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TOPICAL REPORT
THE OUTPUT CHARACTERISTICS OF A
VAPOR-DEPOSITED TUNGSTEN EMITTER
AND A MOLYBDENUM COLLECTOR

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I. INTRODUCTION

Emission data from a duplex vapor-deposited tungsten emitter and a molybdenum collector were reported in reference 1. The test vehicle was a variable spacing converter with an emitter area of 3 cm^2 , a collector area of 2 cm^2 , and an active guard ring. The data consisted of variable spacing and variable cesium families for the emitter temperature range of 1600 to 1900°K. In the present work, the performance data from this converter were extended to 2000°K, and the following additional data were obtained.

The cesiated work function of the emitter was measured for the emitter temperatures of 1600, 1700, 1800, 1900, and 2000°K and for a wide range of cesium temperatures, so that there is considerable overlap in the range of work functions for each emitter temperature. This feature makes the data useful for evaluation of work function correlations, such as T_e/T_r , since it provides sufficient data at a given value of T_e/T_r but at various values of T_e and T_r .

The collector work function was measured by back-emission and retarding-plot techniques; the results appear to be in good agreement. The dependence of output voltage on collector temperature in the high power region was compared with the dependence of collector work function on collector temperature; the two are not in agreement. Optimum collector temperature occurs at a value of T_c/T_r where the collector work function is about 0.3 eV higher than its minimum value. The discrepancy begins at a back-emission value which is much less than one percent of the forward current. According to most of the recent plasma theories,²⁻⁵ such low levels of back

emission should be negligible. The dependencies on collector temperature were recorded for a wide range of cesium pressure at interelectrode spacings of 2-1/2 and 10 mils.

II. PERFORMANCE DATA

Cesium families were obtained at an emitter temperature of 2000°K and interelectrode spacings of 0.5, 1-1/4, 2-1/2, 5, 10, 20, and 40 mils. The emitter temperature represents the temperature at the emitting surface; the collector temperature is near its optimum value for an emitter temperature of 2000°K. In order to facilitate the use of these data for analysis and correlation of converter parameters, the cesium pressures (P) and the interelectrode spacings (d) in these data are chosen to provide the Pd products of , 5, 10, 20, 40, mil-torr. A chart for converting cesium reservoir temperature to cesium pressure is shown in Table I. The data at the emitter temperature of 2000°K complete the performance map for the practical range of interest (1600 to 2000°K).

The cesium optimized performance of this converter for various interelectrode spacings is shown in Figures II-1 through II-5 for emitter temperatures of 1600, 1700, 1800, 1900, and 2000°C; the original data are presented in Appendix A. * The collector temperatures in these data were maintained close to their optimum value, and the output voltage is measured by the voltage taps at the end of the emitter heat choke; it requires a correction of 1.5 mV/amp-cm^2 for conversion to electrode voltage.

The efficiency of this converter was calculated at the spacing of 10 mils using the following equation:

*The data for the emitter temperature range of 1600 to 1900°K have been reported previously in Reference 1. They are included in Appendix A for the sake of completion, along with a description of the converter.

$$\eta = \frac{P_o}{Q_{ec} + Q_r + Q_c}$$

where η is the efficiency, P_o is the electrode power density, Q_{ec} is electron cooling, Q_r is radiation cooling, and Q_c is cesium conduction. The effective emissivity of the electrodes was assumed to be 0.18, and cesium conduction was assumed to be 1.5 watts/cm² (Figure II-6). The calculated efficiency is plotted versus emitter temperature at the electrode voltages of 0.6, 0.7, and 0.8 volt in Figure II-7.

TABLE I
CESIUM VAPOR PRESSURE

CESIUM TEMPERATURE		CESIUM PRESSURE
°C	°K	Torr
163	436	0.016
171	444	0.022
179	452	0.031
187	460	0.044
196	469	0.063
204	477	0.088
214	487	0.13
223	496	0.178
234	507	0.25
244	517	0.35
255	528	0.50
266	539	0.71
278	551	1.0
291	564	1.4
304	577	2.0
318	591	2.8
332	605	4.0
347	620	5.7
363	636	8.0
380	653	11.
398	671	16.
416	689	23.

