EVALUATION PROGRAM

for

SECONDARY SPACECRAFT CELLS

SYNCHRONOUS ORBIT TESTING
OF
6.0 AMPERE-HOUR SEALED NICKEL-CADMIUM CELLS

MANUFACTURED BY
GENERAL ELECTRIC COMPANY

prepared for
GODDARD SPACE FLIGHT CENTER
CONTRACT W12,397

QUALITY EVALUATION LABORATORY

NAD CRANE, INDIANA

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EVALUATION PROGRAM FOR SECONDARY SPACECRAFT CELLS

SYNCHRONOUS ORBIT TESTING OF GENERAL ELECTRIC COMPANY 6.0 AMPERE-HOUR NICKEL-CADMIUM CELLS

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Enclosure (1)

REPORT BRIEF

RESULTS OF SYNCHRONOUS ORBIT TESTING OF 6.0 AMPERE-HOUR SEALED NICKEL-CADMIUM CELLS MANUFACTURED BY GENERAL ELECTRIC COMPANY

Ref: (a) NASA Purchase Order Number W12-397
(b) NASA ltr BRA/VBK/pad of 25 September 1961 w/BUWEPS first end FQ-1:WSK of 2 October 1961 to CO NAD Crane
(c) NASA Work Sheet of April 1967

I. TEST ASSIGNMENT BRIEF

A. In compliance with references (a) and (b), evaluation of sealed nickel-cadmium cells was begun according to the program outline of reference (c).

B. The purpose of this evaluation program is to gather performance information concerning sealed nickel-cadmium cells operating under a synchronous orbit regime. Such a regime simulates a space satellite maintaining a position over a fixed point on earth as the earth rotates on its axis and revolves about the sun.

II. SUMMARY OF RESULTS

A. A temperature of 40° C is very detrimental to cells in a synchronous orbit regime.

B. A temperature of -20° C results in high cell voltages during charge, and an extremely low trickle charge (c/240) must be maintained to keep the voltage at or near 1.50 volts. In general as the environmental temperature goes down, the charge voltage goes up. Also at low temperature, the charge voltage fluctuates more radically with slight variations of test conditions, such as capacity checks.

C. Coulometers are effective charge control devices (particularly at -20° C) when operative. However, they have shorter lives than the cells they control.

D. The voltage balance, during discharge, between the high and low cells of a synchronous pack is best at 25° C and worst at 40° C. Also age and greater depths of discharge result in greater degradation of pack voltage balance.

E. The capacity checks performed during the middle of each eclipse season initiated the following:

1. A slight increase in average discharge voltage generally occurs within 1 or 2 days following the capacity check except for operation at 40° C. The reverse is noted for 40° C.

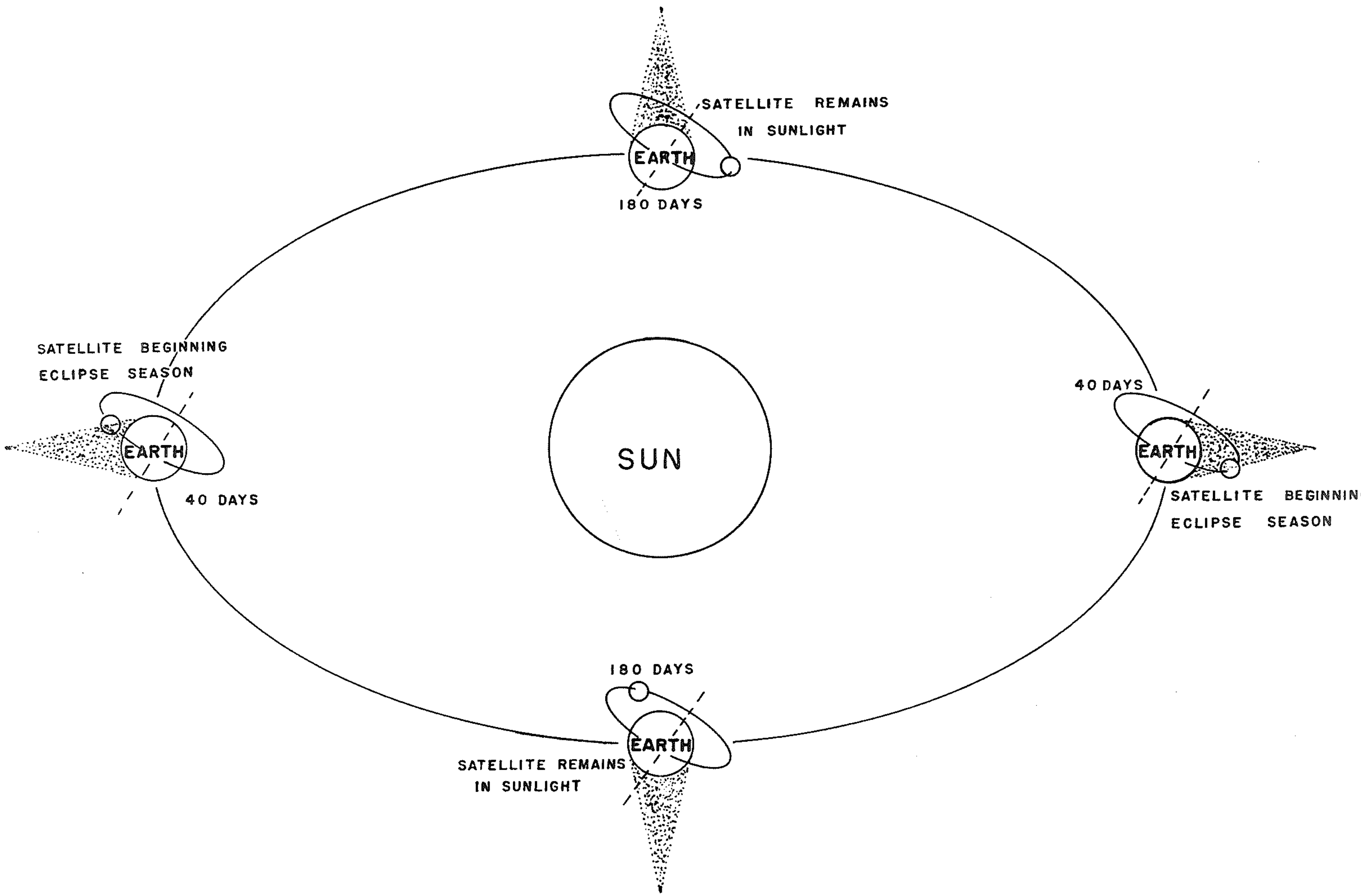
2. For non-coulometer controlled cells, the average positive slope (discharge voltage) following the check slightly exceeds the negative slope preceding the check.

RESULTS OF CONTINUOUS SYNCHRONOUS ORBIT TESTING
ON
6.0 AMPERE-HOUR SEALED NICKEL-CADMIUM CELLS
MANUFACTURED BY
GENERAL ELECTRIC COMPANY

I. INTRODUCTION

A. The synchronous orbit tests were begun on six, 5-cell packs on 18 July 1967. They have completed six eclipses and contine to cycle with one exception. Pack 4 failed on 6 February 1968 and was replaced by pack 4B (with a coulometer) on 2 August 1968. Pack 4B has completed four eclipses. Note: A separate report will cover synchronous orbit testing on auxiliary electrode cells.

B. In a synchronous orbit, the velocity of a satellite and its distance from the earth are adjusted such that one revolution of the satellite matches one rotation of the earth. Such a satellite remains fixed over one location on the earth. The earth's shadow cone changes relative to the satellite's plane of orbit. (See diagram.) Thus every 180 days the satellite enters an eclipse season. This season lasts approximately 40 days after which the remaining 140 days are in continuous sunlight. At the beginning of an eclipse season, the satellite first moves through the outer area of the earth's shadow cone. Each day of the eclipse season it progresses through a different section of the shadow cone until it has completely transversed the cone at the end of the season. The satellite's time within the shadow cone thus varies from day to day within the eclipse season beginning with a minimum, progressing to a maximum, and returning to a minimum.


