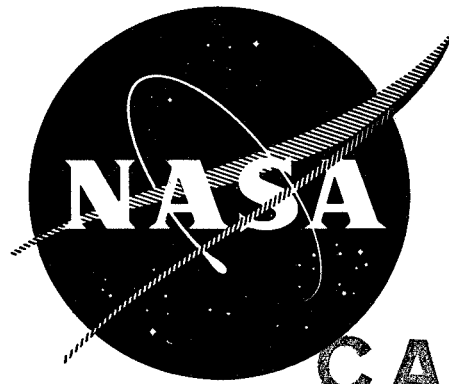


N71-33326
NASA CR-121450



**CASE FILE
COPY**

EVALUATION PROGRAM

for

SECONDARY SPACECRAFT CELLS

**SYNCHRONOUS ORBIT TESTING
OF**

12.0 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

DEPARTMENT OF THE NAVY
NAVAL AMMUNITION DEPOT
QUALITY EVALUATION LABORATORY DEPARTMENT
CRANE, INDIANA 47522

EVALUATION PROGRAM
FOR
SECONDARY SPACECRAFT CELLS

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

QE/C 71-183

10 JUNE 1971

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Enclosure (1)

REPORT BRIEF

SYNCHRONOUS ORBIT TESTING
OF
12 AMPERE-HOUR SEALED NICKEL-CADMIUM CELLS
WITH AUXILIARY ELECTRODES
MANUFACTURED BY
GENERAL ELECTRIC COMPANY

Ref: (a) NASA Purchase Order W12,397
(b) NASA Work Sheet of Apr 1967
(c) NAD Crane Report QE/C 70-634 of 14 Aug 1970

I. TEST ASSIGNMENT BRIEF

A. This activity was funded for Synchronous Orbit Testing on cells of the same lot as the cells aboard the Applications Technology Satellite (ATS) through reference (a). The evaluation followed the program outline of reference (b).

B. This evaluation program started March 1969 and is continuing on test. Its purpose is to gather performance information concerning sealed nickel-cadmium cells, with auxiliary electrodes, operating under a synchronous orbit regime. Such a regime simulates a space satellite maintaining a position over a fixed point on the 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. At this temperature, the measured capacity averages slightly more than half (8.0 ampere-hours) the manufacturer's rated capacity. The charge current and trip voltage of the auxiliary electrodes are difficult to maintain such that the cell voltage and pressure do not exceed the test limits and yet, allow the cells to receive adequate charge.

B. Performance at -20° C presents the same problems as those encountered at 40° C. The basic operational difference required is in the trickle charge following the auxiliary electrode trip. The trickle charge current must be kept very low, 40 to 120 milliamperes, at -20° C and frequent open circuiting is necessary to allow cell voltage and pressure to go down. After 183 days of testing, an open circuit following the auxiliary electrode trip has been used exclusively. The capacity at this temperature averages 10.7 ampere-hours--slightly more than the cells operating at 40° C.

C. A temperature of 0° C gives the best capacity, averaging 16.6 ampere-hours. Cells operating at 20° C run a close second in capacity (averaging 14.8 ampere-hours) and overall performance. However, the capacity for cells operating at 20° C has shown a tendency to drop during the time on test thus far at 80 percent depth of discharge; while those cells operating at 0° C have shown a slight increase in capacity during the time on test thus far, regardless of depth of discharge.

D. The auxiliary electrodes have shown a tendency to become "desensitized" to the oxygen produced during charge. This happens gradually over a period of time and may be noted in any one of three ways: (1) The auxiliary electrode voltage during the trickle charge of the sunlight period tends to decrease from one period to the next, yet the pressure tends to remain constant. This is noted for all temperature regimes. (2) During successive capacity checks, the auxiliary electrode voltage tends to decrease, showing less of a "swing" in the graphs of the capacity checks. Again, this is generally true at all temperatures. (3) At 40° C and -20° C, the trip voltage is continually lowered, or third electrode control is completely removed, because the cells receive too much charge before the "desensitized" electrode reaches its trip voltage.

E. The voltage balance, during discharge, between high and low cells is best at temperatures of 0° C and 20° C and worst at temperatures of 40° C and -20° C. During charge, 20° C shows the best voltage balance.

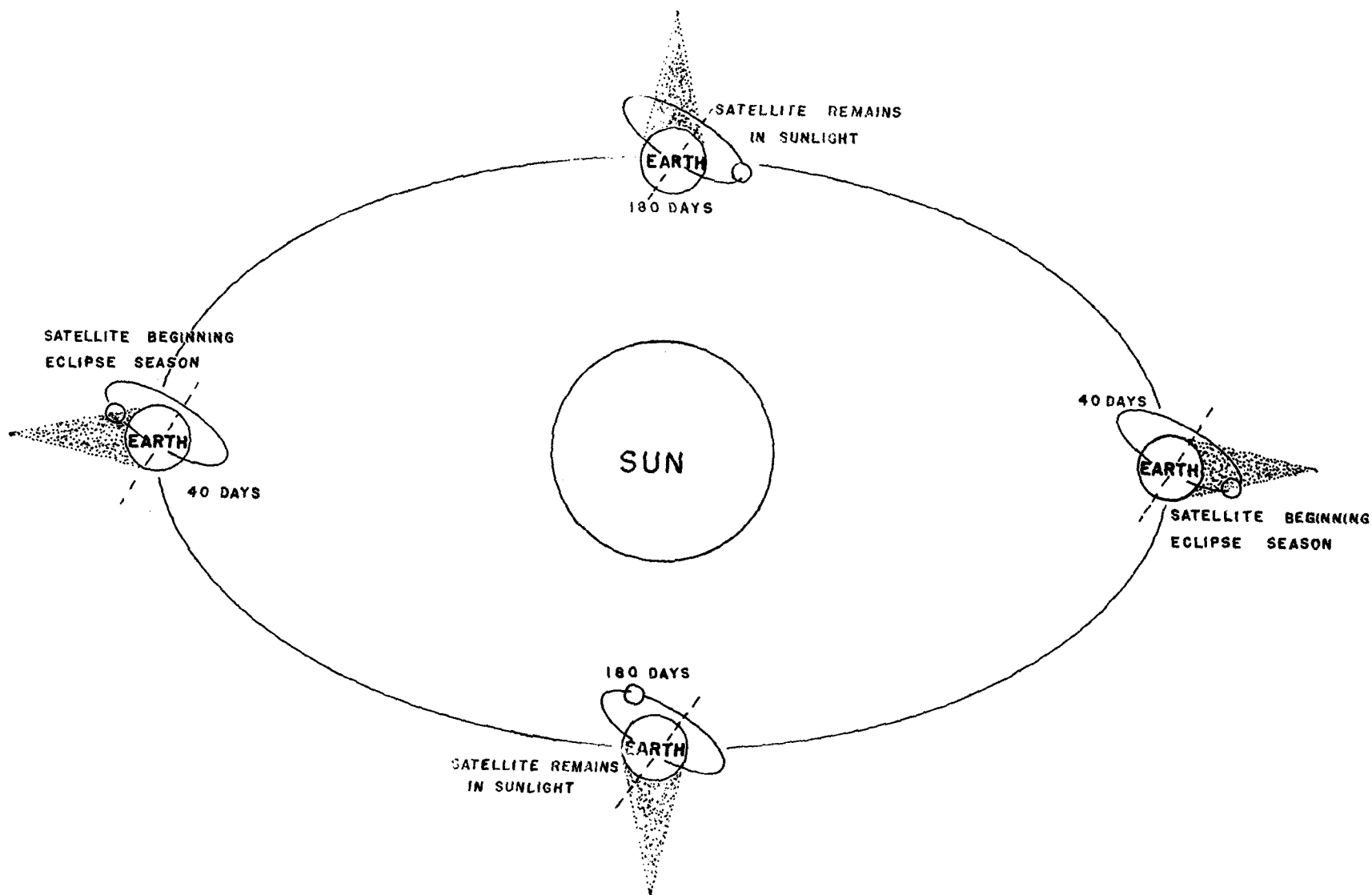
F. Concerning percent depth of discharge, it has been found that, for equal temperature regimes, the greater depths of discharge are the most detrimental to the capacity.

RESULTS OF
CONTINUOUS SYNCHRONOUS ORBIT TESTING
ON
12 AMPERE-HOUR SEALED NICKEL-CADMIUM CELLS
WITH AUXILIARY ELECTRODES
MANUFACTURED BY
GENERAL ELECTRIC COMPANY

I. INTRODUCTION

A. The synchronous orbit tests were begun on six, 5-cell packs on 22 March 1969. They have completed four eclipses and continue on test. NAD Crane report, reference (c), covers synchronous orbit testing on 6.0 ampere-hour cells without auxiliary electrodes.

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 traversed 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.



II. TEST CONDITIONS

A. The synchronous packs on test were equipped with one or more cells having an auxiliary electrode for charge control. Following discharge, each pack of cells was charged at its respective rate until a preset voltage was reached by the controlling auxiliary electrodes. The reaction of oxygen (produced on charge) with the active material of the auxiliary electrode produces a voltage in direct proportion to the oxygen pressure and, consequently the amount of charge returned to the cell. After reaching the preset voltage of the auxiliary electrode, the charging circuit automatically lowers the charge current to another preset value, depending on the pack parameters. The cells then trickle charge at this lower rate until the beginning of the next discharge.

B. To simulate the conditions experienced by the space cells aboard a synchronous orbiting satellite, the following 182-day test regime was adopted.

1. Period simulating continuous sunlight (140 days):

a. The cells of packs 7 through 10 (following the initial trip of the auxiliary electrode) were continuously charged at 200 milliamperes. Pack 11 (40° C) was continuously charged at 600 milliamperes following the trip. However pack 12 (-20° C) had to remain on open circuit following trip in order to avoid high pressure and excessive cell voltages.

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 average cell voltage was not allowed to drop below 1.00.

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 12 minutes, the same as the first day. The cells then returned to continuous charge (sunlight) completing the 180-day cycle.

C. Table I identifies the synchronous packs and gives the test parameters of each pack plus the changes that have been required in the parameters during the eclipse seasons to date.

TABLE I

PARAMETERS OF CELLS EXPERIENCING THE SUCCESSIVE ECLIPSE SEASON OF A SYNCHRONOUS ORBIT REGIME

Sync Pack	Temp (°C)	Depth of Discharge (Percent)	Discharge (Amps)	Charge Current (Amps) Before Trip	Charge Current (Amps) After Trip	Trip Voltage	Controlling AE Cells	Parameter Change Day--ECL--Reason		
7	0	60	6.00	3.00	0.20	300 mv	1			
	0	60	6.00	1.50	0.20	300 mv	1	11	1	High cell voltage.
	0	60	6.00	1.50	0.20	150 mv	1	15	1	High cell voltage.
8	0	80	8.00	3.00	0.20	300 mv	2 & 3			
	0	80	8.00	3.00	0.20	150 mv	2 & 3	15	1	High cell voltage.
9	20	60	6.00	3.00	0.20	300 mv	4 & 5			
10	20	80	8.00	3.00	0.20	300 mv	1 & 5			
11	40	60	6.00	3.00	0.20	300 mv	3 & 4			
	40	60	6.00	3.00	0.60	300 mv	3 & 4	17	1	Short discharge.
	40	60	6.00	3.00	0.60	500 mv	3 & 4	20	1	Short discharge.
	40	60	6.00	3.00	0.60	---	3 & 4	186	2	Trip voltage not reached, continued 3.0 A charge from day 186 to 224.
	40	60	6.00	3.00	0.20	200 mv	3 & 4	370	3	High pressure and voltage, cell voltage imbalance.
	40	60	6.00	3.00	0.60	200 mv	3 & 4	371	3	High pressure corrected.
	40	60	6.00	3.00	0.60	300 mv	3 & 4	387	3	Short discharge.
	40	60	6.00	3.00	0.20*	300 mv	3 & 4	547	4	High pressure.
	40	60	6.00	1.20	1.20	---	---	570	4	Short discharge, removed AE control, used manual trip.
	40	60	6.00	3.00	0.20	200 mv	3 & 4	370	3	High pressure and voltage, cell voltage imbalance.
12	-20	80	8.00	3.00	0.20	300 mv	4 & 5			
	-20	80	8.00	--	0.00	---	4 & 5	4	1	High pressure and voltage, pack open circuited.
	-20	80	8.00	0.40	0.00	300 mv	4 & 5	9	1	Remained open circuit after correction to pressure and voltage.
	-20	80	8.00	0.40	0.00	150 mv	3 & 5	10	1	High pressure and voltage, increased pressure limit from 75 to 100 psig.
	-20	80	8.00	0.40	0.00	---	---	16	1	AE voltages remained slightly negative or nearly zero, AE control removed.
	-20	80	8.00	0.60	0.12	150 mv	3 & 5	23	1	Short discharge.
	-20	80	8.00	0.60	0.04	150 mv	3 & 5	27	1	High cell voltage.
	-20	80	8.00	0.60	0.00	150 mv	3 & 5	183	2	High voltage.
	-20	80	8.00	0.60	0.00	160 mv	1	365	3	AE of cell 1 reached trip first.
	-20	80	8.00	0.60	0.00	150 mv	1 & 3	393	3	Low voltage discharge.