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Figure II-1. Cesium Optimized Performance for Several Interelectrode Spacings at $T_E = 1600^\circ\text{K}$.

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Figure II-2. Cesium Optimized Performance for Several Interelectrode Spacings at $T_E = 1700^\circ\text{K}$.

68-TR-10-11

Figure II-3. Cesium Optimized Performance for Several Interelectrode Spacings at $T_E = 1800^\circ\text{K}$.

68-TR-10-14

Figure II-4. Cesium Optimized Performance for Several Interelectrode Spacings at $T_E = 1900^\circ\text{K}$.

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Figure II-5. Cesium Optimized Performance for Several Interelectrode Spacings at $T_E = 2000^\circ K$.

Figure II-6. Calculated Heat Loss as a Function of Current Density at Various Emitter Temperatures with an Emissivity of 0.18 and Cesium Conduction of 1.5 watts/cm².

Figure II-7. Calculated Efficiency at an Interelectrode Spacing of 10 mils.

III. WORK FUNCTION MEASUREMENTS

A. EMITTER WORK FUNCTION

The bare work function of the emitter was measured in our previous work¹ to be 4.87 eV (see Appendix A). In the present work, a set of emitter work function measurements was obtained for the emitter temperatures of 1600, 1700, 1800, 1900, and 2000°K. At each emitter temperature, the cesium temperature covered a wide range in order to yield the same work function values at various combinations of emitter temperature and cesium pressures. This feature makes the data useful for investigating various work function correlations. The data were obtained under highly ion-rich conditions and at an interelectrode spacing of less than 1 mil in order to minimize space charge and transport losses. The volt-ampere characteristic in this region shows a well-defined saturation (Figure III-1). The work function values were deduced from the saturation currents and Richardson's equation:

$$J = AT_E^2 \exp (-\phi_E/kT_E)$$

where J is the current density, T_E is the emitter temperature, ϕ_E is the emitter work function, k is the Boltzmann constant and A is Richardson's constant. The reduced data are presented in tabular form in Table II and are plotted in Figure III-2 as a function of inverse reservoir temperature. The analysis of these data will be presented shortly, in a separate topical report.

Figure III-1. Typical Volt-Ampere Characteristics for Emitter Work Function Measurements.

Figure III-2. Cesium Work Functions of Duplex Tungsten for Several Emitter Temperatures.

TABLE II

EMITTER WORK FUNCTION BY ELECTRON CURRENT MEASUREMENTS

Run	T_E (°K)	$kT_E \ln p/p^\circ$ *	T_R (°K)	T_E/T_R	ϕ_E (eV)	Run	T_E (°K)	$kT_E \ln p/p^\circ$ *	T_R (°K)	T_E/T_R	ϕ_E (eV)
36253	1600	-2.70	425	3.77	3.77	36282	1800	-2.49	514	3.50	3.26
36254	1600	-2.58	444	3.60	3.45	36283	1800	-2.43	526	3.42	3.16
36255	1600	-2.51	456	3.51	3.31	36284	1800	-2.38	536	3.36	3.07
36256	1600	-2.43	471	3.40	3.15	36285	1900	-3.27	417	4.56	4.49
36257	1600	-2.37	482	3.32	3.04	36286	1900	-3.19	428	4.44	4.38
36258	1600	-2.31	494	3.24	2.94	36287	1900	-3.10	440	4.32	4.28
36259	1600	-2.27	502	3.19	2.87	36288	1900	-3.02	450	4.22	4.18
36264	1700	-2.94	415	4.10	4.05	36289	1900	-2.94	462	4.11	4.05
36265	1700	-2.86	427	3.98	3.94	36290	1900	-2.87	473	4.02	3.92
36266	1700	-2.79	437	3.89	3.81	36291	1900	-2.80	484	3.93	3.82
36267	1700	-2.72	448	3.80	3.68	36292	1900	-2.73	496	3.83	3.70
36268	1700	-2.66	458	3.71	3.57	36293	1900	-2.67	507	3.75	3.59
36269	1700	-2.59	469	3.63	3.46	36294	1900	-2.61	517	3.68	3.50
36270	1700	-2.47	490	3.47	3.24	36295	1900	-2.56	528	3.60	3.38
36271	1700	-2.38	509	3.34	3.05	36296	1900	-2.50	540	3.52	3.27
36272	1700	-2.29	528	3.22	2.91	36298	2000	-3.38	425	4.71	4.58
36273	1800	-3.10	417	4.32	4.28	36299	2000	-3.27	438	4.57	4.49
36249	1800	-3.08	420	4.29	4.24	36300	2000	-3.19	449	4.45	4.40
36274	1800	-3.02	428	4.21	4.16	36301	2000	-3.11	460	4.35	4.30
36275	1800	-2.93	440	4.09	4.03	36302	2000	-3.03	471	4.25	4.19
36250	1800	-2.90	445	4.05	3.97	36303	2000	-2.95	483	4.14	4.08
36276	1800	-2.86	450	4.00	3.91	36304	2000	-2.88	495	4.04	3.96
36277	1800	-2.80	460	3.91	3.81	36305	2000	-2.81	507	3.95	3.84
36278	1800	-2.73	471	3.82	3.69	36306	2000	-2.75	518	3.86	3.73
36279	1800	-2.67	482	3.73	3.57	36307	2000	-2.69	529	3.78	3.62
36280	1800	-2.60	493	3.65	3.46	36308	2000	-2.61	544	3.68	3.49
36281	1800	-2.55	503	3.58	3.36						

