations induced by grain growth in the emitter

The improvement of performance proved to be an elusive goal. Both variations of emitter surface treatments and collector materials had negligibly small effects on the performance at the particular operating conditions of the T-200 converter: 2000°K emitter temperature, 2 mil spacing. The only other means known to improve converter performance (reduction of spacing and use of cesium additives) were not practicable, the first because the minimum spacing had been set to a value of 2 mils, which was the value used, and the second because it fell outside the scope of this program.

Converter T-210, the last converter built under this program, successfully embodied all the improvements made, and its performance nearly matched that of the best of the converters tested: T-206 and T-209.

TASK II

The generator design effort developed the first known analytic technique for the calculation of heat transfer in solar cavities with converters having different sight angles to the cavity aperture. The analysis was simplified by approximating the radiant input intensity distribution with that of a point source in front of the cavity aperture; however, it arrived at solutions for the even distribution of cavity flux, and at important conclusions regarding thermal balance with changes in thermal flux, which are considered to have general application and validity.

A modular converter mounting technique was developed in the generator design, and this approach simplified considerably the assembly procedure; as a result, the fabrication of a 16-converter generator is not significantly more complicated than that of existing 4-converter generators.

APPENDIX 1

ELECTROLYTIC PROCESSING OF Re EMITTERS

APPENDIX 1

ELECTROLYTIC PROCESSING OF Re EMITTERS

Electrolyte:

350 ml. alcohol

175 ml. perchloric acid sp. gr. = 1.54, 60% conc.

50 ml. ethylene glycol monobutyl ether

Mix above solutions in glass with glass rod. Do not allow solution to come in contact with any metal other than S.S. beaker used in treatment of emitter. Place S.S. beaker with solution into ice bucket to bring the temperature of the both below 10°C. Stir electrolyte to keep temperature uniform

Treatment:

a. Vacuum anneal Re for 1/2 hour at 1600 - 1700°C.
b. Electropolish: 20 - 25 volts, 5 A/cm^2, 5 - 15 sec.
c. Electroetch: 5 volts, voltage is important, 1 A/cm^2, 1 min.

APPENDIX 2

TEST DATA FROM CONVERTER T-201

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Sheet 1 of 9

Converter No T-201 Run No 1 Observer PB & RS

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date 1966		1-20	1-20	1-20	1-20	1-20					
Time		9 15	9 50	10 32	13·05	13 10					
Elapsed Time, Hours		—	0 6	1 3	3 8	3.9					
T_O, °C		—	1536	1644	1750	—					
T_O Corrected, °C		—	1544	1653	1760	—					
$\Delta T_{Bell\ Jar}$, °C		—	11	12	15	—					
T_H, °C		—	1555	1665	1775	—					
ΔT_E, °C		—	-5	-5	-5	—					
T_E, °K		—	1823	1933	2043	—					
V_O, volts		—	.499	1.350	.004	—					
I_O, amps		—	0	0	0	—					
P_O, watts		—	0	0	0	—					
I-V Trace No		—	—	—	—	—					
T_R (11)	mv	—	10 5	13.0	15.3	—					
	°C	—	258	319	374	—					
	°K	—	531	592	647	—					
T_C (—)	mv	—	1-83[illegible]	2-0[illegible]	2-1[illegible]						
	°C	—	437	530	596	—					
	°K	—	710	803	869	—					
T_C base inner (14)	mv	—	16.1	19.5	21.9	—					
	°C	—	393	473	529	—					
T_C base outer (13)	mv	—	16.0	19.5	21.9	—					
	°C	—	391	473	529	—					
$T_{Radiator}$ (12)	mv	—	15.1	18.0	20 0	—					
	°C	—	369	438	485	—					
V_{eb}, volts		0	1010	1002	991	0					
I_{eb}, mA		0	121	155	192	0					
$E_{Filament}$, volts		*	4.4	4.5	4.7	0					
$I_{Filament}$, amps		*	21 5	22.0	22.5	0					
$I_{Coll\ Heater}$, amps		*	0	5	6	—					
$I_{Res\ Heater}$, amps		*	0	0	0	—					
Vacuum, 10^{-6} mm Hg		3.0	7.6	6 6	3.4	—					
Measured Efficiency, %		—	—	—	—	**					

NOTES * APPLIED CURRENT TO OUTGAS. $\Delta T_o = 8°C$ @ 1500, 9°C @ 1600 & 10°C @ 1700°C
$\Delta T_{Bell\ Jar} = 12°C$ @ 1600°C, 14°C @ 1700°C $\Delta T_E = -(5 + 164 I)$

** SHUT-OFF, DIODE FAILED TO OPERATE WITHOUT VISIBLE SIGN OF DAMAGE. WITH $T_C = 350°C$, INTERNAL RESISTANCE MEASURED 9.5 KΩ HEATING RESERVOIR MOMENTARILY TO 750°C REDUCED THIS VALUE TO 4 KΩ.

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Sheet 2 of 9

Converter No T-201 Run No 2 & 3 Observer PB & RS

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date 1966		1-28	1-28	1-28	1-28	1-28	1-28		1-28	1-28	1-28
Time		1048	1330	1450	1502	1513	1521		1551	1700	1733
Elapsed Time, Hours		0	2.6	3 9	4.1	4.3	4.5		5.0	6 1	6.7
T_0, °C		—	1380	1710	1710	1710	1710		1713	1713	1713
T_0 Corrected, °C		—	1388	1720	1720	1720	1720		1723	1723	1723
$\Delta T_{Bell\ Jar}$, °C		—	10	14	14	14	14		14	14	14
T_H, °C		—	1398	1734	1734	1734	1734		1737	1737	1737
ΔT_E, °C		—	-5	-7*	-7	-7	-7		-10	-10	-10
T_E, °K		—	1666	2000	2000	2000	2000		2000	2000	2000
V_0, volts		—	—	—	—	—	—		—	—	—
I_0, amps		—	—	—	—	—	—		1/4 SCALE	—	—
P_0, watts		—	—	—	—	—	—		—	—	—
I-V Trace No		—	—	1	2	3	4		**	5	6
T_R	mv	—	14 1	16.7	16 8	17 1	16 8		**	14.5	11 9
	°C	—	345	407	409	417	409		—	355	292
11	°K	—	628	680	682	690	682		—	628	565
T_C	mv	—	1-925	2-338	2-438	2-538	2-638		**	2-500	2-300
	°C	—	463	669+	719	769	819		—	750	650
	°K	—	740	942	992	1042	1092		—	1023	923
T_C base inner	mv	—	16 9	23.5	24.5	26 6	28 7		—	25 9	23.3
14	°C	—	412	567	590	640	690		—	623	562
T_C base outer	mv	—	16 6	23 0	24.9	26.1	28 1		—	25.5	23.1
13	°C	—	405	555	579	628	675		—	614	558
$T_{Radiator}$	mv	—	15 7	20.9	21 6	23 1	24 5		—	22 7	20.8
12	°C	—	383	504	522	558	590		—	548	504
V_{eb}, volts		1008	1009	985	984	985	985		—	989	995
I_{eb}, mA		105	107	262	262	262	262		—	251	195⊙
$E_{Filament}$, volts		4	4 2	4.8	4 8	4.8	4 8		—	4 8	4.5
$I_{Filament}$, amps		20	21	22	22	22	22		—	22	21
$I_{Coll\ Heater}$, amps		0	0	0	4	9	12		0	8	10
$I_{Res\ Heater}$, amps		0	2	2	2	2	0.5		0	0	0
Vacuum, 10^{-6} mm Hg		3.8	1 6	2.0	2.2	2 8	3.4		2.0	1.5	1 3
Measured Efficiency, %		—	—	—	—	—	—		—	—	—

NOTES *) AVERAGE CURRENT OF 15 A ASSUMED + DRIFTED TO 2-393 DURING SWEEP.
** ALL ATTEMPTS TO SWEEP -0.1 TO 1 6 VOLTS FAILED DUE TO CONVERTER OVERHEATING EVEN WHEN THE EMITTER TEMPERATURE WAS ALLOWED TO DROP TO 1400 °C DECIDED TO LIMIT MAX CURRENT TO 60 AMPS, INSTEAD OF 250 A.
⊙ ALL POWER TURNED OFF AT t = 1738 HRS.

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Sheet 3 of 9

Converter No T-201 Run No 4 Observer R Slosek & P. Brosseau

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date 1966		2-1	2-1	2-1	2-1	2-1	2-1	2-2	2-2	2-2	2-2
Time		1000	1117	1220	1312	1622	1725	0957	1113	1135	1200
Elapsed Time, Hours		—	—	—	—	0	1.0	17 6	18 8	19.2	19 6
T_O, °C		1676	1678	1676	—	1713	1715	1708	1674	1670	1717
T_O Corrected, °C		1686	1688	1686	—	1723	1725	1718	1684	1680	1727
$\Delta T_{Bell\ Jar}$, °C		14	14	14	—	14	14	14	14	14	14
T_H, °C		1700	1702	1700	—	1737	1739	1732	1698	1694	1741
ΔT_E, °C		—	8	8	—	10	10	11	8	8	10
T_E, °K		—	1967	1965	—	2000	2002	1994	1963	1959	2004
V_o, volts		—	1003	.9022	—	.593	.592	.587	1.002	.900	.604
I_o, amps		—	15.1	16.7	—	356	369	408	17 2	19 2	384
P_o, watts		—	1515	1507	—	21 2	21.9	23.9	17.2	17.3	23.2
I-V Trace No		—	—	—	—	—	—	—	—	—	—
T_R	mv	—	131	13.5	—	14 0	14.2	14.2	13.7	13.9	14.4
	°C	—	322	331	—	343	348	348	336	341	353
	°K	—	595	604	—	616	621	621	609	614	626
T_C	mv	—	2-224	2-270	—	2-50[illegible]	2-530	2-556	2-312	2-357	2-518
	°C	—	612	635	—	75.	765	778	656	678	759
	°K	—	885	908	—	1023	10[illegible]8	1051	929	951	932
T_C base inner	mv	—	21 3	21.8	—	24.9	25 2	25.6	22 9	23.5	25 3
	°C	—	515	52.7	—	600	[illegible]07	616	553	567	609
T_C base outer	mv	—	20.9	21.4	—	24 8	24.5	24 9	22 6	23.0	24 6
	°C	—	506	518	—	586	590	600	546	555	593
$T_{Radiator}$	mv	—	19 2	19.6	—	21 9	22.0	22.3	20.5	20 9	22 1
	°C	—	466	476	—	527	532	539	497	506	534
V_{eb}, volts		—	9903	9902	—	982	981	977	989	989	981
I_{eb}, mA		—	221.5	2247	—	305	309	323	229	238	297
$E_{Filament}$, volts		—	4 6	4 6	—	4 9	4.9	5.0	4 6	4 6	4.8
$I_{Filament}$, amps		—	21 5	21 5	—	22 5	22.5	22 0	21 5	21 5	22
$I_{Coll\ Heater}$, amps		—	—	—	—	0	0	0	5.5	5.5	0
$I_{Res\ Heater}$, amps		—	—	—	—	2.5	2.5	2 5	4	4	5.5
Vacuum, 10^{-6} mm Hg		1 3	.89	.86	.80	6	2	1	1	1	1
Measured Efficiency, %		*	—	—	**	†	—	—	⊕	⊕	—

NOTES * CONVERTER STARTED ** SHUT OFF TO ADD COOLING STRAP TO RESERVOIR
† START OF STEADY STATE RUN. ⊕ INCORRECT INTERPRETATION OF TEST PROCEDURE RESULTED IN TAKING THESE TWO MEASUREMENTS.

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ENGINEERING CORPORATION

Sheet 4 of 9

Converter No T-201 Run No 4 Observer P.B and R.S.

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date 1966		2-2	2-3	2-4	2-4	2-4	2-6	2-6	2-8	2-8	
Time		1732	1038	0850	1020	1642	1230	1300	0845	0945	
Elapsed Time, Hours		25 1	42 2	58.4	59 9	66.3	108	108.5	152.4	153.4	
T_O, °C		1718	1711	—	1713	1720	—	1715	1720	1720	
T_O Corrected, °C		1728	1721	—	1723	1730	—	1725	1730	1730	
$\Delta T_{Bell\ Jar}$, °C		14	14	—	14	14	—	14	14	14	
T_H, °C		1744	1735	—	1737	1744	—	1739	1744	1744	
ΔT_E, °C		11	10	—	10	10	—	10	10	10	
T_E, °K		2006	1998	—	2000	2007	—	2002	2007	2007	
V_O, volts		.604	.600	—	.599	.598	—	.599	.598	.598	
I_o, amps		38.3	35.9	—	38.0	37.6	—	39 1	39.4	38.9	
P_O, watts		23.2	21 6	—	22 8	22 5	—	23.4	23.6	23.3	
I-V Trace No		—	—	—	—	—	—	—	—	—	
T_R	mv	14.5	14.2	—	14.3	14.2	—	14.4	14.2	14.2	
	°C	355	348	—	350	348	—	353	348	348	
	°K	628	621	—	623	621	—	626	621	621	
T_C	mv	2-534	2-514	—	2-514	2-514	—	2-520	2-540	2-540	
	°C	767	757	—	757	757	—	760	770	770	
	°K	1040	1030	—	1030	1030	—	1033	1043	1043	
T_C base inner	mv	25.4	25.1	—	25.2	25 1	—	25.3	25.4	25.2	
	°C	612	604	—	607	604	—	607	612	607	
T_C base outer	mv	24.7	24.5	—	24.6	24 5	—	24 6	24.7	24.6	
	°C	595	590	—	593	590	—	593	595	593	
$T_{Radiator}$	mv	22.2	22.1	—	22 1	22.0	—	22.1	22.1	22.1	
	°C	537	534	—	534	532	—	534	534	534	
V_{eb}, volts		979	980	989	981	978	983	981	977	978	
I_{eb}, mA		310	305	275	308	309	311	311	316	313	
$E_{Filament}$, volts		48	48	—	48	48	4.8	48	48	4.8	
$I_{Filament}$, amps		22	22	—	22	22 5	22 0	22	22	22	
$I_{Coll\ Heater}$, amps		0	0	0	0	0	0	0	0	0	
$I_{Res\ Heater}$, amps		5.5	5 5	5.5	5 5	5.5	6.5	5.5	5.5	5.5	
Vacuum, 10^{-6} mm Hg		.84	.70	85	60	.59	1	.64	.46	.46	
Measured Efficiency, %		—	*	—	—	—	**	—	—	†	

NOTES * POWER FAILURE CAUSED UNIT TO SHUT OFF @ 58 4 HRS.
** POWER FAILURE CAUSED UNIT TO SHUT OFF @ 108 HRS.
† SHUT OFF – END OF RUN

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 5 of 9

Converter No T-201 Run No 5 Observer P. Brosens & R Slosek

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		2-14	2-14	2-14	2-14	2-15	2-15	2-15	2-15	2-15	2-15
Time		1709	1719	1735	1747	0943	0958	1047	1115	1128	1139
Elapsed Time, Hours		179.9	180 1	180 4	180 6	196 5	196 8	197.6	198.0	198.2	198.4
T_O, °C		1710	1710	1710	1710	1712	1712	1612	1612	1612	1612
T_O Corrected, °C		1720	1720	1720	1720	1722	1722	1621	1621	1621	1621
$\Delta T_{Bell\ Jar}$, °C		14	14	14	14	14	14	12	12	12	12
T_H, °C		1734	1734	1734	1734	1736	1736	1633	1633	1633	1633
ΔT_E, °C		7	7	7	7	9	9	6	6	6	6
T_E, °K		2000	2000	2000	2000	2000	2000	1900	1900	1900	1900
V_O, volts		—	—	—	—	—	—	—	—	—	—
I_O, amps		—	—	—	18†	22	22	3	6.5	13	21
P_O, watts		—	—	—	—	—	—	—	—	—	—
I-V Trace No		7	8	9	10	11	12	13	14	15	16
T_R	mv	11 0	11.8	12 6	13.4	14 3	15.2	11 0	11.8	12.6	13.4
	°C	271	290	310	329	350	372	271	290	310	329
	°K	544	563	583	602	623	645	544	563	583	602
T_C	mv	2-356	2-424	2-474	2-538	2-584	2-628	2-356	2-408	2-478	2-558
	°C	678	712	737	759	792	814	678	704	739	779
	°K	951	985	1010	1032	1065	1087	951	977	1012	1052
T_C base inner	mv	24.2	25.6	26 4	27 4	28.0	28.7	25.1	26.1	26.9	27.8
	°C	583	616	635	659	673	690	604	628	647	668
T_C base outer	mv	24 0	25.4	26 2	27.1	27.6	28.3	25.1	26 0	26.6	27.5
	°C	579	612	630	652	663	680	604	626	640	661
$T_{Radiator}$	mv	21.5	22.5	23.0	23.9	23.9	24.5	22.2	22 9	23.3	23.9
	°C	520	543	555	576	576	590	537	553	562	576
V_{eb}, volts		1000	999	997	994	987	985	1003	1001	997	993
I_{eb}, mA		184	193	209	229	258	268	153	156	180	203
$E_{Filament}$, volts		4 4	4.4	4 4	4 6	4.8	4.8	4.4	4 4	4.5	4.5
$I_{Filament}$, amps		21	21	21	21	21 5	21.5	20.5	20.5	20.5	21
$I_{Coll\ Heater}$, amps		11	11 5	11 5	11 5	12.0	12.0	12 3	13.0	13.0	13.0
$I_{Res\ Heater}$, amps		3	4	4	5	5.5	5 5	2.5	3	3.5	4
Vacuum, 10^{-6} mm Hg		2.6	2.7	2.7	2.7	2.6	2.7	2.6	2 7	2.7	2.7
Measured Efficiency, %		*	—	—	—	—	—	—	—	—	—

NOTES DELAY FROM 2-8 TO 2-14 CAUSED BY DIGITAL VOLTMETER FAILURE

* T_C / T_R = 175 (SSK & PB SAN DIEGO - PAPER)

† AVG I_O READ BY DIGITAL VOLTMETER LEFT OVERNIGHT AT THIS POINT

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 6 of 9

Converter No T-201 Run No 5 & 6 Observer P Brosens

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		2-15	2-15	2-15	2-15	2-15	2-15	2-15	2-15	2-16	2-16
Time		1155	1210	1639	1649	1655	1705	1734	1746	1532	1641
Elapsed Time, Hours		198.7	199.0	203.4	203.6	203.7	203.9	204.4	204.6	226.3	227.5
T_O, °C		1612	1612	1514	1514	1514	1514	1514	1514	1710	1710
T_O Corrected, °C		1621	1621	1522	1522	1522	1522	1522	1522	1720	1720
$\Delta T_{Bell\ Jar}$, °C		12	12	10	10	10	10	10	10	14	14
T_H, °C		1633	1633	1532	1532	1532	1532	1532	1532	1734	1734
ΔT_E, °C		6	6	5	5	5	5	5	5	7	7
T_E, °K		1900	1900	1800	1800	1800	1800	1800	1800	2000	2000
V_O, volts		—	—	—	—	—	—	—	—	—	—
I_O, amps		21.6	20.8	3.3	5.0	5.9	6.3	7	19.3	21.2	21.1
P_O, watts		—	—	—	—	—	—	—	—	—	—
I-V Trace No		17	18	19	20	21	22	23	24	25	26
T_R	mv	14.3	15.2	11.0	11.8	12.6	13.4	14.3	15.2	16.7	16.7
	°C	350	372	271	290	310	329	350	372	407	407
	°K	623	645	544	563	583	602	623	645	680	680
T_C	mv	2-594	2-594	2-356	2-364	2-378	2-400	2-400	2-534	2-388	2-588
	°C	797	797	678	682	689	700	700	767	694	794
	°K	1070	1070	951	955	962	973	973	1040	967	1067
T_C base inner	mv	28.4	28.5	25.2	25.6	25.8	26.1	26.4	27.6	23.4	27.6
	°C	682	685	607	616	621	628	635	663	564	663
T_C base outer	mv	28.1	28.2	25.2	25.6	25.7	26.0	26.3	27.4	23.0	27.3
	°C	675	678	607	616	618	626	633	659	555	656
$T_{Radiator}$	mv	24.3	24.4	22.3	22.6	22.7	22.9	23.1	23.9	20.9	23.9
	°C	586	588	539	546	548	553	558	576	506	576
V_{eb}, volts		992	993	1011	1009	1008	1007	1005	1001	987	988
I_{eb}, mA		218	215	121	131	135	142	145	178	270	262
$E_{Filament}$, volts		4.6	4.7	4.3	4.3	4.4	4.4	4.4	4.4	4.8	4.8
$I_{Filament}$, amps		21	21	20	20	20	20	20	20	21	21
$I_{Coll\ Heater}$, amps		13	13	13	13	13	13	13	13	0	11
$I_{Res\ Heater}$, amps		5	5	2.5	3	4	4.5	5	5.5	6.5	6.5
Vacuum, 10^{-6} mm Hg		2.7	2.7	2.6	2.6	2.6	2.8	2.8	2.8	2.7	2.7
Measured Efficiency, %		—	—	—	—	—	—	—	—	* —	—

NOTES * START RUN No. 6 (COLLECTOR ϕ), REPEAT OF I-V's No: 2 and 4.

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 7 of 9

Converter No T-201 Run No 7 (Cs) Observer P Brosens

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date 1966		2-16									2-16
Time		1711									1805
Elapsed Time, Hours		228.0									228.9
T_O, °C		1708									1708
T_O Corrected, °C		1718									1718
$\Delta T_{Bell\ Jar}$, °C		14									14
T_H, °C		1732									1732
ΔT_E, °C		5									5
T_E, °K		2000									2000
V_O, volts		—									—
I_O, amps		0									0
P_O, watts		—									—
I-V Trace No		—									—
T_R	mv	7 0	8.0	9 0	10 0	11.0	12 0	13.0	14 0	15 0	16.0
	°C	172	197	222	246	271	295	319	343	367	391
	°K	445	470	495	519	544	568	592	616	640	664
T_C	mv	2-254	2-254	2-254	2-254	2-254	2-254	2-254	2-254	2-254	2-254
	°C	627	627	627	627	627	627	627	627	627	627
	°K	900	900	900	900	900	900	900	900	900	900
T_C base inner	mv	—									—
	°C	—									—
T_C base outer	mv	—									—
	°C	—									—
$T_{Radiator}$	mv	—									—
	°C	—									—
V_{eb}, volts		1001	1003	1004	1004	1004	1003	1003	1003	1001	1001
I_{eb}, mA		170 0	169.0	171 4	175.8	178.3	180.8	183.6	193 3	198.8	203.8
$E_{Filament}$, volts		4.4									4.6
$I_{Filament}$, amps		20									21
$I_{Coll\ Heater}$, amps		10									7 0
$I_{Res\ Heater}$, amps		0									7.0
Vacuum, 10^{-6} mm Hg		2.7									2 7
Measured Efficiency, %		—									—

NOTES

THERMO ELECTRON ENGINEERING CORPORATION

Sheet 8 of 9

Converter No T-201 Run No 8 Observer P Brown

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		2-17	2-17	2-17	2-17	2-17	2-17	2-17	2-17	2-17	2-17
Time		0955	1005	1015	1025	1035	1050	1102	1112	1122	1133
Elapsed Time, Hours		244.7	244.9	245.0	245.2	245.4	245.6	245.8	246.0	246.2	246.3
T_O, °C		1579	1579	1579	1579	1579	1676	1676	1676	1676	1676
T_O Corrected, °C		1588	1588	1588	1588	1588	1686	1686	1686	1686	1686
$\Delta T_{Bell\ Jar}$, °C		12	12	12	12	12	14	14	14	14	14
T_H, °C		1600	1600	1600	1600	1600	1700	1700	1700	1700	1700
ΔT_E, °C		7	7	6	6	5	11	8	7	7	6
T_E, °K		1866	1866	1867	1867	1868	1962	1965	1966	1966	1967
V_o, volts		0.600	0.800	1.000	1.200	1.400	0.600	0.800	1.000	1.200	1.400
I_o, amps		13.0	11.4	8.8	5.7	2.6	37.0	18.7	14.8	10.5	6.4
P_o, watts		7.8	9.1	8.8	6.8	3.6	22.2	15.0	14.8	12.6	8.9
I-V Trace No		—	—	—	—	—	—	—	—	—	—
T_R	mv	13.0	12.8	12.3	12.3	12.1	13.9	13.6	13.4	13.1	12.7
	°C	319	314	302	302	297	341	333	329	321	312
	°K	592	587	575	575	570	614	606	602	594	585
T_C	mv	2-148	2-120	2-074	2-030	2-000	2-450	2-278	2-226	2-168	2-120
	°C	574	560	537	515	500	725	639	613	584	560
	°K	847	833	810	788	773	998	912	886	857	833
T_C base inner	mv	19.9	19.6	19.0	18.3	17.8	23.9	21.5	20.9	20.1	19.5
	°C	483	476	461	445	433	576	520	506	487	473
T_C base outer	mv	19.9	19.4	18.7	18.1	17.6	23.4	21.4	20.8	20.0	19.4
	°C	483	471	454	440	428	564	518	504	485	471
$T_{Radiator}$	mv	18.3	18.0	17.5	17.0	16.5	21.2	19.6	19.1	18.5	18.0
	°C	445	438	426	414	402	513	476	464	450	438
V_{eb}, volts		998	1000	1000	1003	1005	985	991	993	995	998
I_{eb}, mA		183	178	168	160	150	286	234	222	208	194
$E_{Filament}$, volts		4.5	4.5	4.5	4.5	4.4	4.8	4.7	4.7	4.7	4.6
$I_{Filament}$, amps		21	21	21	21	20	21.7	21	21	21	20.5
$I_{Coll\ Heater}$, amps		0	0	0	0	0	0	0	0	0	0
$I_{Res\ Heater}$, amps		5.5	5.5	5.0	5.0	5.0	6.0	6.0	5.5	5.5	5.5
Vacuum, 10^{-6} mm Hg		2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
Measured Efficiency, %		4.3	5.1	5.2	4.2	2.2	7.9	6.5	6.7	6.1	5.2
NOTES.	P	183	178	168	160	151	282	232	222	208	194
	q_{cs}	9	9	9	9	9	13	13	13	13	13
	$P-q_{cs}$	174	169	159	151	142	269	219	209	195	181

THERMO ELECTRON
ENGINEERING CORPORATION

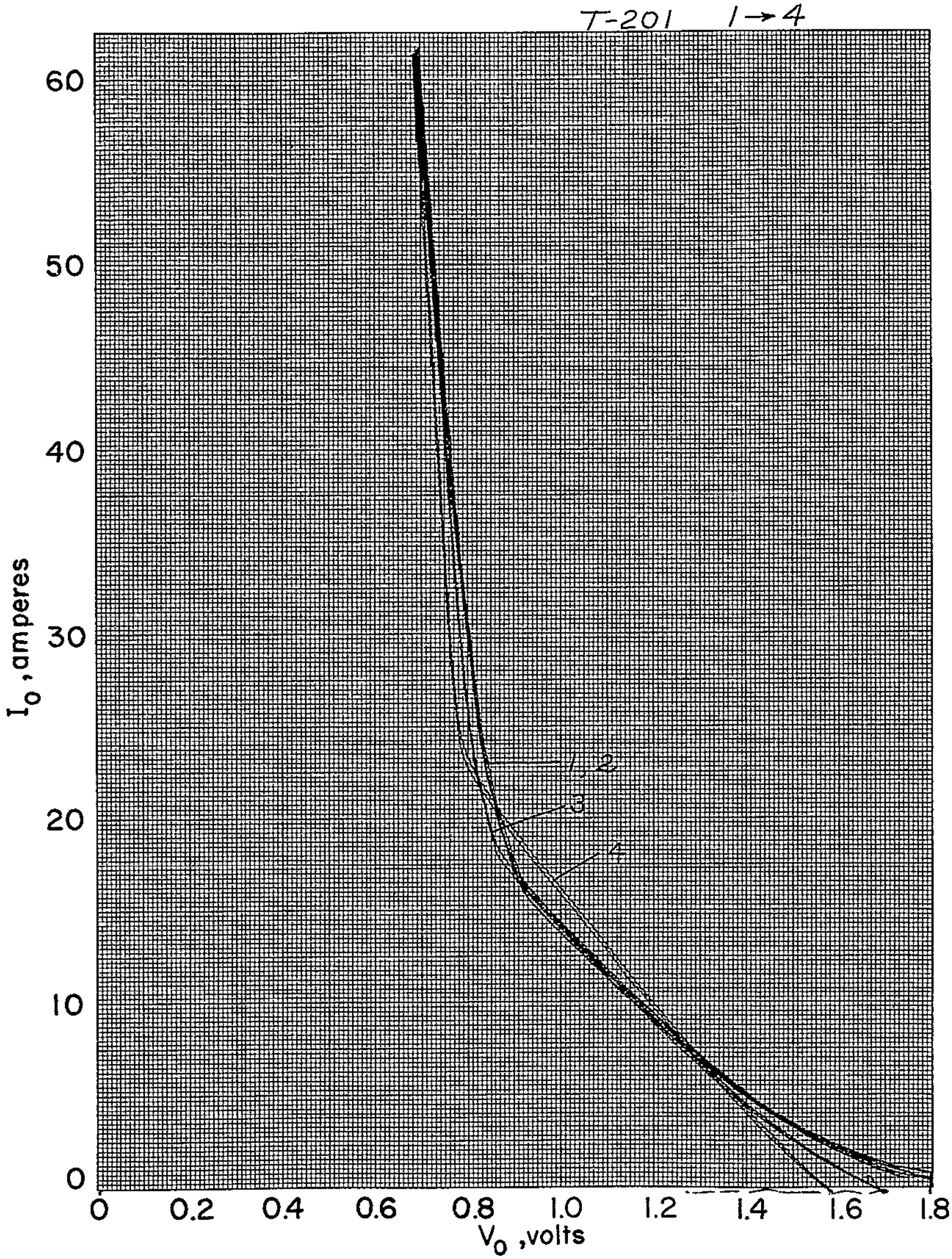
Sheet 9 of 9

Converter No T-201 Run No 8 Observer P. Brosser

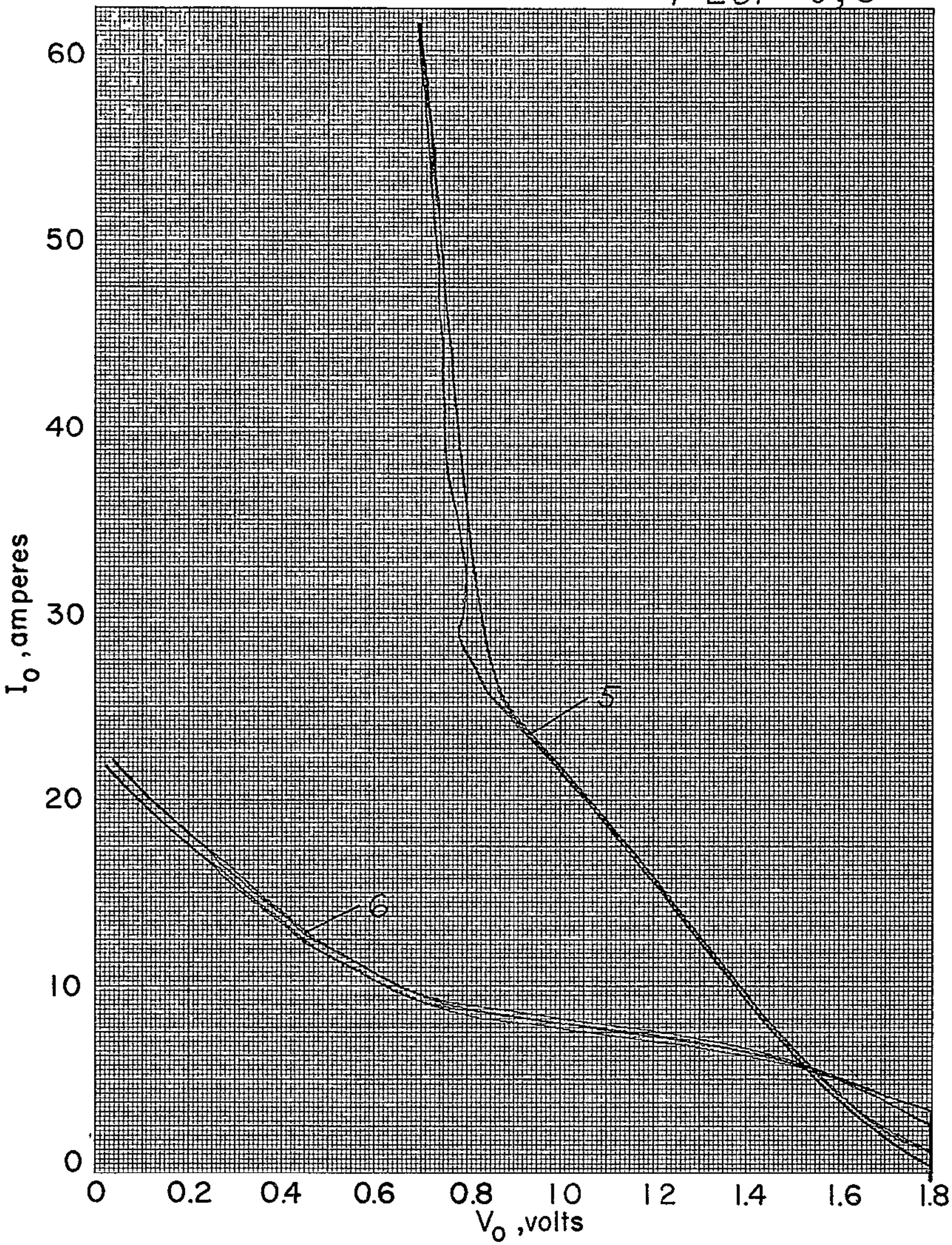
VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		2-17	2-17	2-17	2-17	2-17	2-17				
Time		1146	1158	1208	1416	1426	1430				
Elapsed Time, Hours		246.5	246.7	246.8	249.1	249.2	249.3				
T_O, °C		1773	1773	1773	1773	1773	1773				
T_O Corrected, °C		1784	1784	1784	1784	1784	1784				
$\Delta T_{Bell\ Jar}$, °C		16	16	16	16	16	16				
T_H, °C		1800	1800	1800	1800	1800	1800				
ΔT_E, °C		13	11	9	8	7	7				
T_E, °K		2060	2062	2064	2065	2066	2066				
V_o, volts		.600	.800	1.000	1.200	1.400	1.400				
I_o, amps		50.7	39.0	25.2	18.9	13.1	13.1				
P_o, watts		30.4	31.2	25.2	22.7	18.3	18.3				
I-V Trace No		—	—	—	—	—	—				
T_R	mv	14.7	14.4	14.2	14.1	14.0	14.0				
	°C	360	353	348	345	343	343				
	°K	633	626	621	618	616	616				
T_C	mv	2-680	2-554	2-430	2-346	2-288	2-289				
	°C	840	777	715	673	644	644				
	°K	1113	1050	988	946	917	917				
T_C base inner	mv.	27.0	25.3	23.6	22.6	21.9	21.8				
	°C	649	609	569	546	529	527				
T_C base outer	mv	26.2	24.7	23.3	22.4	21.7	21.6				
	°C	630	595	562	541	525	522				
$T_{Radiator}$	mv	23.2	22.2	21.2	20.4	19.9	19.9				
	°C	560	537	513	494	483	483				
V_{eb}, volts		976	980	985	986	989	989				
I_{eb}, mA		376	342	299	282	261	263				
$E_{Filament}$, volts		5.1	5.0	4.8	4.8	4.7	4.7				
$I_{Filament}$, amps		22.3	22	22	21.5	21	21				
$I_{Coll\ Heater}$, amps		0	0	0	0	0	0				
$I_{Res\ Heater}$, amps		5.5	5.5	5.5	5.5	5.5	5.5				
Vacuum, 10^{-6} mm Hg		2.6	2.6	2.6	2.6	2.6	2.6				
Measured Efficiency, %		8.3	9.3	8.4	8.1	7.1	*				

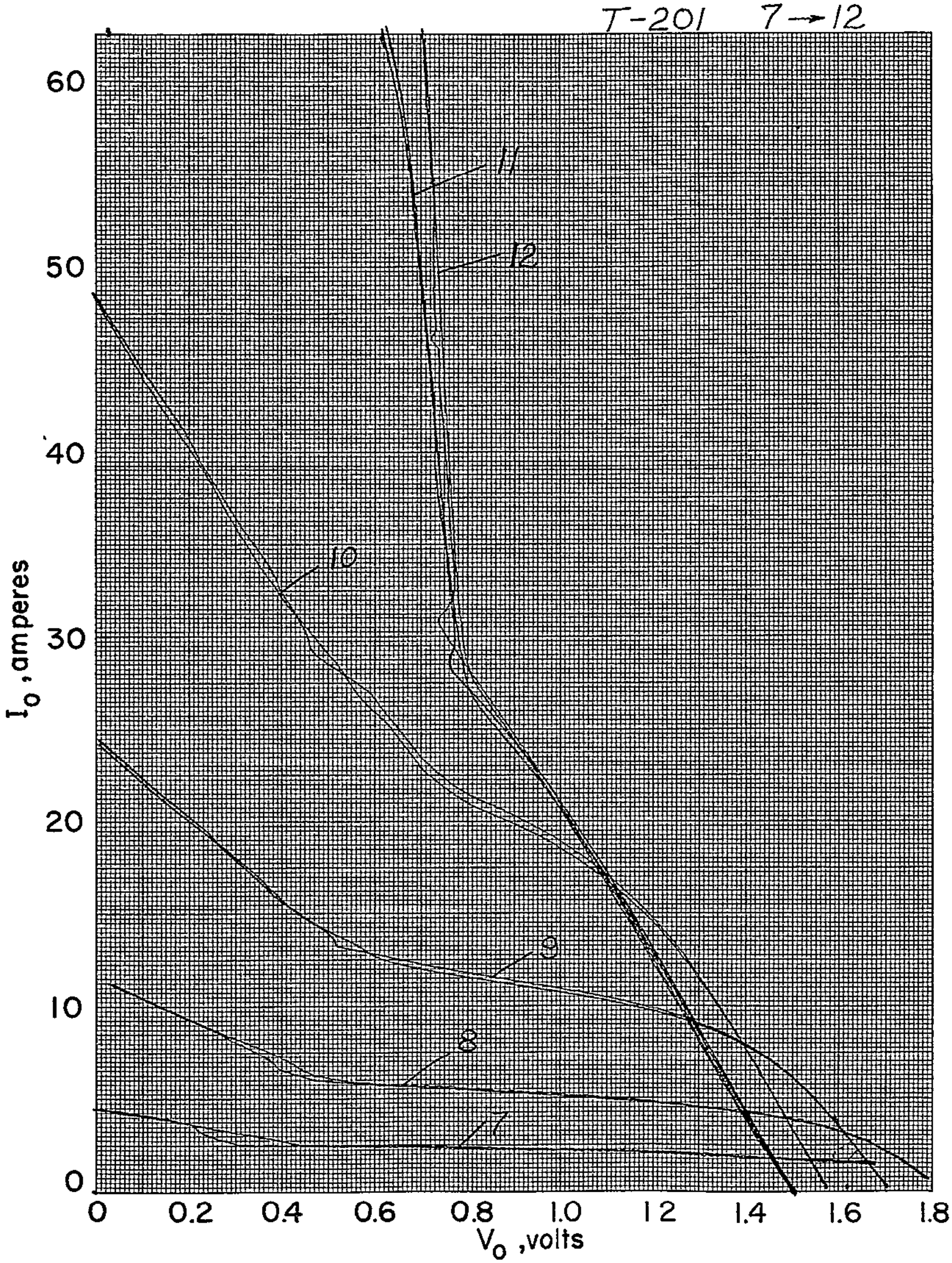
NOTES. * END OF T-201 TESTING

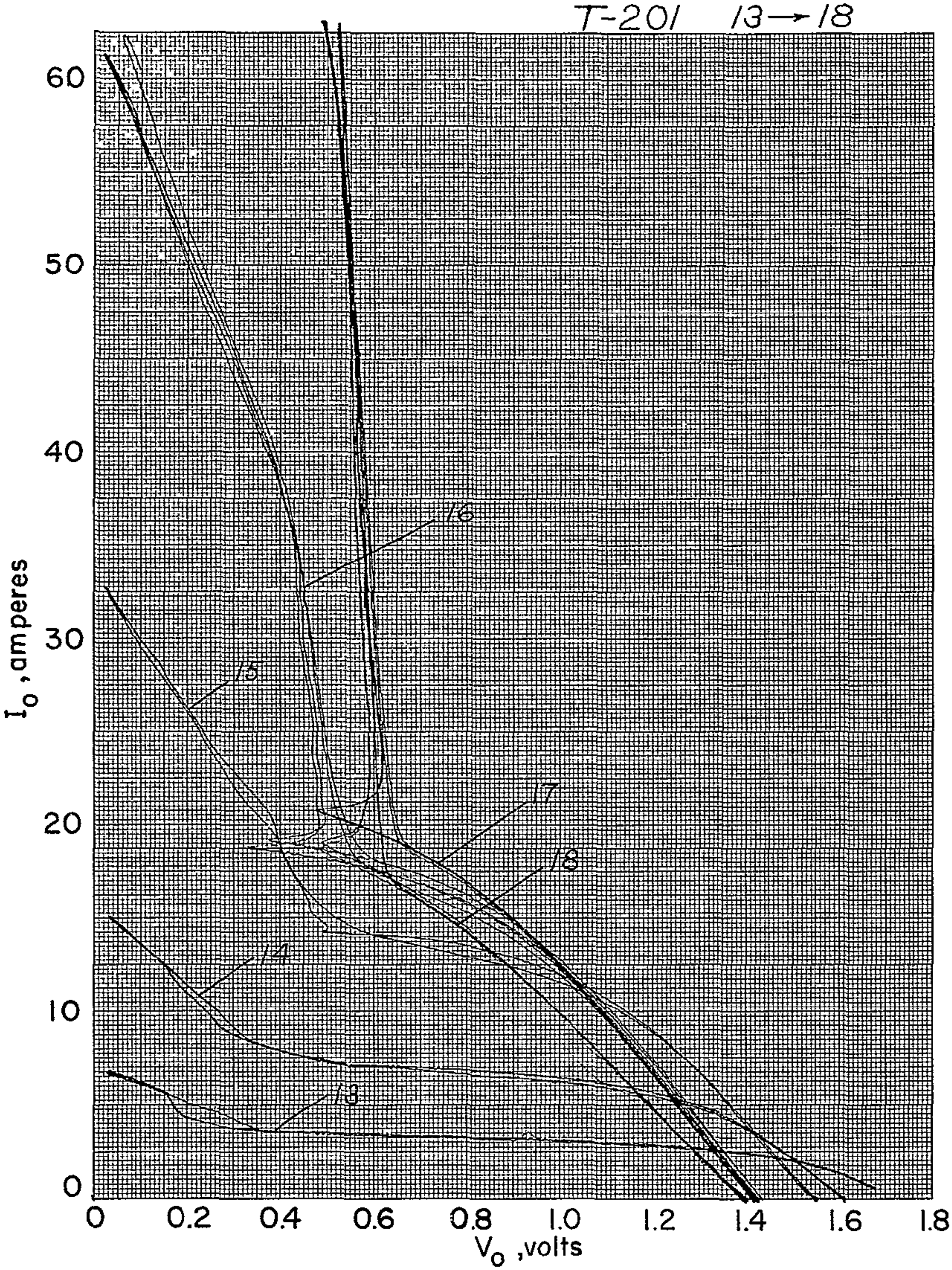
	1	2	3	4	5
P	367	333	294	278	258
q_{cs}	20	19	18	17	16
$P-q_{cs}$	347	314	276	261	242

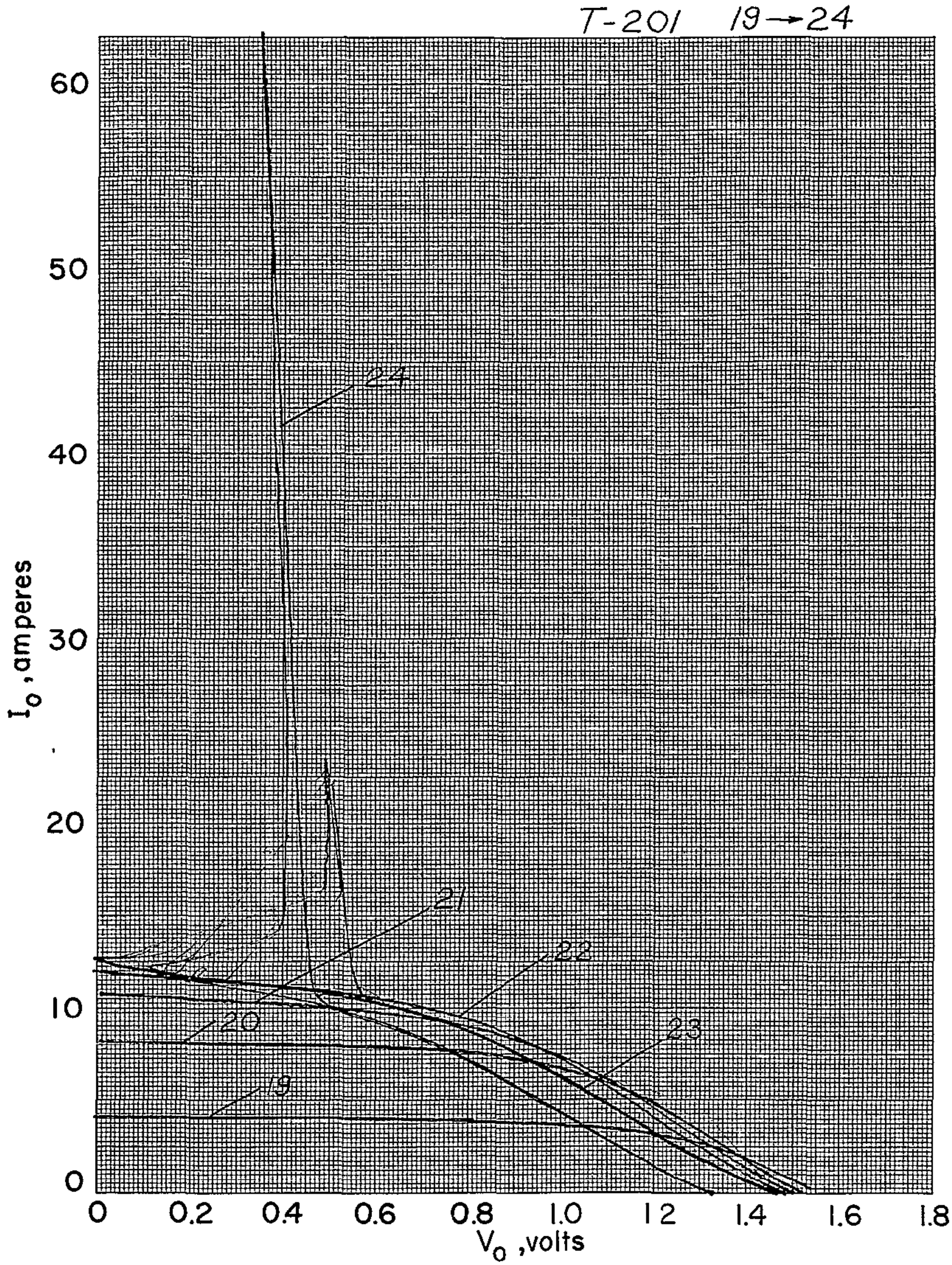

T-201 1→4
0
10
20
30
40
50
60
I_0 , amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_0 ,volts
1, 2
3
4

T-201 5,6

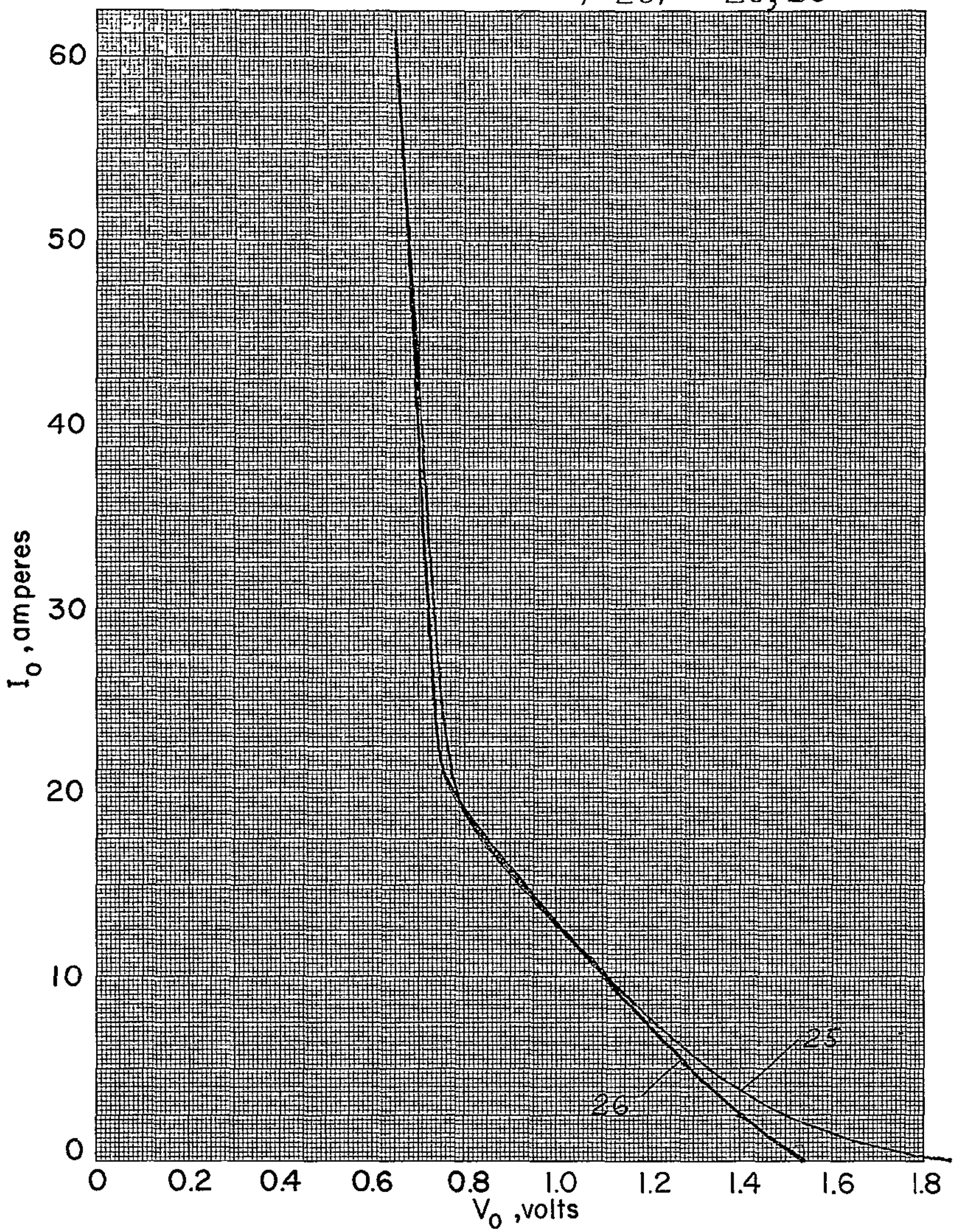

60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts
5
6


T-201 7 → 12
60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts
11
12
10
9
8
7


T-201 13→18
60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts
16
15
17
18
14
13


T-201 19→24
60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts
24
21
22
20
23
19

T-201 25, 26


60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts
25
26

APPENDIX 3

COLLECTOR-RADIATOR TEMPERATURE DISTRIBUTION

APPENDIX 1-1

Sheet 1 of 2

THERMO ELECTRON
ENGINEERING CORPORATION

COLLECTOR-RADIATOR TEMPERATURE DISTRIBUTION

Run No. 1 Observer F. Brosem

		1	2	3	4	5	6
Date		1-11-66	→	→	→	→	→
Time		14 10	14.20	14 30	14 40	14 50	15·00
E_f, volts		5.4	5 2	5 0	5 0	5 0	5.0
I_f, amps		16	16	16	16	16	16
E_b, volts		0	0	0	0	0	0
I_b, mA		0	0	0	0	0	0
T_1	mV	100	2 25	3 15	3 93	4.48	4.87
	°C	25	55	77	96	110	118
T_2	mV	1.00	2 10	3 00	3.73	4.27	4 66
	°C	25	52	74	91	104	113
T_3	mV	100	2 10	3 00	3 71	4 25	4 64
	°C	25	52	74	91	103	113
T_4	mV	100	2 10	2.97	3 70	4 25	4 62
	°C	25	52	73	91	103	112
T_5	mV	1.00	2 05	2 95	3 68	4 20	4.58
	°C	25	51	72	90	102	112
T_6	mV	100	1.90	2 72	3 46	4.00	4 41
	°C	25	47	67	85	98	107
T_7	mV	100	1.50	2 20	2.92	3 45	3.87
	°C	25	37	54	71	84	94
T_8	mV	100	1.50	2 20	2 92	3 45	3 87
	°C	25	37	54	71	84	94

THERMO ELECTRON
ENGINEERING CORPORATION

COLLECTOR-RADIATOR TEMPERATURE DISTRIBUTION

Run No. 2, 3 & 4 & 5 Observer F. Brosens

		R.2			R3	R4	R5
		1	2	3	4	5	6
Date		1-11-66	1-11-66	1-11-66	1-12-66	1-12-66	2-7-66
Time		15 35	16 00	16·27	13 15	16 17	11:45
E_f, volts		4 25	475	4.90	4.77	5 00	4 10
I_f, amps		14.1	15 2	16 0	15.2	15 2	15 2
E_b, volts		1000	1000	1000	1000	1000	1000
I_b, mA		100	200	300	200	200	200
T_1	mV	24 40	34.00	41.36	33 90	33 67	† 33 45
	°C	588	817	1002	815	809	827
T_2	mV	20 36	26 85	31.05	26.75	26.55	† 26.00
	°C	494	646	746	643	638	648
T_3	mV	20 04	26.16	30.06	26 04	25.85	† 25.69
	°C	486	629	722	627	622	641
T_4	mV	19.48	25 07	28 64	25.15	24.90	† 24 25
	°C	473	603	688	605	600	617
T_5	mV	18 47	23 15	25.95	23 25	23 02	† 22.25
	°C	449	559	625	561	555	561
T_6	mV	16 88	21 30	24.05	21 03	20 90	† 21.80
	°C	412	516	580	509	506	550
T_7	mV	13 75	17 26	19 26	17 42	12.89	*† 5 19
	°C	337	420	467	424	317	620
T_8	mV	13 72	17 20	19.15	17 35	12 81	**† 5.95
	°C	336	419	465	423	314	693

* inner & ** outer braze joint thermocouples (Pt, Pt-10% Rh) † add 23 °C for room temperature

APPENDIX 4

COLLECTOR ETCHING PROCEDURE FOR CONVERTER T-202

APPENDIX 4

COLLECTOR ETCHING PROCEDURE FOR CONVERTER T-202

Dip collector for 2-minute intervals adding up to 15 minutes max. in solution of:

100 vol saturated $K_3Fe(CN)6$
5 vol saturated KOH
95 vol H_2O

agitated at the 2-minute intervals. Planes developed are [110].

Ref. C.S. Barrett, Structure of Metals, McGraw-Hill, 1952, p. 194.

APPENDIX 5

TEST DATA FROM CONVERTER T-202 .

