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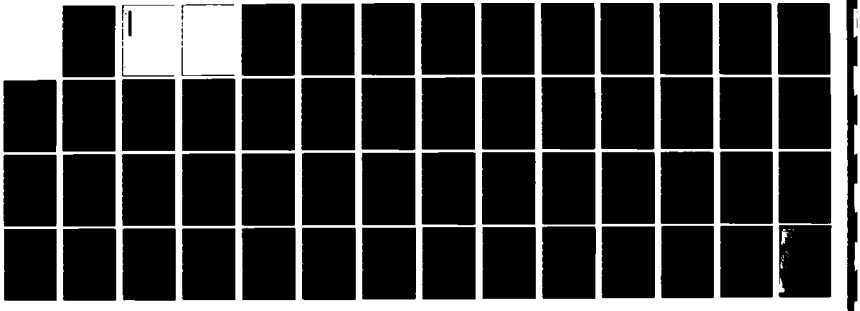

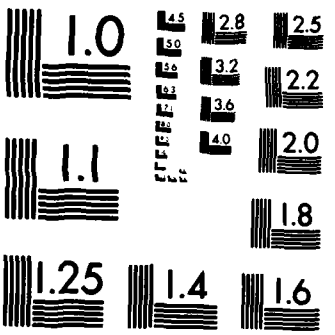

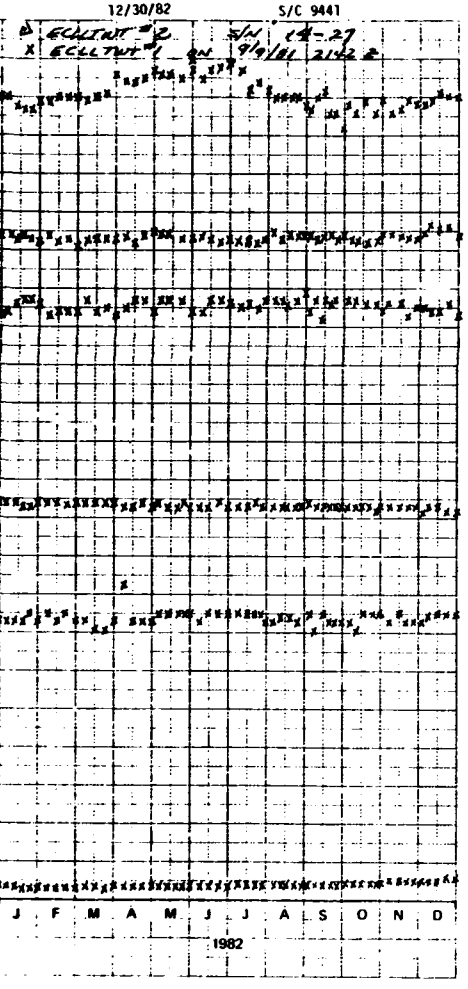
12/30/82
S/C 9441
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9/9/81 2142 Z
J F M A M J J A S O N D
1982

REPORT DOCUMENTATION PAGE

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Presents the results of an investigation of the cause of rising helix current over several years of orbital operation. Ascribes the symptoms to voltage drop in the cathode, and examines various possible manufacturing defects which can cause this effect.

DSCS II LLTWTA HELIX
CURRENT ANOMALY

CDRL No.'s 009A2 and 009A3
F04701-80-C-0022
01 March 1983

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Prepared by: P. Fowler
P. H. Fowler

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Manager
DSCS II Project

Approved: _____
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DSCS II Orbital Operations

TRW

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1. INTRODUCTION

The DSCS II satellite uses a low-power TWTA as a driver stage for the power output tube. The tube is operated in a highly backed-off mode for linearity, giving an output of the order 23 dbm (maximum output power is 28 dbm). The preceding stage is a limiter, and the system is set up with attenuator pads so that the maximum limiter output just saturates the output TWTA. Forty-four of the driver amplifiers have been operated in orbit, for intervals ranging from a few days (orbital testing redundant chain) to over nine years.

Several of the driver tubes have caused problems of varying severity by losing gain, to the point the output tube could no longer be driven to saturation. To date no service has been cut short of its design life by this problem as there has always been a working backup to complete the mission.

The immediate cause of the gain loss is a rise in helix current to as much as 20 percent of the beam, accompanied by a slow loss of about 20 percent of the cathode current. Several investigations have been made into the mechanism underlying this effect, leading to some tentative conclusions.

The amplifiers are built by Hughes Electron Dynamics Division, the tube type being 263H and amplifier 1200H.

This report presents the studies and experiments made over the last five years, the hypotheses explored, and the consensus findings.

2. ON-ORBIT SYMPTOMS

Figures 1 thru 7 show the significant telemetry indications from the amplifiers showing the problem. Note there are many other units in orbit whose performance has been stable for periods in excess of nine years. Experience with both the driver and power output tube in this and other programs shows that the problem is not intrinsic to the cathode type - lives well in excess of ten years appear to be routinely obtainable.

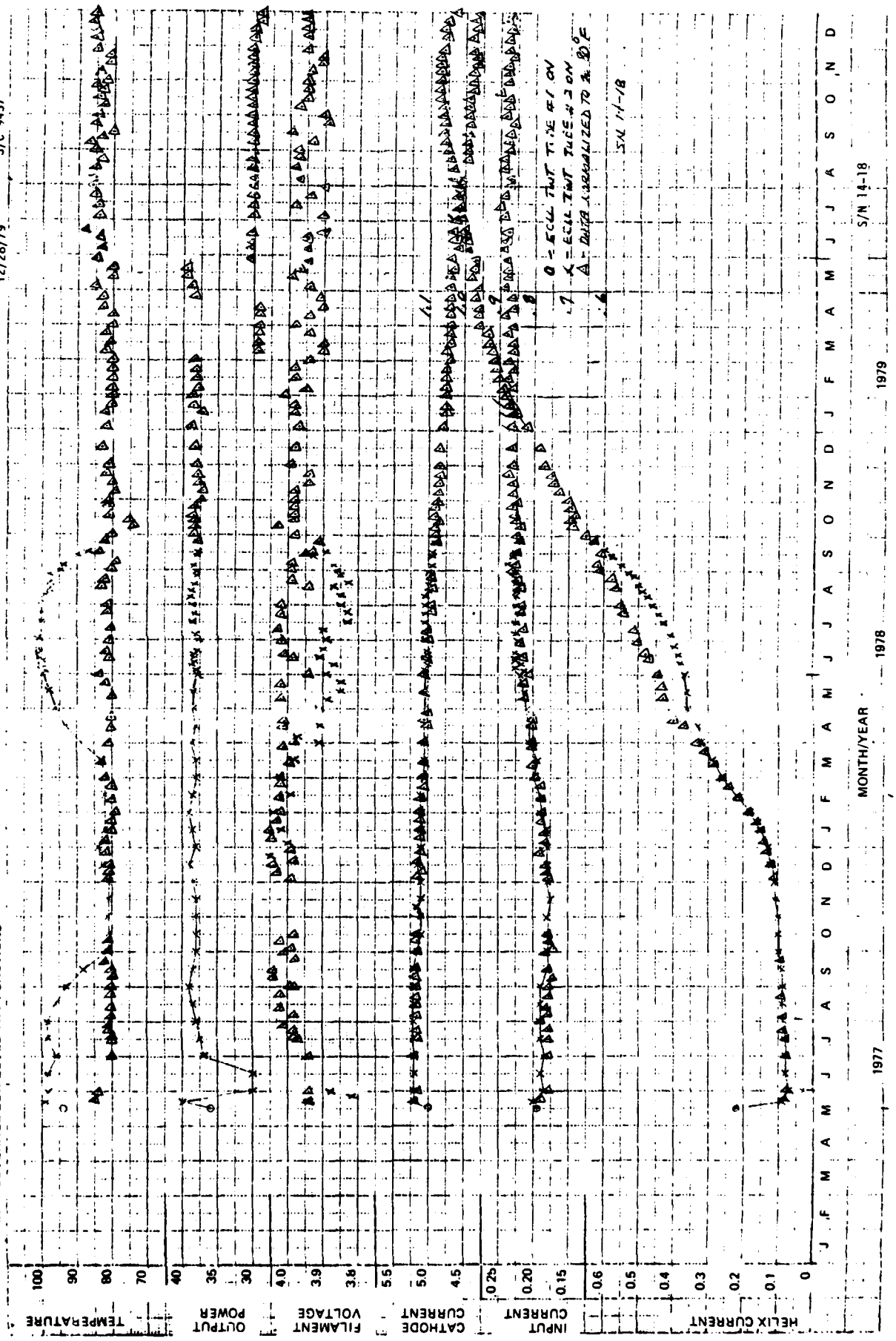
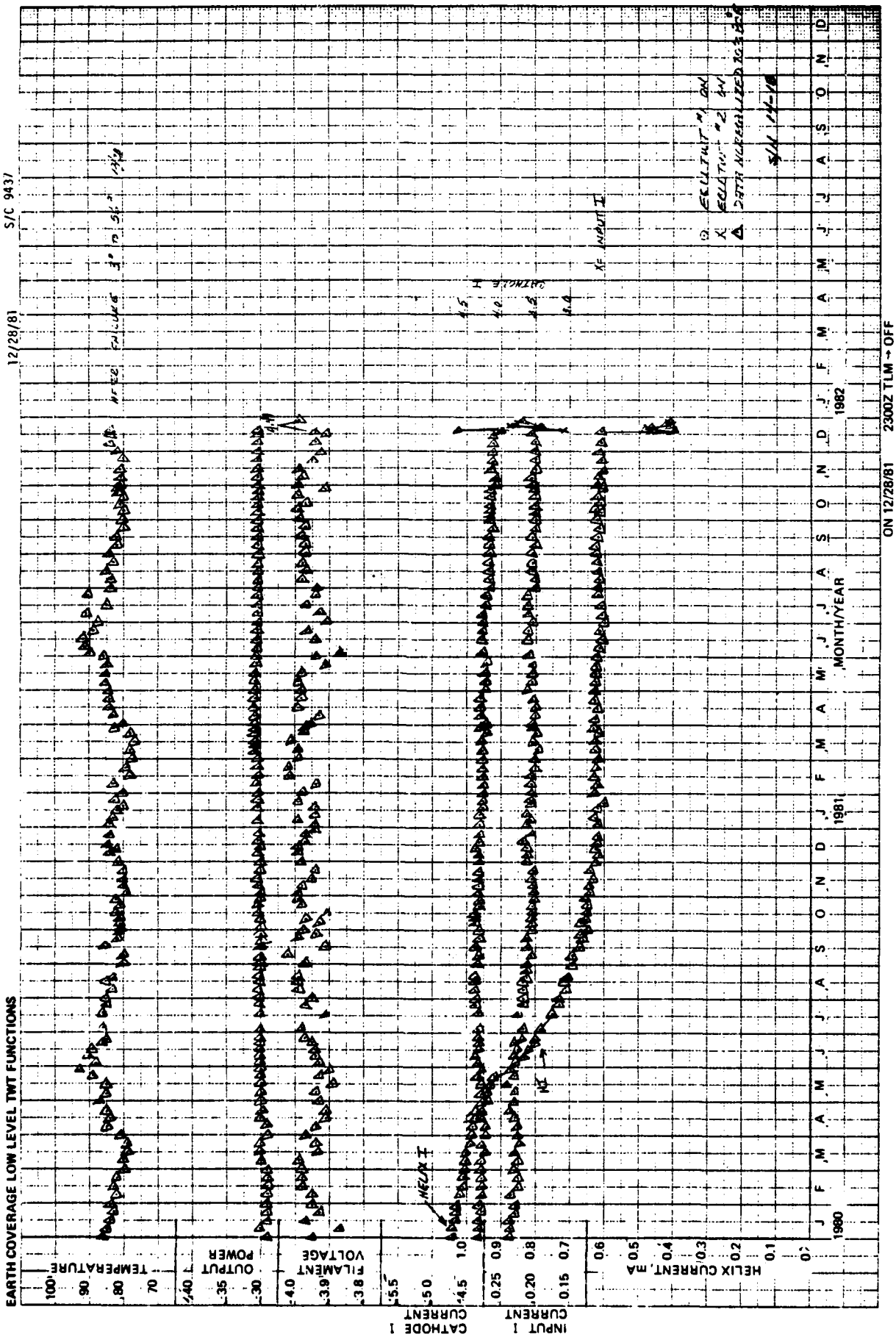

EARTH COVERAGE LOW LEVEL TWT FUNCTIONS
12/28/79
S/C 9437
TEMPERATURE
OUTPUT POWER
FILAMENT VOLTAGE
CATHODE CURRENT
INPUT CURRENT
HELIX CURRENT
MONTH/YEAR
1977
1978
1979
S/N 14-18
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D

