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TECHNICAL REPORT ECOM-01698-6

LONG-LIFE COLD CATHODE STUDIES FOR CROSSED-FIELD TUBES

PROGRESS REPORT

by

L. Lesensky - M. Arnum - C.R. McGeoch

JULY 1967

ECOM

UNITED STATES ARMY ELECTRONICS COMMAND · FORT MONMOUTH, N.J.

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Contract DA28-043-AMC-01698 (E)

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Technical Report ECOM-01698-6 July 1967

LONG-LIFE COLD CATHODE STUDIES FOR CROSSED-FIELD TUBES

Sixth Quarterly Report

15 January to 15 April 1967

Report No. 6
Contract No. DA28-043-AMC-01698(E)
DA Project No. 7900-21-223-12-00

Prepared by

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U.S. Army Electronics Command
Fort Monmouth, N.J.

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ABSTRACT

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A polished beryllium target was evaluated in the Electron Bombardment Vehicle (EBV) for 38 hours. δ was observed as a function of electron bombardment level (up to 0.5 amps/cm^2), sense of electric field in front of target, and partial pressure of oxygen. An aluminum target (alloy 6061) was similarly evaluated in the EBV for 92 hours. The possibility of stabilizing δ_{max} of either target at values of 3 to 4 through the use of oxygen pressures of 5×10^{-6} to 1×10^{-5} torr in the presence of electron bombardment at 0.5 amps/cm^2 was indicated by the results.

A barium-calcium-aluminate impregnated tungsten emitter was operated at full power in the QKS1194 test vehicle prior to thermal activation.

An aluminum cold cathode was evaluated in the high-stress level CFA test vehicle QKS1397. Operation at 0.001 duty cycle and approximately 3 amps/cm^2 electron bombardment was stabilized using oxygen pressures in the range 10^{-6} to 10^{-5} torr.

FOREWORD

Long-life cold cathode studies for crossed-field tubes are authorized by the United States Army Electronics Command, Fort Monmouth, New Jersey, under DA Project No. 7900-21-223-12-00. The work was prepared under the support of the Advanced Research Projects Agency under Order No. 345 and is conducted under the technical guidance of the U. S. Army Electronics Command, Fort Monmouth, N. J. 07703.

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1. INTRODUCTION

The objective of the present cold cathode study program is to achieve long life cold cathode performance for crossed-field amplifiers. This program is being performed for the United States Army Electronics Command, Fort Monmouth, New Jersey, under contract DA-28-043-AMC-01698 (E).

In this study, selected cold cathode materials will be evaluated as to: their secondary emission properties, their ability to withstand environmental factors expected in a crossed-field amplifier, and their crossed-field amplifier performance. Based on the above experimental information and pertinent theoretical calculations, a life prediction chart will be established for a number of cold cathode materials.

The program is divided into two concurrent phases, Phase A being concerned with the measurement of various pertinent properties of cold cathode materials outside of the tube environment, and Phase B involving the evaluation and life testing of selected cathodes in a crossed-field amplifier.

The first quarterly report of this contract (Technical Report ECOM 01698-1) contains a discussion of the objectives and plans for the over-all program. Quarterly report no. 5 contains a description of the CFA test vehicles used in this program.

2. PHASE A - MATERIALS EVALUATION

2.1 Polished Beryllium Sample No. 3. Data on δ_{max} vs time for Be sample no. 2, under various conditions of electron bombardment in the EBV, were reported in the fifth quarterly report. Near the end of that experimental run of approximately 80 hours, a water failure caused over-heating of the Be target and reduction of the secondary emission ratio. Upon subsequent disassembly, the surface of the Be target was found to be slightly darkened in the bombarded area. Also, several small dark spots (holes or pits) were present.

The Be sample no. 2 was polished to remove the darkened area. It was then reinstalled in the EBV as Be sample no. 3. The data obtained in the EBV are shown in Figure 1. δ_{max} is plotted for a period of 38 hours in the EBV. Observations were directed toward determining:

1. the effects of varying the electron bombardment level,
2. the sense of the electric field in front of the target, and
3. the presence of O_2 at partial pressures in the range of $1\text{-}3 \times 10^{-6}$ torr.

In Figure 1, the number appearing immediately above the δ_{max} values, e.g. 3, 10, etc., represents the target bombardment current in milliamperes 10 ma bombardment corresponds to a current density of 0.5 amp/cm^2. The electric field in front of the target is denoted as negative if the target potential is lower than the anode potential. In this condition, for example, positive ions will be driven into the target.