* Charge current 0.20 amps since day 456 of prior sunlight period.

AE - Auxiliary Electrode
ECL - Eclipse

III. CELL DESCRIPTION

A. The cells are nickel-cadmium, 12 ampere-hour, manufactured by General Electric. They are rectangular and hermetically sealed with stainless steel containers and covers. The separator material is pellow. 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. The auxiliary electrode terminals are stainless steel tabs welded to the cell covers. The auxiliary electrode is welded to the inner surface of the cell container.

IV. TEST RESULTS

A. The test results are shown graphically in Figures 1 through 37. The graphs pertaining to each synchronous (Sync) pack immediately follow the discussion of the pack.

1. The first graph for each Sync gives data pertinent to the four successive eclipse seasons completed to date. The following seven items were graphed during the eclipse seasons: (1) Average end of discharge voltage, ***; (2) Average cell voltage at trip, %%; (3) Average end of charge voltage, &&&; (4) Auxiliary electrode voltage at end of discharge, +++; (5) Auxiliary electrode voltage at trip, ...; (6) Pressure at end of discharge, XXX; (7) Pressure at trip, YYY.

2. The second graph for each pack shows the following three items: (1) Ampere-hours out on discharge (AHO, ***) during the capacity check of each eclipse season; (2) Ampere-hours in on charge (AHI, total, %%%); (3) Ampere-hours in on charge (AHI, at trip, &&&).

3. The remaining graphs for each pack show the capacity check cycle for each successive eclipse season. The capacity checks occurred on the following days: Eclipse (ECL) 1, day 21; ECL 2, day 203; ECL 3, day 385; ECL 4, day 567.

4. The last graph (Figure 37) summarizes the capacity, in ampere-hours by pack for the total time on test thus far.

5. The discussion of each Sync gives all data pertinent to the eclipse seasons first, then follows this with a summary of the intervening data during the sunlight periods.

B. Synchronous Packs 7 through 12:

1. Sync 7 (Eclipse Seasons): All data except ampere-hours (in and out) and the successive capacity check cycles are shown in

Figure 1. In all such computer printouts, if two characters share the same location on the page, only one will be printed. Thus the auxiliary electrode voltage on the first day of eclipse 1 (+) occupies the same location as the end of discharge voltage of the same day, but the latter symbol (*) is implied rather than appear as a strikeover. Similar examples occur throughout, in the graphs of this type. The order of priority for printout is as follows: (1) Pressure at trip, Y; (2) Pressure at end of discharge, X; (3) Auxiliary electrode voltage at trip, .; (4) Auxiliary electrode voltage at end of discharge, +; (5) Average cell voltage at end of charge, &; (6) Average cell voltage at trip, %; (7) Average cell voltage at end of discharge, *.

a. Average End of Discharge Voltage (***): The basic profile of the end of discharge voltage remains the same from the first to the fourth eclipse (referred to as shadows 1 to 4 on Figure 1). The following tabulation condensed from Table II helps to visually summarize the effect of aging with respect to the end of discharge voltage, and also the effects of the capacity check each eclipse (ECL).

	First Day	Day Prior to Capacity Check	Day After Capacity Check	Last Day of Eclipse
ECL 1	1.298	1.218	1.234	1.288
ECL 2	1.280	1.200	1.224	1.290
ECL 3	1.268	1.197	1.218	1.284
ECL 4	1.275	1.198	1.216	1.284

Though not so noticeable at this temperature (0° C), the trend is toward a decreasing voltage at each corresponding day of successive eclipse seasons. Further each capacity check thus far has shown a rejuvenation effect on the end of discharge voltage by causing it to increase 0.01 to 0.02 volt following the capacity check.

b. Average Cell Voltage at Trip (%%): The charge voltage per cell at the trip point of the auxiliary electrode stabilized at 1.44 volts per cell early in eclipse 1 and continued through eclipse 3. This stabilized level has dropped to 1.43 volts in eclipse 4.

c. Average End of Charge Voltage (&&): The cells continue to trickle charge following the auxiliary electrode trip voltage. Thus the end of charge voltage stabilized at 1.52 volts

per cell during the fourth eclipse. The end of charge cell voltage exceeds the cell voltage at trip voltage by approximately 0.08 volt.

d. Average Auxiliary Electrode Voltage at End of Discharge (+++): The profile of the auxiliary electrode voltage very closely resembles that of the cell voltage at end of discharge. The voltage reaches a low plateau corresponding to the maximum discharge period of the eclipse. This plateau varies from an initial 53-millivolt level to 0.0 millivolt during the second and fourth eclipses.

e. Auxiliary Electrode Voltage at Trip (...): The auxiliary electrode trip is automatic. Thus the exact voltage at trip is not recorded. The computer printout gives the auxiliary electrode voltages at the time of the first recorded drop in charge current. The charge current is recorded once every 15 minutes during the first hour and hourly thereafter. Thus, the voltages graphed average somewhat lower than the actual trip voltage. Therefore no major significance is attached to this graph for Syncs 7 through 12 except that in Syncs 11 and 12 it reflects numerous changes that were necessary in the auxiliary electrode trip levels (see Table I).

f. Pressure: The piezoelectric characteristic of the crystal in the transducer of Sync 7 has changed. This caused erratic readings for both end of discharge (XXX) and trip (YYY) pressures as noted in Figure 1.

g. Sync 7 (Ampere-Hours During Successive Eclipse Seasons): The three different aspects of ampere-hours considered in Figure 2 are (1) Ampere-hours out on discharge (AHO, ***); (2) Ampere-hours in, on charge to the auxiliary electrode trip (AHI, &&&); and (3) Ampere-hours in, total, which includes the amount added during the trickle charge following the auxiliary electrode trip (AHI-total, %%%).

(1) Ampere-Hours Out (AHO, ***): The ampere-hours removed on discharge is controlled very rigidly throughout the successive eclipse seasons. This is noted from the inverted pyramid curves of Figure 2. During maximum discharge 7.20 ampere-hours are removed. (Note that the AHO scale of Figure 2 increases from top to bottom while the reverse is true for the other scales.)

(2) Ampere-Hours In to Trip (AHI, &&&): The ampere-hours restored at the point of trip depends on the function of the auxiliary electrode. Thus the time to trip will vary causing the ampere-hours returned to vary. In general, the ampere-hours returned decreases slightly (0.3 to 0.4 ah) with each successive eclipse.

(3) Ampere-Hours In, Total (AHI-Total, %%%): The total ampere-hours returned at the end of the trickle charge gives a profile identical to that of the ampere-hours returned at trip.

h. Sync 7 (Capacity Checks): Figures 3 through 6 show the capacity checks at the middle of each eclipse season. Cell voltage (average, +++; high cell, ...; and low cell, ***), auxiliary electrode voltage (%%%), and pressure (\$\$\$) are plotted against time on discharge to the low cell cutoff. The same parameters are plotted on charge to the end of the 24-hour day.

(1) In general, the profiles of the auxiliary electrode voltage and pressure are identical. They show a continuous drop during discharge; they reach a low plateau at end of discharge and maintain this plateau until near end of charge. Then the profiles show a sharp increase during the last 14 hours of charge.

i. Sync 7 (Summary of Parameters During Periods of Constant Sunlight): The three parameters considered are: (1) Cell voltage; (2) Auxiliary electrode voltage; and (3) Pressure.

(1) Cell Voltage (Sunlight): The cells averaged 1.52 volts with an average high cell of 1.54 volts and an average low cell of 1.47 volts.

(2) Auxiliary Electrode Voltage (Sunlight): Following the first eclipse, the auxiliary electrode averaged 115 millivolts. The average increased to 140 millivolts following the second eclipse. Then the average dropped 80 millivolts following the third eclipse.

(3) Pressure (Sunlight): No trends are considered due to a bad pressure transducer.

KEY
 * AVE END DISCHARGE VOLTAGE
 % AVE CELL VOLTAGE AT TRIP
 & AVE CELL VOLTAGE AT EOD
 + AVE AUX-ELECT. VOLT. AT EOD
 . AVE AUX-ELECT. VOLT. AT TRIP
 X PRESSURE TRANS. AT EOD
 Y PRESSURE TRANS. AT TRIP

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 7

DEPTH DISCHARGE 60.0
 TEMPERATURE 0.0 C
 AMPERE RATE 12.0
 CATALOG 428012AB
 SERIAL 9-4, 10-10, 10-12, 9-15, 9-19
 GENERAL ELECTRIC CELLS
 PROJECT ATS F&G

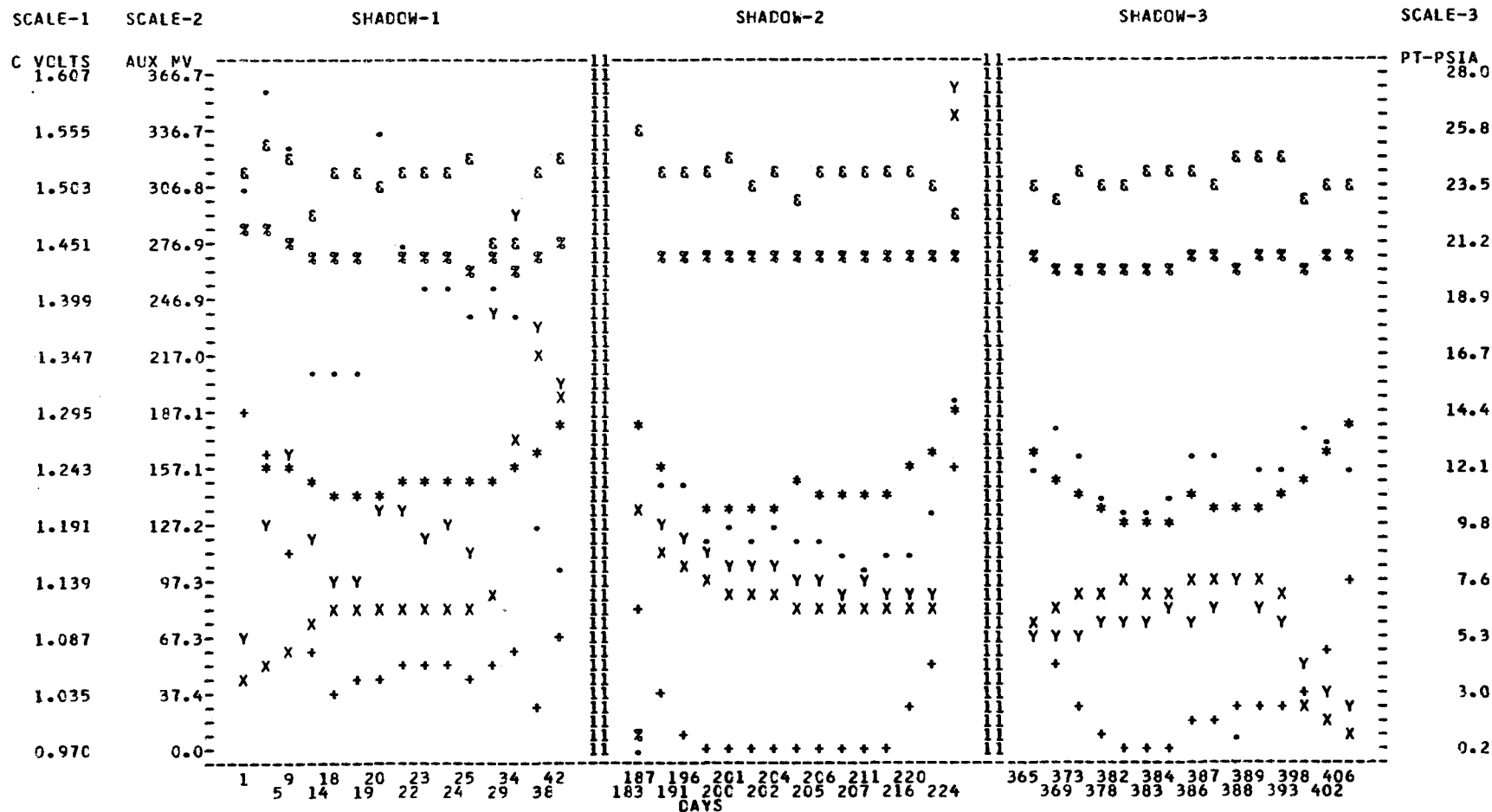


FIGURE 1

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 7



KEY
 * AHO
 % AHI-TOTAL
 & AHI AT TRIP

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 7

DEPTH DISCHARGE 60.0
 TEMPERATURE 0.0 C
 AMPERE RATE 12.0
 CATALOG 428012AB
 SERIAL 9-4, 10-10, 10-12, 9-15, 9-19
 GENERAL ELECTRIC CELLS
 PROJECT ATS F&G