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 1 of 7

Converter No T-202 Des II Run No 1 & 2 Observer B. Gunther

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		3-11-66	—	—	—	—	—	—	3-14-66	—	3-15-66
Time		1050	1110	1350	1430	1540	1610	1640	1120	1250	0900
Elapsed Time, Hours		—	—	—	—	—	—	—	0	15.	21 6
T_0, °C		1708	1708	1708	1703	1714	1711	1704	1710	1713	1708
T_0 Corrected, °C		1718	1718	1718	1713	1724	1721	1714	1720	1723	1718
$\Delta T_{Bell\ Jar}$, °C		18	18	18	18	18	18	18	18	18	18
T_H, °C		1736	1736	1736	1731	1742	1739	1732	1738	1741	1736
ΔT_E, °C		8	8	8	7	15	12	8	12	12	12
T_E, °K		2001	2001	2001	1997	2000	2000	1997	1999	2002	1997
V_0, volts		—	—	—	—	.60	.80	1.00	.80	.80	.80
I_0, amps		23 av.	23 av	28 av	13 av	63.7	40.0	17.9	41.1	40 7	42.0
P_0, watts		—	—	—	—	38.2	32.0	17.9	32.9	32.6	33.6
I-V Trace No		1	2	3	4	—	—	—	—	—	—
T_R	mv	16.7	16.7	14.3	11.8	15.4	14.0	13.2	14.4	14.4	14.3
	°C	407	407	350	290	376	343	324	353	353	350
	°K	680	680	623	563	649	616	597	626	626	623
T_C	mv	2-538	2-376	2-532	2-332	2-682	2-460	2-225	2-466	2-466	2-466
	°C	769	688	766	666	841	730	613	733	733	733
	°K	1042	961	1039	939	1114	1003	886	1006	1006	1006
T_C base inner	mv	27.2	23.7	26.8	24.2	27.5	24 7	21.6	25.0	24.9	24.9
	°C	654	572	644	583	661	595	522	602	600	600
T_C base outer	mv	27.0	23 2	26.5	24.3	27.0	24.2	21.2	24.5	24.4	24.4
	°C	649	560	637	586	649	583	513	590	588	588
$T_{Radiator}$	mv	23.2	20.7	22.9	21.1	23.2	21.3	19.1	21.6	21.5	21.5
	°C	560	501	553	511	560	516	464	522	520	520
V_{eb}, volts		988	988	988	997	977	984	993	980	979	981
I_{eb}, mA		260	258	260	189	364	299	230	302	302	303
$E_{Filament}$, volts		4.9	4.9	4.8	4.6	5.2	5	4.8	5	5	5
$I_{Filament}$, amps		21	21	21	20	23	21.5	21	21.5	21.5	215
$I_{Coll\ Heater}$, amps		9	0	9	9	0	0	0	0	0	0
$I_{Res\ Heater}$, amps		~2	~4	~2	~1	~4	~3	~3	~3	~3	~3
Vacuum, 10^{-6} mm Hg		6.6	6.4	5	4.6	4.4	4.2	4.2	4.0	3.8	3.4
Measured Efficiency, %											

NOTES

THERMO ELECTRON ENGINEERING CORPORATION

Sheet 2 of 7

Converter No T-202 Des. II Run No 2 & 3 Observer B. Gunther

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		3-15-66	3-16-66	3-17-66	3-21-66	3-21-66	—	—	—	—	—
Time		1710	1050	1145	0915	1448	1502	1518	1530	1543	1557
Elapsed Time, Hours		29.8	47.5	72.4	165.9	—	—	—	—	—	—
T_0, °C		1707	1708	1696	1702	1712	1710	1710	1710	1710	1708
T_0 Corrected, °C		1717	1718	1706	1712	1722	1720	1720	1720	1720	1718
$\Delta T_{Bell\ Jar}$, °C		18	18	18	18	13	13	13	13	13	13
T_H, °C		1735	1736	1724	1730	1735	1733	1733	1733	1733	1731
ΔT_E, °C		12	12	12	12	9	9	10	8	7	6
T_E, °K		1996	1997	1985	1991	1999	1997	1996	1998	1999	1998
V_0, volts		.80	.80	.80	.80	—	—	—	—	—	—
I_0, amps		42.2	43.4	43.3	42.7	24av	25av	28	18	13	6
P_0, watts		33.8	34.7	34.7	34.2	—	—	—	—	—	—
I-V Trace No		—	—	—	—	5	6	7	8	9	10
T_R	mv	14.2	14.2	14.3	14.2	15.2	14.3	13.4	12.6	11.8	11.0
	°C	348	348	350	348	372	350	329	309	290	271
	°K	621	621	623	621	645	623	602	582	563	544
T_C	mv	2-466	2-466	2-466	2-466	2-712	2-634	2-558	2-494	2-424	2-356
	°C	733	733	733	733	856	817	779	747	712	678
	°K	1006	1006	1006	1006	1129	1090	1052	1020	985	951
T_C base inner	mv	24.8	24.9	24.8	24.9	30.8	29.3	27.5	26.9	26.0	23.6
	°C	597	600	597	600	740	704	661	647	626	569
T_C base outer	mv	24.3	24.4	24.3	24.4	30.7	29.3	27.4	26.7	26.0	23.3
	°C	586	588	586	588	737	704	659	642	626	562
$T_{Radiator}$	mv	21.4	21.5	21.4	21.5	25.5	24.6	23.5	23.0	22.5	21.0
	°C	518	520	518	520	614	593	567	555	543	508
V_{eb}, volts		982	981	983	980	988	988	988	993	994	998
I_{eb}, mA		302	303	301	302	251	250	249	212	200	178
$E_{Filament}$, volts		5	5	5	5	4.9	4.9	4.9	4.8	4.7	4.6
$I_{Filament}$, amps		21.5	21.5	21.5	20.5	20	20	20	19.5	19	19
$I_{Coll\ Heater}$, amps		0	0	0	0	14	12	11	11	12	0*
$I_{Res\ Heater}$, amps		~3	~3	~3	~3	~2	~2	~2.0	~2	~0	~0
Vacuum, 10^{-6} mm Hg		3.3	3.2	3.0	2.7	5.2	5.0	4.8	4.7	4.6	4.6
Measured Efficiency, %											

NOTES. * Collector heater failed during data point 10
Bell Jar calibrated at end of

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 3 of 7

Converter No T-202 Des. II Run No 3 Observer B. Gunther

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		3-22-66	—	3-23-66	—	--	-	--		--	--
Time		1540	1552	1257	1307	1317	1327	1337	1347	1440	1450
Elapsed Time, Hours		---	-			-	-		--	--	--
T_O, °C		1712	1710	1615	1615	1614	1613	1612	1612	1518	1518
T_O Corrected, °C		1722	1720	1624	1624	1623	1622	1621	1621	1526	1526
$\Delta T_{Bell\ Jar}$, °C		13	13	11	11	11	11	11	11	9	9
T_H, °C		1735	1733	1635	1635	1634	1633	1632	1632	1535	1535
ΔT_E, °C		11	9	9	9	9	8	7	6	9	9
T_E, °K		1997	1997	1899	1899	1898	1898	1898	1899	1799	1799
V_O, volts		.829	—	—	—	—	—				—
I_O, amps		39.7	27	23	24	23	20	10	6	22	22
P_O, watts		32.9	--	—	—	-		.			.
I-V Trace No		-	11	12	13	14	15	16	17	18	19
T_R	mv	14.3	14.3	15.2	14.3	13.4	12.6	11.8	11.0	15.2	14.3
	°C	350	350	372	350	329	310	290	271	372	350
	°K	623	623	645	623	602	583	563	544	645	623
T_C	mv	2-448	2-448	2-518	2-448	2-400	2-320	2-254	2-194	2-518	2-448
	°C	724	724	759	724	700	660	627	597	759	724
	°K	997	997	1032	997	973	933	900	870	1032	997
T_C base inner	mv	24.6	25.4	27.2	25.8	25.0	23.7	22.9	22.1	27.5	26.0
	°C	593	612	654	621	602	572	553	534	661	626
T_C base outer	mv	24.1	25.4	27.0	25.6	24.6	23.4	22.9	22.1	27.2	26.0
	°C	581	612	649	616	593	564	553	534	654	626
$T_{Radiator}$	mv	21.4	22.0	23.3	22.3	21.7	20.8	20.3	19.7	23.4	22.6
	°C	518	532	562	562	525	504	492	478	564	546
V_{eb}, volts		985	990	992	992	992	994	999	1002	996	996
I_{eb}, mA		297	255	212	214	209	191	159	146	178	176
$E_{Filament}$, volts		5.1	5	4.8	4.8	4.8	4.8	4.6	4.6	4.6	4.6
$I_{Filament}$, amps		20.5	20	19.5	19.5	19.5	19.5	19	19	19	19
$I_{Coll\ Heater}$, amps		0	7	11	11	11	7	7	7	13	12
$I_{Res\ Heater}$, amps		~3	~3	~3	~3	~3	~2	~2	~2	~3	~3
Vacuum, 10^{-6} mm Hg		5.8	5.6	5	5	4.8	4.8	4.8	4.8	4.4	4.4
Measured Efficiency, %											

NOTES.

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 4 of 7

Converter No T 202 Des II Run No 3, 4 & 5 Observer B. Gunther

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		3-23-66	—	—	—	—	—	3-24-66	—	—	—
Time		1500	1510	1520	1530	1558	1630	0940	1002	1015	1028
Elapsed Time, Hours		—	—	—	—	—	—	—	—	—	—
T_O, °C		1518	1518	1517	1516	1711	1711	1710	1710	1710	1710
T_O Corrected, °C		1526	1526	1525	1524	1721	1721	1720	1720	1720	1720
$\Delta T_{Bell\ Jar}$, °C		9	9	9	9	13	13	13	13	13	13
T_H, °C		1535	1535	1534	1533	1734	1734	1733	1733	1733	1733
ΔT_E, °C		9	9	7	6	9	9	5	5	5	5
T_E, °K		1799	1799	1800	1800	1998	1998	2001	2001	2001	2001
V_O, volts		—	—	—	—	—	—	2.09	2.07	2.04	2.02
I_O, amps		22	23	12	6	23	22	0	0	0	0
P_O, watts		—	—	—	—	—	--	0	0	0	0
I-V Trace No		20	21	22	23	24	25	—	—	—	—
T_R	mv	13.4	12.6	11.8	11.0	16.7	16.7	17.0	16.0	15.0	14.0
	°C	329	309	290	271	407	407	414	391	367	343
	°K	602	582	563	544	680	680	687	664	640	616
T_C	mv	2-400	2-320	2-254	2-194	2-538	2-376	2-254	2-254	2-254	2-254
	°C	700	660	627	597	769	688	627	627	627	627
	°K	973	933	900	870	1042	961	900	900	900	900
T_C base inner	mv	25.2	23.7	23.0	22.6	27.0	23.6	22.9	22.9	22.9	23.1
	°C	607	572	555	546	649	569	553	553	553	558
T_C base outer	mv	25.0	23.5	23.1	22.5	26.6	23.1	22.6	22.6	22.5	22.9
	°C	602	567	558	543	640	558	546	546	543	553
$T_{Radiator}$	mv	21.9	20.8	20.3	20.0	23.0	20.7	20.3	20.2	20.3	20.4
	°C	529	504	492	485	555	501	492	489	492	494
V_{eb}, volts		997	999	1002	1006	988	988	998	998	998	999
I_{eb}, mA		176	167	139	120	250	250	189	187	183	179
$E_{Filament}$, volts		4.8	4.8	4.6	4.6	4.9	4.9	4.6	4.6	4.6	4.6
$I_{Filament}$, amps		19	19	18.5	18.5	20	20	19	19	19	19
$I_{Coll\ Heater}$, amps		11	9	11	10	9	~2	6	6	6	6
$I_{Res\ Heater}$, amps		~2	~2	~2	~1	4	5.5	2	2	2	2
Vacuum, 10^{-6} mm Hg		4.3	4.3	4.3	4.3	4.3	4.3	3.6	3.6	3.6	3.6
Measured Efficiency, %											

NOTES.

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 5 of 7

Converter No T 202 Des II   Run No 5 & 6   Observer B. Gunther

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		3-24-66	—	—	—	0925	0935	0945	0955	1005	1020
Time		1042	1055	1115	1137	3-25-66	↓	↓	↓	↓	↓
Elapsed Time, Hours		—	—	—	—	—	—	—	—	—	—
T_0, °C		1710	1710	1710	1710	1580	1580	1580	1580	1580	1676
T_0 Corrected, °C		1720	1720	1720	1720	1589	1589	1589	1589	1589	1686
$\Delta T_{Bell\ Jar}$, °C		13	13	13	13	11	11	11	11	11	13
T_H, °C		1733	1733	1733	1733	1600	1600	1600	1600	1600	1699
ΔT_E, °C		5	5	5	5	12	6	6	6	5	15
T_E, °K		2001	2001	2001	2001	1861	1867	1867	1867	1868	1957
V_0, volts		2.02	1.97	1.95	1.95	.60	.80	1.00	1.20	1.40	60
I_0, amps		0	0	0	0	41.7	8.5	6.9	4.9	2.5	60.0
P_0, watts		0	0	0	0	25.0	6.8	6.9	5.9	3.5	36.0
I-V Trace No		—	—	—	—	—	—	—	—	—	—
T_R	mv	13.0	12.0	11.0	10.5	13.9	12.3	12.2	11.8	11.6	14.7
	°C	319	295	271	258	341	302	300	290	285	360
	°K	592	568	544	531	614	575	573	563	558	633
T_C	mv	2-254	2-254	2-254	2-254	2-379	2-060	2-014	1-986	1-956	2-606
	°C	627	627	627	627	627	530	507	493	478	803
	°K	900	900	900	900	900	803	780	766	751	1076
T_C base inner	mv	23.0	23.4	23.4	23.4	23.5	19.1	18.6	18.0	17.4	26.5
	°C	555	564	564	564	567	464	452	438	424	637
T_C base outer	mv	23.0	23.5	23.4	23.2	23.0	19.0	18.3	17.7	17.2	25.9
	°C	555	567	564	560	555	461	445	431	419	623
$T_{Radiator}$	mv	20.4	20.7	20.7	20.6	20.4	17.4	16.9	16.4	16.0	22.6
	°C	494	501	501	499	494	424	412	400	391	546
V_{eb}, volts		1000	1000	1001	1000	987	1000	1000	1003	1005	977
I_{eb}, mA		173	170	166	165	252	158	152	146	141	335
$E_{Filament}$, volts		4.6	4.6	4.6	4.6	5.0	4.6	4.6	4.6	4.6	5.2
$I_{Filament}$, amps		19	19	19	19	20	18	18	19	19	20.5
$I_{Coll\ Heater}$, amps		7	10	9	9	0	0	0	0	0	0
$I_{Res\ Heater}$, amps		4	3	1	0	3	4	4	3	3	4
Vacuum, 10^{-6} mm Hg		3.6	3.6	3.6	3.6	3.2	3.2	3.2	3.2	3.2	3.2
Measured Efficiency, %											

NOTES.

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 6 of 1

Converter No T 202 Des II Run No 6 Observer B. Gunther

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		3-25-66	—	—	—	—	—	—	—	—	
Time		1030	1040	1050	1100	1120	1130	1140	1150	1200	
Elapsed Time, Hours		—	—	—	—	—	—	—	—	—	
T_O, °C		1678	1676	1676	1676	1772	1772	1772	1770	1774	
T_O Corrected, °C		1688	1686	1686	1686	1783	1783	1783	1781	1785	
$\Delta T_{Bell\ Jar}$, °C		13	13	13	13	15	15	15	15	15	
T_H, °C		1701	1699	1699	1699	1798	1798	1798	1796	1800	
ΔT_E, °C		11	7	6	6	17	14	10	7	7	
T_E, °K		1963	1965	1965	1965	2054	2057	2061	2062	2066	
V_o, volts		.80	1.00	1.20	1.40	.60	.80	1.00	1.20	1.40	
I_o, amps		33.6	12.3	8.8	5.3	72.1	52.2	30.2	15.0	10.9	
P_o, watts		26.9	12.3	10.6	7.4	43.2	41.8	30.2	18.0	15.3	
I-V Trace No		—	—	—	—	—	—	—	—	—	
T_R	mv	13.5	13.0	12.6	12.1	15.2	14.7	13.9	13.4	13.1	
	°C	331	319	309	293	372	360	341	329	321	
	°K	604	592	582	566	645	633	614	602	594	
T_C	mv	2-364	2-158	2-108	2-054	2-778	2-600	2-396	2-253	2-202	
	°C	682	579	554	527	889	800	698	627	601	
	°K	955	852	827	800	1162	1073	971	896	874	
$T_{C\ base\ inner}$	mv	23.4	20.5	19.9	19.1	28.7	26.5	23.9	21.9	21.1	
	°C	564	497	483	464	690	637	576	529	511	
$T_{C\ base\ outer}$	mv	22.9	20.2	19.5	18.9	27.9	25.9	23.2	21.4	20.7	
	°C	553	489	473	459	671	623	560	518	501	
$T_{Radiator}$	mv	20.4	18.4	17.9	17.2	24.0	22.6	20.8	19.3	18.9	
	°C	494	447	436	419	579	546	504	468	459	
V_{eb}, volts		985	993	995	999	968	974	982	988	989	
I_{eb}, mA		266	203	191	173	411	360	293	248	234	
$E_{Filament}$, volts		5.0	4.8	4.8	4.6	5.4	5.2	5.0	4.8	4.8	
$I_{Filament}$, amps		20	19	19	19	21.5	21	20	19.5	19.5	
$I_{Coll\ Heater}$, amps		0	0	0	0	0	0	0	0	0	
$I_{Res\ Heater}$, amps		4	3	3	3	3	3	3	3	3	
Vacuum, 10^{-6} mm Hg		3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	
Measured Efficiency, %											

NOTES

THERMO ELECTRON ENGINEERING CORPORATION

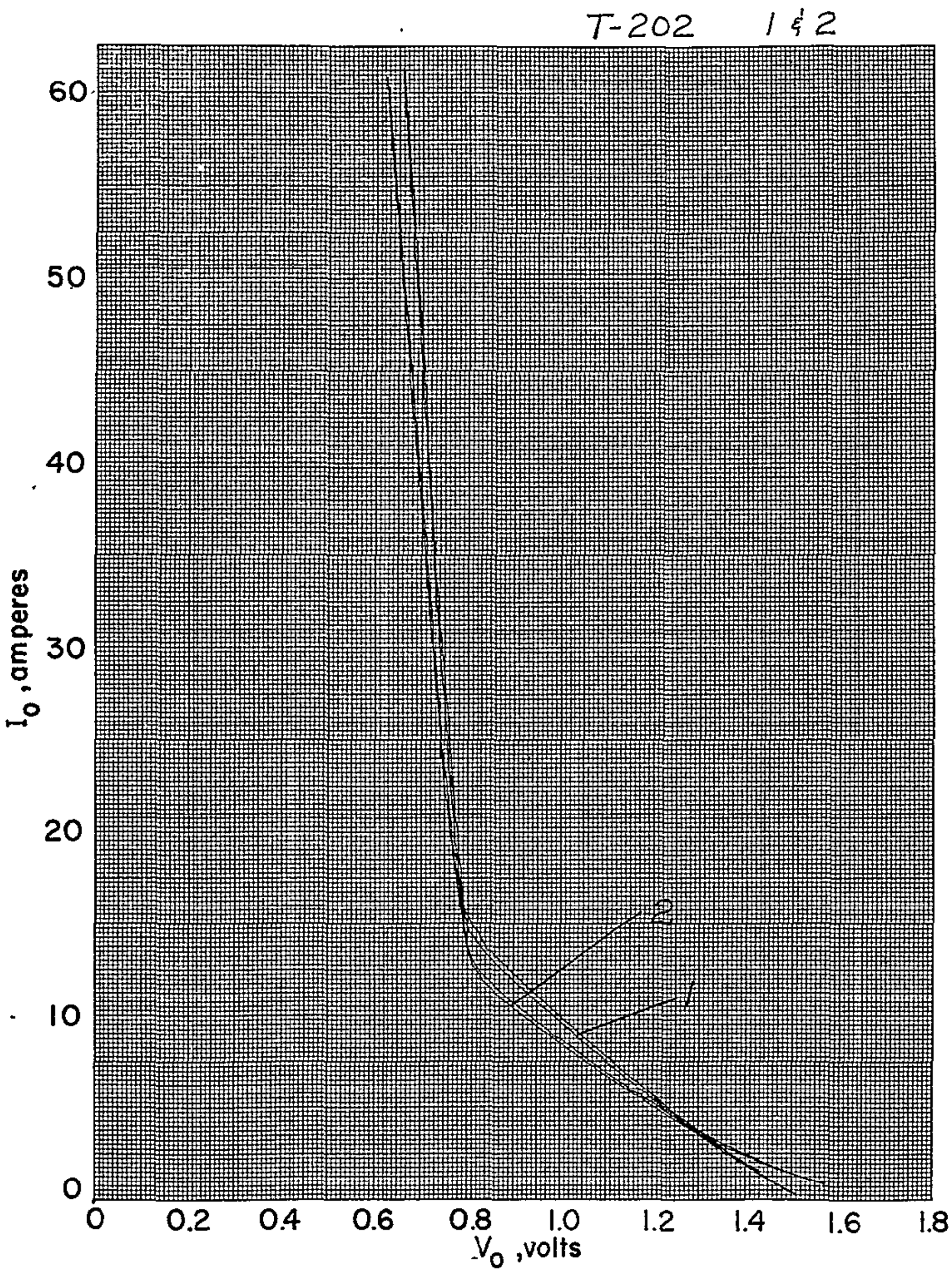
Sheet 7 of 7

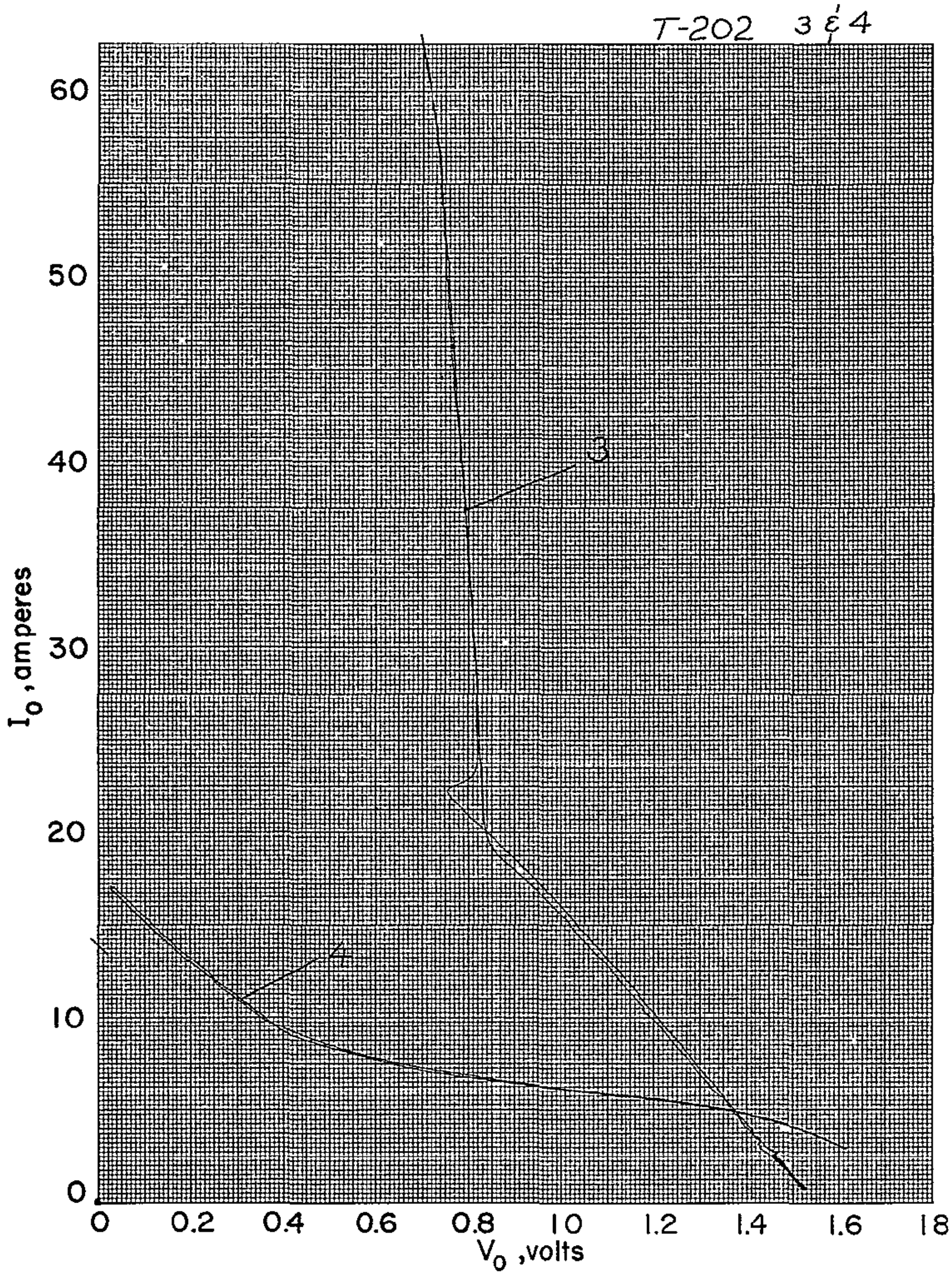
Converter No T-202 Run No 7 Observer B. Gunther

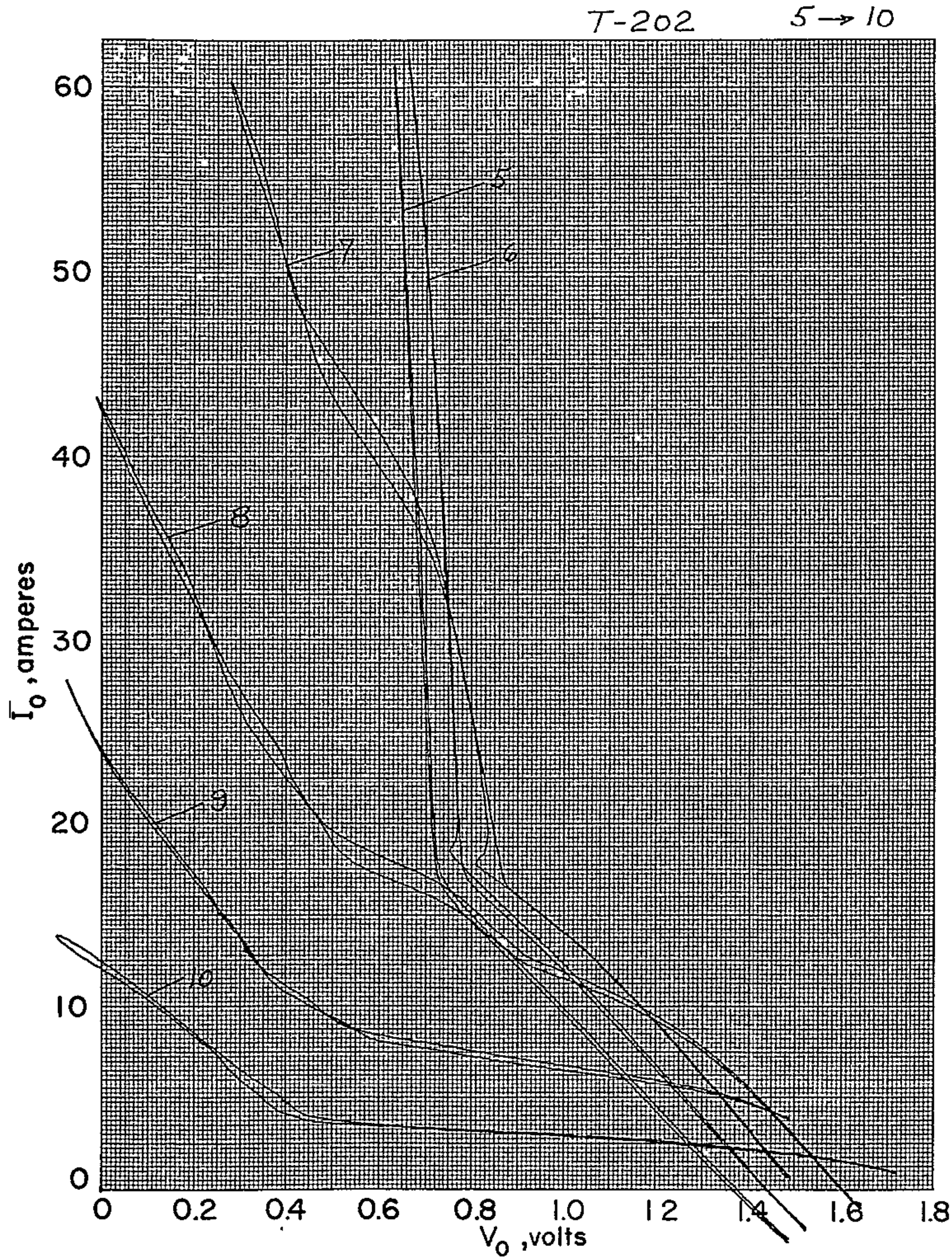
VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		3-28-66	—	—	—	—	—				
Time		1045	1105	1120	1300	1313	1327				
Elapsed Time, Hours		—	—	—	—	—	198.3				
T_0, °C		1682	1700	—	—	—	—				
T_0 Corrected, °C		1692	1710	—	—	—	—				
$\Delta T_{Bell\ Jar}$, °C		13	13	—	—	—	—				
T_H, °C		1705	1723	—	—	—	—				
ΔT_E, °C		7	5	—	—	—	—				
T_E, °K		1971	1991	—	—	—	—				
V_0, volts		1.00	2.25	—	—	—	—				
I_0, amps		9.4	0	—	—	—	—				
P_0, watts		9.4	0	—	—	—	—				
I-V Trace No											
T_R	mv	14.9	15.2	15.9	16.0	15.6	15.0				
	°C	364	372	388	391	381	367				
	°K	637	645	661	664	654	640				
T_C	mv	2-162	2-162	2-162	2-162	2-162	2-162				
	°C	581	581	581	581	581	581				
	°K	854	854	854	854	854	854				
T_C base inner	mv	20.8	21.3	21.4	20.9	20.9	20.9				
	°C	504	516	518	506	506	506				
T_C base outer	mv	20.4	21.0	21.1	20.6	20.6	20.5				
	°C	494	508	511	499	499	497				
$T_{Radiator}$	mv	18.6	19.1	19.2	18.8	18.8	18.7				
	°C	452	464	466	457	457	454				
V_{eb}, volts		991	999	—	—	—	—				
I_{eb}, mA		205	182	—	—	—	—				
$E_{Filament}$, volts		4.8	4.6	—	—	—	—				
$I_{Filament}$, amps		19	19	—	—	—	—				
$I_{Coll\ Heater}$, amps		0	5	.5	4	4	4				
$I_{Res\ Heater}$, amps		0	0	.585V 1.5A	.780V 2.0A	.587V 1.5A	0				
Vacuum, 10^{-6} mm Hg		3.4	3.4	3.4	3.4	3.4	3.4				
Measured Efficiency, %											

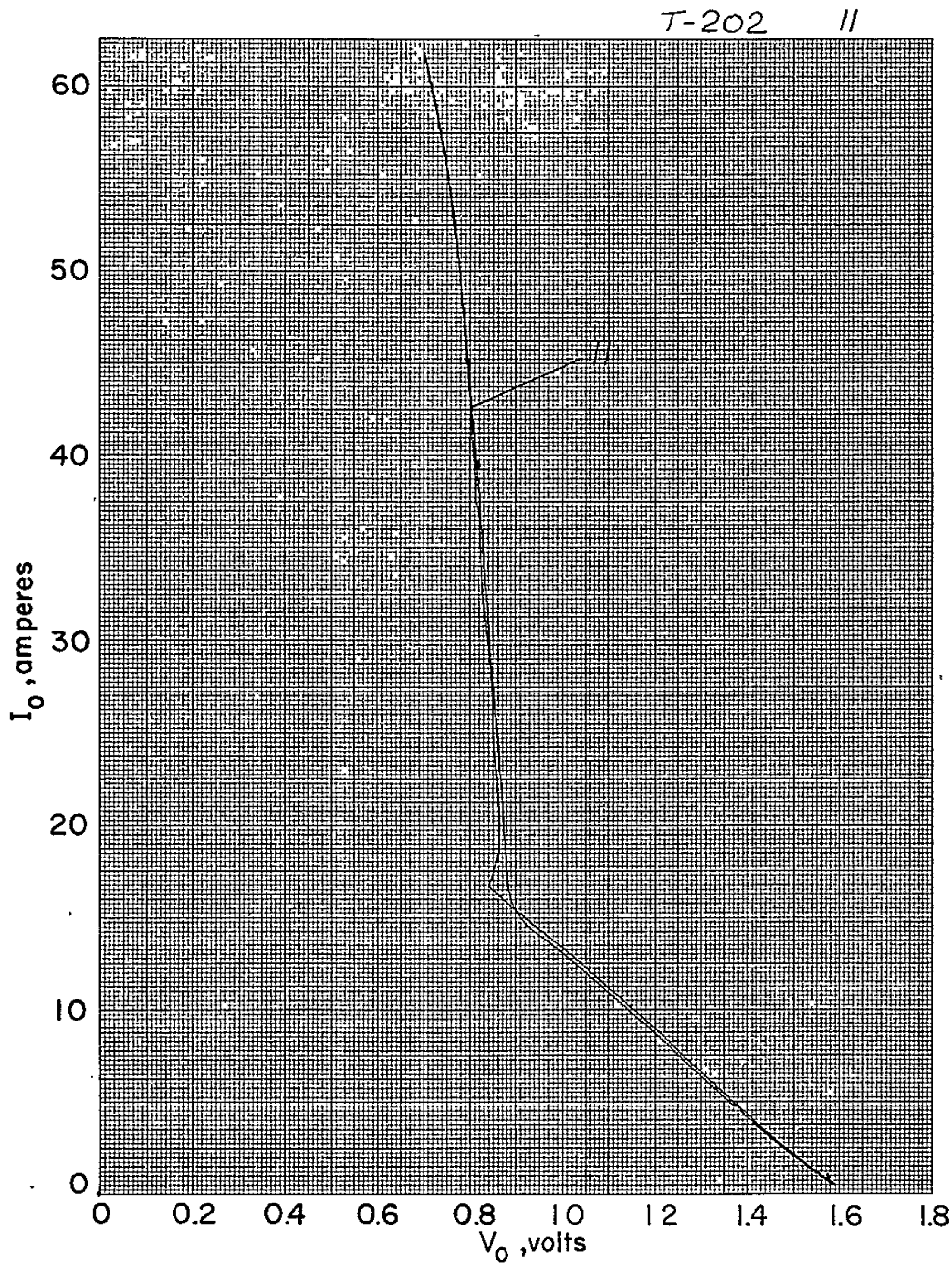
NOTES. No cooling strap on reservoir during run 7. Data points 4, 5 & 6 give T_R vs. heater power at constant T_C base inner.

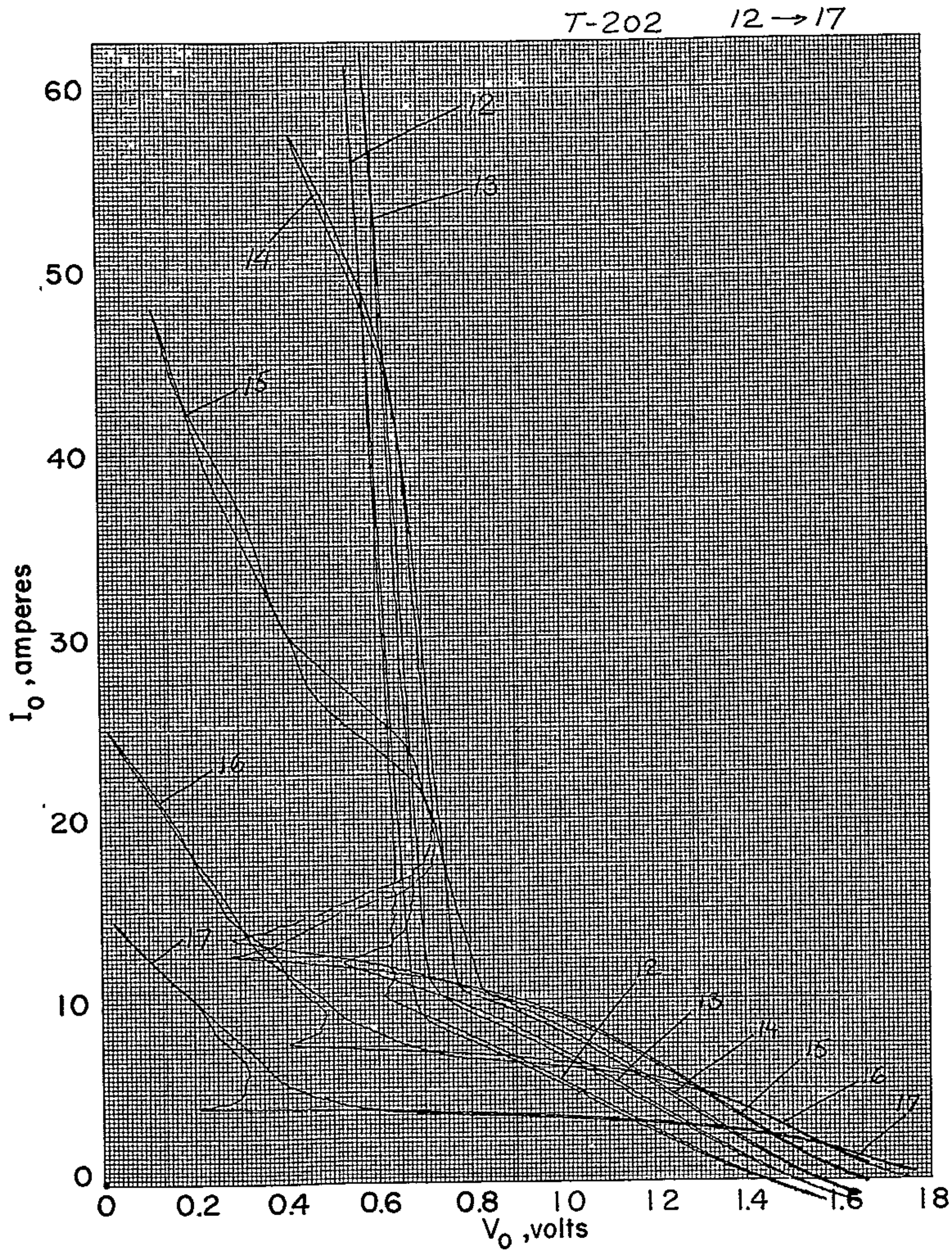
7322

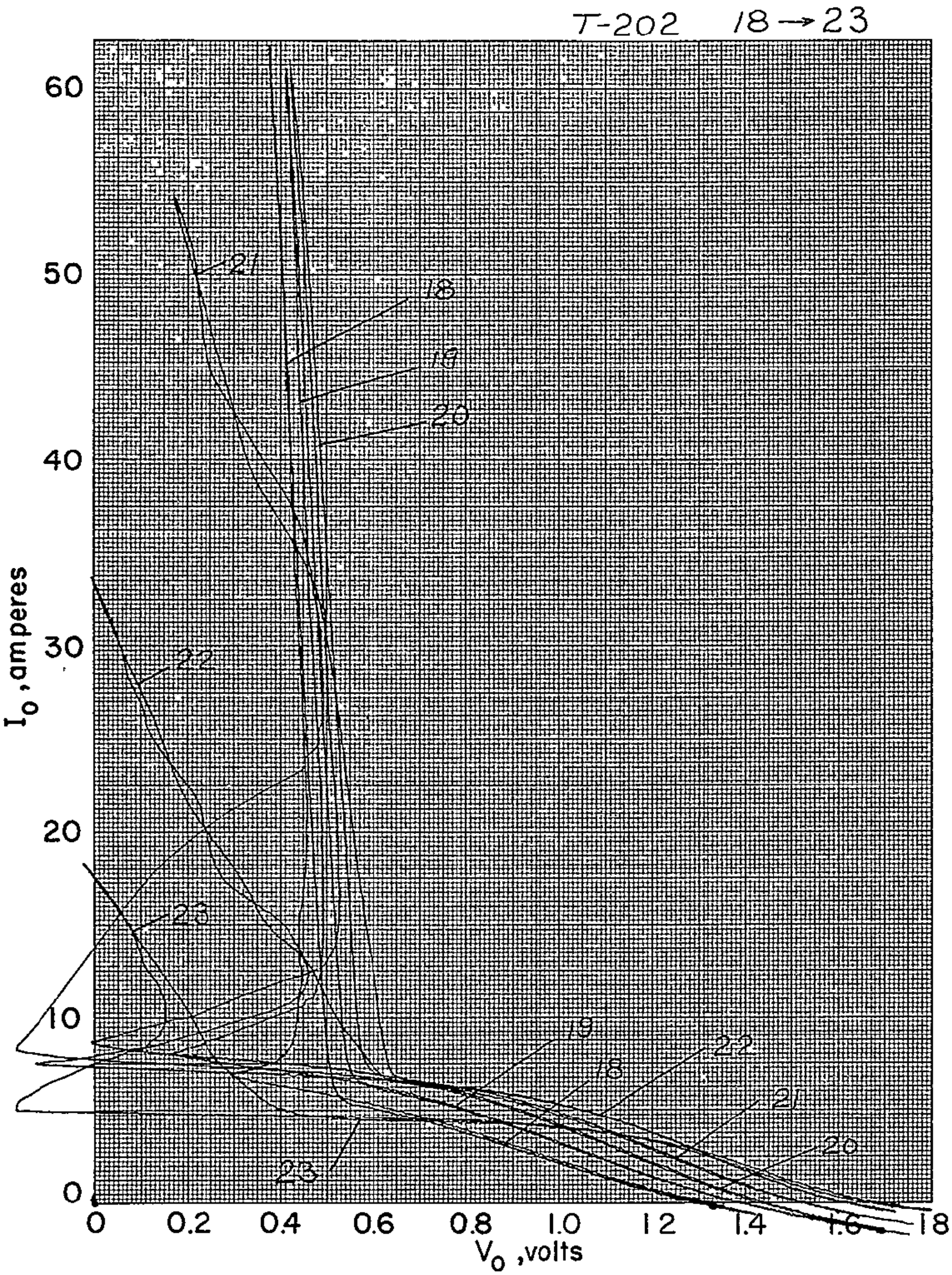

T-202 1 & 2
60
50
40
30
20
10
0
I_0, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_0, volts
2
1

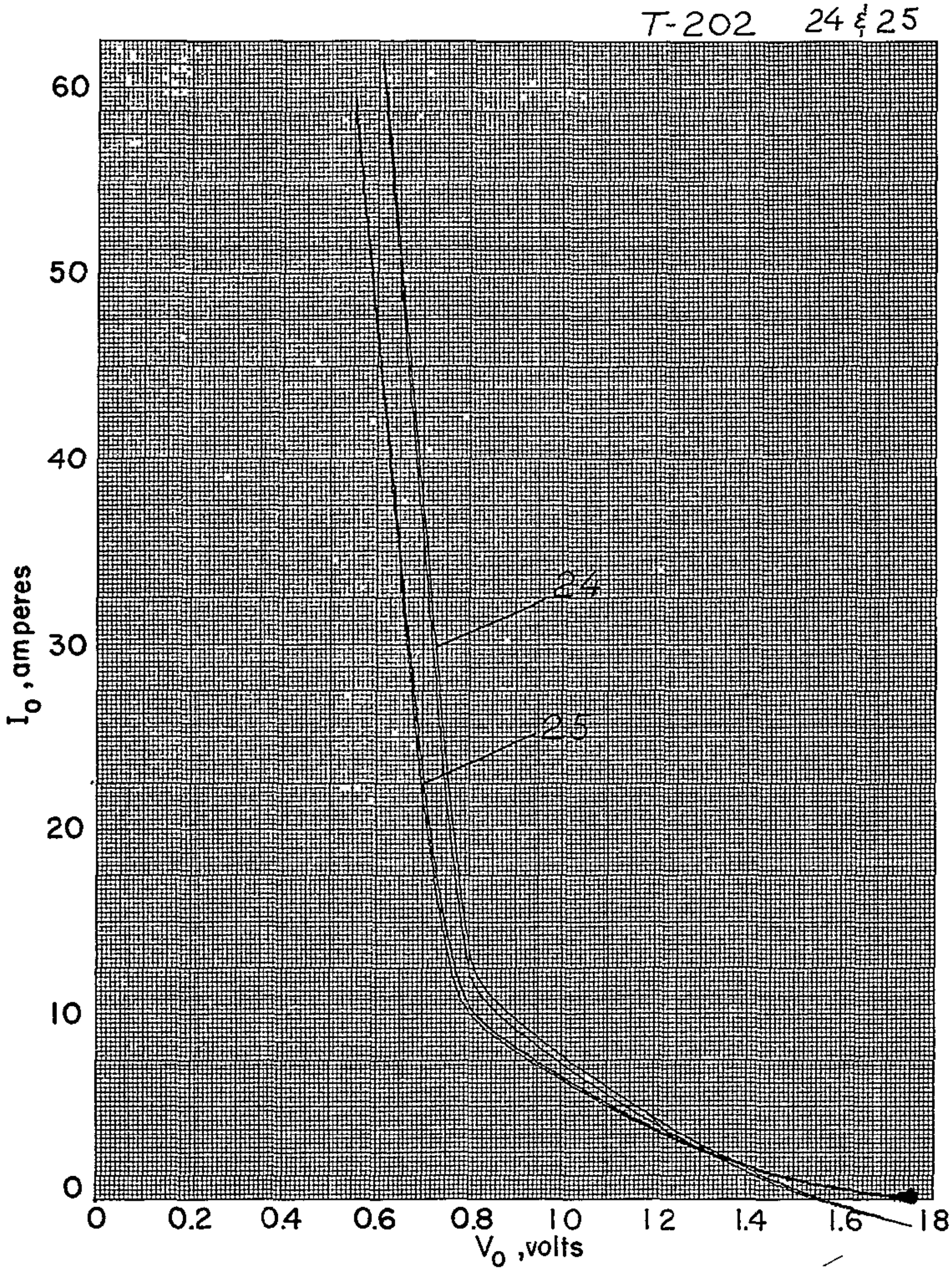

T-202 3 & 4
60
50
40
30
20
10
0
I_0, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_0, volts
3
4


T-202
5 → 10
60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts
5
6
7
8
9
10


T-202 11
11
I_o, amperes
0
10
20
30
40
50
60
V_o, volts
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8


T-202
12 → 17
60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts
12
13
14
15
16
17


T-202 18 → 23
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
I_o , amperes
V_o , volts
21
18
19
20
22
23
19
18
22
21
20
23
18


T-202 24 & 25
60
50
40
30
20
10
0
I_o, amperes
24
25
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts

APPENDIX 6

TEST DATA FROM CONVERTER T-203B

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 1 of 8

Converter No TE203B Run No ______ Observer RB Slos ___

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		6/20	—	—	6/21	—	—	—	—	—	
Time		1105	1424	1700	1030	1047 [4]	1142	1206	1225	1240	
Elapsed Time, Hours		—	—	—	—	—	—	—	—	—	
T_0, °C		1680	1680	1680	1679	1679	1680	1679	1680	1680	
T_0 Corrected, °C		1690	1690	1690	1689	1689	1690	1689	1690	1690	
$\Delta T_{Bell\ Jar}$, °C		14	14	14	14	14	14	14	14	14	
T_H, °C		1703	1703	1703	1702	1702	1703	1702	1703	1703	
ΔT_E, °C											
T_E, °K		1966	1970	1970	1970	1970	1966	1965	1966	1969	
V_0, volts		.8033	—	—	—	.8010	.8079	.8070	.8081	.8042	
I_0, amps		27.8	0	0	0	.100	31.2	30.2	30.1	10.4	
P_0, watts		22.3	—	—	—	.0801	25.2	24.4	24.3	8.4	
I-V Trace No		—	—	—	—	—	—	—	—	—	
T_R	mv	132	59 [1]	70 [2]	73 [3]	111	134	0-650 13.4	0-655 13.5	0-515 12.1	
	°C	324	144	172	179	273	329	329	331	297	
	°K	597	417	445	452	546	602	602	604	570	
T_C	mv	5-272	0 859	0-880	0-872	0-945	5-300	5-279	5-295	5-088	
	°C	636	430	440	436	473	650	640	647	544	
	°K	909	703	713	709	746	923	913	920	817	
T_C base inner	mv	229	167	17.1	17.0	18.1	236	23.1	23.3	20.4	
	°C	553	407	417	414	440	569	558	562	494	
T_C base outer	mv	22.9	166	173	17.0	191	23.2	23.0	23.2	20.2	
	°C	553	405	421	414	440	560	555	560	489	
$T_{Radiator}$	mv	204	153	15.9	15.9	166	205	20.4	20.6	184	
	°C	494	374	388	388	405	497	494	499	447	
V_{eb}, volts		978	996	995	995	991	977	978	978	985	
I_{eb}, mA		248	149	150	151.6	169.1	268	259	257	190.1	
$E_{Filament}$, volts		4.8	4.9	4.8	4.7	4.7	5.0	4.9	4.8	4.6	
$I_{Filament}$, amps		19	19	18.5	18.5	18.5	19	19	19	18.2	
$I_{Coll\ Heater}$, amps		0	0	0	0	0	0	0	0	0	
$I_{Res\ Heater}$, amps		0	0	0	0	3	3.5	3.5	3.5 [5]	3.0 [6]	
Vacuum, 10^{-6} mm Hg		.74	68.	38	3.0	3.2	4.8	2.4	1.8	0.86	
Measured Efficiency, %											

NOTES
1 Res. has a cooling FIN ≈ 2.5 sq in of radiating area.
2. " " " " " ≈ 1.25 sq in " " "
3 " " " " " ≈ 0.625 sq in " " "
4. Io first observed under these conditions.
5. I_R Decreased to 3A after readings where taken Io began to decrease.
6. I_R Decreased to 0 after readings where taken Io began to decrease

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 2 of 8

Converter No TE 203B Run No ____ Observer RB Slosek

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		6/21 [11]	6/22 [12]	—	— [14]	—	—	—	6/23	—	
Time		1620	1150	1116	1439	1522	1622	1700	1042	1255	
Elapsed Time, Hours		—	—	—	—	—	—	—	—	—	
T_O, °C		1690	1680	1680	1682	1690	1690	1690	1690	1690	
T_O Corrected, °C		1700	1690	1690	1692	1700	1700	1700	1700	1700	
$\Delta T_{Bell\ Jar}$, °C		14	14	14	14	14	14	14	14	14	
T_H, °C		1714	1703	1703	1706	1714	1714	1714	1714	1714	
ΔT_E, °C											
T_E, °K		2002	1970	1966	1974	2002	2002	1976	1976	2002	
V_O, volts		.7440	7523	.8024	7598	.7909	.7946	.8097	8089	.7940	
I_O, amps		0	.1	30.2	.2	1.2	1.6 [16]	31.7	31.5	1.7	
P_O, watts		0	.0752	24.23	.152	.949	.4767	25.64	25.58	1.355	
I-V Trace No		—	—	—	—	—	—	—	—	—	
T_R	mv	0-402 8.3	0-420 8.9	0-654 13.9	0-420 9.0	0-495 10.4	0-506 10.6	0-654 13.6	0-662 13.9	0-511 10.6	
	°C	204	219	341	222	256	261	333	341	261	
	°K	477	492	614	495	529	534	606	614	534	
T_C	mv	0-900	0-884	5-280	0-870	0-934	0-944	5-314	5-299	0-961	
	°C	450	442	640	435	467	472	657	649	480	
	°K	723	715	913	708	740	745	930	922	753	
T_C base inner	mv	17.2	17.3	23.4	17.0	18.0	18.1	23.3	23.6	18.2	
	°C	419	421	564	414	438	440	562	569	443	
T_C base outer	mv	17.2	17.2	23.2	17.0	17.9	18.1	23.3	23.5	18.2	
	°C	419	417	560	414	436	440	562	567	443	
$T_{Radiator}$	mv	15.9	15.9	20.5	15.9	16.5	16.7	20.5	20.9	16.7	
	°C	388	388	497	388	402	407	497	506	407	
V_{eb}, volts		994	995	978	994	991	990	975	978	989	
I_{eb}, mA		156	152	261	154	163	164	274	269	164	
$E_{Filament}$, volts		4.6	4.6	5.0	4.7	4.6	4.6	4.9	4.8	4.5	
$I_{Filament}$, amps		18.4	18.3	19.0	18.5	18.1	18	19	19	18	
$I_{Coll\ Heater}$, amps		0	0	0	0	0	0	0	0	0	
$I_{Res\ Heater}$, amps		0	0	2 [13]	0	0	0 [15]	1.2 [12]	1.3 [17]	0	
Vacuum, 10^{-6} mm Hg		3.2	5.0	3.8	8.0	2.0	0.98	1.4	0.46	.24	
Measured Efficiency, %											

NOTES
1. Painted Disc.
2. ≈ 1/3 of ? Painted
3. I_R decreased to 0 after readings were taken. I_O began to dec.
4. No Paint on disc.
5. I_R applied after readings where taken
6. Equilibrium
7. I_R decreased to 0 after readings taken.