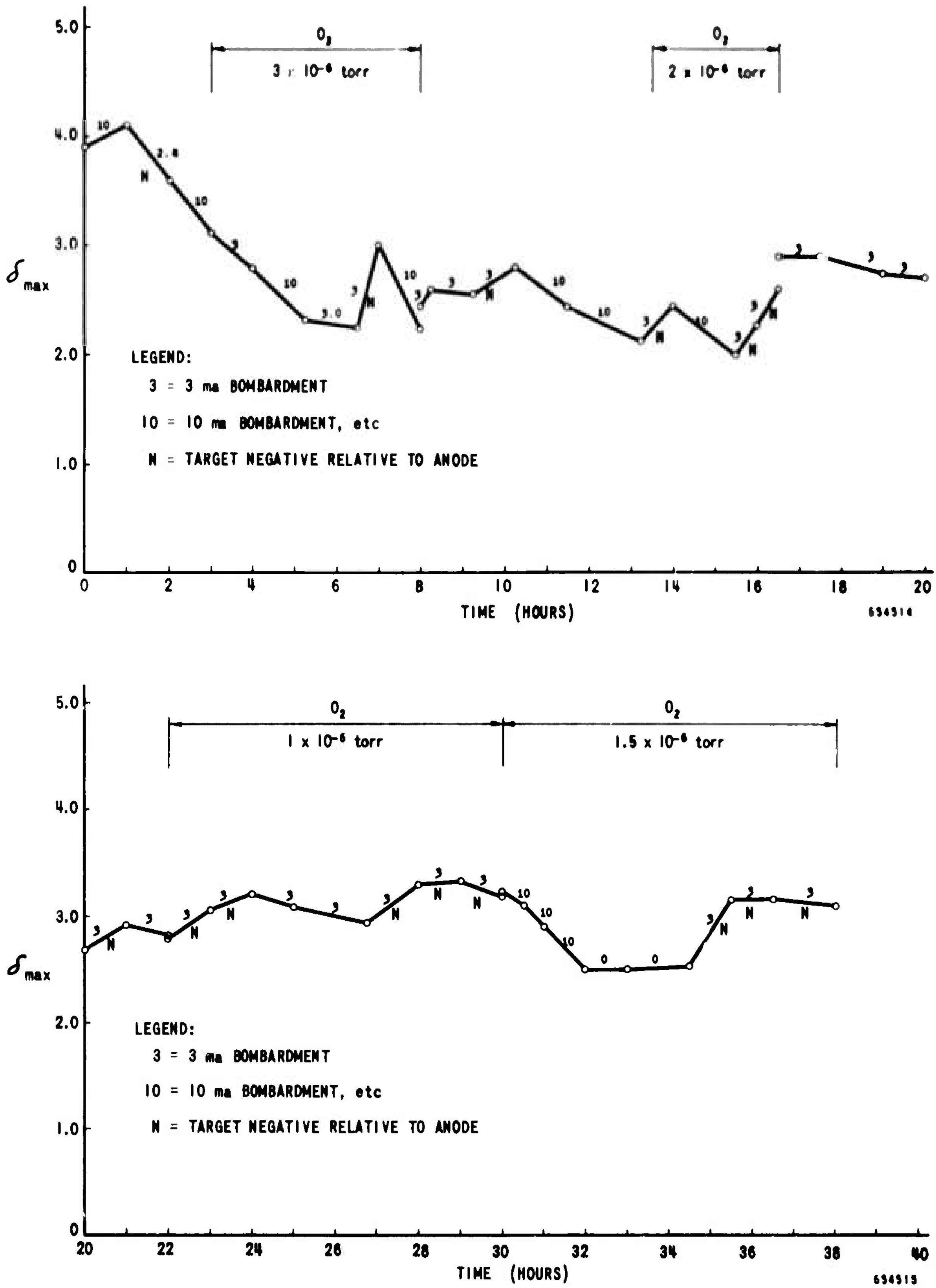


Figure 1. δ_{max} vs Electron Bombardment Time for Polished Beryllium Sample No. 3

It is observed that the degradation of δ was greater at 10 ma than at 3 ma. Also, while positive-sense bombardment at 3 ma caused δ to decrease, negative-sense bombardment at this level usually caused δ to increase. It is supposed that the bombardment of the target by positive oxygen ions may be responsible for this effect. It appeared possible to achieve and maintain a δ_{max} of approximately 3.2 for this Be sample under conditions of negative-sense bombardment at the 3 ma level. Negative-sense bombardment is considered to be more simulative of the conditions in the CFA.

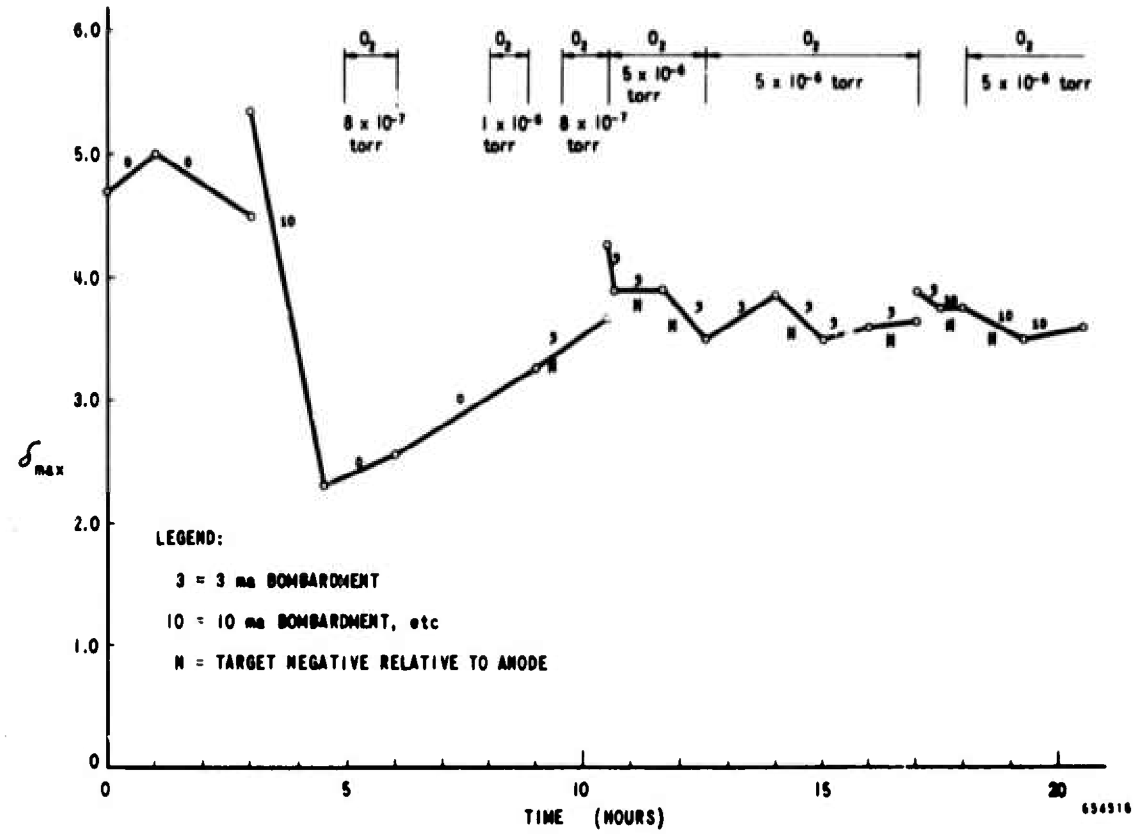
It seems that electron bombardment of oxides causes δ to decrease due to the displacement and removal of oxygen atoms. The depth from which oxygen atoms can escape from the surface will be limited and depend on oxide structure, temperature, and electron bombardment energy and density. A partial pressure of oxygen can suppress the process. A negative electric field in front of the target can cause further enhancement of δ due to oxygen ion bombardment; the degree of enhancement would presumably depend on the energy and density of the bombardment.