SATELLITE REMAINS
IN SUNLIGHT
EARTH
180 DAYS
SATELLITE BEGINNING
ECLIPSE SEASON
EARTH
40 DAYS
SUN
40 DAYS
EARTH
SATELLITE BEGINNING
ECLIPSE SEASON
180 DAYS
EARTH
SATELLITE REMAINS
IN SUNLIGHT

II. TEST CONDITIONS

A. To simulate the conditions experienced by the space cells aboard a synchronous orbiting satellite, the following 183-day test regime was adopted.

1. Period simulating continuous sunlight (141 days):

a. The cells were continuously charged at 200 milliamperes except the cells in pack 4B whose coulometer limited them to 25 milliamperes.

2. Period simulating eclipse season (42 days):

a. All cells were discharged for 12 minutes the first day of the eclipse season. The discharge time increased by 3 to 4 minutes per day for 18 days to a maximum of 1 hour and 12 minutes. This maximum discharge then occurs once a day for 8 days (18th through 25th day of eclipse season) with one exception--a capacity check was always run during the middle of each eclipse season.

b. The capacity check was run on the 21st day of the eclipse season. The capacity check consisted of a constant current discharge (rate depending on the depth of discharge) to an average voltage of 1.00 volt per cell or 0.50 volt on the low cell, whichever came first. This differed from the other daily discharges during an eclipse only in that the low cell was then allowed to go as low as 0.00 volt before termination of the discharge.

c. Following the capacity check, the cells continued the daily discharge of 1 hour and 12 minutes through the 25th day of the season. From the 26th day to the end of the season, the discharge was shortened by 3 to 4 minutes per day. The last day's discharge was was 12 minutes, the same as the first day. The cells then returned to continuous charge (sunlight) completing the 180-day cycle.

B. The following table identifies the synchronous packs and gives the test parameters of each pack.

Pack Number	Temp ° C	Percent Depth of Discharge	Charge Rate (ma)	Discharge Rate (Amps)	Charge Control
1	40	40	200	2.0	None**
2	25	40	200	2.0	None**
3	0	40	200	2.0	None**
4	-20	40	200	2.0	None**
4B	-20	40	200*	2.0	Coulometer
5	0	60	300*	3.0	Coulometer
6	0	80	400*	4.0	Coulometer

* These cells are charged at the specified rates until limited by their respective coulometers to 25 milliamperes (4B) or 200 milliamperes (5 and 6).

** The charge currents are controlled by regulated power supplies.

III. CELL DESCRIPTION

A. The cells are nickel-cadmium, 6.0 ampere-hour, manufactured by General Electric. They are rectangular and hermetically sealed with stainless steel containers and covers. The separator material is pellon. The terminals are insulated from the cell cover by ceramic seals, and the terminals protrude through the cover with solder tabs welded to the top.

IV. TEST RESULTS

A. The test results are shown graphically in Figures 1 to 8. Explanations of the first four graphs are considered separately in this section. The first three graphs show only the successive eclipse seasons and omit the 140-day continuous charge between the eclipse seasons. Graph 4 shows the entire sunlight and eclipse season cycle for synchronous pack 4 due to its erratic nature and short life. Five items are plotted versus the number of days on cycle: (1) average end-of-charge voltage (ooo), (2) average end-of-discharge voltage (xxx), (3) high cell, end-of-discharge (△△△), (4) low cell, end-of-discharge (▲▲▲), and (5) the time on discharge (in hours) as it varies each day of each eclipse season. This latter item forms a large pyramid curve for each eclipse season below the other plotted data.

1. The discharge data for the capacity check is omitted in Figures 1 through 4. The capacity check data is considered separately in Figure 5.

2. The end-of-discharge (e.o.d.) voltage for the high or low cells was plotted only if it varied from the average by 0.05 volt or more. This value was arbitrarily set to prevent the symbols from running together. In all applicable cases the low cell shows much greater deviation from the mean than the high cell and this deviation shows up sooner and lasts longer.

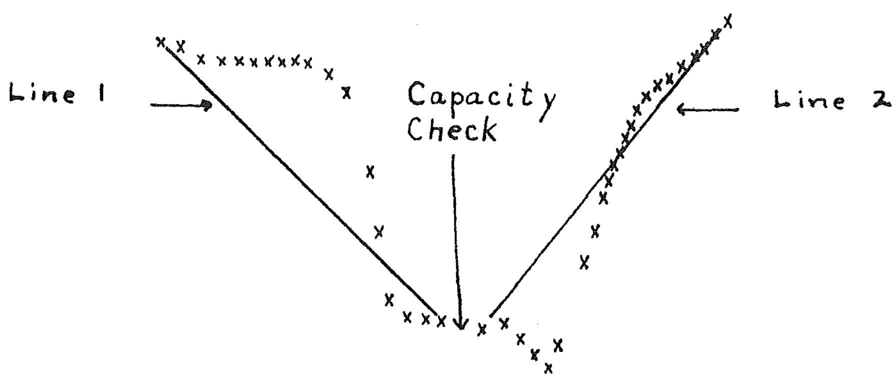
3. The coulometers of Syncs 4B, 5 and 6 are diode protected such that voltage on charge never goes above 0.703 volt. Voltage variations below 0.703 volt occur during discharge, where the voltage is negative, and on charge when the coulometer is shorted or not fully recharged.

B. As the individual synchronous (sync) packs are presented, some comparisons are noted between Syncs 1 through 4 because they were all operated at 40 percent depth of discharge and without coulometer control. Thus the differences are a function of temperature only. Also some comparisons are made between Syncs 4B, 5 and 6 because these packs all contain coulometers. References to voltage refer to the average for each pack unless specified as the high or low cell of the pack.

1. Sync 1: The successive eclipse seasons for this pack are shown in Figure 1.

a. End-of-Charge (e.o.c.) Voltage: The e.o.c. voltage tends to increase by 0.01 volt from the beginning of one eclipse season to the next. Also the e.o.c. voltage of the cells showed a slight lack of stability in the last two eclipse seasons as exemplified in Figure 1 by a small undulation of the plotted e.o.c. voltage. This undulation and the small increase in voltage with time is felt due simply to aging.

b. End-of-Discharge (e.o.d.) Voltage: Without exception, the e.o.d. voltage of the cells drops following the capacity check during the middle of each eclipse season. This is shown in Figure 1 as a dip in the average e.o.d. voltage. This occurs even though the time on discharge lacks a few minutes of going the full 1.2 hours due to the low cell reaching 0.00 volt. Thus the capacity check for Sync 1 (40° C) indicates an immediate detrimental effect on the cells ability to deliver power. However, as the time on discharge is decreased during the last half of the eclipse season, the cell's ability to deliver power is increased over that of the first half of the season. For example, the following sketch is typical of the e.o.d. curves of Sync 1, Figure 1.



Line 1 is drawn from the e.o.d. voltage of the first day to that of the day prior to the capacity check. Line 2 is drawn from the e.o.d. voltage on the day following capacity check to that of the last day of the eclipse. By observation and calculation the positive slope of line 2 is greater than the negative slope of line 1. Thus with a constant discharge current but increasing cell voltage the data indicates a slight increase in the cells' capability to deliver power during the last half of each eclipse season following a capacity check. The percent difference in the average slopes for the six eclipse seasons of Sync 1 is 5.0 percent as shown in the table below. The data for this table were taken directly from the graphs of Figures 1 through 4.

Sync Pack	Avg Neg Slope Line 1	Avg Pos Slope Line 2	Difference of Avg Slopes Line 2 - Line 1	Percent Difference
	($X\ 10^{-3}$ volts/day)			
1	23.6	24.8	+1.2	5.1
2	3.57	3.81	+0.27	7.6
3	4.18	4.58	+0.40	9.6
4*	--	--	--	--
4B	3.35	2.65	-0.70	26.0
5	4.75	3.81	-0.94	25.0
6	7.62	9.26	+1.6	21.0

* No conclusive data generated for pack 4.

c. Capacity: The cells of Sync 1 have never delivered the manufacturer's rated capacity of 6 ampere-hours by a factor of 3. The capacity checks are plotted in Figure 5. The table below gives the capacity at each eclipse season.