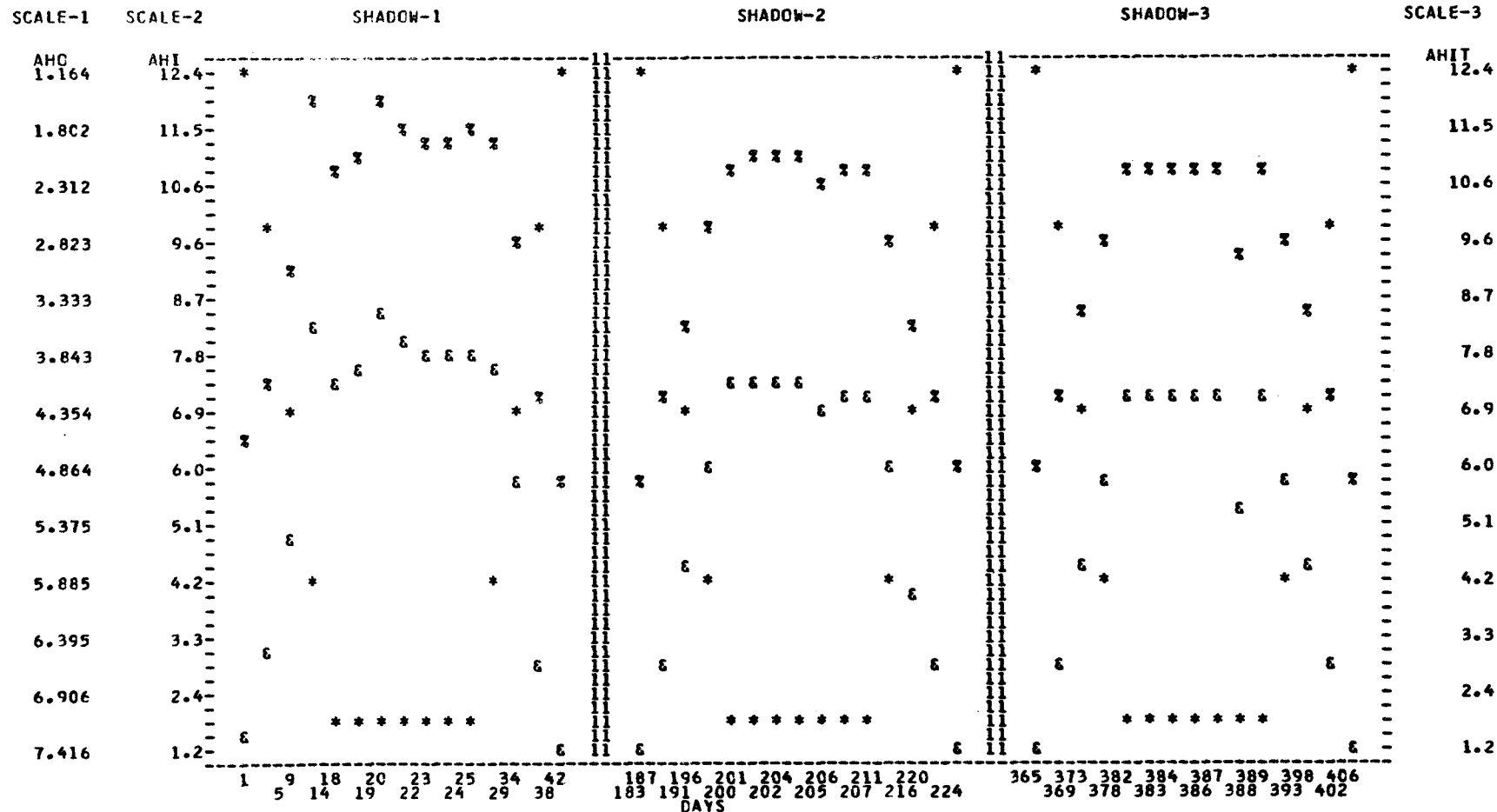


FIGURE 2

QE/C 71-133

KEY
* AHD
% AHI-TOTAL
E AHI AT TRIP

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 7

DEPTH DISCHARGE 60.0
TEMPERATURE 0.0 C
AMPERE RATE 12.0
CATALOG 42B012AB
SERIAL 9-4, 10-10, 10-12, 9-15, 9-19
GENERAL ELECTRIC CELLS
PROJECT ATS F&G

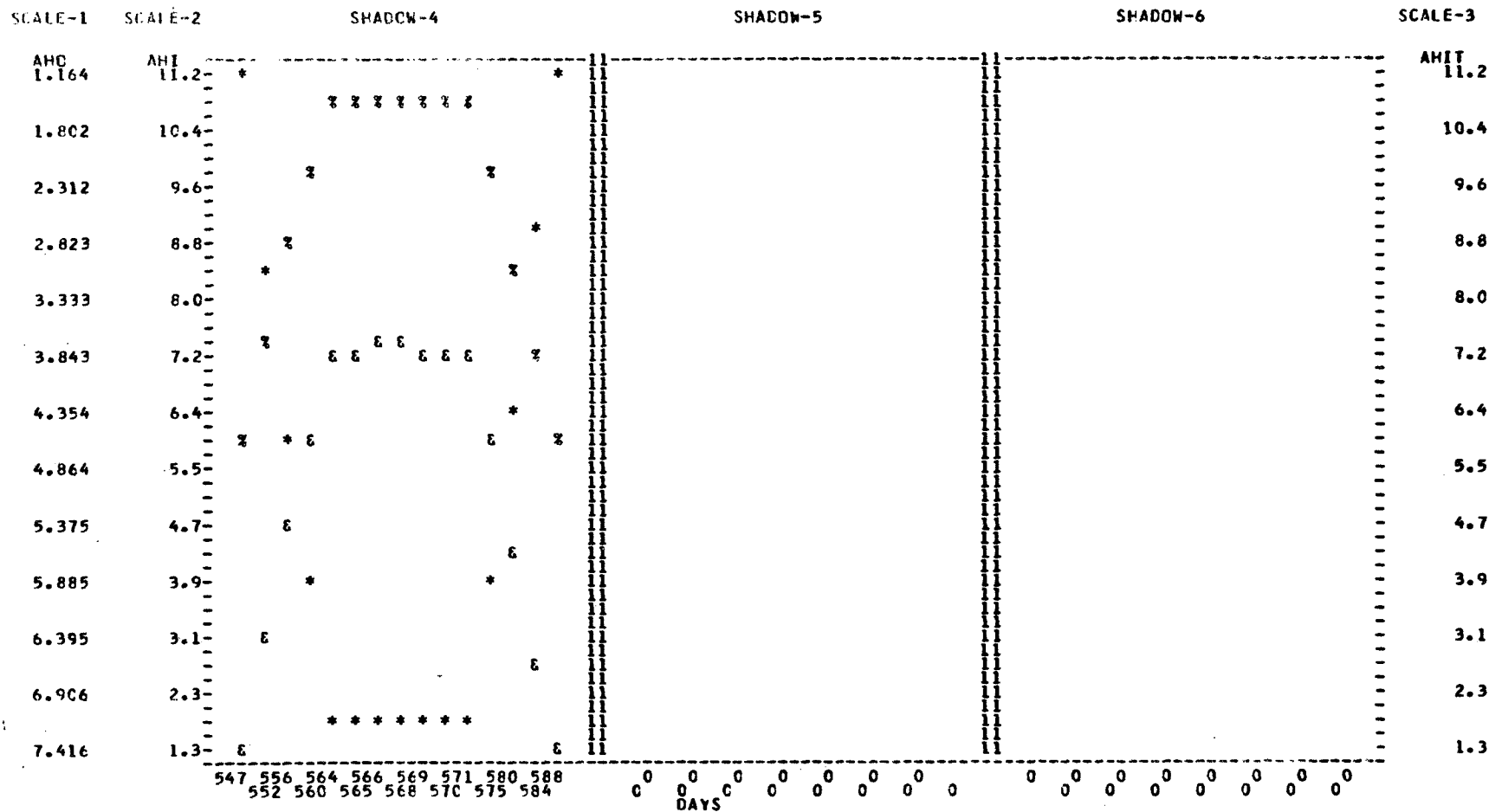


FIGURE 2 (Contd)

EVALUATION OF AUX ELECTRODE CHARGE CONTROL
IN SYNCHRONOUS TYPE ORBIT
GENERAL ELECTRIC CELLS
PROJECT ATS F+G
SERIAL NO ARE 9-4,10-10,10-12,9

ECLIPSE SEASON 1.
 AMPERE HOUR RATE IS 12
 DEPTH OF DISCHARGE IS 60
 TEMPERATURE IS 00
 CELL NO CATALOG IS 428012AB
 5 5 5 5 5 5 5 5 5 0



EVALUATION OF AUX ELECTRODE CHARGE CONTROL
IN SYNCHRONOUS TYPE ORBIT
GENERAL ELECTRIC CELLS
PROJECT ATS F+G
SERIAL NO ARE 8-4-10-10-10-12-9

ECLIPSE SEASON 2.
 AMPERE HOUR RATE IS 12
 DEPTH OF DISCHARGE IS 60
 TEMPERATURE IS 00
 CELL NO CATALOG IS 42B012AB
 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0



FIGURE 5

CODE
+ = AVERAGE CELL VOLT
• = HIGH CELL VOLT
* = LOW CELL VOLT

EVALUATION OF AUX ELECTRODE CHARGE CONTROL
IN SYNCHRONOUS TYPE ORBIT
GENERAL ELECTRIC CELLS
PROJECT AT5 F+G

ECLIPSE SEASON 4.
 AMPERE HOUR RATE IS 12
 DEPTH OF DISCHARGE IS 60
 TEMPERATURE IS 00
 CELL NO CATALOG IS 42B012AB
 5 5 5 5 5 5 5 5 5 5 5 5