Figure 1



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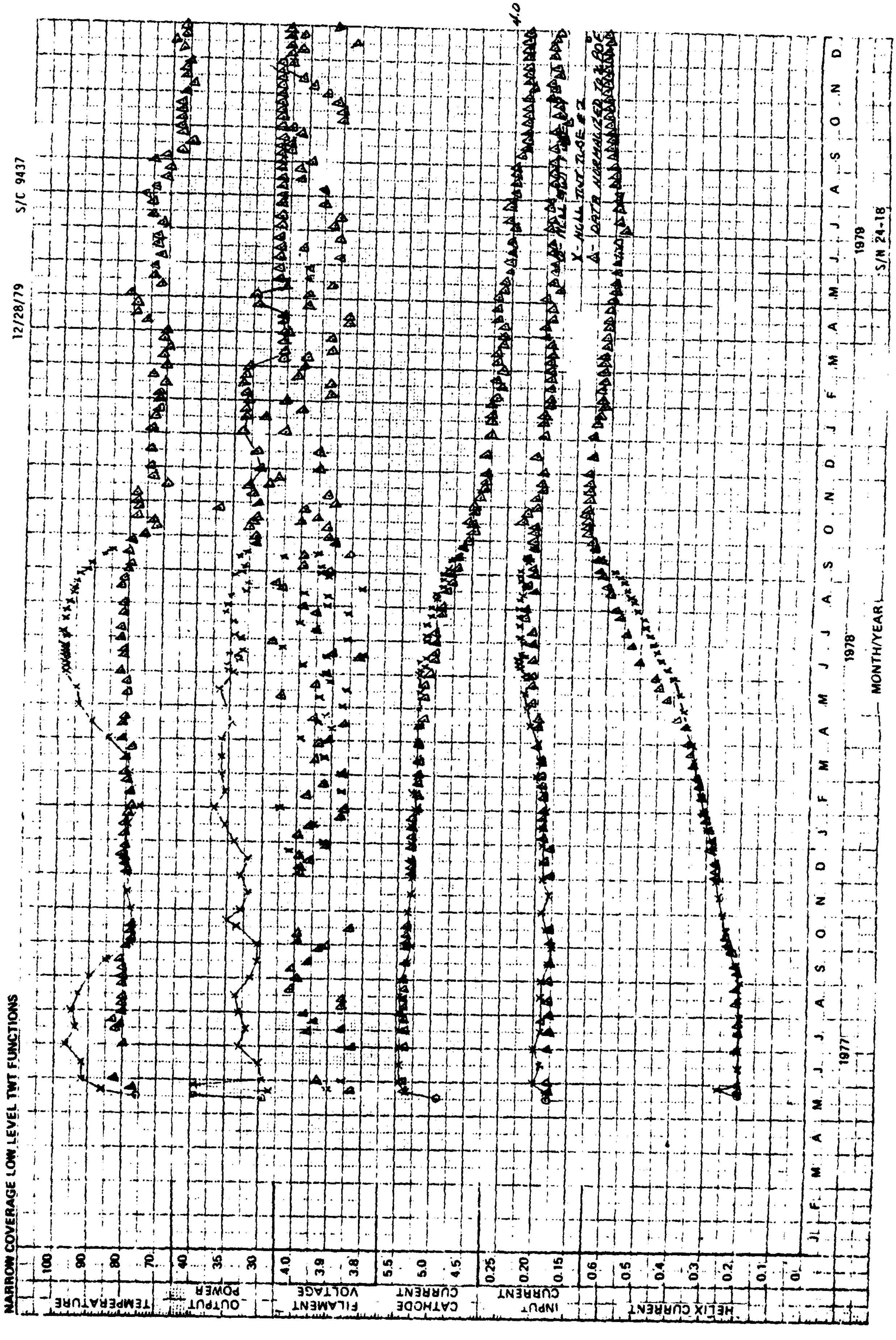
NARROW COVERAGE LOW LEVEL TWT FUNCTIONS
12/28/79
S/C 9437
S/N 24-18
TEMPERATURE
OUTPUT POWER
FILAMENT VOLTAGE
CATHODE CURRENT
INPUT CURRENT
HELIX CURRENT
MONTH/YEAR
1977
1978
1979

Figure 2

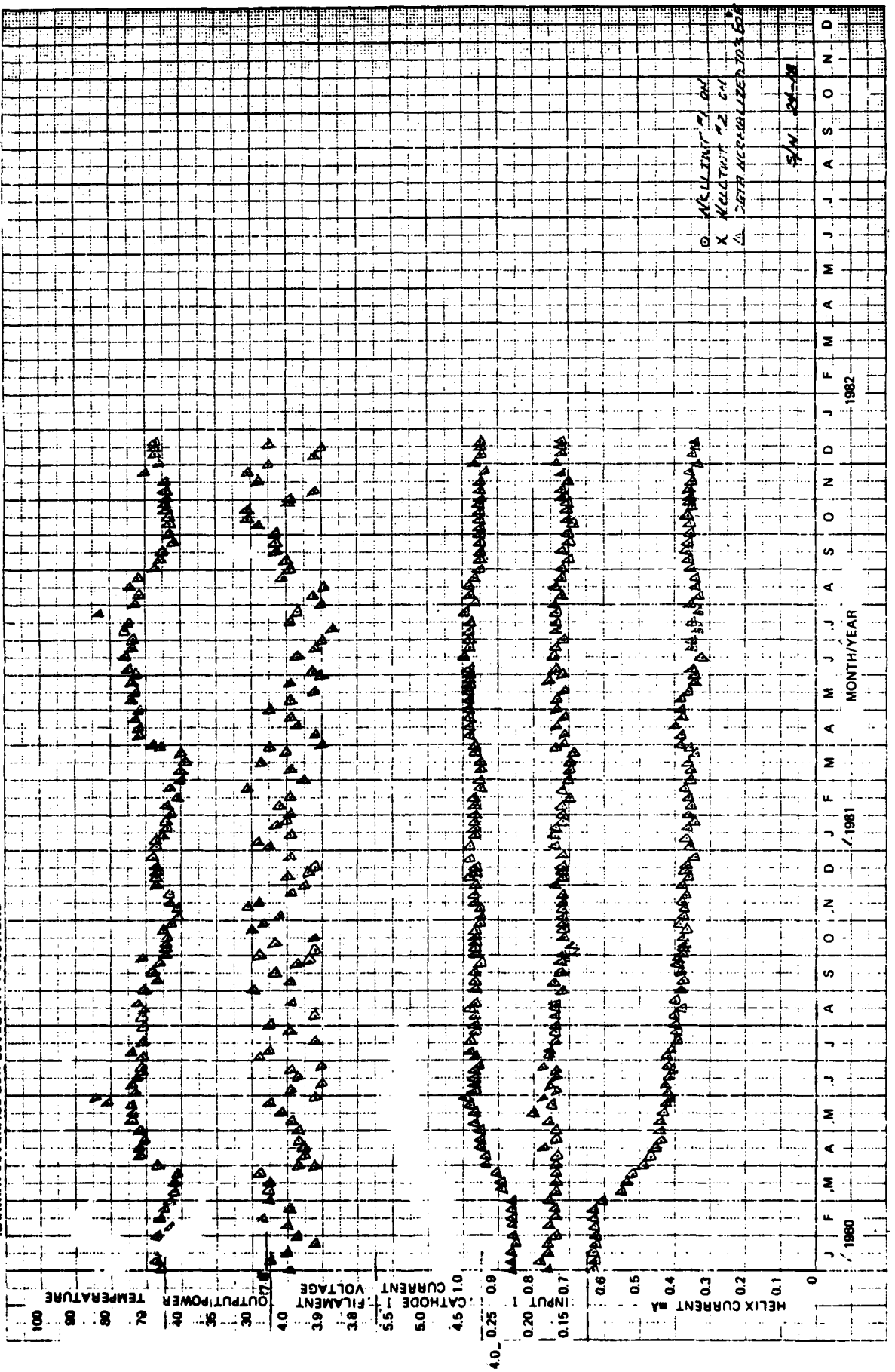

Figure 2 (Cont'd)

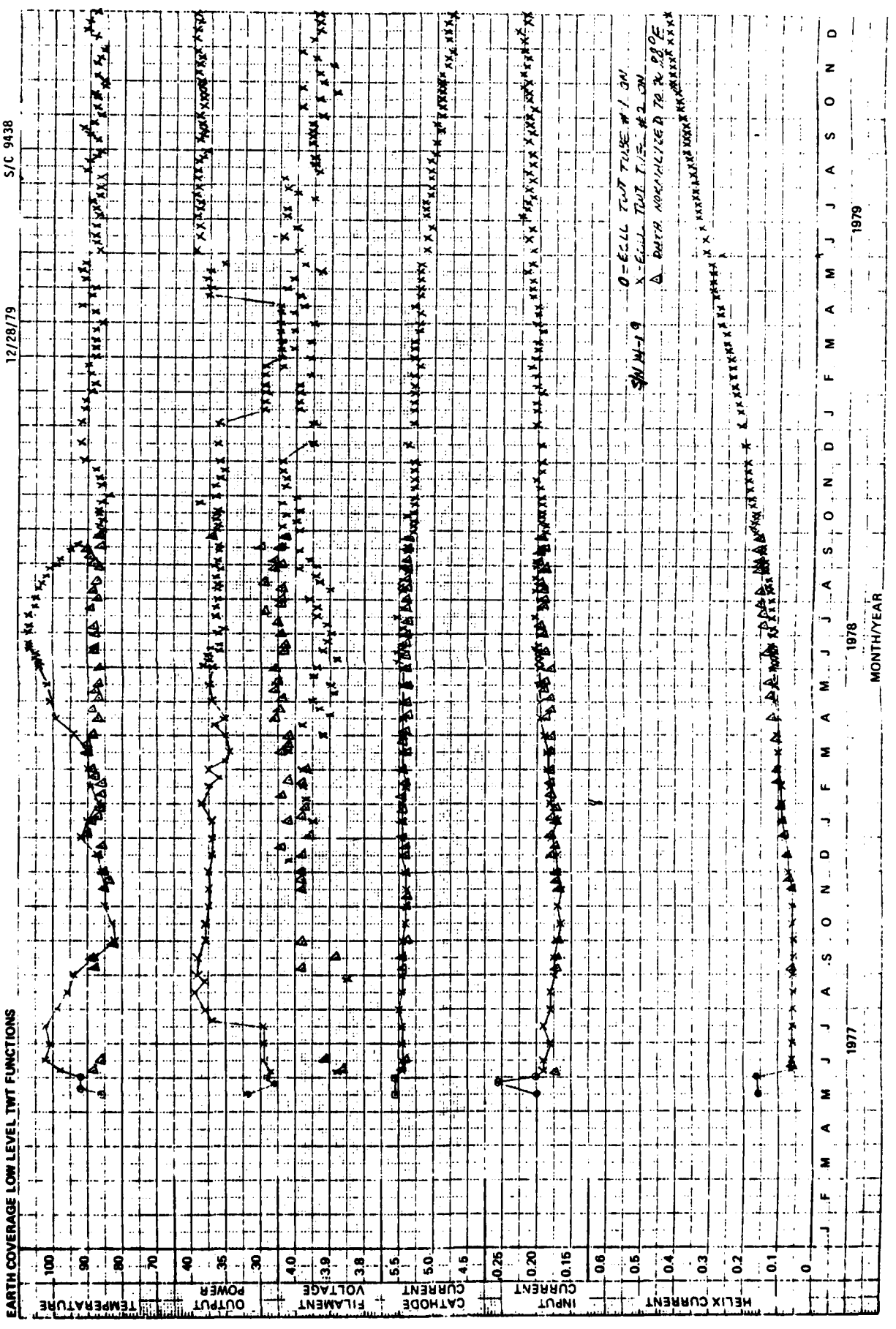
EARTH COVERAGE LOW LEVEL TWT FUNCTIONS
12/28/79
S/C 9438
TEMPERATURE
OUTPUT POWER
FILAMENT VOLTAGE
CATHODE CURRENT
INPUT CURRENT
HELIX CURRENT
O-ECLL TEST TUBE #1 SN
X-ECLL TEST TUBE #2 SN
△ EARTH COVERAGE TWT PROTOTYPE
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1977
1978
1979
MONTH/YEAR

Figure 3

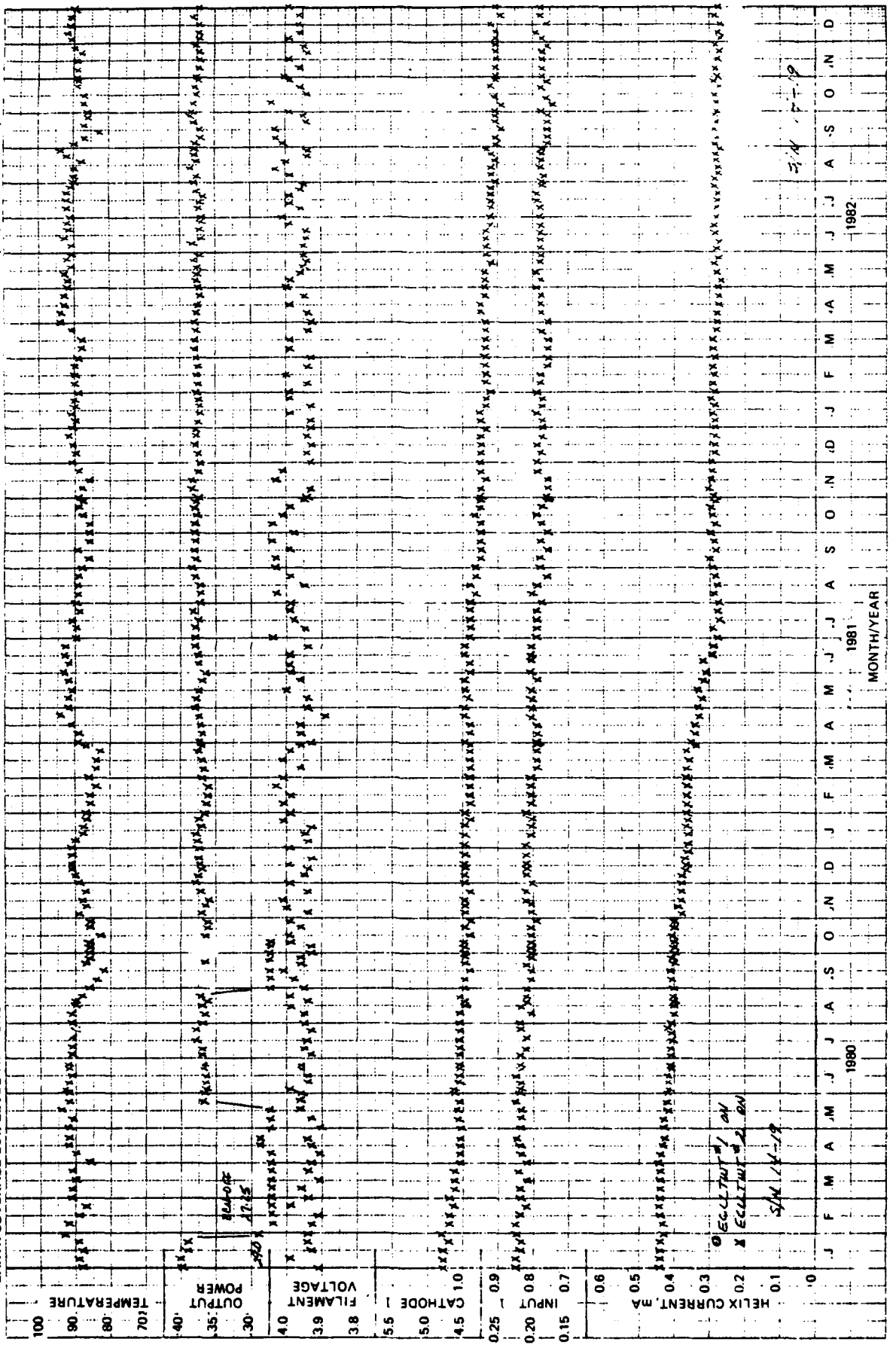

Figure 3 (Cont'd)