Eclipse Season	1	2	3	4	5	6
Capacity (ah)	1.74	1.80	1.74	1.66	2.00	1.70

2. Sync 2: The successive eclipse seasons for this pack are shown in Figure 1 below the heavy, dark line. The high and low cell was not plotted because, at no time, was the difference more than 0.03 volt from the average.

a. End-of-Charge Voltage: The eclipse seasons had no visible effect on the charge voltage as shown in Figure 1. The e.o.c. voltage during the eclipse remained constant and was the same as the stabilized charge voltage of the sunlight period on either side of each eclipse season (not shown). Comparing Sync 2 with Sync 1, the e.o.c. voltage of the first eclipse season for Sync 2 is 0.05 volt greater. This difference diminishes with time as the e.o.c. voltage of Sync 2 remains constant and that of Sync 1 increases as noted in paragraph IV.B.1.a. Thus Sync 2 at 25° C does not give the indication of aging that was noted for Sync 1.

b. End-of-Discharge Voltage: The cells of Sync 2 showed a slight increase in e.o.d. voltage (0.01-0.02 volt) following the capacity check of each eclipse season. This is illustrated in Figure 1 and indicates a slight rejuvination of the cells as a result of the capacity check. Also the cells of Sync 2 remain evenly matched. This is observed in Figure 1, in that, the high or low cell has never varied a sufficient amount from the average to require plotting (see paragraph IV.B.2.). Furthermore Sync 2 discharged the maximum time for each eclipse season with no cutoff for low average voltage or low cell voltage. Finally the average decent and ascent slope (see paragraph IV.B.1.b.) of the plotted e.o.d. voltages on either side of each capacity check vary by an average of 7.6 percent; the ascent slope following the capacity check is greater than the descent slope preceding the check. This is consistent with the data noted for Sync 1 though less obvious.

c. Capacity: Figure 5 indicates only eclipse seasons 5 and 6 dropping below the 6 ampere-hour rated capacity. The following table gives the capacity at each eclipse season for Sync 2.

Eclipse Season	1	2	3	4	5	6
Capacity (ah)	7.66	6.54	6.24	6.04	5.64	5.54

3. Sync 3: The successive eclipse seasons for this pack are shown in Figure 2 above the heavy, dark line. The high and low cells did not vary from the average cell voltage on discharge by more than 0.03 volt, and therefore, they were not plotted.

a. End-of-Charge Voltage:

(1) The voltage of the cells during sunlight periods (constant charge) gradually taper downward from 1.55 volts, preceding the first eclipse season, to 1.48 volts preceding the sixth eclipse season--a decline of about 0.01 volt per 180 days. The first two seasons have no noticeable effect on this decline. That is, the e.o.c. voltage during the first two eclipse seasons matches the stabilized, sunlight voltages on either side of the eclipse seasons. However the third eclipse season through the sixth eclipse season initiates increases of 0.04 to 0.05 volt in the e.o.c. voltage, within these seasons, over that of the sunlight period on either side of the season. Thus the e.o.c. voltages of Figure 2, eclipses 3 to 6, average about 0.04 volt above the sunlight charge voltage between the eclipse seasons.

(2) During some of the eclipses, particularly eclipse 5, the cells show a low e.o.c. voltage at the beginning of the eclipse. This is initiated by the eclipse season because it stabilizes out within 5 to 6 days after the beginning of the season

and the sunlight voltage is stable before and after the eclipse season. This results from aging. Also during the successive eclipse seasons, the e.o.c. voltage of the cells drops approximately 0.15 volt on the day of the capacity check. (See Figure 2.) The voltage returns to its level prior to the capacity check within 2 or 3 days. This is due to insufficient time to recharge at the cycle rate for 0° C.

(3) As the temperature goes down, the charge voltage goes up. This is true for synchronous packs. Sync 3 (0° C) averaged 0.15 volt higher than Sync 2 (25° C); and Sync 2 started 0.05 volt higher than Sync 1 (40° C).

b. End-of-Discharge Voltage: A slight increase in e.o.d. voltage (0.02-0.03 volt) was noticed, always on the second day following the capacity check. This indicates a slight rejuvination as a result of the capacity check for cells operating at 0° C. Also, at this temperature, the cells remain well balanced during discharge and they have always discharged the maximum time (1.2 hours per day) for the 8-day period each eclipse season corresponding to this maximum. Further, the average decent and ascent slope (see paragraph IV.B.1.b.) of the plotted e.o.d. voltages on both sides of each capacity check vary by an average percent difference of 9.6 percent in accordance with the same trend noted in the previous paragraph.

c. Capacity: Figure 5 indicates the usual decline in capacity with age. However Sync 3 has maintained the 6 ampere-hour rated capacity longer than any other pack--failing to meet or exceed it only in the sixth eclipse season, to date. The following table gives the capacity at each eclipse season for Sync 3.

Eclipse Season	1	2	3	4	5	6
Capacity (ah)	6.86	6.86	6.56	6.34	6.06	5.46

4. <u>Sync 4</u>: This was the most erratic pack during its relatively short life of any of the original six. It failed during charge on the second day of the second eclipse season due to one cell shorting. For comparative purposes, the first and only completed eclipse season along with the first three days of the second season are shown in Figure 2, lower left corner. However due to its erratic behavior, the entire history of Sync 4 (including the sunlight trickle charge on both sides of the completed eclipse season) is contained in Figure 4.

a. Charge Voltage: The charge voltage of the cells during the sunlight period preceding the first eclipse season was excessively high for Sync 4 at -20° C. Figure 4 shows an initial voltage of 1.63 volts and a peak voltage of 2.11 volts just prior to the first eclipse season. The eclipse season had a stabilizing effect on the e.o.c. voltage within the season causing it to average out at approximately 1.67 volts. Following the first eclipse season the voltage during sunlight again increased to a peak of 1.75 volts 5 days prior to the second eclipse season. Thus a charge current of 200 milliamperes was entirely too high for a Sync pack operating at -20° C. This problem was corrected for Sync 4B--see Table of paragraph II.B.

b. End-of-Discharge Voltage: The average e.o.d. voltage of the cells tapers downward near the end of the first eclipse season. This is atypical of all other Sync packs discussed in this report and is accompanied by a wide divergance between the high and low cells. Even though the cells all went the maximum time on discharge, these irregularities indicate that -20° C is a harsh environment for cells. Charge rates that are satisfactory at higher temperatures, prove damaging to the cells and result in imbalance and low capacity during subsequent discharges.

c. Capacity: Figure 5 shows 4.05 ampere-hours as the pack's capacity during the first, and only, eclipse season. The 1.00 volt average and 0.50 volt low-cell-limit were reached simultaneously after 2 hours and 2 minutes.

5. Sync 4B: This pack replaced Sync 4 at the time corresponding to the beginning of the third eclipse season for the other Sync packs. Thus Sync 4B lags the original six packs by two eclipse seasons--approximately 1 year. Sync 4B is equipped with a coulometer which cuts the charge current from 200 milliamperes to 25 milliamperes at the trip level; this is the only difference in packs 4 and 4B. Sync 4B is illustrated in Figure 2 on the lower right half of the page.

a. End-of-Charge Voltage: The e.o.c. voltage is kept at approximately 1.50 volts with much less overall variation than seen in Sync 4. The previous difficulty of too much charge at low temperature is effectively eliminated by the coulometer. However Figure 2 shows the e.o.c. voltage of the cells continues to be more ragged and susceptible to variations of test conditions, such as capacity checks, at low temperatures (-20° C).

b. End-of-Discharge Voltage: The high and low cells of Sync 4B have never varied more than 0.04 volt from the average and all the cells have gone the maximum time on discharge. The ascent and descent slope information explained in paragraph IV.B.1.b. shows a reversal in the trend noted for the first three Sync packs. The descent slope averages 26 percent over that of the ascent slope. As an additional notation, a trend may be forming in the fourth eclipse season. Here the e.o.d. voltage seems to be dropping to a minimum following the capacity check. This has not been observed in the previous capacity checks and is likely due to aging.

c. Coulometer Characteristics: The coulometer voltage at the e.o.d. is very erratic for Sync 4B. In particular, the first 10 days each eclipse season show the most fluctuation of the coulometer e.o.d. voltages as illustrated by Figure 2. Figure 6 gives the ampere-hours returned to the respective Sync packs (4B, 5 and 6) just prior to the coulometer trip voltage. If the coulometer is functioning properly, the graph will closely resemble the discharge time pyramids of Figures 1 and 2. Thus, Figure 6 shows that the coulometer of Sync 4B has maintained its integrity through four eclipse seasons.

d. Capacity: Figure 5 shows that Sync 4B has never delivered the rated capacity of 6.0 ampere-hours. The cells showed a slight gain in capacity during eclipse season 2 over that of eclipse season 1, and only eclipse season 4 has shown a large loss. The capacity check of eclipse season 4 was determined by a low cell limit of 0.50 volt rather than a pack average of 1.00 volt. The following table gives the capacity at each eclipse season for Sync 4B.