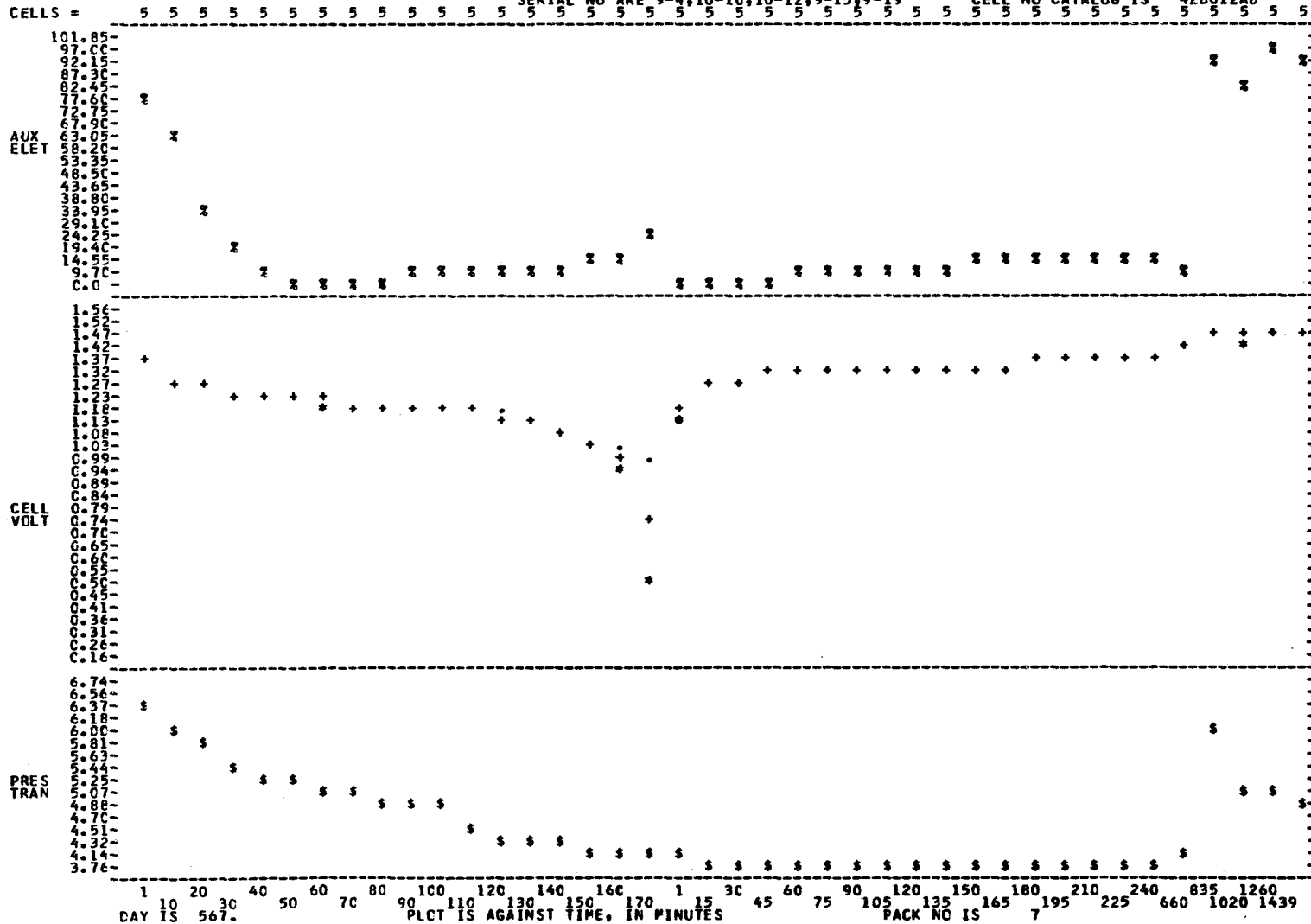


FIGURE 6

2. Sync 8 (Eclipse Seasons): The format of the data presentation for this and the succeeding Sync packs is identical to that of Sync 7. Thus to avoid unnecessary repetition, the explanation of the type data presented has been given only once.

a. Average End of Discharge Voltage (***): The basic profile remains the same as may be seen in Figure 7 and noted in the following tabulation.

	First Day	Day Prior to Capacity Check	Day After Capacity Check	Last Day of Eclipse
ECL 1	1.270	1.204	1.212	1.260
ECL 2	1.250	1.176	1.192	1.268
ECL 3	1.238	1.169	1.189	1.213
ECL 4	1.245	1.173	1.186	1.263

In all cases thus far the capacity check cycles has produced an increase in end of discharge voltage on days immediately following the capacity check. Secondly, the voltage tends to drop on corresponding days from one eclipse season to the next.

b. Average Cell Voltage at Trip (%%): The cell voltage at trip remains relatively constant within each eclipse season but the overall average drops approximately 0.01 volt per season--1.45, ECL 1; 1.44, ECL 2; 1.43, ECL 3; and 1.42, ECL 4. With time, the cell voltage at trip shows greater variation for succeeding eclipses.

c. Average End of Charge Voltage (&&): The end of charge voltage has averaged 1.51 volts each eclipse season but shows more random variation with successive seasons. This "scattering" is greater than the corresponding voltages at trip, previously cited. The end of charge voltage exceeds the trip voltage by approximately 0.07 volt.

d. Average Auxiliary Electrode Voltage (++): The auxiliary electrode voltages remain at or near zero millivolts during the bulk of each eclipse season. In general, only the first and last days of the respective seasons show an increase in voltage--approximately 30 millivolts. This corresponds to the shortest discharge periods and consequently, the longest charge periods.

e. Pressure at End of Discharge (XXX) and at Trip (YYY): The end of discharge and trip pressures closely follow the profile of

the end of discharge cell voltage except during eclipse 4. In this latter eclipse, the pressures track the end of discharge cell voltage except when the season nears its end and the length of discharge diminishes daily. Although the pressure at trip exceeds the end of discharge pressure by approximately 5 psia, neither pressure rises much above a vacuum--15 psia. The most noticeable exceptions are found at the beginning or end of an eclipse season when the cells are on charge for longer periods of time.

f. Sync 8 (Ampere-Hours During Successive Eclipse Seasons):

(1) Ampere-Hours Out (AHO, ***): Figure 8 shows that the graph of the ampere-hours removed is very symmetrical due to precise control of time and rate of discharge. The maximum ampere-hours removed is constant at 9.60 (see Table I for rate of discharge).

(2) Ampere-Hours In to Trip (AHI, &&): The ampere-hours returned to the point of trip have remained very stable for this pack--approximately 9.6 ampere-hours through four eclipse seasons during the days corresponding to the maximum discharge.

(3) Ampere-Hours In, Total (AHI-Total, %%%): The graph of total ampere-hours returned closely follows that of the ampere-hours to trip. The total ampere-hours returned exceed the ampere-hours to trip by 4 ampere-hours.

g. Sync 8 (Capacity Checks): Figures 9 through 12 show the capacity checks at the middle of the successive eclipse seasons.

(1) The general profiles of the auxiliary electrode voltage and pressure are the same--gradual tapering downward during discharge, plateauing at or before end of discharge, and then increasing during the last half of charge. This pattern is typical and shall be referred to as "typical" in later discussions.

(2) It should be noted that the initial downward taper of the auxiliary electrode voltage and its final upward swing are not as great for later eclipses as they are for the first ones. The pressures, however, do not vary greatly. This indicates a "desensitizing" of the auxiliary electrode to oxygen developed during charge.

h. Sync 8 (Summary of Parameters During Periods of Constant Sunlight):

(1) Cell Voltage (Sunlight): During the continuous trickle charge, the average cell voltage has dropped by 0.01 volt

each of the three sunlight periods thus far. The first plateau averaged 1.51 volts per cell, the second averaged 1.50 volts, and the third averaged 1.49 volts. The high cell remained 0.02 volt above the average, and the low cell remained 0.04 volt below the average.

(2) Auxiliary Electrode Voltage (Sunlight): Beginning each sunlight period, the auxiliary electrode has a relatively high voltage--100 millivolts. This voltage then tapers downward to 30 millivolts or less just prior to the next eclipse season. Further, each successive sunlight period starts with an auxiliary electrode voltage slightly less than the preceding period; it tapers more quickly; and it tapers to a lower level (see table below).

Sunlight Period	Initial Voltage	Taper Characteristics	Voltage at End of Period
1	114 MV	Gradual to 29 MV	29 MV
2	103 MV	Sharp decline to 36 MV within 30 days	11 MV
3	90 MV	Sharp decline to 30 MV within 15 days	5 MV

Thus the auxiliary electrode shows a tendency to become "desensitized" to the oxygen produced during the trickle charge of the sunlight period.

(3) Pressure (Sunlight): The pressure remains constant at 14 psia during the first two sunlight periods. The average pressure increases to 20 psia during the third sunlight period. This further supports the fact that the auxiliary electrode shows less sensitivity to gas pressure with time--the average pressure has increased but the average auxiliary electrode voltage has decreased.

D/C 71-183

KEY
 * AVE END DISCHARGE VOLTAGE
 % AVE CELL VOLTAGE AT TRIP
 & AVE CELL VOLTAGE AT EOD
 + AVE AUX-ELECT. VOLT. AT EOD
 + AVE AUX-ELECT. VOLT. AT TRIP
 X PRESSURE TRANS. AT EOD
 Y PRESSURE TRANS. AT TRIP

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 8

DEPTH DISCHARGE 80.0
 TEMPERATURE 0.0 C
 AMPERE RATE 12.0
 CATALOG 428012AB
 SERIAL 10-3, 9-5, 9-12, 10-11, 10-14
 GENERAL ELECTRIC CELLS
 PROJECT AFS F&G

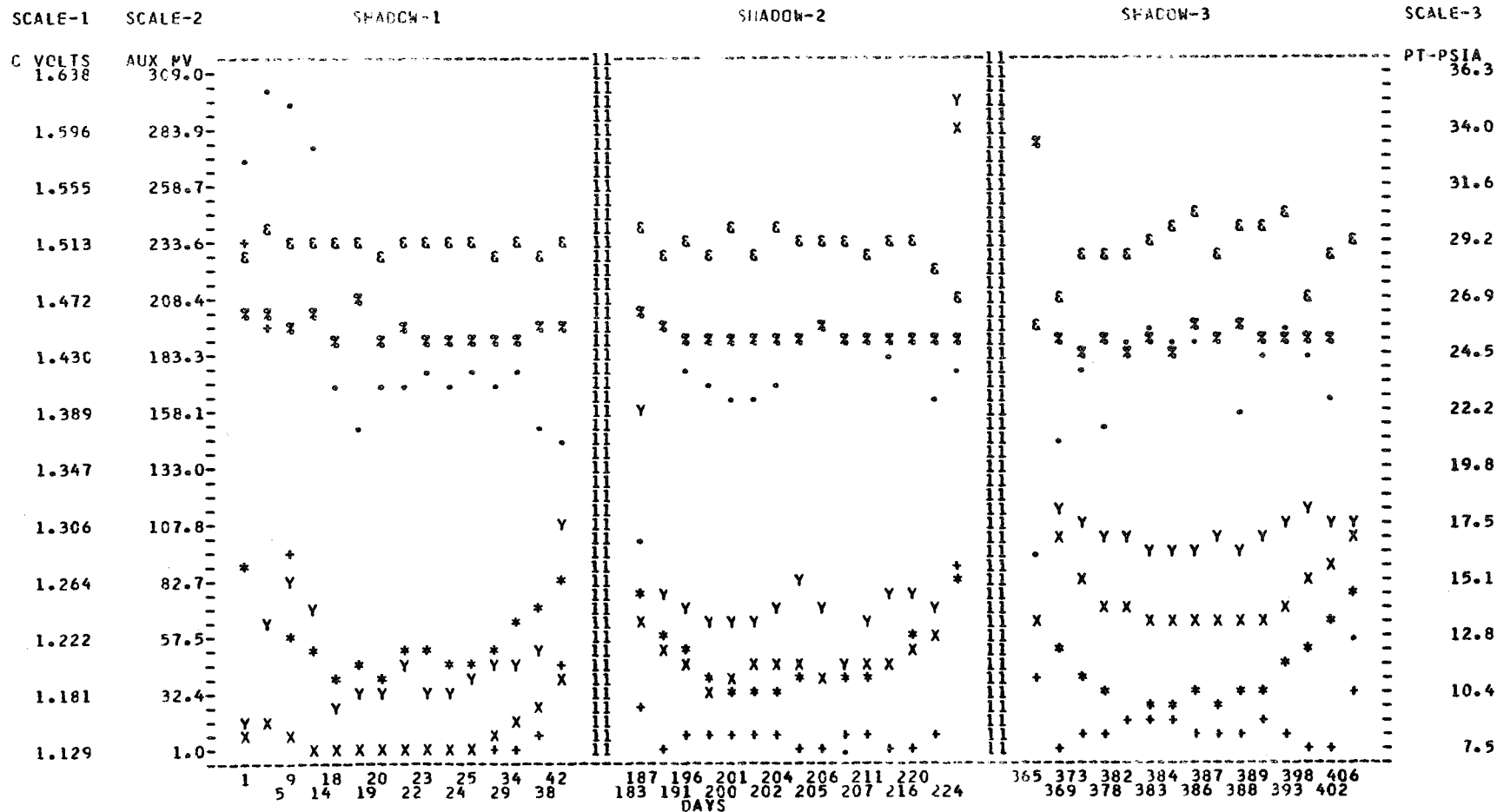


FIGURE 7

KEY
 * AVE END DISCHARGE VOLTAGE
 % AVE CELL VOLTAGE AT TRIP
 & AVE CELL VOLTAGE AT EOC
 + AVE AUX-ELECT. VOLT. AT EOD
 . AVE AUX-ELECT. VOLT. AT TRIP
 X PRESSURE TRANS. AT EOD
 Y PRESSURE TRANS. AT TRIP

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 8

DEPTH DISCHARGE 80.0
 TEMPERATURE 0.0 C
 AMPERE RATE 12.0
 CATALOG 428012AB
 SERIAL 10-3, 9-6, 9-12, 10-13, 10-14
 GENERAL ELECTRIC CELLS
 PROJECT ATS F&G