* $p^\circ = 3 \times 10^{-6}$ torr

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B. COLLECTOR WORK FUNCTION MEASUREMENTS

The first step in this investigation was to determine the collector work function by retarding and back-emission techniques. The difficulties in such measurements are well known and the sources of error are discussed in references 6 and 7. Interelectrode spacing and emitter temperature are two of the important parameters that influence collector work function measurements and were first observed by Breitwieser⁶ and Houston.⁷ A detailed discussion and analysis of these effects is given by Hansen.⁸

In the retarding technique, collector work function was deduced from the Boltzmann region of the volt-ampere characteristics and the equation

$$J = AT_E^2 \exp \left(- \frac{\phi_c + V}{kT_E} \right)$$

The interelectrode spacing was kept at 1 mil where the transport losses are low.⁹ The emitter and collector temperatures were chosen so that ion current and back-emission were much lower than electron current in the Boltzmann region. Typical raw data are shown in Figures III-3 and III-4 and in Appendix C.

In the back-emission technique, the collector work function is deduced from the measurements of the collector saturation current. Data were obtained at the interelectrode spacing of 1 mil to minimize transport losses and emitter temperatures much lower than 1300°K where ion currents are negligible. At higher emitter temperatures, the reverse current showed a dependence upon emitter temperature which was much stronger than that expected

from the Saha-Langmuir equation. This phenomenon has been observed previously by Houston.⁷ Typical raw data are shown in Figure III-5 and in Appendix D, and a summary of the results obtained by the two techniques is shown in Figure III-6. These points represent the region where it was possible to obtain collector work function data from this converter. An attempt was made to extend this region; however, it was not possible to obtain well-defined Boltzmann lines or saturation currents. The collector work function values obtained by the two techniques appear to be in good agreement.

The present data are compared with collector work function data reported in reference 10 (Figure III-7). The previous data show a lower collector work function. In the present converter, the interelectrode space is surrounded by niobium shields to minimize oxygen partial pressure during the outgassing of the converter. The converter in reference 10 was not equipped with this feature. It is possible that the lower collector work function in reference 10 is caused by a thin layer of molybdenum oxide on the collector.

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Figure III-3. Typical Volt-Ampere Characteristics for Retarding Plot Measurements.

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Figure III-4. Typical Raw Data for Collector Work Function Measurements.

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Figure III-5. Typical Raw Data for Collector Work Function Measurements by Back-Emission Technique.

Figure III-6. Work Function of Molybdenum Collector by Back-Emission and Retarding Plot Techniques.

Figure III-7. Comparison of the Present Collector Work Function Data with Previous Work.