Eclipse Season	1	2	3	4
Capacity (ah)	5.20	5.74	5.34	2.34

6. Sync 5: The successive eclipse seasons of this pack are shown in Figure 3 above the heavy, dark line. The time pyramids do not accompany Sync packs of Figure 3.

a. End-of-Charge Voltage: After the cells of Sync 5 had aged (beginning with eclipse season 3), the e.o.c. voltage during the eclipse averaged nearly 0.10 volt higher than the constant current, sunlight voltage (not shown) before and after the successive eclipse seasons.

b. End-of-Discharge Voltage: During all eclipse seasons but the sixth, the cells experienced a slight increase in the e.o.d. voltage following the day of the capacity check. This indicates an immediate rejuvination of the cells by the capacity checks as noted in previous Syncs. However the descent and ascent information of paragraph IV.B.1.b. gives a percent difference of 25 percent in which the descent slope is greater. This would indicate an overall decrease in the cells' ability to deliver power following the capacity check. Also, the greater depth of discharge (60 percent) for Sync 5 caused an imbalance to develop in the cells of this pack. This imbalance was not noticed in Sync 3 (same temperature but 40 percent depth). The effect is always greatest on the low cell and is greatly aggravated as the cells age. Even with this imbalance, there were no premature cutoffs during discharge; the cells all discharged the maximum time (1.2 hours per day) during the midportion of each eclipse season.

c. Coulometer Characteristics: Figures 3 and 6 show the coulometer of Sync 5 to be functioning properly except during eclipse seasons 3 and 6. These exceptions correspond to a coulometer change in eclipse season 3 and a malfunctioning coulometer in eclipse season 6. During this latter season, the coulometer did start functioning properly the last few days of the season. However for this temperature (0° C) and depth of discharge (60 percent), the trend thus established, indicates that the life of a coulometer, controlling a synchronous regime, is only two complete cycles.

d. Capacity: Figure 5 shows graphically the capacity degradation of Sync 5 with time. The following table gives the capacity at each eclipse season for Sync 5.

Eclipse Season	1	2	3	4	5	6
Capacity (ah)	6.30	6.21	5.94	5.55	5.55	3.51

7. <u>Sync 6</u>: The successive eclipse seasons of Sync 6 are shown in Figure 3 on the lower half of the page.

a. End-of-Charge Voltage: The e.o.c. voltage characteristics during each of the eclipse seasons are essentially the same as those noted for Sync 5 in paragraph IV.B.6.a. The only difference is that the increase in e.o.c. voltage above the sunlight charge voltage on either side of an eclipse season is less that previously observed in Sync 5. The average increase was approximately 0.05 volt.

b. End-of-Discharge Voltage: Beginning with eclipse season 4, the average e.o.d. voltage of the cells gradually drops lower with successive eclipses. Also the high depth of discharge (80 percent) causes the e.o.d. voltage to drop to a much lower value during the middle of each eclipse season than in Syncs 3 and 5; these Syncs operated at the same temperature (0° C) but lesser depths of discharge--40 and 60 percent respectively. However Sync 6 has always discharged the full time each eclipse season with no cutoffs for the low cell reaching 0.0 volt even at 80 percent depth of discharge. The high depth of discharge does account for the high amount of imbalance among the cell voltages of this pack. This latter point is shown in Figure 3 by observing the wide range in the voltages plotted for the high and low cells. For Sync 6, the descent and ascent information of paragraph IV.B.1.b. shows the same trend developed by the first three Sync packs--an increased capability of the cells to deliver power following the capacity check. The average ascent slope exceeds the descent slope by 21 percent.

c. Coulometer Characteristics: The coulometer voltage at e.o.d. is constant for the first two eclipse seasons. Coulometer failure occurred in the third eclipse season (though replacement was effected in the fourth eclipse season) resulting in a drop in the e.o.d. coulometer voltage (see Figure 3). A corresponding failure of the coulometer to reach the trip voltage on charge is noted in Figures 3 and 6. Similar e.o.d. voltage drops have occurred in eclipse seasons 5 and 6 signifying impending coulometer failure though this has not occurred and is so indicated in Figure 6.

d. Capacity: Figure 5 shows graphically the capacity degradation of Sync 6 with time. The following table gives the capacity at each eclipse season for Sync 6.

Eclipse Season	1	2	3	4	5	6
Capacity (ah)	5.84	6.00	5.72	5.20	4.60	3.88

C. Voltage Cross-Sections Versus Temperature or Depth of Discharge:

1. Voltage Versus Temperature: Figure 7 depicts average, high, and low cell voltages as the temperature varies for Syncs 1, 2, 3, 4 and 4B. These Sync packs are representative of the four different temperature regimes. The cross-sections are taken at three points: (1) Sunlight charge voltage 1 day prior to each eclipse season (top section of graph), (2) e.o.d. voltage 2 days prior to the capacity check during the midportion of each eclipse season (middle section of graph), and (3) e.o.d. voltage 2 days after the capacity check at the midportion of the eclipse season (lower section of graph). The different eclipse seasons are numbered across the page.

a. Sunlight Charge Voltage: From Figure 7, an obvious effect of temperature is a general lowering of the sunlight charge voltage as the temperature is increased. Furthermore the initial voltage difference between the high and low cell is generally more extreme at the low temperature (-20° C), but this difference is also noticed at the other higher temperatures as the cells age.

b. End-of-Discharge Voltage:

(1) Before and after the capacity check, a slight peak in voltage is noted at 0° C in most cases. The voltage drops sharply at 40° C.

(2) The balance between the high and low cell is better, overall, at 25° C. The balance is worst at 40° C.

(3) The average voltage values are the same or slightly greater (by 0.01 to 0.03 volt) 2 days after the capacity check as opposed to 2 days prior to the capacity checks. This is true of all temperatures except 40° C. At 40° C the voltage averages considerably more preceding the capacity check than following it (difference ranges from 0.01 to 0.26 volts). This trend begins at the second eclipse and the differences are greatest in the last three eclipse seasons.