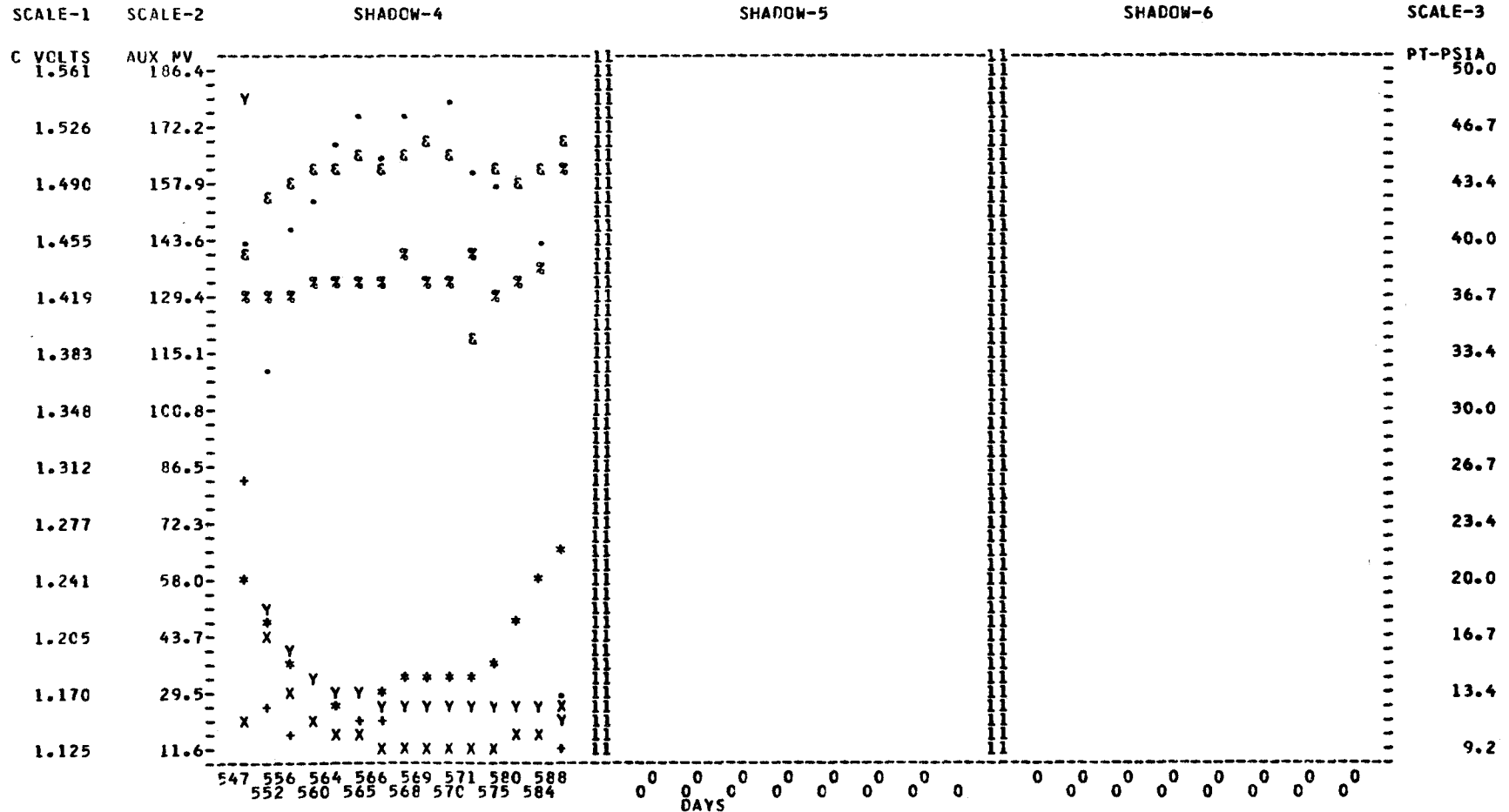


FIGURE 7 (Contd)

QE/C 71-183

KEY
* AHO
% AHI-TOTAL
& AHI AT TRIP

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 8

DEPTH DISCHARGE 80.0
TEMPERATURE 0.0 C
AMPERE RATE 12.0
CATOLOG 42B012AB
SERIAL 10-3,9-6,9-12,10-13,10-14
GENERAL ELECTRIC CELLS
PROJECT AYS F&G

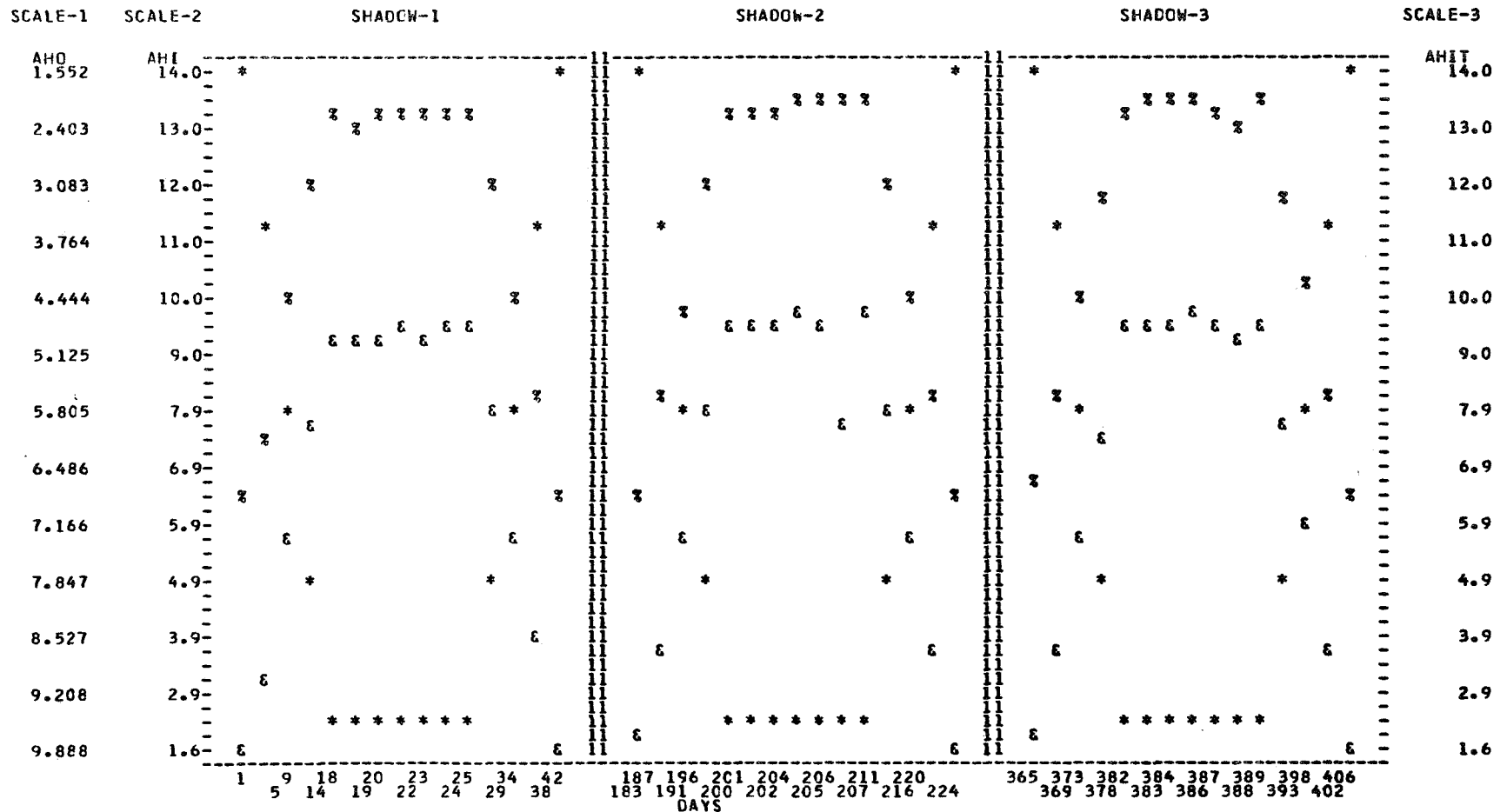


FIGURE 8

KEY
 * AHO
 % AHI-TOTAL
 & AHI AT TRIP

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 8

DEPTH DISCHARGE 80.0
 TEMPERATURE 0.0 C
 AMPERE RATE 12.0
 CATALOG 428012AB
 SERIAL 10-3, 9-6, 9-12, 10-13, 10-14
 GENERAL ELECTRIC CELLS
 PROJECT ATS F&G

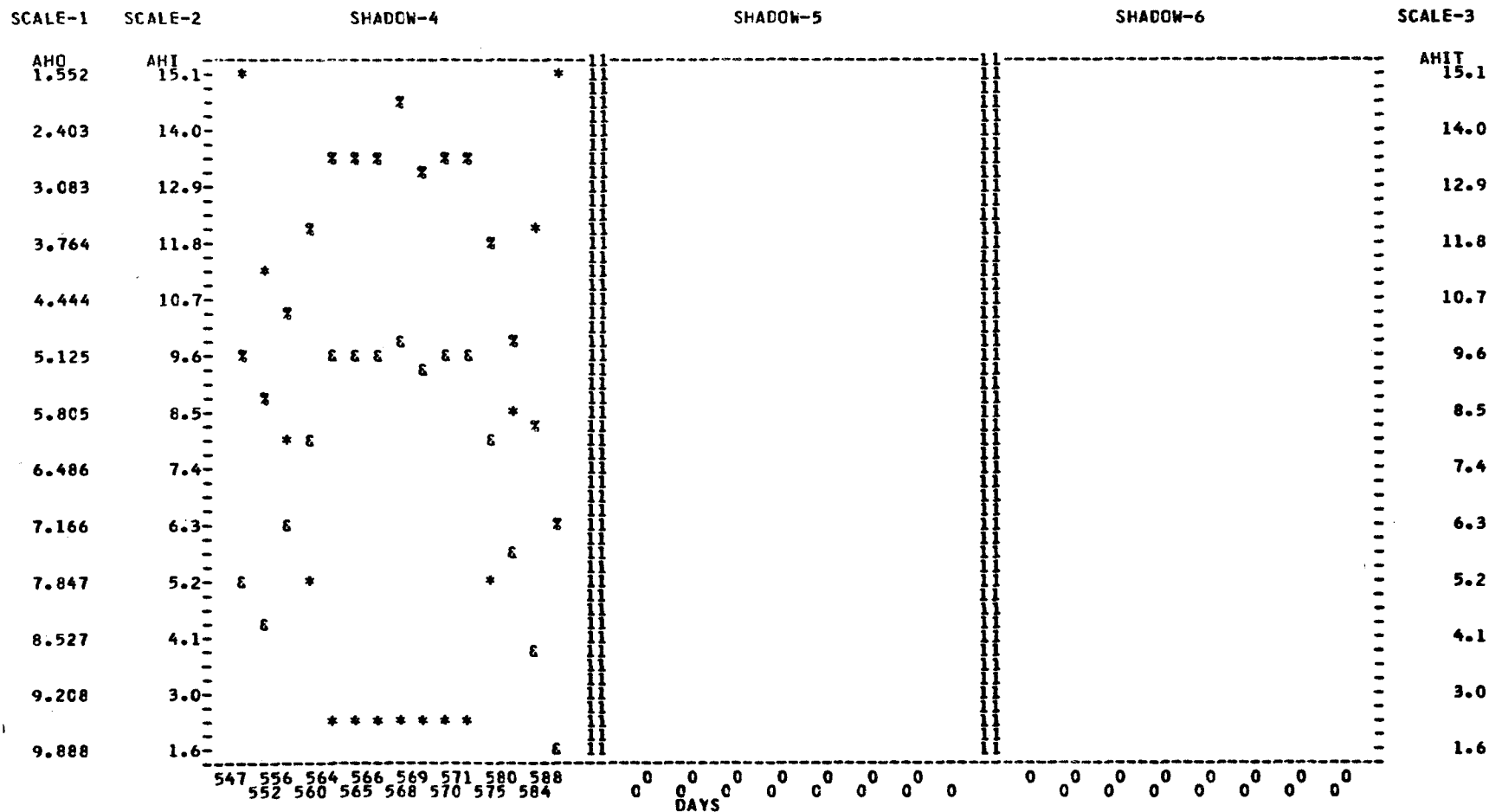


FIGURE 8 (Contd)

1. 12 80
IS 00
428012AB
0 0 0 0 0

EVALUATION OF AUX ELECTRODE CHARGE CONTROL
IN SYNCHRONOUS TYPE ORBIT
GENERAL ELECTRIC CELLS
PROJECT ATS F+G
SERIAL NO ARE 10-3,9-6,9-12,10-
5 5 5 5 5 5 5 5 5 5 5 5

```

ECLIPSE SEASON      1.
AMPERE HOUR RATE IS 12
DEPTH OF DISCHARGE IS 80
TEMPERATURE IS      00
CELL NO CATALOG IS  428012AB
5 5 5 5 5 5 0 0 0 0