Figure 1a shows recovery of δ while the equipment is off overnight; this can be seen at t = 8 hours and t = 16.5 hours. The effect has been previously reported in this program. It is possible that a relaxation of the dislocated oxygen atoms occurs during the off period.

2.2 Aluminum Target, Alloy 6061. An aluminum target (alloy 6061) was cleaned and the surface prepared in a manner similar to that required for plating. The aluminum target was then mounted in the EBV and evaluated for 92 hours. The resultant data are summarized in Figure 2. The same parameters were investigated as for the Be sample no. 3, namely, the level of electron bombardment, the sense of the electric field in front of the target, and the presence of O_2. The residual gas pressure was approximately 5×10^{-8} torr. Additional oxygen was supplied from an auxiliary, thermally activated, CuO source.

The initial value of δ_{max} was approximately 5 and stands out as an unexpected result. Previous δ measurements here on room temperature, air-oxidized, aluminum alloy 6061 showed δ_{max} values of approximately 2. δ_{max} values ≈ 5 have been obtained for bulk, crystalline, aluminum oxide. We have also observed such high δ values for Al_2O_3 films deposited on a M_o substrate by electron beam evaporation techniques. However all previous room temperature, air-oxidized, aluminum samples had δ_{max} values less than 2.5 and typically 2.0. Further effort on the present program will be directed to discovering oxide film properties which give higher δ values.

Figure 2a shows that bombardment at the 10 ma level (i.e. 0.5 amps/cm^2) results in rapid degradation of δ and some recovery occurs with the beam turned off. As seen in Figure 2c, an O_2 pressure of 1×10^{-5} torr was sufficient to maintain a δ_{max} in excess of 3 during 0.5 amps/cm^2 bombardment. O_2 pressures less than 5×10^{-6} torr allowed degradation at this bombardment level. It appears that, in general, O_2 pressures in the range 10^{-6} - 10^{-5} torr are needed to maintain δ of an aluminum target at high bombardment levels.



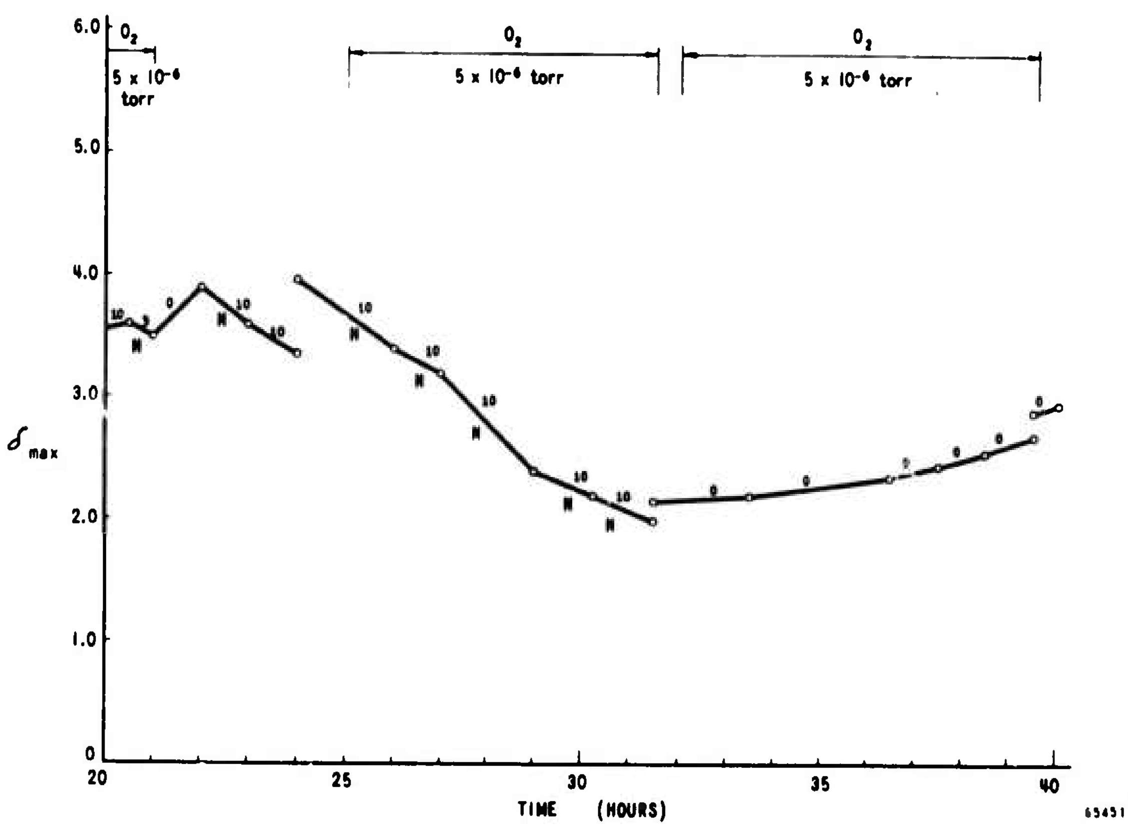


Figure 2. δ_{max} vs Time in Electron Bombardment Vehicle for Aluminum (Alloy 6061) Target