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IV. DEPENDENCE OF THE VOLT-AMPERE CHARACTERISTICS ON COLLECTOR TEMPERATURE

The effect of collector work function and temperature on the volt-ampere characteristics has been the subject of minimal experimental or theoretical investigations. In principle, variations in collector temperature influence the volt-ampere characteristics by changing collector work function and back emission. Under the conditions where back-emission is small (low collector temperature and high work function), an increase in temperature results in a decrease in work function, and, hence, in an increase in output voltage such that:

$$\Delta V = -\Delta\phi_c$$

At the other extreme, where the collector temperature is high, the effect of back-emission becomes important and the above equality does not hold true. It is not known, however, when back-emission becomes important. Based upon most of the recent plasma theories,²⁻⁵ back-emission becomes important when it is comparable to the forward electron current. Experimental results, however, show discrepancies at back-emission values which are much lower than forward current.

Preliminary data were reported¹¹ on the effect of collector temperature on output voltage. The results showed that depending on the value of cesium pressure, ΔV can be less than or greater than $\Delta\phi_c$. The discrepancies could not be accounted for by back-emission or by the presence of a double sheath, as suggested in Reference 12. Using the preliminary data, it was not possible to define accurately the deviations between ΔV and $\Delta\phi_c$ under various operating conditions.

The raw data in the previous work were obtained by recording the output voltage as collector temperature was varied; hence, there is a possibility that the data points did not belong to the same region of the J-V characteristics. Complete J-V curves were not obtained to show the mode of operation.

The purpose of the present work is to record the dependence of the I-V characteristics on collector temperature in a systematic manner so that it can be compared with the dependence of collector work function on collector temperature. An attempt was made to separate the contributions of collector work function and back emission.

The first step in this investigation was to determine the collector work function accurately near the high power region, which is of practical interest. The collector work function measurements are presented in Section IIIB of this report. A series of J-V characteristics was obtained by varying the collector temperature in the range of 600 to 1000°K while the other converter variables were held constant. The data cover the cesium reservoir temperature range of 560 to 620°K, at an emitter temperature of 1800°K and interelectrode spacings of 2-1/2 and 10 mils.

A typical collector family is shown in Figure IV-1 and the rest of the data are shown in Appendix D. Increasing the collector temperature in the range of 630 to 775°K corresponds to a monotonic translation of the J-V curve in the positive voltage direction. Further increase in collector temperature still results in an increase in output voltage, but at a lower rate. When the collector temperature exceeds the value of 970°K, an increase in collector

Figure IV-1. Typical Raw Data Showing the Dependence of J-V Characteristics on Collector Temperature.

temperature corresponds to a decrease in output voltage. A crossplot of these data at the current density of 12 amps/cm^2 is shown in Figure IV-2. This value of current density was selected because it is near the optimum power point of the J-V curve and is in the same region of J-V characteristics for all of the collector temperatures.

If back-emission were negligible, the curve in Figure IV-2 would have exactly the same shape as the collector work function curve. It is interesting to determine where the two curves depart from each other. For this purpose, the curve in Figure IV-2 is superimposed on the collector work function plot in Figure IV-3. Note that the ordinate in Figure IV-2 expresses the variations in output voltage; its reference point is therefore arbitrary and can be selected so that the variations in output voltage coincide with the variations in collector work function at the low values of T_c/T_r . Under these conditions, the collector work function is high and its temperature is low; hence, back-emission is low. The variation in output voltage follows the changes in collector work function exactly up to a T_c/T_r of approximately 1.3; then it levels cut while the collector work function keeps on decreasing.

The data obtained at other cesium temperatures are shown to have the same general characteristics (Figure IV-4). Similar data for the interelectrode spacing of 10 mils is shown in Figure IV-5. It is clear that the curves follow the collector work function data closely in the T_c/T_r range of 1 to 1.3, and that they indicate a definite departure as the temperature ratio is further increased. It is surprising to note, however, that the back-emission currents at the departure point are approximately 10^{-4} to $10^{-3} \text{ amps/cm}^2$,

Figure IV-2. Crossplot of Figure IV-1 at a Current Density of 12 amps/cm².