```



EVALUATION OF AUX ELECTRODE CHARGE CONTROL
IN SYNCHRONOUS TYPE ORBIT
GENERAL ELECTRIC CELLS
PROJECT ATS F-6
SERIAL NO ARE 1C-3,9-6,9-12,10-13,10-14



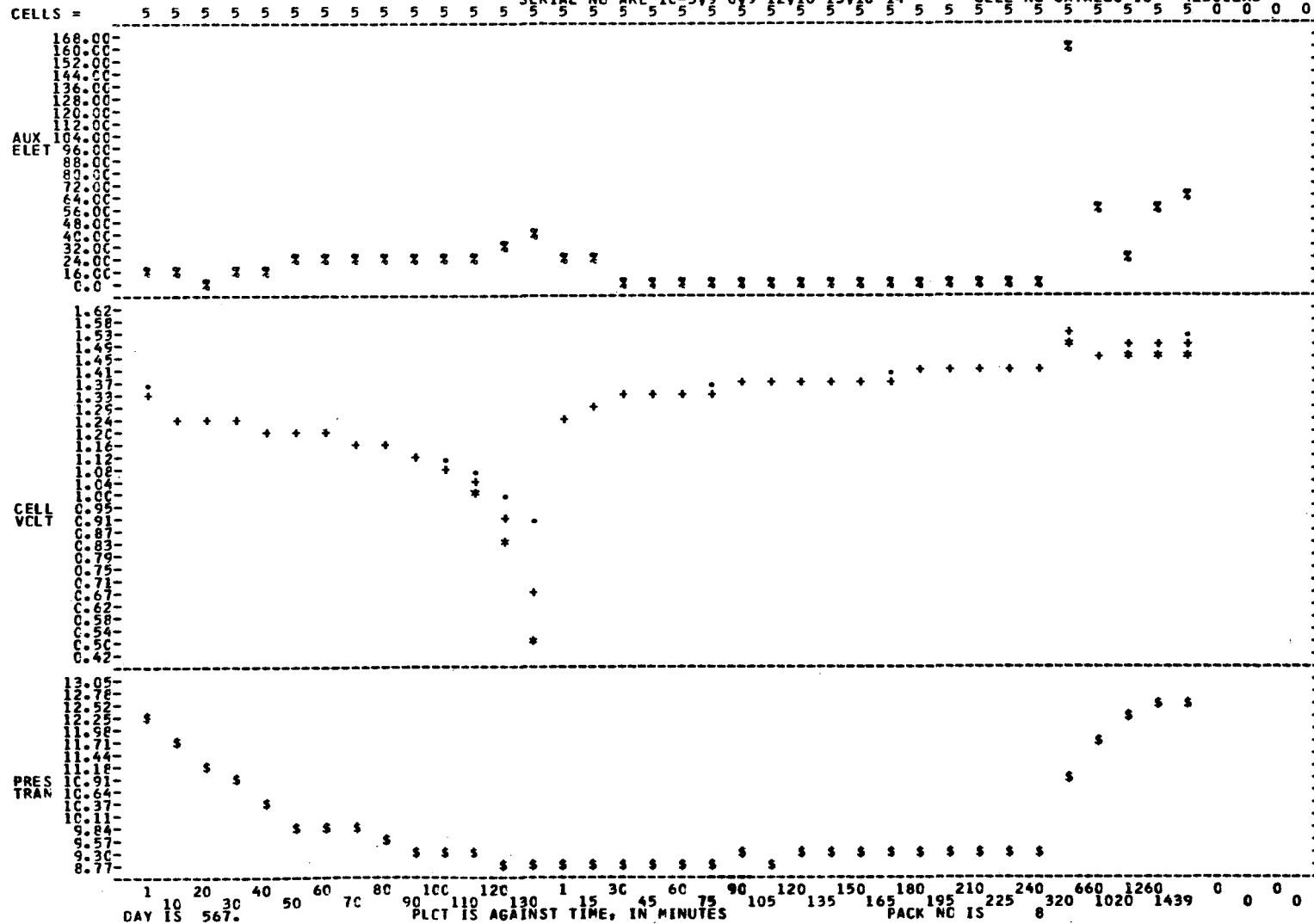
EVALUATION OF AUX ELECTRODE CHARGE CONTROL
IN SYNCHRONOUS TYPE ORBIT
GENERAL ELECTRIC CELLS
PROJECT ATS F+G
SERIAL NO ARE 10-3,9-6,9-12,10-
5 5 5 5 5 5 5 5 5 5 5 5

ECLIPSE SEASON 3.
AMPERE HOUR RATE IS 12
DEPTH OF DISCHARGE IS 80
TEMPERATURE IS 00
CELL NO CATALOG IS 42B012AB



EVALUATION OF AUX ELECTRODE CHARGE CONTROL
IN SYNCHRONOUS TYPE ORBIT
GENERAL ELECTRIC CELLS
PROJECT ATS F+G
SERIAL NO ARE 1C-3,9-6,9-12,10-

ECLIPSE SEASON 4.
AMPERE HOUR RATE IS 12
DEPTH OF DISCHARGE IS 80
TEMPERATURE IS 00
CELL NO CATALOG IS 42B012AB
5 5 5 5 5 5 5 5



28

3. Sync 9 (Eclipse Seasons):

a. Average End of Discharge Voltage (***): Figure 13 shows a sharp increase in the end of discharge voltage following each capacity check. The increase (0.03 volt, average) has occurred each eclipse thus far (see tabulation below).

	First Day	Day Prior to Capacity Check	Day After Capacity Check	Last Day of Eclipse
ECL 1	1.294	1.220	1.240	1.286
ECL 2	1.280	1.190	1.230	1.276
ECL 3	1.279	1.188	1.222	1.287
ECL 4	1.282	1.184	1.221	1.288

The end of discharge voltage drop with time is not so noticeable for this pack at the beginning or end of the eclipse periods but averages 0.01 volt per eclipse just prior to the capacity check.

b. Average Cell Voltage at Trip (%%): The voltage at trip has shown a random distribution, averaging 1.40 volts. The only exception to this was during the first eclipse. Here the voltage tapered downward from 1.43 to 1.40 volts.

c. Average End of Charge Voltage (&&): The end of charge voltage shows a definite tendency to taper downward from the beginning to the end of each eclipse season. This is particularly noticeable during the first and third eclipses. The overall average has dropped from 1.41 in the first eclipse to 1.40 in the fourth. Another notation, is that, the end of charge cell voltage exceeds that of the cell voltage at trip by only 0.01 volt on the average. This difference was greater in Syncs 7 and 8.

d. Average Auxiliary Electrode Voltage at End of Discharge (+++): The auxiliary electrode voltage at end of discharge has closely followed the profile of cell voltage at end of discharge with two exceptions: (1) the auxiliary electrode voltage remains linear during maximum discharge each eclipse and does not track increased cell voltage at end of discharge following each capacity check. This linear level has increased from 65 millivolts in eclipse 1 to 95 millivolts in eclipse 3. Eclipse 4 shows a general increase in auxiliary electrode voltage over most of the season--varying from 50 millivolts on the 10th day to 123 millivolts on the 42nd day.

e. Pressure at End of Discharge (XXX) and at Trip (YYY): Both pressures tend to follow the same pattern with respect to each other. However, excepting eclipse 1, these pressures show no obvious relationship to cell or auxiliary electrode voltage. In eclipse 1, both pressures track the end of discharge cell voltage very closely. A further observation is, that the pressures tend to taper downward from a slight vacuum at the beginning of the eclipse to a hard vacuum toward the end. Exceptions are noted in the first and fourth eclipses where the pressures start above atmospheric.

f. Sync 9 (Ampere-Hours During Successive Eclipse Seasons):

(1) Ampere-Hours Out (AHO,***): Figure 14 shows the same symmetrical graph for ampere-hours removed as noted in previous packs. The ampere-hours removed during periods of maximum discharge is 7.20.

(2) Ampere-Hours In to Trip (AHI, &&&): The profile of the ampere-hours returned to the trip point has remained almost as perfectly symmetrical as that of the ampere-hours out profile, during the first two eclipses. The ampere-hours returned begin to show some variation in the third and fourth eclipses. The average overall is 7.4 ampere-hours.

(3) Ampere-Hours In, Total (AHI-Total, %%%): The total ampere-hours returned forms a profile almost identical to the ampere-hour profile at trip. One exception is noted in the first three eclipses. The ampere-hours returned prior to the capacity check is slightly greater than afterward.

g. Sync 9 (Capacity Checks): Figures 15 through 18 show the capacity checks at the middle of the successive eclipse seasons.

(1) The profile of the auxiliary electrode voltage and the pressure are typical (see paragraph IV.B.2.g.). The "desensitizing" of the auxiliary electrode is also noted.

h. Sync 9 (Summary of Parameters During Sunlight):

(1) Cell Voltage (Sunlight): The cell voltage has averaged 1.41 volts for the three sunlight periods. Furthermore the entire pack has remained in near perfect voltage balance for most of the three sunlight periods. Only within the last 30 days of the third sunlight period did the individual cell voltages begin to vary appreciably from the average. During this time, the maximum

variation from high to low cell was 0.06 volt--1.47 versus 1.41 with an increased average of 1.44 volts.

(2) Auxiliary Electrode Voltage (Sunlight): There is a general trend for the auxiliary electrode voltage to diminish with time. During the first sunlight period the auxiliary electrode voltage opposes this trend and gradually increases by 20 to 80 millivolts, depending on the individual auxiliary electrode. During the second sunlight period, the voltages remain relatively stable but at a level 15 to 20 millivolts below the level established at the end of the first sunlight period. There was one exception out of the three auxiliary electrodes in this pack. This electrode's voltage showed a 40 millivolt increase over the previous level at the start of the second sunlight period; the voltage increased an additional 30 millivolts to a maximum and gradually descended to the initial level at the end of the period. The third sunlight period showed two of the auxiliary electrode voltages starting at the previous established level and remaining there through half of the period. The latter half showed a gradual descent in voltage (20 mv) until the last 30 days of the period. During the last 30 days the voltages dropped sharply (70 mv). During this same third sunlight period, the auxiliary electrode that had previously shown high voltage started at a much lower level--approximately 150 millivolts less. It displayed a fluctuation of + 30 millivolts, but remained at the same overall level throughout the period.

(3) Pressure (Sunlight): The pressure remains at approximately 5 psia throughout the three sunlight seasons. This illustrates two things:

(a) Pressure at this temperature (20° C) poses no problem and stabiliation is quickly effected during the long trickle charge period.

(b) The auxiliary electrode shows a tendency to become desensitized to the oxygen present as time increases.