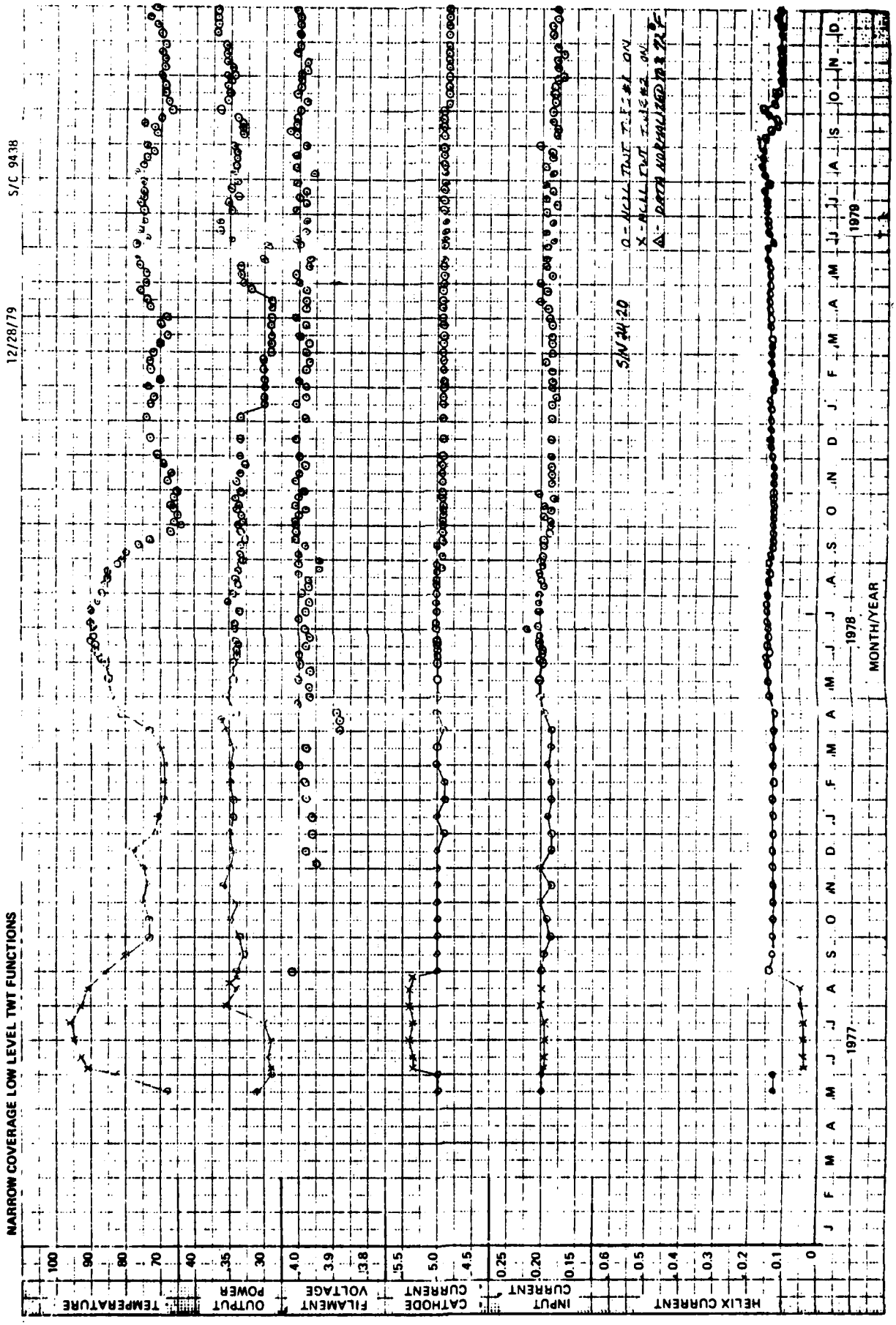
NARROW COVERAGE LOW LEVEL TWT FUNCTIONS
12/28/79
S/C 9438
TEMPERATURE
OUTPUT POWER
FILAMENT VOLTAGE
CATHODE CURRENT
INPUT CURRENT
HELIX CURRENT
MONTH/YEAR
1977
1978
1979
S/N 2420
O - NULL TWT T.E. #1 ON
X - NULL TWT T.E. #2 ON
Δ - DATA NORMALIZED TO 2 T.E.'S

Figure 4

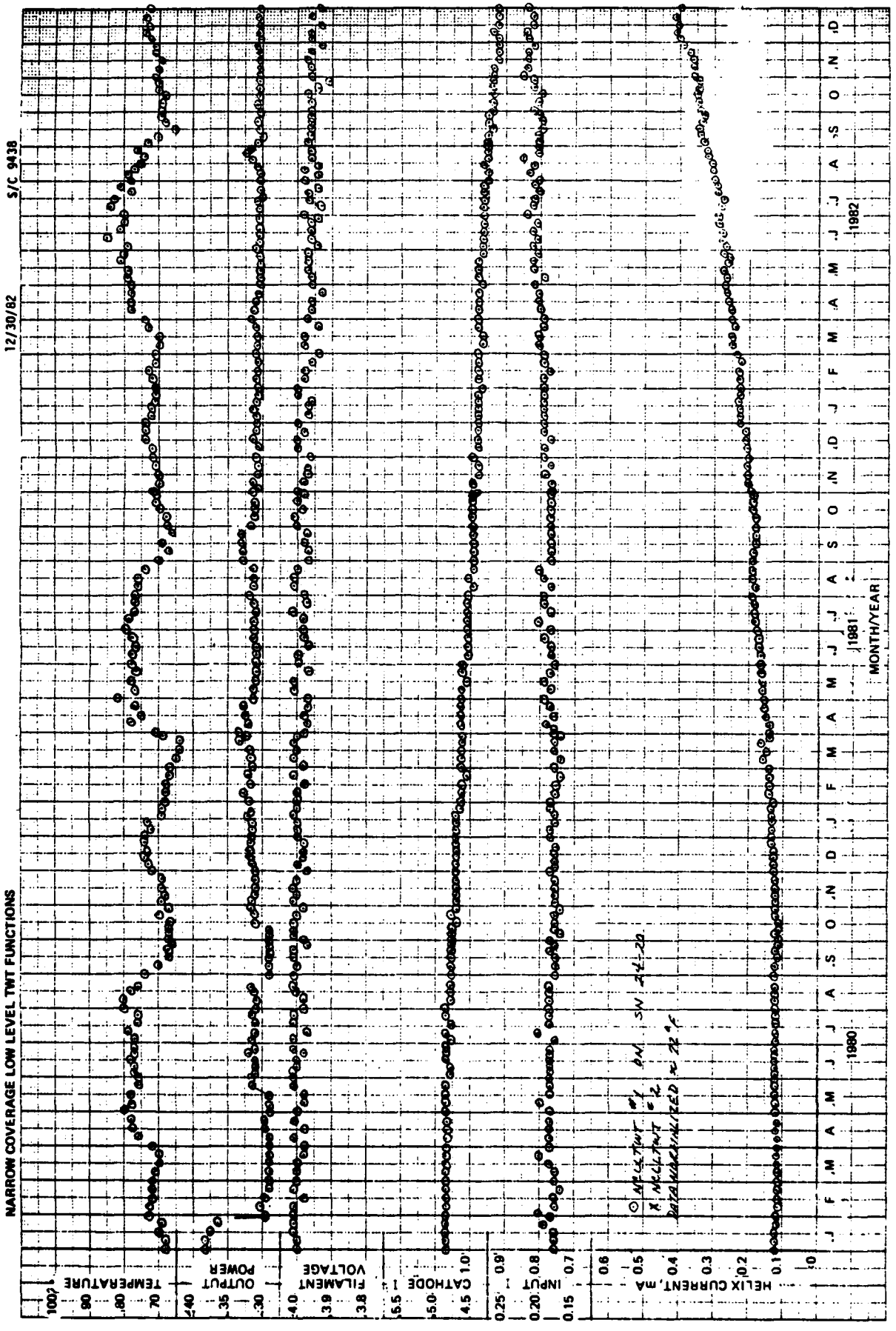

Figure 4 (Cont'd)

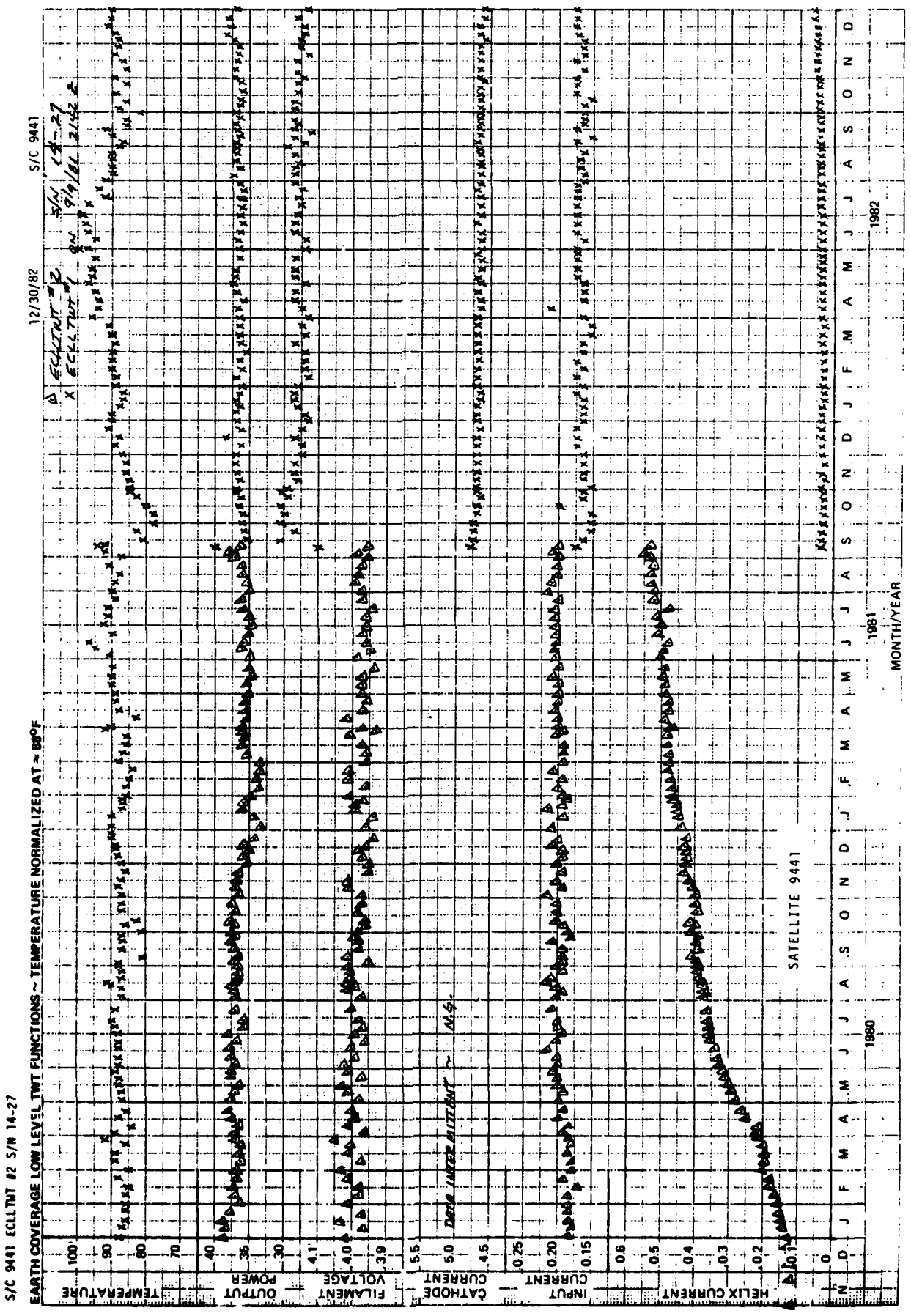
S/C 9441 ECLTWT #2 S/N 14-27
EARTH COVERAGE LOW LEVEL TWT FUNCTIONS ~ TEMPERATURE NORMALIZED AT ≈ 88°F
12/30/82
S/C 9441
△ ECLTWT #2
X ECLTWT #1 ON S/N 14-27 9/9/81
TEMPERATURE
OUTPUT POWER
FILAMENT VOLTAGE
CATHODE CURRENT
INPUT CURRENT
HELIX CURRENT
Data interrupt ~ N.S.
SATELLITE 9441
1980
1981
1982
MONTH/YEAR

Figure 5

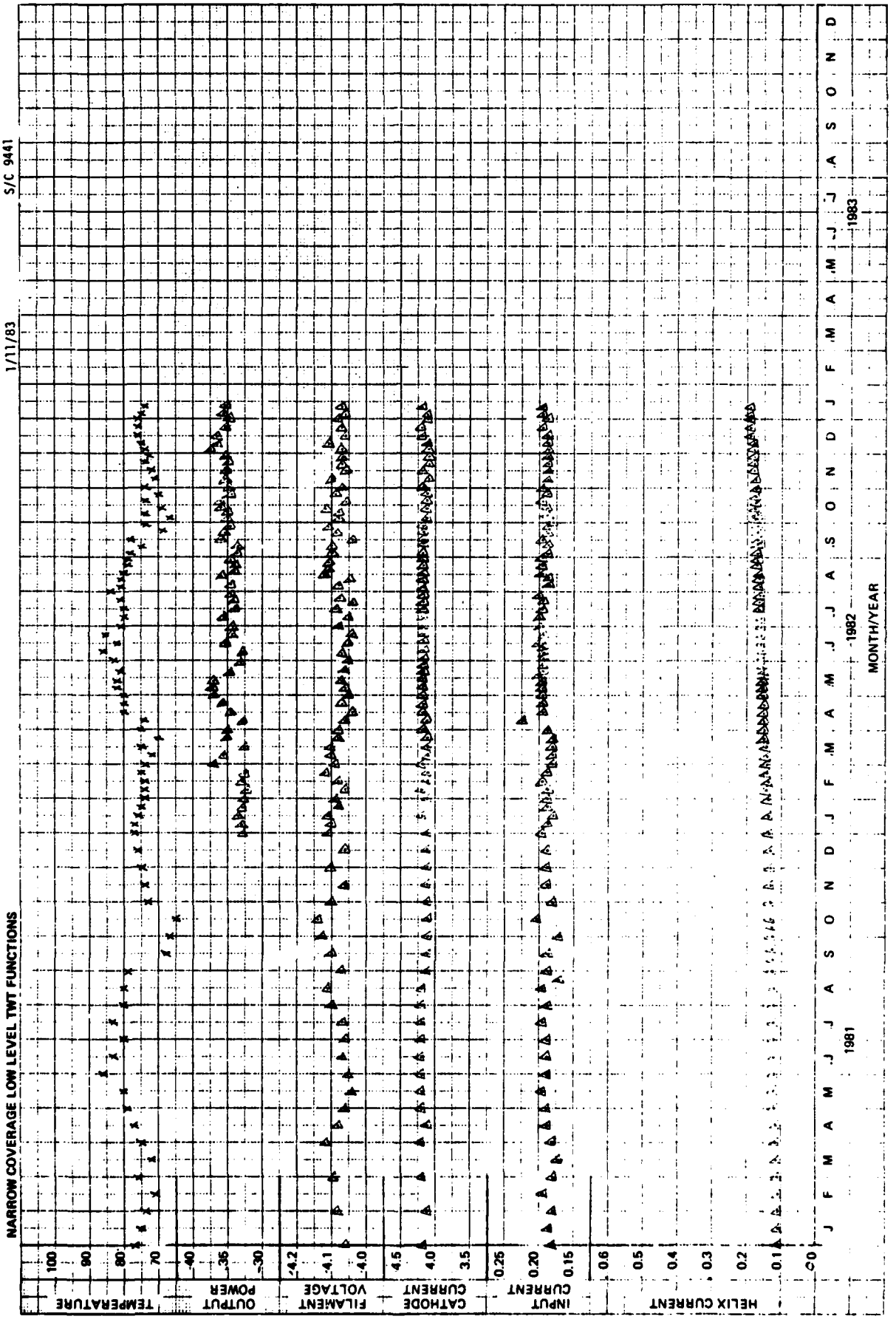

Figure 5 (Cont'd)