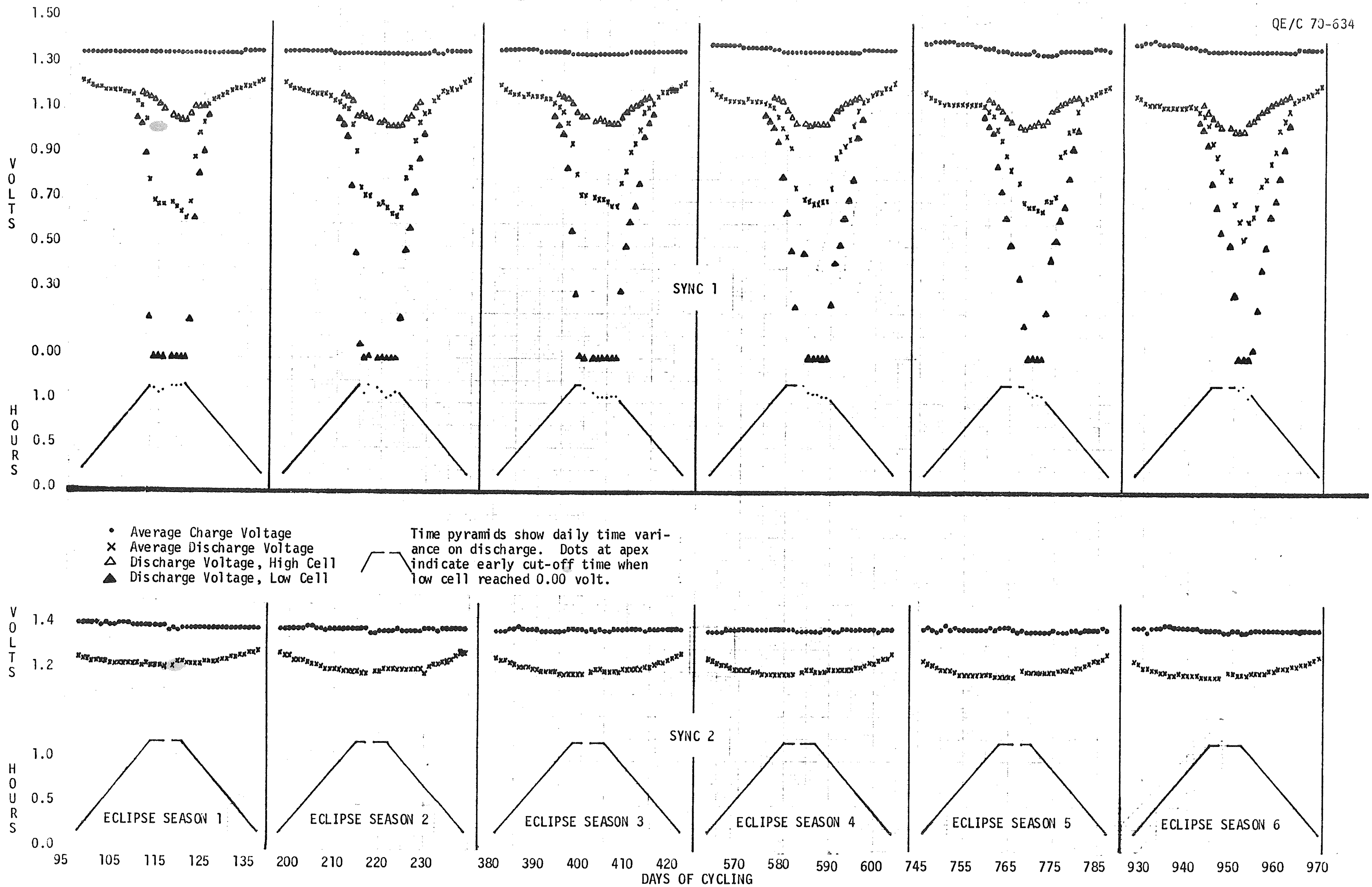
(4) The e.o.d. voltage of the low cell at 40° C shows a definite increase with each successive eclipse beginning with the fourth season. The reading 2 days prior to capacity check increases more rapidly per eclipse season than its corresponding reading 2 days after the capacity check.

2. Voltage Versus Depth of Discharge: Figure 8 is similar to Figure 7 except the independent variable is depth of discharge instead of temperature.

a. Sunlight Charge Voltage: The depth of discharge indicates little effect on the average sunlight voltage of the cells just prior to the eclipse seasons. However the voltage range (between the high and low cells) during the sunlight charge increases in the first two eclipse seasons and then remains relatively constant through the sixth eclipse season. The range for the 60 percent depth is slightly greater, in most cases, than for the 40 or 80 percent depths.

b. End-of-Discharge Voltage: Regardless of the depth of discharge, the e.o.d. voltage is 0.01 to 0.03 volts greater 2 days after the capacity check than 2 days prior to the check.

However the range between the high and low cells vary noticeably--increases with increasing depth of discharge. With each successive eclipse season this difference is amplified due largely to the low cell's much more rapid decline in voltage.