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 3 of 8

Converter No TE-203B Run No 1,2 & 3 Observer R B Slosek

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		6/23	6/23	6/24	—	—	—	—	6/27	6/27	6/28
Time		1612	1626	0942	1003	1051	1156	1755	0850	1642	0848
Elapsed Time, Hours		—	—	—	—	0 [12]	1.1	6.0	69.9	77.8	93.8
T_O, °C		1710	1710	1710	1710	1720	1715	1721	1720	1720	1722
T_O Corrected, °C		1720	1720	1720	1720	1730	1725	1731	1730	1730	1732
$\Delta T_{Bell\ Jar}$, °C		14	14	14	14	14	14	14	14	14	14
T_H, °C		1734	1734	1734	1734	1744	1739	1745	1744	1744	1746
ΔT_E, °C											
T_E, °K		1998	1998	1998	1998	1998	2006	2005	2004	2004	2006
V_O, volts		1.34	1.344	1.341	1.342	.9019	.8009	.7999	.7990	.8059	.8069
I_O, amps		21.4 (1)	26.5 (2)	24.1 (3)	26.1 (4)	38.8	39.1	40.2	37.9	38.3	38.6
P_O, watts		28.68	35.62	32.99	35.3	31.1	31.32	32.2	30.3	30.9	31.2
I-V Trace No		1	2	3	4	—	—	—	—	—	—
T_R	mv	0-814 16.9	0-814 16.9	0-642 11.9	0-722 13.3	0-668 13.9	0-666 13.9	0-674 13.9	0-666 13.9	0-666 13.9	0-669 13.9
	°C	412	412	292	326	341	341	341	34.1	341	341
	°K	685	685	565	599	614	614	614	614	614	614
T_C	mv	5-338	5-538	5-350	5-518	5-380	5-396	5-416	5-396	5-401	5-405
	°C	669	769	675	759	690	698	708	698	700.5	702
	°K	942	1042	948	1032	963	971	981	981	973.5	975
T_C base inner	mv	24.4	27.3	22.9	26.3	24.9	24.9	24.6	24.4	24.9	24.9
	°C	588	656	553	633	600	600	592	588	600	600
T_C base outer	mv	24.3	27.9	22.9	26.3	24.9	24.9	24.9	24.2	24.9	24.9
	°C	586	671	553	635	600	600	600	583	600	600
$T_{Radiator}$	mv	21.4	23.9	19.9	22.2	21.9	21.9	21.9	21.9	21.9	21.9
	°C	518	576	483	537	529	529	529	529	529	529
V_{eb}, volts		979	977	984	982	976	975	974	974	974	975
I_{eb}, mA		256.5	269	249.2	259	299	300	365	298.3	301.6	304
$E_{Filament}$, volts		4.8	4.8	4.8	4.8	5.0	5.0	5.0	4.9	5.0	5.0
$I_{Filament}$, amps		19	19	18.8	18.9	19.1	19.1	19.4	19	19.1	19.1
$I_{Coll\ Heater}$, amps		3	9.5	7	10	0	0	0	0	0	0
$I_{Res\ Heater}$, amps		2	1.0	0	0	0	0	0	0	0	0
Vacuum, 10^{-6} mm Hg		0.48	0.8	0.54	0.54	0.36	0.34	0.25	0.32	0.12	0.11
Measured Efficiency, %											

NOTES. 1. [illegible] REACHED.
2. [illegible]

THERMO ELECTRON ENGINEERING CORPORATION

Sheet 4 of 8

Converter No TE203B Run No 344 Observer R.B. Slosek

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		6/28	6/28	6/29	7/1	—	—	—	—	—	—
Time		1405	1540	0935	0850	1645	1654	17.03	17.12	1724	1735
Elapsed Time, Hours		99.2	100.7	118.6	165.9	—	—	—	—	—	—
T_O, °C		1728	1721	1725	1720	1720	1730	1730	1720	1730	17.10
T_O Corrected, °C		1738	1731	1735	1730	1730	1740	1740	1730	1740	1720
$\Delta T_{Bell\ Jar}$, °C		14°	14	14	14	14	14	14	14	14	14
T_H, °C		1762	1745	1750	1744	1744	1754	1754	1744	1754	1734
ΔT_E, °C											
T_E, °K		2015	2005	2009	1998	1998	2022	2020	1998	2019	1999
V_o, volts		.8642	.8059	.8070	.8069	—	—	—	—	—	—
I_o, amps		33.2	39.3	39.5	36.9	4.9 av	7.9 av	14.9 av	22.9 av	22.0 av	24.9 av
P_o, watts		26.7	31.7	31.9	29.8	—	—	—	—	—	—
I-V Trace No		—	—	—	—	5	6	7	8	9	10
T_R	mv	0-649 13.1	0-674 13.9	0.674 13.9	0-659 13.9	0-542 11.9	0-580 11.9	12.9	0-658 13.4	0-700 14	0-771 15.2
	°C	321	341	341	341	292	292	317	329	343	372
	°K	594	614	614	614	565	565	590	602	616	645
T_C	mv	5-356	5-413	5-419	5-382	5-194	5-254	5-320	5-400	5-448	5-518
	°C	678	706	709	691	597	627	660	700	724	759
	°K	951	979	982	964	870	900	933	973	997	1032
T_C base inner	mv	23.9	24.7	24.9	24.9	22.9	23.1	24.9	25.9	26.1	27.9
	°C	576	595	600	600	553	576	600	623	628	671
T_C base outer	mv	23.9	24.7	24.9	24.9	22.9	23.9	24.9	25.9	26.0	27.9
	°C	576	595	600	600	553	576	600	623	626	671
$T_{Radiator}$	mv	20.9	21.9	21.9	21.9	20.0	20.9	21.9	22.0	22.9	23.9
	°C	506	529	529	529	485	506	529	532	553	576
V_{eb}, volts		975	975	973	972	994	971	986	982	982	982
I_{eb}, mA		288.9	307.5	309.9	300	173.9	206.9	230	259	257	260
$E_{Filament}$, volts		4.9	5.0	5.0	5.0	4.8	4.8	4.8	4.9	4.8	4.8
$I_{Filament}$, amps		19	19	19.1	19.1	18.5	18.8	18.9	19	19	19
$I_{Coll\ Heater}$, amps		0	0	0	0	9	9	9.5	9.5	9.5	10.0
$I_{Res\ Heater}$, amps		0	0	0	0	2	2	2	2.5	3.0	3.0
Vacuum, 10^{-6} mm Hg		0.088	0.1	0.14	.062	11.0	6.2	4.4	4.2	3.4	4.2
Measured Efficiency, %											

NOTES

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 5 of 8

Converter No TT 263 B. Run No 4 Observer RB Slosek

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		7/5	—	—	—	—	—	—	—	—	—
Time		1038	1050	1125	1138	1150	1204	1322	1350		1412
Elapsed Time, Hours		—	—	—	—	—	—	—	—	—	—
T_0, °C		1610	1620	1630	1618	1630	1621	1500	1520	1500	1510
T_0 Corrected, °C		1619	1629	1639	1627	1639	1630	1509	1529	1509	1519
$\Delta T_{Bell\ Jar}$, °C		12	12	12	12	12	12	12	12	12	12
T_H, °C		1632	1642	1652	1640	1652	1641	1518	1539	1518	1529
ΔT_E, °C											
T_E, °K		1898	1908	1918	1902	1918	1905	1786	1806	1786	1792
V_0, volts		—	—	—	—	—	—	—	—	—	—
I_0, amps		12 am	18.4 am	15.30 am	27.9 am	28 am	29 am	3.4 am	4.9 am	20 am	27.9 am
P_0, watts		—	—	—	—	—	—	—	—	—	—
I-V Trace No		11	12	13	14	15	16	17	18	19	20
T_R	mv	0-542 11.2	0-580 12	0-620 12.9	0-658 13.7	0-700 14.0	0-744 15.4	0-542 11.4	580 11.9	0-620 12.9	0-658 13.5
	°C	276	295	317	336	343	376	280	292	317	331
	°K	549	568	590	609	616	649	553	565	590	604
T_C	mv	5-194	5-254	5-320	5-400	5-448	5-518	5-194	5-254	5-320	5-400
	°C	597	627	660	700	724	759	597	627	660	700
	°K	870	900	933	973	997	1032	870	900	933	973
T_C base inner	mv	23.0	23.8	24.9	25.9	26.0	27.9	23.1	24.0	24.9	26.0
	°C	555	574	600	623	626	671	558	579	600	626
T_C base outer	mv	22.9	23.8	24.9	25.9	26.0	27.9	23.1	24.2	24.9	26.0
	°C	553	574	600	623	626	671	558	583	600	626
$T_{Radiator}$	mv	20.2	20.9	21.6	22.5	23.0	23.9	20.4	21.2	21.8	22.5
	°C	489	506	522	543	555	576	494	513	527	543
V_{eb}, volts		990	986	986	980	979	980	999	995	988	982
I_{eb}, mA		153	180	193	230	238	232.9	121.9	136.4	162.9	200
$E_{Filament}$, volts		4.5	4.6	4.6	4.7	4.8	4.8	4.4	4.4	4.6	4.6
$I_{Filament}$, amps		17.5	18.0	18	18.2	18.5	18.5	17.2	17.5	18.0	18.0
$I_{Coll\ Heater}$, amps		8.5	8.5	9	9.5	9.6	10.5	10	10.5	10.5	10.5
$I_{Res\ Heater}$, amps		1	1	1	1	1	2	1	2	2	2
Vacuum, 10^{-6} mm Hg		.32	.32	.32	.44	.72	1.0	1.0	.40	.24	.30
Measured Efficiency, %											

NOTES

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 6 of 8

Converter No TE-203B Run No 4,5-6 Observer RB Slosek

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		7/5	—	7/6	—	—	—	—	—	—	—
Time		1552	1555	1035	1100	1145	1200	1215	1255	1307	1420
Elapsed Time, Hours		—	—	—	—	—	—	—	—	—	—
T_O, °C		1520	1510	1715	1718	1710	1710	1712	1718	1710	1705
T_O Corrected, °C		1529	1519	1725	1728	1720	1720	1722	1728	1720	1715
$\Delta T_{Bell\ Jar}$, °C		12	12	14	14	14	14	14	14	14	14
T_H, °C		1539	1529	1740	1742	1734	1734	1736	1742	1734	1729
ΔT_E, °C											
T_E, °K		1802	1792	2000	2004	2002	2002	2004	2010	2002	1997
V_O, volts		—	—	—	—	0	0	0	0	0	0
I_O, amps		26.2a	27.2a	27.1a	27.2a	0	0	0	0	0	0
P_O, watts		—	—	—	—	—	—	—	—	—	—
I-V Trace No		21	22	23	24	—	—	—	—	—	—
T_R	mv	0-700 14.9	0-744 15.2	0-814 16.9	0-814 16.9	10.3	11.4	12.1	13.0	14.1	15
	°C	364	372	412	412	253	280	297	319	345	367
	°K	637	645	685	685	526	553	570	592	618	640
T_C	mv	5-448	5-518	5-338	5-538	5-254	5-254	5-254	5-254	5-254	5-254
	°C	724	759	669	769	627	627	627	627	627	627
	°K	997	1032	942	1042	900	900	900	900	900	900
T_C base inner	mv	26.5	26.9	23.9	27.9	24.3	24.1	24.0	24.4	24.0	23.6
	°C	637	647	576	671	586	581	579	588	579	569
T_C base outer	mv	26.9	27.0	23.9	27.9	24.3	24.2	24.2	24.4	24.2	23.6
	°C	647	649	576	671	586	581	581	588	583	569
$T_{Radiator}$	mv	23.0	23.2	20.9	23.9	21.2	21.3	21.3	21.2	21.2	20.9
	°C	555	560	506	576	513	516	516	513	513	506
V_{eb}, volts		984	984	979	978	995	995.1	992.9	992	991.9	990
I_{eb}, mA		193	191.7	279	276.7	167	168.9	175.4	180.0	181.9	191
$E_{Filament}$, volts		4.6	4.6	4.8	4.8	4.5	4.5	4.5	4.55	4.55	4.6
$I_{Filament}$, amps		18	18	18.8	18.8	17.6	17.6	17.8	17.9	17.9	18
$I_{Coll\ Heater}$, amps		10.5	10.5	0	9	11	11	11	11	11	8.5
$I_{Res\ Heater}$, amps		2	2	5	4	0	1	1	1	2.5	3
Vacuum, 10^{-6} mm Hg		.48	.48			.20	.68	.68	.68	.20	.20
Measured Efficiency, %											

NOTES

166.16 168.07 174.15 178.56 180.42 189.09

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 7 of 8

Converter No TE-203B Run No 6+7 Observer R.B. Slosek

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		7/6	—	7/7	—	—	—	—	—	—	—
Time		1430	1445	1315	1328	1340	1355	1410	1425	1440	1500
Elapsed Time, Hours		—	—	—	—	—	—	—	—	—	—
T_0, °C		1710	1710	1580	1580	1580	1585	1580	1675	1680	1675
T_0 Corrected, °C		1720	1720	1589	1589	1589	1594	1589	1684	1689	1684
$\Delta T_{Bell\ Jar}$, °C		14	14	12	12	12	12	12	14	14	14
T_H, °C		1734	1734	1600	1600	1600	1606	1600	1698	1704	1698
ΔT_E, °C											
T_E, °K		2002	2002	1866	1866	1866	1872	1869	1960	1966	1963
V_0, volts		0	0	.6009	.8073	1.0	1.204	1.349	.6135	.8022	1.00
I_0, amps		0	0	16.0	11.3	8.4	4.5	2.0	49.8	25	17.6
P_0, watts		0	0	9.6	9.1	8.4	5.4	2.7	30.6	20.1	17.6
I-V Trace No		—	—	—	—	—	—	—	—	—	—
T_R	mv	16	17.1	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9
	°C	391	417	341	341	341	341	341	341	341	341
	°K	664	690	614	614	614	614	614	614	614	614
T_C	mv	5-254	5-254	5-108	5-070	5-023	5-000	5-00	5-423	5-254	5-195
	°C	627	627	554	535	511.5	500	500	736	627	592
	°K	900	900	827	808	784.5	773	773	1009	900	865
T_C base inner	mv	23.5	23.9	20.5	20.0	19.3	18.7	18.4	25.5	22.6	21.5
	°C	567	576	497	485	468	454	447	614	546	520
T_C base outer	mv	23.9	23.9	20.3	19.7	19.2	18.9	18.3	25.4	22.6	21.3
	°C	576	576	492	478	466	459	445	612	546	576
$T_{Radiator}$	mv	20.9	20.9	18.4	17.9	17.9	17.1	16.9	22.1	20.1	19.2
	°C	506	506	447	436	436	417	412	534	487	466
V_{eb}, volts		989.5	988.9	985	988	990	992	994	971	979.5	983
I_{eb}, mA		197.9	202.4	191.5	181	173.2	162.7	155.1	315.5	248.0	229.9
$E_{Filament}$, volts		4.6	4.6	4.6	4.6	4.6	4.6	4.45	5.0	4.8	4.7
$I_{Filament}$, amps		18	18	18	18	18	18	17.8	19	18.5	18.25
$I_{Coll\ Heater}$, amps		8.5	8.5	0	0	0	0	0	0	0	0
$I_{Res\ Heater}$, amps		4.5	4.5	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Vacuum, 10^{-6} mm Hg		.20	.20	.10	.10	.10	.10	.10	.12	.10	.10
Measured Efficiency, %					179					243	

NOTES 1. Highest V_0 possible,
2. Lowest V_0 "
195.82 200.15

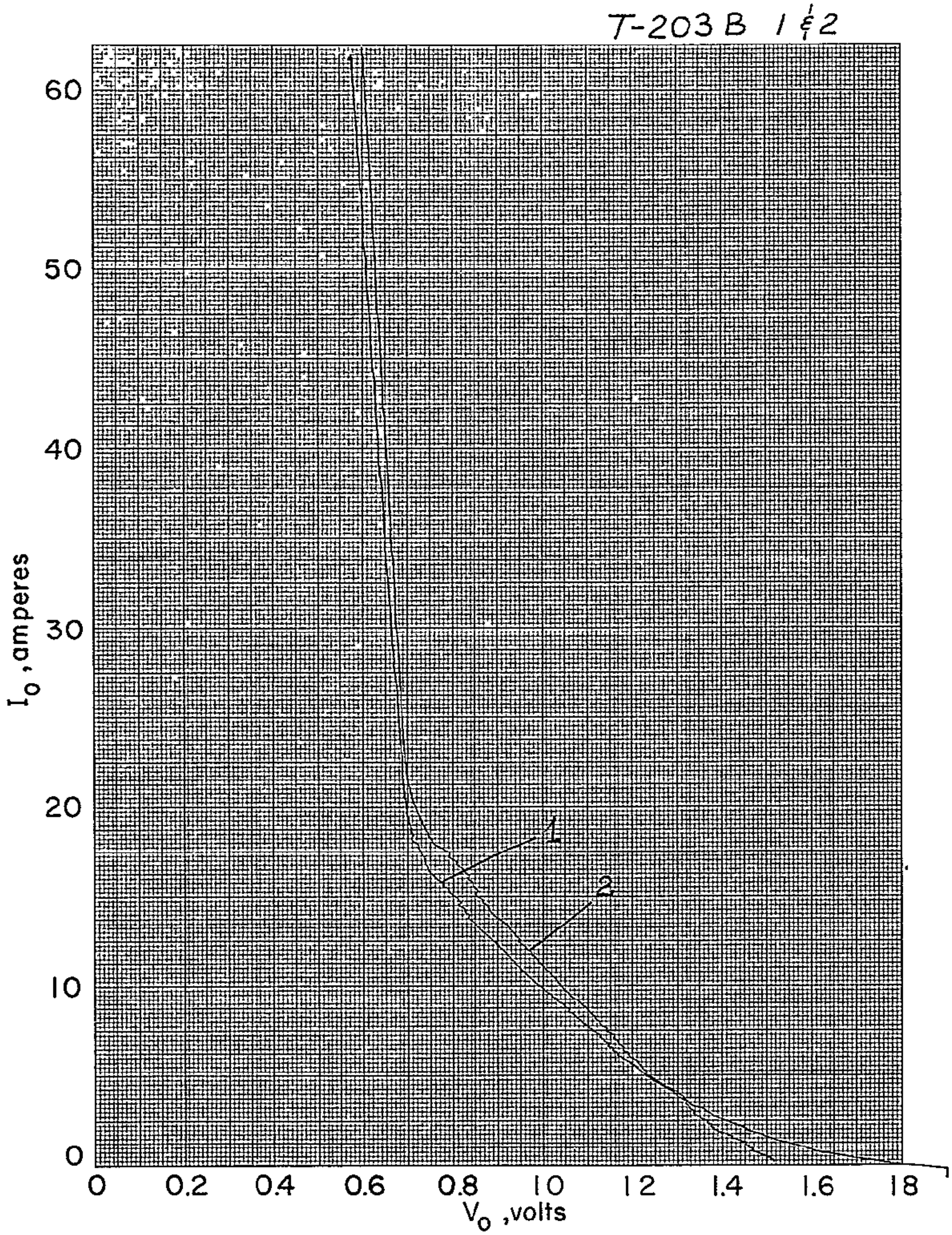
THERMO ELECTRON
ENGINEERING CORPORATION

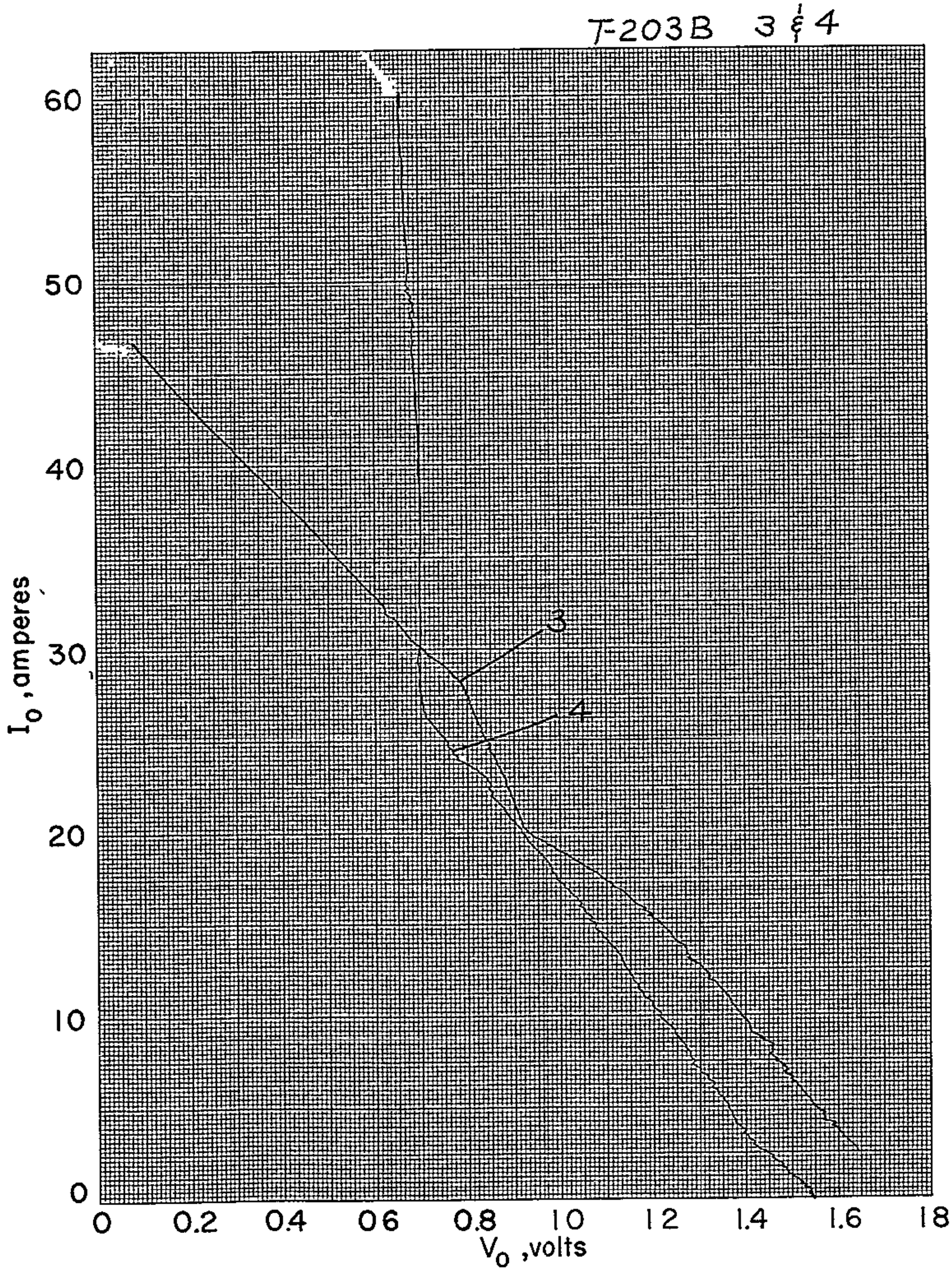
Sheet 8 of 8

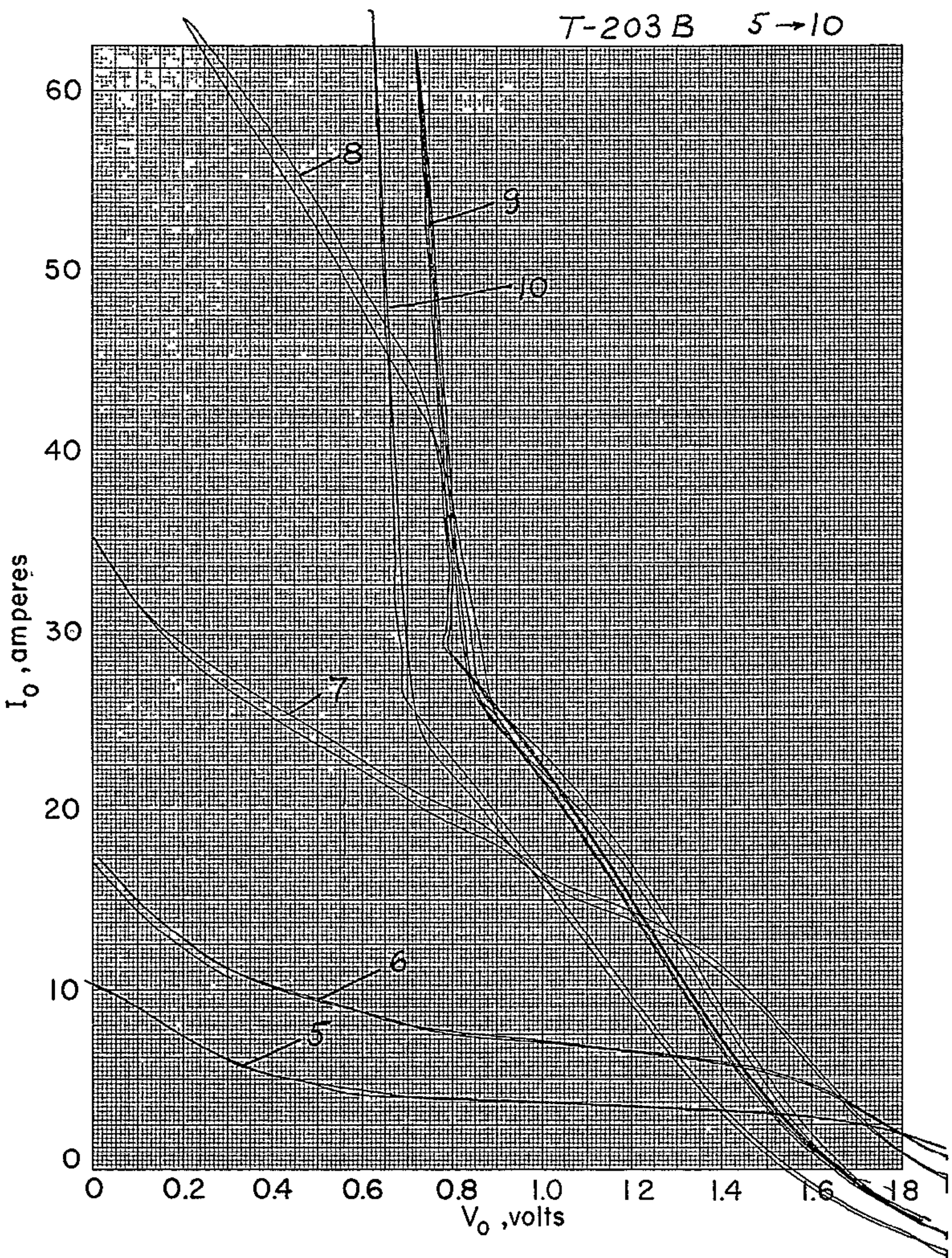
Converter No TE-203B Run No 7 Observer RB Slosek

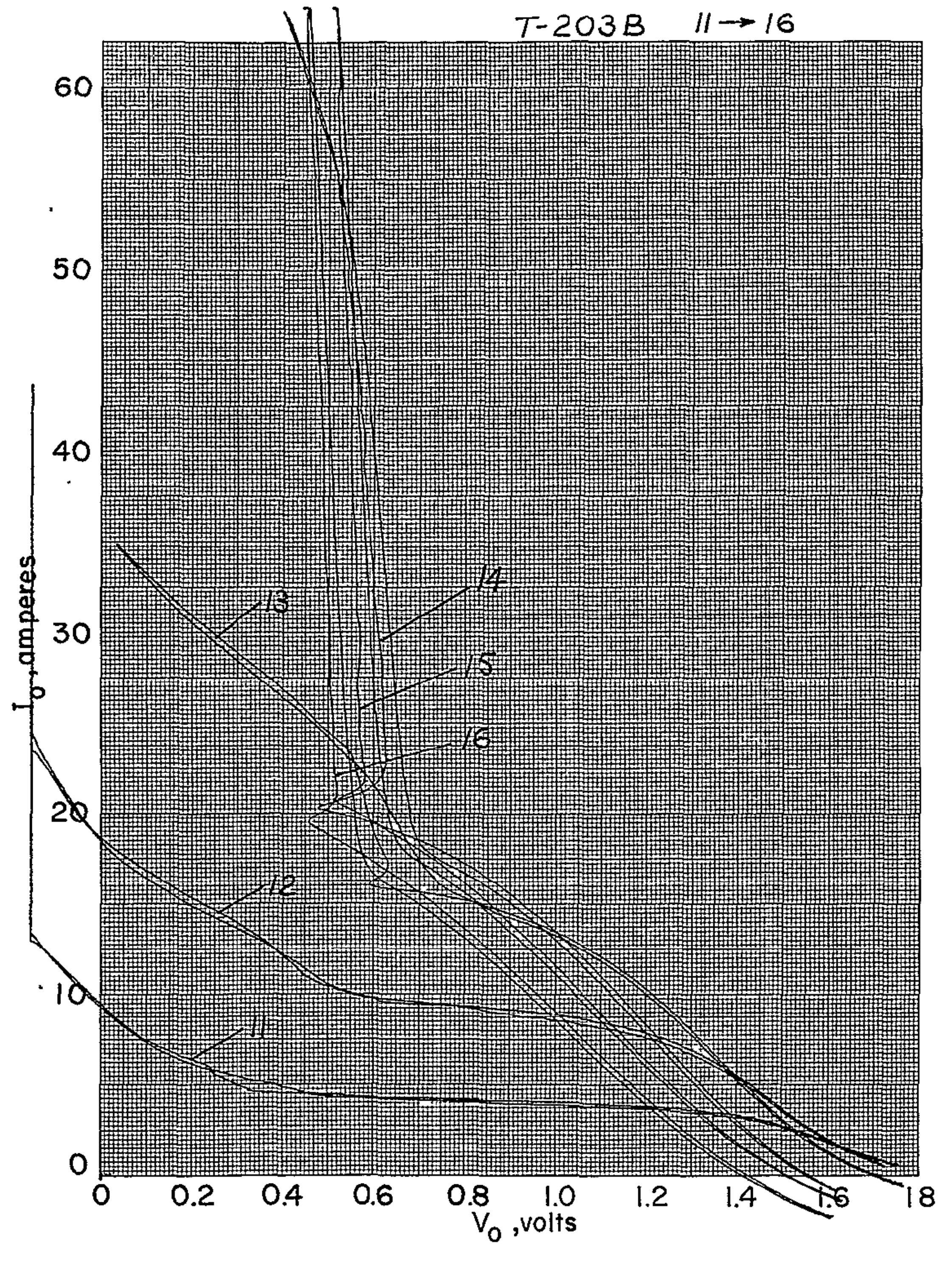
VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		7/7	—	—	7/8	—	—	—			
Time		1537	1622	1700	0920	0945	1000	1035			
Elapsed Time, Hours		—	—	—	—	—	—	—			
T_0, °C		1680	1680	1770	1770	1775	1775	1780			
T_0 Corrected, °C		1690	1690	1780	1780	1785	1785	1719			
$\Delta T_{Bell\ Jar}$, °C		14	14	14	14	14	14	19			
T_H, °C		1704	1704	1796	1796	1800	1800	1806			
ΔT_E, °C											
T_E, °K		1969	1969	2053	2055	2063	2063	2072			
V_0, volts		1.20	1.356	.6329	.8057	1.00	1.199	1.354			
I_0, amps		12.2	7.4	59.0	44.9	28.6	21.0	15.9			
P_0, watts		14.6	10.03	37.6	36.2	28.6	25.2	21.5			
I-V Trace No		—	—	—	—	—	—	—			
T_R	mv	13.9	13.9	14.1	14.0	13.9	13.9	13.9			
	°C	341	341	345	343	341	341	341			
	°K	614	614	618	616	614	614	614			
T_C	mv	5-125	5-076	5-612	5-486	5-339	5-262	5-220			
	°C	562	538	806	743	670	631	610			
	°K	855	811	1079	1016	943	904	883			
T_C base inner	mv	20.7	20.0	27.4	26.0	23.9	22.9	22.0			
	°C	501	485	659	635	576	553	532			
T_C base outer	mv	20.9	19.9	27.3	25.9	23.9	22.9	21.9			
	°C	506	483	656	623	576	553	529			
$T_{Radiator}$	mv	19.9	18.0	23.3	22.3	20.9	20.0	19.9			
	°C	459	438	562	539	506	485	483			
V_{eb}, volts		985	997	965	968	973	978	979			
I_{eb}, mA		216	200.6	374	344	300	278	264			
$E_{Filament}$, volts		4.6	4.6	5.8	5.0	4.9	4.8	4.8			
$I_{Filament}$, amps		18.0	18.0	19.5	19.0	19.0	18.7	18.5			
$I_{Coll\ Heater}$, amps		0	0	0	0	0	0	0			
$I_{Res\ Heater}$, amps		2.0	3.0	3.0	3.0	3.0	3.0	3.0			
Vacuum, 10^{-6} mm Hg		.10	.10	.10	.094	.094	.094	.094			
Measured Efficiency, %					333						

NOTES 1. Highest V_0 possible.

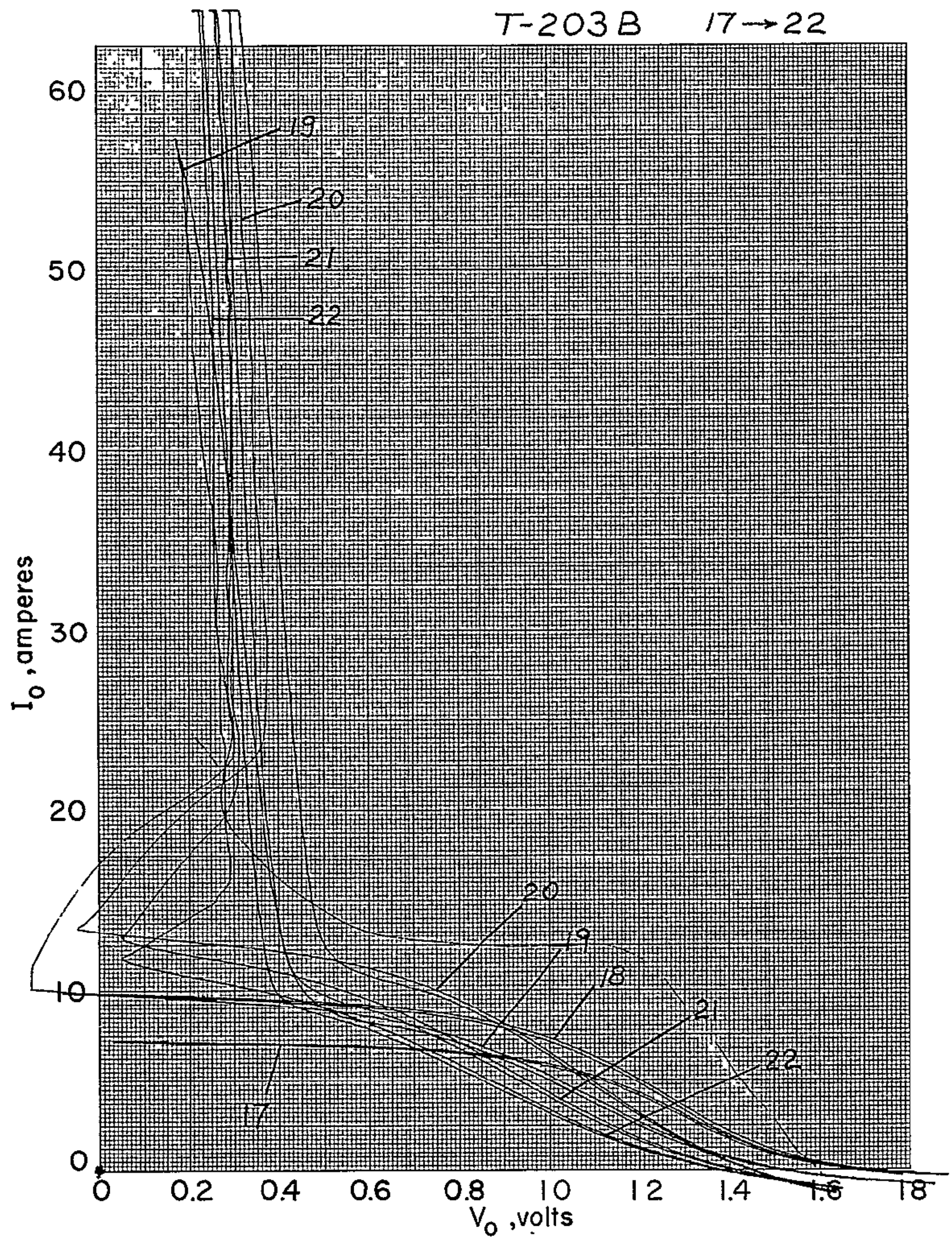

T-203 B 1 & 2
60
50
40
30
20
10
0
I_o, amperes
1
2
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts

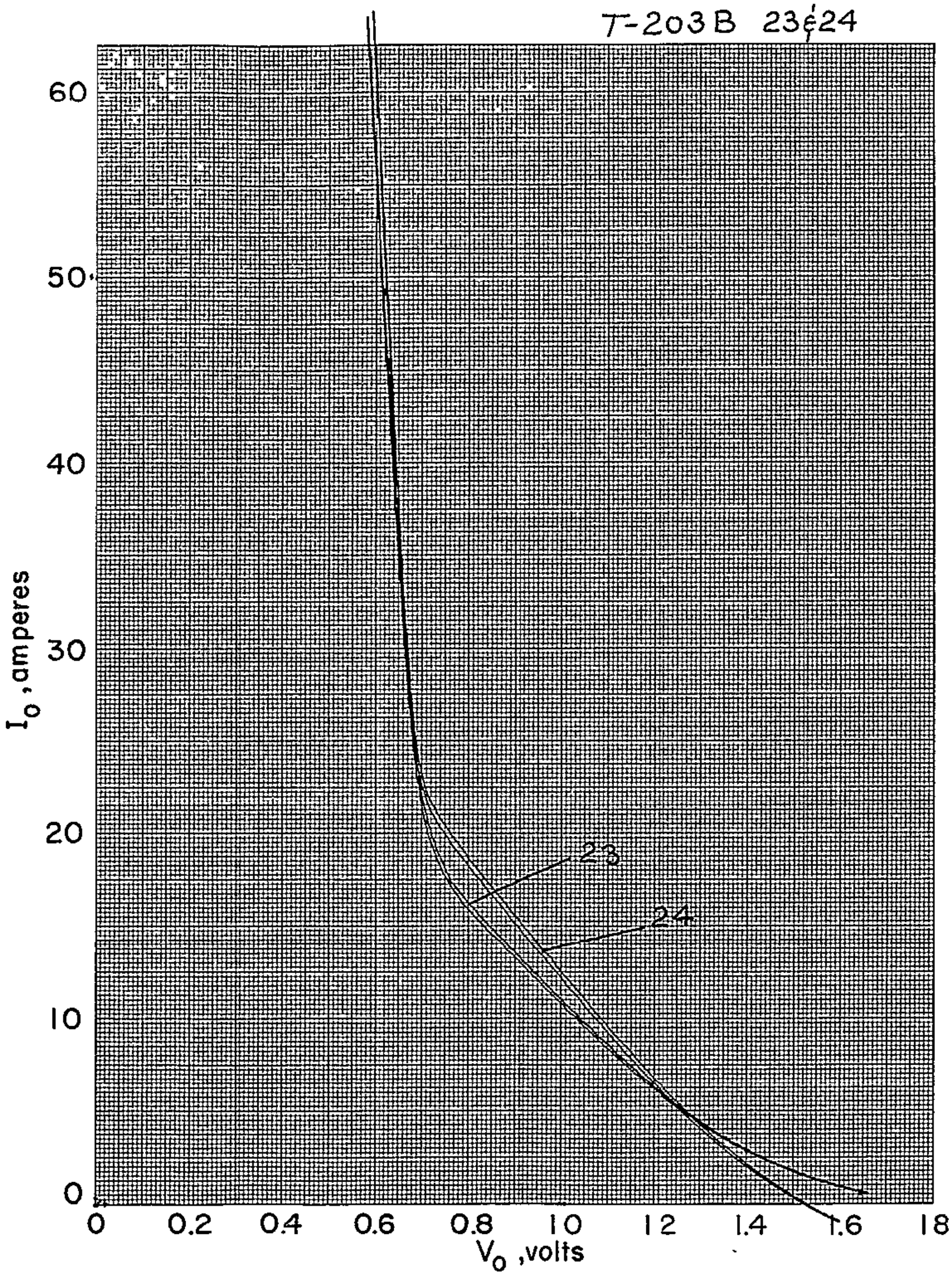

T-203B 3 & 4
60
50
40
30
20
10
0
I_o, amperes
3
4
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts


T-203 B 5→10
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
I_o, amperes
V_o, volts
5
6
7
8
9
10


T-203B 11 → 16
60
50
40
30
20
10
0
13
14
15
16
12
11
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
18
V_0 ,volts
I_0, amperes

7360


T-203 B 17→22
60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts
19
20
21
22
20
19
18
21
22
17


T-203B 23&24
60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts
23
24

APPENDIX 7

TEST DATA FROM CONVERTER T-204

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 1 of 6

Converter No T-204 Run No 1, 2 + 3 Observer R B Slosek

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		8/22	—	—	—	—	—	8/23	—	8/24	—
Time		1300	1325	1400	1440	1535	1650	0845	1610	0837	1625
Elapsed Time, Hours		—	—	—	—	0 (2)	1.2	17.1	24.5	41.0	48.8
T_O, °C		1710	1710	1720	1710	1710 (3)	1720	1720	1710	1710	1720
T_O Corrected, °C		1720	1720	1730	1720	1720	1730	1730	1720	1720	1730
$\Delta T_{Bell\ Jar}$, °C		14	14	14	14	14	14	14	14	14	14
T_H, °C		1734	1734	1744	1734	1734	1744	1744	1734	1734	1744
ΔT_E, °C											
T_E, °K		1976	1976	1992	1976	1970	1974	1974	1970	1970	1974
V_o, volts		1.31	1.23	1.66	1.24	.9023	.7731	.7839	.7834	.7839	.7691
I_o, amps		22an	23an	15an	24an	39.9	40.6	39.1	38.1	38.9	41.4
P_o, watts		—	—	—	—	36	31.2	30.7	29.8	30.5	31.8
I-V Trace No		1	2	3	4	—	—	—	—	—	—
T_R	mv	0-814 16.5	0-814 16.5	0-580 11.9	0-700 14.2	0-700 14.2	0-700 14.1	0-700 14.2	0-700 14.0	0-700 14.0	0-700 14.1
	°C	402	402	292	348	348	345	348	343	343	345
	°K	675	675	565	621	621	618	621	616	616	618
T_C	mv	2-486	2-538	2-352	2-532	2-638	2-598	2-591	2-575	2-575	2-602
	°C	743	769	666	766	819	799	795	787	787	801
	°K	1016	1042	939	1039	1092	1072	1068	1060	1060	1074
T_C base inner	mv	—	—	—	—	—	—	—	—	—	—
	°C	—	—	—	—	—	—	—	—	—	—
T_C base outer	mv	—	—	—	—	—	—	—	—	—	—
	°C	—	—	—	—	—	—	—	—	—	—
$T_{Radiator}$	mv	21.4	22.0	20.2	22.3	22.9	22.3	22.2	22.0	22.0	22.4
	°C	518	532	489	539	553	539	537	532	532	541
V_{eb}, volts		977	977	985	978	967	971	969	967	970	969
I_{eb}, mA		292	296	229	284	357	330	325	323	325	334
$E_{Filament}$, volts		4.8	4.8	4.6	4.8	5.0	4.9	4.9	4.9	4.9	4.9
$I_{Filament}$, amps		18	18.2	18	18.1	19	19	18.9	18.5	18.7	18.7
$I_{Coll\ Heater}$, amps		—	2	6	6.5	0	0	0	0	0	0
$I_{Res\ Heater}$, amps		4	4	2	2	2	2	2	2	2	2
Vacuum, 10^{-6} mm Hg		.54	.8	.26	.28	.3	.23	.14	.14	.14	.12
Measured Efficiency, %											

NOTES
1. Lowest Temp Possible
2. Timer Set.
3. ?

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 2 of 6

Converter No T-204 Run No 3+4 Observer R.B. Slosek

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		8/25	—	8/26	—	8/29	—	—	—	—	—
Time		0850	1610	0952	1612	0920	1340	1420	1432	1450	1525
Elapsed Time, Hours		65.2	72.5	90.2	96.5	161.6	162.5	163.2	163.5	163.7	164.2
T_0, °C		1710	1710	1710	1710	1710	1710	1710	1720	1715	1720
T_0 Corrected, °C		1720	1720	1720	1720	1720	1720	1720	1730	1725	1730
$\Delta T_{Bell\ Jar}$, °C		14	14	14	14	14	14	14	14	14	14
T_H, °C		1734	1734	1734	1734	1734	1734	1734	1744	1739	1744
ΔT_E, °C											
T_E, °K		1966	1964	1966	1966	1966	1984	1982	1990	1985	1990
V_0, volts		.7691	.7685	.7679	.7765	.7783	1.263	1.155	1.109	1.175	1.314
I_0, amps		39.1	39.9	39.9	38.3	38.3	6.6a	11.9a	20.1a	24.5a	22.9a
P_0, watts		30	30.7	30.6	29.7	29.8	—	—	—	—	—
I-V Trace No		—	—	—	—	—	5	6	7	8	9
T_R	mv	0-700 14.2	0-700 14.1	0-700 14.2	0-700 14.1	0-700 14.1	0-542 11.1	0-580 11.9	0-620 12.6	0-658 13.2	0-700 13.9
	°C	348	345	348	345	345	273	292	309	324	341
	°K	621	618	621	618	618	546	565	582	597	614
T_C	mv	2-575	2-575	2-575	2-575	2-575	2-194	2-254	2-320	2-400	2-448
	°C	787	787	787	787	787	597	627	660	700	744
	°K	106	1860	1060	1060	1060	870	900	933	973	1017
T_C base inner	mv	—	—	—	—	—	—	—	—	—	—
	°C	—	—	—	—	—	—	—	—	—	—
T_C base outer	mv	—	—	—	—	—	—	—	—	—	—
	°C	—	—	—	—	—	—	—	—	—	—
$T_{Radiator}$	mv	22.3	22.3	22.2	22.1	22.0	19.5	20.1	20.2	20.9	21.6
	°C	539	539	537	534	532	473	487	489	506	522
V_{eb}, volts		969	969	968	969	969	989	985	981	978	977
I_{eb}, mA		323	327	323	323	323	194	210	242	266	276
$E_{Filament}$, volts		4.9	4.9	4.9	4.9	4.9	4.6	4.6	4.6	4.7	4.7
$I_{Filament}$, amps		18.9	18.9	18.5	18.5	18.5	17.5	17.7	18	18	18
$I_{Coll\ Heater}$, amps		0	0	0	0	0	8	8	5	5	7
$I_{Res\ Heater}$, amps		2	2	2	2	2	2	2	3	3	4
Vacuum, 10^{-6} mm Hg		.1	.1	.1	.1	.095	2.4	1.2	1.1	1.0	1.0
Measured Efficiency, %											

NOTES. 1. Cooling strap on fin and Res.

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 3 of 6

Converter No T-204 Run No 4 Observer R.B Slosek

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		8/29	—	—	—	—	—	—	5/130	—	—
Time		1548	1615	1630	1645	1700	1712	1725	0915	0935	0955
Elapsed Time, Hours		164.6	165.1	165.3	165.6	165.8	166.0	166.2	182.1	182.4	182.8
T_O, °C		1730	1610	1615	1615	1620	1605	1610	1520	1525	1525
T_O Corrected, °C		1740	1619	1624	1624	1629	1614	1619	1529	1534	1534
$\Delta T_{Bell\ Jar}$, °C		14	12	12	12	12	12	12	12	12	12
T_H, °C		1754	1631	1636	1636	1651	1625	1631	1539	1544	1544
ΔT_E, °C											
T_E, °K		1996	1880	1892	1884	1884	1868	1864	1792	1794	1786
V_O, volts		1.251	1.219	1.079	1.020	1.152	1.129	1.049	1.049	1.039	.9615
I_O, amps		23.7a	6.9a	12.9a	21.9a	21.9a	21.9a	22.9a	2.9a	13.9a	21a
P_O, watts		—	—	—	—	—	—	—	—	—	—
I-V Trace No		10	11	12	13	14	15	16	17	18	19
T_R	mv	0-744 14.9	0-542 10.9	0-580 11.9	0-620 12.3	0-658 13.0	0-700 13.9	0-744 14.9	0-542 10.9	0-580 11.9	0-620 12.9
	°C	364	268	292	302	319	341	364	268	292	317
	°K	637	541	565	575	592	614	637	541	565	590
T_C	mv	2-518	2-194	2-254	2-320	2-400	2-448	2-518	2-194	2-254	2-320
	°C	759	597	627	660	700	724	759	597	627	660
	°K	1032	870	900	933	973	997	1032	870	900	933
T_C base inner	mv	—	—	—	—	—	—	—	—	—	—
	°C	—	—	—	—	—	—	—	—	—	—
T_C base outer	mv	—	—	—	—	—	—	—	—	—	—
	°C	—	—	—	—	—	—	—	—	—	—
$T_{Radiator}$	mv	22.1	19.9	19.9	20.4	21.1	21.9	22.9	19.9	19.9	20.9
	°C	511	483	483	494	511	529	553	483	483	506
V_{eb}, volts		976	992	988	984	983	982	981	995	990	986
I_{eb}, mA		286	160	180	206	223	224	233	129	154	178
$E_{Filament}$, volts		4.7	4.4	4.4	4.6	4.6	4.6	4.6	4.3	4.4	4.4
$I_{Filament}$, amps		18	17	17	17.5	17.8	17.8	18	17	17	17.1
$I_{Coil\ Heater}$, amps		7	9.5	9.0	6	8	9	10.5	11	10	10
$I_{Res\ Heater}$, amps		4	2	2.5	2.5	2.5	4	4.5	1	2	2
Vacuum, 10^{-6} mm Hg		.84	.52	.52	.44	.44	.46	.54	.12	.14	.14
Measured Efficiency, %											

NOTES

THERMO ELECTRON ENGINEERING CORPORATION

Sheet 4 of 6

Converter No T-204 Run No 4,5+6 Observer R.B.Slosek

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		8/30	—	—	—	—	—	—	—		
Time		1015	1040	1115	1350	1400	1430	1450	1530	1550	1610
Elapsed Time, Hours		183.1	183.5	184.1	185.4	185.7	186.1	186.5	187.2	187.5	187.8
T_0, °C		1520	1525	1530	1710	1710	1715	1720	1720	1720	1720
T_0 Corrected, °C		1529	1534	1537	1720	1720	1725	1730	1730	1730	1730
$\Delta T_{Bell\ Jar}$, °C		12	12	12	14	14	14	14	14	14	14
T_H, °C		1539	1544	1548	1734	1734	1739	1744	1744	1744	1744
ΔT_E, °C											
T_E, °K		1782	1786	1792	1976	1976		1997	1997	1997	1997
V_0, volts		1.000	.9769	.9311	1.514	1.235	—	0	0	0	0
I_0, amps		21 a	21.4 a	21 a	21.2 a	26 a	—	0	0	0	0
P_0, watts		—	—	—	—	—	—	0	0	0	0
I-V Trace No		20	21	22	23	24	—	—	—	—	—
T_R	mv	0-658 13.2	0-700 13.9	0-744 14.9	0-814 16.3	0-814 16.4	10 mv	10	11	12	13
	°C	324	341	364	398	400	246	246	271	295	319
	°K	597	614	637	671	673	519	519	544	568	592
T_C	mv	2-400	2-448	2-518	2-376	2-538	2-254	2-254	2-254	2-254	2-254
	°C	700	724	759	688	769	627	627	627	627	627
	°K	973	997	1032	961	1042	900	900	900	900	900
T_C base inner	mv	—	—	—	—	—	—	—	—	—	—
	°C	—	—	—	—	—	—	—	—	—	—
T_C base outer	mv	—	—	—	—	—	—	—	—	—	—
	°C	—	—	—	—	—	—	—	—	—	—
$T_{Radiator}$	mv	21.9	21.9	23	19.9	22.2	20.1	20.3	20.3	20.2	20.3
	°C	529	529	555	483	537	487	492	492	489	492
V_{eb}, volts		985	984	984	929	925	983	990	989	989	988
I_{eb}, mA		186	191	196	276	289	187	185	189	194	200
$E_{Filament}$, volts		4.5	4.5	4.5	4.7	4.7	4.4	4.4	4.5	4.5	4.5
$I_{Filament}$, amps		12.5	12.5	12.5	18.0	18	17	17	17.1	17.2	17.4
$I_{Coll\ Heater}$, amps		9.5	10.5	11	0	7	9	9	9	9	9
$I_{Res\ Heater}$, amps		4	4	4	6	6	1	1	1	2	3.5
Vacuum, 10^{-6} mm Hg		.16	.17	10	10	1.0	.38	.32	.28	.26	.24
Measured Efficiency, %											
NOTES		1 ?					183.8	183.1	186.9	191.9	197.6
								0	38	8.8	145

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 5 of 6

Converter No T-204 Run No 647 Observer R.B. Slosek

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		9/30	—	8/31	—	9/1	—	—	—	—	9/2
Time		1640	1705	1025	1055	1605	1620	1630	1645	1658	0955
Elapsed Time, Hours		188.3	188.7	206	206.6	228.6	228.8	229.0	229.2	229.4	246.4
T_0, °C		1710	1710	1705	1710	1790	1800	1810	1810	1815	1700
T_0 Corrected, °C		1720	1720	1715	1720	1800	1810	1820	1820	1825	1710
$\Delta T_{Bell\ Jar}$, °C		14	14	14	14	14	14	14	14	14	14
T_H, °C		1734	1734	1729	1734	1816	1826	1836	1836	1842	1724
ΔT_E, °C											
T_E, °K		1987	1987	1982	1987	2038	2050	2066	2074	2090	1946
V_0, volts		0	0	0	0	.4659	.8014	1.019	1.203	1.353	.6027
I_0, amps		0	0	0	0	67.9	58.7	45.4	34.6	26.5	56.1
P_0, watts		0	0	0	0	45.2	47	46.3	41.6	35.9	33.8
I-V Trace No		—	—	—	—	—	—	—	—	—	—
T_R	mv	14	15	16	16.9	15.9	15.5	14.9	14.9	14.4	14.9
	°C	343	367	391	412	388	379	364	364	353	364
	°K	616	640	664	685	661	652	637	637	626	637
T_C	mv	2-254	2-254	2-254	2-254	2-976	2-895	2-748	2-631	2-544	2-775
	°C	627	627	627	627	988	947	874	815	772	887
	°K	900	900	900	900	1261	1220	1147	1088	1045	1160
T_C base inner	mv	—	—	—	—	—	—	—	—	—	—
	°C	—	—	—	—	—	—	—	—	—	—
T_C base outer	mv	—	—	—	—	—	—	—	—	—	—
	°C	—	—	—	—	—	—	—	—	—	—
$T_{Radiator}$	mv	19.9	19.9	19.9	20.0	25.9	25.4	24.4	23.5	22.9	24.9
	°C	483	483	483	485	623	612	588	567	553	600
V_{eb}, volts		988	988	985	985	958	960	964	967	970	961
I_{eb}, mA		198	206	209	217	475	455	418	386	356	380
$E_{Filament}$, volts		4.5	4.5	4.5	4.5	5.2	5.1	5	4.9	4.8	5
$I_{Filament}$, amps		17.5	17.5	15.5	17.5	19	19	18.5	18.2	18	18.5
$I_{Coll\ Heater}$, amps		8	8	6	6	0	0	0	0	0	0
$I_{Res\ Heater}$, amps		5	5.2	5	5.5	4	4	3.5	4	4	4
Vacuum, 10^{-6} mm Hg		2.2	2.2	.12	.12	4.6	2.6	1.6	1.2	1.0	.22
Measured Efficiency, % W						455.1	436.5	402.8	372.5	345.4	365.1

NOTES.

1956 2015 2059 213.7

175 204 228 306

365.0 watts

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 6 of 6

Converter No T-204 Run No 7 Observer R.B. Slosek

VARIABLE			1	2	3	4	5	6	7	8	9	10
Date			9/2	—	—	—	—	—	—	—	—	
Time			1011	1035	1100	1115	1140	1315	1355	1430	1545	
Elapsed Time, Hours			246.7	247.1	247.5	247.7	248.2	249.7	250.4	251	252.3	
T_O, °C		→	1700	1700	1700	1700	1600	1600	1600	1600	1600	
T_O Corrected, °C			1710	1710	1710	1710	1609	1609	1609	1609	1609	
$\Delta T_{Bell\ Jar}$, °C			14	14	14	14	12	12	12	12	12	
T_H, °C	1735		1724	1724	1724	1724	1620	1620	1620	1620	1620	
ΔT_E, °C												
T_E, °K			1954	1961	1970	1970	1858	1864	1866	1870	1870	
V_o, volts			.8010	1.000	1.201	1.356	.5991	.7999	1.000	1.200	1.354	
I_o, amps	39		42.0	29.0	19.9	13.4	39.1	20.1	15.8	10.6	7.3	
P_o, watts	312		33.6	29	23.9	18.2	23.4	16.1	15.8	12.7	9.9	
I-V Trace No			—	—	—	—	—	—	—	—	—	
T_R	133	mv	14.3	13.9	13.9	13.4	13.5	13.2	13.1	13.0	12.4	
	327	°C	350	341	341	329	331	324	321	319	304	
		°K	623	614	614	602	604	597	594	592	577	
T_C		mv	2-612	2-459	2-353	2-271	2-501	2-280	2-223	2-154	2-093	
	784	°C	806	729	676	635	750	690	611	577	546	
		°K	1079	1002	949	908	1023	913	884	850	819	
T_C base inner		mv	—	—	—	—	—	—	—	—	—	
		°C	—	—	—	—	—	—	—	—	—	
T_C base outer		mv	—	—	—	—	—	—	—	—	—	
		°C	—	—	—	—	—	—	—	—	—	
$T_{Radiator}$	2244	mv	23.4	21.9	20.9	20.1	22.1	20.1	19.4	18.9	18.1	
		°C	564	529	506	487	534	487	471	459	440	
V_{eb}, volts	1372		966	971	975	978	972	978	981	985	986	
I_{eb}, mA	351.2 256		341	301	271	249	278	227	215	199	188	
$E_{Filament}$, volts	51		4.8	4.8	4.6	4.6	4.8	4.6	4.6	4.5	4.5	
$I_{Filament}$, amps	54		18	18	17.9	17.5	18	17.5	17.5	17.1	17.0	
$I_{Coll\ Heater}$, amps			0	0	0	0	0	0	0	0	0	
$I_{Res\ Heater}$, amps			4	4	4	4	4	4	4	4	4	
Vacuum, 10^{-6} mm Hg	.1		.16	.12	.12	.10	.10	.1	.1	.1	.1	
Measured Efficiency, %	39 W		329.8	291.8	264.2	243.8	270.2	222.0	211.0	196.0	185.4	

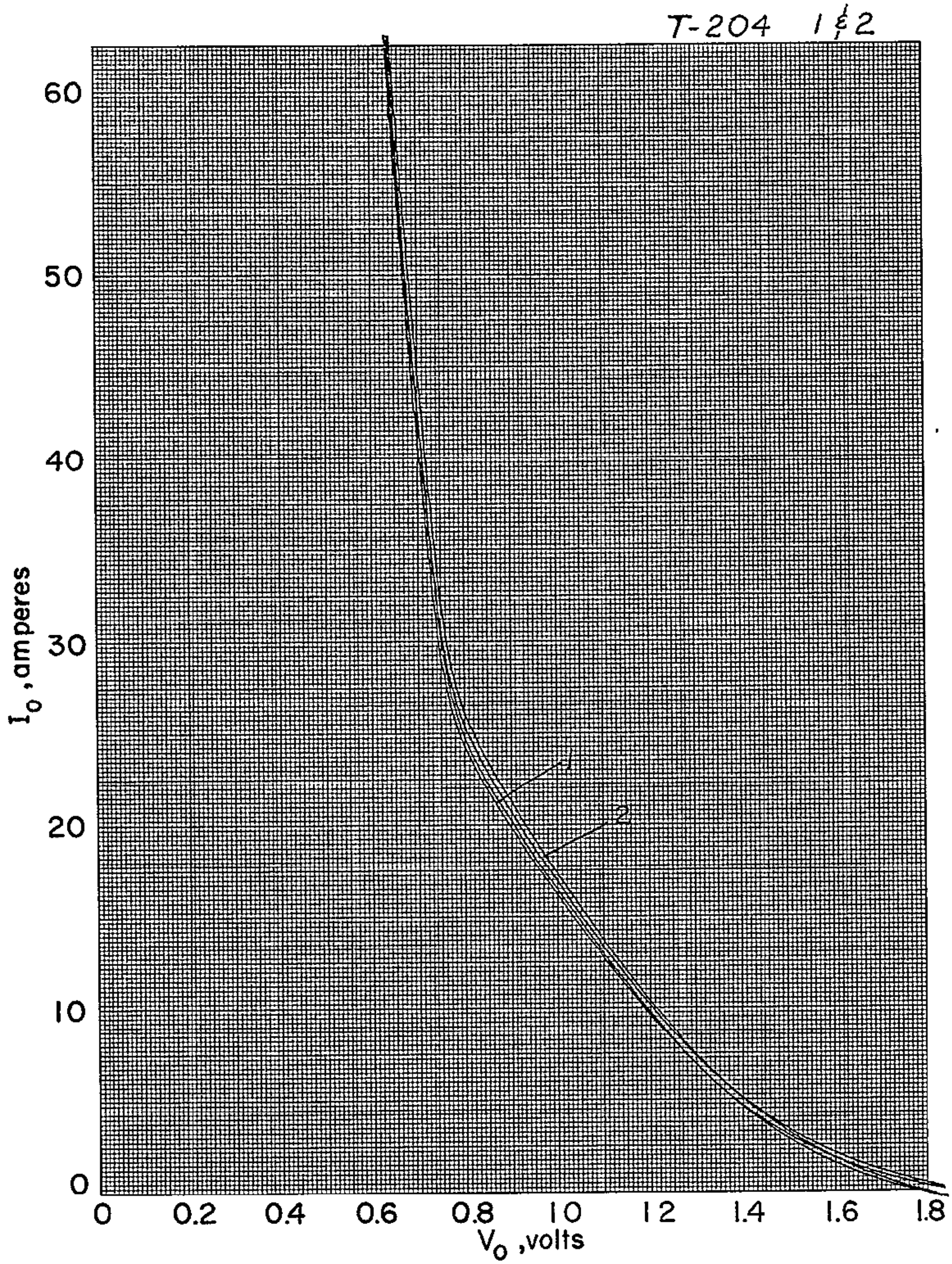
NOTES.