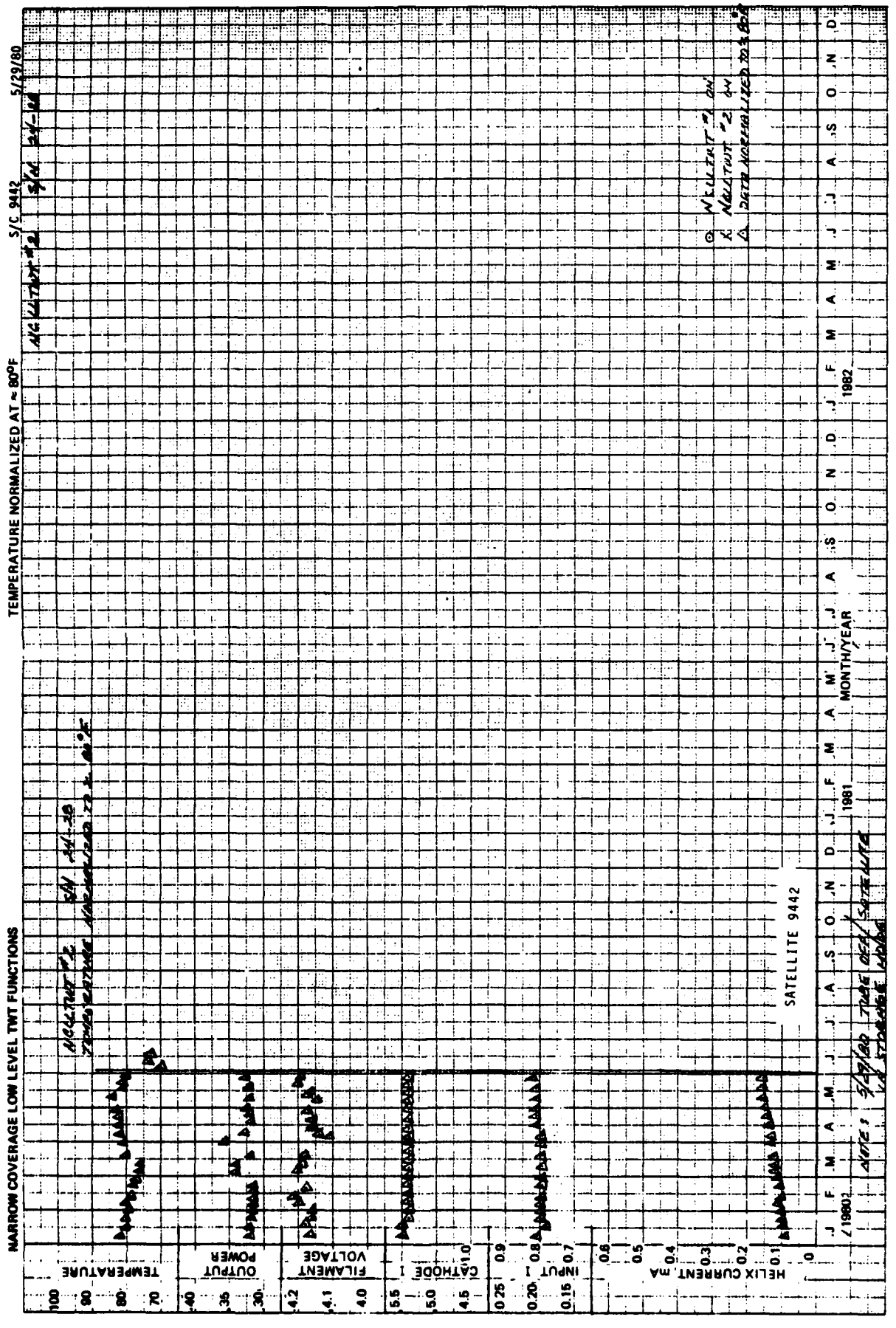
NARROW COVERAGE LOW LEVEL TWT FUNCTIONS
TEMPERATURE NORMALIZED AT ≈ 80°F
S/C 9442
5/29/80
TEMPERATURE
OUTPUT POWER
FILAMENT VOLTAGE
CATHODE I
INPUT I
HELIX CURRENT, mA
SATELLITE 9442
MONTH/YEAR
1981
1982
J F M A M J J A S O N D J F M A M J J A S O N D
1980

Figure 6

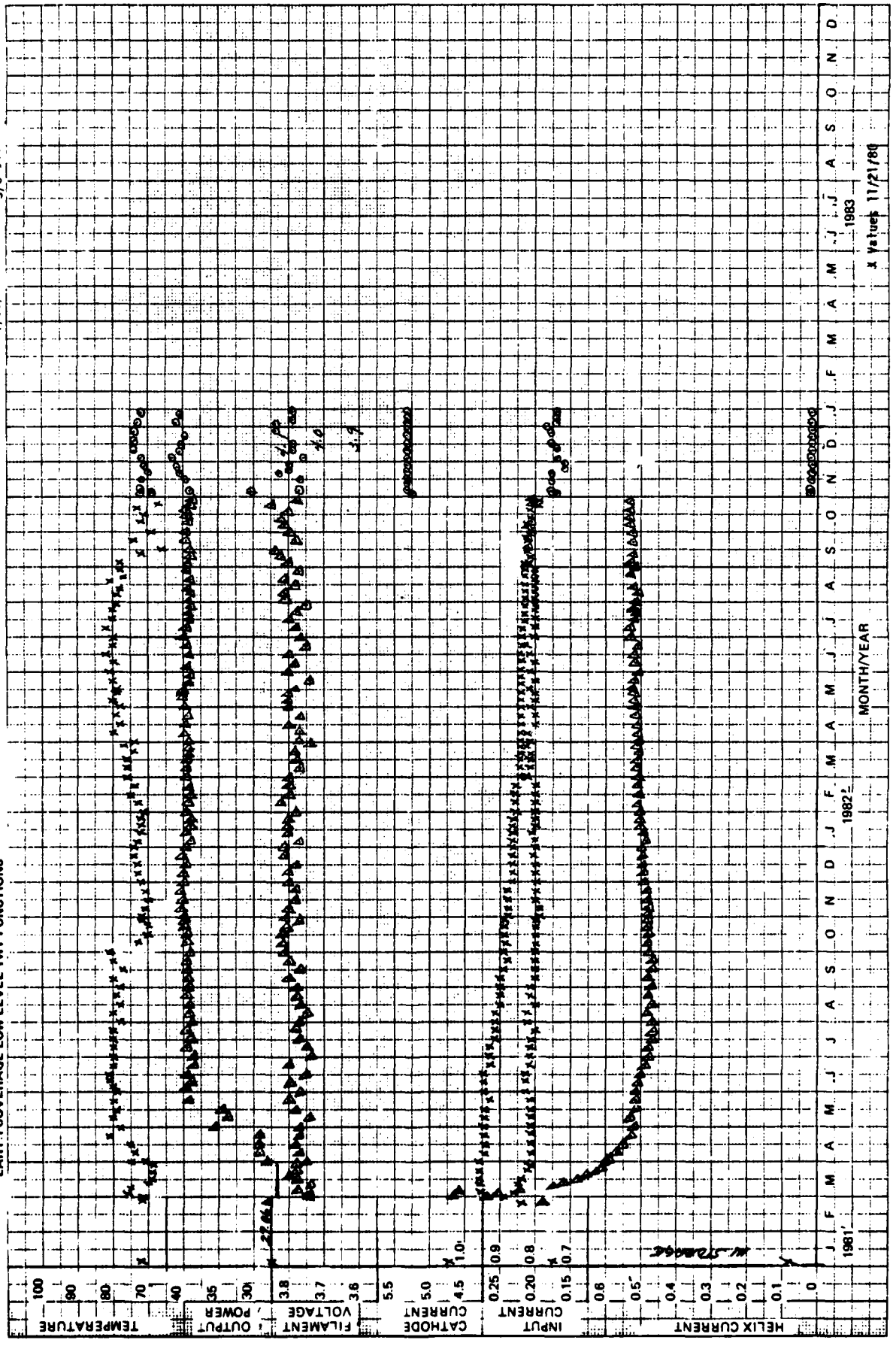
EART-I COVERAGE LOW LEVEL TWT FUNCTIONS
1/11/83
S/C 9444
TEMPERATURE
OUTPUT POWER
FILAMENT VOLTAGE
CATHODE CURRENT
INPUT CURRENT
HELIX CURRENT
J F M A M J J A S O N D J F M A M J J A S O N D
1981
1982
1983
MONTH/YEAR
X Values 11/21/81

Figure 7

On several occasions transponder gain measurements were made (shutting down communication use of the satellite). Gain losses of 3 to 8 db were found, corresponding to what would be expected given the observed tube currents. From this and other indications it can be taken that the currents telemetered are real within the accuracy of the system, i.e., the problem is not a telemetry aberration. Note that power supply voltages as shown by telemetry are normal for all the amplifiers in question, so that the problem is in the tube. The effect on gain of an increased body current varies with the point in the tube at which the interception occurs. If the current reaches ground in the input section of the helix or in the gun, the effect is identical to a cathode current reduction. The gain loss is less as the ground point moves along the output section and reaches zero if the ground point is beyond the output connection. However, the tube gain also depends on the proximity of the beam current flow to the inside of the helix, and defocusing affects this distance. It was found by experiment that the gain loss is 3-6 db per milliamp of helix current increase, the exact behavior depending on the location of the magnet used to produce the defocus.

3. POSSIBLE CAUSES

There are several possible causes of rising helix currents. These have been systematically explored as applicable to this tube, and most can be eliminated:

a) Power Supply Anomalies. Some power supply abnormalities, e.g., drop in filament voltage, produce a drop in cathode current and a rise in helix current. However,

no amplifier shows any abnormal voltage, and in fact it is difficult to imagine any combination of voltage changes which would produce the symptoms in detail. (See Item c below for reasons to reject a change in filament power as a cause.)

b) Disturbance to the Magnetic Focus. Disturbance to the focus magnet strength or position could cause increased helix current. However, nothing outside the gun can reduce the beam current. Focus changes beyond the gun can therefore be eliminated from consideration.

c) Loss of Cathode Activity. At first sight the symptoms are similar to those resulting from the cathode knee temperature approaching the operating temperature (or vice versa). This possibility may be analyzed by plotting the telemetered cathode current on the cathode activity charts taken on the ground, and reading off the corresponding helix current. This has been done for most of the tubes showing orbital abnormalities, and the helix current is always much higher than would be expected if it were due to loss of cathode activity. Note also that the tubes in orbit show a significant increase in helix current well before the cathode current drops noticeably, whereas exactly the opposite is characteristic of a cathode activity curve. It may be concluded therefore that wearout or temperature change in the cathode is not responsible for the orbital effect.

d) Mechanical Damage to the Gun. Considerable time was spent exploring the possibility that the launch or deployment environment might be damaging the gun.

Suspicion especially focused on the pyro shock environment, which occurs when deployable antennas are released. There are several cogent reasons for considering this an unlikely cause. The most significant is that a step change in characteristic from just before to just after launch should be apparent if life limiting damage had been done. Careful comparison of the last system test to first orbital test currents show them to be identical for all amplifiers, within measurement accuracy. Further, the long time constant of the helix current change is difficult to relate to launch damage. One amplifier was subjected to pyro shock on the ground and given a short life test to confirm that shock was not a factor. The tube, serial 245, in fact did later show rising helix current very like the orbital problem. This tube was disassembled and analyzed under the direction of Dr. F. Wachi of Aerospace Corporation, who concluded that mechanical damage was <u>not</u> a factor, and that the physical appearance of this cathode supports a different hypothesis (Section 4d) It was concluded therefore that the effect was not due to an environmental stress.

e) Gas Pressure Increase. Gas can be released in a tube by various mechanisms. The envelope may contain sealed off pockets of trapped process gases which are released by temperature cycling ("virtual leaks"), or water vapor and other materials may migrate through micro cracks from the potting compound around most of the tube into the interior vacuum. The tube is capable of operating with slow leaks for a considerable time without gross symptoms, since two mechanisms protect the cathode. First, this tube has an effective getter capable of

absorbing substantial quantities of gases. Second, the tube operates as an effective ion pump, trapping gases in the collector. Injection of a large amount of gas should cause an abrupt and usually irreversible* drop in cathode current and a significant defocusing with a slow recovery as the tube pumps itself clean. The time scale of such an event should be of the order of hours. It is very difficult to conceive of a condition in which the gas pressure remains high enough to cause 20 percent of the beam to be intercepted for periods of several years, without the cathode being totally destroyed. Also, the characteristic behavior of a rise in helix current followed by a drop in cathode current is the opposite of what would be expected if gas injection were the cause. However, there is one tube on Flight 14 (Figure 7) which does more nearly fit the symptoms of havings a "virtual leak." It is concluded that the orbital symptoms of all but this amplifier are not due to gas in the tube. This amplifier might have suffered a rise in gas pressure in the tube during the period it was stored in orbit, resulting in the short time scale deterioration seen.

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*The effect may be reversible by heating the cathode to well above the normal operating temperature, but this is not possible in a working amplifier.

f) Change in Gun Geometry. The orbital symptoms can be matched by moving the cathode relative to the focus electrode. There are several strong arguments against this hypothesis, the most telling being that a helix current recovery without a restoration of cathode current is impossible by small motions in the gun. Several tubes (Figure 1 for example) show a significant helix current recovery, so it is concluded that changes in gun geometry are not responsible. It may also be noted that no mechanism of long term motion of gun parts has been proposed.

g) Asymmetric Aging of the Cathode. If the cathode lost emission from a substantial portion of its surface so as to leave a very asymmetric emitter, symptoms like the anomaly might appear (no test to confirm this has been made). However, the observed helix current recovery without either a cathode current recovery o. further substantial cathode current loss is inconceivable in this model, so it is concluded that this is not the cause.

h) Virtual Cathode Motion. A rapid defocusing and some change in cathode current is produced by creating a voltage difference between the emitting surface and the focus electrode. Such a voltage is caused by development of electrical resistance within the coating or (more usually) between the coating and the substrate. Tube 245, mentioned above, was found to have abnormal cathode coating adherence, and did show symptoms close to those in orbit. It was found by experiment that small voltages produce drastic changes

in focus, and as little as 1/2 volt drop between the cathode and substrate would duplicate the orbital symptoms. It is concluded that the observed orbital symptoms are probably caused by development of a cathode interface resistance, though the chemical cause and the mechanics of the time history are still obscure. This failure mechanism is explored further in Section 4 below.