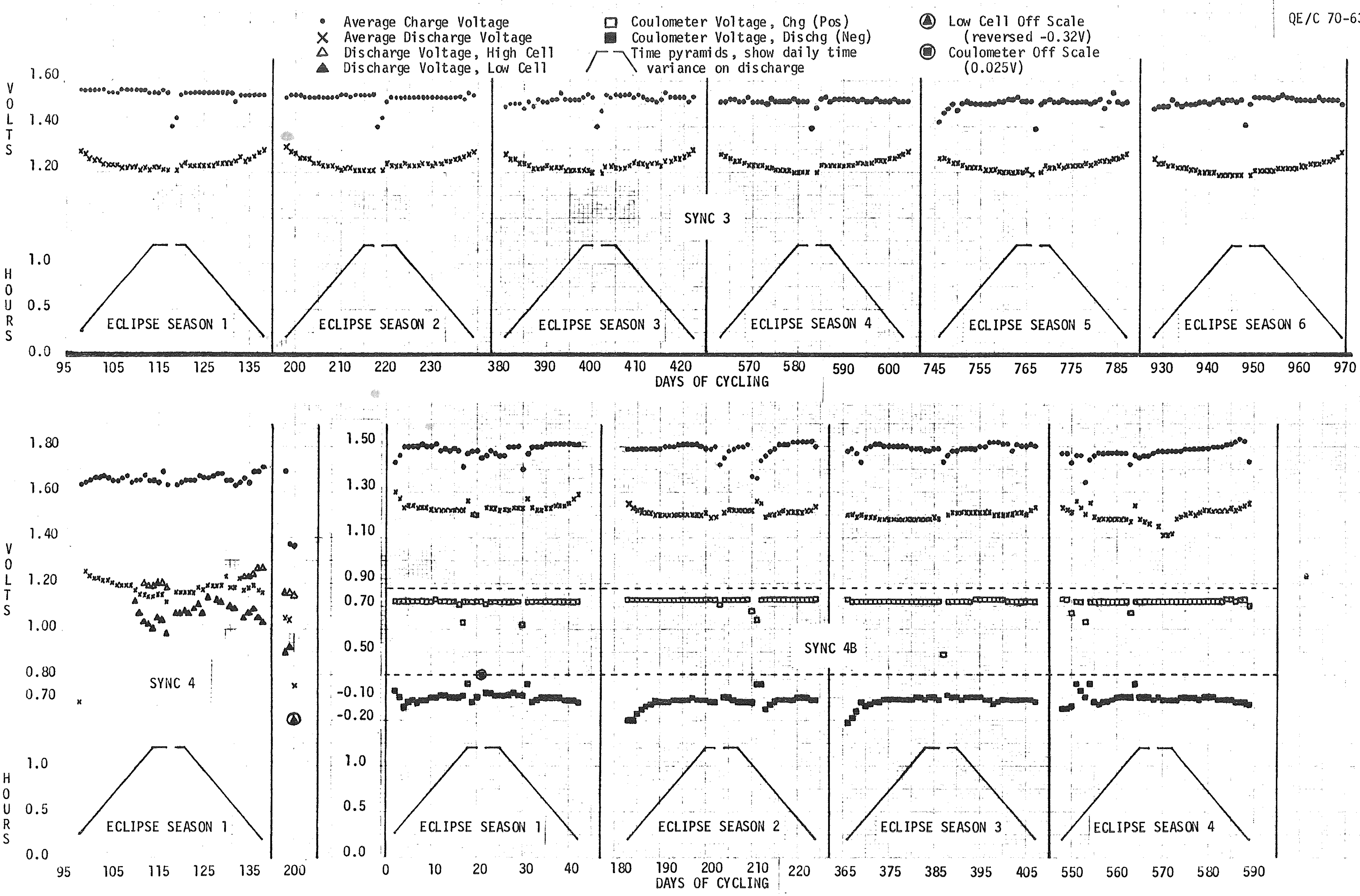


VOLTAGE CHARACTERISTICS OF SYNCHRONOUS PACKS VERSUS DAYS OF CYCLING FOR SUCCESSIVE ECLIPSE SEASONS

FIGURE 1

FOLDOUT FRAME 2

FOLDOUT FRAME 1

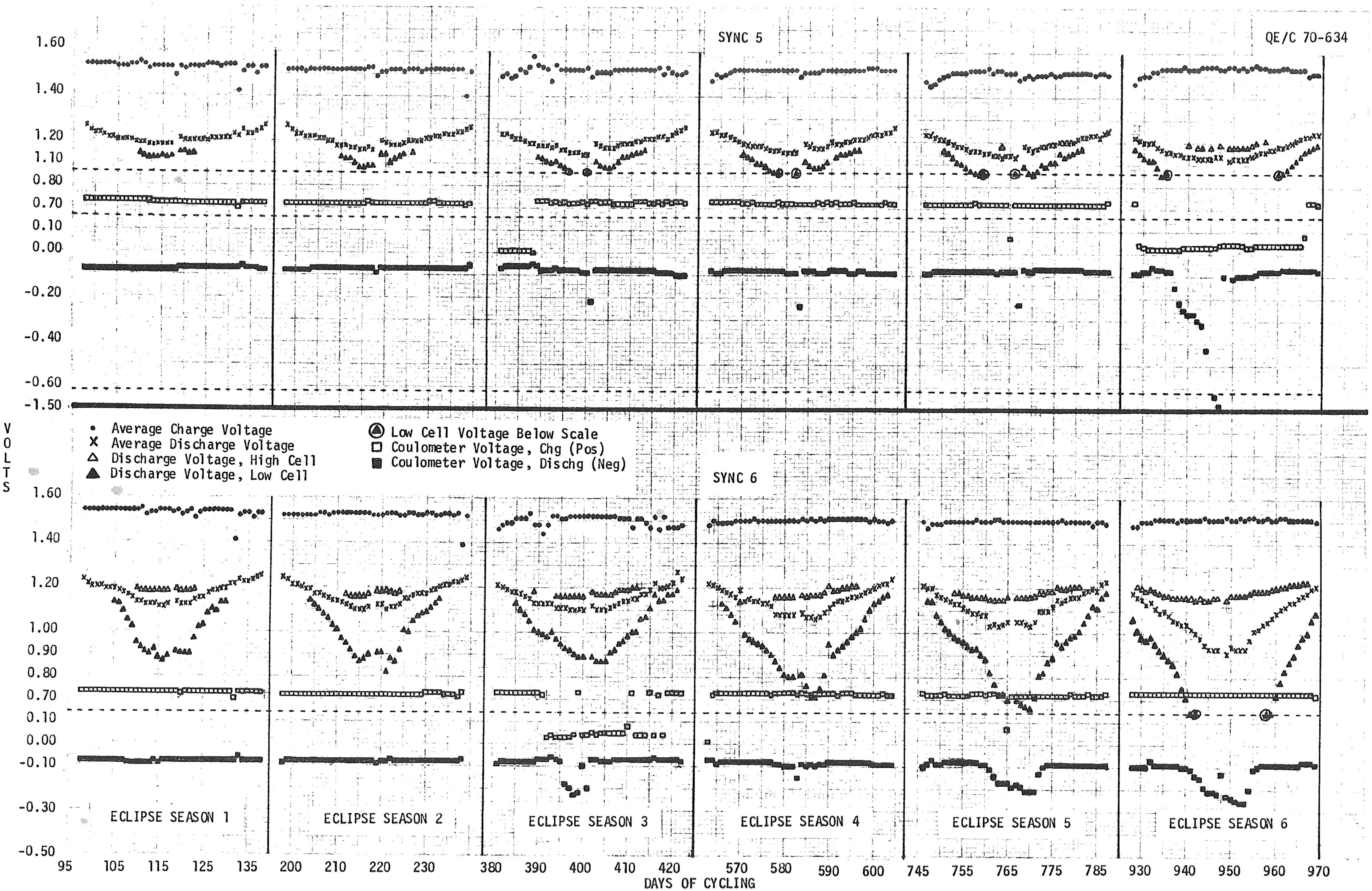


VOLTAGE CHARACTERISTICS OF SYNCHRONOUS PACKS VERSUS DAYS OF CYCLING FOR SUCCESSIVE ECLIPSE SEASONS

FIGURE 2

FOLDOUT FRAME 1

FOLDOUT FRAME 2