Figure IV-3. Superposition of Figure IV-2 on Collector Work Function Plot.

Figure IV-4. Summary of the Data at Several Cesium Temperatures and Current Levels for the Interelectrode Spacing of 2-1/2 mils.

Figure IV-5. Summary of the Data at Several Cesium Pressures and Current Levels for the Interelectrode Spacing of 10 mils.

while the forward currents are several orders of magnitude higher. According to most plasma theory, such low levels of back-emission should be negligible.

The departure from the collector work function curve, V^* (Figure IV-3), is plotted as a function of back-emission current J_c in Figure IV-6 and as a function of the ratio J_c/J in Figure IV-7. Neither of the two plots shows a good correlation. The discrepancy between the variations in voltage and the ϕ_c curve can be caused by several phenomena. As suggested in reference 1, a double sheath could be built up at the collector side to limit back-emission current below a certain level. However, the criterion or mechanism for this phenomenon is unknown. As shown in Figure IV-6, 100 mV discrepancy occurs at a back-emission value of 10 mAmps and at a forward current value of 2 amps. In reference 1, it is suggested that the double sheath is built up to maintain the inequality:

$$J + 2 J_c \leq 500 J_i$$

where J is forward current, J_c is back-emission current, and J_i is ion current at the collector side of the plasma. The data are not in agreement with this relation, since the back-emission is less than one percent of the forward current. To keep the left-hand side constant, the output voltage has to change by only 1 mV (using either Richardson's equation or the shape of the I-V curves in Figure IV-1), as compared to the 100 mV which is actually observed. This relation also suggests that the level at which back-emission becomes significant depends upon the value of ion current. It is shown in reference 2 that changing the Pd from 3 to 15 mil-torr

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Figure IV-6. Deviations from the Collector Work Function Plot as a Function of Back Emission Current.

Figure IV-7. Deviations from the Collector Work Plot Function as a Function of J_c/J

causes a substantial change in ion current. The present data were obtained at the interelectrode spacings of 2-1/2 and 10 mils, covering the Pd range of 3 to 17 mil-torr. No definite dependence upon Pd was observed. Furthermore, ion current and other plasma properties are expected to depend upon the mode of operation (position on the J-V curve). The raw data in Figure IV-1 show that a change in collector temperature produces approximately the same change in voltage in all regions of the J-V characteristics.

The discrepancy can also be caused by the T_c/T_r correlation which is used in this analysis. This appears unlikely, because the work function measurements were performed for the cesium temperature range of 420 to 570°K and the collector temperature range of 670 to 900°K. The collector temperature effects were studied in the cesium temperature range of 560 to 1000°K; hence, there is a considerable region of overlap. One other possible explanation for the discrepancy is that retarding plots or back-emission measurements are invalid techniques for collector work function determinations. Unfortunately, a third technique is not available at the present time to evaluate this possibility. The present data indicate a discrepancy of 0.2 eV between the measured collector work function and that which can be achieved in the practical region of operation. This would reduce the presently accepted value of the internal arc drop by 0.2 eV.

In summary, as the collector temperature is increased in the T_c/T_r range of 1 to 1.3, an increase in voltage is observed that is in good agreement with the decrease in collector work function; i. e.,

$$\Delta V = - \Delta \phi_c .$$

As the collector temperature is further increased, ΔV becomes smaller than $\Delta\phi_c$, and, finally, the output voltage decreases while the collector work function still decreases. The qualitative nature of this behavior is expected; however, it is surprising that the departure from the above relation occurs at such low values of collector temperature or back-emission. For example, a difference of 0.1 volt is observed between ΔV and ϕ_c at a back-emission value of 10^{-2} amps, as compared to a forward current of 2 amps. According to most of the plasma theories for these current levels, the difference between ΔV and $\Delta\phi_c$ should be of the order of 10^{-3} volts. At the present, it is not possible to determine whether the discrepancy is due to plasma or surface phenomena.