4. CATHODE INTERFACE RESISTANCE

The behavior of a 263H tube with a variable interface resistance in the cathode has been studied by Hughes, with results detailed in Appendix I. The evidence of the cathode from tube 245 (Appendix II) is that a tube can meet all flight specification requirements with a cathode improperly adhering to the substrate.

Several mechanisms of poor adherence or growing interface resistance have been suggested:

a) An appearance similar to that of the cathode in tube 245 can be caused by overheating the cathode during processing. For the usual oxide cathode mixes, temperatures over 1000°C are believed to cause sintering of the coating. There is no evidence that the 263H tubes have been subject to excess temperature.

b) It has been suggested that some gases, if present during tube processing, may produce a similar effect. However, there is no reason to believe these tubes have been exposed to unusual atmospheres.

c) Contamination of the substrate with certain chemicals, especially manganese, interferes with the chemistry of operation of the cathode. Both reduced emission and

unusual interface resistance may result. As explained in Appendix I, Hughes concludes that this is the likely cause of the problem with the 263H tube. Note that a previous study (Reference 1) concluded that this was the probable mechanism, prior to a sample actually displaying the symptoms becoming available. Also note that the reversal of the helix current trend without a corresponding cathode current recovery is still difficult to explain. A possible explanation is that the increased voltage drop in the cathode produces the defocusing, but does not cause the majority of the drop in cathode current. Recovery of the resistance, e.g., by exhaustion of a thin layer of contaminant, then restores the tube focus. The drop in cathode current would, in this view, include a separate effect of the contaminant acting on the emitting surface. Recovery from this effect may be impossible, or may have a much longer time constant than recovery of the interface. Since no direct measurements or experiments have been made, this or any explanation is entirely speculative. Note, however, that Figure 2 shows at least one tube did have some cathode current recovery.

d) Numerous cathodes of different manufacturer and tube type have been found to suffer a loss of adherence to the substrate due to abnormality of the condition of the nickel substrate. This problem has been found apparently at random interspersed in runs of good tubes, and on other occasions has appeared for a time in 100 percent of some types. As explained in Appendix II, the problem is characterized by abnormal concentration of the minor constituents of the cathode nickel (e.g., zirconium). The problem has sometimes been found to be created during pre-coating firing

processes. Neither the physics nor chemistry of the problem nor its effect on the cathode are known, however, a reasonable speculation as follows may explain the main features. Studies of concentration gradients in very old cathodes suggest that the reducing effect of the substrate on the coating is produced by oxygen diffusion into the nickel, and not by zirconium diffusion into the coating. The reducing additives in the nickel thus work by maintaining the substrate de-oxygenated through tube manufacture so that it may act as an oxygen sink for the life of the tube. In this model it is evident that any processing step which saturates the nickel with oxygen will destroy its effectiveness in supporting the cathode life. It can also be speculated that such a saturation might concentrate the zirconium in the form of zirconia nodules, giving the appearance of the tube 245 cathode. While tube 245 clearly had this abnormality, it is not obvious that the majority of orbital abnormalities can be so explained. The principle difficulty is to account for the recovery of the helix current accompanied by stabilizing or minor improvement in the cathode current. Note that if the refocusing were due to regaining of symmetry by loss of emission from further area round the edges, the cathode current should drop as much again as it did when the peak defocusing occurred. This did not happen is a single case.

It is reasonable to question why the driver tube has the problem while the output tube, made at the same time by the same supplier, does not seem to. Several factors may bear on this, though again in the absence of definitive experimental work their interaction is speculative:

a) The cathode operating temperature of the 263H tube is low, in the vicinity of 680°C. The output tube runs some 40°C hotter than this. It has previously been observed that the time constant of damage by manganese is very temperature sensitive in this range (Reference 1). It is possible therefore that some output tubes are eliminated from the program in early testing for defective cathodes, which would have shown similar symptoms in orbit had they been operated cooler.

b) The 263H tube has a perveance of about .06 X 10^{-6}, and the output tube about .2 X 10^{-6}. The effect of cathode resistance should be greater for lower perveance. Also, at the higher temperature the resistance in the cathode may be somewhat lower if it has a negative coefficient as might be expected. The output tube might then show the symptoms much more weakly or in a different form. In fact, several of the output tubes do show a slow downward drift of cathode current on the order of 0.2 percent per year. It is not known what the no-signal helix current trend is, because most of the output tube helix current is traffic related. It is thus possible that some output tubes show a very mild form of the same symptoms.

c) The 263H cathode is very small and of a slightly different geometry than that of the larger tube. This may produce some unsuspected process sensitivity. However, nothing in the processing is known to be significantly different.

5. CONCLUSIONS

The following expresses the consensus of the parties involved in investigating the 263H helix current problem. However, it should be noted that tests and analyses have not been carried to the point of a scientific level of proof:

a) The majority of cases of rising helix current in 263H tubes in orbit are due to increased series resistance in the cathode.

b) The increased resistance is probably related to contamination of the cathode substrate during processing.

c) Deposition of manganese during gun part processing is the prime, but not the only, suspect contaminating process.

d) Gas evolution in orbit and oxygen saturation of the cathodes in processing may account for some of the orbital effects.

6. CORRECTIVE ACTION

Since no further production of this tube is contemplated, long range corrective action is deferred to other programs, e.g., the generic tube. For the DSCS II project, existing amplifiers have been subject to extra burn-in with close

monitoring of helix current. One tube out of ten tested did change helix current, but this was of different characteristic and apparently due to a magnet change. Numerous process improvements have been introduced by Hughes during the life of the DSCS II program, many directed to avoiding gun contamination and improving process control.

REFERENCE

1. Aerospace Report TOR-0079(4403-02)-4, "Investigation of DSCS II Low-Level TWTA Anomaly," F. M. Wachi, August 1979.

APPENDIX I

HUGHES REPORT ON POSSIBLE MECHANISMS OF HELIX CURRENT RISE

Comments On Low Level Amplifiers

Questions (Q) and Answers (A): Reference TRW TWX, DSCS-B1A-3109

Q.1. Comment on the suggestion that orbital (and in one case ground test) increases in helix current and drops in cathode current are due to random cases of cathode being sintered (heated over 1000°C) in processing. If necessary, consult Dr. Wachi for details of the analysis of the tube that showed the symptoms in ground test.

A1. It is the considered opinion of the author that sintering does not, and cannot play a part in the anomalies observed on DSCS II spacecraft 7, TWTA's 14-18 and 24-18, spacecraft 8, TWTA 14-19, Spacecraft 11, TWTA 14-27 and possibly spacecraft 14, TWTA 24-28. My reasoning is based on a paper by C. H. Meltzer and E. G. Widell (1):

"Gas poisoning (during conversion) due to carbon dioxide, carbon monoxide, and oxygen are, in effect, the result of harmful equalibrium processes of these gases that tend to extend the low-melting actions of the eutectic phase of the barium carbonate. Where the barium phases are depleted due to the interaction with these gases, the cathode system can bring about a recovery from the effect by the replenishment of the barium by means of the reducing activity of the agents in the nickel alloy. Where the malfunction has been brought about by sintering of the coating, no recovery can be obtained; further processing by activation aging schedules only worsens the melt situation and increases the bulk resistance of the coating."

We know that TWTAs 14-18, 24-18 and 14-19 went from increasing helix current to decreasing helix current, and in at least one case from decreasing cathode current to increasing cathode current. The other two TWTAs (14-27 and 24-28) have not been operated for a long enough time to reach the turn-around point, if they even could.

The spacecraft data from Flights 7 and 8 are suggestive of a chemical reaction which decreases cathode current and causes an increase in helix current. After 29 months of decreasing cathode current the reaction reaches a limit and a second reaction starts a limited recovery. What mechanisms available in these tubes fit the pattern? One possible explanation might be as follows.

1) We know that during the build of the 263HA TWTs that 200 nickel was used for cathode support sleeves for serial number tubes on spacecraft 7 and above through TWT serial number 228. Tubes on spacecraft with TWT serial numbers above 228 have 270 nickel cathode support sleeves. The major difference between the two nickels is the higher impurity content of the 200 nickel, particularly manganese.

2) It was found during the D-429 (nickel) high and low level anomaly investigations and during further testing in the low level anomaly investigation (1978) that during vacuum firing of the cathode support assembly (cathode, cathode support sleeve, etc.) that manganese and chromium evaporated from the 200 nickel support sleeve and condensed on the cathode to an equivalent thickness of 10°A. (2). The cathode is hot at the time of the deposition of the manganese and chromium which causes diffusion of the material into the cathode.

3) The vacuum fired cathode is coated (spray) with a barium-strontium carbonate ($BaCO_3$ - $SrCO_3$) final-assembled and placed on bake-out, where the cathode is converted.

4) For the sake of simplicity only manganese and only barium carbonate-barium oxide will be treated, but chromium and strontium carbonate-strontium oxide could be described in a similar fashion.

5) During conversion some of the manganese will react (see par ex. Rittner (3)) with the barium carbonate in accordance with the following:

$$BaCO_3(S) + Mn(S) = BaO(S) + MnO(S) + CO(g)$$

6) During life, up until most of the manganese has been bound up with oxygen, or been evaporated from the cathode, the following reaction can take place according to Rittner (3):

$$BaO(S) + Mn(S) = MnO(S) + Ba(g)$$

Note: Rittner further explains that the reaction listed above is more favorable than analogous reactions leading to the following products MnO_2 $BaMnO_4$ - - - - .

7) MnO has never been identified at the interface or as an interface resistence so far as I could find in the literature, but is well known to have a deleterious effect on oxide cathode emission. For the purpose of this discussion, let us consider it to cause an interface and have some value of resistance.

8) An interface resistance can be depicted as in Figure 1. The voltage drop across the interface resistance causes the vacuum surface of the cathode coating to be closer to anode potential than the cathode itself. This causes cathode current to decrease as we noted on spacecraft 7 and 8.

9) In order to simulate an interface resistance, data has been taken on a demountable 263H electron gun, where the cathode can be run at potentials (ΔV) other than the potential of the focus electrode (-1900V). Data of beam minimum location and cathode current were taken as shown in Table 1. The data is plotted in Figure 2.

10) Consider the narrow coverage low level TWTA on S/C 9437 (Figure 3). According to the drop in cathode current from September 1977 to February 1980, the cathode resistance should have increased by about 580 ohms (approx. 16 ohms per sq. cm) and the beam minimum position should have moved toward the gun by 0.130 inches. With the magnetic half period of the PPM stack of 0.160 inches an appreciable defocussing would occur. From March 1980 to June 1981 the cathode current increased and reached a relative value of $\frac{\Delta V}{V_o} \times 10^3 = 0.67$ or a resistance of about 230 ohms (approx. 6 ohms per sq. cm) and the beam minimum moved back about 0.070 inches toward the gun.

11) A reaction which could cause the turn around in cathode current and helix current could be by the zirconium in the cathode pellet reducing the MnO by:

$$Zr + 2MnO = ZrO_2 + 2Mn$$

The other manganese compounds, if formed, could be reduced in a similar fashion - in addition, tungsten is present in the cathode pellet which could also act to reverse the process. The manganese released can diffuse through the cathode and evaporate to the focus electrode as seen on many tubes, or react with the BaO to produce MnO and free a Barium to enhance emission.

The mechanism on spacecraft 9444, TWTA 34-33 TWT S/N 299 (Figure 4) is very different from the previously described anomaly. The tube had run at a very constant level of helix current for about one (1) year prior to TWTA shut-down to store the spacecraft. When the TWTAs on the spacecraft were turned on, a drop in cathode current occurred from 4.7 mA before to 4.25 mA after. The helix change across the shut down was from .08 mA to .78 mA which then increased for a few days to a peak of 1.03 mA before dropping to a value of .5 mA. This type of behavior is indicative of a peeling cathode where peeling at one spot on the O.D. of the cathode can greatly affect the focusing and hence helix current.

It has been known for years that a peeling cathode is more likely to occur with highly active alloys than with others (4). It has been suggested that the peeling in early life (first 20,000 hours) may be due to insufficient wet hydrogen fire and the creation of a barium zirconite ($BaZrO_3$) interface which can be thick enough and cause brittleness to cause peeling. The forces generated by the differential thermal expansion during the turn-off or the turn-on could have precipitated the peel.

Q.2. The low level tube shows an abnormal scatter of cathode activity. Comment on the suggestion this is due to an abnormal scatter of cathode temperature under fixed operating condition, and the possibility this is the cause of some tubes being overheated.

A.2. Nothing in the data on the low level tube (263HA) suggests sintering of the cathode coating as a cause of the scatter in cathode activity. It is true that a large scatter does exist for this tube which may be caused by one or more of the following:

1) Variation in cold heater resistance, from tube to tube and heater batch to heater batch, due to variations in the conductivity of the non-sag tungsten heater wire, could cause variation in heater and cathode temperatures.

2) Variation in bake-out temperature due to processing on different bake-out stations.

3) Variation in cathode conversion parameters, such as heater currents. Time at each step, pumping capability of differing Vac-Ion pumps, and the maximum pressure achieved.

4) Differences in thermal conduction paths due to spotweld of heater legs and spring assembly of stacked gun.

Of these, item 3 is probably the greatest cause of cathode activity variations.

Q.3. Examine the tube design and manufacturing and attempt to define the source of the above abnormal variations.

A.3. Hughes EDD completed and submitted a final report on "The Oxide Cathode Conversion and Activation Study on The PRAM 8200H" (Triode) on Contract No. F04701-73-C-0094 P00038. One of the major findings was that cathode conversion should take place at the lowest pressure. This result is directly applicable to the 263HA, in that the 8200H is identically the 263H electron gun. The PRAM study was done at five (5) different Vac-Ion pump pressures as indicated by the Vac-Ion pump current. These were:

I_v = 0.02, 0.06, 0.26, 0.46 and 0.5 mA.
on a sample of 15 8200H tubes.

The TWTs on flights 7 and 8, plus TWT S/N 227 which was transferred to flight 11 had conversion pressures in the range 0.23 to 0.68 mA, with the majority in excess of 0.30 mA. The tubes on Flights 11 and higher had conversion pressures in the range 0.06 to 0.20 mA, with the majority below 0.16 mA. The change in conversion pressure

came about by reducing the amount of change in heater current at each step during conversion from 0.02 A to 0.01 A. This has the effect of slowing down the conversion and lowering conversion pressure. Based on the later PRAM data, it is in the right direction to increase time to the knee and possibly reduce the spread in cathode activity.