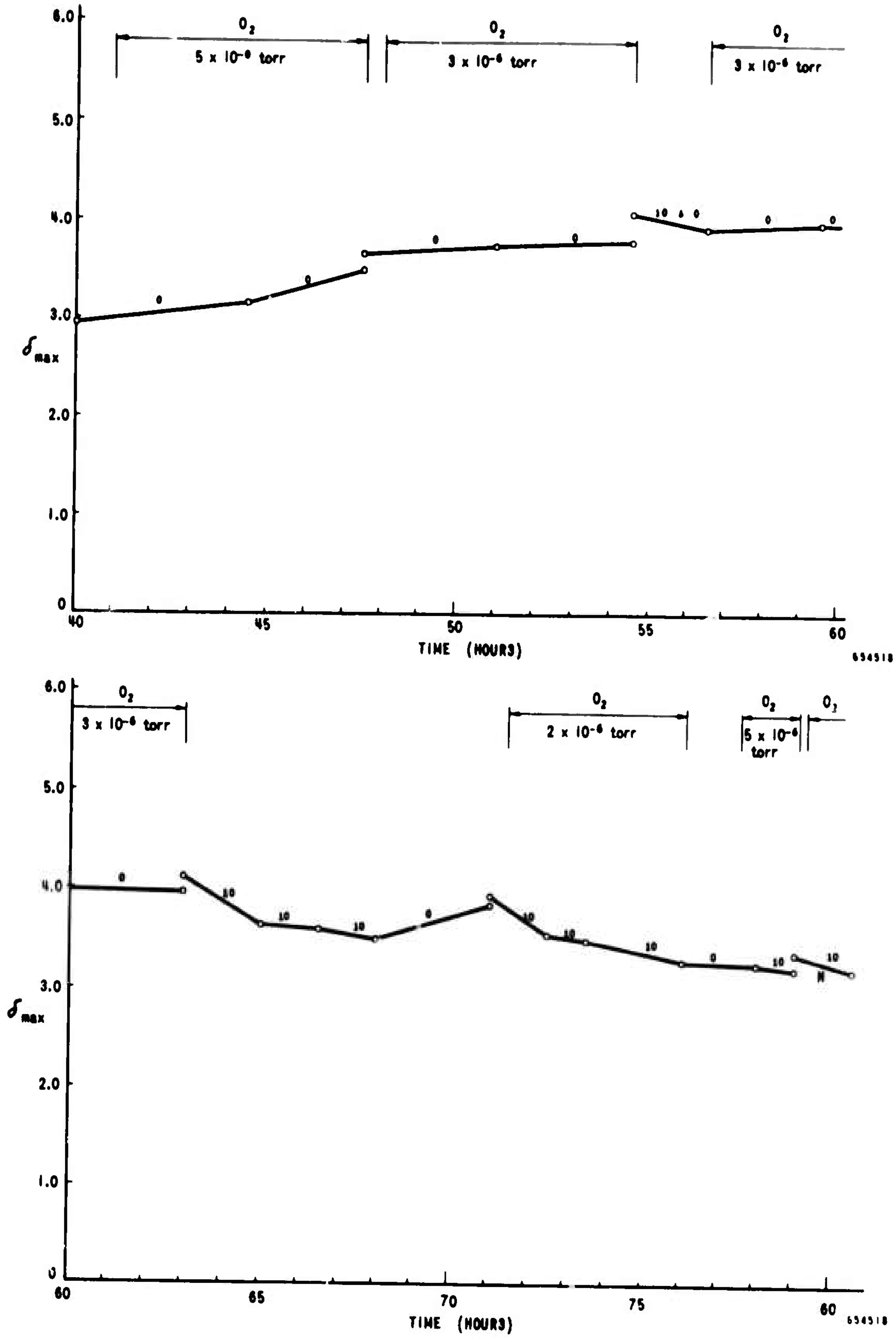


Figure 2. δ_{max} vs Time in Electron Bombardment Vehicle for Aluminum (Alloy 6061) Target (continued)

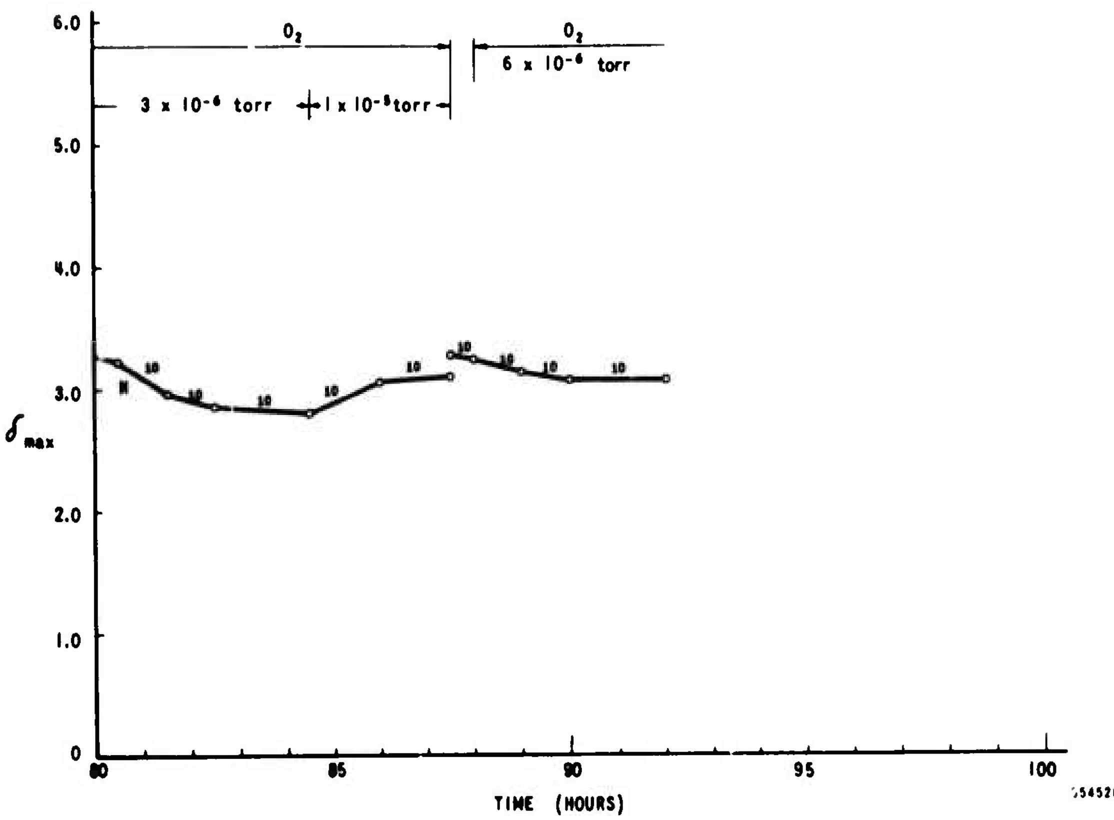


Figure 2. δ_{max} vs Time in Electron Bombardment Vehicle for Aluminum (Alloy 6061) Target (continued)

2.3 Boron Nitride Films. Two additional 200 Å boron nitride film samples were prepared during this quarter by chemical-vapor-deposition techniques on a well outgassed, clean, molybdenum substrate. These will be evaluated in the EBV during the next quarterly period.