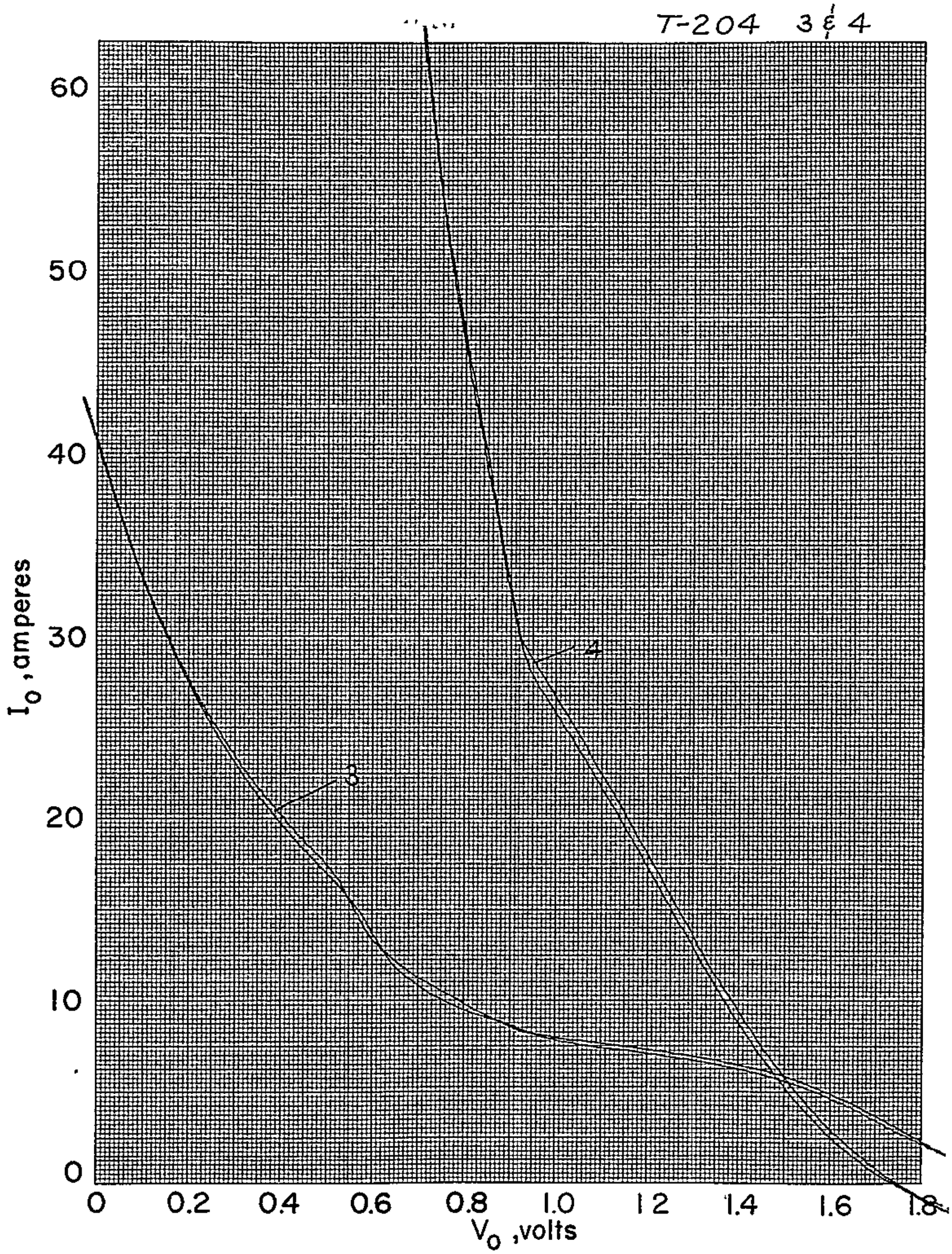
330.0 292 264 244

564°C 837°K at 0.6 ∈ 279 w/cm² v0.6 Collector T ~ 70°C/amp

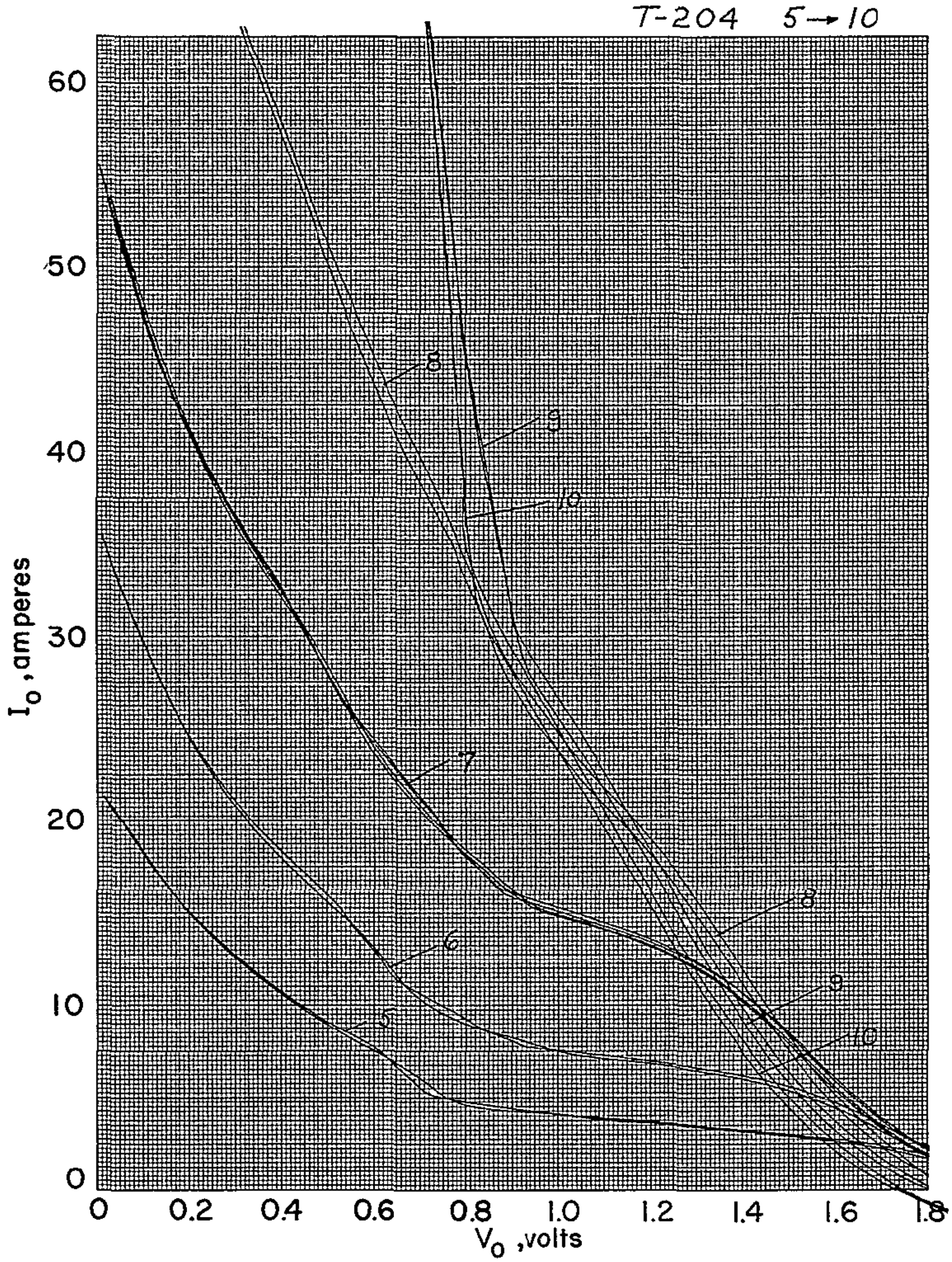
↓ at 0.8 1674/0.8 = 2.07

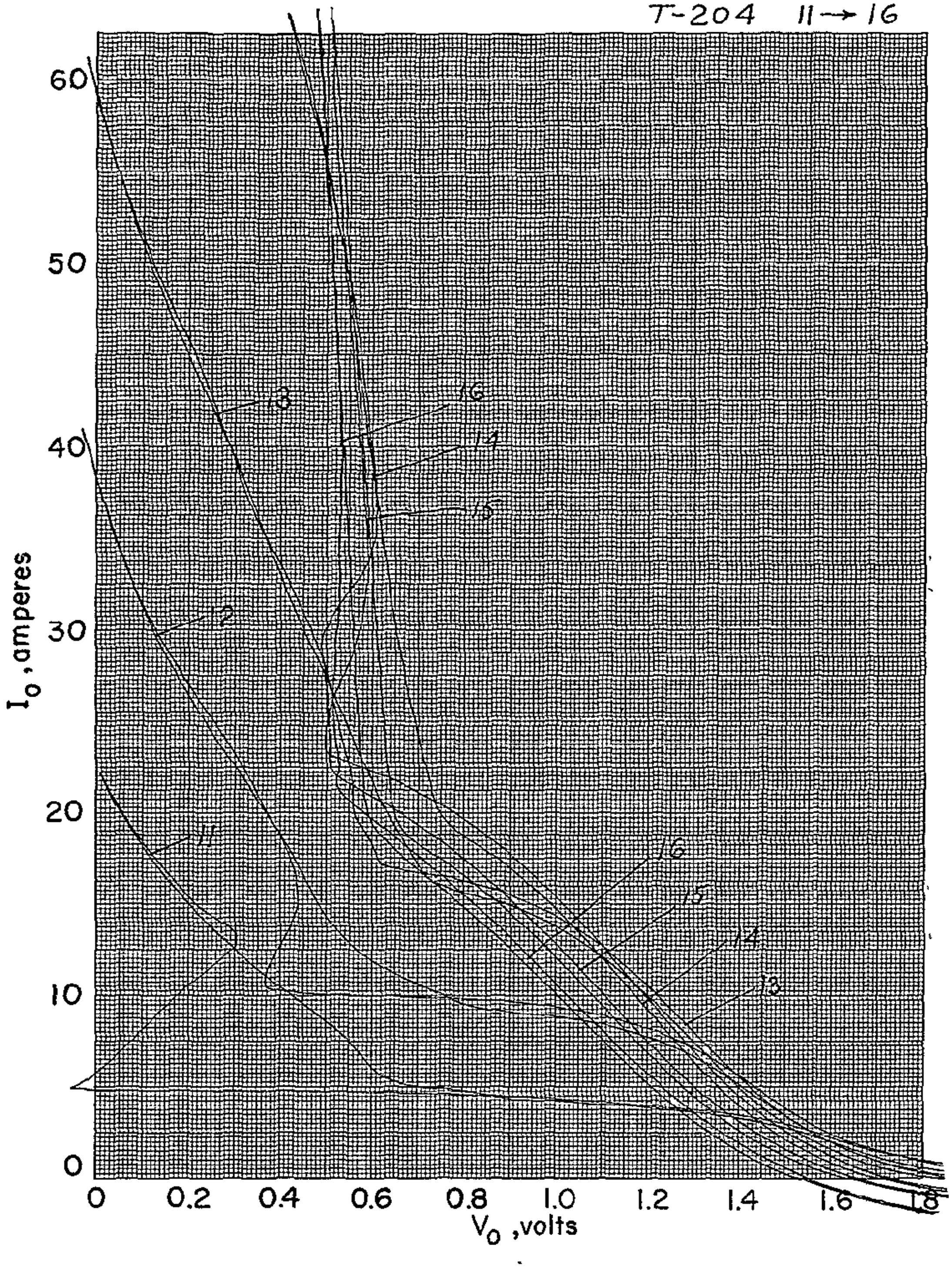
778°K Δ = 59°C


T-204 1 & 2
60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts
1
2

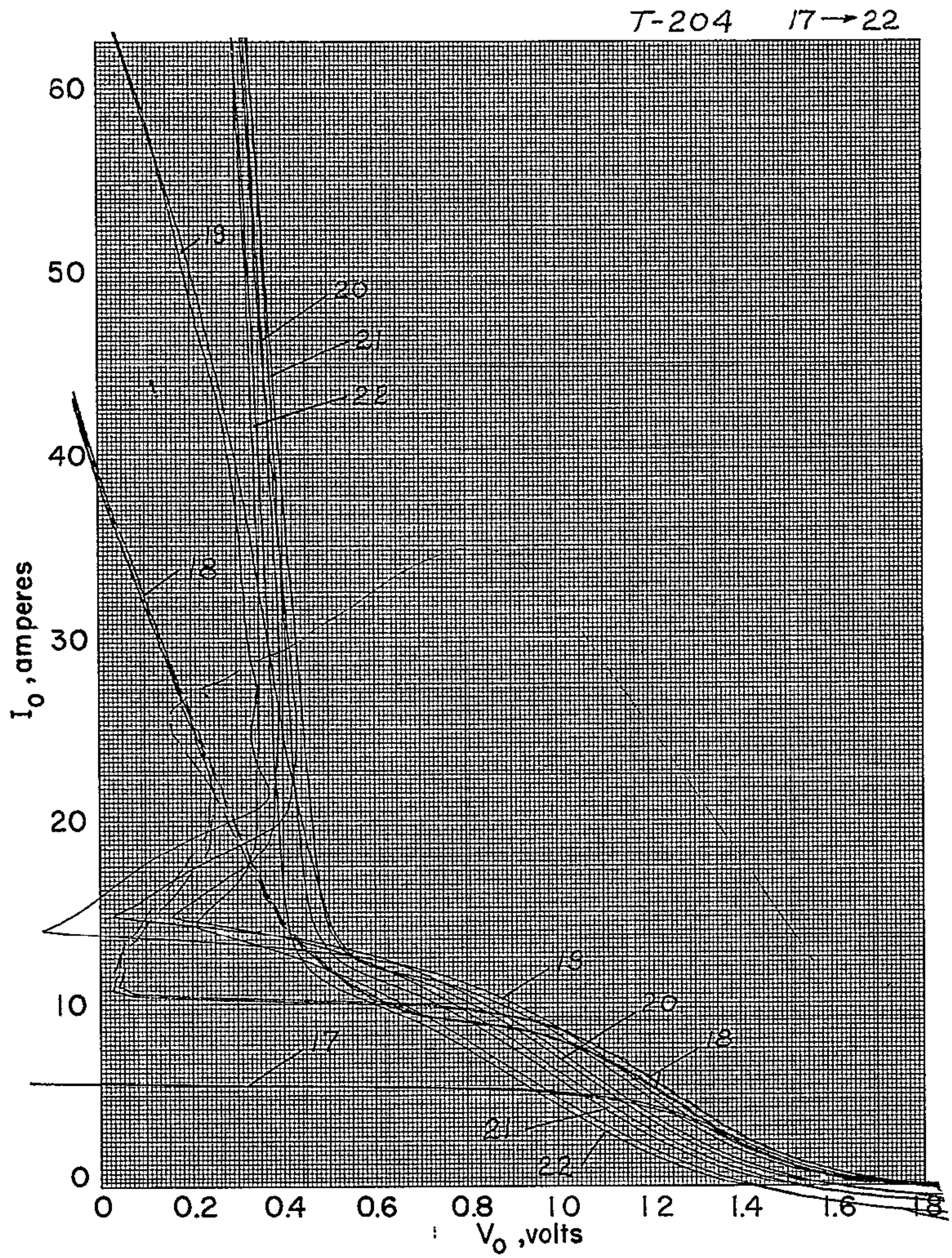

T-204 3 & 4
60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts
3
4

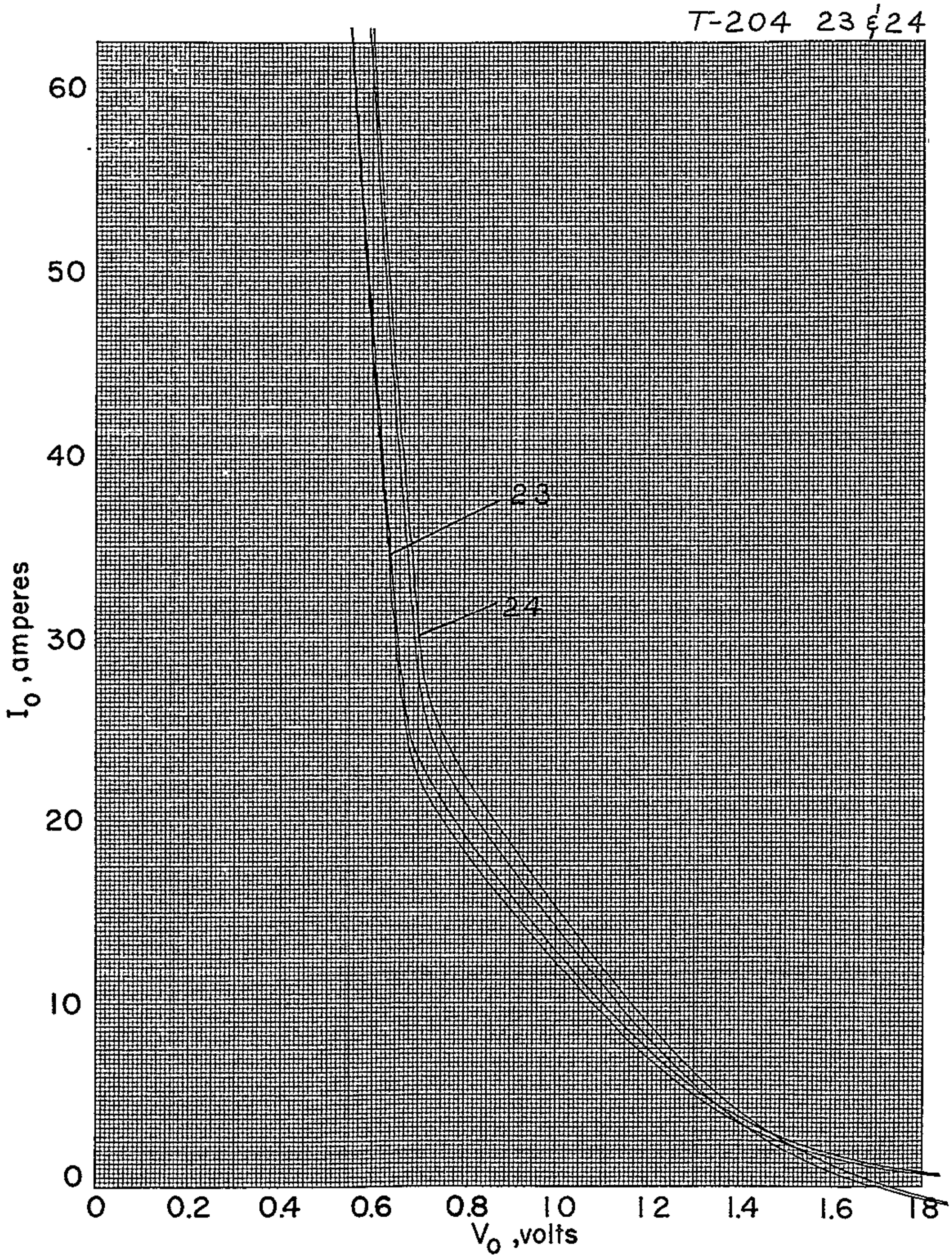
7437


T-204 5→10
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
I_o, amperes
V_o, volts
5
6
7
8
9
10
8
9
10


T-204 11 → 16
60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts
13
16
14
15
12
11
16
15
14
13

7432


T-204 17→22
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
I_o, amperes
V_o, volts
19
20
21
22
18
17
19
20
18
21
22


T-204 23 & 24
60
50
40
30
20
10
0
I_0, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_0, volts
23
24

APPENDIX 8

TEST DATA FROM CONVERTER T-205

THERMO ELECTRON ENGINEERING CORPORATION

Sheet 1 of 6

Converter No T-205 Run No 1 & 2 Observer [illegible]

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		10-17	10-17	10-17	10-17	10-17	10-17	10-18	10-18	10-19	
Time		11 18	11.45	13:33	13 46	14:30	17:24	14 55	17 13	10-18	
Elapsed Time, Hours		0	0 4	2.2	2 4	3.1	61	98	121	292	
T_O, °C		1731	1710	1738	1738	1738	1740	1740	1750	1752	
T_O Corrected, °C		1741	1724	1748	1748	1748	1750	1750	1760	1762	
$\Delta T_{Bell\ Jar}$, °C		14	14	14	14	14	14	14	14	14	
T_H, °C		1755	1738	1762	1762	1762	1764	1764	1774	1776	
ΔT_E, °C		35	31	35	35	35	35	45	45	44	
T_E, °K		1993	1980	2000	2000	2000	2002	1992	2002	2005	
V_o, volts		898	—	—	—	.920	902	772	759	716	
I_o, amps		292	27	30	30	309	309	493	49.0	47.5	
P_o, watts		—	—	—	—	29.4	—				
I-V Trace No		—	1	2	3	—	—	—	—	—	
T_R	mv	12 2	167	11.8	14.3	13.1	12 9	13 9	13 9	13 9	
	°C	300	407	290	350	321	317	341	341	341	
	°K	573	680	563	623	594	590	614	619	614	
T_C	mv	—	—	—	—	—	—	—	—	—	
	°C	730	769	732	745	745	745	770	770	765	
	°K	1003	1042	1005	1018	1018	1018	1043	1043	1038	
T_C base inner	mv						SHUT OFF				
	°C						(1)			(2)	
T_C base outer	mv										
	°C										
$T_{Radiator}$	mv	21.3	22.6	21.6	21 6	21.6	21 6	20.1	20 0	20.1	
	°C	516	546	522	522	522	522	487	485	487	
V_{eb}, volts		973	972	970	970	968	968	961	961	962	
I_{eb}, mA		302	297	296	312	320	320	377	377	377	
$E_{Filament}$, volts		52	52	5	5	5	5	52	5.2	5.2	
$I_{Filament}$, amps		18	18	17 5	17 5	17	17	18	18	18	
$I_{Coll\ Heater}$, amps		0	4	0	0	0	0	0	0	0	
$I_{Res\ Heater}$, amps		0	1	0	1	1	1	1	1	1	
Vacuum, 10^{-6} mm Hg		12	10	4	4	3.6	3.0	4	3.6	2.8	
Measured Efficiency, %		—	—	—	—	9.4	—	—	—	—	

NOTES (1) SHUT OFF TO ADD COLLECTOR COOLING ADDED COLD STRAP + 4 ADDITIONAL FINS (ZrO_2).

(2) SHUT OFF TO CLEAN BELLJAR.

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 2 of 6

Converter No T-205 Run No 3 Observer P. Brosens

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		10-19	10-19	10-19	10-19	10-19	10-19	10-19	10-20	10-20	10-20
Time		14:28	14:35	14:50	15:05	15:15	15:25	15:58	9:05	9:36	10:56
Elapsed Time, Hours		31.0	31.2	31.4	31.7	31.8	32.0	32.5	49.7	50.2	50.5
T_0, °C		1732	1731	1739	1741	1739	1739	1630	1635	1639	1639
T_0 Corrected, °C		1742	1741	1749	1751'	1749	1749	1639	1645	1649	1649
$\Delta T_{Bell\ Jar}$, °C		14	14	14	14	14	14	12	12	12	12
T_H, °C		1756	1755	1763	1765	1763	1763	1651	1657	1661	1661
ΔT_E, °C		25	28	34	35	34	34	24	30	34	34
T_E, °K		2004	2000	2002	2003	2002	2002	1900	1900	1900	1900
V_0, volts											
I_0, amps		$\overline{10}$	$\overline{16}$	$\overline{28}$	$\overline{30}$	$\overline{28}$	$\overline{28}$	$\overline{8}$	$\overline{20}$	$\overline{28}$	$\overline{28}$
P_0, watts											
I-V Trace No		4	5	6	7	8	9	10	11	12	13
T_R	mv	11.0	11.8	12.6	13.4	14.3	15.2	11.0	11.8	12.6	13.4
	°C	271	290	310	329	350	372	271	290	310	329
	°K	544	563	583	602	623	645	544	563	583	602
T_C	mv										
	°C	597	627	660	700	724	759	597	627	660	700
	°K	870	900	933	973	997	1032	870	900	933	973
T_C base inner	mv										
	°C										
T_C base outer	mv										
	°C										
$T_{Radiator}$	mv										
	°C										
V_{eb}, volts		—	—	—	—	—	—	—	—	—	—
I_{eb}, mA		—	—	—	—	—	—	—	—	—	—
$E_{Filament}$, volts		—	—	—	—	—	—	—	—	—	—
$I_{Filament}$, amps		—	—	—	—	—	—	—	—	—	—
$I_{Coll\ Heater}$, amps		—	—	—	—	—	—	—	—	—	—
$I_{Res\ Heater}$, amps		—	—	—	—	—	—	—	—	—	—
Vacuum, 10^{-6} mm Hg		3.2	3.2	3.2	3.1	3.1	3.1	2.7	2.2	2.2	2.2
Measured Efficiency, %											

NOTES

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 3 of 6

Converter No T-205 Run No 3 & 4 Observer P Brosius

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		10-20	10-20	10-20	10-20	10-20	10-20	10-20	10-20	10-20	
Time		10.11	10 19	13 00	13.12	13.21	13.28	14:10	14 40	15:00	
Elapsed Time, Hours		50 8	50.9	53.6	53 8	54 0	54.1	54 9	55 3	55.6	
T_0, °C		1638	1638	1534	1538	1541	1543	1542	1542	1710	
T_0 Corrected, °C		1648	1648	1542	1546	1549	1551	1550	1550	1724	
$\Delta T_{Bell\ Jar}$, °C		12	12	10	10	10	10	10	10	14	
T_H, °C		1660	1660	1552	1556	1559	1561	1560	1560	1738	
ΔT_E, °C		33	33	25	29	32	34	33	33	31	
T_E, °K		1900	1900	1800	1800	1800	1800	1800	1800	1980	
V_0, volts											
I_0, amps		$\overline{26}$	$\overline{27}$	$\overline{10}$	$\overline{18}$	$\overline{24}$	$\overline{28}$	$\overline{26}$	$\overline{26}$	$\overline{27}$	
P_0, watts											
I-V Trace No		14	15	16	17	18	19	20	21	22	
T_R	mv	14.3	15 2	11.0	11 8	12 6	13 4	14.3	15.2	16.7	
	°C	350	372	271	290	310	329	350	372	407	
	°K	623	645	544	563	583	602	623	645	680	
T_C	mv										
	°C	724	759	597	627	660	700	724	759	769	
	°K	997	1032	870	900	933	973	997	1032	1042	
T_C base inner	mv										
	°C										
T_C base outer	mv										
	°C										
$T_{Radiator}$	mv									217	
	°C									525	
V_{eb}, volts										971	
I_{eb}, mA										315	
$E_{Filament}$, volts										5	
$I_{Filament}$, amps										17	
$I_{Coll\ Heater}$, amps										9	
$I_{Res\ Heater}$, amps										1	
Vacuum, 10^{-6} mm Hg		2 2	2.2	2.2	2 2	2.2	2.2	2 2	2 2	2.2	
Measured Efficiency, %											

NOTES

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 4 of 6

Converter No T-205 Run No 5 Observer P. Brosens

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		10-20	10-20	10-20	10-20	10-20	10-20	10-20			
Time		15:35									
Elapsed Time, Hours		562									
T_O, °C		1723									
T_O Corrected, °C		1733									
$\Delta T_{Bell\ Jar}$, °C		14									
T_H, °C		1747									
ΔT_E, °C		20									
T_E, °K		2000									
V_O, volts											
I_O, amps		0	0	0	0	0	0	0			
P_O, 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										
	°C	627	627	627	627	627	627	627			
	°K	900	900	900	900	900	900	900			
T_C base inner	mv										
	°C										
T_C base outer	mv										
	°C										
$T_{Radiator}$	mv										
	°C										
V_{eb}, volts		987	987	9864	985.6	985.2	984.9	984.4			
I_{eb}, mA		213.0	217.1	221.4	225.6	230.0	233.9	235.5			
$E_{Filament}$, volts		4.8									
$I_{Filament}$, amps		16.0									
$I_{Coil\ Heater}$, amps		8									
$I_{Res\ Heater}$, amps		0									
Vacuum, 10^{-6} mm Hg		2.2	2.2	2.2	2.2	2.2	2.2	2.2			
~~Measured Efficiency, %~~		210.2	214.3	218.4	222.3	226.6	230.4	231.8			

NOTES SHUT OFF AT END OF RUN TO REMOVE ADDED FINS.
4.2 8.3 12.4 16.3 20.6 24.4 25.8

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 5 of 6

Converter No T-205 Run No 6 Observer P. Brosius

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		10-21	10-21	10 21	10-21	0 21	10-21	10-21	10 21	10 21	10-21
Time		11 42	13 20	13 32	14 02	14:36	14.53	14.59	15.28	16:00	16 11
Elapsed Time, Hours		59 4	61 0	61.2	61 7	62.3	62 6	62 7	63 2	63.7	63.9
T_0, °C		1591				1591	1689				
T_0 Corrected, °C		1588	†			1588†	1686	†			
$\Delta T_{Bell\ Jar}$, °C		12				12	14				
T_H, °C		1600 ←	—	1620† —	→	1600	1700	← —	— 17	20† —	→
ΔT_E, °C		21	22	24	27	10	23	25	28	37	47
T_E, °K		1872	1871	1869	1866	1853	1970	1968	1965	1956	1946
V_0, volts		1.4	1.2	1.0	0.8	0.6	1 4	1.2	1 0	0.8	0.6
I_0, amps		2 7	5.2	7.4	13.3	39.1	6 2	9 6	17.1	34.2	54.9
P_0, watts											
I-V Trace No		—			*						
T_R	mv	11.3	11.6	12.2	12.5	13.5	12 3	12.6	12.9	13.7	14.3
	°C	278	285	300	307	331	302	309	317	336	350
	°K	551	558	573	580	604	575	582	590	609	623
T_C	mv										
	°C	508	529	551	590	740	590	610	655	752	855
	°K	781	802	824	863	1013	863	883	928	1025	1128
T_C base inner	mv										
	°C										
T_C base outer	mv										
	°C										
$T_{Radiator}$	mv	17.0	17.5	17.9	18 7	21.5	18 7	19 1	20 0	21.9	23.4
	°C	414	426	436	454	520	454	464	485	529	564
V_{eb}, volts		990	988	986	984	974	984	982	980	973	967
I_{eb}, mA		170	180	189	207	283	225	237	262	317	369
$E_{Filament}$, volts		4.7				5					
$I_{Filament}$, amps		16				17					
$I_{Coll\ Heater}$, amps		0				0	0				
$I_{Res\ Heater}$, amps		0.5	1 55	1.79	1.79	177	1.64	1 80	1.79	1.75	1 76
Vacuum, 10^{-6} mm Hg		2.4				2.5					2.6
Measured Efficiency, % W_{in}		168			2c4		221			309	

NOTES. Pyrometer calibration 1673°C observed = 1690 true $\Delta T_{pyro} = -3$ †

* CONVERTER OUTPUT INCREASED STEPWISE AT 0 8 V.

† NOTE ADDED 11-1-66 - PYROMETER CALIBRATION DATA WAS READ INCORRECTLY AND SHOULD BE - 1693°C OBS = 1710 true $\Delta T_{pyro} = 17°C$ - ALL EMITTER TEMPERATURES ARE 20° HIGHER THAN RECORDED ON PAGES 5 & 6 -
T_E VALUES HAVE BEEN CORRECTED TO READ EXACT VALUE

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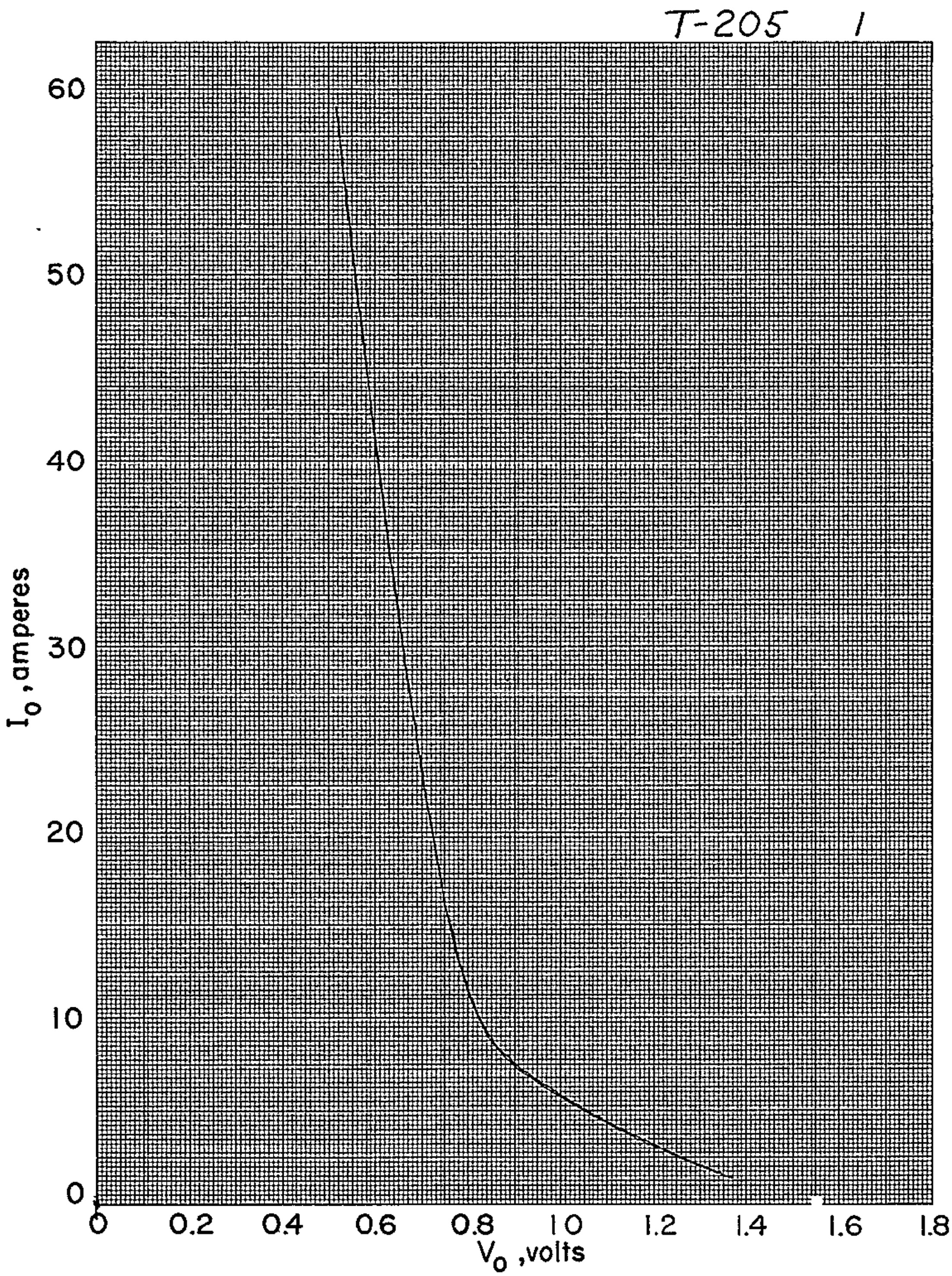
THERMO ELECTRON
ENGINEERING CORPORATION

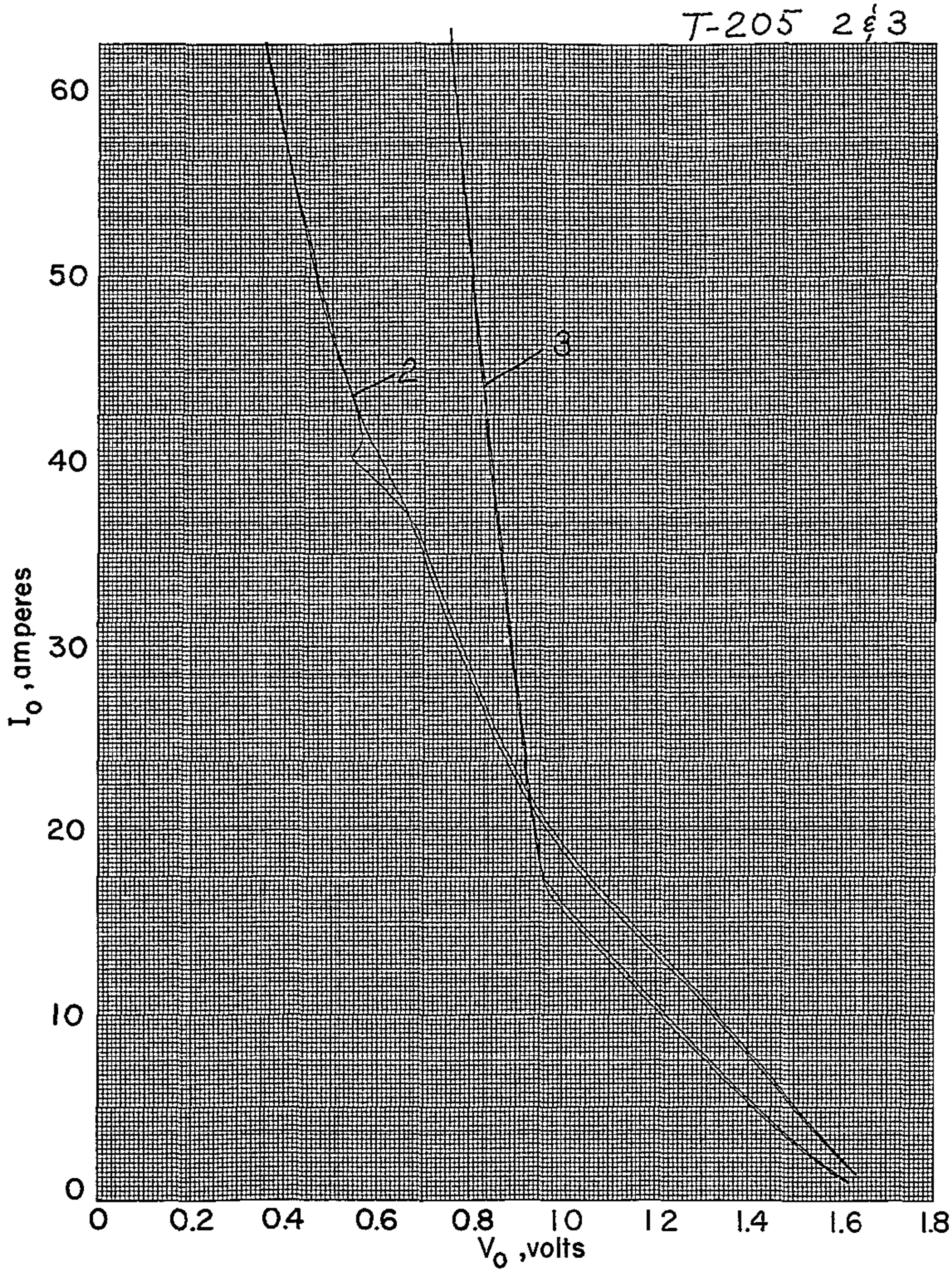
Sheet 6 of 6

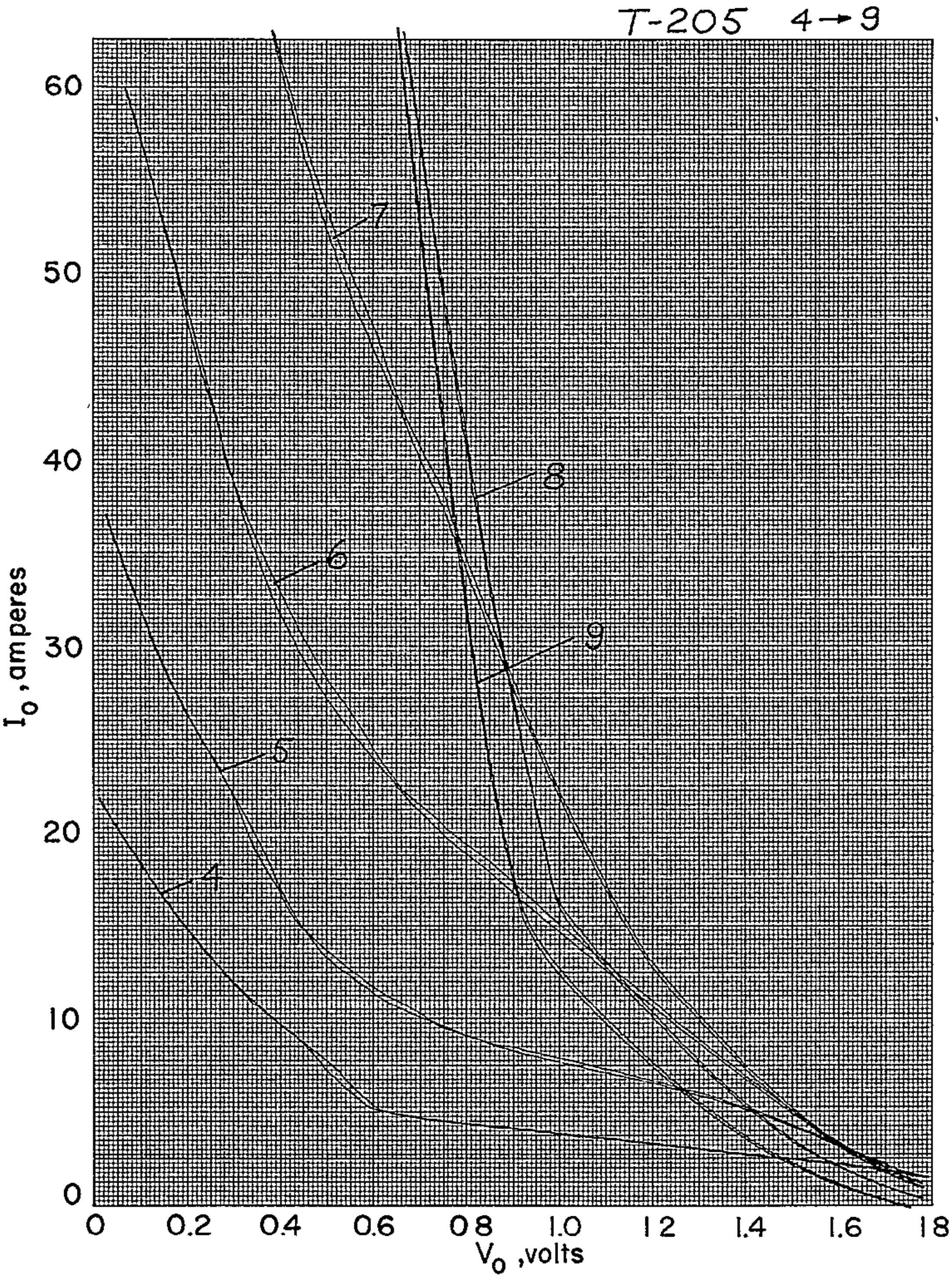
Converter No T-205 Run No 6 Observer P. Brown

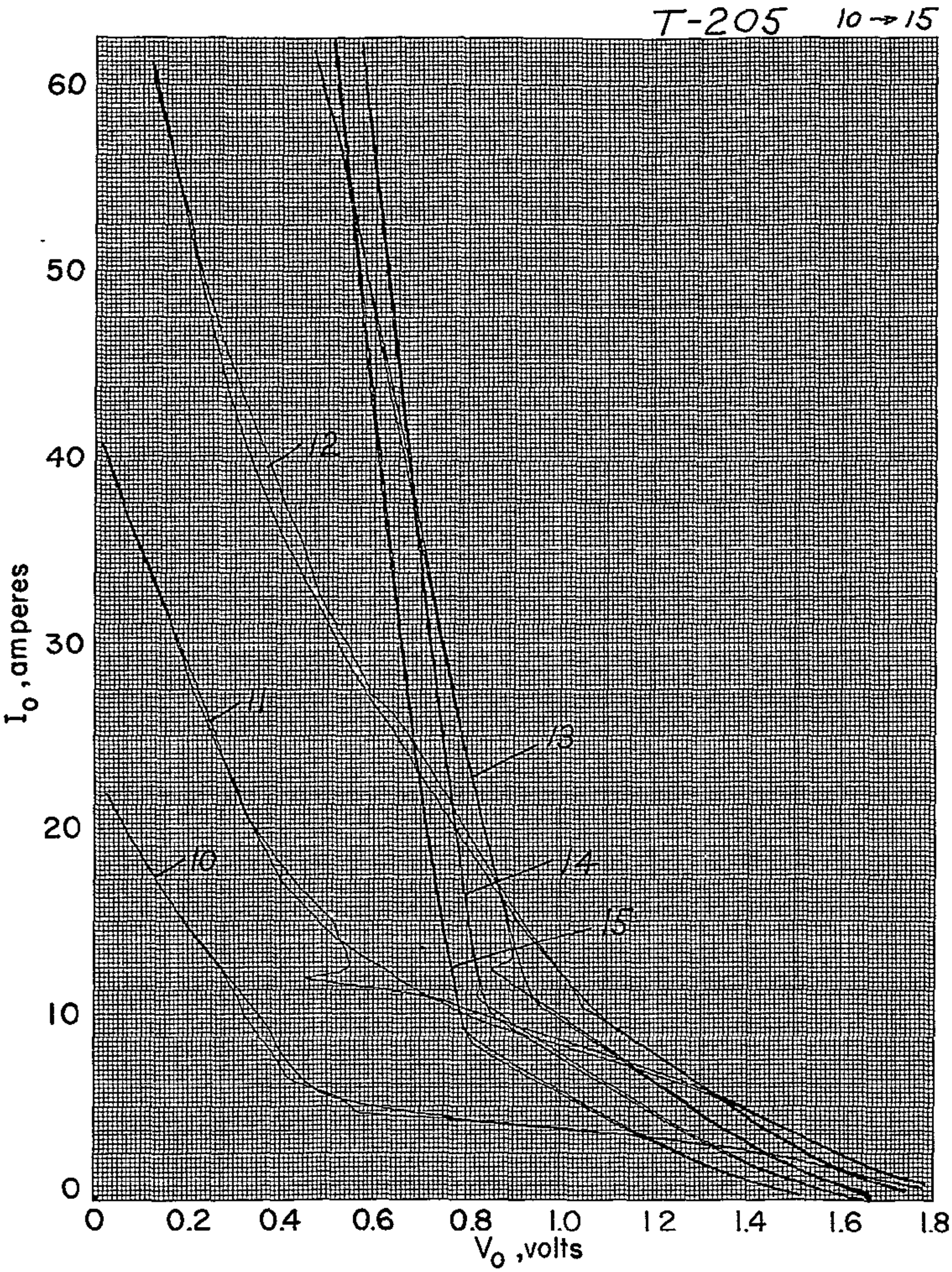
VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		10-21	10-21	10-21	10-21	10-21					
Time		16.52	17.01	17 12	17 22	17 40					
Elapsed Time, Hours		64.5	64 7	64 9	65 0	65.3					
T_O, °C		1737									
T_O Corrected, °C		1784*									
$\Delta T_{Bell\ Jar}$, °C		16									
T_H, °C		1800 ←	←	1820* →	→	→					
ΔT_E, °C		25	28	34	43	53					
T_E, °K		2068	2065	2059	2050	2040					
V_o, volts		1.4	1 2	1.0	0 8	0.6					
I_o, amps		10 0	16 8	28 9	47.0	66.2					
P_o, watts		14	20.4	28.9	37.6	39.7					
I-V Trace No											
T_R	mv	13.0	13 1	13 6	14.3	15 0					
	°C	319	321	333	350	367					
	°K	592.	594	606	623	640					
T_C	mv										
	°C	655	700	765	855	950					
	°K	928	973	1038	1128	1223					
T_C base inner	mv										
	°C										
T_C base outer	mv										
	°C										
$T_{Radiator}$	mv	20.1	20.7	21.9	23.5	25.0					
	°C	487	501	529	567	602					
V_{eb}, volts		979	976	971	965	958					
I_{eb}, mA		283	305	346	403	459					
$E_{Filament}$, volts		5									
$I_{Filament}$, amps		17									
$I_{Coll\ Heater}$, amps		0									
$I_{Res\ Heater}$, amps		1.67	1.71	1.71	1.65	1.59					
Vacuum, 10^{-6} mm Hg		2.3				3.0					
Measured Efficiency, % W_{in}		279			339						

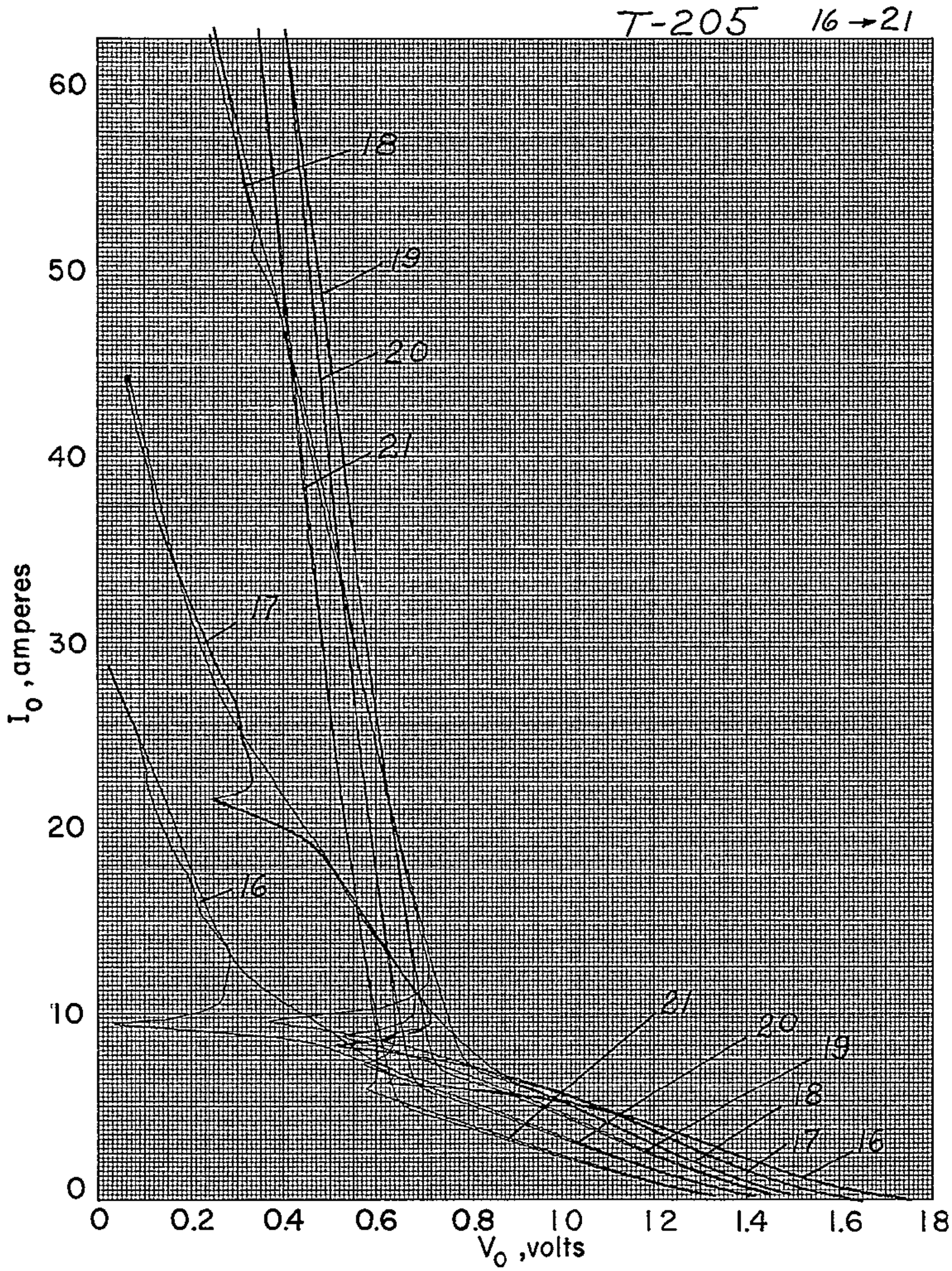
NOTES * See previous page, note †.

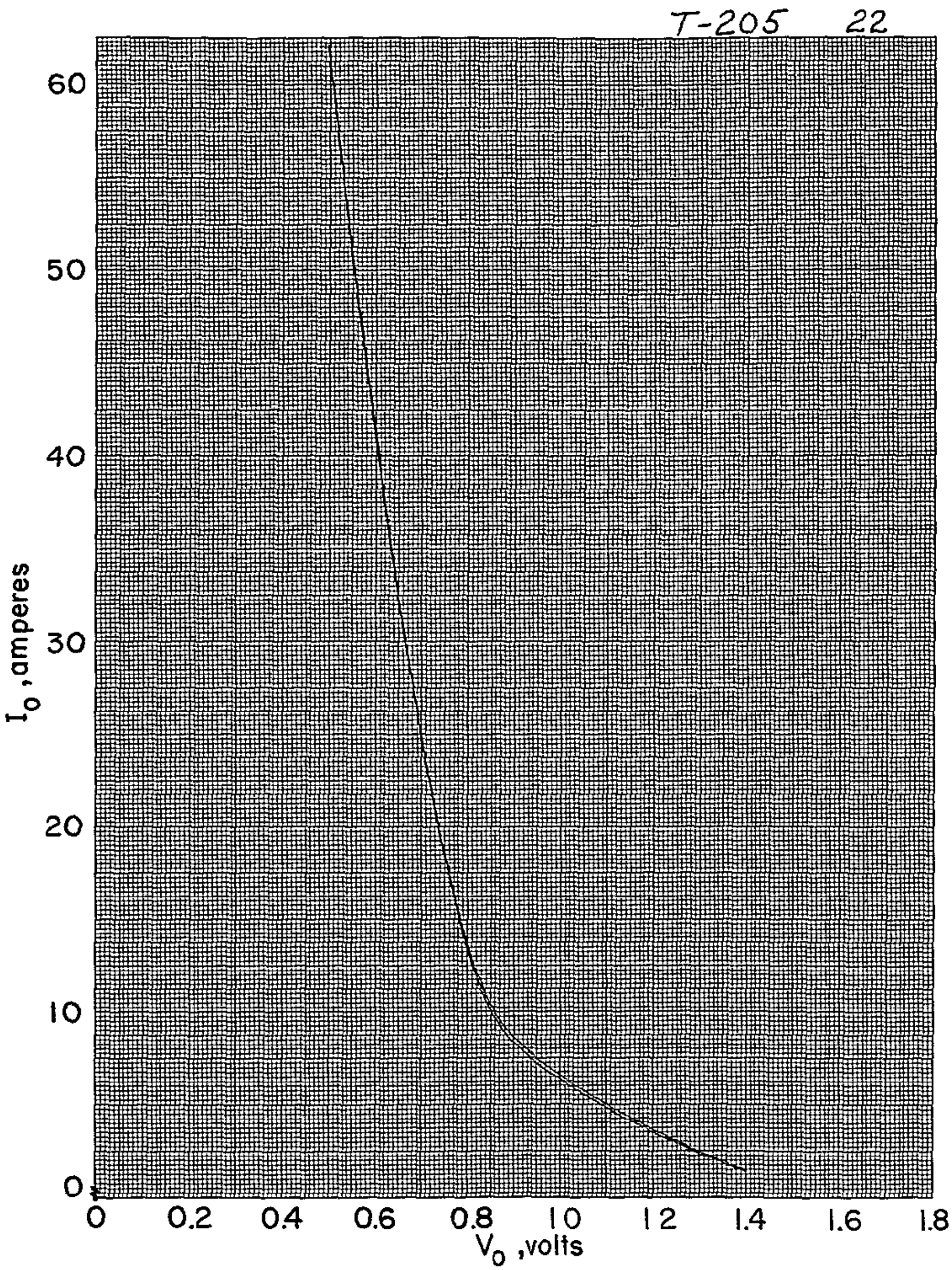

T-205 1
60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts


T-205 2 & 3
60
50
40
30
20
10
0
I0 , amperes
2
3
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V0 ,volts


T-205 4→9
60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts
4
5
6
7
8
9


T-205 10 → 15
60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts
10
11
12
13
14
15


T-205 16 → 21
I_0, amperes
V_0, volts
0
10
20
30
40
50
60
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
16
17
18
19
20
21
21
20
19
18
17
16


T-205 22
60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts

APPENDIX 9

DATA FROM COLLECTOR-RADIATOR

MODEL NO. 2

CALCULATION OF FILAMENT HEATING CONTRIBUTION AND ESTIMATED COLLECTOR HEAT TRANSFER

APPENDIX 9

CALCULATION OF FILAMENT HEATING CONTRIBUTION

Assuming that all of the heat input is radiated by the radiator,

$$q_{in} = \epsilon A \sigma T_{Rad}^4$$

where ϵ is the emissivity of the radiator surface

A is the effective radiator surface

T_{Rad} is the average radiator temperature.

For data point No. 5, the average radiator temperature is

$$T_{Rad} = (233 + 223)/2 = 228°C$$

$$q_{Fil} \text{ at } 22.8 \text{ amps} = \epsilon A \sigma (228 + 273)^4$$

For data point No. 4, the average radiator temperature is:

$$T_{Rad} = (656 + 548)/2 = 602°C$$

$$q_{Fil} \text{ at } 22.8 \text{ amps} + q_{eb} = \epsilon A \sigma (602 + 273)^4$$

where $q_{eb} = 244$ watts

Taking the ratio of these two expressions, the term $\epsilon A \sigma$ drops out:

$$\frac{q_{Fil\,@\,22.8\,A}}{q_{Fil\,@\,22.8\,A} + 244} = \left(\frac{501}{875}\right)^4 = 0.107$$

and

$$q_{Fil} \text{ @ } 22.8 \text{ A} = \frac{244 \times 0.107}{1 - 0.107} = \underline{29.2 \text{ watts}}$$

ESTIMATED COLLECTOR HEAT TRANSFER

Cesium Conduction Loss:

Obtained from Fig. 38, assuming an interelectrode spacing of 1.8 mils (see Table I, p. 2a, and p. 44), and an optimum reservoir temperature of 620°K at 2000°K (see Table on p. 55, and I-V trace No. 9 on p. 7-9 of Appendix 7). Value plotted is 16.0 watts.

Interelectrode Radiation:

Using Fig. 51, it was assumed that both the emitter and the collector have an effective emissivity of 0.28:

$$Q_r = \frac{2.5\,\sigma}{\frac{1}{0.28} + \frac{1}{0.28} - 1} \left[(2000)^4 - (1040)^4\right]$$

$$= (90.86 - 6.64) \times 2.5/6.12 = \underline{34.4 \text{ watts}}$$

In the above, the emitter temperature was assumed to be 2000°K, and the collector temperature, 1040°K, which is the value at which VIII-P-3 operated when the equivalent output current was 72 amperes (see Fig. 41).

Additional Interelectrode Radiation:

This radiator term was assumed to correspond to radiation from the emitter area that extends beyond the edge of the collector. The amount of radial overhang was assumed to equal 6 mils. For a 0.706" emitter diameter, the corresponding area is:

$$\pi \times (0.006 \times 2.54) \times (0.706 \times 2.54) = 0.0865 \text{ cm}^2$$

The radiated power was estimated using an effective emissivity of

0.28 for the emitter, and 1.0 for the gap opposite the radiating area

$$Q_{additional} = 0.28 \times 0\ 0865\ \sigma \left[(2000)^4 - (1040)^4\right]$$

$$= 0.28 \times 0.0865\ (90.86 - 6.64)$$

$$= \underline{2.05} \text{ watts}$$

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 1 of 1

Converter No COLLECTOR RADIATOR #2 Run No 1 Observer P Brosens

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date 1961		1-12	1-12	1-12	1-12	1-13					
Time		13 03	13 35	14 43	15.32	9 33					
Elapsed Time, Hours		—	—	—	-	—					
T_O, °C				—		-					
T_O Corrected, °C		-		-	-	-					
$\Delta T_{Bell\ Jar}$, °C		-		—		-					
T_H, °C		-		-		-					
ΔT_E, °C		—		—	-	-					
T_E, °K		—		—	-						
V_O, volts		-		—	-	-					
I_O, amps		—	-	—	-	-					
P_O, watts		-		—							
I-V Trace No		—	—	—	—	-					
T_R 15	mv	3.69	10 25	12 05	12.82	6 50					
	°C	91	252	296	314	159					
	°K	364	525	569	587	432					
T_C 14	mv	4.61	23 63	33 28	*	9 58					
	°C	112	570	800	—	236					
	°K	385	843	1073	—	509					
T_C base inner 13	mv	4 55	19 50	25 21	27 50	9.45					
	°C	111	473	607	661	233					
T_C base outer 12	mv	4.51	19 38	25 00	27 32	9 44					
	°C	110	471	602	656	233					
$T_{Radiator}$ 11	mv	4 45	17 26	21.35	22 68	9 05					
	°C	108	420	517	548	223					
V_{eb}, volts		0	1003	982.2	974 5	0					
I_{eb}, mA		0	100.4	200.6	249 9	0					
$E_{Filament}$, volts		3.6	4.8	5 0	5.2	5.2					
$I_{Filament}$, amps		17.5	21 6	22 5	22 8	22.8					
$I_{Coll\ Heater}$, amps		—	—	-	-	-					
$I_{Res\ Heater}$, amps		—	—	-	-	—					
Vacuum, 10^{-6} mm Hg		3 4	6 8	6.3	5 5	3.5					
Measured Efficiency, %		—	—	-	—	—					

NOTES. EB Power, w 0 1007 197 244 0

* Thermocouple emf dropped because braze melted

APPENDIX 10

TEST DATA FROM CONVERTER T-206

THERMO ELECTRON ENGINEERING CORPORATION

Sheet 1 of 5

Converter No T-206 Run No 1 & 2 Observer P. Brosen

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date 1967		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
$\Delta T_{Bell\ Jar}$, °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		377	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	12.6
	°C	355	290	271	309	329	350	372	271	290	309
	°K	628	563	544	582	602	623	645	544	563	582
T_C	mv	31.8	26.5	24.4	29 3	30.1	30.3	30.4	22.7	24.3	27.4
	°C	764	637	588	704	723	728	730	548	586	659
	°K	1037	910	861	977	996	1001	1003	821	859	932
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	19 5
	°C	518	464	443	489	501	504	504	424	440	473
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
$I_{Coll\ Heater}$, amps		—	—	—	—	—	—	—	—	—	—
$I_{Res\ Heater}$, 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, % EB/POWER		362	273	247	312	330	336	337	209	228	264

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

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 2 of 5

Converter No T-206 Run No 2 & 3 Observer P Brosens

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_O, °C		1630	1630	1630	1521	1524	1531	1531	1532	1532	
T_O Corrected, °C		1639	1639	1639	1529	1532	1539	1539	1540	1540	
$\Delta T_{Bell\ Jar}$, °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_O, volts		—	—	—	—	—	—	—	—	—	
I_O, amps		$\overline{29}$	$\overline{27}$	$\overline{26}$	$\overline{5}$	$\overline{15}$	$\overline{24}$	$\overline{26}$	$\overline{26}$	$\overline{25}$	
P_O, 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	
$I_{Coll\ Heater}$, amps		—	—	—	—	—	—	—	—	—	
$I_{Res\ Heater}$, 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, %$_{EB\ POWER}$		283	278	279	169	187	224	234	234	230	.