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(1) C. H. Meltzer and E. G. Widel. "Electron Emission Coating for The Oxide Cathode." Electron Tube Design pp. 37-63 R.C.A. Harrison

(2) "Actions of General Session Meeting, Low Level Anomaly Investigation", pg. 3, Sept. 7, 1978.

(3) E. S. Rittner. "Theoretical Study of The Chemistry of Oxide Cathodes." Philips Research Report Vol. 8 pp. 184-238, 1953.

(4) E. J. Hannig. "The Interface and Other Oxide-Cathode Impedances." Electron Tube Design, pp. 77-89 R.C.A. Harrison

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Electron Dynamics Division

FIGURE 1. PHYSICAL LAYOUT OF A DIODE SHOWING AN INTERFACE RESISTANCE AND THE RESULTING POTENTIAL DISTRIBUTION.

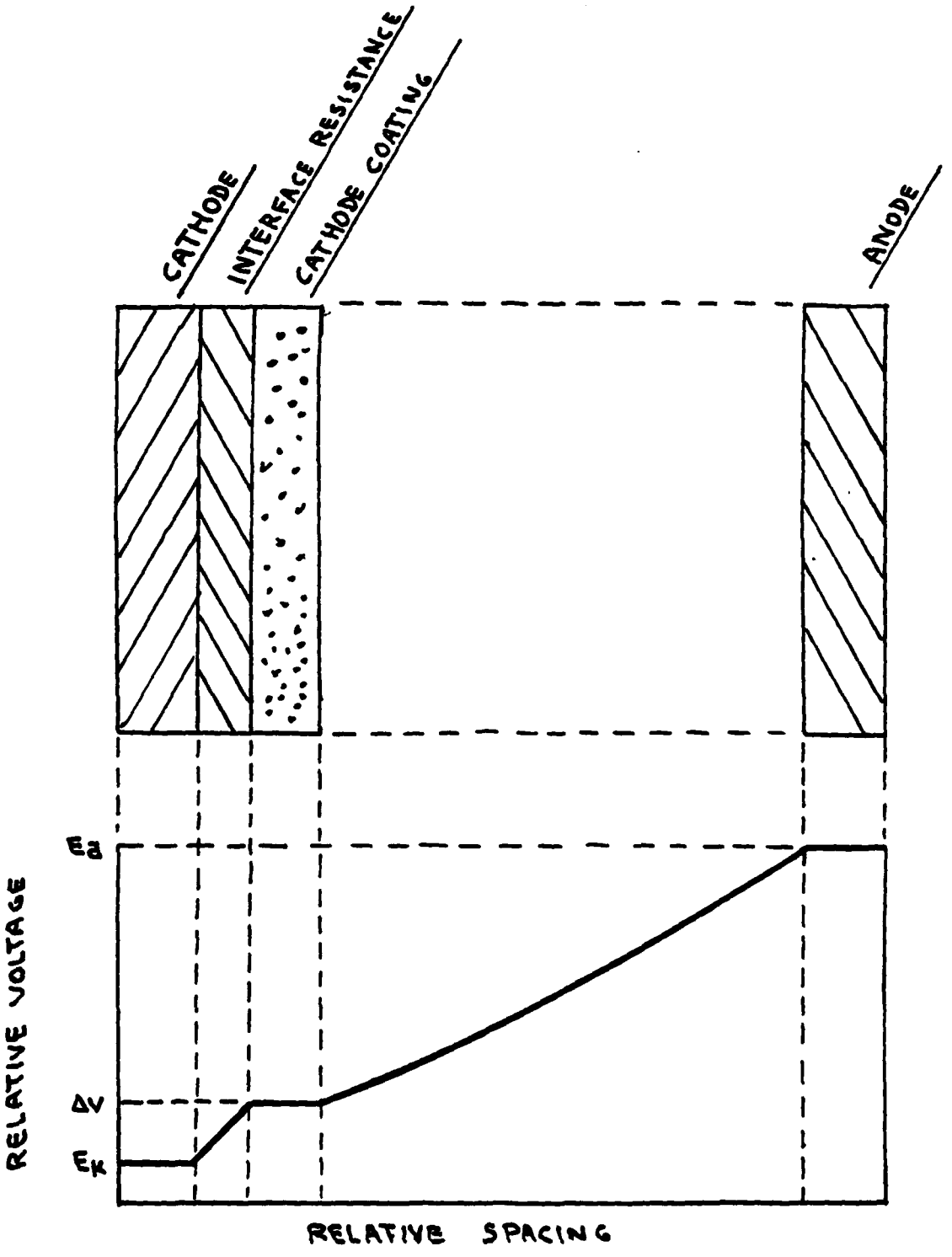
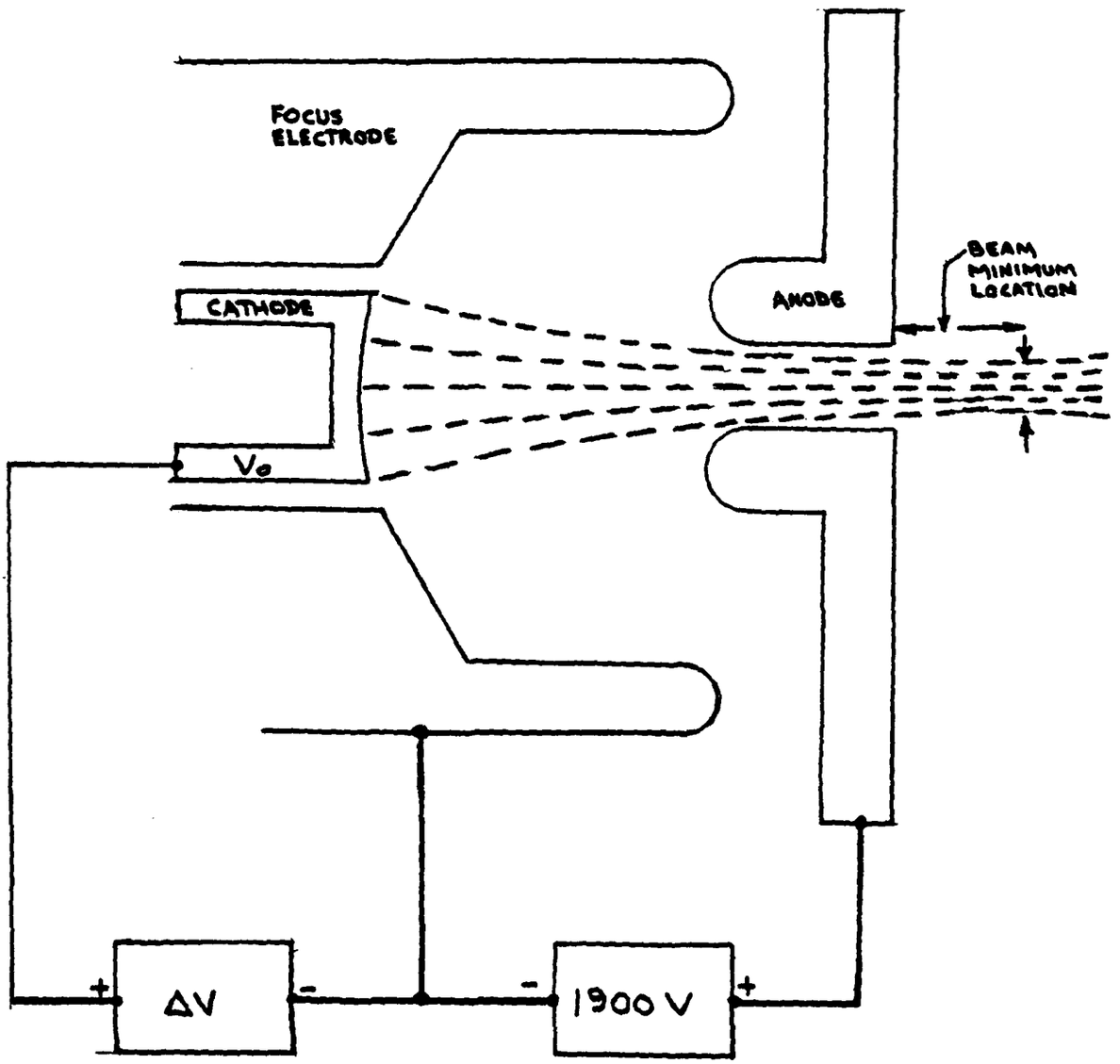
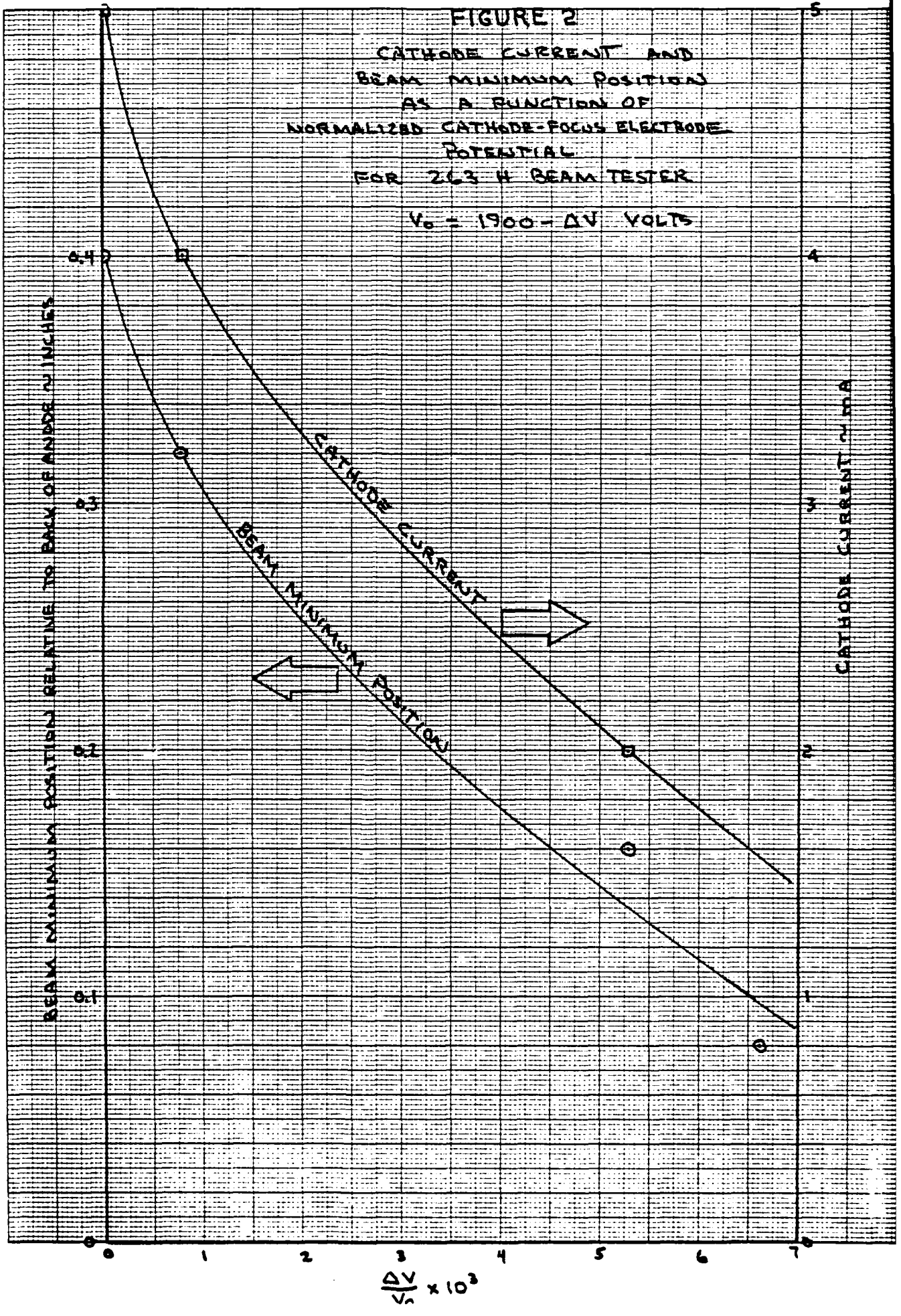
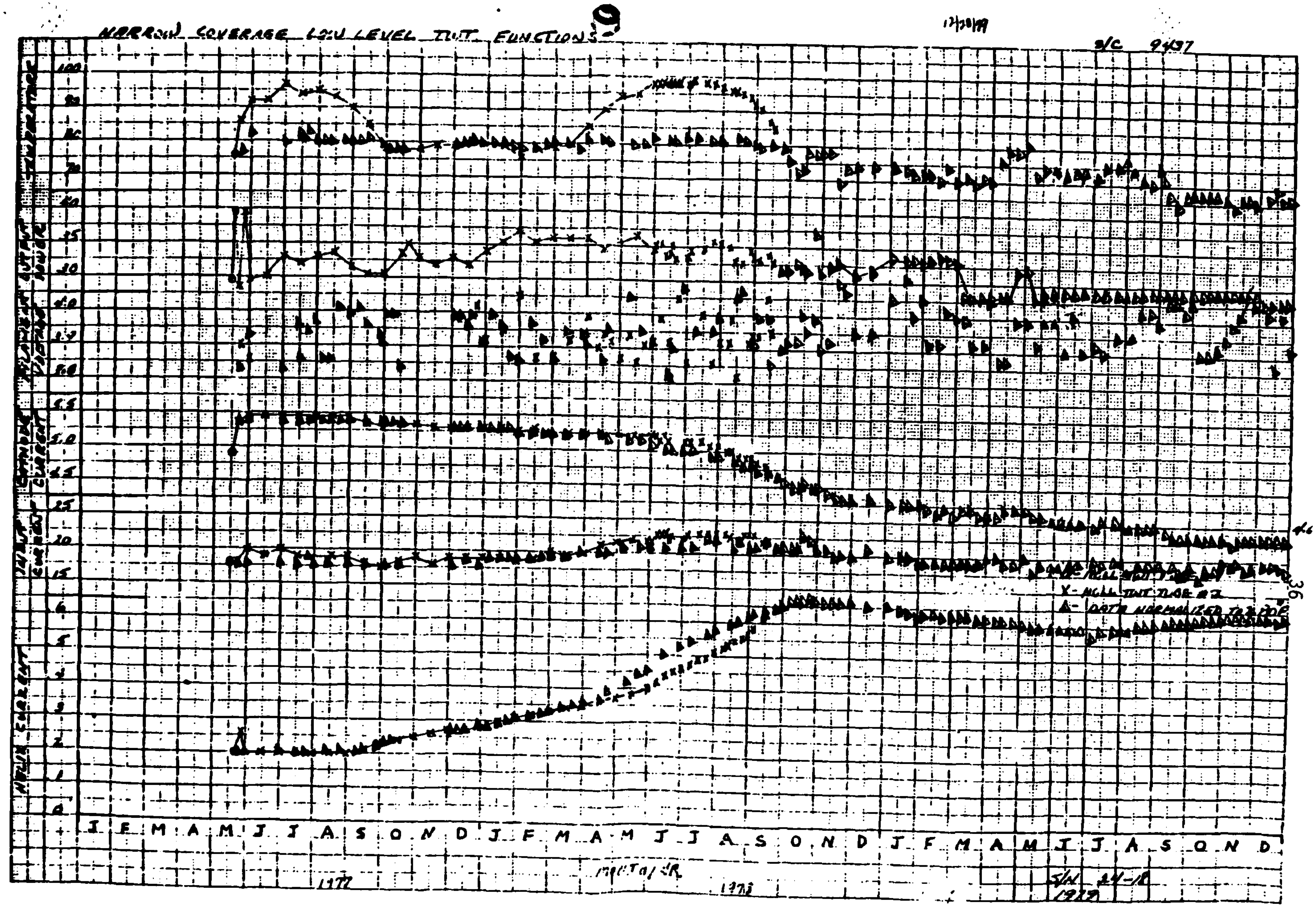