2.4 Impregnated Tungsten Sample in Hot/Cold EBV. A standard barium-calcium-aluminate impregnated tungsten sample was installed in the hot/cold EBV. Observations of δ_{max} vs time were made over a period of one week. δ_{max} varied between 1.4 and 2.2 while repeated heating at 1100 °C was carried out to activate the sample. The auxiliary oxygen source was used but δ_{max} never exceeded 2.2. Upon disassembly it was discovered that the sample appeared to be coated with foreign material due to the reaction of the alumina insulation with the tungsten heater. The hot/cold EBV is being repaired.

2.5 High Stress Level EBV. In accordance with the revised program for the second half of the contract period, it is desirable to evaluate the effect of high current density electron bombardment (5 to 10 amps/cm^2) on δ. The EBV will be operated at as high a current density as can be achieved consistent with heat removal limitations at the target. Previously, targets were threaded into a water-cooled support. For high stress operation, the poor heat transfer of the threads will be improved by diffusion bonding the Be or Al targets to the water-cooled copper target support block. During the present quarter, a molybdenum clamp was constructed to achieve the desired diffusion bonding. Two new dc power supplies were procured for high stress operation; each is capable of 500 ma at 3 kv. A primary current of 100 ma at the target would correspond to 5 amps/cm^2.

As a preliminary test, a copper target was brazed to the water-cooled copper support block.

Using the two new power supplies, the copper target was bombarded at up to 2 amps/cm^2 and 2 kv, corresponding to 4 kw/cm^2. Bombardment at 2 amp/cm^2 for 2 hours was observed. During this time, δ_{max} remained constant at 1.21. This value is 7% lower than the standard value of 1.30.

3. PHASE B - CFA TESTING

3.1 QKS1194 Test Vehicle. The QKS1194 test vehicle was sealed in with a barium-calcium-aluminate impregnated tungsten cathode, baked out, and operated in the final amplifier position of the S-band chain test setup. The attempt to age in the test vehicle to high efficiency, high power output without heater activation was successful. Operating gauss line data are shown in Figure 3. Low gauss ecb data with normal drive power were taken after aging the test vehicle with high drive. The plotted e.c.b. data are shown in Figure 4.

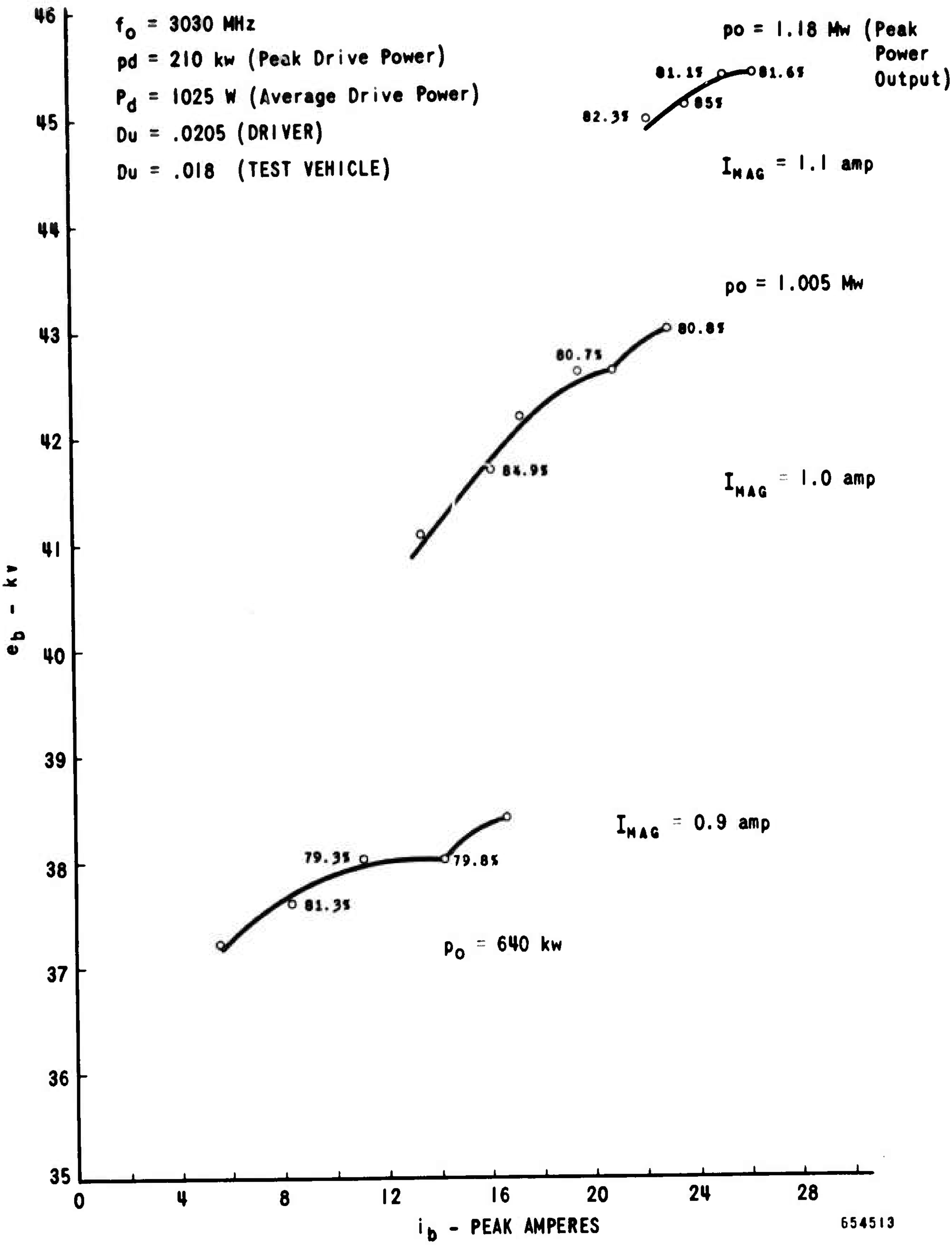


FIGURE 3 QKS1194 Test Vehicle Operating Gauss Lines (Impregnated Tungsten Emitter)