NOTES.

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 1 of 5

Converter No T-206 Run No 1 & 2 Observer P Brosen

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date 1967		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_O, °C		1731	1720	1722	1730	1728	1728	1730	1624	1624	1630
T_O Corrected, °C		1741	1730	1732	1740	1738	1738	1740	1633	1633	1639
$\Delta T_{Bell\ Jar}$, °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_O, volts (2)		.912	—	—	—	—	—	—	—	—	—
I_O, amps		377	20	12	30	31	30	29	10	15	28
P_O, 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	12.6
	°C	355	290	271	309	329	350	372	271	290	309
	°K	628	563	544	582	602	623	645	544	563	582
T_C	mv	31.8	26.5	24 4	29 3	30.1	30.3	30.4	22.7	24.3	27 4
	°C	764	637	588	704	723	728	730	548	586	659
	°K	1037	910	861	977	996	1001	1003	821	859	932
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	19.5
	°C	518	464	443	489	501	504	504	424	440	473
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
$I_{Coll\ Heater}$, amps		—	—	—	—	—	—	—	—	—	—
$I_{Res\ Heater}$, 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, % EB/POWER		362	273	247	312	330	336	337	209	228	264

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

THERMO ELECTRON ENGINEERING CORPORATION

Sheet 2 of 5

Converter No T-206 Run No 2 & 3 Observer [illegible signature]

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	237	23.8	26 5	26 7	26 8	27.0	27.1	27 4	
T_O, °C		1630	1630	1630	1521	1524	1531	1531	1532	1532	
T_O Corrected, °C		1639	1639	1639	1529	1532	1539	1539	1540	1540	
$\Delta T_{Bell\ Jar}$, °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_o, volts		—	—	—	—	—	—	—	—	—	
I_o, amps		$\overline{29}$	$\overline{27}$	$\overline{26}$	$\overline{5}$	$\overline{15}$	$\overline{24}$	$\overline{26}$	$\overline{26}$	$\overline{25}$	
P_o, 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	
$I_{Coll\ Heater}$, amps		—	—	—	—	—	—	—	—	—	
$I_{Res\ Heater}$, 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, % EB/POWER		283	278	279	169	187	224	234	234	230	

NOTES.

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 3 of 5

Converter No T-206 Run No 4 Observer J 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			
$\Delta T_{Bell\ Jar}$, °C		14	—	—	—	—	—	14			
T_H, °C		1727	—	—	—	—	—	1727			
ΔT_E, °C		10	—	—	—	—	—	10			
T_E, °K		1990	—	—	—	—	—	1990			
V_o, volts		2 46	2.45	2 44	2.41	2 39	2 35	2.30			
I_o, amps		0	0	0	0	0	0	0			
P_o, 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			
$I_{Coll\ Heater}$, amps		—	—	—	—	—	—	—			
$I_{Res\ Heater}$, 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, % EB 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.

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 4 of 5

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	319	352	35.4	35.5	35.8
T_O, °C		1676	1676	1676	1676	1676	1676	1579	1579	1579	1579
T_O Corrected, °C		1686	1686	1686	1686	1686	1686	1588	1588	1588	1588
$\Delta T_{Bell\ Jar}$, °C		14	14	14	14	14	14	12	12	12	12
T_H, °C		1700	1700	1700	1700	1700	1700	1600	1600	1600	1600
ΔT_E, °C		10	15	18	22	31	41	10	12	14	16
T_E, °K		1963	1958	1955	1951	1942	1932	1863	1861	1859	1857
V_O, volts		2.42	1.4	1.2	1.0	0 8	0.6	2 17	1.4	1.2	1.0
I_O, amps		0	10.6	16.9	23.3	41.2	62.7	0	4.3	8.0	12.9
P_O, 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
	°C	271	319	331	338	348	360	271	292	300	312
	°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
	°C	525	597	637	668	754	852	476	506	529	564
	°K	798	870	910	941	1027	1125	749	779	802	837
T_C base inner	mv										
	°C										
T_C base outer	mv										
	°C										
$T_{Radiator}$	mv	16.9	18.4	19 2	19.7	21 2	22.7	15 8	16 4	16 9	17 7
	°C	41 2	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
$I_{Coll\ Heater}$, amps		—	—	—	—	—	—	—	—	—	—
$I_{Res\ Heater}$, 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, $\%_{POWER}^{EB}$		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.

THERMO ELECTRON ENGINEERING CORPORATION

Sheet 5 of 5

Converter No T-206 Run No 6 & 7 Observer P Brosens

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
$\Delta T_{Bell\ Jar}$, °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
$I_{Coll\ Heater}$, amps		—	—	—	—	—	—	—	—	—	—
$I_{Res\ Heater}$, 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

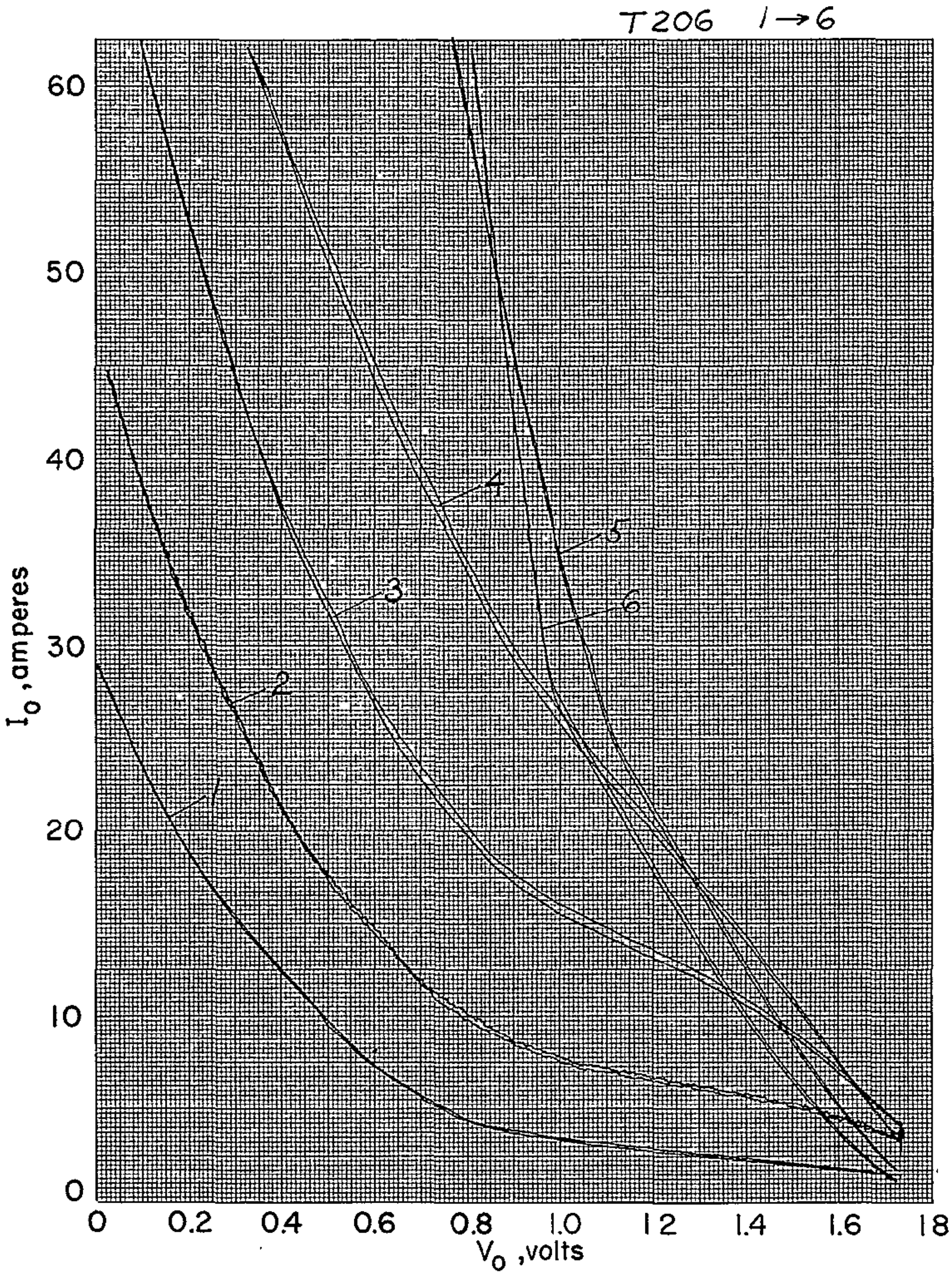
THERMO ELECTRON
ENGINEERING CORPORATION

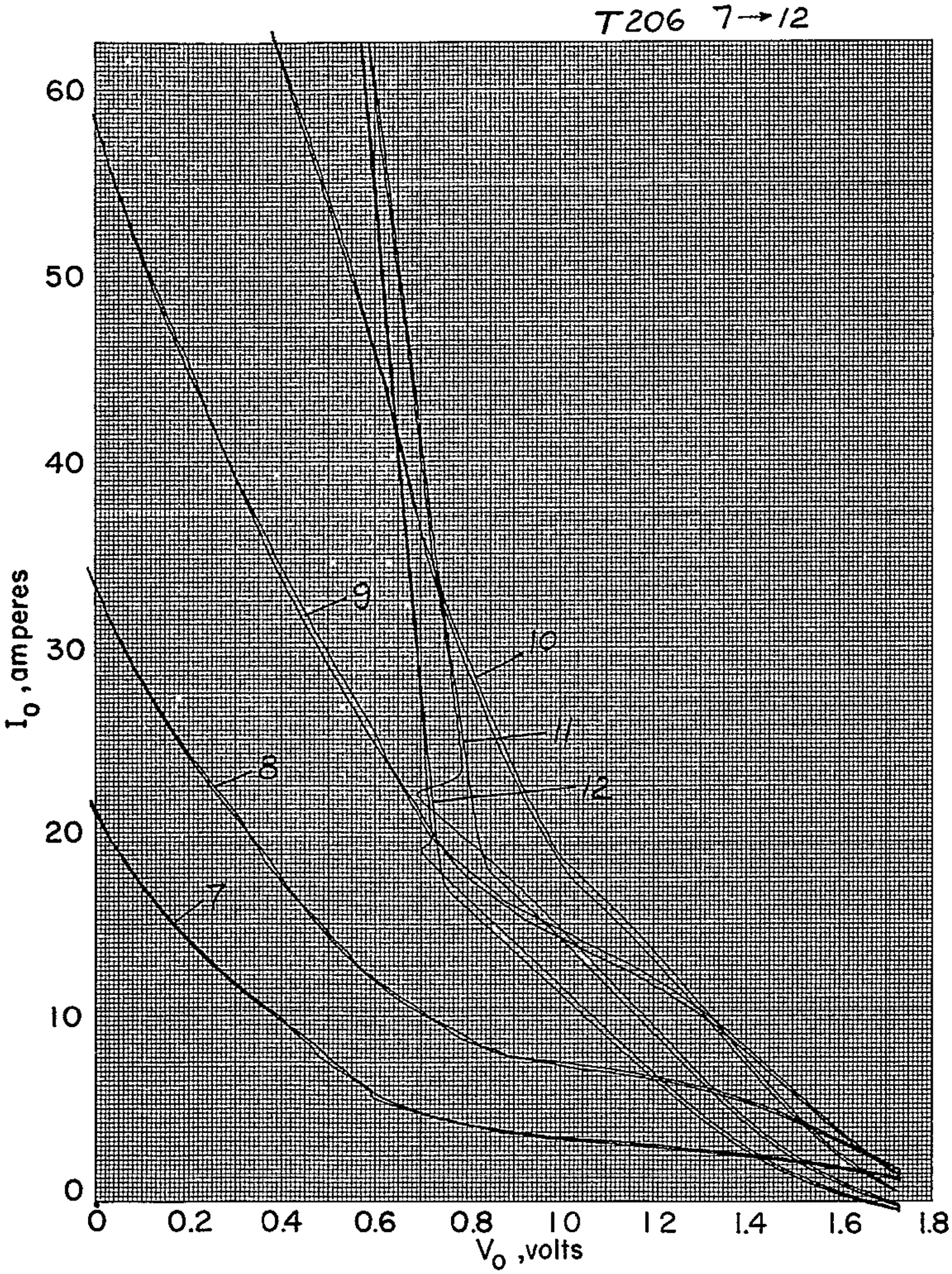
Sheet 1 of 1

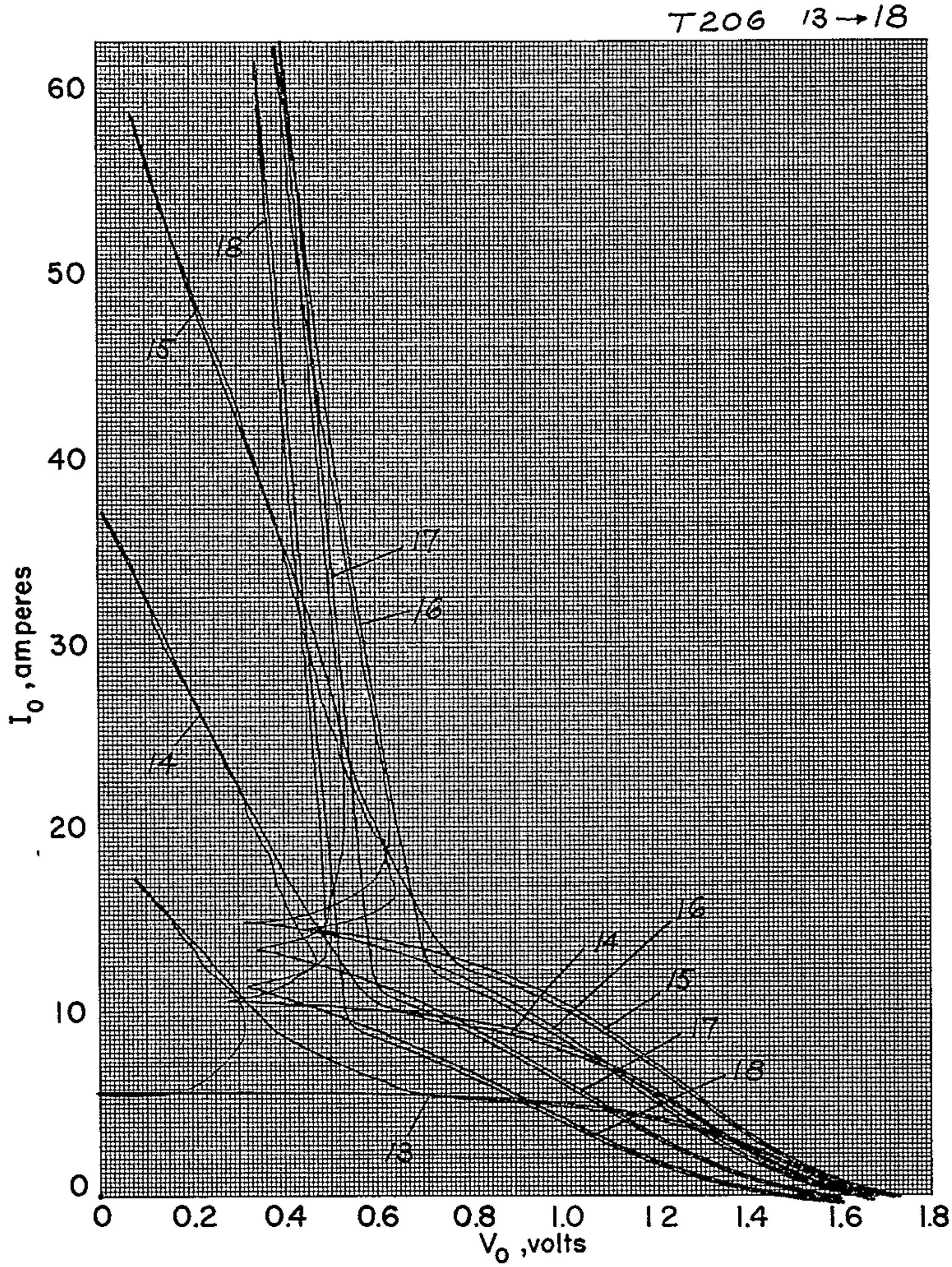
Converter No T-206 Run No 8 Observer O. Brosen

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		7-21	7-24	7-25	7-25	7-25	7-26				
Time		14:12	15.07	9:30	11.25	14.05	9.59				
Elapsed Time, Hours		.00	44	22.8	24.6	27.2	47.1				
T_O, °C		1700	1697	1699	1698	1698	1700				
T_O Corrected, °C		1706	1703	1705	1704	1704	1706				
$\Delta T_{Bell\ Jar}$, °C		11	11	11	11	11	11				
T_H, °C		1717	1714	1716	1715	1715	1717				
ΔT_E, °C		23	23	23	23	31	31				
T_E, °K		1967	1964	1966	1965	1957	1959				
V_o, volts		.982	.996	1.000	1.003	.787	.799				
I_o, amps		22.9	22.2	21.6	21.9	40.9	41.2				
P_o, watts											
I-V Trace No			(2)		(3)		(4)				
T_R	mv	13.1	13.6	13.3	13.2	13.9	14.0				
	°C	321	333	326	324	341	343				
	°K	594	606	599	597	614	616				
T_C	mv	(1)	26.9	26.5	26.5	30.1	30.2				
	°C		647	637	637	723	725				
	°K		920	910	910	996	998				
T_C base inner	mv										
	°C										
T_C base outer	mv										
	°C										
$T_{Radiator}$	mv										
	°C										
V_{eb}, volts		975	976	975	976	970	967				
I_{eb}, mA		300.2	301.9	300.4	302.9	356.3	358.2				
$E_{Filament}$, volts		4.8	4.9	4.8	4.8	4.9	4.9				
$I_{Filament}$, amps		19.5	19.5	19	19	19.5	19.5				
$I_{Coll\ Heater}$, amps		—	—	—	—	—	—				
$I_{Res\ Heater}$, amps		~2	2.63	2.63	2.56	2.59	2.59				
Vacuum, 10^{-6} mm Hg		3.0	3.6	2.2	2.2	2.2	2.1				
Measured Efficiency, % EB Power		292.5	294.5	292.7	295.5	345.5	346.5				

NOTES
(1) TC SHORTED - VOLTAGE TAPS REVERSED POLARITY - STOPPED TESTING TO CORRECT WIRING.
(2) LEFT TO RUN OVERNIGHT.
(3) SHIFTED LOAD TO CHECK 0.8 Volt OUTPUT.
(4) END OF TEST.


T206 1→6
60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts
1
2
3
4
5
6


T206 7→12
60
50
40
30
20
10
0
I_o, amperes
9
10
11
12
8
7
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts


T206 13→18
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
I_0, amperes
V_0, volts
18
15
17
16
14
16
14
15
17
18
13

APPENDIX 11

TEST DATA FROM CONVERTER T-207

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 1 of 5

Converter No T-207 Run No 1 & 2 Observer P Brosens

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		9-11-67	9-12	9-12	9-12	9-12	9-12	9-12	9-12	9-12	9-12
Time		17:10	9 40	10.23	10 47	11:00	11:11	11:20	15:52	16:02	16:07
Elapsed Time, Hours		5 8	22.3	23.0	23.4	23.6	23 8	23.9	28 5	28.7	28.8
T_0, °C		1412	1724	1726	1729	1729	1728	1728	1628	1630	1630
T_0 Corrected, °C (1)		1412	1726	1728	1731	1731	1730	1730	1628	1630	1630
$\Delta T_{Bell\ Jar}$, °C		10	14	14	14	14	14	14	12	12	12
T_H, °C		1422	1740	1742	1745	1745	1744	1744	1640	1642	1642
ΔT_E, °C (2)		—	13	15	18	18	17	17	13	15	15
T_E, °K		—	2000	2000	2000	2000	2000	2000	1900	1900	1900
V_0, volts		0.064	—	—	—	—	—	—	—	—	—
I_0, amps		3.0	$\overline{12}$	$\overline{20}$	$\overline{30}$	$\overline{30}$	$\overline{28}$	$\overline{28}$	$\overline{12}$	$\overline{20}$	$\overline{22}$
P_0, watts		—	—	—	—	—	—	—	—	—	—
I-V Trace No		—	1	2	3	4	5	6	7	8	9
T_R	mv	10.4	11.0	11.8	12.6	13.4	14.3	15.2	11.0	11.8	12.6
	°C	256	271	290	309	329	350	372	271	290	309
	°K	529	544	563	582	602	623	645	544	563	582
T_C	mv	16 3	23.0	25.6	27.9	28.7	28.5	29.2	22.0	24.0	25.7
	°C	398	555	616	671	690	685	702	532	579	618
	°K	671	828	889	944	963	958	975	785	852	891
T_C base inner	mv										
	°C										
T_C base outer	mv										
	°C										
$T_{Radiator}$	mv										
	°C										
V_{eb}, volts		991	974	971	969	968	968	967	982	978	975
I_{eb}, mA		115	236 3	263.2	293.5	312.0	314 0	325 0	196 0	225.3	249.6
$E_{Filament}$, volts		4.2	4.8	4.8	4.8	5.0	4.9	4.9	4.6	4.7	4 8
$I_{Filament}$, amps		18	20	20	20	20	20	20	19	19	20
$I_{Coll\ Heater}$, amps		—	—	—	—	—	—	—	—	—	—
$I_{Res\ Heater}$, amps		1.96	1 20	1 53	2.04	2.56	2 96	3.47	1 59	1.92	2.23
Vacuum, 10^{-6} mmHg		2 6	3.0	3.0	3.0	3.0	3.0	3.0	2 2	2.2	2 2
Measured Efficiency, %											

NOTES (1) PYROMETER CORRECTIONS −1°C @ 1500°C +2°C @ 1700°C
(2) $\Delta T_E = 10 + 0.25\ I$ (4TH QUARTERLY P 12)

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 2 of 5

Converter No T-207 Run No 2 & 3 Observer P. Brosen

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		9-12	9-12	9-12	9-12	9-12	9-12	9-12	9-12	9-12	
Time		16:20	16:35	16:41	17:02	17:07	17:15	17:25	17:30	17:35	
Elapsed Time, Hours		28.9	29.2	29.3	29.6	29.7	29.9	30.0	30.1	30.2	
T_O, °C		1631	1631	1631	1529	1531	1531	1533	1534	1534	
T_O Corrected, °C		1631	1631	1631	1528	1530	1530	1532	1533	1533	
$\Delta T_{Bell\ Jar}$, °C		12	12	12	10	10	10	10	10	10	
T_H, °C		1643	1643	1643	1538	1540	1540	1542	1543	1543	
ΔT_E, °C		16	16	16	11	13	13	15	16	16	
T_E, °K		1900	1900	1900	1800	1800	1800	1800	1800	1800	
V_o, volts		—	—	—	—	—	—	—	—	—	
I_o, amps		$\overline{26}$	$\overline{26}$	$\overline{26}$	$\overline{5}$	$\overline{10}$	$\overline{12}$	$\overline{22}$	$\overline{26}$	$\overline{26}$	
P_o, 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	26.7	27.4	27.5	19.9	20.4	21.5	24.9	25.4	25.7	
	°C	642	659	661	483	494	520	600	612	618	
	°K	915	932	934	756	767	793	873	885	891	
T_C base inner	mv										
	°C										
T_C base outer	mv										
	°C										
$T_{Radiator}$	mv										
	°C										
V_{eb}, volts		975	974	975	991	989	987	981	981	981	
$-I_{eb}$, mA		259.1	268.7	269.2	157.8	173.3	187.3	221.7	221.7	229.9	
$E_{Filament}$, volts		4.8	4.8	4.8	4.6	4.6	4.6	4.7	4.8	4.8	
$I_{Filament}$, amps		20	20	20	19	19	19	19	20	20	
$I_{Coll\ Heater}$, amps		—	—	—	—	—	—	—	—	—	
$I_{Res\ Heater}$, amps		2.60	3.17	3.40	2.14	2.59	2.64	2.81	3.44	3.52	
Vacuum, 10^{-6} mm Hg		2.2	2.2	2.2	2.2	2.1	2.1	2.1	2.1	2.1	
Measured Efficiency, %											

NOTES.

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 3 of 5

Converter No T-207 Run No 4 Observer P Brosen

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		9-15	—	—	—	—	—	—	—	—	9-15
Time		11:05	—	—	—	—	—	—	—	—	11:42
Elapsed Time, Hours		32.0	—	—	—	—	—	—	—	—	32.7
T_O, °C (1)		1721	—	—	—	—	—	—	—	—	1721
T_O Corrected, °C		1723	—	—	—	—	—	—	—	—	1723
$\Delta T_{Bell\ Jar}$, °C		14	—	—	—	—	—	—	—	—	14
T_H, °C		1737	—	—	—	—	—	—	—	—	1737
ΔT_E, °C		10	—	—	—	—	—	—	—	—	10
T_E, °K		2000	—	—	—	—	—	—	—	—	2000
V_o, volts		—	—	—	—	—	—	—	—	—	—
I_o, amps		0	0	0	0	0	0	0	0	0	0
P_o, watts		—	—	—	—	—	—	—	—	—	—
I-V Trace No		—	—	—	—	—	—	—	—	—	—
T_R	mv	10.0	11.0	12.0	12.5	13.0	14.0	14.5	15.0	16.0	17.0
	°C	246	271	295	307	319	343	355	367	391	414
	°K	519	544	568	580	592	616	628	640	664	687
T_C	mv	20.4	20.9	21.0	21.4	21.9	22.3	22.9	22.9	23.6	24.1
	°C	494	506	508	518	529	539	553	553	569	581
	°K	767	779	781	791	802	812	826	826	842	854
T_C base inner	mv										
	°C										
T_C base outer	mv										
	°C										
$T_{Radiator}$	mv										
	°C										
V_{eb}, volts		985	985	984	983	983	982	982	981	980	979
I_{eb}, mA		210.6	212.0	216.3	218.9	220.5	225.3	228.0	231.1	238.9	245.9
$E_{Filament}$, volts		4.5	—	—	—	—	—	—	—	—	4.7
$I_{Filament}$, amps		18.5	—	—	—	—	—	—	—	—	19
$I_{Coil\ Heater}$, amps		—	—	—	—	—	—	—	—	—	—
$I_{Res\ Heater}$, amps		0.99	2.22	2.47	2.94	2.94	3.38	3.73	3.73	4.16	4.56
Vacuum, 10^{-6} mm Hg		2 1	—	—	—	—	—	—	—	—	2.2
Measured Efficiency, %		207.44	208.82	212.8	215.2	216.7	221.9	223.9	226.7	234.1	240.7

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

THERMO ELECTRON ENGINEERING CORPORATION

Sheet 4 of 5

Converter No T-207 Run No 5 & 6 Observer E. Peredetto, P. Brosens

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		9-18	9-18	9-18	9-18	9-18	9-18	9-18	9-18	9-18	9-18
Time		10.57	11:15	11:51	13;17	1351	14:12	14.41	15.40	16'00	16.40
Elapsed Time, Hours		37.2	37.5	381	39.6	40.1	40.5	410	419	42.3	43.0
T_O, °C		1684	1684	1684	1684	1684	1684	1588	1588	1588	1588
T_O Corrected, °C		1686	1686	1686	1686	1686	1686	1588	1588	1588	1588
$\Delta T_{Bell\ Jar}$, °C		14	14	14	14	14	14	12	12	12	12
T_H, °C		1700	1700	1700	1700	1700	1700	1600	1600	1600	1600
ΔT_E, °C		10	11	12	13	15	20	10	10	11	12
T_E, °K		1963	1962	1961	1960	1958	1953	1863	1863	1862	1861
V_o, volts		2.03	1.4	1.2	1.0	0.8	0.6	192	1.4	1.2	1.0
I_o, amps		0	3.9	8.4	14.2	22.0	41.1	0	13	3.2	5.9
P_o, watts		0	5.5	10.1	14.2	17.6	24.7	0	1.8	3.8	5.9
I-V Trace No		—	—	—	—	—	—	—	—	—	—
T_R	mv	12.0	12.0	12.5	12.7	131	13.9	110	10.7	114	11.9
	°C	295	295	307	312	321	341	271	263	280	292
	°K	568	568	580	585	594	614	544	536	553	565
T_C SEE NOTE (1)	mv	17.4	18.0	18.9	19.9	215	250	15.9	15.8	164	171
	°C	424	438	459	483	520	602	388	386	400	417
	°K	697	711	732	756	793	875	661	659	673	690
T_C base inner	mv										
	°C										
T_C base outer	mv										
	°C										
$T_{Radiator}$	mv										
	°C										
V_{eb}, volts		989	984	981	977	972	966 0	992 0	990.0	987.0	986 0
I_{eb}, mA		194.0	2071	224 0	240.0	268 0	329.0	153.	156.0	167 0	177 0
$E_{Filament}$, volts		4.4	4.4	4 5	4.7	4 8	5.0	4.5	4 5	4.6	4.6
$I_{Filament}$, amps		18	18	19	19	20	20	19	19	19	19
$I_{Coll\ Heater}$, amps		—	—	—	—	—	—	—	—	—	
$I_{Res\ Heater}$, amps DC		2.27	2.11	2.37	2.29	2 31	2 55	170	172	1.99	2 24
Vacuum, 10^{-6} mm Hg		2	2	2	2	2	2.2	2	2	2	2
Measured Efficiency, %		191.9	203.8	2197	234 5	260.5	317 8	151 8	154.5	164.5	174.5

NOTES (1) THERMOCOUPLE READING ON COLLECTOR UNSTEADY, CONVERTER WAS OVERHEATED JUST PRIOR TO THIS RUN AND COLLECTOR THERMOCOUPLE MAY HAVE LOOSENED.

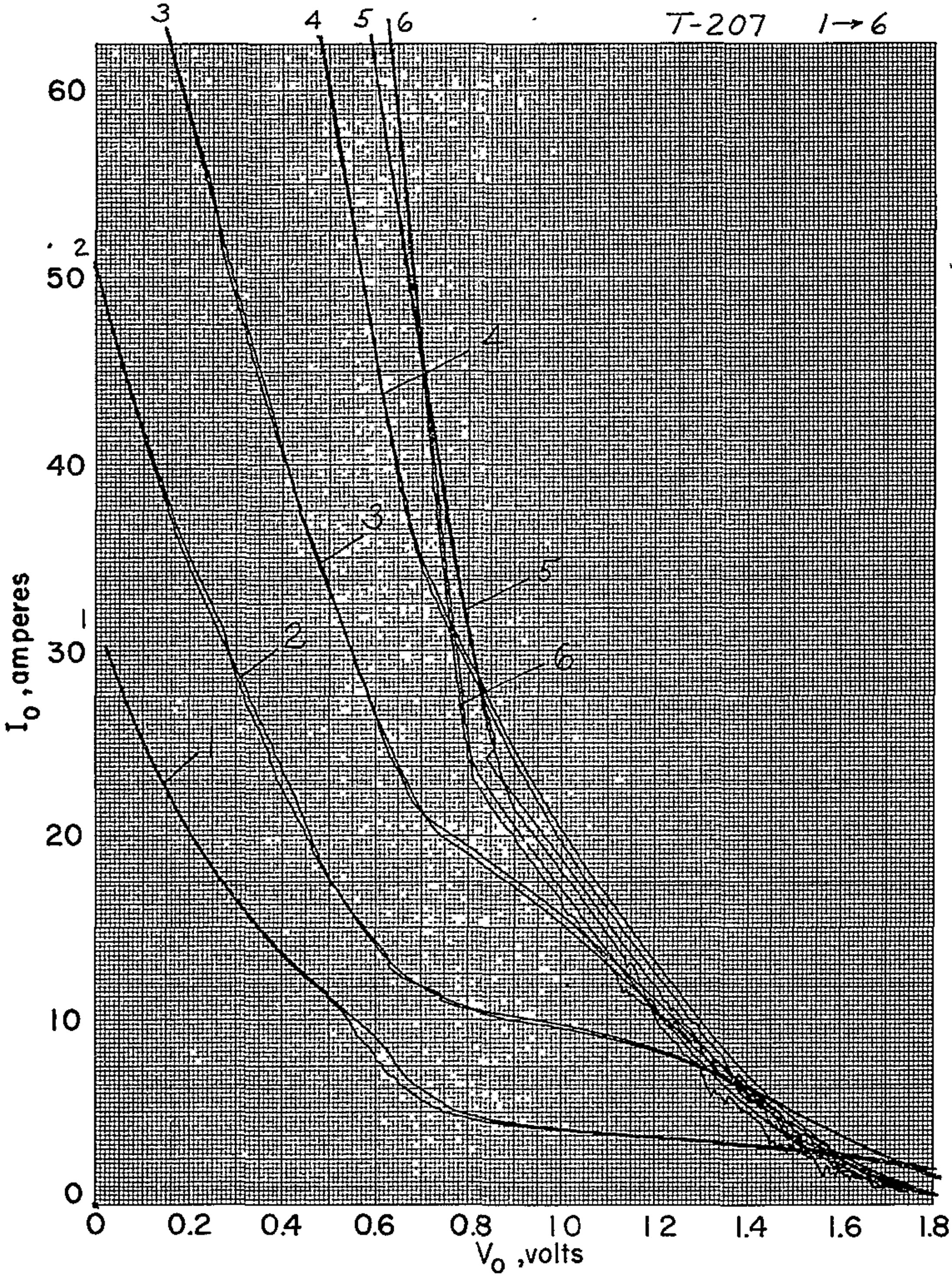
THERMO ELECTRON
ENGINEERING CORPORATION

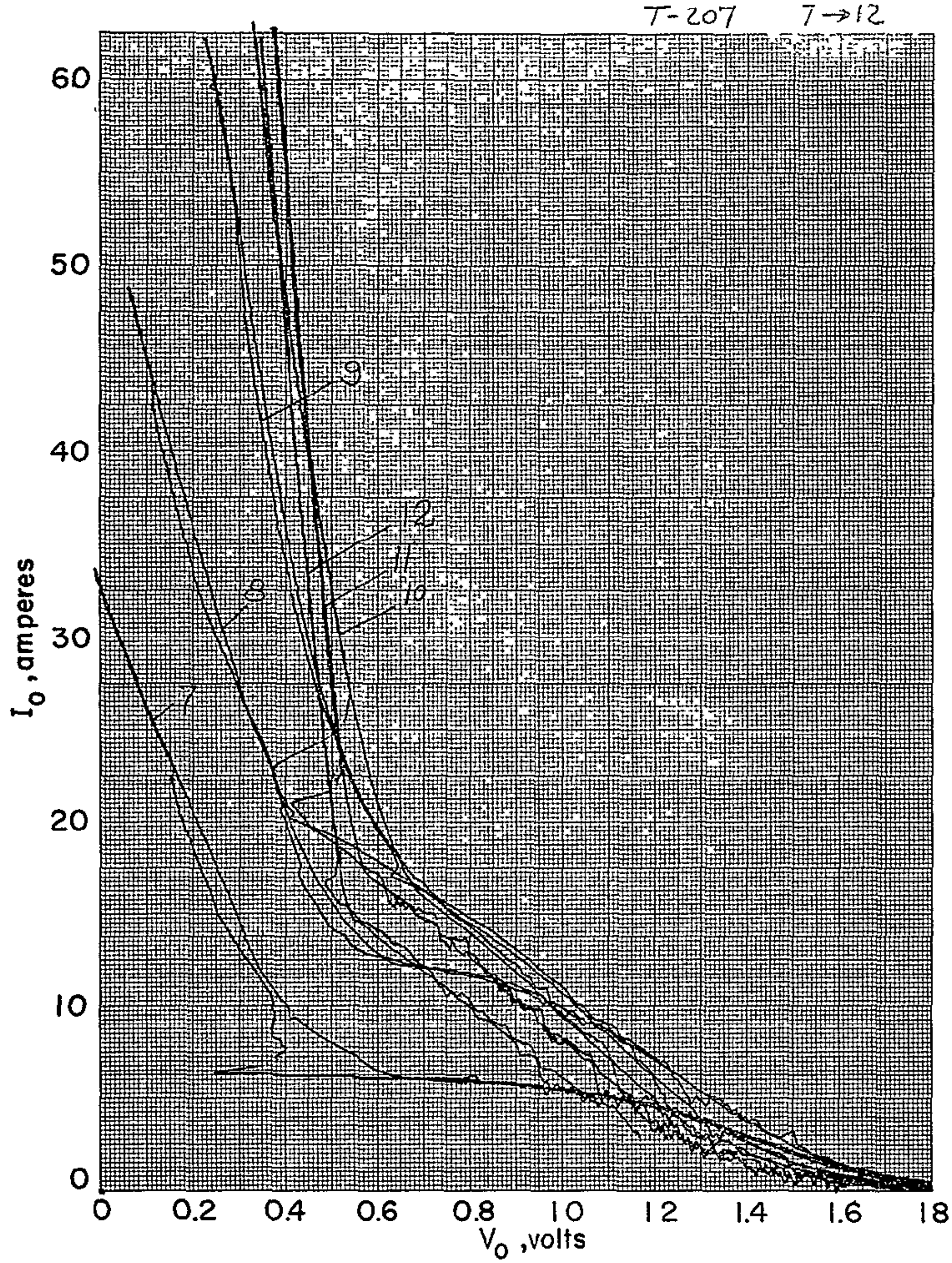
Sheet 5 of 5

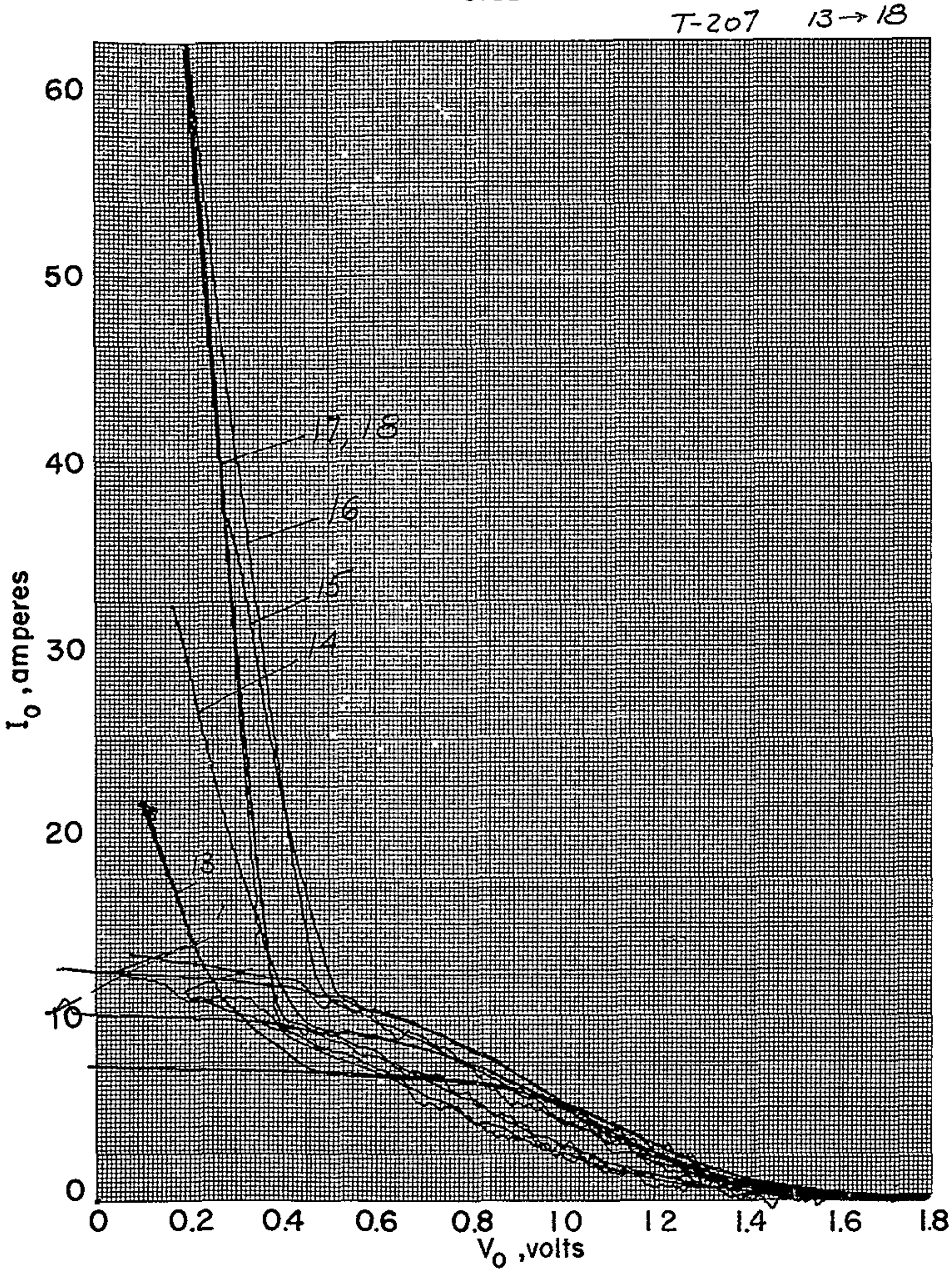
Converter No T-207 Run No 6 & 7 Observer E Peredetto & P. Brosens

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		9-18	9-18	9-19	9-19	9-19	9-19	9-19	9-19		
Time		17:00	17:12	9:52	10:31	10:52	11:21	13:20	13:42		
Elapsed Time, Hours		43.3	43.5	44.3	45.0	45.3	45.8	47.3	48.2		
T_0, °C		1588	1588	1780	1780	1780	1780	1780	1780		
T_0 Corrected, °C		1588	1588	1784	1784	1784	1784	1784	1784		
$\Delta T_{Bell\ Jar}$, °C		12	12	16	16	16	16	16	16		
T_H, °C		1600	1600	1800	1800	1800	1800	1800	1800		
ΔT_E, °C		12	13	10	12	14	16	20	35		
T_E, °K		1861	1860	2063	2061	2059	2057	2053	2038		
V_0, volts		0.8	0.6	2.28	1.4	1.2	1.0	0.8	0.6		
I_0, amps		10.0	13.3	0	9.9	17.4	25.4	42.0	58.9		
P_0, watts		8.0	8.0	0	13.9	20.9	25.4	33.6	35.3		
I-V Trace No		—	—	—	—	—	—	—	—		
T_R	mv	12.1	12.9	12.0	12.5	13.2	13.9	13.2	13.7		
	°C	297	317	295	307	324	341	324	336		
	°K	570	590	568	580	597	614	597	609		
T_C SEE NOTE (1) p. 4	mv	18.0	19.0	18.8	20.6	22.1	23.7	26.2	29.0		
	°C	438	461	457	499	534	572	630	697		
	°K	711	734	730	772	807	845	903	970		
T_C base inner	mv								(1)		
	°C										
T_C base outer	mv										
	°C										
$T_{Radiator}$	mv										
	°C										
V_{eb}, volts		983.0	981.	985	976	972	968	961	956		
I_{eb}, mA		190.0	205.3	230.9	269.0	297.0	328	377	432		
$E_{Filament}$, volts		4.6	4.7	4.6	4.8	4.8	4.8	5.0	5.0		
$I_{Filament}$, amps		19.0	19	19	19	20	20	20	20		
$I_{Coll\ Heater}$, amps		—	—	—	—	—	—	—	—		
$I_{Res\ Heater}$, amps		2.21	2.59	2.06	2.06	2.37	2.63	2.05	2.03		
Vacuum, 10^{-6} mm Hg		2	2	2	2	2.2	2.2	2.2	2.5		
Measured Efficiency, %		186.8	201.4	227.4	262.5	288.7	317.5	362.3	413.0		

NOTES (1) END OF TEST


T-207 1→6
3
4
5
6
2
1
4
3
5
2
6
60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts


T-207 7→12
60
50
40
30
20
10
0
I_0, amperes
9
12
11
10
8
7
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_0, volts


T-207 13 → 18
60
50
40
30
20
10
0
I_0, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_0, volts
17, 18
16
15
14
13

APPENDIX 12

TEST DATA FROM CONVERTER T-208

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 1 of 4

Converter No T-208 Run No 1, 2 & 3 Observer P. Brosens

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date	1968	2-26	2-26	2-26	2-26	2-26	2-26	2-26	2-26	2-26	2-26
Time		14 43	14 54	15 01	15.06	15 21	15 30	15 37	15:44	16 15	16 19
Elapsed Time, Hours		1 4	1 6	1.7	1.8	2 1	2 2	2 3	2 5	3.0	3.1
T_0, °C (1)		1721	1725	1725	1725	1629	1629	1629	1629	1533	1533
T_0 Corrected, °C		1726	1730	1730	1730	1631	1631	1631	1631	1532	1532
$\Delta T_{Bell\ Jar}$, °C		14	14	14	14	11	11	11	11	8	8
T_H, °C		1740	1744	1744	1744	1642	1642	1642	1642	1540	1540
ΔT_E, °C (2)		13	17	17	17	15	16	16	16	13	13
T_E, °K		2000	2000	2000	2000	1900	1900	1900	1900	1800	1800
V_0, volts		—	—	—	—	—	—	—	—	—	—
I_0, amps		$\overline{18}$	$\overline{28}$	$\overline{28}$	$\overline{28}$	$\overline{20}$	$\overline{24}$	$\overline{24}$	$\overline{24}$	$\overline{12}$	$\overline{20}$
P_0, watts		—	—	—	—	—	—	—	—	—	—
I-V Trace No		1	2	3	4	5	6	7	8	9	10
T_R	mv	12.4	13.4	14 3	15.2	12.5	13.4	14 8	15.2	12.7	13.4
	°C	304	329	350	372	307	329	350	372	312	329
	°K	577	602	623	645	580	602	623	645	585	602
T_C	mv	26.4	28.1	28.7	28.3	25 8	26 8	26.9	26 9	24.8	25 2
	°C	635	675	690	680	621	644	647	647	597	607
	°K	908	948	963	953	894	917	920	920	870	880
T_C base inner	mv	—	—	—	—	—	—	—	—	—	—
	°C										
T_C base outer	mv	—	—	—	—	—	—	—	—	—	—
	°C										
$T_{Radiator}$	mv	—	—	—	—	—	—	—	—	—	—
	°C										
V_{eb}, volts		975	971	969	969	978	976	975	975	981	981
I_{eb}, mA		243.0	280.7	301 7	300 0	221.2	238.8	248	248	198 4	203.3
$E_{Filament}$, volts		4 8	5.0	5.0	5.0	4.8	4.9	4.9	4.9	4.8	4 8
$I_{Filament}$, amps		19	19	19 5	19.5	19.0	19.0	19.0	19.0	19 0	19.5
$I_{Coil\ Heater}$, amps		—	—	—	—	—	—	—	—	—	—
$I_{Res\ Heater}$, amps		0	.45	1.50	1.80	0	1.45	1 58	2 18	1 30	1.63
Vacuum, 10^{-6} mm Hg		18	18	18	18	16	14	14	14	12	12
~~Measured Efficiency, %~~ P_{eb}		236.9	272 8	292 3	290 7	216 3	232.8	241 8	241.8	194 6	199 4

NOTES (1) PYROMETER CORRECTIONS −1°C @ 1500°C; +2°C @ 1600°C; +5°C @ 1700°C
BELL JAR CORRECTIONS. +8°C @ 1500°C; +11°C @ 1600°C, +14°C @ 1700°C
(2) $\Delta T_E = 10 + 0.25\ I$
(3) HIGHER T_R OBSERVED (THICK WALLED CS TUBE)

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 2 of 4

Converter No T-208 Run No 3 & 4 Observer P Brosen

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		2-26	2-26	2-26	—	—	—	—	—	—	2-26
Time		16 27	16:30	17 00	—	—	—	—	—	—	17:23
Elapsed Time, Hours		3.2	3.3	3.7	—	—	—	—	—	—	4.0
T_O, °C		1535	1535	1718	—	—	—	—	—	—	1718
T_O Corrected, °C		1534	1534	1723	—	—	—	—	—	—	1723
$\Delta T_{Bell\ Jar}$, °C		8	8	14	—	—	—	—	—	—	14
T_H, °C		1542	1542	1737	—	—	—	—	—	—	1737
ΔT_E, °C		15	15	10	—	—	—	—	—	—	10
T_E, °K		1800	1800	2000	—	—	—	—	—	—	2000
V_O, volts		—	—	—	—	—	—	—	—	—	—
I_O, amps		$\overline{20}$	$\overline{20}$	0	0	0	0	0	0	0	0
P_O, watts		—	—	—	—	—	—	—	—	—	—
I-V Trace No		11	12	—	—	—	—	—	—	—	—
T_R	mv	14 3	15 2	11.7	12.5	13.0	14 0	14 5	15 0	16.0	17.0
	°C	350	372	288	307	3 19	343	355	367	391	414
	°K	623	645	561	580	592	616	628	640	664	687
T_C	mv	25.6	25.7	24.2	24 4	24.6	24.9	25.0	25.2	25 4	25 6
	°C	616	618	583	588	593	600	602	607	612	616
	°K	889	891	856	861	866	873	875	880	885	889
T_C base inner	mv	—	—	—	—	—	—	—	—	—	—
	°C										
T_C base outer	mv	—	—	—	—	—	—	—	—	—	—
	°C										
$T_{Radiator}$	mv	—	—	—	—	—	—	—	—	—	—
	°C										
V_{eb}, volts		980	980	983 2	982.7	982.9	982.2	981.7	981 5	981 1	*
I_{eb}, mA		207.3	206.9	221 1	225 5	227 6	232.0	233 8	236 4	238.6	*
$E_{Filament}$, volts		4 8	4 8	4.8	—	—	—	—	—	—	4 8
$I_{Filament}$, amps		19 0	19 0	19.0	—	—	—	—	—	—	19.0
$I_{Coll\ Heater}$, amps		—	—	—	—	—	—	—	—	—	—
$I_{Res\ Heater}$, amps		2.30	2 58	0	1.12	1.54	2.01	2.16	2.45	2.89	3.20
Vacuum, 10^{-6} mm Hg		12	12	12	—	—	—	—	—	—	12
Measured Efficiency, %		203.1	202.7	217.4	221 7	223 7	228 0	229 5	232.0	234 1	—

NOTES * NO READING BECAUSE SERVO-OPTICS WERE ACCIDENTALLY DISPLACED

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 3 of 4

Converter No T-208 Run No 5 & 6 Observer P Brosius & E. Peredelto

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		2-26	2-27	2-27	2-27	2-27	2-27	2-27	2-27	2-27	2-27
Time		17:36	11:24	11:32	11.44	11.57	13 10	13:25	13 36	13:46	13:55
Elapsed Time, Hours		4 3	22.1	22 3	22.5	22.7	23.9	24 2	24 4	24 5	24.7
T_O, °C		1681	1681	1681	1681	1681	1587	1587	1587	1587	1587
T_O Corrected, °C		1686	1686	1686	1686	1686	1589	1589	1589	1589	1589
$\Delta T_{Bell\ Jar}$, °C		14	14	14	14	14	11	11	11	11	11
T_H, °C		1700	1700	1700	1700	1700	1600	1600	1600	1600	1600
ΔT_E, °C		11	12	13	15	18	10	11	11	12	13
T_E, °K		1962	1961	1960	1958	1955	1863	1862	1862	1861	1860
V_O, volts		1.400	1.200	1.000	.800	.600	1.400	1 200	1.000	.800	.600
I_O, amps		5 1	9.0	13.4	20.1	32.2	2.0	3 1	5.8	9.0	14 3
P_O, watts		7 14	10 8	13.4	16.1	19.3	2.8	3.7	5.8	7 2	8 6
I-V Trace No		—	—	—	—	—	—	—	—	—	—
T_R	mv	14.2	13 3	13.5	13 9	14 3	11 5	11.9	12.1	12.5	13 0
	°C	348	326	331	341	350	283	292	297	307	319
	°K	621	599	604	614	623	556	565	570	580	592
T_C	mv	24.8	25 3	26.0	27.0	28.7	22.7	16.6	17.0	24.0	24 9
	°C	597	609	626	649	690	548	(1)	(1)	579	600
	°K	870	882	899	922	963	821	—	—	852	873
T_C base inner	mv	—	—	—	—	—	—	—	—	—	—
	°C										
T_C base outer	mv	—	—	—	—	—	—	—	—	—	—
	°C										
$T_{Radiator}$	mv	—	—	—	—	—	—	—	—	—	—
	°C										
V_{eb}, volts		981	975	973	970	965	984	984	982	980	977
I_{eb}, mA		219 8	246 5	262.7	279 9	315.8	181.2	183.4	188.9	201 1	218.1
$E_{Filament}$, volts		4 8	4 8	4.8	5.0	5 0	4 8	4 8	4 8	4.8	4.9
$I_{Filament}$, amps		19.0	19.0	19.0	19.0	19.0	18 0	18.4	18 5	18 6	18 8
$I_{Coll\ Heater}$, amps		—	—	—	—	—	—	—	—	—	—
$I_{Res\ Heater}$, amps		2.07	1.43	1.35	1 41	1 45	0	1 0	1 26	1 25	1 85
Vacuum, 10^{-6} mm Hg		12	10	10	10	10	10	10	10	10	10
~~Measured Efficiency, %~~ P_{eb}		215 6	240 3	255.6	271 5	304 7	178 3	180 5	185.5	197.1	213.1