TABLE 1 RECORDED AND CALCULATED DATA FOR 263HA BEAM TESTER CONFIGURED AS BELOW

V_{FE} VOLTS	ΔV VOLTS	V_o VOLTS	$\Delta V/V_o$ —	I_K mA	$I_K/V_o^{3/2}$ $\mu\mho$	BEAM MINIMUM LOCATION INCHES
-1900	0.0	-1900	0.0	5.0	.060	.400
-1900	1.5	-1898.5	$.790\times10^{-3}$	4.0	.048	.320
-1900	10.0	-1890	5.29×10^{-3}	2.0	.024	.160
-1900	12.5	-1887.5	6.62×10^{-3}	....	---	.080







NARROW COVERAGE LOW LEVEL TWT FUNCTIONS
S/C 9437
X - HELL TWT TUBE #2
▲ - DATA NORMALIZED TO 3 DOF
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1977
1978
1979

FIGURE 3

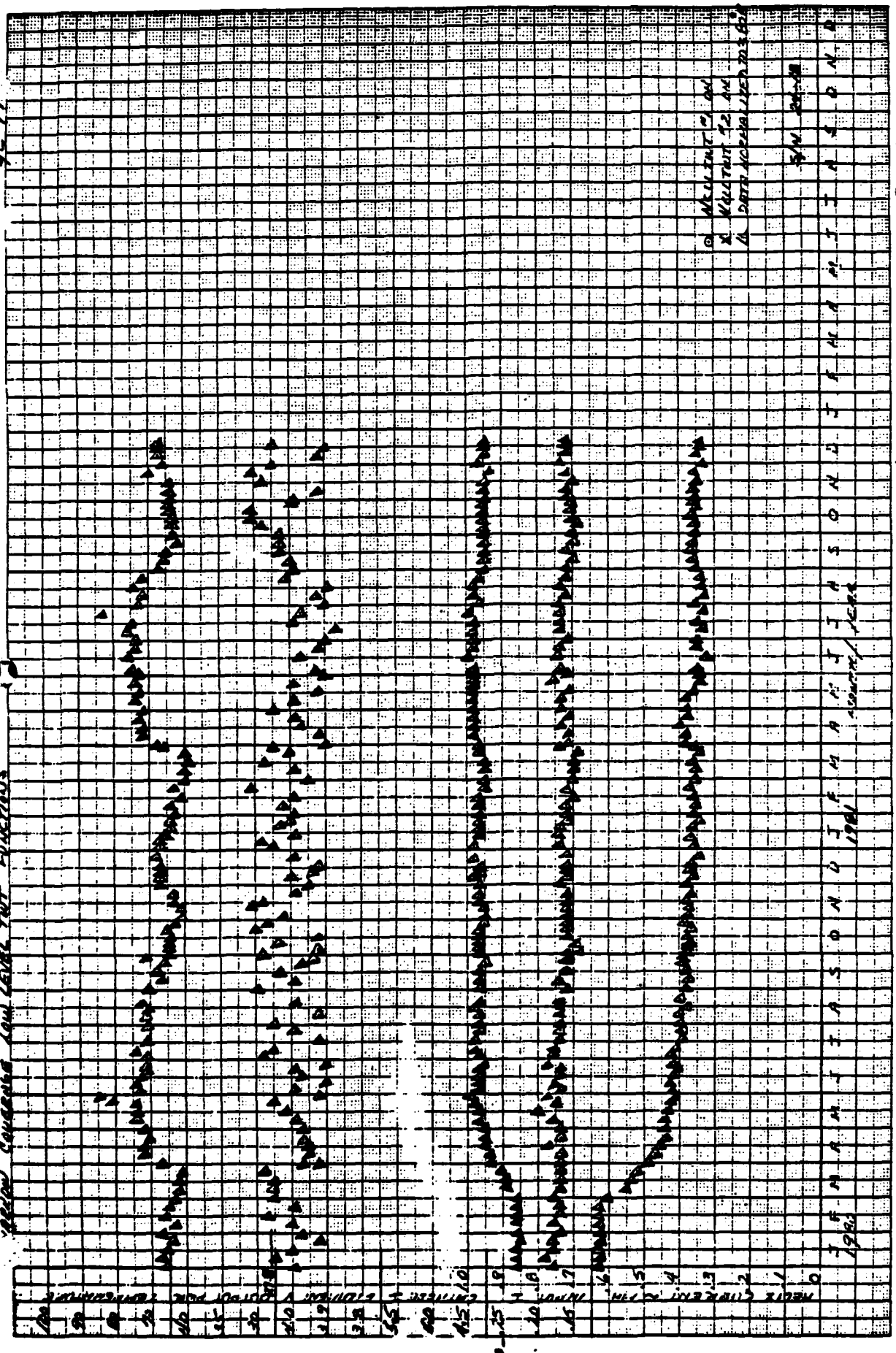


FIGURE 3 (cont'd)

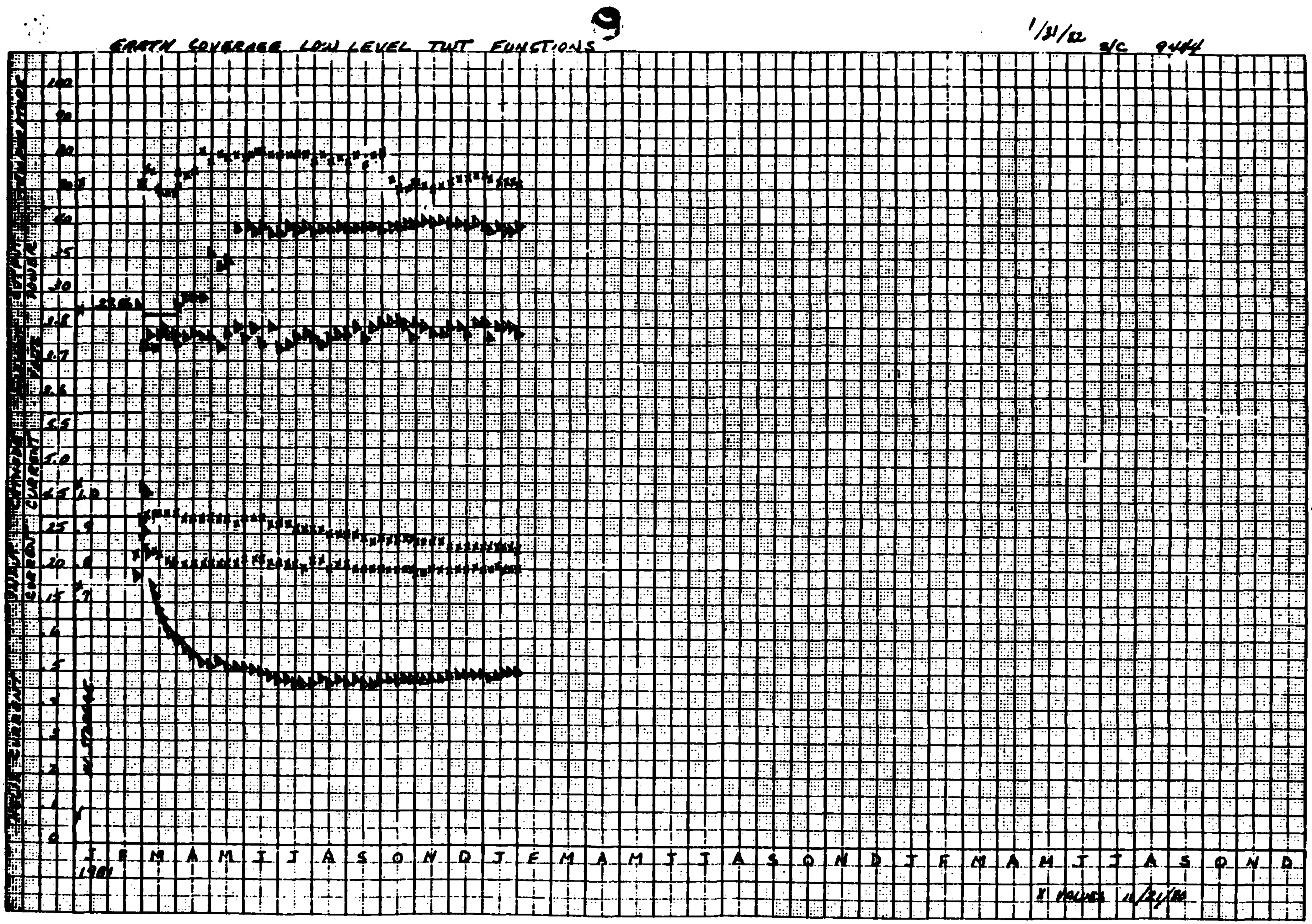

9
EARTH COVERAGE LOW LEVEL TWT FUNCTIONS
1/31/82 S/C 9444
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1981

FIGURE 4

APPENDIX II

EXTRACTS FROM AEROSPACE REPORT "DESTRUCTIVE PHYSICAL ANALYSIS OF 263HA TWT SN 245," WACHI, CONNELL, MARQUEZ, SU, BROSE & RIANDA

EXCERPTED WITH PERMISSION OF AEROSPACE CORPORATION. FOR DETAILS, PHOTOMICROGRAPHS, ETC., SEE ORIGINAL REPORT

INTRODUCTION

During the early stages of the LLTWTA anomaly investigation, it was speculated that the LLTWTA orbital anomaly is a manifestation of the effects of a higher shock level that an amplifier experiences at position 2 relative to position 1 on the despun platform of the spacecraft during appendage deployment. This hypothesis evolved from the observation that only the LLTWTAs in position 2 were showing anomalous orbital performance signatures. Amplifier SN 24-20 located in position 1 had not yet shown any drift in I_w when this hypothesis was postulated. To test this hypothesis, a 1200H TWTA SN 24-23 was selected as a test vehicle to pursue the investigation of its behavior after subjection to pyrotechnic shock. This amplifier was pyrotechnically shocked four times on a despun platform at TRW and then was placed on extended burn-in for ~2200 hours. During extended burn-in this LLTWTA continued to exhibit gradual changes in cathode and helix currents resembling those of the orbital LLTWTAs (Figure 7). No abrupt changes in either I_w or I_k were observed after completion of pyroshock testing. However, at the end of the extended burn-in, cathode activity had degraded significantly (Figure 8). The TWT, 263HA SN 245, was removed from the amplifier and transferred to The Aerospace Corporation for destructive physical analysis.

The objectives of this present investigation were to determine the possible cause(s) of the observed degradation in cathode activity and drifts in cathode and helix currents of 263HA TWT SN 245 and ascertain whether a correlation exists between the possible cause(s) and TWT manufacturing processes, materials, and acceptance testing, especially the effect of pyrotechnic shock testing.

DISCUSSION OF RESULTS

A. TWT GAS ANALYSIS

The continuous rise of the helix current is 263HA TWT SN 245 during burn-in of LLTWTA SN 24-23 does not appear to be the