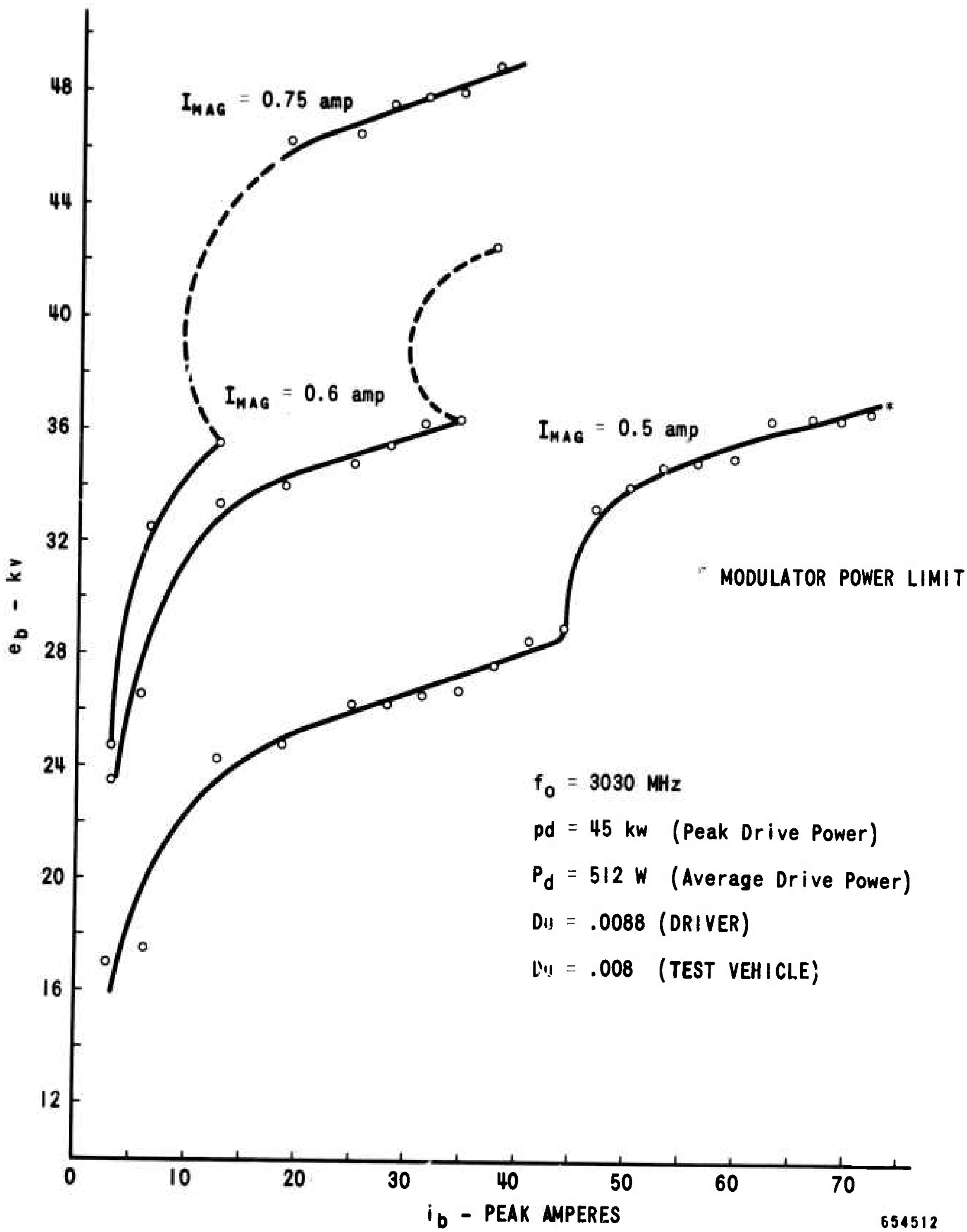


FIGURE 4 QKS1194 CCS Test Vehicle Low Gauss e_b - i_b Data (Impregnated Tungsten Emitter)

A maximum current of 75 peak amperes was obtained at the lowest magnetic field gauss line (magnet current = 0.5 ampere). This may be compared to a maximum value of approximately 60 peak amperes which has been obtained with the thoriated-tungsten emitter normally used in the QKS1194 amplifier. The 75 peak amperes limit of the barium-calcium-aluminate impregnated tungsten emitter is not an emission current boundary but is limited by available modulator power.

The value of δ may be calculated from the operating gauss line data by using the relationship between measured values of i_a and e_b, and the synchronous voltage (V_o) and characteristic current (i_o), for the QKS1194. The effective secondary emission ratio (δ) is proportional to the ratio (i_a/i_o) and $(V_a/V_o)^{3/2}$ and may be written:

$$\frac{i_a}{i_o} = 0.0244\ (\delta - 1) \left(\frac{V_a}{V_o}\right)^{3/2}$$

The calculated value of δ for the barium-calcium-aluminate emitter in the QKS1194 test vehicle is 3.5. This value of δ is in reasonable agreement with directly measured values of δ_{max} for an activated emitter and after several hours of high current density electron bombardment.

3.2 QKS1397 Test Vehicle

3.2.1 Model No. 8. Construction of a QKS1397 test vehicle, model no. 8, was completed during the report period. The stub-supported meanderline was used as the slow-wave circuit, which consisted of 0.070 in. OD tubings spaced 0.040 in. from a backwall ridge. An "oversize" aluminum (AA1100-F) cathode emitter 1.702 in. OD was used to extend the cathode stress level. An oxygen source was incorporated for life test evaluation of cathode emission.

Bakeout processing was conducted at a temperature of 400°C for 12 hours. Further processing was conducted at the test station with the use of a VacIon appendage pump during initial test evaluation.

Test evaluation of the tube was conducted with the use of a conventional pulse modulator. Strong pi-mode oscillation prevented proper tube operation at the normal drive power level of 25 to 50 kw peak. A drive power of 200 kw peak was required to "lock out" the pi-mode oscillation at a sufficiently low current level to give a reasonable dynamic operating range for the tube. At a duty factor of 0.001, the maximum peak current was 106 amperes, for a cathode stress level of 5.7 amps/sq cm. The peak rf power output was 1.3 Mw. Curve no. 8 of Figure 5 shows the emission current boundary for various magnetic fields.