NOTES (1) INCORRECT READING, TC SHORTED TO POTENTIOMETER WITH SETTING FOR T_R

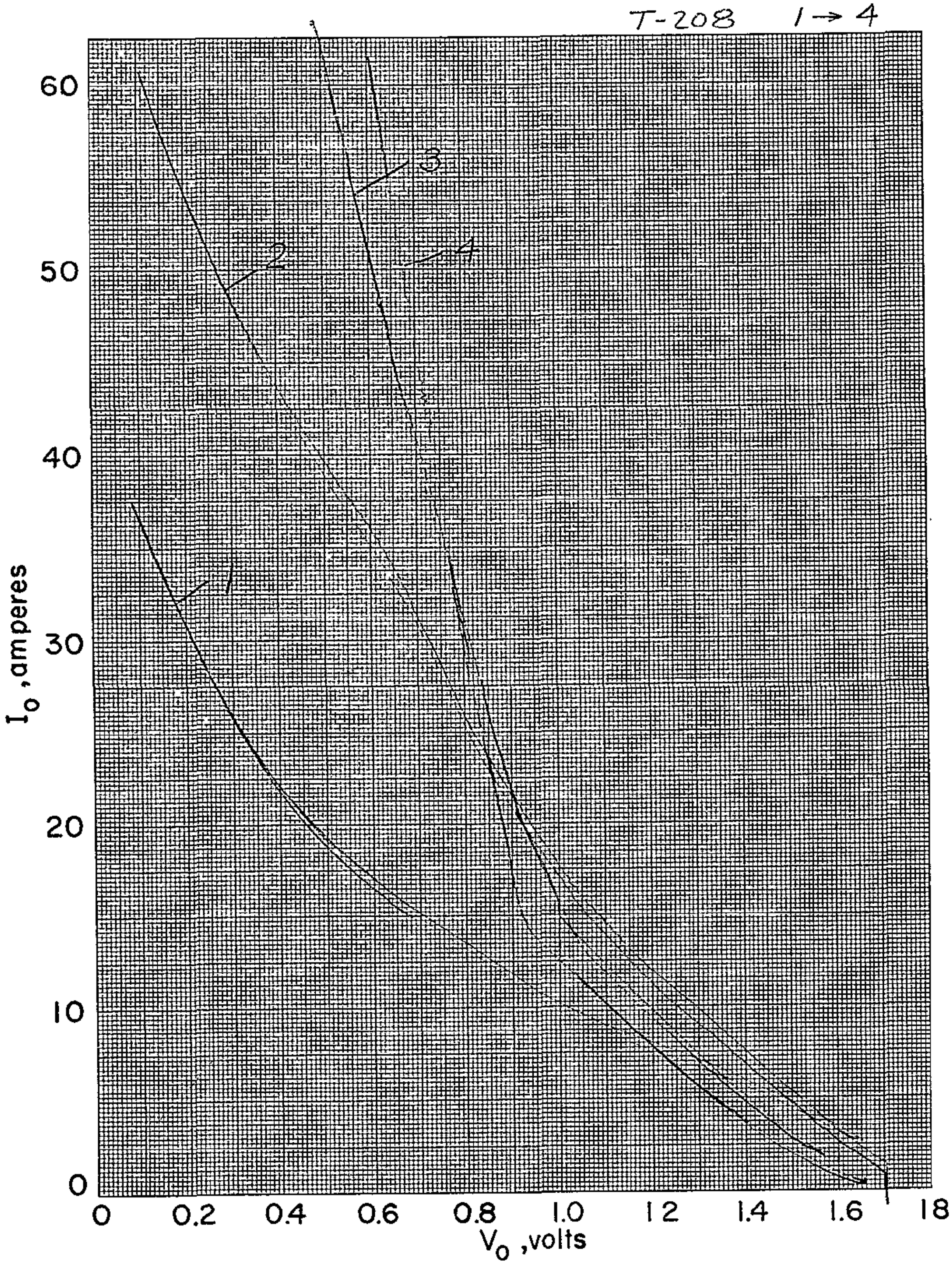
THERMO ELECTRON
ENGINEERING CORPORATION

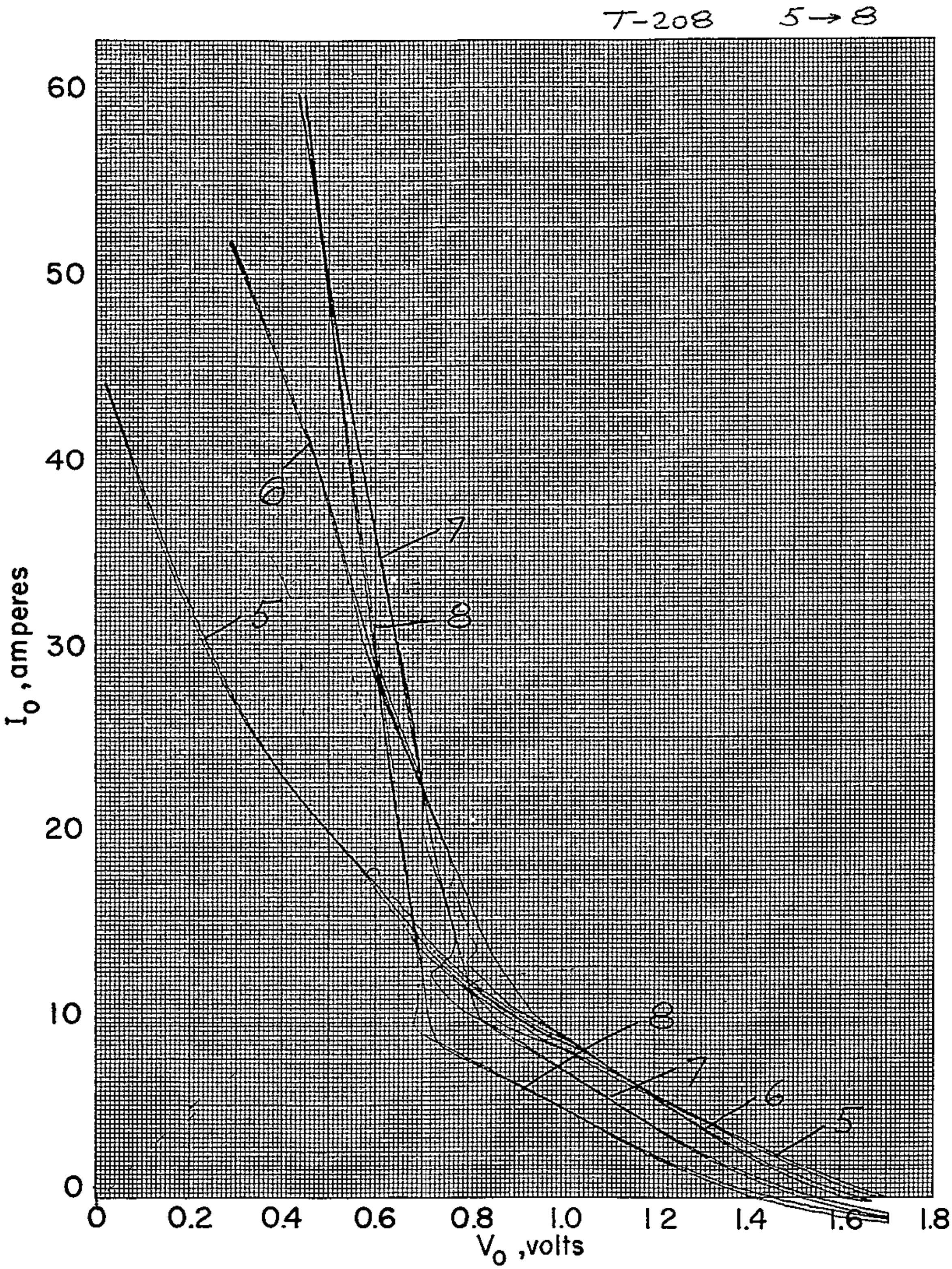
Sheet 4 of 4

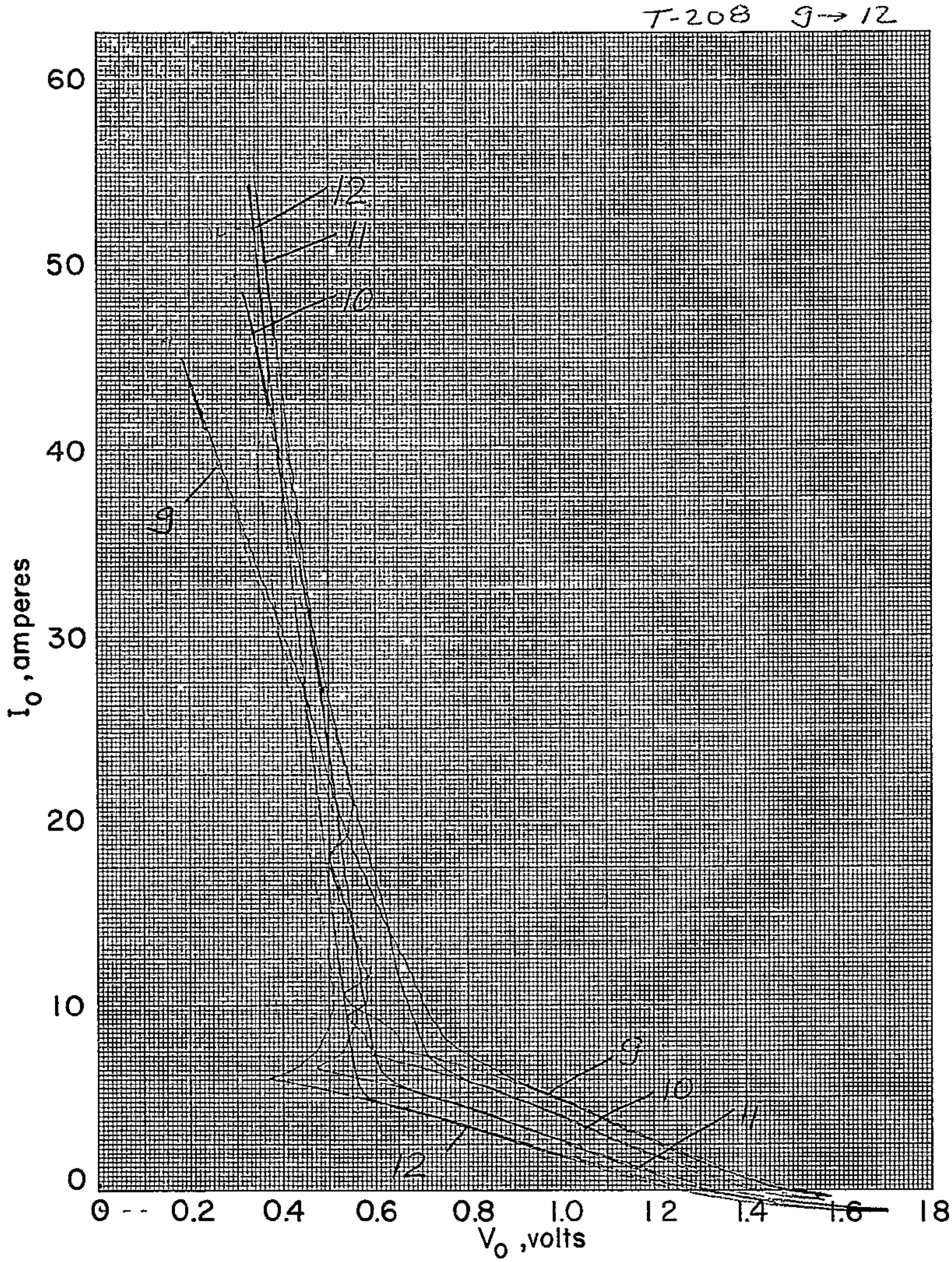
Converter No T-208 Run No 7 Observer E. Peredetto & P Brosens

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		2-27	2-27	2-27	2-27	2-27					
Time		14.43	14.50	14 56	15 03	15.16					
Elapsed Time, Hours		25 4	25 5	25.6	25.8	26.0					
T_0, °C		1775	1775	1775	1775	1775					
T_0 Corrected, °C		1783	1783	1783	1783	1783					
$\Delta T_{Bell\ Jar}$, °C		17	17	17	17	17					
T_H, °C		1800	1800	1800	1800	1800					
ΔT_E, °C		12	13	15	17	20					
T_E, °K		2061	2060	2058	2056	2053					
V_0, volts		1 400	1 200	1 000	800	.600					
I_0, amps		7.4	12.4	19.0	28.9	41.4					
P_0, watts		10 4	14 9	19 0	23.1	24 8					
I-V Trace No		—	—	—	—	—					
T_R	mv	137	13.9	14 0	14.7	15 0					
	°C	336	341	343	360	367					
	°K	609	614	616	633	640					
T_C	mv	26.6	27.2	28.1	29.3	31.0					
	°C	640	654	675	704	744					
	°K	913	927	948	977	1017					
T_C base inner	mv	—	—	—	—	—					
	°C										
T_C base outer	mv	—	—	—	—	—					
	°C										
$T_{Radiator}$	mv	—	—	—	—	—					
	°C					*					
V_{eb}, volts		972	969	966	962	957					
I_{eb}, mA		295 5	310 8	333 9	366 4	408.3					
$E_{Filament}$, volts		4.9	5.0	5 0	5.0	5.1					
$I_{Filament}$, amps		19.0	19 0	19.0	19 0	19 2					
$I_{Coll\ Heater}$, amps		—	—	—	—	—					
$I_{Res\ Heater}$, amps		1 48	1 36	1.42	1 38	1 40					
Vacuum, 10^{-6} mm Hg		10	10	10	10	10					
Measured Efficiency, %		287 2	301 2	322 5	352 5	390.7					

NOTES * END OF TEST


T-208 1 → 4
60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts
1
2
3
4


T-208 5→8
60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts
6
7
8
5
8
7
6
5


T-208 9→12
60
50
40
30
20
10
0
I_o, amperes
12
11
10
9
9
10
11
12
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts

APPENDIX 13

DESIGN OF 100-MESH CAPILLARY

APPENDIX 13

DESIGN OF 100-MESH CAPILLARY

Heat Transfer from Emitter:

Electron cooling:

Output power = 50 watts at 0.6 volt

Output current = 50/0.6 = 83.3 A

Output current density = 83.3/2.55 cm^2 = 32.6 A/cm^2

Effective emitter work function, as given by Richardson's equation for 32.6 A/cm^2 at 2000°K = 2.85 ev.

Electron cooling = 2.85 x 32.6 = 93.0 w/cm^2

Radiation heat transfer, cesium conduction, lead loss:

Given on p. 7 of the Final Report, Heat Pipe Thermionic Converter Development, Contract No. 951465, December 1967, prepared for the Jet Propulsion Laboratory.

q_r = 11.9 w/cm^2

q_{cs} = 4.1 w/cm^2

q_ℓ = 6.2 w/cm^2

Total heat transfer, including electron cooling: 115.2 w/cm^2

Heat Transfer to Collector:

Allowing for an electrical output of 20 w/cm^2, the heat transfer to the collector is 115.2 - 20 = 95.2 w/cm^2. The total heat transfer to the collector is then

$$95.2 \times 2.55 = 242 \text{ watts}$$

where 2.55 is the electrode area in cm^2 as calculated in the above reference.

The output leads serve to dissipate a portion of the heat load to the collector, and the corresponding heat transfer was estimated at 10 watts/lead.

The net heat transfer to the collector heat pipe is then

$$242 - 2 \times 20 = 222 \text{ watts}$$

Heat Pipe Mass Flow Rate:

Assuming an operating temperature of 700°C, the latent heat of vaporization for niobium, given by Fig. 13-1, is 3900 joules/gram The heat pipe mass rate of flow required to transport 222 watts is then:

$$M = 222/3900 = 8.3 \times 10^{-2} \text{ gm/sec}$$

Heat Pipe Vapor Pressure Drop:

$$\Delta p_g = 8 \nu_g \dot{M} L/\pi R_v^4$$

where ν_g is the kinematic viscosity of sodium vapor, given in Fig. 13-2, L is the length, and R_v is the radius of the vapor passage.

L for T-209 and T-210 = 4.8 in. = 12.2 cm

R_v = 0.29 in. = 0.74 cm

ν_g = 2.2 cm^2/sec

$\Delta p_g = 8 \times 2.2 \times 8.3 \times 10^{-2} \times 12.2/\pi \times (0.74)^4$

= 19.0 dynes/sq cm., which is negligibly small

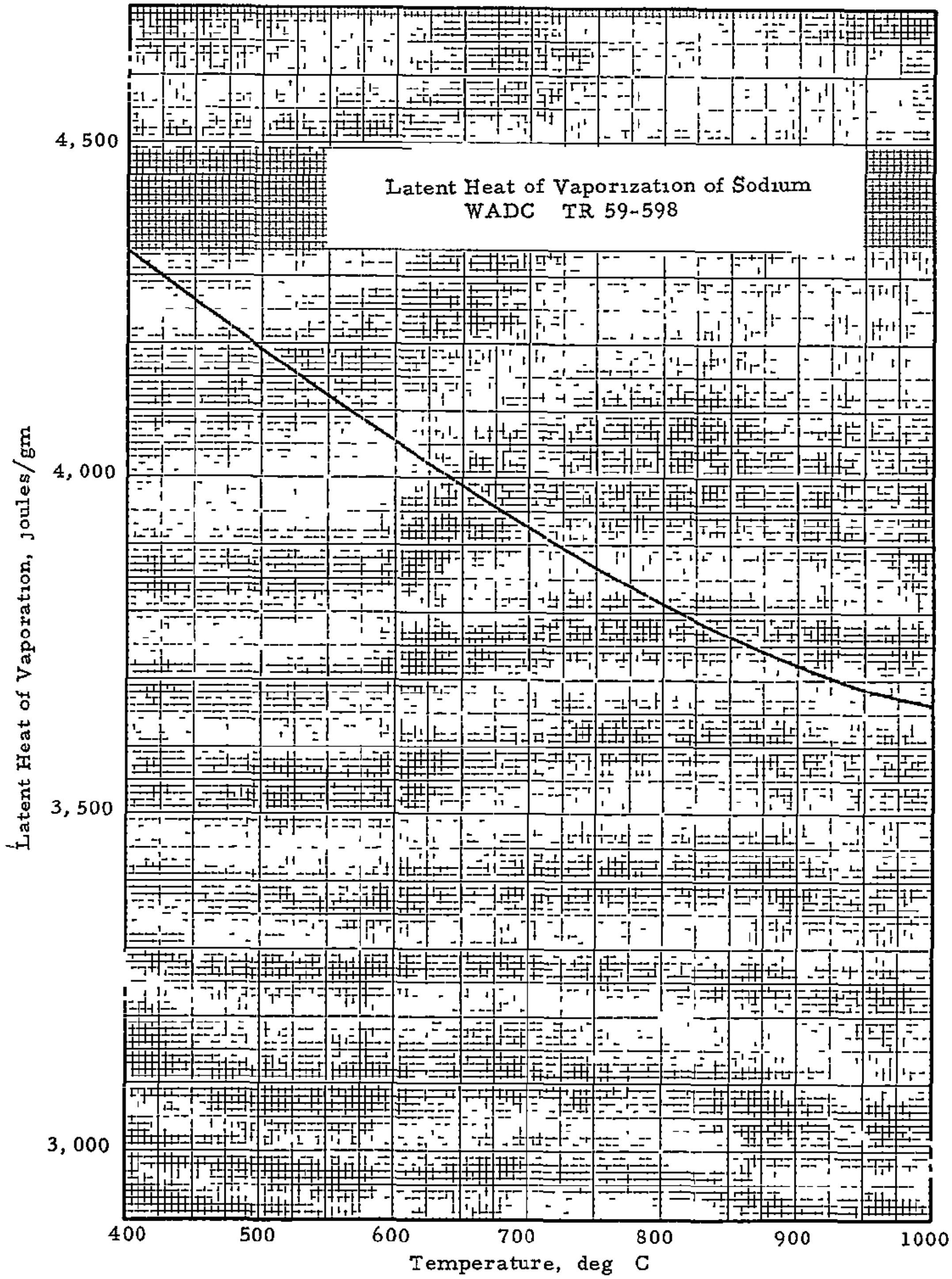

Latent Heat of Vaporization of Sodium
WADC TR 59-598
4,500
4,000
3,500
3,000
Latent Heat of Vaporation, joules/gm
400
500
600
700
800
900
1000
Temperature, deg C

Figure 13-1

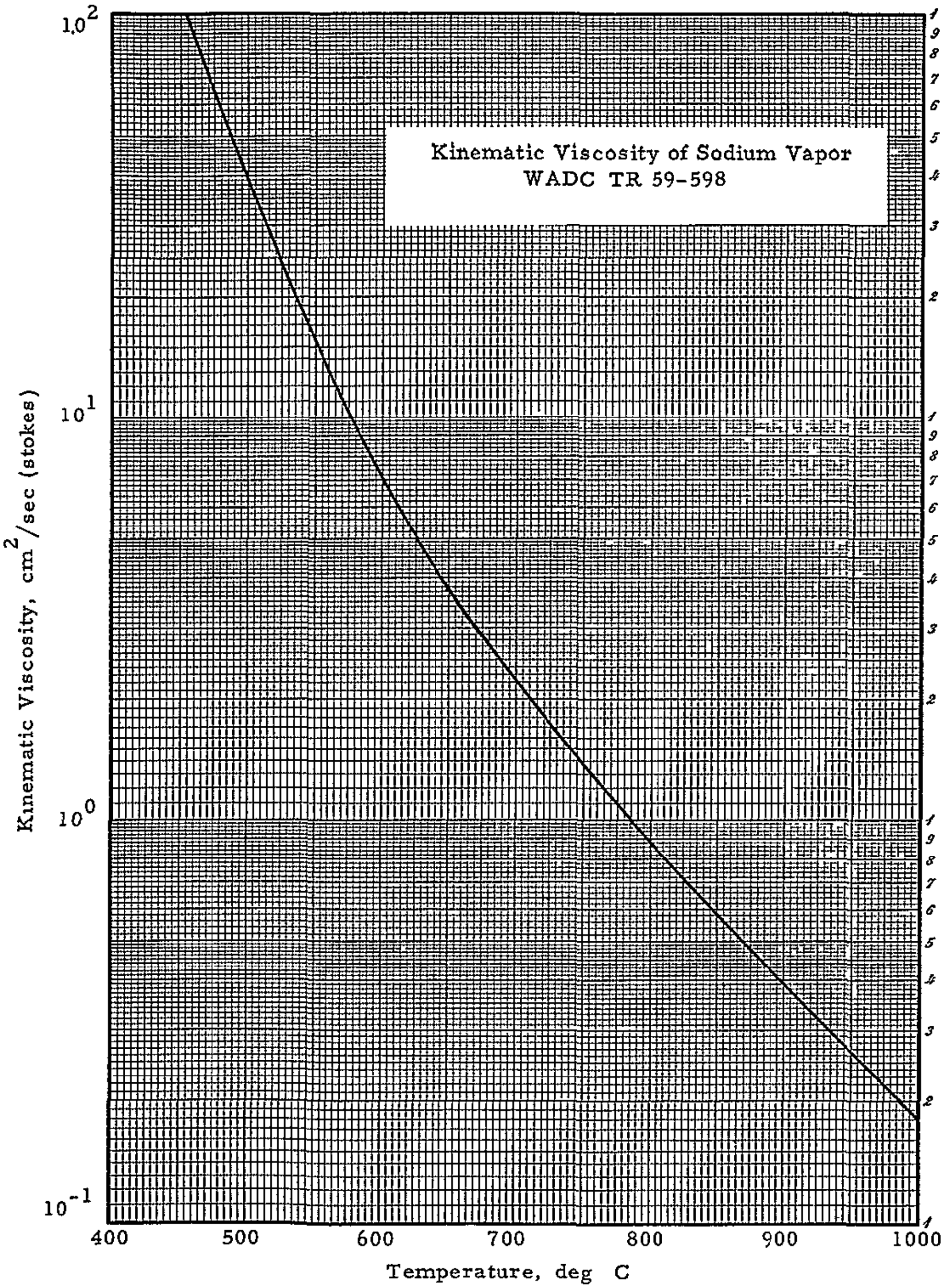

Kinematic Viscosity of Sodium Vapor
WADC TR 59-598
10^2
10^1
10^0
10^{-1}
Kinematic Viscosity, cm^2/sec (stokes)
400
500
600
700
800
900
1000
Temperature, deg C

Figure 13-2

Pressure Drop Due to Gravity:

$\Delta p_h = \rho g h$

$g = 981 \text{ cm/sec}^2$

$h = 12.2 \text{ cm}$

$\rho = \text{liquid density} = 0.776 \text{ gm/cc}$

$$\Delta p_h = 0.776 \times 981 \times 12.2 = 9300 \text{ dynes/sq cm}$$

Pressure Drop in Capillary:

$$\Delta p_f = 8 \nu_f \dot{M} L / \pi N r_c^4$$

where ν_f is the kinematic viscosity of the liquid, given in Fig. 13-3, N is the number of capillary channels, and r_c is the effective capillary radius. For 100-mesh screen, made of 0.0035 in. dia. wire, the open space between consecutive wires will be 0.0065 in., which corresponds to an effective capillary diameter of at least 0.005 in., and a capillary radius of 0.0025 in. = 0.0063 cm

$$\Delta p_f \leq 8 \times 0.0024 \times 8.3 \times 10^{-2} \times 12.2/\pi N (.0063)^4$$
$$\leq 4 \times 10^6/N \text{ dynes/sq cm}$$

Available Capillary Force:

$$\Delta p_{max} = 4\sigma/e$$

where σ is the surface tension of the liquid, given in Fig. 13-4, and e is the spacing between wires of 0.0065 in. = 0.0166 cm

$$\Delta p_{max} = 4 \times 132/0\ 0166 = 32,000 \text{ dynes/sq cm}$$

7460

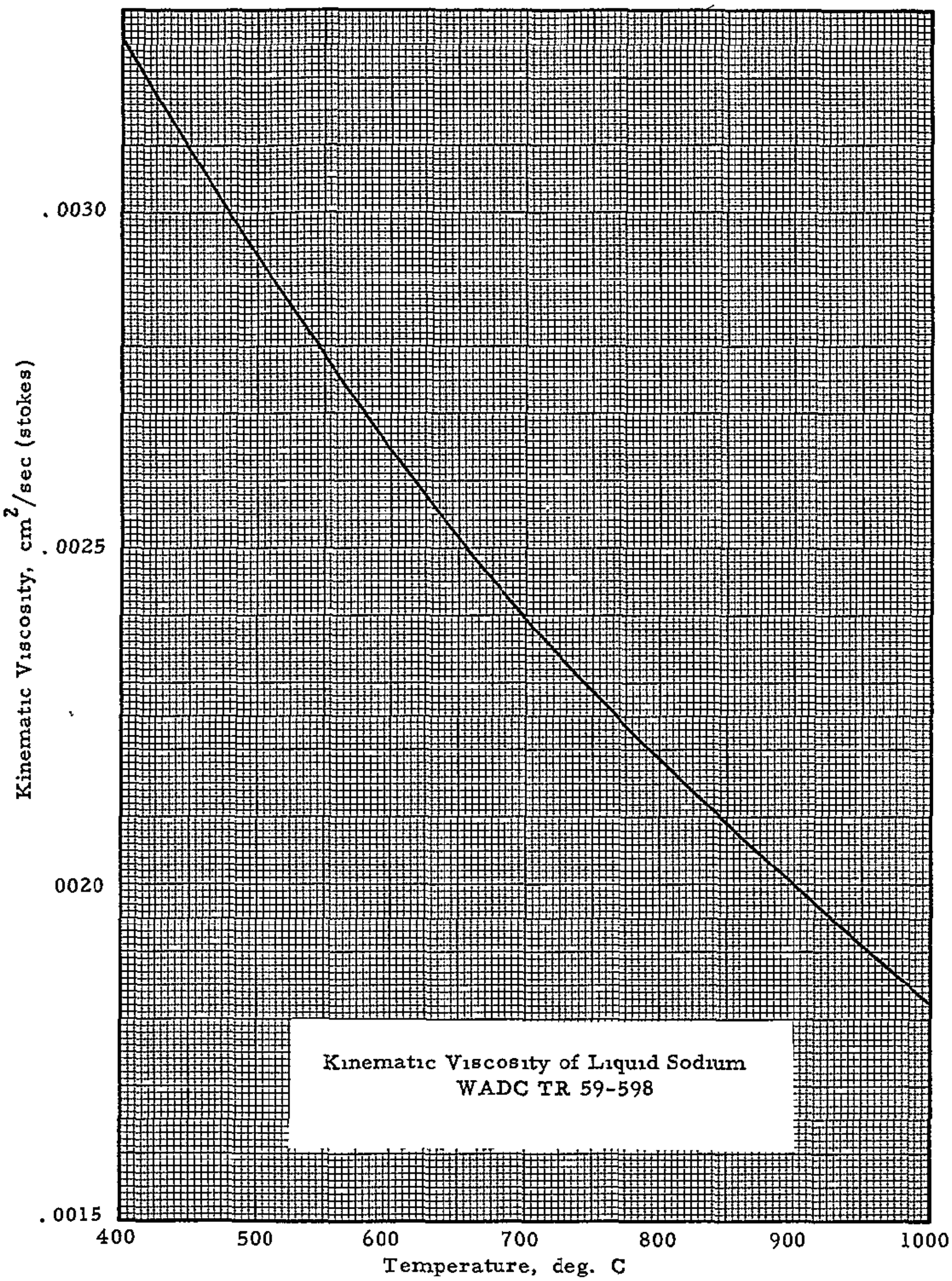
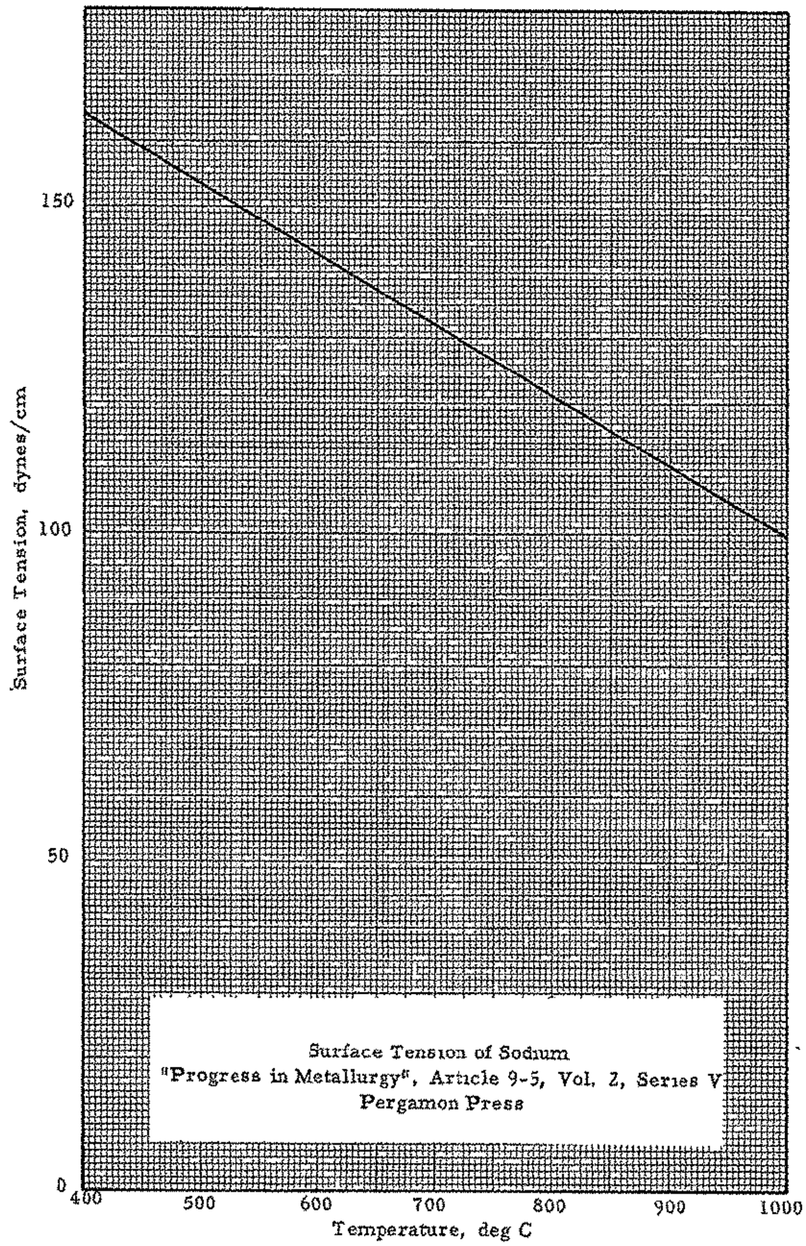


Figure 13-3



Surface Tension of Sodium
"Progress in Metallurgy", Article 9-5, Vol. 2, Series V
Pergamon Press

Figure 13-4

Capillary Mesh Equilibrium:

$$\Delta p_{max} \geq \Delta p_g + \Delta p_h + \Delta p_f$$

$$32,000 \geq 19 + 9300 + 4 \times 10^6/N$$

This equation can then be solved for the number of capillaries required:

$$N = 4 \times 10^6/(32000 - 9319)$$

$$N = 176 \text{ capillaries}$$

Therefore, the width of 100-mesh capillary screen required is

176/100 = 1.76 in   Two wraps will provide

$$N = 2 \times \pi D \times 100$$

$$D = 0.6 \text{ in.}$$

$$N = 375 \text{ capillaries}$$

and is therefore a sufficient amount of capillary structure.

APPENDIX 14

TEST DATA FOR CONVERTER T-209

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 1 of 5

Converter No T-209 Run No 1 & 2 Observer P Brosen

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date May 1968		20	20	20	20	20	20	20	20	20	20
Time		11 33	13 25	13:43	13.50	13 57	14:05	14:17	14:24	14:39	14:43
Elapsed Time, Hours		0.8	2.6	2.9	3 1	3 2	3 3	3.5	3.6	3.8	3.9
T_O, °C (1)		1548	1497	1722	1724	1724	1727	1727	1727	1619	1620
T_O Corrected, °C		1549	1498	1723	1725	1725	1728	1728	1728	1620	1621
$\Delta T_{Bell\ Jar}$, °C		19	19	17	17	17	17	17	17	19	19
T_H, °C		1568	1517	1740	1742	1742	1745	1745	1745	1639	1640
ΔT_E, °C		13	15	13	15	15	18	18	18	12	13
T_E, °K		1828	1775	2000	2000	2000	2000	2000	2000	1900	1900
V_O, volts		0.322	0.522	—	—	—	—	—	—	—	—
I_O, amps		12 3	20 2	12	~20	21	31	28	28	10	12
P_O, watts		—	—	—	—	—	—	—	—	—	—
I-V Trace No		—	—	1	2	3	4	5	6	7	8
T_R	mv	11 5	11.7	11.0	11.8	12.6	13 4	14.3	15.2	11.0	11.8
	°C	283	288	271	290	306	329	350	372	271	290
	°K	556	561	544	563	579	602	623	645	544	563
T_C	mv	20 0	20 5	21.2	21.5	23.0	24.4	24.6	24.7	20.1	20 5
	°C	485	497	513	520	555	588	593	595	487	497
	°K	758	770	786	793	828	861	866	868	760	770
T_C base inner	mv										
	°C										
T_C base outer	mv										
	°C										
$T_{Radiator}$	mv										
	°C										
V_{eb}, volts		985	985	975	975	971	967	967	967	983	981
I_{eb}, mA		160	160	221.1	227.3	256 3	294.8	307.9	308.5	177	189
$E_{Filament}$, volts		6.1	6.0	6.2	6.2	6.2	6 3	6.4	6.4	6.0	6.0
$I_{Filament}$, amps		26.2	26	26	26	26	27	27	27	26	26
$I_{Coll\ Heater}$, amps		—	—	—	—	—	—	—	—	—	—
$I_{Res\ Heater}$, amps		1 65	1 65	.65	1.65	1.66	2 01	2 27	2 64	~.65	1.79
Vacuum, 10^{-6} mm Hg		16	10	10	10	10	10	11	10	9	9
Measured Efficiency, %		157.6	157 6	215 6	221.6	248 9	285.1	297.7	298 3	174.0	185.4

NOTES 1 Pyrometer Corrections +1.0°C at all temp 1600°C to 1800°C
Bell jar +19°C at 1600, +17 at 1700, +17 at 1800
Unit tested with double spiral filament.
$\Delta T_E = 10 + 0\ 25\ I_o$

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 2 of 5

Converter No T-209 Run No 2 & 3 Observer P. Brown

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date May 1968		20	20	20	20	20	20	20	20	20	20
Time		14:55	15.07	15:16	15:21	15:35	15'41	15:48	15:53	16:00	16:04
Elapsed Time, Hours		4.1	4.3	4.5	4.6	4.8	4 9	5.0	5 1	5.2	5.3
T_O, °C		1622	1624	1624	1624	1521	1522	1524	1524	1525	1525
T_O Corrected, °C		1623	1625	1625	1625	1522	1523	1525	1525	1526	1526
$\Delta T_{Bell\ Jar}$, °C		19	19	19	19	17	17	17	17	17	17
T_H, °C		1642	1644	1644	1644	1539	1540	1542	1542	1543	1543
ΔT_E, °C		15	17	17	17	12	13	15	15	16	16
T_E, °K		1900	1900	1900	1900	1800	1800	1800	1800	1800	1800
V_O, volts		—	—	—	—	—	—	—	—	—	—
I_O, amps		$\overline{22}$	$\overline{28}$	$\overline{28}$	$\overline{27}$	$\overline{8}$	$\overline{12}$	$\overline{20}$	$\overline{22}$	$\overline{24}$	$\overline{24}$
P_O, watts		—	—	—	—	—	—	—	—	—	—
I-V Trace No		9	10	11	12	13	14	15	16	17	18
T_R	mv	12.6	13.4	14.3	15.2	11.0	11 8	12 6	13.4	14.3	15.2
	°C	306	329	350	372	271	290	306	329	350	372
	°K	579	602	623	645	544	563	579	602	623	645
T_C	mv	22.1	23.6	23 5	24.0	18.9	19.7	21.2	22.2	22 3	22.5
	°C	534	569	567	579	459	478	513	537	539	543
	°K	807	842	840	852	732	751	786	810	812	816
T_C base inner	mv										
	°C										
T_C base outer	mv										
	°C										
$T_{Radiator}$	mv										
	°C										
V_{eb}, volts		977	973	973	972	990	985	982	979	979	977
I_{eb}, mA		213.0	248.2	254 4	259.1	141 1	161.1	181 4	203.8	203 8	211 6
$E_{Filament}$, volts		6.1	6.2	6.2	6.2	5.9	6	6	6.1	6 1	6.1
$I_{Filament}$, amps		26	26	26	26	25	25	26	26	26	26
$I_{Coll\ Heater}$, amps		—	—	—	—	—	—	—	—	—	—
$I_{Res\ Heater}$, amps		1.94	2 07	2 62	3.06	1.78	1 92	2.26	2 59	2 80	3.21
Vacuum, 10^{-6} mm Hg		8	9	9	9	8	8	8	8	8	8
Measured Efficiency, %		208.1	241 5	247.5	251.8	139 7	158.7	178.1	199 5	199.5	206 7

NOTES

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 3 of 5

Converter No T-209 Run No 4 Observer P Brosens

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date May 1968		20	—	—	—	—	—	—	—	—	20
Time		16:26	—	—	—	—	—	—	—	—	16:58
Elapsed Time, Hours		5.6	—	—	—	—	—	—	—	—	6 2
T_O, °C		1719	—	—	—	—	—	—	—	—	1719
T_O Corrected, °C		1720	—	—	—	—	—	—	—	—	1720
$\Delta T_{Bell\ Jar}$, °C		17	—	—	—	—	—	—	—	—	17
T_H, °C		1737	—	—	—	—	—	—	—	—	1737
ΔT_E, °C		10	—	—	—	—	—	—	—	—	10
T_E, °K		2000	—	—	—	—	—	—	—	—	2000
V_O, volts		2 237	—	—	—	—	—	—	—	—	1.889
I_O, amps		0	0	0	0	0	0	0	0	0	0
P_O, watts		—	—	—	—	—	—	—	—	—	—
I-V Trace No		—	—	—	—	—	—	—	—	—	—
T_R	mv	10.0	11.0	12.0	12.5	13 0	14 0	14 5	15 0	16 0	17.0
	°C	246	271	295	307	319	343	355	367	391	414
	°K	519	544	568	580	592	616	628	640	664	687
T_C	mv	20.0	20.3	20.7	209	20.9	21.1	21.3	219	219	22 0
	°C	485	492	501	506	506	511	516	529	529	532
	°K	758	765	774	779	779	784	789	802	802	805
T_C base inner	mv										
	°C										
T_C base outer	mv										
	°C										
$T_{Radiator}$	mv										
	°C										
V_{eb}, volts		979	978	978	977	977	976	976	976	975	975
I_{eb}, mA		2047	2086	212 6	2152	217.1	222.4	224 8	227 3	231 3	234 2
$E_{Filament}$, volts		6.0	—	—	—	—	—	—	—	—	6 1
$I_{Filament}$, amps		26	—	—	—	—	—	—	—	—	26
$I_{Coll\ Heater}$, amps		—	—	—	—	—	—	—	—	—	—
$I_{Res\ Heater}$, amps		0	1 36	1 78	2.03	2 22	2 71	2.97	3.14	3 59	4.00
Vacuum, 10^{-6} mm Hg		8	—	—	—	—	—	—	—	—	8
Measured Efficiency, %		200.4	2040	2079	210.2	212.1	217.1	2194	2218	2255	2283

NOTES

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 4 of 5

Converter No T-209 Run No 5 & 6 Observer P. Brosnan

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date May 1968		20	20	20	20	20	23	23	23	23	23
Time		17:11	17:19	17:37	17:45	17:51	12:45	12:57	13:06	13:15	13:26
Elapsed Time, Hours		6.4	6.5	68	6.9	70	10.5	10.7	108	11.0	112
T_0, °C		1682	1682	1682	1682	1682	1580	1580	1580	1580	1580
T_0 Corrected, °C		1683	1683	1683	1683	1683	1581	1581	1581	1581	1581
$\Delta T_{Bell\ Jar}$, °C		17	17	17	17	17	19	19	19	19	19
T_H, °C		1700	1700	1700	1700	1700	1600	1600	1600	1600	1600
ΔT_E, °C		12	13	14	18	22	11	12	12	13	18
T_E, °K		1961	1960	1959	1955	1951	1862	1861	1861	1860	1855
V_0, volts		1.400	1.200	1.000	800	.600	1.400	1.200	1 000	800	.600
I_0, amps		74	11.9	16.5	32.7	49 0	3 2	6 9	9 8	12.1	34.0
P_0, watts		10.4	14.3	16 5	26 2	29 4	4.5	8.3	9.8	9.7	20.4
I-V Trace No		—	—	—	—	—	—	—	—	—	—
T_R	mv	12 4	13.1	13 5	14.2	14 1	11.3	12.1	12.7	13.2	13 9
	°C	304	321	331	348	345	278	297	312	324	341
	°K	577	594	604	621	618	551	570	585	597	614
T_C	mv	21.1	21 9	22 7	24 7	26.1	19.1	20.1	20.7	21 2	24.0
	°C	511	529	548	595	628	464	487	501	513	579
	°K	784	802	821	868	901	737	760	774	786	852
T_C base inner	mv										
	°C										
T_C base outer	mv										
	°C										
$T_{Radiator}$	mv										
	°C										
V_{eb}, volts		976	974	973	967	964	984	981	980	979	971
I_{eb}, mA		218.7	234.1	250 6	303 5	332.9	161.2	178 9	190 4	199.6	261 1
$E_{Filament}$, volts		6.1	6 1	6.2	6 3	6 4	5.9	6.0	6.0	6.0	6.2
$I_{Filament}$, amps		26	26	26	27	27	25	25.5	26	26	26 5
$I_{Coll\ Heater}$, amps		—	—	—	—	—	—	—	—	—	—
$I_{Res\ Heater}$, amps		1.98	2.19	2.36	2.42	1.72	1.64	1.89	2 19	2.28	2.17
Vacuum, 10^{-6} mm Hg		8	8	8	8	8	5	5	5	5	5
Measured Efficiency, %		213 4	228 0	243 8	293 5	320.9	158 6	175 5	186 6	195 4	253 5

NOTES

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 5 of 5

Converter No T-209 Run No 7 & 8 Observer P Brosens

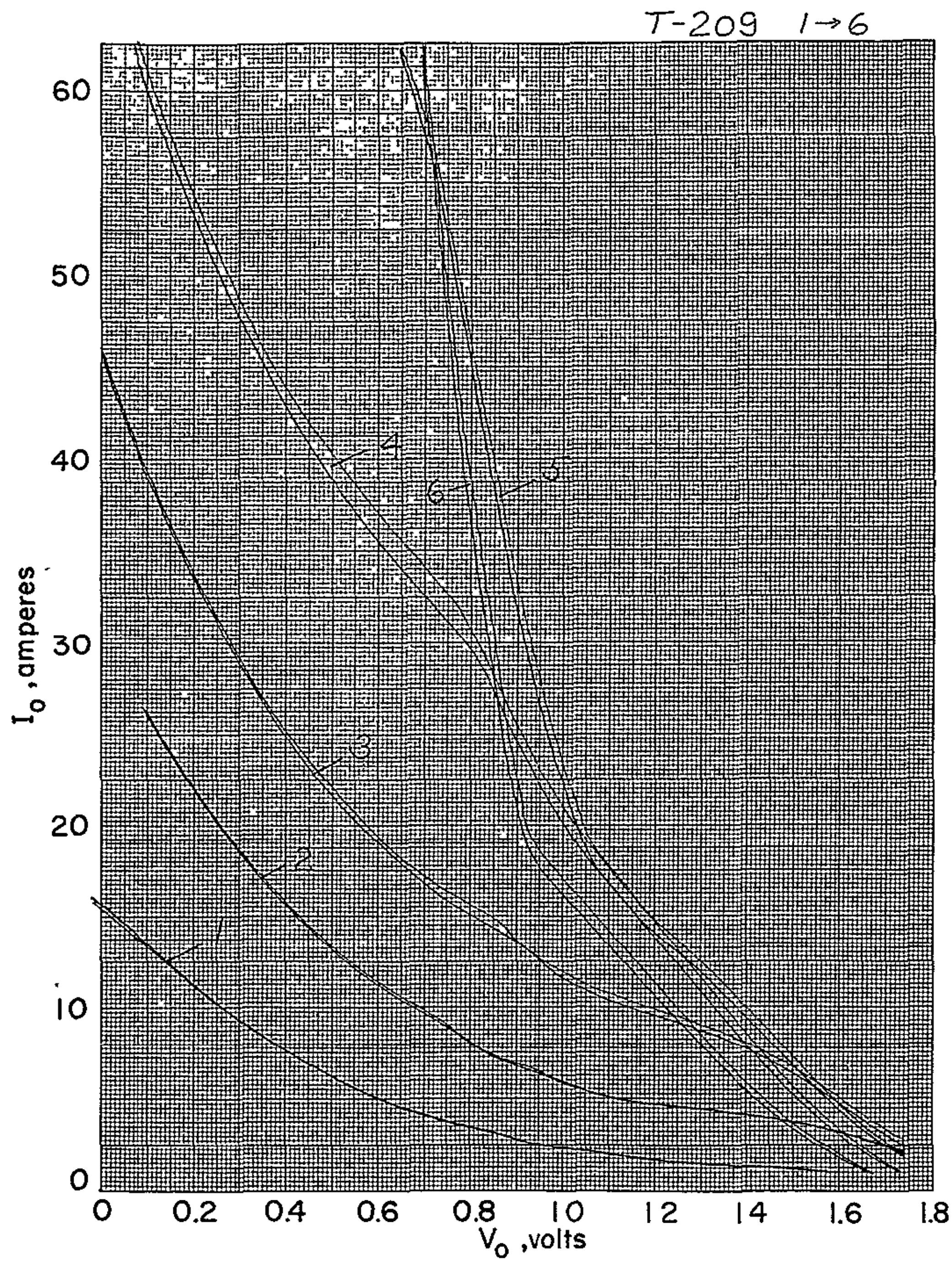
VARIABLE		1	2	3	4	5	6	7	8	9	10
Date May 1968		23	23	23	23	23		23	24	24	24
Time		13:43	13:55	14:04	14:34	14·44		16:01	8·56	9:36	9:44
Elapsed Time, Hours		11.5	11.7	11.8	12 3	12.5		13.1	29 9	30.6	30.7
T_0, °C		1782	1782	1782	1782	1782		1682	1668	1706	1727
T_0 Corrected, °C		1783	1783	1783	1783	1783		1683	1669	1707	1728
$\Delta T_{Bell\ Jar}$, °C		17	17	17	17	17		17	?	?	?
T_H, °C		1800	1800	1800	1800	1800		1700	—	—	—
ΔT_E, °C		14	15	18	20	24		18	—	—	—
T_E, °K		2059	2058	2055	2053	2049		1955	—	—	—
V_0, volts		1.400	1.200	1.000	.800	.600		.650	.600	—	—
I_0, amps		14.3	21.0	31.3	40.4	55.7		32 7	32.7	27	27
P_0, watts		20.02	25.20	31 3	32.3	33 4		21 25	19.6	—	—
I-V Trace No		—	—	—	—	—		—	—	19	20
T_R	mv	14.0	14 0	14.3	14.8	15.3		14.2	14.2	14.3	14 3
	°C	343	343	350	362	374		348	348	350	350
	°K	616	616	623	635	647		621	621	623	623
T_C	mv	23.9	24.5	25.6	26.9	28.3		25.0	25.0	24.9	25.2
	°C	576	590	616	647	680		602	602	600	607
	°K	849	863	889	920	953		875	875	873	880
T_C base inner	mv					(1)		(2)	(3)		(4)
	°C										
T_C base outer	mv										
	°C										
$T_{Radiator}$	mv										
	°C										
V_{eb}, volts		967	966	963	961	956		970	970	970	969
I_{eb}, mA		300.2	320 8	352.5	381.2	425.7		303.0	303.9	307 9	321.9
$E_{Filament}$, volts		6.2	6.2	6.3	6.4	6 4		6 3	6.1	6 2	6.2
$I_{Filament}$, amps		26	26 5	26.5	27	27		27	26	26	26
$I_{Coil\ Heater}$, amps		—	—	—	—	—		—	—	—	—
$I_{Res\ Heater}$, amps		2 21	2.12	2.04	2.12	2.08		2.41	2.27	2 34	2 36
Vacuum, 10^{-6} mmHg		5	5	6	6	6		11	4	4	4
Measured Efficiency, %		290.3	309 9	339.4	366 3	407 0		293.9	294 8	298.7	311.9

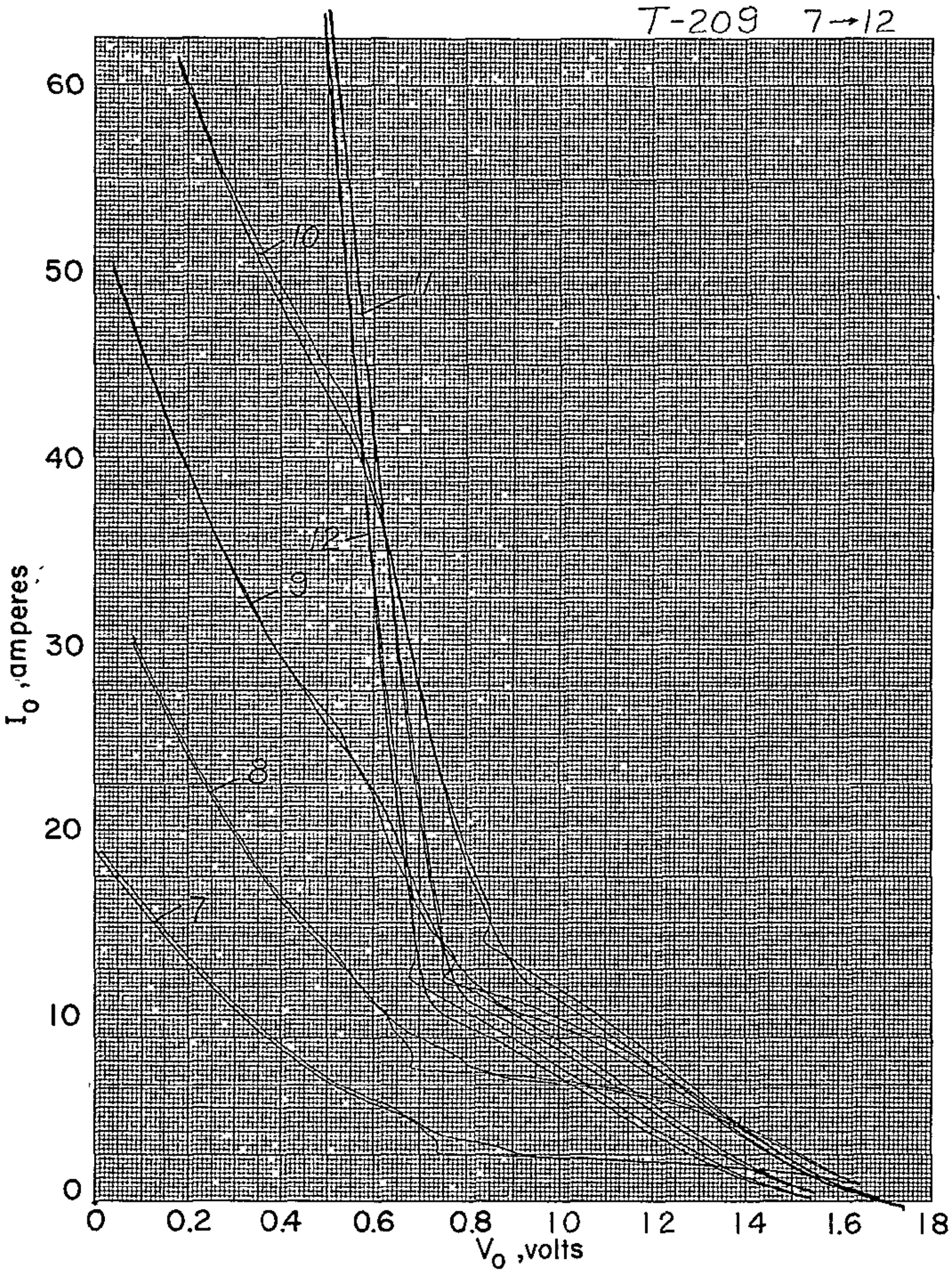
NOTES (1) OUTPUT SEEMED TO DEGRADE SLIGHTLY, COULD NOT REPRODUCE DATA PT OF PA No. 4 @ 1700 °C, 0.8 V – DECIDED TO SHUT-OFF AND EXAMINE VOLTAGE TAP CONNECTIONS – VOLTAGE TAPS WERE FOUND FIRMLY ATTACHED – PUMPED SYSTEM BACK DOWN TO RUN AT THE CONDITIONS OF DATA PT. OF PA No 4.

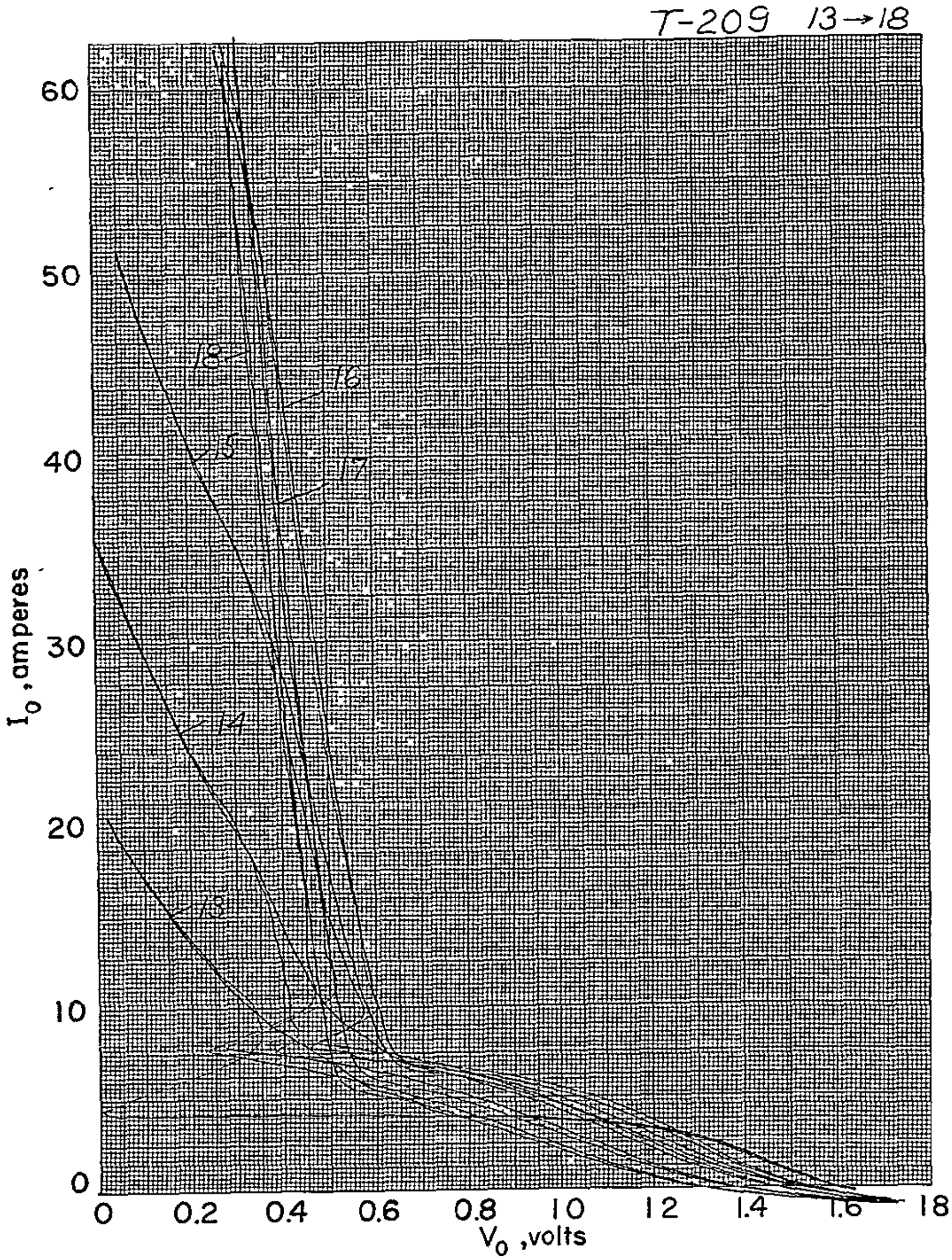
(2) LEFT TO RUN OVERNIGHT.