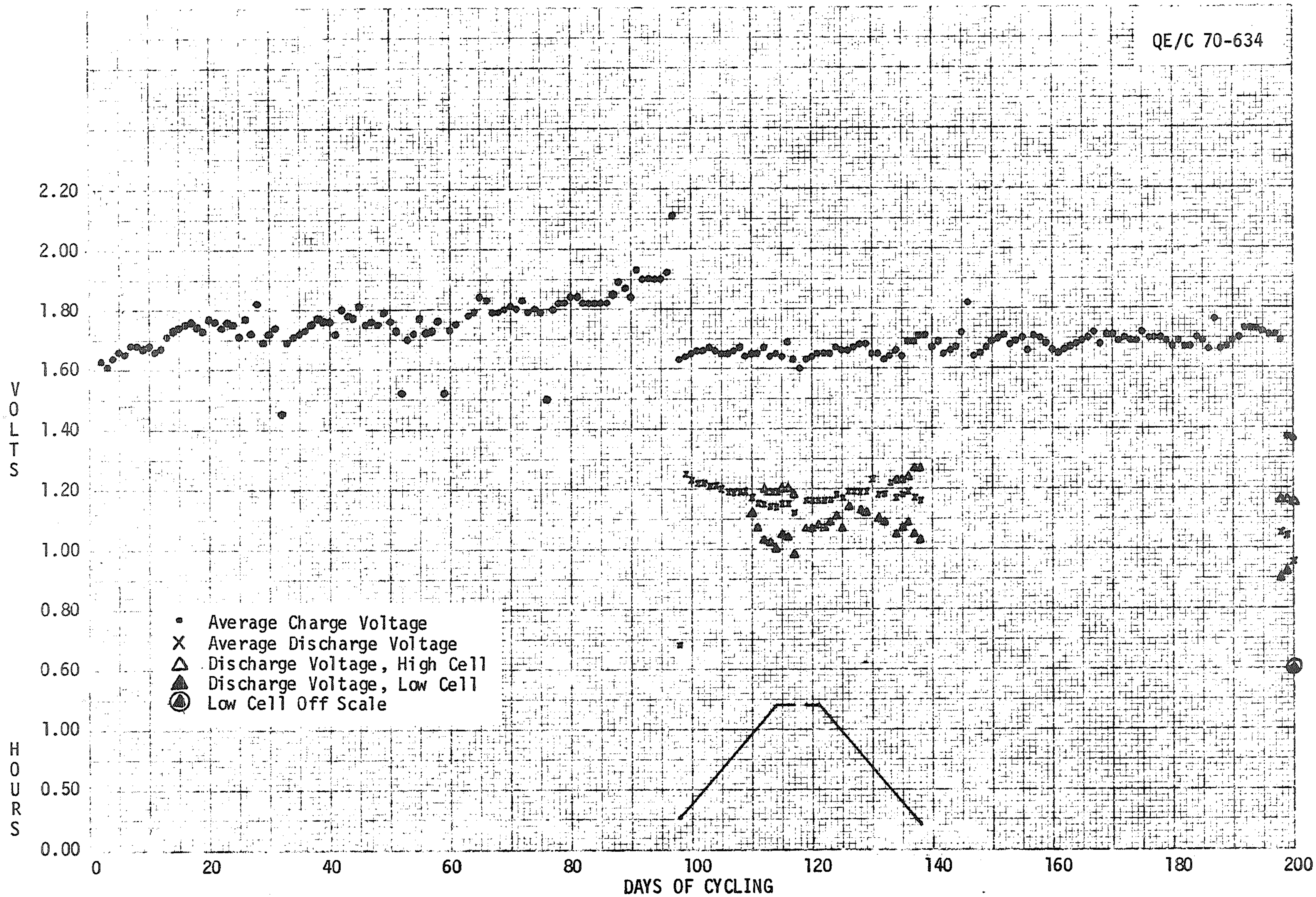


VOLTAGE CHARACTERISTICS OF SYNCHRONOUS PACKS VERSUS DAYS OF CYCLING FOR SUCCESSIVE ECLIPSE SEASONS

FIGURE 3

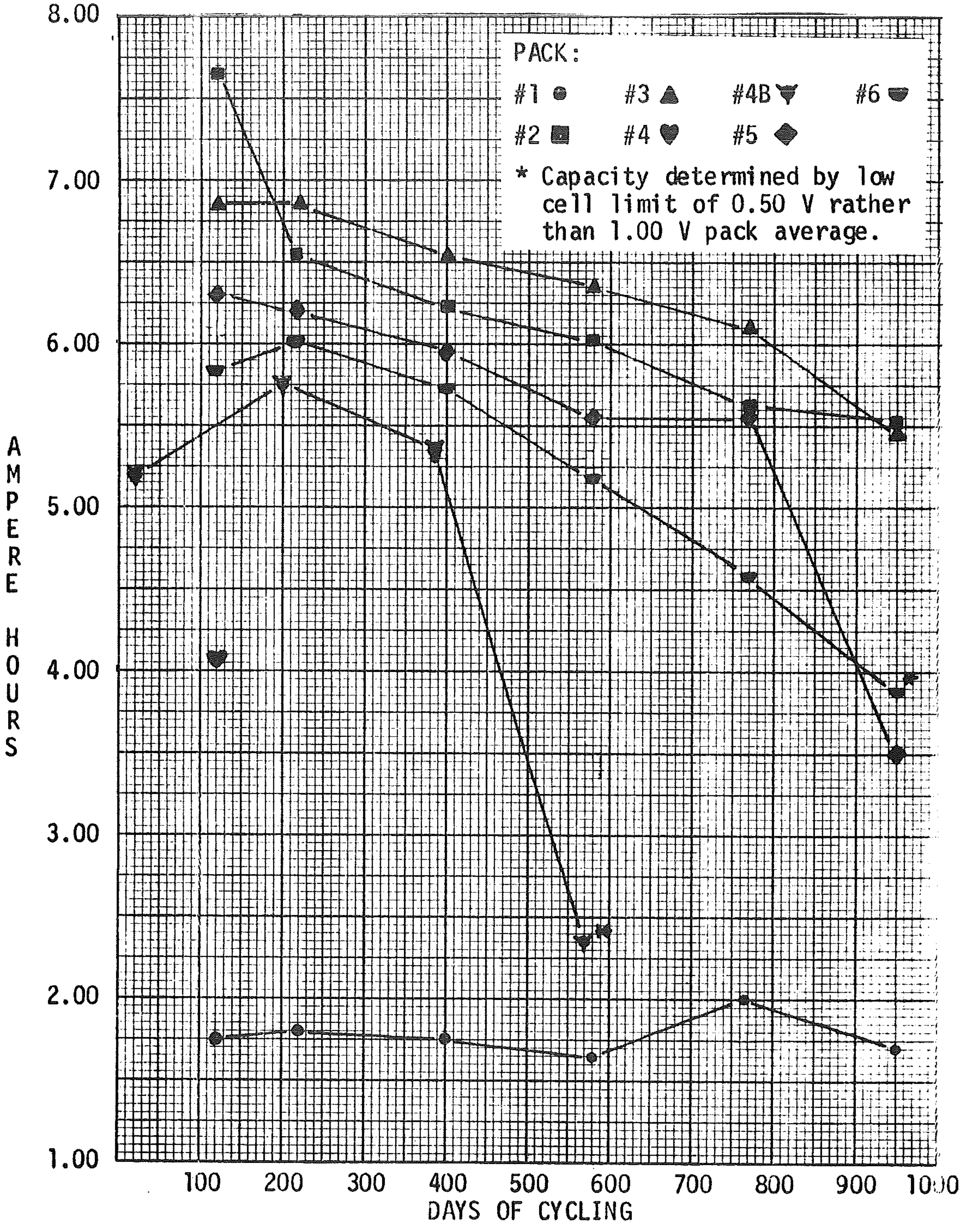
FOLDOUT FRAME (

FOLDOUT FRAME 2



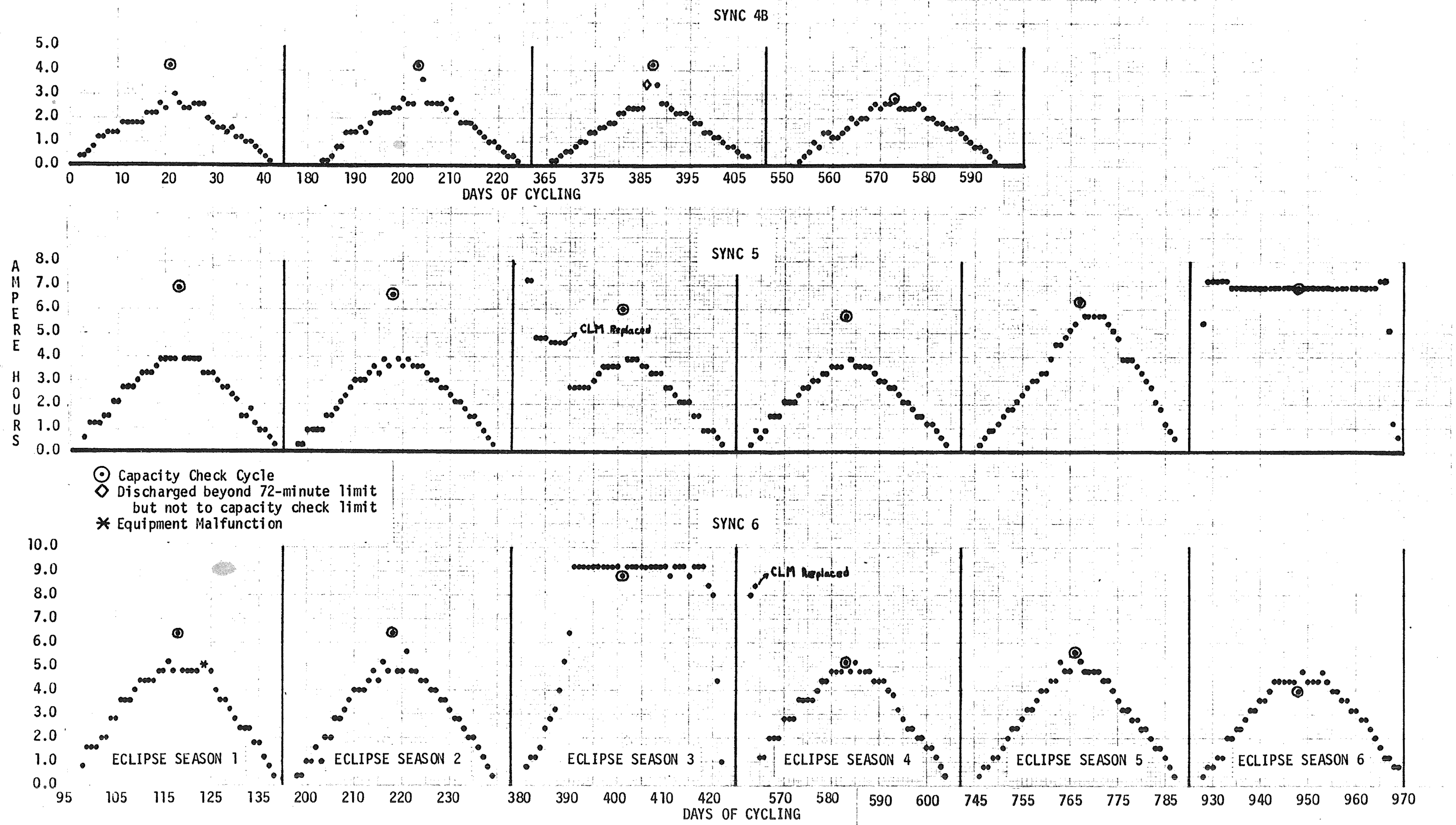
COMPLETE VOLTAGE HISTORY OF SYNC 4 VERSUS DAYS OF CYCLING FOR SUNLIGHT AND ECLIPSE SEASONS COMPLETED