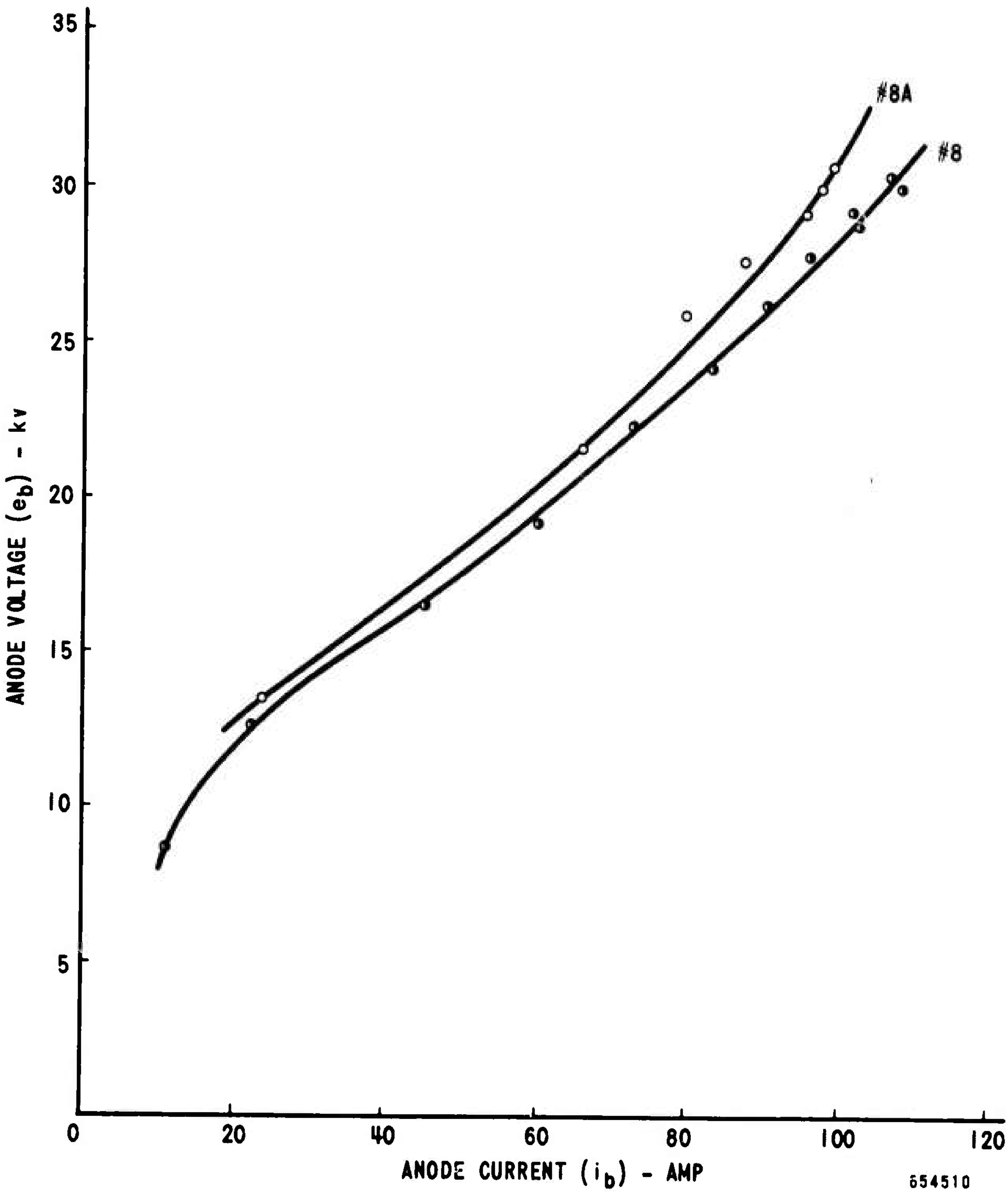


Figure 5. QKS1397 Emission Current Boundary (Various Magnetic Fields)

The pi-mode oscillation reappeared for higher duty factor operation (du > 0.0015) and prevented normal tube operation. Evaluation of the tube was terminated because the severe pi-mode oscillation was considered due to the large diameter cathode.

3.2.2 Model No. 8A. The test vehicle was rebuilt as model no. 8A with a smaller diameter (1.690 in.) aluminum cathode. Bakeout and initial test processing remained as before.

A drive power of 125 kw peak was now required to suppress pi-mode oscillation for a reasonable dynamic operating range. A peak current of 98 amperes was reached at a 0.001 duty factor, representing a cathode stress level of 5.3 amps/sq cm. Curve no. 8A of Figure 5 shows the emission current boundary for various magnetic fields.

Cathode emitter life test was initiated at a peak current of 72.5 amperes at a 0.003 duty factor, with the oxygen source heater power off. Operation at this duty factor continued for 8 hours; at this time the peak current had decreased to 66.7 amperes. The solid curve of Figure 6 shows the peak tube current as a function of time during this phase of the life test. The average power added by the CFA at the initial current level was 2970 watts, at an efficiency of 46.5%, with the cathode backbombardment power measured as 370 watts.

The oxygen source was then outgassed and the cathode emission replenished to a peak current level of 83 amperes (du = 0.001). The dashed curve of Figure 6 shows the oxygen source heater power as a function of time. From this curve it may be observed that attempts to operate the tube,at 0.001 duty factor, with the oxygen source heater power off or at a reduced power level, resulted in a decreased cathode emission. Hence, cathode emission life evaluation was continued (du = 0.003) with the oxygen source heater power initially at 55 watts. Only after the oxygen source heater power was increased to 60 watts did the peak cathode emission reactivate to 72.5 amperes. At this peak current level an average power of 2700 watts was added by the CFA. The tube efficiency had now decreased to 42.5%, while the cathode back-bombardment power remained at 370 watts. After 7 hours of operation at 0.003 duty factor, the peak current emission had decreased to 54.7 amperes.