Fig. 7

Cathode and Helix Current Data for 263HA TWT SN245

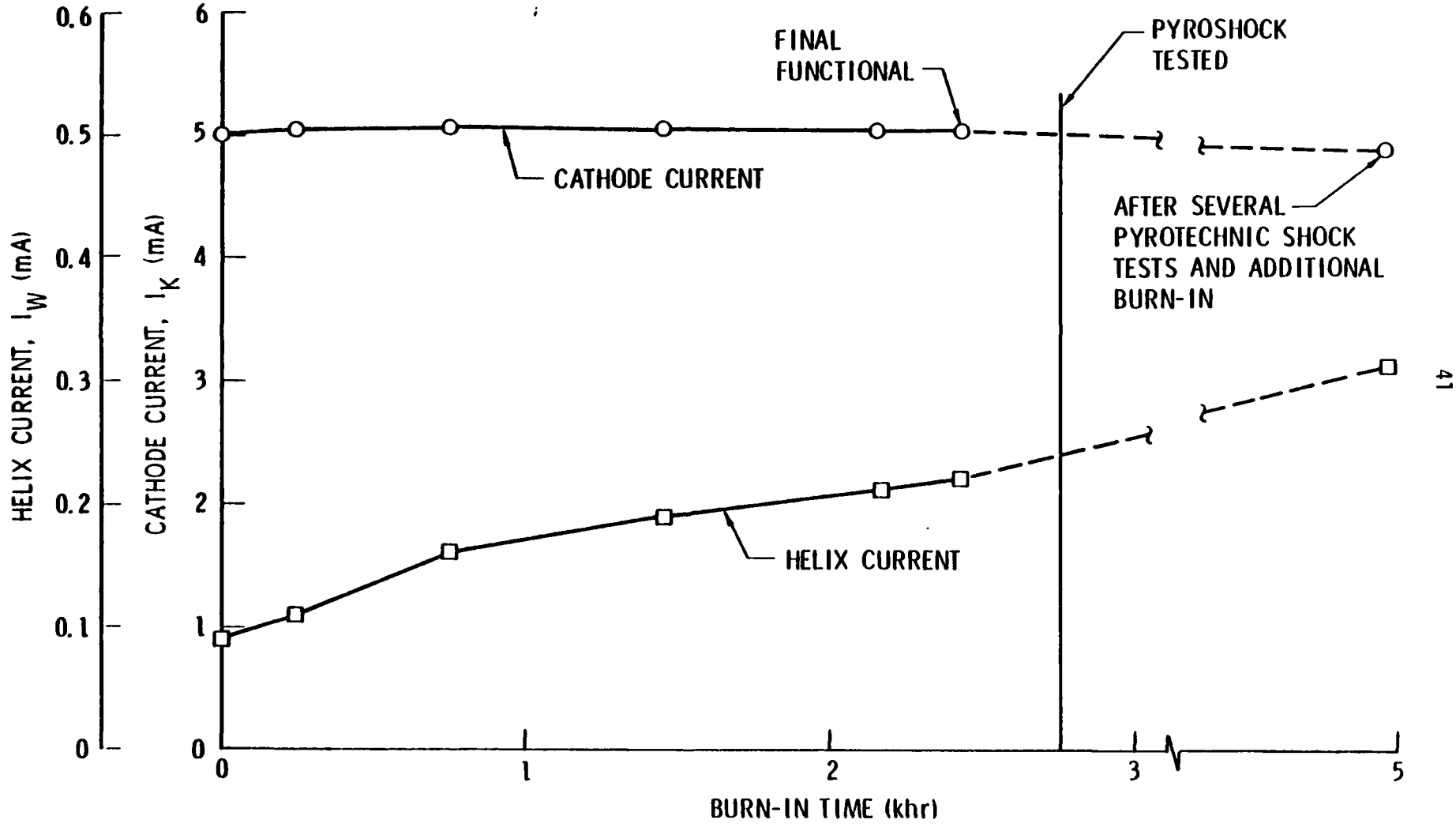
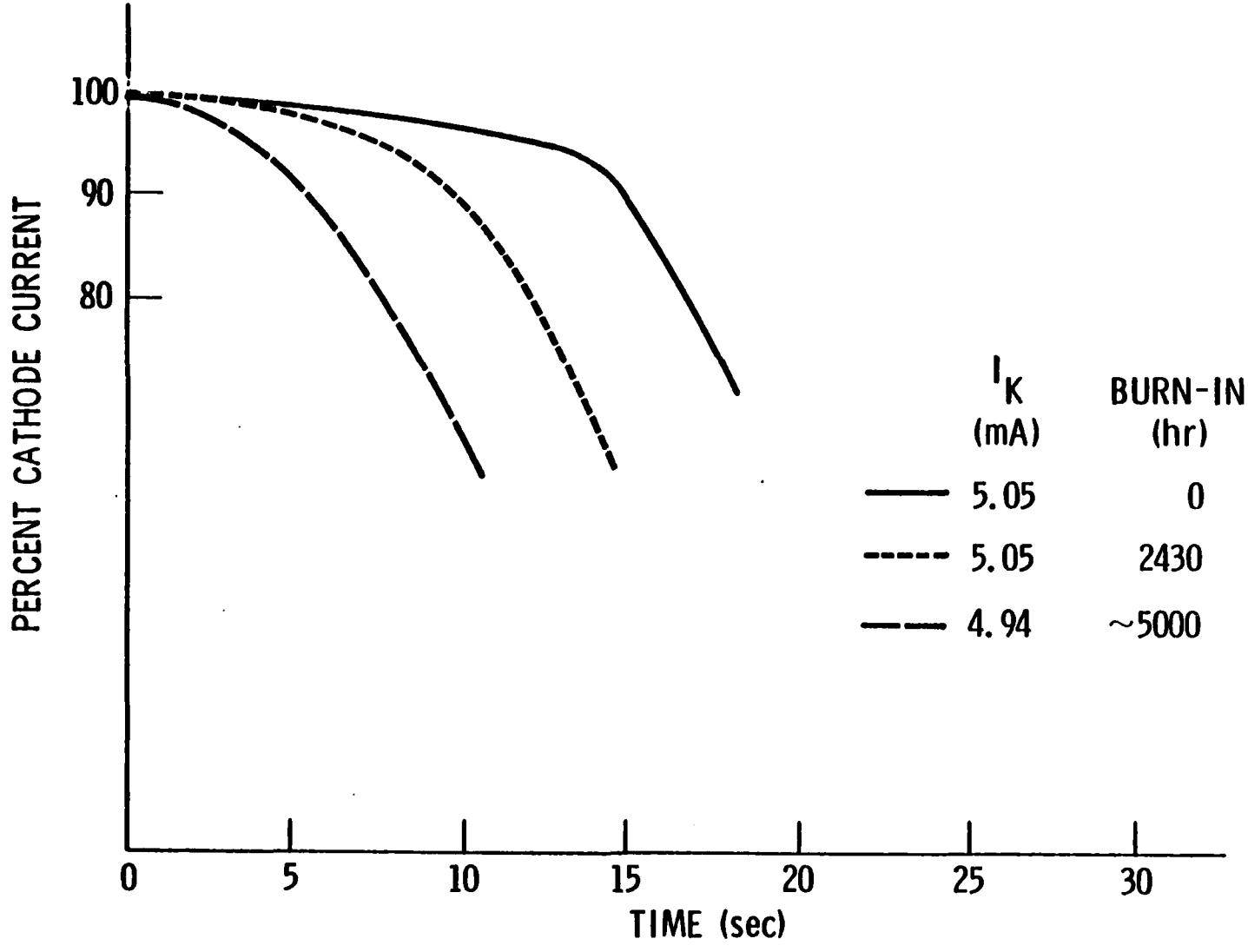


Fig. 8

Cathode Activity Test

(263HA TWT SN 245)



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result of residual gases in the tube. The gas content was reported by Graven and Gilmartin to be extremely low. After the TWT was depotted, a gas pressure of 2×10^{-8} Torr was measured by the modified Bayard-Alpert ion current measurement technique. The gas pressure increased to 5.7×10^{-7} Torr after attachment and bakeout of the puncture assembly. The constituents were identified as argon and helium which most likely were ion implanted in the collector during the early stages of tube operation but were released during depotting of the tube and bakeout of the puncture assembly prior to gas analysis. Thus, it is concluded that the TWT gas pressure during the burn-in phase was $\leq 2 \times 10^{-8}$ Torr.

B. OXIDE CATHODE COATING

Visual examination of the oxide coating after the electron gun was disassembled in an argon atmosphere revealed slight lifting of the oxide coating at the edge of the cathode. No evidence of ion etching of the oxide coating was seen. This latter observation is consistent with the low gas content found by the residual gas analysis technique. Photographs taken immediately after the cathode assembly had been transferred into the SEM in an argon atmosphere confirmed the visual observation that the oxide coating was partially lifted at the edge of the cathode. No evidence of sintering or fusion of the emissive coating was observed.

The cathode assembly was then removed from the SEM chamber, inverted in an attempt to dislodge the foreign particle located on the interior wall of the focus electrode, and placed back in the SEM for further examination. These operations were all performed in ambient atmosphere in less than 2 minutes. SEM photographs showed that several cracks have developed in the (Ba, Sr)O coating. Development of these cracks suggests that the oxide coating is brittle and that these cracks were induced by chemical reactions occurring within the oxide coating

and/or at the interface between the coating and the nickel substrate after the cathode assembly had been exposed to ambient atmosphere. Optical photographs of the cathode were taken immediately after the cathode assembly was removed from the SEM. Partial lifting of the oxide coating starting from the edge is evident; the cracks are barely visible. The cathode assembly was placed in a plastic box and stored in ambient atmosphere for 2 days. No visible change in coating appearance had occurred during storage. The cathode assembly was then inverted, placed on a filter paper with the focus electrode as the support structure, and allowed to remain in this quiescent position for 15 minutes before it was set upright and re-photographed. Separation of the oxide coating from the substrate was seen to have progressed from the edge towards the center and the cracks are now much more pronounced. The cathode assembly was again inverted and placed on a filter paper. The back end of the focus electrode was gently tapped three times. After this operation, half of the oxide coating fell off. The remaining half did not fall off but most of the oxide coating was lifted off the nickel substrate. Both halves of the brittle oxide coating were transferred to a special plastic container for chemical analysis by the neutron activation technique. As yet, this analysis has not been performed.

C. IMMA RESULTS ON THE CATHODE BUTTON

The cathode button of 263HA TWT SN 245 was machined from Z-8182 Ni alloy, which is an ultrahigh purity Ni doped with 0.1 wt. % zirconium (Zr) and $\sim$ 2 wt. % tungsten. IMMA spectra of the eloxed surface of the cathode Ni button were made before and after the residual oxide coating was removed with a 50 percent by volume solution of acetic acid and deionized water. IMMA results indicated that the eloxed surface of the Ni button from

tube SN 245 was contaminated with small quantities of Mn and Cr and that the $^{90}Zr^{+}/^{58}Ni^{+}$ and $^{138}Ba^{+}/^{58}Ni^{+}$ ion current ratios were about an order of magnitude greater than that for the cathode from the life-test tube, indicating an abundance of Ba and Zr on the eloxed surface.

The concentrations of Mn and Cr on the eloxed surface were found to be ∿50 ppm and ∿90 ppm, respectively. These values are not too different than those (38 ppm Mn and 40 ppm Cr) found on the surface of the cathode from tube SN 102. These measured concentrations represent steady-state values attained after the initially higher Mn and Cr levels were reduced by surface evaporation and by diffusion during tube operation. Since the Ni button was machined from an ultrahigh-purity Ni alloy, the Mn and Cr concentrations should have beer < 5 ppm (Ref. 6) if the eloxed surface had not been contaminated.

An earlier investigation established that the cathode Ni buttons could be contaminated with Mn and Cr during vacuum firing if the cathode sub-assemblies were fired together with other contaminated parts or in a vacuum firing can containing these residual contaminants from previous firings. The source of these contaminants found on the cathode Ni button from tube SN 245 appears to be the type 270 nickel cathode support sleeve (ring) that was contaminated with Mn and Cr during one of the high temperature firing processes.

In-depth concentration profiles for Mn and Cr obtained from the convex outer surface of the cathode support ring were made. Although the cathode support sleeve was machined from an ultrahigh-purity type 270 nickel, it was contaminated with Mn and Cr during wet hydrogen firing. At the firing temperature of ∿1000°C, both Mn and Cr deposited on the not Ni surface diffused into the bulk Ni forming solid solutions of Mn-Ni and Cr-Ni.

After the cathode support sleeve was integrated with the cathode Ni button to form the cathode subassembly and subsequently vacuum fired at ∿1000°C, part of the Mn and Cr was lost by vaporization near the surface of the Ni ring; the remainder continued to diffuse deeper into the bulk Ni. Contamination of the adjacent cathode Ni button occurred by vapor deposition of Mn and Cr. These small quantities of Mn (∿50 ppm) and Cr (∿90 ppm) have been shown not to affect the performance and life of oxide cathodes.

Ion yield ratios for several selected elements are tabulated in Table 3 for several cathodes and nickel alloys. Vacuum fired nickel buttons and raw stock Ni alloys are included for comparison purposes. The most significant difference between the good cathode from 263H TWT SN 102 and that from 263HA TWT SN 245 is found in the elemental composition of the nickel substrate surface. High values for the $^{90}Zr^{+}/^{58}Ni^{+}$ and $^{138}Ba^{+}/^{58}Ni^{+}$ ion current ratios for the Ni button from tube SN 245 are indicative of an abundance of Ba and Zr at or near the surface to a depth of ∿250 Å (Ref. 8). The abundance of Ba and Zr arises from the interface compound $BaZrO_3$ that has been identifed by x-ray diffraction analysis. Similar high values for the $^{90}Zr^{+}/^{58}Ni^{+}$ and $^{138}Ba^{+}/^{58}Ni^{+}$ ion current ratios were also observed for another cathode from a dual diode, 262H SN 69B, whose oxide coating had lifted off from the Ni substrate during disassembly of the electron gun. This diode was scrapped after 7954 hours of operation because of poor cathode activity. Deterioration in cathode activity, declining I_k and rising T_w seen in 263HA TWT SN 245 appear to result from the formation of $BaZrO_3$ at the interface between the Ni substrate and the oxide coating.

Scanning ion micrographs of the eloxed surface at the center and edge of the cathode Ni button were made.

Table 3. IMMA Data On Cathode Nickel Buttons and Nickel Alloys

Specimen	Operating Time (hr)	Ion Current Ratios* Al^+/Ni^+	Zr^+/Ni^+	Ba^+/Ni^+	Sr^+/Ni^+	Remarks
263HA TWT SN 245	∿5000	0.013	0.10	1.1	0.24	Untreated eloxed surface, partially lifted coating
		0.022	0.16	1.4	0.056	Cleaned** eloxed surface
		0.0035	0.022	∿0	∿0	Cleaned ledge surface
263H TWT SN 102	62,551	0.025	0.0085	0.16	0.13	Untreated eloxed surface life-test good TWT
		0.032	0.011	0.17	0.019	Cleaned eloxed surface
		0.018	0.0062	∿0	∿0	Untreated ledge surface
		0.022	0.011	∿0	∿0	Cleaned ledge surface
262H Dual Diode SN 69B	7,954	0.027	0.056	0.19	0.034	Cleaned eloxed surface, good coating adhesion region
		0.051	0.25	3.8	0.20	Cleaned eloxed surface, lifted coating region
		0.056	0.051	∿0	∿0	Cleaned ledge surface
249 #270	0	0.014	0.028	N.D.+	N.D.	Eloxed surface after vac-fire
293H #89	0	0.091	0.026	N.D.	N.D.	Eloxed surface after vac-fire
Raw Stock Z-8182	0	0.0038	0.0027	N.D.	N.D.	
Raw Stock X-3012	0	0.0038	0.0032	N.D.	N.D.	

*Average of several measurements
**Rinsed with acetic acid solution and ultrahigh purity water
+Not detected

These ion images, produced with the IMMA using an $^{18}O_2^+$ ion beam of ~3μm in diameter, depict the elemental distribution within the areas analyzed. These photos show that the elements Ba, Sr, and Zr are coincident and are localized at the grain boundaries, as will be shown in a subsequent section.

D. SEM/EDAX ANALYSIS OF THE CATHODE Ni BUTTON

The SEM/EDAX photomicrographs of the eloxed surface of the cathode Ni button from 263H TWT SN 245 show that the surfaces of the Ni grains are very smooth and the grain boundaries are replete with nodules rich in Ba, Sr, and Zr. These photomicrographs corroborate the scanning ion micrograph data that showed the spatial distribution of Ba, Sr, and Zr to be coincident and concentrated essentially at the grain boundaries. Some Zr-rich nodules were found within Ni grains at the edge of the cathode Ni button. These Zr-rich particles are a mixture of $SrZrO_3$ and $BaZrO_3$. Photomicrographs of surfaces that were not in direct contact with the oxide coating show the grain boundary particles on the side are also rich in Zr.

These surface features have also been observed on other cathode Ni buttons whose oxide coatings were found to be partially lifted near the periphery of the cathode or completely lifted from the nickel substrate when the electron guns were disassembled.

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