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V. ION CURRENT MEASUREMENTS

The data used for the retarding plots (Section IIIB and Appendix B) are also quite appropriate for ion current measurements, since, under these conditions, the emitter is electron-rich and the interelectrode spacing is low so that ion space charge and transport losses are minimized. The reverse current in these data can be entirely attributed to ion current, because the emitter temperature is 1500°K and the collector temperatures are lower than 670°K. The measured ion current values tabulated in Table III are used to calculate the emitter work function from Saha-Langmuir equation:

$$\frac{J_p}{\mu} = \frac{1}{1 + 2 \exp [(V_i - \phi_e)/kT_e]}$$

where J_p is ion current, μ is arrival rate, V_i is ionization potential, ϕ_e is emitter work function, k is Boltzmann constant, and T_e is emitter temperature. The emitter work function values obtained by this technique are compared to those determined by measurements of electron saturation current (Section IIIA) in Figure V-1. It is interesting to notice that the two sets of data are in good agreement except for the work function values in the vicinity of 2.7 eV. In this region, the work function determined from ion current is lower than the true work function because the ion richness value is close to unity and the flow of ions begins to be impeded by space charge. The quantity $kT_e \ln P$ is similar to T_e/T_R . Its significance will be discussed in a later report.

TABLE III
EMITTER WORK FUNCTION BY ION CURRENT MEASUREMENTS

Run	T_E , °K	T_R , °K	T_E/T_R	$k T_E \ln p/p^\circ$	J_i , A/cm ²	ϕ_E , eV
36316	1500	560	2.68	-1.90	2.7×10^{-5}	2.18
36317	1500	575	2.60	-1.84	2.6×10^{-5}	2.13
36321	1500	540	2.78	-1.97	3.7×10^{-5}	2.30
36322	1500	520	2.89	-2.05	5.0×10^{-5}	2.41
36323	1500	500	3.00	-2.14	8.2×10^{-5}	2.56
36324	1500	480	3.13	-2.23	1.2×10^{-4}	2.71
36371	1500	416	3.15	-2.35	1.4×10^{-4}	2.75
36372	1500	494	3.04	-2.16	7.5×10^{-5}	2.56
36373	1500	517	2.90	-2.06	4.0×10^{-5}	2.40
36374	1500	537	2.79	-1.98	3.3×10^{-5}	2.29

* $p^\circ = 3 \times 10^6$ torr.

Figure V-1. Comparison of Emitter Work Function Determined by Electron and Ion Saturation Currents.
($p^0 = 3 \times 10^6$ torr)

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APPENDIX A

PERFORMANCE AND VARIABLE SPACING DATA FROM
A DUPLEX VAPOR-DEPOSITED TUNGSTEN EMITTER
WITH A MOLYBDENUM COLLECTOR

68-TR-12-2

Figure A-1. Schematic Diagram of a Research Thermionic Converter.

68-TR-11-19

Figure A-2. Cross-Section of Emitter Showing Columnar Deposit of Tungsten from the Chloride Which Provides Emitting Surface.

68-TR-10-16

Figure A-3. Summary of Bare Work Function Data.

68-TR-10-2

Figure A-4. Emitter Work Function Data.

68-TR-11-3

Figure A-5. Variable Cesium Pressure Family at $T_E = 1600^\circ \text{K}$ and $d = 0.5 \text{ mils}$.

68-TR-11-4

Figure A-6. Variable Cesium Pressure Family at $T_E = 1600^\circ K$ and $d = 1.25 \text{ mils}$.

68-TR-11-5

Figure A-7. Variable Cesium Pressure Family at $T_F = 1600^\circ \text{ K}$ and $d = 2.5 \text{ mils}$.

68-TR-10-40

Figure A-8. Variable Cesium Pressure Family at $T_f = 1600^\circ K$ and $d = 5 \text{ mils}$.

68-TR-10-41

Figure A-9. Variable Cesium Pressure Family at $T_g = 1600^\circ \text{ K}$ and $d = 10 \text{ mils}$.

68-TR-11-6

Figure A-10. Variable Cesium Pressure Family at $T_f = 1600^\circ \text{K}$ and $d = 20 \text{ mils}$.

68-TR-11-7

Figure A-11. Variable Cesium Pressure Family at $T_e = 1600^\circ \text{ K}$ and $d = 40 \text{ mils}$.