KEY
 * AVE END DISCHARGE VOLTAGE
 x AVE CELL VOLTAGE AT TRIP
 & AVE CELL VOLTAGE AT EOC
 + AVE AUX-ELECT. VOLT. AT EOD
 x AVE AUX-ELECT. VOLT. AT TRIP
 x PRESSURE TRANS. AT EOD
 y PRESSURE TRANS. AT TRIP

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 9

DEPTH DISCHARGE 60.0
 TEMPERATURE 20.0 C
 AMPERE RATE 12.0
 CATALOG 428012AB
 SERIAL 10-5,10-6,9-8,9-10,9-13
 GENERAL ELECTRIC CELLS
 PROJECT ATS F&G

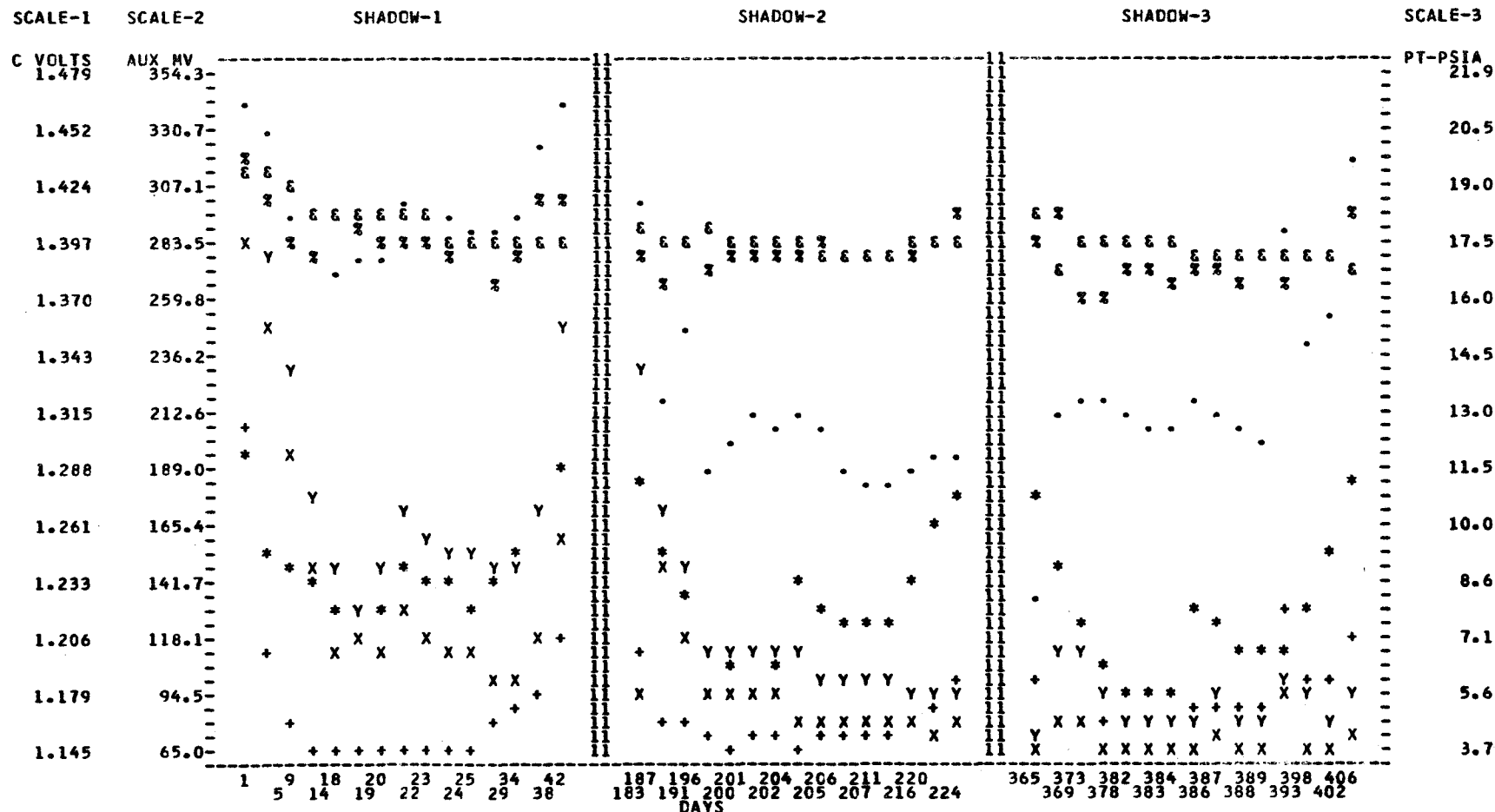


FIGURE 13

QE/C 71-183

KEY
 * AVE END DISCHARGE VOLTAGE
 % AVE CELL VOLTAGE AT TRIP
 & AVE CELL VOLTAGE AT EOC
 + AVE AUX-ELECT. VOLT. AT EOC
 + AVE AUX-ELECT. VOLT. AT TRIP
 X PRESSURE TRANS. AT EOC
 Y PRESSURE TRANS. AT TRIP

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 9

DEPTH DISCHARGE 60.0
 TEMPERATURE 20.0 C
 AMPERE RATE 12.0
 CATALOG 42B012AB
 SERIAL 10-5, 10-6, 9-8, 9-10, 9-13
 GENERAL ELECTRIC CELLS
 PROJECT ATS F&G

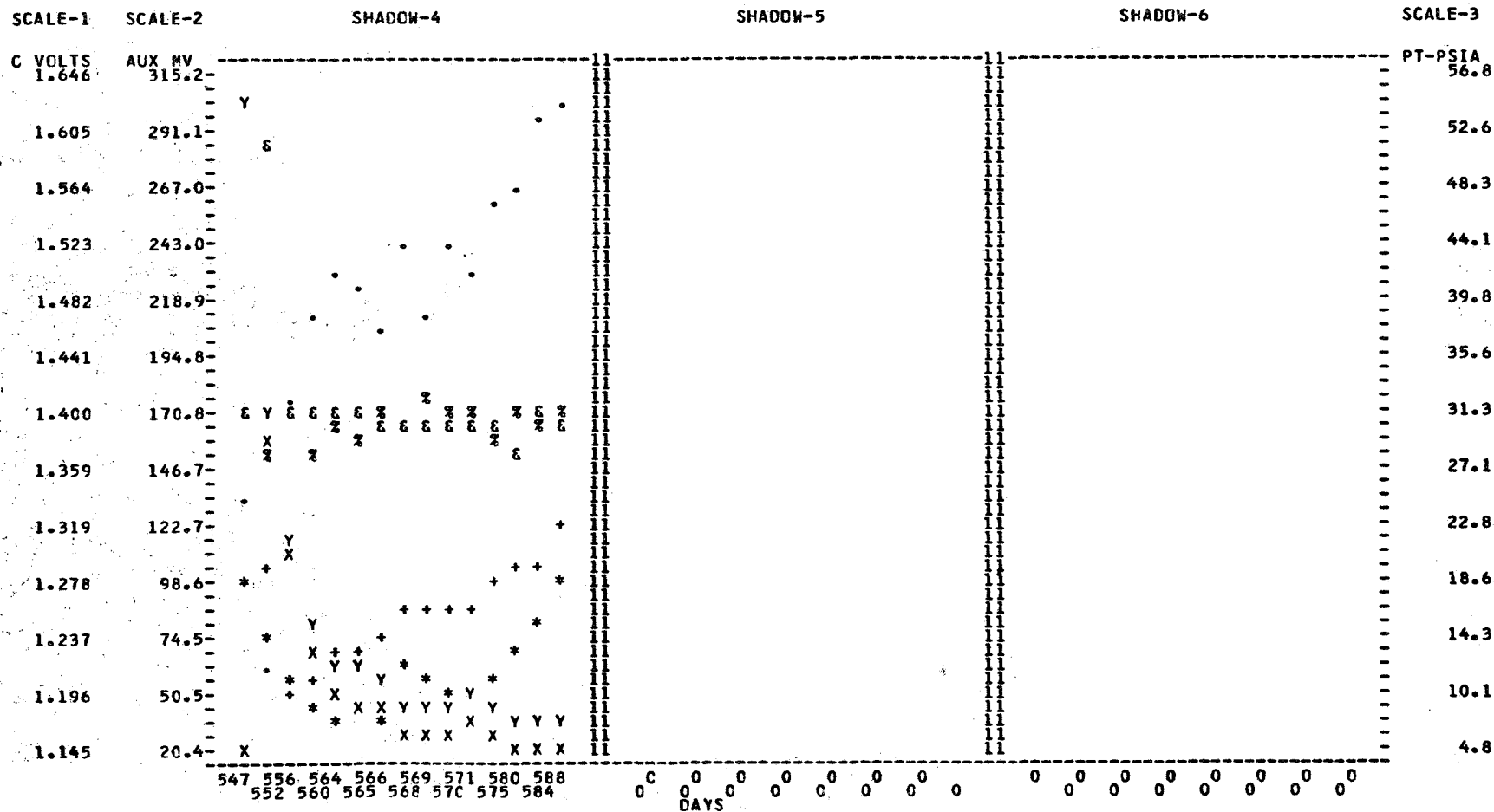


FIGURE 13 (Contd)

KEY
 * AHO
 % AHI-TOTAL
 & AHI AT TRIP

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 9

DEPTH DISCHARGE 60.0
 TEMPERATURE 20.0 C
 AMPERE RATE 12.0
 CATALOG 42B012AB
 SERIAL 10-5,10-6,9-8,9-10,9-13
 GENERAL ELECTRIC CELLS
 PROJECT ATS F&G

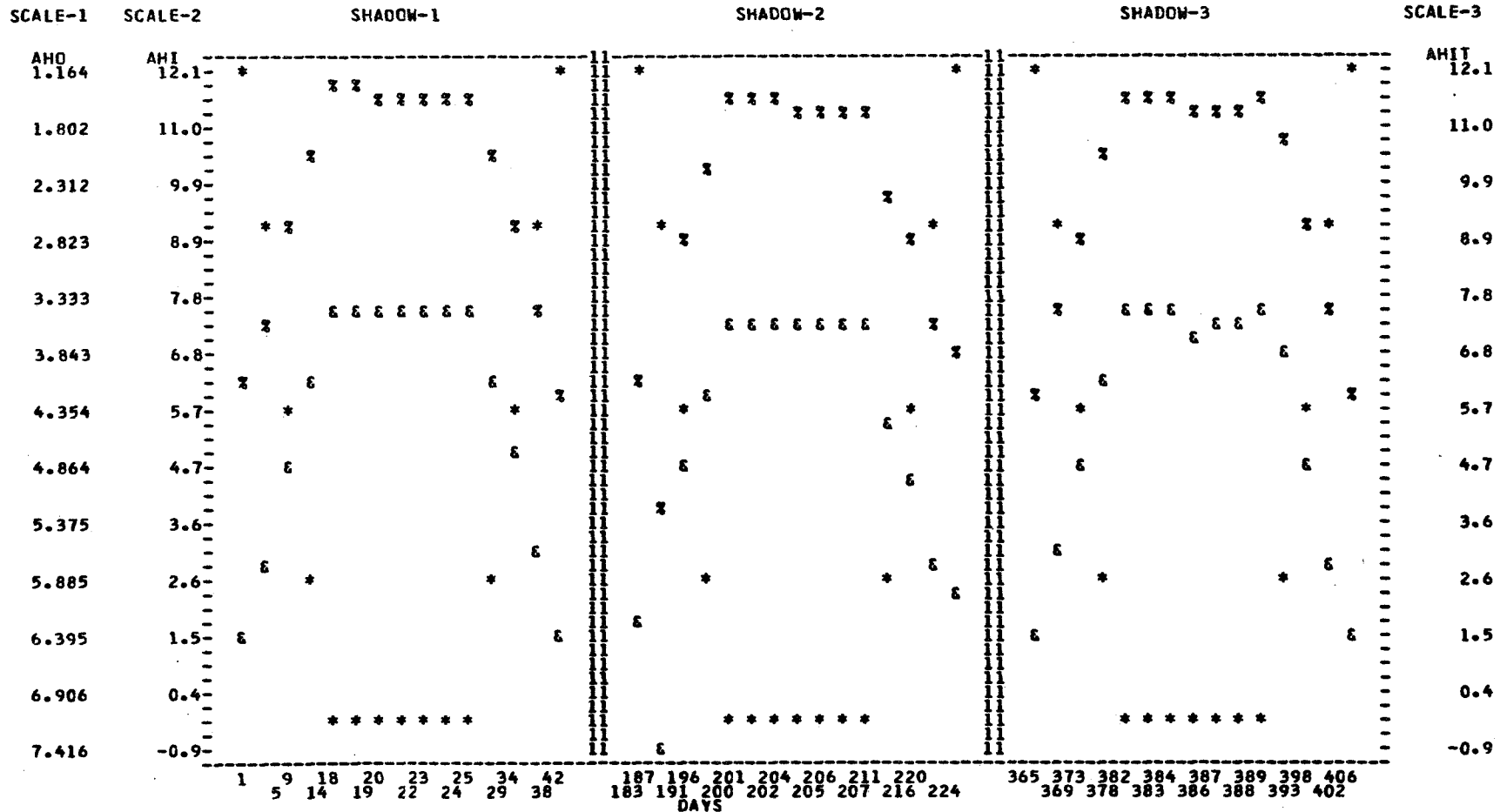


FIGURE 14

DEPTH DISCHARGE 60.0
TEMPERATURE 20.0 C
AMPERE RATE 12.0
CATALOG 42B012AB
SERIAL 10-5, 10-6, 9-8, 9-10, 9-13
GENERAL ELECTRIC CELLS
PROJECT ATS F&G