FIGURE 4



CAPACITY VERSUS CYCLE TIME

FIGURE 5

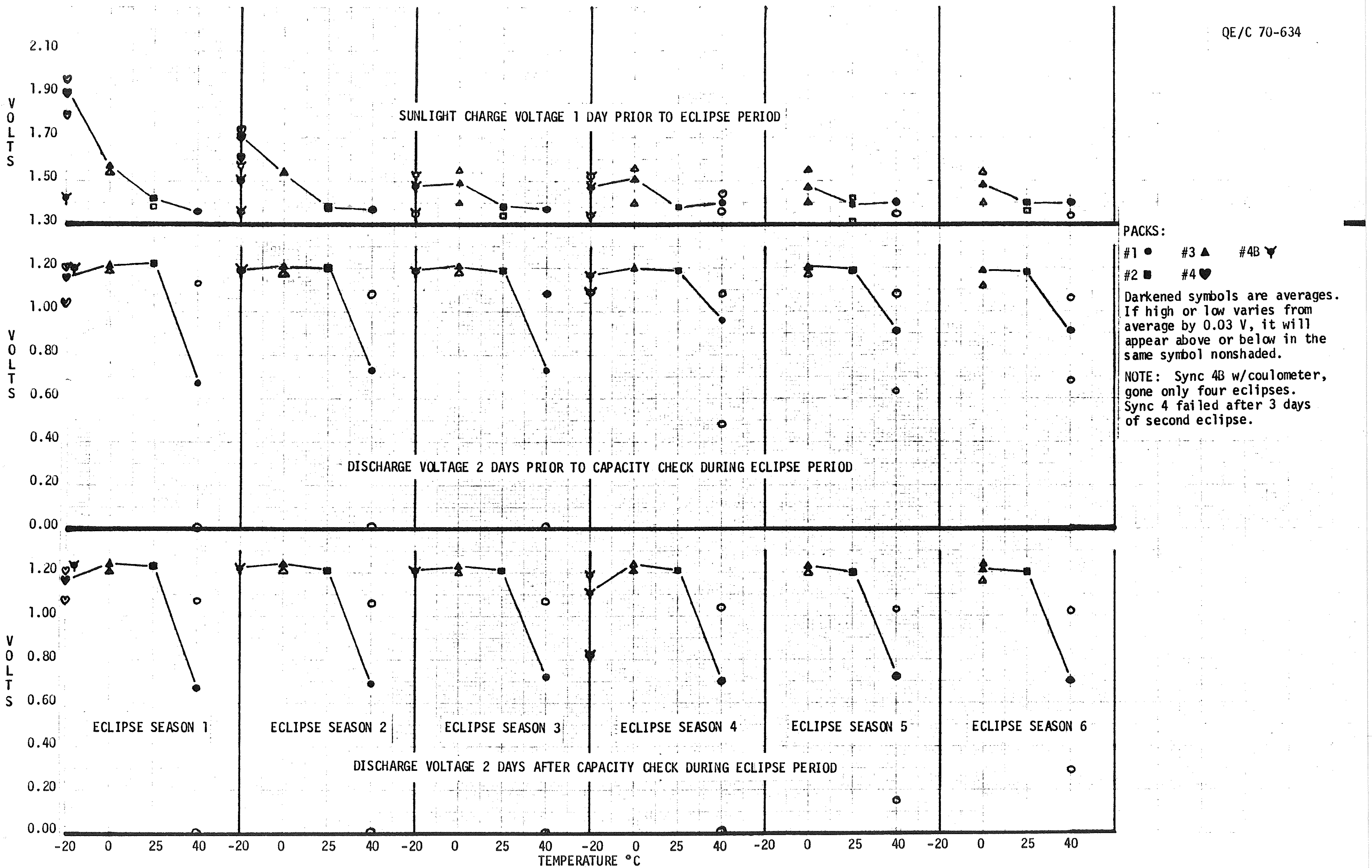


AMPERE-HOURS RETURNED, TO COULOMETER TRIP VOLTAGE VERSUS DAYS OF CYCLING FOR SUCCESSIVE ECLIPSE SEASONS

FIGURE 6

FOLDOUT FRAME

FOLDOUT FRAME

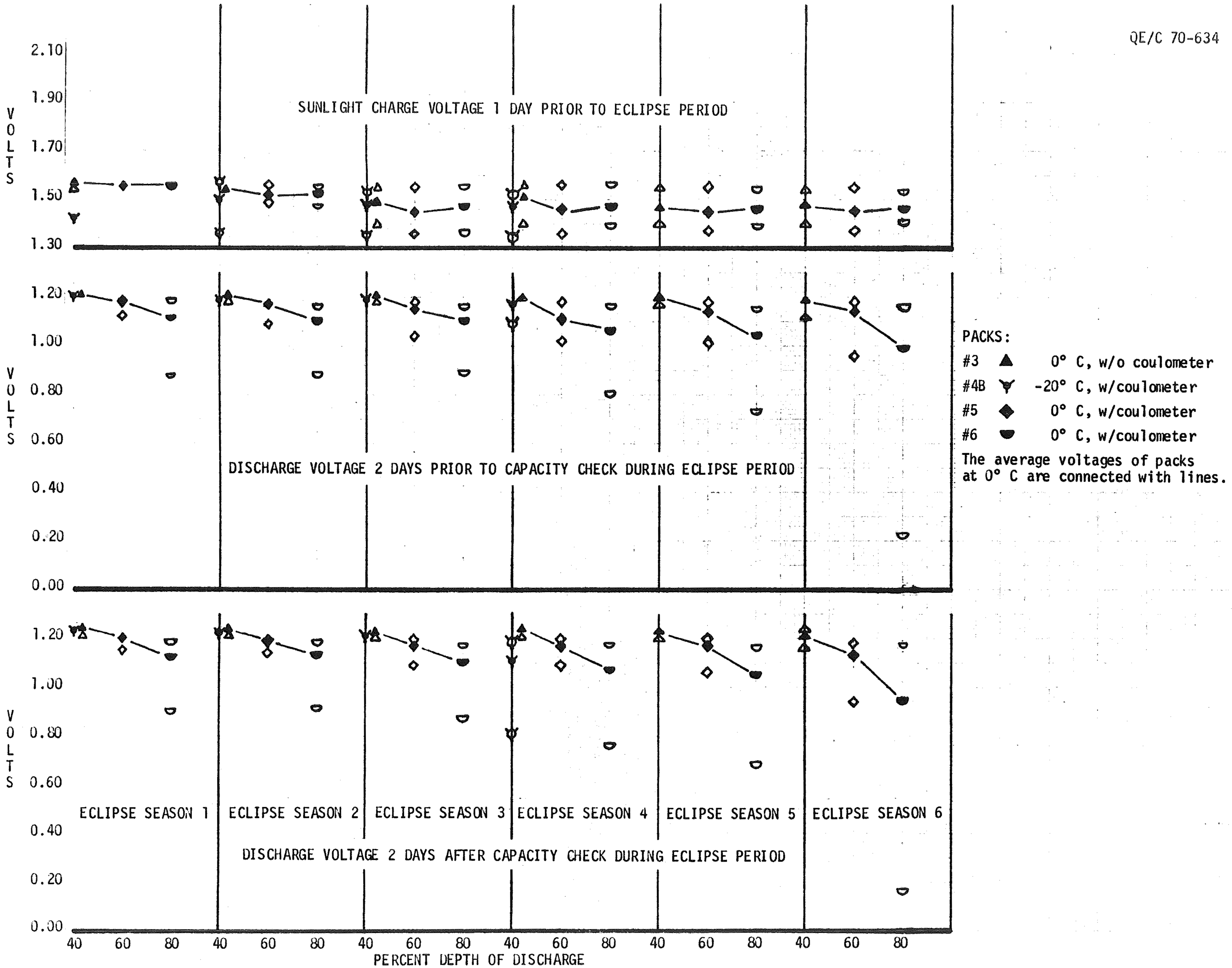


CROSS-SECTIONAL VOLTAGE CHARACTERISTICS VERSUS TEMPERATURE

FIGURE 7

FOLDOUT FRAME 1

FOLDOUT FRAME 2



CROSS-SECTIONAL VOLTAGE CHARACTERISTICS VERSUS DEPTH OF DISCHARGE

FIGURE 8

FOLDOUT FRAME

FOLDOUT FRAME

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