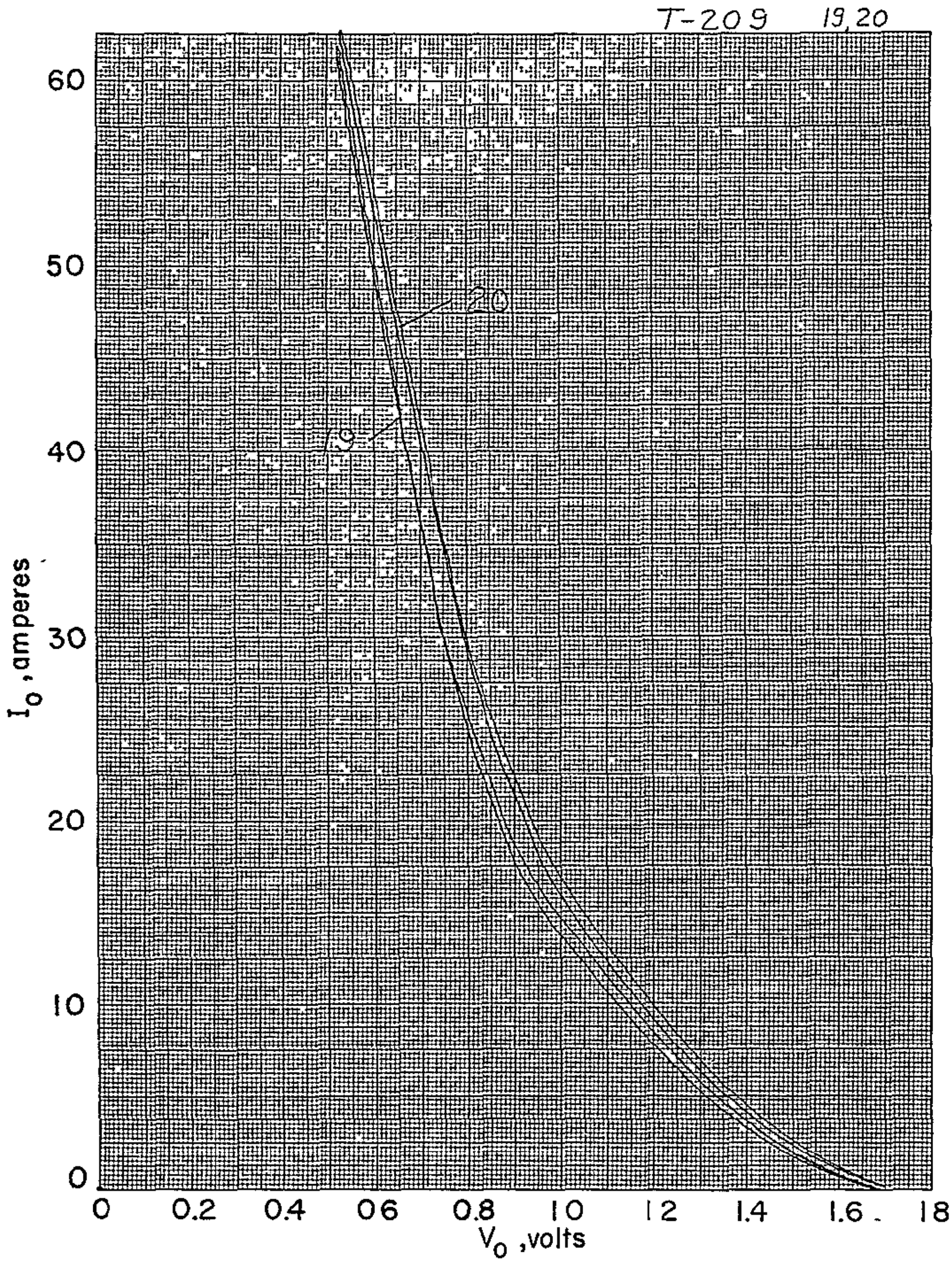
(3) PREPARED FOR CONVERTER MAPPING, REPEAT OF I-V No 5

(4) END OF TEST


T-209 1→6
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
I_o, amperes
V_o, volts
1
2
3
4
5
6


T-209 7→12
60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts
10
11
12
9
8
7


T-209 13→18
60
50
40
30
20
10
0
I_0, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
18
V_0, volts
18
16
15
17
14
13


T-209 19,20
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
I_o, amperes
V_o, volts
20
19

APPENDIX 15

TEST DATA FROM CONVERTER T-210

THERMO ELECTRON ENGINEERING CORPORATION

Sheet 1 of 5

Converter No T-210 Run No 1 & 2 Observer P. Brosens

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		7-16-68	16	16	16	16	16	16	16	16	16
Time		11.50	13:02	13:11	13:22	13:30	13:34	13:48	13 52	13:59	14.07
Elapsed Time, Hours		0.7	1.8	2.0	2.2	2.3	2.4	2.6	2.7	2 8	3.0
T_O, °C		1712	1714	1714	1714	1716	1716	1620	1620	1623	1623
T_O Corrected, °C (1)		1724	1726	1726	1726	1728	1728	1626	1626	1629	1629
$\Delta T_{Bell\ Jar}$, °C		16	16	16	16	16	16	13	13	13	13
T_H, °C		1740	1742	1742	1742	1744	1744	1639	1639	1642	1642
ΔT_E, °C		13	15	15	15	17	17	12	12	15	15
T_E, °K		2000	2000	2000	2000	2000	2000	1900	1900	1900	1900
V_O, volts		—	—	—	—	—	—	—	—	—	—
I_O, amps		$\overline{12}$	$\sim\overline{20}$	$\sim\overline{20}$	$\sim\overline{20}$	$\sim\overline{30}$	$\sim\overline{30}$	$\sim\overline{10}$	$\sim\overline{10}$	$\sim\overline{20}$	$\sim\overline{20}$
P_O, watts		—	—	—	—	—	—	—	—	—	—
I-V Trace No		1	2	3	4	5	6	7	8	9	10
T_R	mv	11.0	11.8	12.6	13.4	14.3	15.2	11 0	11 8	12.6	13.4
	°C	271	290	306	329	350	372	271	290	306	329
	°K	544	563	579	602	623	645	544	563	579	602
T_C	mv	—	21.9	23.0	24.7	24.8	25.0	19.9	20 4	22.0	23 6
	°C	—	529	555	595	597	602	483	494	532	569
	°K	—	802	828	868	870	875	556	567	805	842
T_C base inner	mv										
	°C										
T_C base outer	mv										
	°C										
$T_{Radiator}$	mv										
	°C										
V_{eb}, volts		981	977	975	971	969	968	982	981	977	973
I_{eb}, mA		206.9	226.1	246.9	285.2	304.9	311.6	176 0	186 6	215 0	249.0
$E_{Filament}$, volts		6.0	6.0	6 0	6 0	6.0	6.0	5.6	5.7	5.8	6
$I_{Filament}$, amps		25.0	25	25	26	26	26	25	25	25	25
$I_{Coll\ Heater}$, amps		—	—	—	—	—	—	—	—	—	—
$I_{Res\ Heater}$, amps		0	.90	1.50	1.58	2.03	2.54	0.69	1.49	1.72	1.54
Vacuum, 10^{-6} mm Hg		7.8	3.8	3.6	3.8	4.0	4 0	2.8	2.8	2, 8	2.9
Measured Efficiency, %											

NOTES. (1) PYROMETER CORRECTIONS: 1600 +6°C BELL JAR: +13°C
1700 +12°C +16°C
1800 +18°C +19°C

(2) $\Delta T_E = 10 + 0.25\ I$ (4TH QUARTERLY P.12)

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 2 of 5

Converter No T-210 Run No 2 & 3 Observer P. Brosseau

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		7-16-68	16	16	16	16	16	16	16		
Time		14:45	14:50	15:14	15:18	15:23	15:27	15:31	15:35		
Elapsed Time, Hours		3.6	3.7	4.1	4.2	4.3	4.3	4.4	4.5		
T_O, °C		1625	1625	1529	1530	1532	1532	1532	1532		
T_O Corrected, °C		1631	1631	1529	1530	1532	1532	1532	1532		
$\Delta T_{Bell\ Jar}$, °C		13	13	10	10	10	10	10	10		
T_H, °C		1644	1644	1539	1540	1542	1542	1542	1542		
ΔT_E, °C		17	17	12	13	15	15	15	15		
T_E, °K		1900	1900	1800	1800	1800	1800	1800	1800		
V_O, volts		—	—	—	—	—	—	—	—		
I_O, amps		28	28	8	12	20	20	20	20		
P_O, watts		—	—	—	—	—	—	—	—		
I-V Trace No		11	12	13	14	15	16	17	18		
T_R	mv	14.3	15.2	11.0	11.8	12.6	13.4	14.3	15.2		
	°C	350	372	271	290	306	329	350	372		
	°K	623	645	544	563	579	602	623	645		
T_C	mv	23.5	23.7	18.9	19.9	21.2	22.3	22.4	22.6		
	°C	567	572	459	483	513	539	541	546		
	°K	840	845	732	756	786	812	814	819		
T_C base inner	mv										
	°C										
T_C base outer	mv										
	°C										
$T_{Radiator}$	mv										
	°C										
V_{eb}, volts		975	975	990	987	983	980	979	979		
I_{eb}, mA		2540	257.7	146.4	1599	1865	2070	212.9	212.0		
$E_{Filament}$, volts		5.9	5.9	5.5	5.6	5.7	5.8	5.9	5.9		
$I_{Filament}$, amps		26	26	24	25	25	25	25	25		
$I_{Coll\ Heater}$, amps		—	—	—	—	—	—	—	—		
$I_{Res\ Heater}$, amps		2.21	2.65	1.31	1.63	1.81	1.95	2.42	2.82		
Vacuum, 10^{-6} mm Hg		2.6	2.6	2.1	2.1	2.1	2.1	2.1	2.1		
Measured Efficiency, %											

NOTES.

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 3 of 5

Converter No T-210 Run No 4 Observer P. Brosen

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		7-16-68	16	16	16	16	16	16	16	16	16
Time		15:56	—	—	—	—	—	—	—	—	16:22
Elapsed Time, Hours		4.8	—	—	—	—	—	—	—	—	5.2
T_0, °C		1709	—	—	—	—	—	—	—	—	1709
T_0 Corrected, °C		1721	—	—	—	—	—	—	—	—	1721
$\Delta T_{Bell\ Jar}$, °C		16	—	—	—	—	—	—	—	—	16
T_H, °C		1737	—	—	—	—	—	—	—	—	1737
ΔT_E, °C		10	—	—	—	—	—	—	—	—	10
T_E, °K		2000	—	—	—	—	—	—	—	—	2000
V_0, volts		—	—	—	—	—	—	—	—	—	—
I_0, amps		0	0	0	0	0	0	0	0	0	0
P_0, watts		—	—	—	—	—	—	—	—	—	—
I-V Trace No		—	—	—	—	—	—	—	—	—	—
T_R	mv	10.0	11.0	12.0	12.5	13.0	14.0	14.5	15.0	16.0	17.0
	°C	246	271	295	307	319	343	355	367	391	414
	°K	519	544	568	580	592	616	628	640	664	687
T_C	mv	19.9	20.1	20.4	20.6	20.9	21.1	21.0	21.1	21.3	21.4
	°C	483	487	494	499	506	511	508	511	516	518
	°K	756	760	767	772	779	784	781	784	789	791
T_C base inner	mv										
	°C										
T_C base outer	mv										
	°C										
$T_{Radiator}$	mv										
	°C										
V_{eb}, volts		986.5	986.2	985.7	985.4	985.1	984.9	984.4	984.1	984.0	983.6
I_{eb}, mA		199.0	201.6	204.9	206.9	208.4	212.1	213.8	215.3	218.1	219.5
$E_{Filament}$, volts		57	—	—	—	—	—	—	—	—	57
$I_{Filament}$, amps		25	—	—	—	—	—	—	—	—	25
$I_{Coll\ Heater}$, amps		—	—	—	—	—	—	—	—	—	—
$I_{Res\ Heater}$, amps		0.12	1.08	1.60	1.76	1.98	2.56	2.76	2.92	3.37	3.82
Vacuum, 10^{-6} mm Hg		2.0	—	—	—	—	—	—	—	—	3.0
~~Measured Efficiency, %~~		196.3	198.8	202.0	203.9	205.3	208.9	210.4	211.9	214.6	215.9

NOTES

THERMO ELECTRON
ENGINEERING CORPORATION

Sheet 4 of 5

Converter No T-210 Run No 5 & 6 Observer P. Brosemer

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		7-16-68	16	16	16	16	17	17	17	17	17
Time		16:38	16:45	16:53	17:01	17:10	9:10	9.19	9:27	9:37	9:52
Elapsed Time, Hours		5 5	5.6	5.7	5.9	6.1	22.0	22.1	22.3	22.4	22 7
T_0, °C		1672	1672	1672	1672	1672	1581	1581	1581	1581	1581
T_0 Corrected, °C		1684	1684	1684	1684	1684	1587	1587	1587	1587	1587
$\Delta T_{Bell\ Jar}$, °C		16	16	16	16	16	13	13	13	13	13
T_H, °C		1700	1700	1700	1700	1700	1600	1600	1600	1600	1600
ΔT_E, °C											
T_E, °K											
V_0, volts		1.400	1.200	1.000	.800	.600	1 400	1.200	1000	.800	.600
I_0, amps		6 2	9.4	15.1	37.1	59.5	2.9	4.9	6.9	13.9	42.0
P_0, watts		8.7	11.3	15.1	29.6	35.7	4.1	5.9	6.9	11.1	25.2
I-V Trace No		—	—	—	—	—	—	—	—	—	—
T_R	mv	12.8	13.1	13 5	14 5	14 5	11.8	12.2	12.6	13.1	14.2
	°C	314	321	331	355	355.	290	300	309	321	348
	°K										
T_C	mv	21 3	21.9	22.5	25.1	27.3	19.1	19.9	20.1	21.3	24 9
	°C	516	529	543	604	656	464	483	487	516	600
	°K	789	802	816	877	929	737	756	760	789	873
T_C base inner	mv										
	°C										
T_C base outer	mv										
	°C										
$T_{Radiator}$	mv										
	°C										
V_{eb}, volts		981	979	977	969	963	987	984	983	980	970
I_{eb}, mA		219.6	232.3	245.9	318.9	376.5	164.1	176.1	184.2	204 4	287.0
$E_{Filament}$, volts		5.7	5.8	5.8	6	6.2	5.6	5.6	5.6	5.7	6 0
$I_{Filament}$, amps		25	25	25	26	26	24	24	24	25	26
$I_{Coll\ Heater}$, amps		—	—	—	—	—	—	—	—	—	—
$I_{Res\ Heater}$, amps		1.86	1.90	2.12	2.29	1.76	1.77	1.83	1.85	2 04	1.97
Vacuum, 10^{-6} mm Hg		2.0	2.6	2.2	2.3	3.0	1.2	1.2	1 2	1.2	1.2
Measured Efficiency, %		215 4	227 4	240 2	309.0	362.5	162.0	173 3	181 0	200.3	278.3

NOTES

THERMO ELECTRON ENGINEERING CORPORATION

Sheet 5 of 5

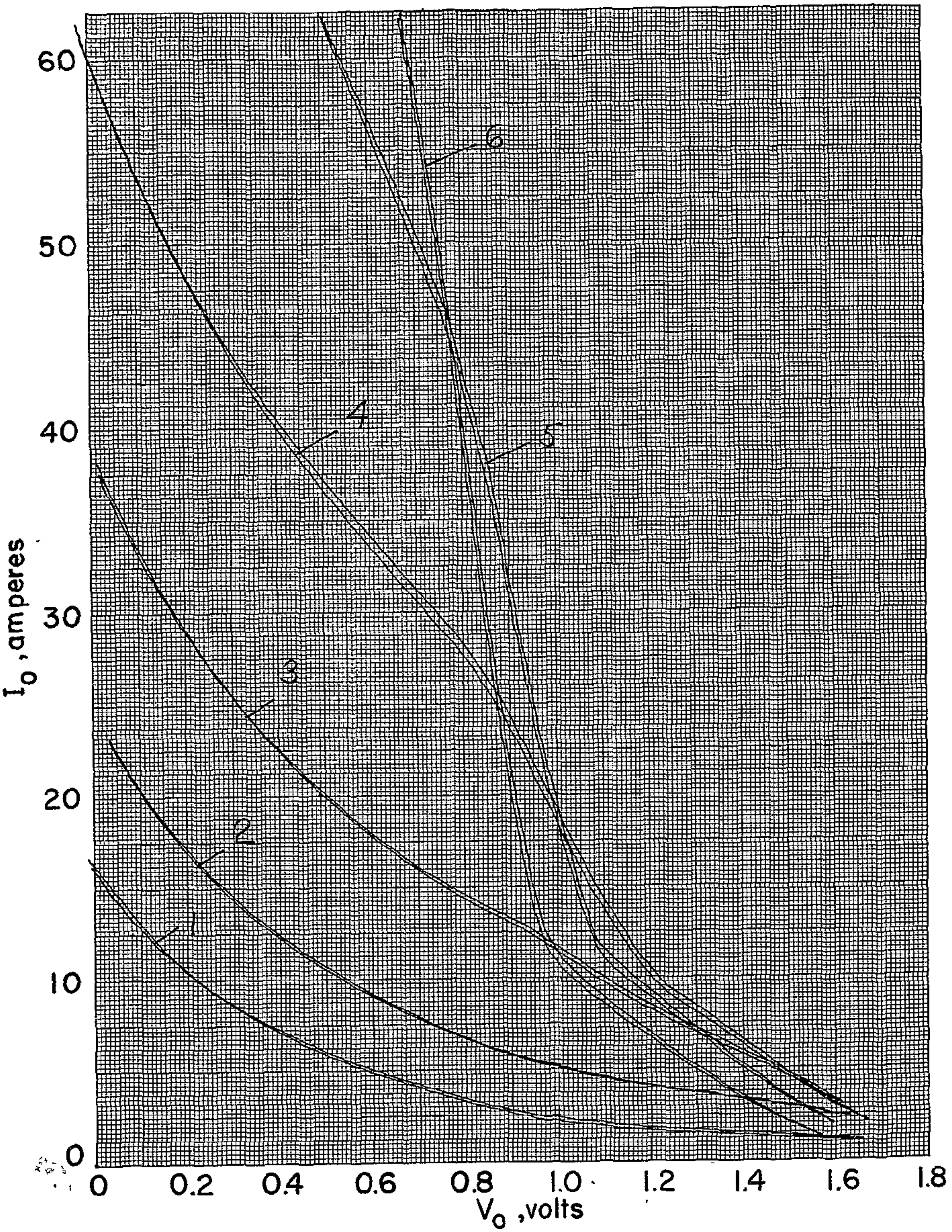
Converter No T-210 Run No 7 Observer P Brosens

VARIABLE		1	2	3	4	5	6	7	8	9	10
Date		7-17-68	17	17	17	17		17	17		
Time		10:20	10:54	11:05	13:07	(1)		13.41	13:46		
Elapsed Time, Hours		23.2	23.7	23.9	25.9			26.5	26.6		
T_O, °C		1763	1763	1763	1763	1763		1705	1710		
T_O Corrected, °C		1781	1781	1781	1781	1781		1717	1722		
$\Delta T_{Bell\ Jar}$, °C		19	19	19	19	19		16	16		
T_H, °C		1800	1800	1800	1800	1800		1733	1738		
ΔT_E, °C											
T_E, °K											
V_o, volts		1.400	1.200	1.000	.800	.600		.700	.800		
I_o, amps		9.9	15.9	29.9	56.9	—		61.1	44.5		
P_o, watts		13.9	19.1	29.9	45.5	—		42.8	35.6		
I-V Trace No		—	—	—	—	—		—	—		
T_R	mv	13.8	13.8	14.2	15.0			15.1	14.6		
	°C	338	338	348	367			369	357		
	°K							642	630		
T_C	mv	22.9	23.9	25.2	28.1			28.0	26.5		
	°C	553	576	607	675			673	637		
	°K	826	849	880	948			946	910		
T_C base inner	mv										
	°C										
T_C base outer	mv										
	°C										
$T_{Radiator}$	mv										
	°C										
V_{eb}, volts		974	970	965	956			958	963		
I_{eb}, mA		276.7	298.9	343.7	449.6			426	376		
$E_{Filament}$, volts		5.8	5.9	6.0	6.2			6.2	6.0		
$I_{Filament}$, amps		25	25	25	26			26	26		
$I_{Coll\ Heater}$, amps		—	—	—	—	—		(2)	(2)		
$I_{Res\ Heater}$, amps		1.91	1.91	2.09	1.84			1.76	1.97		
Vacuum, 10^{-6} mm Hg		1.3	1.4	1.4	1.6			1.7	1.4		
Measured Efficiency, %		269.5	289.9	331.7	429.8			408	362		

NOTES (1) THIS DATA PT NOT TAKEN BECAUSE OF EXCESSIVE POWER INPUT REQUIRED (LIMITED BY JPL TO 380 WATTS)

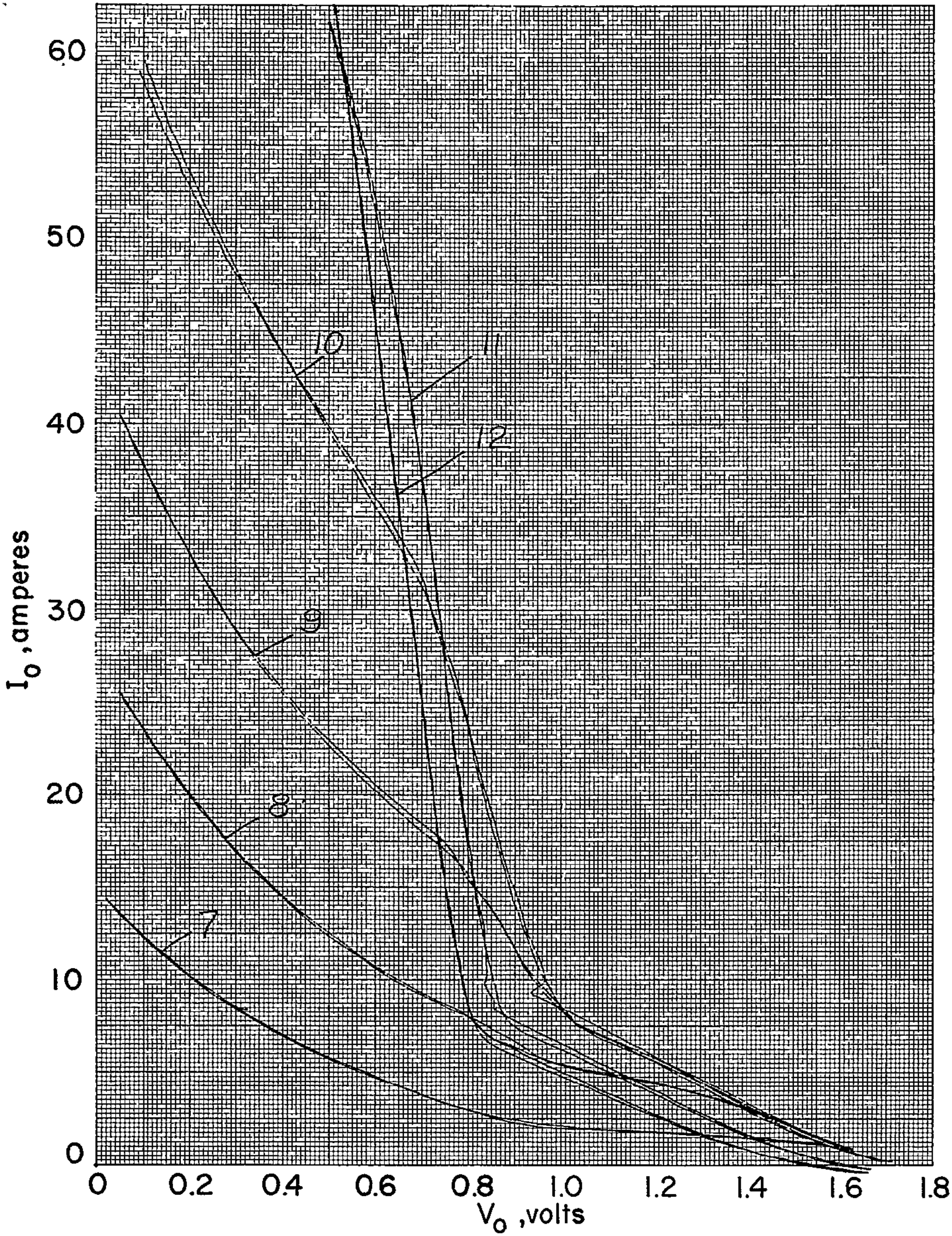
(2) SPECIAL TESTS

8779 T-210 1→6

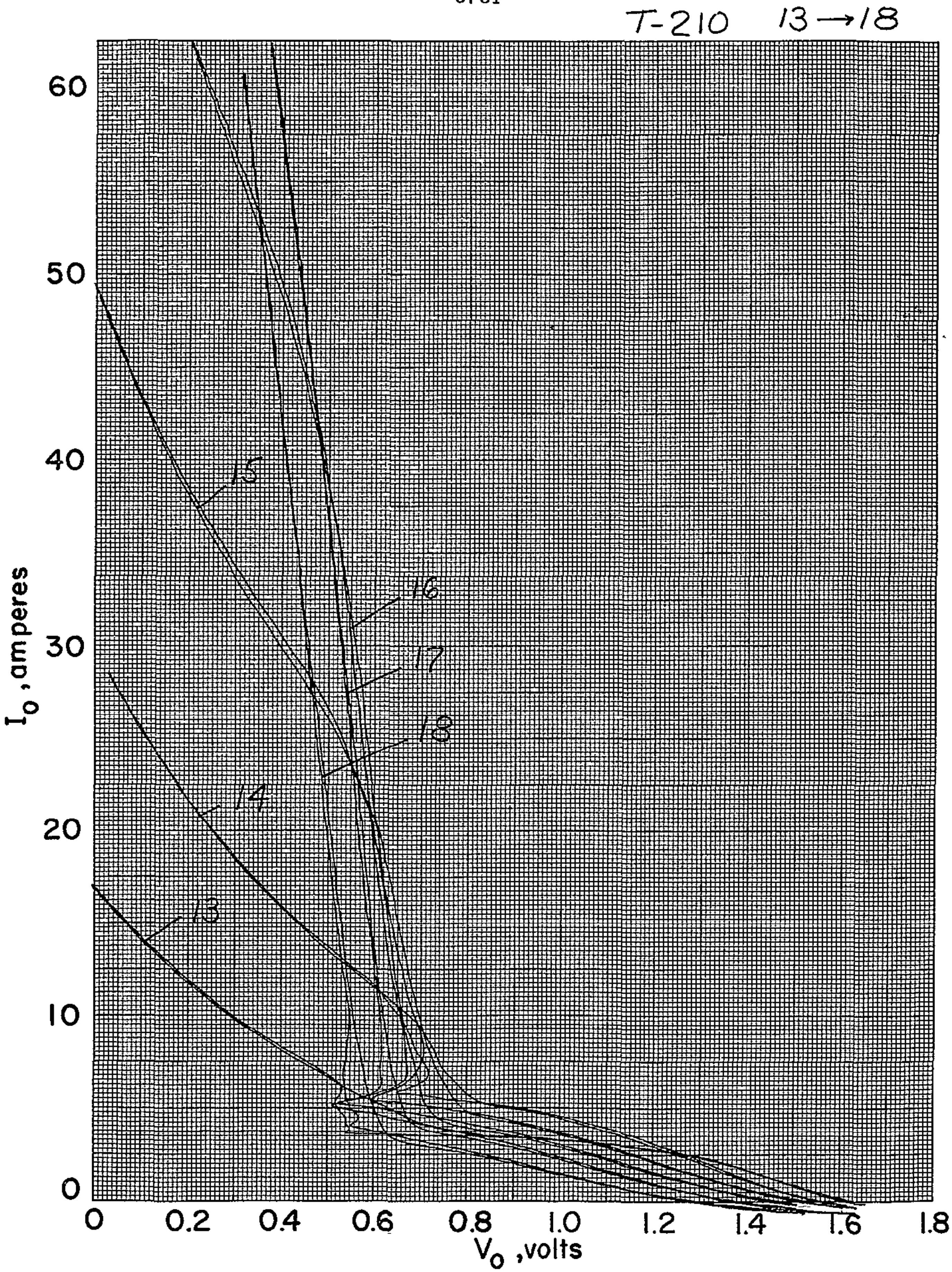

60
50
40
30
20
10
0
I_o, amperes
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts
1
2
3
4
5
6

8780

T-210 7-12



8781


T-210 13→18
60
50
40
30
20
10
0
I_o, amperes
15
16
17
18
14
13
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
V_o, volts

APPENDIX 16

PYROMETER AND BELL JAR CALIBRATION

THERMO ELECTRON
ENGINEERING CORPORATION

PYROMETER AND BELL JAR CALIBRATION RECORD

Sheet 1 of 2

Instrument No M 5217

Date January 18, 1966

NBS Lamp No 186792

Temp. Level, °C 1500

(meter upright)

(T-201)

		OBSERVER 1 Name R Slosek	OBSERVER 2 Name P Brosens
	Lamp Current, Amps.	8 87	8 87
	Lamp Brightness Temp., °C	1500 ±4	1500 ±4
PYROMETER CALIBRATION	Bright to Dark Reading, °C	1492	1498
	Dark to Bright Reading, °C	1490	1490
	Dark to Bright Reading, °C	1492	1490
	Bright to Dark Reading, °C	1490	1492
	Average Reading, °C	1491.0	1492.5
	Correction to be Applied to Pyrometer, °C	+9.0	+7.5
BELL JAR CALIBRATION	Bright to Dark Reading, °C		
	Dark to Bright Reading, °C		
	Dark to Bright Reading, °C		
	Bright to Dark Reading, °C		
	Average Reading, °C		
	Bell Jar Correction, °C		

Average of Pyrometer Corrections, Observers 1 & 2, °C + 8.3

Average of Bell Jar Corrections, Observers 1 & 2, °C ________

THERMO ELECTRON
ENGINEERING CORPORATION

PYROMETER AND BELL JAR CALIBRATION RECORD

Sheet 2 of 2

Instrument No. M5217
Date January 18, 1966
NBS Lamp No. 186792
Temp. Level, °C 1700

(T-201)

		OBSERVER 1 Name R Slosek	OBSERVER 2 Name P Brosens
	Lamp Current, Amps.	10.58	10.58
	Lamp Brightness Temp., °C	1700	1700
PYROMETER CALIBRATION	Bright to Dark Reading, °C	1692	1692
	Dark to Bright Reading, °C	1689	1688
	Dark to Bright Reading, °C	1690	1688
	Bright to Dark Reading, °C	1690	1689
	Average Reading, °C	1690.3	1689.2
	Correction to be Applied to Pyrometer, °C	+ 9.7	+ 10.8
BELL JAR CALIBRATION	Bright to Dark Reading, °C		
	Dark to Bright Reading, °C		
	Dark to Bright Reading, °C		
	Bright to Dark Reading, °C		
	Average Reading, °C		
	Bell Jar Correction, °C		

Average of Pyrometer Corrections, Observers 1 & 2, °C + 10.2

Average of Bell Jar Corrections, Observers 1 & 2, °C ______

THERMO ELECTRON
ENGINEERING CORPORATION

PYROMETER AND BELL JAR CALIBRATION RECORD

Sheet 1 of 2

Instrument No. M5217

Date January 19, 1966

NBS Lamp No 186792

Temp.Level,°C 1600

(T-201)

		OBSERVER 1 Name R Slosek	OBSERVER 2 Name P Brosen
	Lamp Current, Amps.	9.69	9.69
	Lamp Brightness Temp.,°C	1600	1600
PYROMETER CALIBRATION	Bright to Dark Reading,°C	1590	1592
	Dark to Bright Reading,°C	1590	1590
	Dark to Bright Reading,°C	1590	1590
	Bright to Dark Reading,°C	1590	1593
	Average Reading,°C	1590	159125
	Correction to be Applied to Pyrometer, °C	+100	+875
BELL JAR CALIBRATION	Bright to Dark Reading,°C	1578	1579
	Dark to Bright Reading,°C	1579	1576
	Dark to Bright Reading,°C	1578	1578
	Bright to Dark Reading,°C	1579	1578
	Average Reading,°C	1578.50	157775
	Bell Jar Correction,°C	11.50	13.50

Average of Pyrometer Corrections, Observers 1 & 2,°C + 9.37

Average of Bell Jar Corrections, Observers 1 & 2,°C + 12.50

THERMO ELECTRON
ENGINEERING CORPORATION

PYROMETER AND BELL JAR CALIBRATION RECORD

Sheet 2 of 2

Instrument No M 5217

Date January 19, 1966

NBS Lamp No 186792

Temp. Level, °C 1700

(T-201)

		OBSERVER 1 Name R Seosek	OBSERVER 2 Name P Brosens
	Lamp Current, Amps.	10 58	10.58
	Lamp Brightness Temp., °C	1700	1700
PYROMETER CALIBRATION	Bright to Dark Reading, °C		
	Dark to Bright Reading, °C		
	Dark to Bright Reading, °C		
	Bright to Dark Reading, °C		
	Average Reading, °C	1690.3*	1689 2*
	Correction to be Applied to Pyrometer, °C		
BELL JAR CALIBRATION	Bright to Dark Reading, °C	1677	1678
	Dark to Bright Reading, °C	1675	1675
	Dark to Bright Reading, °C	1675	1676
	Bright to Dark Reading, °C	1675	1676
	Average Reading, °C	1675.50	1676.25
	Bell Jar Correction, °C	14.8	13 0

* January 18 data

Average of Pyrometer Corrections, Observers 1 & 2, °C ——

Average of Bell Jar Corrections, Observers 1 & 2, °C +13 9

THERMO ELECTRON
ENGINEERING CORPORATION

PYROMETER AND BELL JAR CALIBRATION RECORD

Sheet 1 of 2

Instrument No M5217

Date 2-8-66

NBS Lamp No. 186792

Temp.Level,°C 1600

(T-201 #2)

		OBSERVER 1 Name R Slosek	OBSERVER 2 Name P Brosgar
	Lamp Current, Amps.	9.69	9.69
	Lamp Brightness Temp.,°C	1600	1600
PYROMETER CALIBRATION	Bright to Dark Reading,°C		
	Dark to Bright Reading,°C		
	Dark to Bright Reading,°C		
	Bright to Dark Reading,°C		
	Average Reading,°C Test of 1-19-66	1590.6	1590.6
	Correction to be Applied to Pyrometer, °C Test of 1-19-66	+ 9.4	+9.4
BELL JAR CALIBRATION	Bright to Dark Reading,°C	1579	1578
	Dark to Bright Reading,°C	1578	1576
	Dark to Bright Reading,°C	1578	1573
	Bright to Dark Reading,°C	1578	1578
	Average Reading,°C	1578.25	1576.25
	Bell Jar Correction,°C	+ 12.35	+ 14.35

Average of Pyrometer Corrections, Observers 1 & 2,°C ________

Average of Bell Jar Corrections, Observers 1 & 2,°C + 13.35

THERMO ELECTRON
ENGINEERING CORPORATION

PYROMETER AND BELL JAR CALIBRATION RECORD

Sheet 2 of 2

Instrument No. M5217

Date 2-8-66

NBS Lamp No. 186792

Temp.Level, °C 1700

(T-201) #2

		OBSERVER 1	OBSERVER 2
		Name R. Slosek	Name R. Brosen
	Lamp Current, Amps.	10.58	10.58
	Lamp Brightness Temp., °C	1700	1700
PYROMETER CALIBRATION	Bright to Dark Reading, °C		
	Dark to Bright Reading, °C		
	Dark to Bright Reading, °C		
	Bright to Dark Reading, °C		
	Average Reading, °C Test of 1-18-66	1689.8	1689.8
	Correction to be Applied to Pyrometer, °C Test of 1-18-66	+10.2	+10.2
BELL JAR CALIBRATION	Bright to Dark Reading, °C	1679	1679
	Dark to Bright Reading, °C	1678	1670
	Dark to Bright Reading, °C	1676	1670
	Bright to Dark Reading, °C	1677	1676
	Average Reading, °C	1677.5	1673.75
	Bell Jar Correction, °C	+12.3	+16.05

Average of Pyrometer Corrections, Observers 1 & 2, °C ________

Average of Bell Jar Corrections, Observers 1 & 2, °C +14.17

THERMO ELECTRON
ENGINEERING CORPORATION

PYROMETER AND BELL JAR CALIBRATION RECORD

Sheet 1 of 2

Instrument No. M5217

Date 3-9-66

NBS Lamp No. 186792

Temp. Level, °C 1600

(T-202)

		OBSERVER 1 Name B. Gunther	OBSERVER 2 Name R B Slonck
	Lamp Current, Amps	9.69	9.69
	Lamp Brightness Temp., °C	1600	1600
PYROMETER CALIBRATION	Bright to Dark Reading, °C		
	Dark to Bright Reading, °C		
	Dark to Bright Reading, °C		
	Bright to Dark Reading, °C		
	Average Reading, °C		
	Correction to be Applied to Pyrometer, °C	9.37	9.37
BELL JAR CALIBRATION	Bright to Dark Reading, °C	1577	1570
	Dark to Bright Reading, °C	1577	1570
	Dark to Bright Reading, °C	1574	1575
	Bright to Dark Reading, °C	1575	1570
	Average Reading, °C	1575.8	1571.25
	Bell Jar Correction, °C	14.83	19.38

Average of Pyrometer Corrections, Observers 1 & 2, °C 9.37

Average of Bell Jar Corrections, Observers 1 & 2, °C 17.10

THERMO ELECTRON
ENGINEERING CORPORATION

PYROMETER AND BELL JAR CALIBRATION RECORD

Sheet 2 of 2

Instrument No. M5217

Date March 9, 1966

NBS Lamp No. 186792

Temp. Level, °C 1700

(T-202)

		OBSERVER 1 Name B Gunther	OBSERVER 2 Name R. B. Slosek
	Lamp Current, Amps.	10.58	10.58
	Lamp Brightness Temp., °C	1700	1700
PYROMETER CALIBRATION	Bright to Dark Reading, °C		
	Dark to Bright Reading, °C		
	Dark to Bright Reading, °C		
	Bright to Dark Reading, °C		
	Average Reading, °C	From previous	calibrations
	Correction to be Applied to Pyrometer, °C	10.2	10.2
BELL JAR CALIBRATION	Bright to Dark Reading, °C	1672	1672
	Dark to Bright Reading, °C	1672	1672
	Dark to Bright Reading, °C	1672	1672
	Bright to Dark Reading, °C	1672	1672
	Average Reading, °C	1672	1672
	Bell Jar Correction, °C	17.8	17.8

Average of Pyrometer Corrections, Observers 1 & 2, °C 10.2

Average of Bell Jar Corrections, Observers 1 & 2, °C ~~(1672)~~ 17.8

THERMO ELECTRON
ENGINEERING CORPORATION

PYROMETER AND BELL JAR CALIBRATION RECORD

Sheet 1 of 2

Instrument No. M 5217

Date 3-21-66

NBS Lamp No. 186792

Temp. Level, °C 1700

(T-202) #2

		OBSERVER 1 Name B. Gunther	OBSERVER 2 Name R B Slosek
	Lamp Current, Amps.	10.58	10.58
	Lamp Brightness Temp., °C	1700	1700
PYROMETER CALIBRATION	Bright to Dark Reading, °C		
	Dark to Bright Reading, °C		
	Dark to Bright Reading, °C		
	Bright to Dark Reading, °C		
	Average Reading, °C		
	Correction to be Applied to Pyrometer, °C	10.2	10.2
BELL JAR CALIBRATION	Bright to Dark Reading, °C	1678	1680
	Dark to Bright Reading, °C	1676	1671
	Dark to Bright Reading, °C	1675	1676
	Bright to Dark Reading, °C	1679	1676
	Average Reading, °C	1677	1675.75
	Bell Jar Correction, °C	12.8	14.05

Average of Pyrometer Corrections, Observers 1 & 2, °C 10.2

Average of Bell Jar Corrections, Observers 1 & 2, °C 13.43

THERMO ELECTRON
ENGINEERING CORPORATION

PYROMETER AND BELL JAR CALIBRATION RECORD

Sheet 2 of 2

Instrument No. M5217

Date 3-21-66

NBS Lamp No. 186792

Temp. Level, °C 1600

(T-202) #2

		OBSERVER 1 Name B. Gunther	OBSERVER 2 Name R B Slosek
	Lamp Current, Amps.	9.69	9.69
	Lamp Brightness Temp., °C	1600	1600
PYROMETER CALIBRATION	Bright to Dark Reading, °C		
	Dark to Bright Reading, °C		
	Dark to Bright Reading, °C		
	Bright to Dark Reading, °C		
	Average Reading, °C		
	Correction to be Applied to Pyrometer, °C	9.37	9.37
BELL JAR CALIBRATION	Bright to Dark Reading, °C	1581	1580
	Dark to Bright Reading, °C	1579	1579
	Dark to Bright Reading, °C	1578	1579
	Bright to Dark Reading, °C	1579	1580
	Average Reading, °C	1579.25	1579.50
	Bell Jar Correction, °C	11.38	11.13

Average of Pyrometer Corrections, Observers 1 & 2, °C 9.37

Average of Bell Jar Corrections, Observers 1 & 2, °C 11.25

THERMO ELECTRON
ENGINEERING CORPORATION

PYROMETER AND BELL JAR CALIBRATION RECORD

Sheet 1 of 2

Instrument No. M5217

Date 5/23/66

NBS Lamp No 186792

Temp. Level, °C 1600°

(T-203 B)

		OBSERVER 1 Name B Gunther	OBSERVER 2 Name RB Slack
	Lamp Current, Amps.	9.69	9.69
	Lamp Brightness Temp., °C	1600°c	1600°c
PYROMETER CALIBRATION	Bright to Dark Reading, °C	1591	1594
	Dark to Bright Reading, °C	1592	1592
	Dark to Bright Reading, °C	1591	1592
	Bright to Dark Reading, °C	1590	1590
	Average Reading, °C	1591.00	1592.00
	Correction to be Applied to Pyrometer, °C	9.00	8.00
BELL JAR CALIBRATION	Bright to Dark Reading, °C	1572	1571
	Dark to Bright Reading, °C	1572	1570
	Dark to Bright Reading, °C	1573	1575
	Bright to Dark Reading, °C	1574	1575
	Average Reading, °C	1572.75	1572.75
	Bell Jar Correction, °C	18.25	19.25

Average of Pyrometer Corrections, Observers 1 & 2, °C 8.50°C

Average of Bell Jar Corrections, Observers 1 & 2, °C (18.75) — This figure questionable. Value of 12°C was adopted for correction (conservative).

THERMO ELECTRON
ENGINEERING CORPORATION

PYROMETER AND BELL JAR CALIBRATION RECORD

Sheet 2 of 2

Instrument No. M 5217

Date 5-23-66

NBS Lamp No. 186792

Temp. Level, °C 1700°C

(T-203 B)

		OBSERVER 1 Name B. Gunther	OBSERVER 2 Name R. B. Slocek
	Lamp Current, Amps.	10.58	10.58
	Lamp Brightness Temp., °C	1700°C	1700°C
PYROMETER CALIBRATION	Bright to Dark Reading, °C	1691	1690
	Dark to Bright Reading, °C	1690	1690
	Dark to Bright Reading, °C	1691	1690
	Bright to Dark Reading, °C	1690	1690
	Average Reading, °C	1690.50	1690.00
	Correction to be Applied to Pyrometer, °C	9.50	10.00
BELL JAR CALIBRATION	Bright to Dark Reading, °C	1673	1679
	Dark to Bright Reading, °C	1673	1679
	Dark to Bright Reading, °C	1673	1677
	Bright to Dark Reading, °C	1678	1678
	Average Reading, °C	1674.25	1678.25
	Bell Jar Correction, °C	16.25	11.75

Average of Pyrometer Corrections, Observers 1 & 2, °C 9.75

Average of Bell Jar Corrections, Observers 1 & 2, °C 14.00

THERMO ELECTRON
ENGINEERING CORPORATION

PYROMETER AND BELL JAR CALIBRATION RECORD

Sheet 1 of 2

Instrument No. M5217

Date 7/1/66

NBS Lamp No. 186792

Temp. Level, °C 1600

(T-203 B) #2

		OBSERVER 1 Name F. Marino	OBSERVER 2 Name R. Slosek
	Lamp Current, Amps.	9.69	9.69
	Lamp Brightness Temp., °C	1600 °C	1600 °C
PYROMETER CALIBRATION	Bright to Dark Reading, °C		
	Dark to Bright Reading, °C		
	Dark to Bright Reading, °C		
	Bright to Dark Reading, °C		
	Average Reading, °C	1591.0	1592.0
	Correction to be Applied to Pyrometer, °C	9.0	8.0
BELL JAR CALIBRATION	Bright to Dark Reading, °C	1570	1570
	Dark to Bright Reading, °C	1570	1571
	Dark to Bright Reading, °C	1570	1573
	Bright to Dark Reading, °C	1574	1573
	Average Reading, °C	1571	1571.7
	Bell Jar Correction, °C	20	20.3

Average of Pyrometer Corrections, Observers 1 & 2, °C 8.5

Average of Bell Jar Corrections, Observers 1 & 2, °C 20.15

THERMO ELECTRON
ENGINEERING CORPORATION

PYROMETER AND BELL JAR CALIBRATION RECORD

Sheet 2 of 2

Instrument No M5217

Date 2/1/66

NBS Lamp No. 186792

Temp.Level, °C 1700

(T-203 B) #2

		OBSERVER 1 Name F Marino	OBSERVER 2 Name R Slosek
	Lamp Current, Amps.	10.58	10.58
	Lamp Brightness Temp., °C	1700°	1700°
PYROMETER CALIBRATION	Bright to Dark Reading, °C		
	Dark to Bright Reading, °C		
	Dark to Bright Reading, °C		
	Bright to Dark Reading, °C		
	Average Reading, °C	1690.5	1690.0
	Correction to be Applied to Pyrometer, °C	9.50	10.0
BELL JAR CALIBRATION	Bright to Dark Reading, °C	1678	1678
	Dark to Bright Reading, °C	1678	1679
	Dark to Bright Reading, °C	1679	1679
	Bright to Dark Reading, °C	1679	1678
	Average Reading, °C	1678.5	1678.5
	Bell Jar Correction, °C	12.0	11.5

Average of Pyrometer Corrections, Observers 1 & 2, °C 9.75

Average of Bell Jar Corrections, Observers 1 & 2, °C 11.75

THERMO ELECTRON
ENGINEERING CORPORATION

PYROMETER AND BELL JAR CALIBRATION RECORD

Sheet 1 of 2

Instrument No M5217

Date 1-23-67

NBS Lamp No 186792

Temp. Level, °C 1600

(T-205) after test

		OBSERVER 1 Name R. Sloscik	OBSERVER 2 Name P. Brosseau
	Lamp Current, Amps	9.69	9.69
	Lamp Brightness Temp., °C	1600	1600
PYROMETER CALIBRATION	Bright to Dark Reading, °C	1590	1597
	Dark to Bright Reading, °C	1593	1584
	Dark to Bright Reading, °C	1591	1590
	Bright to Dark Reading, °C	1590	1589
	Average Reading, °C	1591.0	1590.0
	Correction to be Applied to Pyrometer, °C	+9.0	+10.0
BELL JAR CALIBRATION	Bright to Dark Reading, °C	1575	1575
	Dark to Bright Reading, °C	1578	1571
	Dark to Bright Reading, °C	1579	1572
	Bright to Dark Reading, °C	1573	1572
	Average Reading, °C	1576.2	1572.5
	Bell Jar Correction, °C	+14.8	+17.5

Average of Pyrometer Corrections, Observers 1 & 2, °C +9.5

Average of Bell Jar Corrections, Observers 1 & 2, °C +16.1

THERMO ELECTRON
ENGINEERING CORPORATION

PYROMETER AND BELL JAR CALIBRATION RECORD

Sheet 2 of 2

Instrument No. M5217

Date 1-23-67

NBS Lamp No. 186792

Temp.Level, °C 1700

(T-205) after test

		OBSERVER 1 Name R Seosck	OBSERVER 2 Name P. Brosens
	Lamp Current, Amps	10.58	10 58
	Lamp Brightness Temp., °C	1700	1700
PYROMETER CALIBRATION	Bright to Dark Reading, °C	1689	1690
	Dark to Bright Reading, °C	1689	1686
	Dark to Bright Reading, °C	1689	1688
	Bright to Dark Reading, °C	1688	1686
	Average Reading, °C	1688 75	1687.50
	Correction to be Applied to Pyrometer, °C	+11 25	+12 50
BELL JAR CALIBRATION	Bright to Dark Reading, °C	1674	1671
	Dark to Bright Reading, °C	1670	1670
	Dark to Bright Reading, °C	1671	1671
	Bright to Dark Reading, °C	1671	1670
	Average Reading, °C	1671 50	1670.50
	Bell Jar Correction, °C	+17.25	+17 00

Average of Pyrometer Corrections, Observers 1 & 2, °C + 11.9

Average of Bell Jar Corrections, Observers 1 & 2, °C + 17.1

THERMO ELECTRON
ENGINEERING CORPORATION

PYROMETER AND BELL JAR CALIBRATION RECORD

(Prior to 207)

Sheet 1 of 2

Instrument No M5217

Date 5-17-1967

NBS Lamp No. 186792

Temp. Level, °C 1600

		OBSERVER 1 Name P Brosn	OBSERVER 2 Name R. Slosek
	Lamp Current, Amps.	969	969
	Lamp Brightness Temp., °C	1600	1600
PYROMETER CALIBRATION	Bright to Dark Reading, °C	1594	1597
	Dark to Bright Reading, °C	1593	1594
	Dark to Bright Reading, °C	1593	1597
	Bright to Dark Reading, °C	1595	1593
	Average Reading, °C	1593 75	1595 75
	Correction to be Applied to Pyrometer, °C	+6.25	+4.25
BELL JAR CALIBRATION	Bright to Dark Reading, °C		
	Dark to Bright Reading, °C		
	Dark to Bright Reading, °C		
	Bright to Dark Reading, °C		
	Average Reading, °C		
	Bell Jar Correction, °C		

Average of Pyrometer Corrections, Observers 1 & 2, °C + 5.25

Average of Bell Jar Corrections, Observers 1 & 2, °C ______

THERMO ELECTRON
ENGINEERING CORPORATION

PYROMETER AND BELL JAR CALIBRATION RECORD

Sheet 2 of 2

Instrument No M5217

Date 5-17-1967

NBS Lamp No. 186792

Temp.Level,°C 1700

		OBSERVER 1 Name P Brosens	OBSERVER 2 Name R Sloan
	Lamp Current, Amps.	10 58	10.58
	Lamp Brightness Temp.,°C	1700	1700
PYROMETER CALIBRATION	Bright to Dark Reading,°C	1695	1693
	Dark to Bright Reading,°C	1692	1695
	Dark to Bright Reading,°C	1694	1693
	Bright to Dark Reading,°C	1695	1692
	Average Reading,°C	1693.00	1693 25
	Correction to be Applied to Pyrometer, °C	+ 7.00	+ 6.75
BELL JAR CALIBRATION	Bright to Dark Reading,°C		
	Dark to Bright Reading,°C		
	Dark to Bright Reading,°C		
	Bright to Dark Reading,°C		
	Average Reading,°C		
	Bell Jar Correction,°C		

Average of Pyrometer Corrections, Observers 1 & 2,°C + 6.87

Average of Bell Jar Corrections, Observers 1 & 2,°C ______

THERMO ELECTRON
ENGINEERING CORPORATION

PYROMETER AND BELL JAR CALIBRATION RECORD

Sheet 1 of 2

Instrument No. MS217

Date 9-11-67

NBS Lamp No 186792

Temp. Level, °C 1700

(T-207)

		OBSERVER 1	OBSERVER 2
		Name P Brosens	Name E. Peredetto
	Lamp Current, Amps	10 58	10.58
	Lamp Brightness Temp., °C	1700 0	1700.0
PYROMETER CALIBRATION	Bright to Dark Reading, °C	1697	1693
	Dark to Bright Reading, °C	1697	1700
	Dark to Bright Reading, °C	1698	1702
	Bright to Dark Reading, °C	1697	1702
	Average Reading, °C	169725	1699 25
	Correction to be Applied to Pyrometer, °C	+ 275	+ .75
BELL JAR CALIBRATION	Bright to Dark Reading, °C		
	Dark to Bright Reading, °C		
	Dark to Bright Reading, °C		
	Bright to Dark Reading, °C		
	Average Reading, °C		
	Bell Jar Correction, °C		

Average of Pyrometer Corrections, Observers 1 & 2, °C +1.75 °C

Average of Bell Jar Corrections, Observers 1 & 2, °C ______

THERMO ELECTRON
ENGINEERING CORPORATION

PYROMETER AND BELL JAR CALIBRATION RECORD

Sheet 2 of 2

Instrument No. M5217

Date 9-11-67

NBS Lamp No. 186792

Temp. Level, °C 1500

		OBSERVER 1 Name [illegible]	OBSERVER 2 Name [illegible]
	Lamp Current, Amps	8.87	8 87
	Lamp Brightness Temp., °C	1500 0	1500.0
PYROMETER CALIBRATION	Bright to Dark Reading, °C	1502	1506 0
	Dark to Bright Reading, °C	1500	1498
	Dark to Bright Reading, °C	1499	1500
	Bright to Dark Reading, °C	1500	1502
	Average Reading, °C	1500 25	1501 5
	Correction to be Applied to Pyrometer, °C	−0.25	−1.50
BELL JAR CALIBRATION	Bright to Dark Reading, °C		
	Dark to Bright Reading, °C		
	Dark to Bright Reading, °C		
	Bright to Dark Reading, °C		
	Average Reading, °C		
	Bell Jar Correction, °C		

Average of Pyrometer Corrections, Observers 1 & 2, °C − 0.9°C

Average of Bell Jar Corrections, Observers 1 & 2, °C ________

THERMO ELECTRON
ENGINEERING CORPORATION

PYROMETER AND BELL JAR CALIBRATION RECORD

Sheet 1 of 2

Instrument No M-5217

Date 5-17-68

NBS Lamp No 186792

Temp. Level, °C 1600

(T-209)

		OBSERVER 1 Name Perdutto	OBSERVER 2 Name Brosens
	Lamp Current, Amps.	9.69	9.69
	Lamp Brightness Temp., °C	1600	1600
PYROMETER CALIBRATION	Bright to Dark Reading, °C	1598	1600
	Dark to Bright Reading, °C	1600	1598
	Dark to Bright Reading, °C	1601	1598
	Bright to Dark Reading, °C	1600	1600
	Average Reading, °C	1599.75	1599.00
	Correction to be Applied to Pyrometer, °C	+.25	+1.00
BELL JAR CALIBRATION	Bright to Dark Reading, °C	1579	1581
	Dark to Bright Reading, °C	1581	1579
	Dark to Bright Reading, °C	1581	1580
	Bright to Dark Reading, °C	1581	1580
	Average Reading, °C	1580.50	1580.00
	Bell Jar Correction, °C	+19.25	+19.00

Average of Pyrometer Corrections, Observers 1 & 2, °C + 0.62

Average of Bell Jar Corrections, Observers 1 & 2, °C + 19.12

THERMO ELECTRON
ENGINEERING CORPORATION

PYROMETER AND BELL JAR CALIBRATION RECORD

Sheet 2 of 2

Instrument No. M-5217

Date 5-17-68

NBS Lamp No 186792

Temp. Level, °C 1700

		OBSERVER I	OBSERVER 2
		Name Perdutto	Name Brosum
	Lamp Current, Amps.	10.58	10.58
	Lamp Brightness Temp., °C	1700	1700
PYROMETER CALIBRATION	Bright to Dark Reading, °C	1698	1699
	Dark to Bright Reading, °C	1699	1697
	Dark to Bright Reading, °C	1700	1697
	Bright to Dark Reading, °C	1700	1698
	Average Reading, °C	1699.25	1697.75
	Correction to be Applied to Pyrometer, °C	+0.75	+2.25
BELL JAR CALIBRATION	Bright to Dark Reading, °C	1684	1680
	Dark to Bright Reading, °C	1685	1680
	Dark to Bright Reading, °C	1683	1680
	Bright to Dark Reading, °C	1683	1680
	Average Reading, °C	168375	1680.00
	Bell Jar Correction, °C	+ 15.50	+ 17.75

Average of Pyrometer Corrections, Observers 1 & 2, °C +1.50

Average of Bell Jar Corrections, Observers 1 & 2, °C +16.60

THERMO ELECTRON
ENGINEERING CORPORATION

PYROMETER AND BELL JAR CALIBRATION RECORD

Sheet 1 of 2

Instrument No. M 5217

Date 7-15-68

NBS Lamp No. 186792

Temp.Level,°C 1600

(T-210)

		OBSERVER 1 Name E. Perdutto	OBSERVER 2 Name P. Brosey
	Lamp Current, Amps.	9.69	9.69
	Lamp Brightness Temp., °C	1600	1600
PYROMETER CALIBRATION	Bright to Dark Reading, °C	1597	1593
	Dark to Bright Reading, °C	1596	1592
	Dark to Bright Reading, °C	1593	1594
	Bright to Dark Reading, °C	1595	1588
	Average Reading, °C	1595.25	1591.75
	Correction to be Applied to Pyrometer, °C	+4.75	+ 8.25
BELL JAR CALIBRATION	Bright to Dark Reading, °C	1580	1583
	Dark to Bright Reading, °C	1580	1582
	Dark to Bright Reading, °C	1576	1582
	Bright to Dark Reading, °C	1580	1581
	Average Reading, °C	1579.00	1582.00
	Bell Jar Correction, °C	+16.25	+9.75

Average of Pyrometer Corrections, Observers 1 & 2, °C + 6.50

Average of Bell Jar Corrections, Observers 1 & 2, °C + 13.00

THERMO ELECTRON
ENGINEERING CORPORATION

PYROMETER AND BELL JAR CALIBRATION RECORD

Sheet 2 of 2

Instrument No M5217

Date 7-15-68

'NBS Lamp No 186792

Temp. Level, °C 1700

		OBSERVER I Name E. Peradotto	OBSERVER 2 Name P Brosun
	Lamp Current, Amps.	10.58	10 58
	Lamp Brightness Temp., °C	1700	1700
PYROMETER CALIBRATION	Bright to Dark Reading, °C	1689	1690
	Dark to Bright Reading, °C	1688	1686
	Dark to Bright Reading, °C	1687	1687
	Bright to Dark Reading, °C	1688	1687
	Average Reading, °C	1688 00	1687 50
	Correction to be Applied to Pyrometer, °C	+12.00	+12.50
BELL JAR CALIBRATION	Bright to Dark Reading, °C	1669	1676
	Dark to Bright Reading, °C	1667	1675
	Dark to Bright Reading, °C	1673	1673
	Bright to Dark Reading, °C	1670	1675
	Average Reading, °C	1669.75	1674.75
	Bell Jar Correction, °C	+ 18.25	+12 75

Average of Pyrometer Corrections, Observers 1 & 2, °C +12 25

Average of Bell Jar Corrections, Observers 1 & 2, °C +15.50

APPENDIX 17

CAVITY GEOMETRY EQUATIONS

APPENDIX 18

COMPUTER PROGRAM

APPENDIX 17

CAVITY GEOMETRY EQUATIONS

Shoe Piece Geometry·

Trapezoid circumscribed to a circle whose diameter a equals the collector diameter d plus 2u, a radial clearance factor:

$$a = d + 2u$$

The trapezoid sides are inclined by an angle α to the trapezoid center-line:

$$\tan \alpha = (c - b)/2a$$

where b and c are the bases of the trapezoid.