68-TR-11-11

Figure A-12. Variable Cesium Pressure Family at $T_f = 1700^\circ \text{K}$ and $d = 0.5 \text{ mils}$.

68-TR-11-12

Figure A-13. Variable Cesium Pressure Family at T_e = 1700°K and d = 1.25 mils.

68-TR-11-13

Figure A-14. Variable Cesium Pressure Family at $T_f = 1700^\circ\text{K}$ and $d = 2.5 \text{ mils}$.

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Figure A-15. Variable Cesium Pressure Family at $T_e = 1700^\circ \text{ K}$ and $d = 5 \text{ mils}$.

68-TR-10-39

Figure A-16. Variable Cesium Pressure Family at $T_e = 1700^\circ \text{ K}$ and $d = 10 \text{ mils}$.

68-TR-11-14

Figure A-17. Variable Cesium Pressure Family at $T_f = 1700^\circ \text{K}$ and $d = 20 \text{ mils}$.

68-TR-11-15

Figure A-18. Variable Cesium Pressure Family at $T_e = 1700^\circ \text{K}$ and $d = 40 \text{ mils}$.

68-TR-11-9

Figure A-19. Variable Cesium Pressure Family at $T_e = 1800^\circ \text{K}$ and $d = 1.25 \text{ mils}$.

68-TR-10-35

Figure A-20. Variable Cesium Pressure Family at $T_e = 1800^\circ \text{K}$ and $d = 2.5 \text{ mils}$.

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Figure A-21. Variable Cesium Pressure Family at $T_e = 1800^\circ \text{ K}$ and $d = 5 \text{ mils}$.

.68-TR-10-37

Figure A-22. Variable Cesium Pressure Family at $T_e = 1800^\circ \text{ K}$ and $d = 10 \text{ mils}$.

68-TR-11-10

Figure A-23. Variable Cesium Pressure Family at $T_f = 1800^\circ \text{ K}$ and $d = 20 \text{ mils}$.

68-TR-11-16

Figure A-24. Variable Cesium Pressure Family at $T_e = 1900^\circ \text{ K}$ and $d = 0.5 \text{ mils}$.

68-TR-11-17

Figure A-25. Variable Cesium Pressure Family at T_E = 1900° K and d = 1.25 mils.

68-TR-10-34

Figure A-26. Variable Cesium Pressure Family at $T_e = 1900^\circ \text{ K}$ and $d = 2.5 \text{ mils}$.

68-TR-10-32

Figure A-27. Variable Cesium Pressure Family at $T_f = 1900^\circ \text{ K}$ and $d = 5 \text{ mils}$.

68-TR-10-33

Figure A-28. Variable Cesium Pressure Family at $T_f = 1900^\circ \text{K}$ and $d = 10 \text{ mils}$.

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Figure A-29. Variable Cesium Pressure Family at $T_f = 1900^\circ \text{K}$ and $d = 20 \text{ mils}$.

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Figure A-30. Variable Cesium Pressure Family at $T_e = 2000^\circ\text{K}$ and $d = 0.5 \text{ mils}$.

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Figure A-31. Variable Cesium Pressure Family at $T_t = 2000^\circ\text{K}$ and $d = 1.25 \text{ mils}$.

69-TR-6-5

Figure A-32. Variable Cesium Pressure Family at $T_g = 2000^\circ\text{K}$ and $d = 2.5 \text{ mils}$.

69-TR-6-6

Figure A-33. Variable Cesium Pressure Family at $T_f = 2000^\circ\text{K}$ and $d = 5 \text{ mils}$.

69-TR-6-7

Figure A-34. Variable Cesium Pressure Family at $T_f = 2000^\circ\text{K}$ and $d = 10 \text{ mils}$.

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69-TR-6-8

Figure A-35. Variable Cesium Pressure Family at $T_f = 2000^\circ\text{K}$ and $d = 20 \text{ mils}$.

69-TR-6-9

Figure A-36. Variable Cesium Pressure Family at $T_f = 2000^\circ\text{K}$ and $d = 40 \text{ mils}$.