Evaluation of the cathode emission life continued at 0.001 duty factor, starting at a peak current of 83 amperes. The oxygen source heater power was initially 55 watts, but was later increased to 59 watts. Figure 6 again shows both the peak current emission and the oxygen source heater power as a function of time for this operating condition. After 10 hours of operation at 0.001 duty factor, the peak current had decreased to 66 amperes, where it appears to have stabilized, life evaluation is continuing at this operating level.

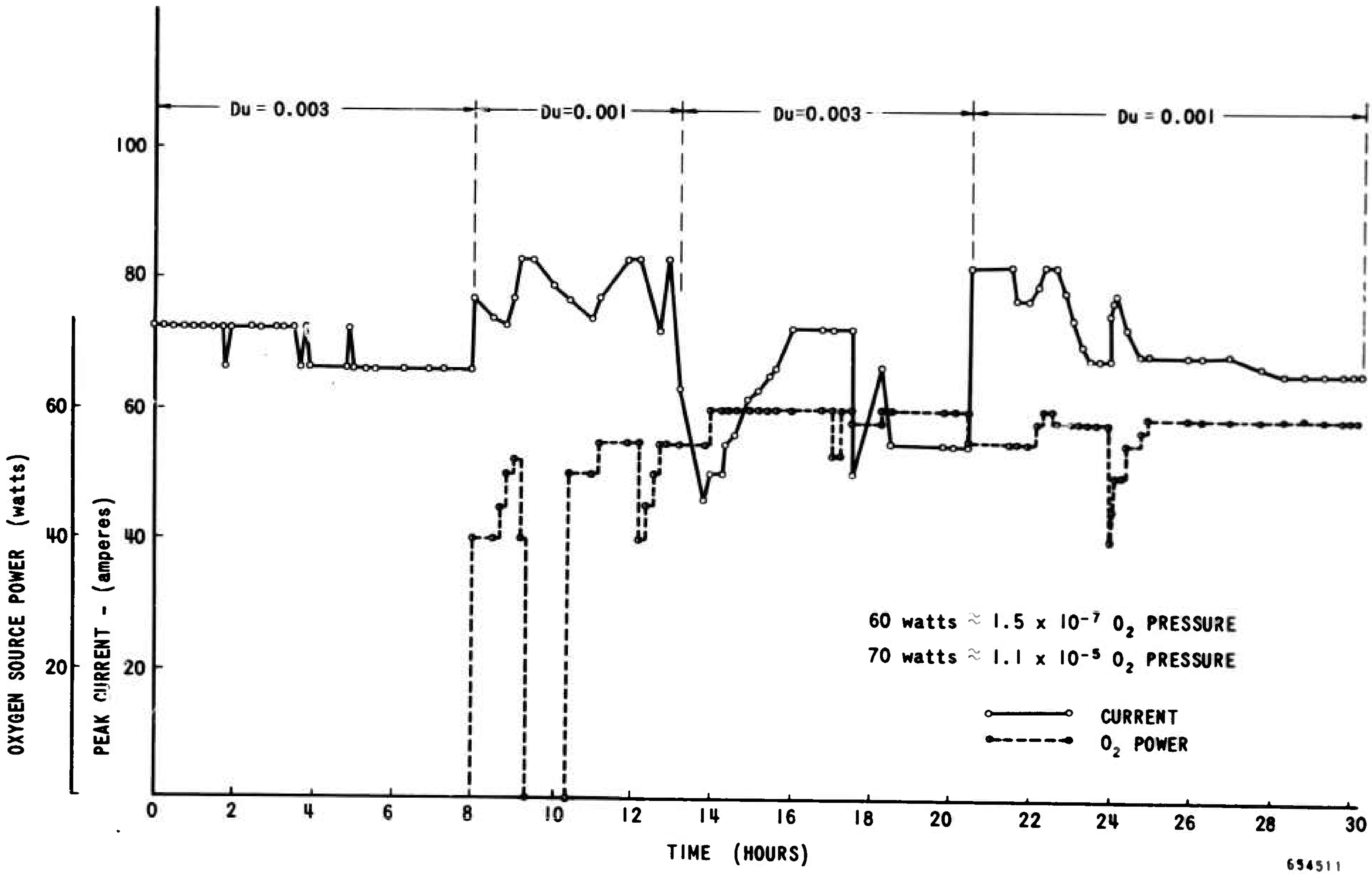


FIGURE 6 QKS1397 No.8A Life Test

4. CONCLUSIONS

4.1 Phase A - Materials Evaluation. Partial pressure of O_2 in the range $5 \times 10^{-6} - 1 \times 10^{-5}$ appear to be sufficient to maintain a δ_{max} in the range 3 to 4 for either a beryllium or aluminum cold cathode under electron bombardment conditions at the 0.5 amps/cm^2 level.

High values of δ_{max} ($\sim$ 5) have now been observed, in the EBV for room temperature, air-oxidized, aluminum. It seems more probable that the previously reported anomalously high effective δ values in a CFA are due to a surface condition rather than angle of incidence factors in the tube or field-assisted enhancement in the oxide film. The surface condition may be related to crystallinity, porosity or other structural factors.

4.2 Phase B - CFA Testing. It has been possible to stabilize the cathode emission of an aluminum cold cathode at a duty cycle of 0.001 and an electron back-bombardment level of approximately 3 amps/cm^2 in the QKS1397 CFA test vehicle through the use of oxygen in the pressure range $10^{-6} - 10^{-5}$ torr.

It has been possible to operate a barium-calcium-aluminate impregnated tungsten cathode in the QKS1194 backward-wave CFA test vehicle at high power without prior thermal activation.

5. PROGRAM FOR NEXT INTERVAL

5.1 Phase A

1. Evaluation of impregnated tungsten sample in hot/cold EBV.
2. Evaluation of boron nitride film samples in EBV.
3. Test Be and/or Al samples in high-stress level mode of EBV in relation to method of surface preparation.

5.2 Phase B

1. Continue evaluation of impregnated tungsten emitter in QKS1194 test vehicle.
2. Continue testing of aluminum cathode in QKS1397 model 8A.
3. Rebuild model 8A with a "normal" diameter (1.680 inches) aluminum cathode emitter and continue evaluation and life testing.

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13. ABSTRACT

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14 KEY WORDS	LINK A		LINK B		LINK C	
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