The value of α is determined by the number of converters N in the generator. Each ring of converters in the generator corresponds to a truncated pyramid with half apex angle of 15°, the tilt of the converters from the plane of symmetry. Analysis of the pyramid geometry gives:

$$\tan \alpha = \sin 15° \tan \beta \quad \text{where } \beta = 360/N$$

and:

$$b = a\,(1/\cos \alpha - \tan \alpha)$$

$$c = a\,(1/\cos \alpha + \tan \alpha)$$

Cavity Geometry·

Length of the cavity	$Z8 = 2a \cos 15°$
Mean cavity diameter	$D_c = (b + c)/2 \tan \beta$
Maximum possible cavity aperture dia	$CA_{max} = b/\tan \beta$

```
      PROGRAM THERMO
      DIMENSION A(7),E(7),XN(4),CA(4),F(9,9),SIFR(9),W(7),T(7),H(7),
     1V(7),Q(7),DUM(7,7),EPS(7),S(9),PNN(7),WATT(2),P(7)
      REWIND 1
      REWIND 4
      READ 1,NN,NA,NC,NW
    1 FORMAT(4I5)
      READ 2,CC53,CC64,BB
      READ 2,(XN(I),I=1,NN)
      READ 2,(CA(I),I=1,NC)
      READ 2,(WATT(I),I=1,NW)
      READ 2,(T(I),I=1,7)
      DO 3 I=1,NA
      READ 2,(A(J),J=1,7)
      READ 2,(E(J),J=1,7)
      WRITE OUTPUT TAPE 1,2,(A(J),J=1,7)
      WRITE OUTPUT TAPE 1,2,(E(J),J=1,7)
    2 FORMAT(8E10.5)
    3 CONTINUE
      REWIND 1
      NNC=NN*NC
      SIGMA = 5.679E-12
      RAD =.01745329
      D = 1.778
      U = .127
      AA = D + 2.*U
      Z8 = 2.*AA*.96593
      Z8S = Z8 * Z8
      Z9 = Z8/2.
      Z9S = Z9 * Z9
      A1 = 52.5*RAD
      SINA1 = SINF(A1)
      COSA1 = COSF(A1)
      TANA1 = SINA1/COSA1
      PI = 3.1415927
      AS= 10.*RAD
      COSAS = COSF(AS)
      PI2 = 2.*PI
      DO 210 IN=1,NN        <------ REWIND 4
      C53 = CC53*XN(IN)/2.
      C64 = CC64*XN(IN)/2.
      BET = 360./XN(IN)*RAD
      SINBET = SINF(BET)
      COSBET = COSF(BET)
      TANBET = SINBET/COSBET
      ALF = ATANF(.25882*TANBET)
      COSALF = COSF(ALF)
      SINALF = SINF(ALF)
      TANALF = SINALF/COSALF
      B = AA * (1./COSALF - TANALF)
      C = AA*  (1./COSALF + TANALF)
      DC = AA/(COSALF* TANBET)
      R8 = B*(1.+COSBET)/(4.*SINBET)
      R8S = R8 * R8
      R9 = C * (1.+COSBET)/(4.*SINBET)
      R9S = R9 * R9
      DO 6 II=1,NC
      R1=CA(II)/2.*2.54
      R1S = R1*R1
      Z18 =(R8-R1)/TANA1
      Z18S = Z18 * Z18
      Z1= Z8 + Z18
      Z1S = Z1 * Z1
      Z19 = Z9 + Z18
      Z19S = Z19 * Z19
      H = Z8+R8/TANA1
      A2 = ATANF(R8/H)
      COSA2 = COSF(A2)
      A9 = ATANF(R9/(H-.5*Z8))
      COSA9 = COSF(A9)
      WRITE OUTPUT TAPE 4,4,XN(IN),BET,ALF,AA,B,C,Z8,R8,R9,Z18
    4 FORMAT(10F10.5)
      IF(R1-R8)44,44,33
   33 PRINT 333
  333 FORMAT (53H R1 IS GREATER THAN R8 PROGRAM CONTINUES TO NEXT CASE)
      PRINT 31,R1,R8
   31 FORMAT(/,5H R1 =,F10.5,7H    R8 =,F10.5)
      GO TO 6
```

18-1

A

```
44 CONTINUE
   S(1)= PI* R1S
   S(2) = PI*R8S
   S(3) = PI/4.*COSALF*PI*(R8+R9)*AA
   S(4) = S(3)
   S(5) = PI * (R8+R9)*AA-S(3)
   S(6) = S(5)
   S(7) = (S(2)-S(1))/SINA1
   S(8) = S(2)
   S(9) = PI*R9S
   S35 = S(3)/(S(3)+S(5))
   S46 = S(4)/(S(4)+S(6))
   S53 = S(5)/S(3)
   S64 = S(6)/S(4)
   SA2S = PI2 *(COSAS-COSA2)
   SA92 = PI2 *(COSA2 -COSA9)
   SA19 = PI2 *(COSA9-COSA1)
   SA1S = PI2*(COSAS-COSA1)
   SIFR(1)= 0.
   SIFR(2)= SA2S/SA1S
   SIFR(3)= S35 * SA19/SA1S
   SIFR(4)= S46 * SA92/SA1S
   SIFR(5)= S53 * SIFR(3)
   SIFR(6)= S64 * SIFR(4)
   SIFR(7)= 0.
C  CALCULATION OF VIEW FACTORS
   F(1,1) =0.
   Y12 =1.+Z1S/R1S + R8S/R1S
   SQ = 2.*(R8/R1)/Y12
   SQS = SQ * SQ
   F(1,2) = .5*Y12*(1.-SQRTF(1.-SQS))
   Y18 = 1.+Z18S/R1S + R8S/R1S
   SQ = 2.*(R8/R1)/Y18
   SQS = SQ*SQ
   F(1,8) =.5*Y18*(1.-SQRTF(1.- SQS))
   Y19 = 1.+Z19S/R1S + R9S/R1S
   SQ = 2.*(R9/R1)/Y19
   SQS = SQ * SQ
   F(1,9) =.5*Y19*(1.-SQRTF(1.-SQS))
   F(1,3) = S35 * (F(1,8)-F(1,9))
   F(1,4) = S46 * (F(1,9)- F(1,2))
   F(1,5) = S53 * F(1,3)
   F(1,6) = S64 * F(1,4)
   F(1,7) = 1.- F(1,8)
   F(2,1) = S(1)/S(2)*F(1,2)
   F(2,2) = 0.
   Y29 = 1.+ Z9S/R8S + R9S/R8S
   SQ = 2.*(R9/R8)/Y29
   SQS = SQ*SQ
   F(2,9) = .5*Y29*(1.-SQRTF(1.-SQS))
   Y28 = 2.+ Z8S/R8S
   SQ = 2./Y28
   SQS = SQ * SQ
   F(2,8)= .5*Y28*(1.-SQRTF(1.-SQS))
   F(2,3)= S35 *(F(2,9)- F(2,8))
   F(2,4)= S46 *(1.- F(2,9))
   F(2,5)= S53 * F(2,3)
   F(2,6)= S64 * F(2,4)
   F(2,7) = F(2,8)- F(2,1)
   F(3,1) = S(1)/S(3)*F(1,3)
   F(3,2) = S(2)/S(3)*F(2,3)
   F(8,9)= F(2,9)
   F(8,3) = S35 * (1.- F(8,9))
   F(9,8) = S(8)/S(9)*F(8,9)
   F(9,3) = S35 * (1.-F(9,8))
   F(3,8) = S(8)/S(3)*F(8,3)
   F(3,9) = S(9)/S(3)*F(9,3)
   F(3,3) = S35 *(1.- F(3,8)-F(3,9))
   F(3,4) = S46 *(F(3,9)-F(3,2))
   F(3,5) = S53 * F(3,3)
   F(3,6) = S64 * F(3,4)
   F(3,7) = F(3,8)- F(3,1)
   DO 11 J=1,3
11 F(4,J) = S(J)/S(4)*F(J,4)
   F(4,4)= F(3,3)
   F(4,5) = F(3,6)
   F(4,6)= F(3,5)
   F(8,2) = S(2)/S(8)*F(2,8)
   F(8,4) = S46 * (F(8,9)- F(8,2))
   F(4,8) = S(8)/S(4)*F(8,4)
   F(4,7) = F(4,8)- F(4,1)
   F(4,9) = F(3,9)
   DO 10 J=1,4
10 F(5,J) = S(J)/S(5)*F(J,5)
   F(5,5)= F(3,3)*S53
   F(5,6)= F(3,6)
   F(5,7)= F(3,7)
   DO 9 J=1,5
```

18-2 A

FOLDOUT FRAME

FOLDOUT FRAME

```
    9 F(6,J) = S(J)/S(6)*F(J,6)
      F(5,8) = F(6,2)
      F(5,9) = 1.-F(5,8)-F(5,3)-F(5,5)
      F(6,6) =  F(4,4) *S64
      F(6,7) = F(4,7)
      F(6,8) = F(5,2)
      F(6,9) = F(5,9)
      DO 8 J=1,6
    8 F(7,J) = S(J)/S(7)*F(J,7)
      F(8,1) = S(1)/S(8)*F(1,8)
      F(8,7) =  1.- F(8,1)
      F(7,8) = S(8)/S(7)*F(8,7)
      F(7,7) =  1.- F(7,1)- F(7,8)
      F(7,9) = F(7,8)-F(7,3)-F(7,5)
      F(8,5) = S(5)/S(8)*F(5,8)
      F(8,6) = S(6)/S(8)*F(6,8)
      F(8,8) =0.
      DO 7 J=1,7
    7 F(9,J) = S(J)/S(9)*F(J,9)
      F(9,9) =0.
      DO 5 IV=1,7
    5 WRITE OUTPUT TAPE 4,2,(F(IV,J),J=1,7)
      DO 6 III=1,NW
      DO 60IIII=1,NA
      READ INPUT TAPE 1,2,(A(J),J=1,7)
      READ INPUT TAPE 1,2,(E(I),I=1,7)
      PRINT 100,CA(II),WATT(III),XN(IN)
  100 FORMAT(1H1,37X,34HCOMPUTED GENERATOR THERMAL BALANCE///,38X,   24H
     1CAVITY APERTURE (INCH) =,F8.3//, 38X,27HTOTAL SOLAR INPUT (WATTS)
     2=,F10.3//,38X,22HNUMBER OF CONVERTERS =,F6.1,/)
      PRINT 101,T(3),T(4)
  101 FORMAT(33H    CONVERTER TEMPERATURES (DEG K)/,7H    T3 =,F10.2,
     17H    T4 =,F10.2/)
      PRINT 102,(SIFR(L),L=1,7)
  102 FORMAT(33H    SOLAR FLUX DISTRIBUTION RATIOS/,7H    F1 =,F6.3,
     17H    F2 =,F6.3,7H    F3 =,F6.3,7H    F4 =,F6.3,7H    F5 =,F6.3,
     27H    F6 =,F6.3,7H    F7 =,F6.3,/)
      PRINT 103,(A(L),L=1,7)
  103 FORMAT(24H    CAVITY ABSORPTIVITIES/,7H    A1 =,F6.3,7H    A2 =,
     1F6.3,7H    A3 =,F6.3,7H    A4 =,F6.3,7H    A5 =,F6.3,7H    A6 =,F6.3
     2,7H    A7 =,F6.3/)
      PRINT 104,(E(L),L=1,7)
  104 FORMAT(22H    CAVITY EMISSIVITIES/,7H    E1 =,F6.3,7H    E2 =,F6.3,
     17H    E3 =,F6.3,7H    E4 =,F6.3,7H    E5 =,F6.3,7H    E6 =,F6.3,
     27H    E7 =,F6.3,/)
   30 P(1)=0.
      DO 112 I=2,7
      TT=1.
      DO 111 J=1,4
  111 TT=TT*T(I)
  112 P(I)=SIGMA*TT
      DO 211 J=1,7
      DO 211 I=1,7
  211 DUM(J,I)=-(1.-A(I))*F(I,J)
      DO 212 K=1,7
      DUM(K,K)=1.+DUM(K,K)
      EPS(K)=E(K)*P(K)*S(K)
  212 W(K) = SIFR(K)*WATT(III)
      N=NXNSOL(7,7,DUM,W)
      IF(N-1)22,22,20
   20 PRINT 21
   21 FORMAT(16H NO ANSWER FOR V)
      STOP
   22 DO 202 I=1,7
  202 V(I)=W(I)
      DO 300 J=1,7
      PNN(J)=0.
      DO 300 I=1,7
  300 PNN(J)=PNN(J)+F(I,J)*EPS(I)
      DO 301 J=1,7
      DO 301 I=1,7
  301 DUM(J,I) = -(1.-E(I))*F(I,J)
      DO 302 K=1,7
  302 DUM(K,K)=1.+DUM(K,K)
      N=NXNSOL(7,7,DUM,PNN)
      IF(N-1)26,26,24
   24 PRINT 25
   25 FORMAT(16H NO ANSWER FOR H)
      STOP
   26 DO 303 I=1,7
  303 H(I)=PNN(I)
      DO 400 I=1,7
```

18-3 A

B

18-4 A

```
400 Q(I) = E(I)*(H(I)-(S(I)*P(I)))+A(I)*V(I)
    ECE = Q(1)/(S(1)*P(3))      <-----  { QC3 = (Q(3) + C53 * (T(5) - T(3))) * 2./XN(IN)
    TN5=T(5)                            { QC4 = (Q(4) + C64 * (T(6) - T(4))) * 2./XN(IN)
 49 TN55=TN5*TN5*TN5
    U5=C53*(TN5-T(3))+S(5)*BB*SIGMA*TN5*TN55-Q(5)
    DU5=C53+4.*S(5)*BB*SIGMA*TN55
    TN5=TN5-(U5/DU5)
    AB5 = ABSF(U5/DU5)-1.
    IF(AB5)50,49,49
 50 TN6=T(6)
 52 TN66=TN6*TN6*TN6
    U6=C64*(TN6-T(4))+S(6)*BB*SIGMA*TN6*TN66-Q(6)
    DU6=C64+4.*S(6)*BB*SIGMA*TN66
    TN6 = TN6-(U6/DU6)
    AB6 = ABSF(U6/DU6)-1.
    IF(AB6)51,52,52
 51 T(5)=.5*(TN5+T(5))
    T(6)=.5*(TN6+T(6))
    AT5=ABSF(T(5)-TN5)
    AT6=ABSF(T(6)-TN6)
    IF(AT6-1.)57,30,30
 57 IF(AT5-1.)58,30,30
 58 ABQ=ABSF((Q(3)-Q(4))/Q(3))
    PRINT 105,(V(J),J=1,7),(H(J),J=1,7)
105 FORMAT(7H    V =,7E13.5/,7H    H =,7E13.5//)
    PRINT 106,Q(1),ECE,Q(2),Q(7),Q(3),Q(4)
106 FORMAT(32H    HEAT RADIATED BY THE CAVITY =,F10.3//
   X33H    EQUIVALENT CAVITY EMISSIVITY =,F8.5//          39H    HEAT ABS
   1ORBED BY REAR CAVITY PIECE =,F10.3//  38H    HEAT ABSORBED BY FRONT
   2 CONE PIECE =,F10.3//,  42H    NET HEAT RECEIVED BY FRONT CONVERTER
   3S =,F10.3//41H    NET HEAT RECEIVED BY REAR CONVERTERS =,F10.3//)
    PRINT 107,ABQ,T(5),T(6)
107 FORMAT(32H    HEAT DISTRIBUTION IMBALANCE =,F8.5//,  33H    FRONT SH
   1OE PIECE TEMPERATURE =,F10.3// 32H    REAR SHOE PIECE TEMPERATURE
   2=,F10.3)
 60 CONTINUE
    REWIND 1
  6 CONTINUE
    REWIND 4
    NPR=1
197 PRINT 108
108 FORMAT(1H1)
    NP = 1
198 READ INPUT TAPE 4,4,XX     ,BET,ALF,AA,B,C,Z8,R8,R9,Z18
    PRINT 40,XX,    BET,ALF,AA,B,C
    PRINT 41,DC,Z8,R8,R9,Z18
    PRINT 42
 40 FORMAT(/,4H N =,F10.5,8H   BET =,F10.5,8H   ALF =,F10.5,
   16H    A =,F10.5,6H    B =,F10.5,6H    C =,F10.5,/)
 41 FORMAT(7H D(C) =,F10.5,7H    Z8 =,F10.5,7H    R8 =,F10.5,
   17H    R9 =,F10.5,8H    Z18 =,F10.5,/)
 42 FORMAT(40X,18HVIEW FACTOR MATRIX,/)
    DO 199 I=1,7
    READ INPUT TAPE 4,2,(F(I,J),J=1,7)
    PRINT 55,(F(I ,J),J=1,7)
 55 FORMAT ( 9F13.5,/)
199 CONTINUE
    IF(NPR-NNC)200,210,210
200 NPR=NPR+1
    IF(NP-2)201,197,197
201 NP=NP+1
    GO TO 198
210 CONTINUE
    STOP
    END
      3200 FORTRAN DIAGNOSTIC RESULTS - FOR    THERMO
```

FOLDOUT FRAME

18-4 B

```
NO ERRORS
CTO,      MOUNT SCRATCH TAPE ON LU 3
EQUIP,01=MTC0E0U02
EQUIP,04=MTC0E0U03
LOAD,56
RUN,10
```

```
SUBP
 24521  Q8QERROR    24777  ABSF       25013  SQRTF      25124  ATANF      25265  SINCOS     25574  Q8QOUTTB
 25575  CONTROL     26333  TAPEHAND   26521  FORMAT     27062  BCDOUT     30613  BCDINP     31607  NXNSOL
 32473  THERMO

ENTR
 24777  XABSF       24777  IABS       24777  ABS        25013  SQRT       25124  ATAN       25265  COS
 25276  SIN         25714  Q8QARRAY   25674  Q8QIOTAB   25575  Q8QENTRY   26422  Q8QENEIL   26335  Q8QBACKS
 25574  Q8QOUTTB    26257  PWRTBL     27163  Q8QLGOTC   27163  Q8QLGOTI   26521  Q8QIFRMT   26552  Q8QFORMT
 25650  Q8QIOSET    25630  Q8QSENSE   26073  Q8QEDITS   24521  Q8QERROR   26255  PWRTBL0    25752  Q8QIOERR
 30712  Q8QLGINC    25624  Q8QEXITS   27632  Q8QENGOT   27170  Q8QLGOTR   27062  Q8QINGOT   30716  Q8QLGINR
 31265  Q8QENGIN    30712  Q8QLGINI   30613  Q8QINGIN   26432  Q8QREWND   24777  ABSF       32026  NXNSOL
 25013  SQRTF       25124  ATANF      25265  COSF       25276  SINF       34702  THERMO     02320  FDPBOXS
 00745  SEL         02433  UST        02473  CST        00060  CIT        02544  RHT        02504  AET
 02705  RDCKSUM     02610  RDCKF1     00107  CIO        02756  START2     03242  LOADER     02564  ACCOUNTS
 02606  MEMORY      02320  ABNORMAL

COMM
    NONE

DATA
    NONE

EXTA
    NONE
```

18-5 A

18-5 B

N69-35512

DESIGN AND FABRICATION OF ADVANCED THERMIONIC CONVERTERS

ımo L'\ ctrun Corporation

November 1968

APPENDIX 19

CALCULATION OF MIRROR PERFORMANCE

APPENDIX 19

CALCULATION OF MIRROR PERFORMANCE

Mirror Diameter, ft	9.5	11.5
Projected Area, sq. ft.	70.88	103.86
Shadow Factor	.02	.05
Projected Shadow Area, sq. ft.	1.42	5.19
Useful Projected Area, sq. ft.	69.46	98.67
Solar Constant, watts/sq. ft.	130	90
Incident Energy, watts	9040	8900
Reflectivity	.89	.88
Reflected Energy, watts	8040	7830
Window Transmissivity	–	.89
Window Loss, watts	–	860
Energy at Focal Plane, watts	8040	6970

Focal Plane Energy Distribution:

JM-5 ft. Mirror		9.5 ft		11.5 ft.	
Aperture Dia. in.	Efficiency	Aperture	Q	Aperture	Q
0.10	0.18	0.19	1650	0.23	1430
0.20	0.40	0.38	3660	0.46	3170
0.30	0.66	0.57	6030	0.69	5220
0.40	0.78	0.76	7130	0.92	6170
0.50	0.83	0.95	7580	1.15	6570
0.70	0.85	1.33	7770	1.61	6730
0.90	0.865	1.71	7910	2.07	6850
∞	0.88	∞	8040	∞	6970

APPENDIX 20

COMPUTED CAVITY PERFORMANCE

Nomenclature

CA	Cavity Aperture Diameter, inches
EC	Equivalent Cavity Emissivity
N	Number of Converters
Q1	Heat Radiated by the Cavity, watts
Q2	Heat Absorbed by Rear Cavity Piece, watts
Q3	Heat Absorbed by Front Converters, watts
Q4	Heat Absorbed by Rear Converters, watts
Q7	Heat Absorbed by Front Cone Piece, watts
T	Converter Temperature, °K
T5	Shoe Piece Temperature, Front Converters
T6	Shoe Piece Temperature, Rear Converters
W	Total Solar Input, watts

NOTE: All computed cases had the following common inputs:

F1 = 0	F2 = .118	F3 = .415
F4 = .272	F5 = .118	F6 = .077
F7 = 0		
A1 = 1.000	A2 = .500	A5 = .500
A6 = .500	A7 = .500	
E1 = 1.000	E2 = .250	E5 = .250
E6 = .250	E7 = .250	

CA = 1.4 W = 6700 N = 14 T = 2000 A3 = 0.50 A4 = 0.50 E3 = 0.25 E4 = 0.25 EC = 1.615 Q1 = 1458 Q2 = 721 Q3 = 341 Q4 = 263 Q7 = 145 T5 = 2084 T6 = 2063	CA = 1.4 W = 6700 N = 14 T = 2000 A3 = 0.50 A4 = 0.75 E3 = 0.25 E4 = 0.40 EC = 1.466 Q1 = 1323 Q2 = 615 Q3 = 313 Q4 = 328 Q7 = 125 T5 = 2077 T6 = 2055
CA = 1.4 W = 6700 N = 14 T = 2000 A3 = 0.50 A4 = 0.875 E3 = 0.25 E4 = 0.563 EC = 1.423 Q1 = 1284 Q2 = 576 Q3 = 303 Q4 = 351 Q7 = 118 T5 = 2074 T6 = 2053	CA = 1.4 W = 6700 N = 14 T = 2000 A3 = 0.75 A4 = 0.50 E3 = 0.40 E4 = 0.25 EC = 1.385 Q1 = 1250 Q2 = 607 Q3 = 427 Q4 = 227 Q7 = 115 T5 = 2075 T6 = 2053

CA = 1.4 W = 6700 N = 14 T = 2000 A3 = 0.75 A4 = 0.75 E3 = 0.40 E4 = 0.40 EC = 1.271 Q1 = 1147 Q2 = 523 Q3 = 398 Q4 = 288 Q7 = 100 T5 = 2069 T6 = 2049	CA = 1.4 W = 6700 N = 14 T = 2000 A3 = 0.75 A4 = 0.875 E3 = 0.40 E4 = 0.563 EC = 1.238 Q1 = 1117 Q2 = 491 Q3 = 387 Q4 = 309 Q7 = 95 T5 = 2068 T6 = 2046
CA = 1.4 W = 6700 N = 14 T = 2000 A3 = 0.875 A4 = 0.50 E3 = 0.563 E4 = 0.25 EC = 1.310 Q1 = 1182 Q2 = 564 Q3 = 459 Q4 = 214 Q7 = 104 T5 = 2071 T6 = 2050	CA = 1.4 W = 6700 N = 14 T = 2000 A3 = 0.875 A4 = 0.75 E3 = 0.563 E4 = 0.40 EC = 1.208 Q1 = 1088 Q2 = 487 Q3 = 429 Q4 = 272 Q7 = 91 T5 = 2087 T6 = 2045

CA = 1.4 N = 14 A3 = 0.875 E3 = 0.563 EC = 1.174 Q1 = 1060 Q2 = 457 Q3 = 418 Q4 = 292 Q7 = 86 T5 = 2065 T6 = 2043	W = 6700 T = 2000 A4 = 0.875 E4 = 0.563
CA = N = A3 = E3 = EC = Q1 = Q2 = Q3 = Q4 = Q7 = T5 = T6 =	W = T = A4 = E4 =
CA = N = A3 = E3 = EC = Q1 = Q2 = Q3 = Q4 = Q7 = T5 = T6 =	W = T = A4 = E4 =
CA = N = A3 = E3 = EC = Q1 = Q2 = Q3 = Q4 = Q7 = T5 = T6 =	W = T = A4 = E4 =

CA = .7 W = 5300 N = 10 T = 2000 A3 = 0.50 A4 = 0.700 E3 = 0.25 E4 = 0.365 EC = 1.835 Q1 = 414 Q2 = 304 Q3 = 454 Q4 = 398 Q7 = 207 T5 = 2119 T6 = 2076	CA = .7 W = 5300 N = 10 T = 2000 A3 = 0.605 A4 = 0.875 E3 = 0.310 E4 = 0.563 EC = 1.581 Q1 = 356 Q2 = 239 Q3 = 478 Q4 = 408 Q7 = 166 T5 = 2106 T6 = 2064
CA = .7 W = 7350 N = 10 T = 2000 A3 = 0.50 A4 = 0.700 E3 = 0.25 E4 = 0.365 EC = 2.229 Q1 = 502 Q2 = 430 Q3 = 641 Q4 = 565 Q7 = 265 T5 = 2171 T6 = 2112	CA = .7 W = 7350 N = 10 T = 2000 A3 = 0.605 A4 = 0.875 E3 = 0.310 E4 = 0.563 EC = 1.861 Q1 = 419 Q2 = 338 Q3 = 674 Q4 = 579 Q7 = 207 T5 = 2154 T6 = 2094

CA =	.8	W	= 5850
N	= 10	T	= 2000
A3 =	.50	A4 =	.700
E3 =	.25	E4 =	.365

EC = 1.938
Q1 = 571
Q2 = 331
Q3 = 498
Q4 = 436
Q7 = 160
T5 = 2131
T6 = 2085

CA =	.8	W	= 5850
N	= 10	T	= 2000
A3 =	.605	A4 =	.875
A4 =	.310	A4 =	.563

EC = 1.657
Q1 = 488
Q2 = 261
Q3 = 525
Q4 = 447
Q7 = 127
T5 = 2118
T6 = 2071

CA =	.8	W	= 7500
N	= 10	T	= 2000
A3 =	.50	A4 =	.700
E3 =	.25	E4 =	.365

EC = 2.259
Q1 = 665
Q2 = 432
Q3 = 648
Q4 = 570
Q7 = 194
T5 = 2173
T6 = 2113

CA =	.8	W	= 7500
N	= 10	T	= 2000
A3 =	.605	A4 =	.875
E3 =	.310	E4 =	.563

EC = 1.885
Q1 = 555
Q2 = 341
Q3 = 682
Q4 = 585
Q7 = 152
T5 = 2156
T6 = 2095

CA = .9 W = 6150 N = 10 T = 2000 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.989 Q1 = 741 Q2 = 342 Q3 = 518 Q4 = 453 Q7 = 94 T5 = 2137 T6 = 2088	CA = .9 W = 6150 N = 10 T = 2000 A3 = .605 A4 = .875 E3 = .310 E4 = .563 EC = 1.696 Q1 = 632 Q2 = 270 Q3 = 547 Q4 = 465 Q7 = 75 T5 = 2123 T6 = 2074
CA = .9 W = 7600 N = 10 T = 2000 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 2.273 Q1 = 847 Q2 = 430 Q3 = 649 Q4 = 569 Q7 = 111 T5 = 2174 T6 = 2113	CA = 0.9 W = 7600 N = 10 T = 2000 A3 = .605 A4 = .875 E3 = .310 E4 = .563 EC = 1.898 Q1 = 708 Q2 = 340 Q3 = 685 Q4 = 585 Q7 = 87 T5 = 2156 T6 = 2095

CA = 1.0 W = 6400 N = 10 T = 2000 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 2.025 Q1 = 932 Q2 = 349 Q3 = 532 Q4 = 464 Q7 = 17 T5 = 2141 T6 = 2091	CA = 1.0 W = 6400 N = 10 T = 2000 A3 = .605 A4 = .875 E3 = .310 E4 = .563 EC = 1.724 Q1 = 793 Q2 = 276 Q3 = 564 Q4 = 477 Q7 = 14 T5 = 2127 T6 = 2076
CA = 1.0 W = 7650 N = 10 T = 2000 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 2.271 Q1 = 1046 Q2 = 424 Q3 = 644 Q4 = 564 Q7 = 20 T5 = 2172 T6 = 2112	CA = 1.0 W = 7650 N = 10 T = 2000 A3 = .605 A4 = .875 E3 = .310 E4 = .563 EC = 1.900 Q1 = 874 Q2 = 335 Q3 = 682 Q4 = 580 Q7 = 15 T5 = 2156 T6 = 2095

CA = .8 W = 5850 N = 12 T = 2000 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.641 Q1 = 483 Q2 = 477 Q3 = 379 Q4 = 359 Q7 = 334 T5 = 2096 T6 = 2066	CA = .8 W = 5850 N = 12 T = 2000 A3 = .605 A4 = .875 E3 = .310 E4 = .563 EC = 1.441 Q1 = 424 Q2 = 391 Q3 = 400 Q4 = 372 Q7 = 272 T5 = 2086 T6 = 2056
CA = .8 W = 7500 N = 12 T = 2000 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.879 Q1 = 553 Q2 = 624 Q3 = 495 Q4 = 470 Q7 = 399 T5 = 2128 T6 = 2090	CA = .8 W = 7500 N = 12 T = 2000 A3 = .605 A4 = .875 E3 = .310 E4 = .563 EC = 1.610 Q1 = 474 Q2 = 511 Q3 = 522 Q4 = 489 Q7 = 319 T5 = 2115 T6 = 2076

CA = .9 W = 6150
N = 12 T = 2000
A3 = .50 A4 = .700
E3 = .25 E4 = .365

EC = 1.600
Q1 = 626
Q2 = 496
Q3 = 395
Q4 = 373
Q7 = 284
T5 = 2100
T6 = 2069

CA = .9 W = 6150
N = 12 T = 2000
A3 = .605 A4 = .875
E3 = .310 E4 = .563

EC = 1.470
Q1 = 548
Q2 = 407
Q3 = 418
Q4 = 388
Q7 = 231
T5 = 2090
T6 = 2059

CA = .9 W = 7600
N = 12 T = 2000
A3 = .50 A4 = .700
E3 = .25 E4 = .365

EC = 1.891
Q1 = 709
Q2 = 624
Q3 = 497
Q4 = 471
Q7 = 332
T5 = 2128
T6 = 2090

CA = .9 W = 7600
N = 12 T = 2000
A3 = .605 A4 = .875
E3 = .310 E4 = .563

EC = 1.620
Q1 = 684
Q2 = 512
Q3 = 525
Q4 = 490
Q7 = 265
T5 = 2115
T6 = 2077

CA = 1.0 W = 6400 N = 12 T = 2000 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.709 Q1 = 785 Q2 = 508 Q3 = 407 Q4 = 384 Q7 = 223 T5 = 2104 T6 = 2072	CA = 1.0 W = 6400 N = 12 T = 2000 A3 = .605 A4 = .875 E3 = .310 E4 = .563 EC = 1.493 Q1 = 687 Q2 = 418 Q3 = 432 Q4 = 399 Q7 = 182 T5 = 2093 T6 = 2061
CA = 1.0 W = 7650 N = 12 T = 2000 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.892 Q1 = 871 Q2 = 618 Q3 = 494 Q4 = 487 Q7 = 255 T5 = 2127 T6 = 2089	CA = 1.0 W = 7650 N = 12 T = 2000 A3 = .605 A4 = .875 E3 = .310 E4 = .563 EC = 1.623 Q1 = 747 Q2 = 508 Q3 = 523 Q4 = 487 Q7 = 204 T5 = 2115 T6 = 2076

CA = 1.1 W = 6550 N = 12 T = 2000 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.719 Q1 = 958 Q2 = 511 Q3 = 412 Q4 = 347 Q7 = 152 T5 = 2105 T6 = 2072	CA = 1.1 W = 6550 N = 12 T = 2000 A3 = .605 A4 = .875 E3 = .310 E4 = .563 EC = 1.502 Q1 = 836 Q2 = 421 Q3 = 434 Q4 = 403 Q7 = 123 T5 = 2095 T6 = 2062
CA = 1.1 W = 7700 N = 12 T = 2000 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.889 Q1 = 1052 Q2 = 611 Q3 = 491 Q4 = 464 Q7 = 172 T5 = 2127 T6 = 2088	CA = 1.1 W = 7700 N = 12 T = 2000 A3 = .605 A4 = .875 E3 = .310 E4 = .563 EC = 1.623 Q1 = 904 Q2 = 503 Q3 = 521 Q4 = 483 Q7 = 137 T5 = 2114 T6 = 2076

CA = .8	W = 5850	CA = .8	W = 5850
N = 14	T = 2000	N = 14	T = 2000
A3 = .50	A4 = .700	A3 = .605	A4 = .875
E3 = .25	E4 = .365	E3 = .310	E4 = .563
EC = 1.449		EC = 1.304	
Q1 = 427		Q1 = 384	
Q2 = 609		Q2 = 512	
Q3 = 297		Q3 = 315	
Q4 = 299		Q4 = 314	
Q7 = 498		Q7 = 417	
T5 = 2073		T5 = 2066	
T6 = 2053		T6 = 2046	
CA = .8	W = 7500	CA = .8	W = 7500
N = 14	T = 2000	N = 14	T = 2000
A3 = .50	A4 = .700	A3 = .605	A4 = .875
E3 = .25	E4 = .365	E3 = .310	E4 = .563
EC = 1.635		EC = 1.436	
Q1 = 481		Q1 = 423	
Q2 = 799		Q2 = 671	
Q3 = 389		Q3 = 412	
Q4 = 394		Q4 = 414	
Q7 = 588		Q7 = 481	
T5 = 2097		T5 = 2088	
T6 = 2073		T6 = 2063	

CA = 1.0 N = 14 A3 = .50 E3 = .25 EC = 1.504 Q1 = 892 Q2 = 652 Q3 = 321 Q4 = 322 Q7 = 411 T5 = 2079 T6 = 2058	W = 6400 T = 2000 A4 = .700 E4 = .365
CA = 1.0 N = 14 A3 = .605 E3 = .310 EC = 1.345 Q1 = 819 Q2 = 550 Q3 = 340 Q4 = 338 Q7 = 341 T5 = 2070 T6 = 2050	W = 6400 T = 2000 A4 = .875 E4 = .563
CA = 1.0 N = 14 A3 = .50 E3 = .25 EC = 1.647 Q1 = 758 Q2 = 795 Q3 = 398 Q4 = 393 Q7 = 465 T5 = 2098 T6 = 2073	W = 7650 T = 2000 A4 = .700 E4 = .365
CA = 1.0 N = 14 A3 = .605 E3 = .310 EC = 1.447 Q1 = 666 Q2 = 669 Q3 = 413 Q4 = 413 Q7 = 380 T5 = 2088 T6 = 2063	W = 7650 T = 2000 A4 = .875 E4 = .563

CA = 1.2 W = 6600 N = 14 T = 2000 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.509 Q1 = 1000 Q2 = 651 Q3 = 323 Q4 = 323 Q7 = 280 T5 = 2040 T6 = 2058	CA = 1.2 W = 6600 N = 14 T = 2000 A3 = .605 A4 = .875 E3 = .310 E4 = .563 EC = 1.351 Q1 = 895 Q2 = 551 Q3 = 344 Q4 = 339 Q7 = 233 T5 = 2072 T6 = 2050
CA = 1.2 W = 7750 N = 14 T = 2000 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.642 Q1 = 1088 Q2 = 780 Q3 = 388 Q4 = 388 Q7 = 314 T5 = 2097 T6 = 2071	CA = 1.2 W = 7750 N = 14 T = 2000 A3 = .605 A4 = .875 E3 = .310 E4 = .563 EC = 1.446 Q1 = 959 Q2 = 659 Q3 = 411 Q4 = 408 Q7 = 257 T5 = 2087 T6 = 2062

CA = 1.4 W = 6700 N = 14 T = 2000 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.494 Q1 = 1348 Q2 = 635 Q3 = 319 Q4 = 317 Q7 = 125 T5 = 2078 T6 = 2057	CA = 1.4 W = 6700 N = 14 T = 2000 A3 = .605 A4 = .875 E3 = .310 E4 = .563 EC = 1.341 Q1 = 1210 Q2 = 538 Q3 = 340 Q4 = 332 Q7 = 104 T5 = 2071 T6 = 2050
CA = 1.4 W = 7800 N = 14 T = 2000 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.622 Q1 = 1463 Q2 = 756 Q3 = 378 Q4 = 378 Q7 = 140 T5 = 2095 T6 = 2069	CA = 1.4 W = 7800 N = 14 T = 2000 A3 = .605 A4 = .875 E3 = .310 E4 = .563 EC = 1.433 Q1 = 1293 Q2 = 641 Q3 = 403 Q4 = 397 Q7 = 114 T5 = 2085 T6 = 2060

CA = 1.2 W = 6600 N = 16 T = 2000 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.367 Q1 = 906 Q2 = 782 Q3 = 261 Q4 = 275 Q7 = 475 T5 = 2063 T6 = 2048	CA = 1.2 W = 6600 N = 16 T = 2000 A3 = .605 A4 = .875 E3 = .310 E4 = .563 EC = 1.249 Q1 = 828 Q2 = 673 Q3 = 278 Q4 = 290 Q7 = 404 T5 = 2057 T6 = 2043
CA = 1.2 W = 7750 N = 16 T = 2000 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.475 Q1 = 977 Q2 = 939 Q3 = 312 Q4 = 330 Q7 = 528 T5 = 2076 T6 = 2059	CA = 1.2 W = 7750 N = 16 T = 2000 A3 = .605 A4 = .875 E3 = .310 E4 = .563 EC = 1.327 Q1 = 880 Q2 = 807 Q3 = 333 Q4 = 350 Q7 = 442 T5 = 2069 T6 = 2052

CA = 1.4, W = 6700 N = 16, T = 2000 A3 = .50, A4 = .700 E3 = .25, E4 = .365 EC = 1.356 Q1 = 1223 Q2 = 766 Q3 = 258 Q4 = 270 Q7 = 334 T5 = 2062 T6 = 2047	CA = 1.4, W = 6700 N = 16, T = 2000 A3 = .605, A4 = .875 E3 = .310, E4 = .563 EC = 1.242 Q1 = 1121 Q2 = 660 Q3 = 276 Q4 = 285 Q7 = 284 T5 = 2056 T6 = 2042
CA = 1.4, W = 7800 N = 16, T = 2000 A3 = .50, A4 = .700 E3 = .25, E4 = .365 EC = 1.460 Q1 = 1317 Q2 = 914 Q3 = 306 Q4 = 323 Q7 = 370 T5 = 2075 T6 = 2058	CA = 1.4, W = 7800 N = 14, T = 2000 A3 = .605, A4 = .875 E3 = .310, E4 = .563 EC = 1.318 Q1 = 1189 Q2 = 788 Q3 = 328 Q4 = 341 Q7 = 310 T5 = 2069 T6 = 2050

CA = 1.6 W = 6750 N = 16 T = 2000 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.334 Q1 = 1572 Q2 = 739 Q3 = 252 Q4 = 262 Q7 = 176 T5 = 2060 T6 = 2046	CA = 1.6 W = 6750 N = 16 T = 2000 A3 = .605 A4 = .875 E3 = .310 E4 = .563 EC = 1.227 Q1 = 1446 Q2 = 639 Q3 = 270 Q4 = 276 Q7 = 150 T5 = 2055 T6 = 2040
CA = 1.6 W = 7850 N = 16 T = 2000 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.438 Q1 = 1695 Q2 = 885 Q3 = 300 Q4 = 314 Q7 = 195 T5 = 2073 T6 = 2056	CA = 1.6 W = 7850 N = 16 T = 2000 A3 = .605 A4 = .875 E3 = .310 E4 = .563 EC = 1.303 Q1 = 1536 Q2 = 765 Q3 = 322 Q4 = 332 Q7 = 164 T5 = 2067 T6 = 2050

CA = 1.8 W = 6800 N = 16 T = 2000 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.307 Q1 = 1950 Q2 = 709 Q3 = 245 Q4 = 253 Q7 = 6 T5 = 2059 T6 = 2044	CA = 1.8 W = 6800 N = 16 T = 2000 A3 = .605 A4 = .875 E3 = .310 E4 = .563 EC = 1.207 Q1 = 1801 Q2 = 616 Q3 = 264 Q4 = 266 Q7 = 5 T5 = 2054 T6 = 2039
CA = 1.8 W = 7900 N = 16 T = 2000 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.412 Q1 = 2106 Q2 = 853 Q3 = 292 Q4 = 304 Q7 = 6 T5 = 2071 T6 = 2054	CA = 1.8 W = 7900 N = 16 T = 2000 A3 = .605 A4 = .875 E3 = .310 E4 = .563 EC = 1.284 Q1 = 1915 Q2 = 740 Q3 = 315 Q4 = 321 Q7 = 5 T5 = 2065 T6 = 2048

CA	=	8	W	=	5850
N	=	14	T	=	1900
A3	=	.50	A4	=	.700
E3	=	.25	E4	=	.365
EC	=	1.599			
Q1	=	383			
Q2	=	621			
Q3	=	304			
Q4	=	307			
Q7	=	462			
T5	=	1977			
T6	=	1958			

CA	=	.8	W	=	5850
N	=	14	T	=	2000
A3	=	.50	A4	=	.700
E3	=	.25	E4	=	.365
EC	=	1.450			
Q1	=	427			
Q2	=	609			
Q3	=	297			
Q4	=	300			
Q7	=	498			
T5	=	2073			
T6	=	2054			

CA	=	.8	W	=	5850
N	=	14	T	=	2100
A3	=	.50	A4	=	.700
E3	=	.25	E4	=	.365
EC	=	1.333			
Q1	=	477			
Q2	=	595			
Q3	=	290			
Q4	=	291			
Q7	=	540			
T5	=	2168			
T6	=	2149			

CA	=	8	W	=	5850
N	=	14	T	=	2200
A3	=	.50	A4	=	.700
E3	=	.25	E4	=	.365
EC	=	1.242			
Q1	=	535			
Q2	=	580			
Q3	=	282			
Q4	=	282			
Q7	=	589			
T5	=	2263			
T6	=	2245			

CA =	.8	W =	7500
N =	14	T =	1900
A3 =	.50	A4 =	.700
E3 =	.25	E4 =	.365
EC =	1.826		
Q1 =	438		
Q2 =	810		
Q3 =	396		
Q4 =	402		
Q7 =	552		
T5 =	2003		
T6 =	1978		

CA =	.8	W =	7500
N =	14	T =	2000
A3 =	.50	A4 =	.700
E3 =	.25	E4 =	.365
EC =	1.636		
Q1 =	482		
Q2 =	799		
Q3 =	390		
Q4 =	395		
Q7 =	588		
T5 =	2098		
T6 =	2074		

CA =	.8	W =	7500
N =	14	T =	2100
A3 =	.50	A4 =	.700
E3 =	.25	E4 =	.365
EC =	1.487		
Q1 =	532		
Q2 =	786		
Q3 =	382		
Q4 =	386		
Q7 =	631		
T5 =	2193		
T6 =	2169		

CA =	.8	W =	7500
N =	14	T =	2200
A3 =	.50	A4 =	.700
E3 =	.25	E4 =	.365
EC =	1.370		
Q1 =	591		
Q2 =	770		
Q3 =	374		
Q4 =	377		
Q7 =	679		
T5 =	2288		
T6 =	2264		

CA	=	1.0	W	=	6400
N	=	14	T	=	1900
A3	=	.50	A4	=	.700
E3	=	25	E4	=	.365
		EC	=	1 669	
		Q1	=	826	
		Q2	=	666	
		Q3	=	328	
		Q4	=	331	
		Q7	=	383	
		T5	=	1984	
		T6	=	1963	

CA	=	1.0	W	=	6400
N	=	14	T	=	2000
A3	=	.50	A4	=	.700
E3	=	25	E4	=	.365
		EC	=	1.504	
		Q1	=	692	
		Q2	=	653	
		Q3	=	321	
		Q4	=	323	
		Q7	=	411	
		T5	=	2080	
		T6	=	2059	

CA	=	1.0	W	=	6400
N	=	14	T	=	2100
A3	=	.50	A4	=	.700
E3	=	.25	E4	=	.365
		EC	=	1.375	
		Q1	=	769	
		Q2	=	636	
		Q3	=	312	
		Q4	=	313	
		Q7	=	443	
		T5	=	2174	
		T6	=	2154	

CA	=	1.0	W	=	6400
N	=	14	T	=	2200
A3	=	.50	A4	=	.700
E3	=	.25	E4	=	.365
		EC	=	1.273	
		Q1	=	858	
		Q2	=	618	
		Q3	=	303	
		Q4	=	302	
		Q7	=	480	
		T5	=	2269	
		T6	=	2249	

CA = 1.0 W = 7650 N = 14 T = 1900 A3 = .50 A4 = 700 E3 = .25 E4 = 365 EC = 1.844 Q1 = 691 Q2 = 808 Q3 = 398 Q4 = 402 Q7 = 437 T5 = 2003 T6 = 1978	CA = 1.0 W = 7650 N = 14 T = 2000 A3 = .50 A4 = .700 E3 = .25 E4 = 365 EC = 1.647 Q1 = 758 Q2 = 795 Q3 = 390 Q4 = 394 Q7 = 465 T5 = 2098 T6 = 2074
CA = 1.0 W = 7650 N = 14 T = 2100 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1 493 Q1 = 835 Q2 = 779 Q3 = 382 Q4 = 384 Q7 = 497 T5 = 2193 T6 = 2168	CA = 1.0 W = 7650 N = 14 T = 2200 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.372 Q1 = 925 Q2 = 761 Q3 = 373 Q4 = 374 Q7 = 534 T5 = 2288 T6 = 2264

CA = 1.2 W = 6600 N = 14 T = 1900 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.681 Q1 = 907 Q2 = 667 Q3 = 332 Q4 = 333 Q7 = 262 T5 = 1985 T6 = 1963	CA = 1.2 W = 6600 N = 14 T = 2000 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.509 Q1 = 1000 Q2 = 651 Q3 = 324 Q4 = 324 Q7 = 280 T5 = 2080 T6 = 2059
CA = 1.2 W = 6600 N = .14 T = 2100 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.374 Q1 = 1108 Q2 = 632 Q3 = 314 Q4 = 313 Q7 = 301 T5 = 2174 T6 = 2154	CA = 1.2 W = 6600 N = 14 T = 2200 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.268 Q1 = 1231 Q2 = 610 Q3 = 304 Q4 = 300 Q7 = 325 T5 = 2269 T6 = 2248

CA =	1.2	W =	7750
N =	14	T =	1900
A3 =	.50	A4 =	.700
E3 =	.25	E4 =	.365

EC =	1.844
Q1 =	995
Q2 =	796
Q3 =	395
Q4 =	398
Q7 =	296
T5 =	2002
T6 =	1977

CA =	1.2	W =	7750
N =	14	T =	2000
A3 =	.50	A4 =	.700
E3 =	.25	E4 =	.365

EC =	1.642
Q1 =	1089
Q2 =	780
Q3 =	387
Q4 =	389
Q7 =	314
T5 =	2097
T6 =	2073

CA =	1.2	W =	7750
N =	14	T =	2100
A3 =	.50	A4 =	.700
E3 =	.25	E4 =	.365

EC =	1.485
Q1 =	1196
Q2 =	762
Q3 =	377
Q4 =	377
Q7 =	334
T5 =	2192
T6 =	2167

CA =	1.2	W =	7750
N =	14	T =	2200
A3 =	.50	A4 =	.700
E3 =	.25	E4 =	365

EC =	1.360
Q1 =	1321
Q2 =	740
Q3 =	367
Q4 =	365
Q7 =	358
T5 =	2286
T6 =	2262

CA = 1.4	W = 6700	CA = 1.4	W = 6700
N = 14	T = 1900	N = 14	T = 2000
A3 = .50	A4 = .700	A3 = .50	A4 = .700
E3 = .25	E4 = .365	E3 = .25	E4 = .365
EC = 1.669		EC = 1.494	
Q1 = 1227		Q1 = 1348	
Q2 = 654		Q2 = 635	
Q3 = 328		Q3 = 319	
Q4 = 328		Q4 = 317	
Q7 = 117		Q7 = 125	
T5 = 1984		T5 = 2079	
T6 = 1962		T6 = 2058	
CA = 1.4	W = 6700	CA = 1.4	W = 6700
N = 14	T = 2100	N = 14	T = 2200
A3 = .50	A4 = .700	A3 = .50	A4 = .700
E3 = .25	E4 = .365	E3 = .25	E4 = .365
EC = 1.357		EC = 1.249	
Q1 = 1488		Q1 = 1650	
Q2 = 612		Q2 = 587	
Q3 = 308		Q3 = 297	
Q4 = 305		Q4 = 291	
Q7 = 134		Q7 = 144	
T5 = 2173		T5 = 2267	
T6 = 2152		T6 = 2247	

CA =	1.4	W =	7800
N =	14	T =	1900
A3 =	.50	A4 =	.700
E3 =	.25	E4 =	.365

EC = 1.826
Q1 = 1342
Q2 = 775
Q3 = 388
Q4 = 389
Q7 = 132
T5 = 2000
T6 = 1975

CA =	1.4	W =	7800
N =	14	T =	2000
A3 =	.50	A4 =	.700
E3 =	.25	E4 =	.365

EC = 1.622
Q1 = 1464
Q2 = 756
Q3 = 379
Q4 = 379
Q7 = 140
T5 = 2095
T6 = 2071

CA =	1.4	W =	7800
N =	14	T =	2100
A3 =	.50	A4 =	.700
E3 =	.25	E4 =	.365

EC = 1.463
Q1 = 1604
Q2 = 734
Q3 = 368
Q4 = 366
Q7 = 148
T5 = 2189
T6 = 2165

CA =	1.4	W =	7800
N =	14	T =	2200
A3 =	.50	A4 =	700
E3 =	.25	E4 =	.365

EC = 1.337
Q1 = 1767
Q2 = 709
Q3 = 357
Q4 = 352
Q7 = 159
T5 = 2284
T6 = 2259

CA	= 1.0	W	= 6400		
N	= 16	T	= 1900		
A3	= .50	A4	= .700		
E3	= .25	E4	= .365		
		EC	= 1.497		
		Q1	= 561		
		Q2	= 799		
		Q3	= 265		
		Q4	= 282		
		Q7	= 547		
		T5	= 1966		
		T6	= 1952		

CA	= 1.0	W	= 6400		
N	= 16	T	= 2000		
A3	= .50	A4	= .700		
E3	= .25	E4	= .365		
		EC	= 1.362		
		Q1	= 627		
		Q2	= 780		
		Q3	= 258		
		Q4	= 274		
		Q7	= 592		
		T5	= 2062		
		T6	= 2048		

CA	= 1.0	W	= 6400		
N	= 16	T	= 2100		
A3	= .50	A4	= .700		
E3	= .25	E4	= .365		
		EC	= 1.256		
		Q1	= 703		
		Q2	= 758		
		Q3	= 250		
		Q4	= 263		
		Q7	= 644		
		T5	= 2157		
		T6	= 2143		

CA	= 1.0	W	= 6400		
N	= 16	T	= 2200		
A3	= .50	A4	= .700		
E3	= .25	E4	= .365		
		EC	= 1.173		
		Q1	= 790		
		Q2	= 732		
		Q3	= 241		
		Q4	= 253		
		Q7	= 704		
		T5	= 2252		
		T6	= 2238		

CA = 1.0 W = 7650
N = 16 T = 1900
A3 = .50 A4 = .700
E3 = .25 E4 = .265

EC = 1.639
Q1 = 614
Q2 = 972
Q3 = 322
Q4 = 343
Q7 = 619
T5 = 1982
T6 = 1965

CA = 1.0 W = 7650
N = 16 T = 2000
A3 = .50 A4 = .700
E3 = .25 E4 = .365

EC = 1.478
Q1 = 680
Q2 = 953
Q3 = 315
Q4 = 335
Q7 = 664
T5 = 2077
T6 = 2061

CA = 1.0 W = 7650
N = 16 T = 2100
A3 = .50 A4 = .700
E3 = .25 E4 = .365

EC = 1.352
Q1 = 756
Q2 = 931
Q3 = 306
Q4 = 325
Q7 = 716
T5 = 2172
T6 = 2156

CA = 1.0 W = 7650
N = 16 T = 2200
A3 = .50 A4 = .700
E3 = .25 E4 = .365

EC = 1.253
Q1 = 844
Q2 = 905
Q3 = 297
Q4 = 314
Q7 = 776
T5 = 2267
T6 = 2251

CA = 1.2 W = 6600 N = 16 T = 1900 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.507 Q1 = 814 Q2 = 804 Q3 = 268 Q4 = 284 Q7 = 440 T5 = 1967 T6 = 1953	CA = 1.2 W = 6600 N = 16 T = 2000 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.367 Q1 = 906 Q2 = 782 Q3 = 261 Q4 = 275 Q7 = 475 T5 = 2065 T6 = 2049
CA = 1.2 W = 6600 N = 16 T = 2100 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1 257 Q1 = 1013 Q2 = 756 Q3 = 251 Q4 = 264 Q7 = 515 T5 = 2157 T6 = 2143	CA = 1.2 W = 6600 N = 16 T = 2200 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.170 Q1 = 1136 Q2 = 726 Q3 = 242 Q4 = 252 Q7 = 561 T5 = 2252 T6 = 2238

CA = 1.2 W = 7750 N = 16 T = 1900 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.640 Q1 = 885 Q2 = 961 Q3 = 320 Q4 = 340 Q7 = 494 T5 = 1981 T6 = 1964	CA = 1.2 W = 7750 N = 16 T = 2000 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.475 Q1 = 978 Q2 = 939 Q3 = 313 Q4 = 331 Q7 = 528 T5 = 2077 T6 = 2060
CA = 1.2 W = 7750 N = 16 T = 2100 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.346 Q1 = 1085 Q2 = 914 Q3 = 303 Q4 = 320 Q7 = 569 T5 = 2171 T6 = 2155	CA = 1.2 W = 7750 N = 16 T = 2200 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.245 Q1 = 1208 Q2 = 884 Q3 = 293 Q4 = 308 Q7 = 615 T5 = 2266 T6 = 2250

CA = 1.4	W = 6700	CA = 1.4	W = 6700
N = 16	T = 1900	N = 16	T = 2000
A3 = .50	A4 = .700	A3 = 50	A4 = .700
E3 = .25	E4 = .365	E3 = .25	E4 = .365
EC = 1.499		EC = 1.356	
Q1 = 1102		Q1 = 1223	
Q2 = 791		Q2 = 766	
Q3 = 266		Q3 = 258	
Q4 = 281		Q4 = 271	
Q7 = 311		Q7 = 334	
T5 = 1967		T5 = 2062	
T6 = 1952		T6 = 2048	
CA = 1.4	W = 6700	CA = 1.4	W = 6700
N = 16	T = 2100	N = 16	T = 2200
A3 = .50	A4 = .700	A3 = .50	A4 = .700
E3 = .25	E4 = .365	E3 = .25	E4 = .365
EC = 1.243		EC = 1.155	
Q1 = 1364		Q1 = 1526	
Q2 = 736		Q2 = 702	
Q3 = 248		Q3 = 237	
Q4 = 258		Q4 = 245	
Q7 = 361		Q7 = 393	
T5 = 2156		T5 = 2251	
T6 = 2142		T6 = 2237	

CA = 1.4 W = 7800 N = 16 T = 1900 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.627 Q1 = 1196 Q2 = 940 Q3 = 316 Q4 = 334 Q7 = 347 T5 = 1980 T6 = 1963	CA = 1.4 W = 7800 N = 16 T = 2000 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.460 Q1 = 1317 Q2 = 914 Q3 = 307 Q4 = 324 Q7 = 370 T5 = 2075 T6 = 2059
CA = 1.4 W = 7800 N = 16 T = 2100 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.329 Q1 = 1458 Q2 = 885 Q3 = 297 Q4 = 311 Q7 = 398 T5 = 2169 T6 = 2153	CA = 1.4 W = 7800 N = 16 T = 2200 A3 = .50 A4 = .700 E3 = .25 E4 = .365 EC = 1.227 Q1 = 1621 Q2 = 851 Q3 = 286 Q4 = 298 Q7 = 429 T5 = 2264 T6 = 2248

CA = 1.6	W = 6750	CA = 1.6	W = 6750
N = 16	T = 1900	N = 16	T = 2000
A3 = .50	A4 = .700	A3 = .50	A4 = .700
E3 = .25	E4 = .365	E3 = .25	E4 = .365
EC = 1.479		EC = 1.334	
Q1 = 1420		Q1 = 1572	
Q2 = 768		Q2 = 739	
Q3 = 261		Q3 = 252	
Q4 = 274		Q4 = 263	
Q7 = 164		Q7 = 176	
T5 = 1965		T5 = 2060	
T6 = 1951		T6 = 2048	

CA = 1.6	W = 6750	CA = 1.6	W = 6750
N = 16	T = 2100	N = 16	T = 2200
A3 = .50	A4 = .700	A3 = .50	A4 = 700
E3 = .25	E4 = .365	E3 = .25	E4 = .365
EC = 1.220		EC = 1.131	
Q1 = 1748		Q1 = 1952	
Q2 = 705		Q2 = 666	
Q3 = 240		Q3 = 228	
Q4 = 249		Q4 = 234	
Q7 = 190		Q7 = 206	
T5 = 2154		T5 = 2249	
T6 = 2140		T6 = 2235	

CA = 1.6	W = 7850	CA = 1.6	W = 7850
N = 16	T = 1900	N = 16	T = 2000
A3 = .50	A4 = .700	A3 = .50	A4 = .700
E3 = .25	E4 = .365	E3 = .25	E4 = .365
EC = 1.607		EC = 1.439	
Q1 = 1543		Q1 = 1696	
Q2 = 914		Q2 = 885	
Q3 = 310		Q3 = 300	
Q4 = 326		Q4 = 315	
Q7 = 183		Q7 = 195	
T5 = 1978		T5 = 2073	
T6 = 1961		T6 = 2057	
CA = 1.6	W = 7850	CA = 1.6	W = 7850
N = 16	T = 2100	N = 16	T = 2200
A3 = .50	A4 = .700	A3 = .50	A4 = .700
E3 = .25	E4 = .365	E3 = .25	E4 = .365
EC = 1.307		EC = 1.203	
Q1 = 1872		Q1 = 2076	
Q2 = 852		Q2 = 813	
Q3 = 289		Q3 = 277	
Q4 = 301		Q4 = 286	
Q7 = 209		Q7 = 226	
T5 = 2167		T5 = 2261	
T6 = 2151		T6 = 2245	