Figure A-37. Cesium Optimized Performance for Several Interelectrode Spacings at $T_E = 1600^\circ\text{K}$.

Figure A-38. Cesium Optimized Performance for Several Interelectrode Spacings at $T_E = 1700^\circ\text{K}$.

Figure A-39. Cesium Optimized Performance for Several Interelectrode Spacings at $T_E = 1800^\circ\text{K}$.

Figure A-40. Cesium Optimized Performance for Several Interelectrode Spacings at $T_E = 1900^\circ\text{K}$.

Figure A-41. Cesium Optimized Performance for Several Interelectrode Spacings at $T_E = 2000^\circ K$.

Figure A-42. Fully Optimized Performance at Several Emitter Temperatures.

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Figure A-43. Variable Spacing Family at $\beta = 10$ and $P = 0.5 \text{ torr}$.

68-TR-10-51

Figure A-44. Variable Spacing Family at $\beta = 10$ and $P = 1 \text{ torr}$.

68-TR-10-46

Figure A-45. Variable Spacing Family at $\beta = 10$ and $P = 2 \text{ torr}$.

68-TR-10-42

Figure A-46. Variable Spacing Family at $\beta = 1$ and $P = 0.5 \text{ torr}$.

68-TR-10-48

Figure A-47. Variable Spacing Family at $\beta = 1$ and $P = 1 \text{ torr}$.

68-TR-10-45

Figure A-48. Variable Spacing Family at $\beta = 1$ and $P = 2$ torr.

68-TR-10-49

Figure A-49. Variable Spacing Family at $\beta = 1$ and $P = 4 \text{ torr}$.

68-TR-10-47

Figure A-50. Variable Spacing Family at $\beta = 0.1$ and $P = 1 \text{ torr}$.

68-TR-10-44

Figure A-51. Variable Spacing Family at $\beta = 0.1$ and $P = 2$ torr.

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68-TR-10-50

Figure A-52. Variable Spacing Family at $\beta = 0.1$ and $P = 4$ torr.

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68-TR-10-46A

Figure A-53. Extinguished Mode Data for Several Interelectrode Spacings at $T_E = 1780^\circ K$

68-TR-10-44A

Figure A-54. Extinguished Mode Data for Several Interelectrode Spacings at $T_E = 1705^\circ K$

Figure A-55. Extinguished Mode Data for Several Interelectrode Spacings at $T_E = 1660^\circ K$

Figure A-56. Extinguished Mode Data for Several Interelectrode Spacings at $T_E = 1635^\circ K$.

68-TR-10-28 ,

Figure A-57. Emission Map of the Emitter Showing Location of the Data Points.

- Work Function Data
- △ Cesium Families
- Spacing Family

Figure A-58. Plot Showing the General Shape of the Volt-Ampere Characteristics as a Function of Pd and β .

APPENDIX B

DATA FOR COLLECTOR WORK FUNCTION
MEASUREMENTS BY RETARDING TECHNIQUE

B-1

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B-3

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69-TR-6-29

B-5

69-TR-6-30

HERMO ELECTRON
CORPORATION

69-TR-6-31

B-7

69-TR-6-32

THE THERMO ELECTRIC CORPORATION

THERMO ELECTRON
CORPORATION

69-TR-6-33

B-9

69-TR-6-34

HERMO ELECTRON
CORPORATION

69-TR-6-35

APPENDIX C

DATA FOR COLLECTOR WORK FUNCTION
MEASUREMENTS BY BACK-EMISSION TECHNIQUE

C-1

69-TR-6-36

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C-2

69-TR-6-37

HERMO ELECTRON
CORPORATION

C-3

69-TR-6-40

THERMO ELECTRON
CORPORATION

C-4

69-TR-6-38

 THERMO ELECTRON

 CORPORATION

C-5

69-TR-6-39

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APPENDIX D

TYPICAL RAW DATA SHOWING THE DEPENDENCE
OF OUTPUT CHARACTERISTICS ON
COLLECTOR TEMPERATURE

69-TR-7-1

69-TR-7-2

69-TR-7-3

69-TR-7-4