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 9

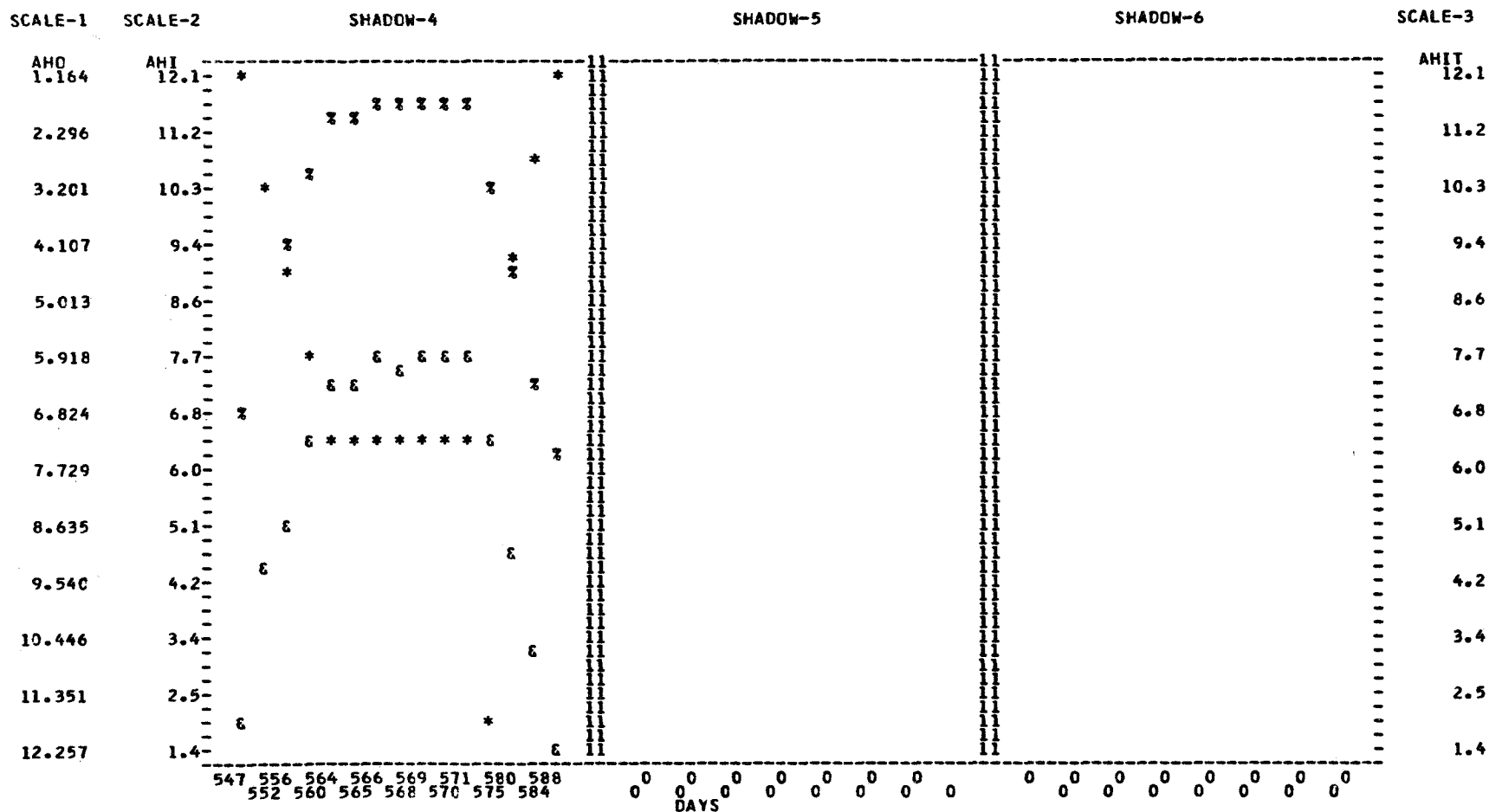


FIGURE 14 (Contd)

FIGURE 15

FIGURE 16

FIGURE 17

FIGURE 18

4. Sync 10 (Eclipse Seasons):

a. Average End of Discharge Voltage (**): Figure 19 shows a sharp increase in the end of discharge voltage following each capacity check. The increase has averaged 0.04 volt for the four capacity checks.

	First Day	Day Prior to Capacity Check	Day After Capacity Check	Last Day of Eclipse
ECL 1	1.276	1.196	1.222	1.272
ECL 2	1.262	1.164	1.200	1.260
ECL 3	1.258	1.153	1.189	1.269
ECL 4	1.260	1.127	1.183	1.271

The tendency thus far shows that the end of discharge voltage prior to the capacity check drops steadily from one eclipse season to the next--averaging 0.02 volt per season. The same tendency exists at all points, but the day following the capacity checks has averaged a loss of only 0.01 volt per season. The first and last days of the season have shown even less of a drop with time. The depth of discharge (80 percent) is the basic reason for the voltage drops at the periods of maximum discharge.

b. Average Cell Voltage at Trip (%%): The cell voltage at trip has remained relatively constant at 1.39 volts through the four eclipse seasons.

c. Average End of Charge Voltage (&&): The end of charge voltage exceeds that of the trip voltage by 0.01 volt on the average, during the first three eclipses. The end of charge and trip voltages are at the same level (1.39 volts) throughout most of the fourth season.

d. Average Auxiliary Electrode Voltage at End of Discharge (++): The auxiliary electrode voltage closely follows the end of discharge cell voltage except during the third eclipse. Here the voltage started low and plateaued higher than for previous eclipse seasons. However the only difference in the profile is during the first portion of the eclipse. The fourth eclipse shows the profile of the auxiliary electrode to continue tracking that of the cell voltage, but the cell voltage is much more erratic for this eclipse just prior to the capacity check.

e. Pressure at End of Discharge (XXX) and at Trip (YYY): The pressures have all remained in a vacuum throughout all four eclipse seasons. However this is the only factor that has remained constant. During the first half of the first eclipse, the pressures followed the profile of the end of discharge cell voltages--the trip pressure exceeding the end of discharge pressure by 3 psia. The latter portion of the first eclipse showed a sharp rise in pressure which had no correlation to the cell voltage or auxiliary electrode voltage. The pressures remained high through the second and third eclipse seasons, showing no correlation with cell voltages. The end of discharge pressure averaged 11 psia with the trip pressure averaging 12 psia during these two seasons. The pressures during the fourth eclipse were completely random; showing no trends or correlations whatever.

f. Sync 10 (Ampere-Hours During Successive Eclipse Seasons):

(1) Ampere-Hours Out (AHO, ***): Figure 20 shows the same symmetrical profile of the previous Sync packs cited--inverted pyramid. The ampere-hours out during maximum discharge is 9.60.

(2) Ampere-Hours In to Trip (AHI, &&&): The profile of the ampere-hours returned to the trip point remains the mirror image of the ampere-hours out, previously cited, through the first two eclipse seasons. The third and fourth eclipse seasons show more variation in the ampere-hours returned during the maximum period of recharge.

(3) Ampere-Hours In, Total (AHI-Total, %%%): The graph of the total ampere-hours returned is identical to the graph of the ampere-hours returned at the trip point except it is 5 ampere-hours greater for each corresponding point--averaging 13.5 ampere-hours for the maximum return.

g. Sync 10 (Capacity Checks): Figures 21 through 24 show the capacity checks at the middle of the successive eclipse seasons.

(1) The profiles of the auxiliary electrode and the pressure are typical (see paragraph IV.B.2.g.) except the upward taper during charge starts much sooner after discharge than for that noted in previous Sync packs. Desensitizing of the auxiliary electrode during capacity checks is not noticeable for this pack. However this is noted during the sunlight period described in the next paragraph.

h. Sync 10 (Summary of Parameters During Sunlight):

(1) Cell Voltage (Sunlight): The cell voltage has averaged 1.40 through all three sunlight periods. Furthermore the cell balance for the pack has remained near perfect throughout this time.

(2) Auxiliary Electrode Voltage (Sunlight): The auxiliary electrode voltages have fluctuated more for this pack than for previous packs, but similar trends exist. The voltage tends to increase gradually through most of the first sunlight period. This trend is countered in the second sunlight period during which the voltages stabilize and, in some instances, drop rapidly during the last 20 days of the period. Beginning the third period, the voltages are all returned to the stabilization levels established during the prior sunlight period. These levels are maintained until the last 20 days of the third period, then they gradually decline.

(3) Pressure (Sunlight): With few exceptions, the pressure has remained approximately 11 psia throughout the three sunlight periods. This indicates once more that there is a tendency for the auxiliary electrodes to become desensitized with elapsed time on test.

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KEY
 * AVE END DISCHARGE VOLTAGE
 % AVE CELL VOLTAGE AT TRIP
 & AVE CELL VOLTAGE AT EOC
 + AVE AUX-ELECT. VOLT. AT EOD
 . AVE AUX-ELECT. VOLT. AT TRIP
 X PRESSURE TRANS. AT EOD
 Y PRESSURE TRANS. AT TRIP

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 10

DEPTH DISCHARGE 80.0
 TEMPERATURE 20.0 C
 AMPERE RATE 12.0
 CATALOG 42B012AB
 SERIAL 9-5,9-7,10-8,10-9,9-14
 GENERAL ELECTRIC CELLS
 PROJECT ATS F&G

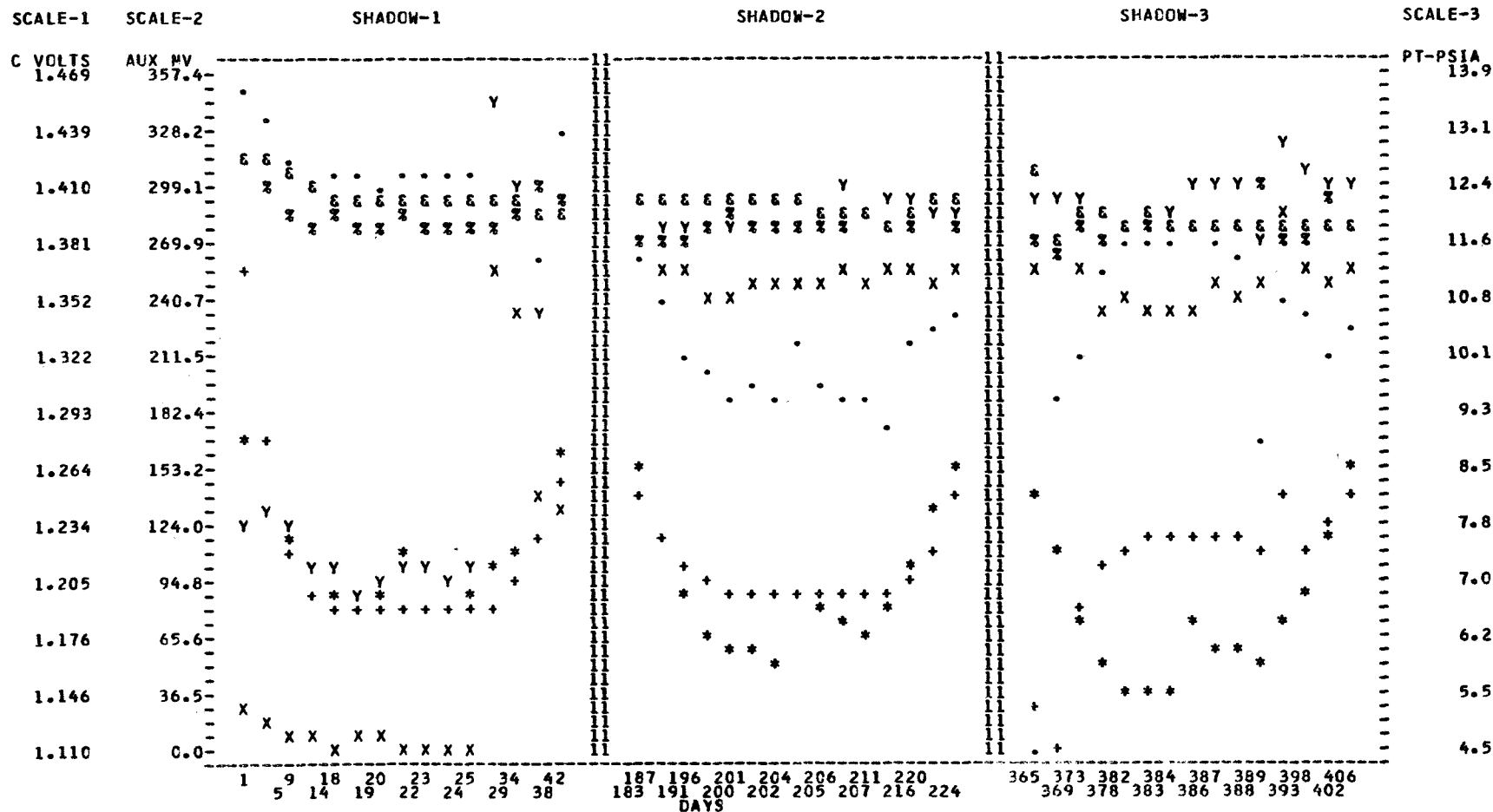


FIGURE 19

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 10

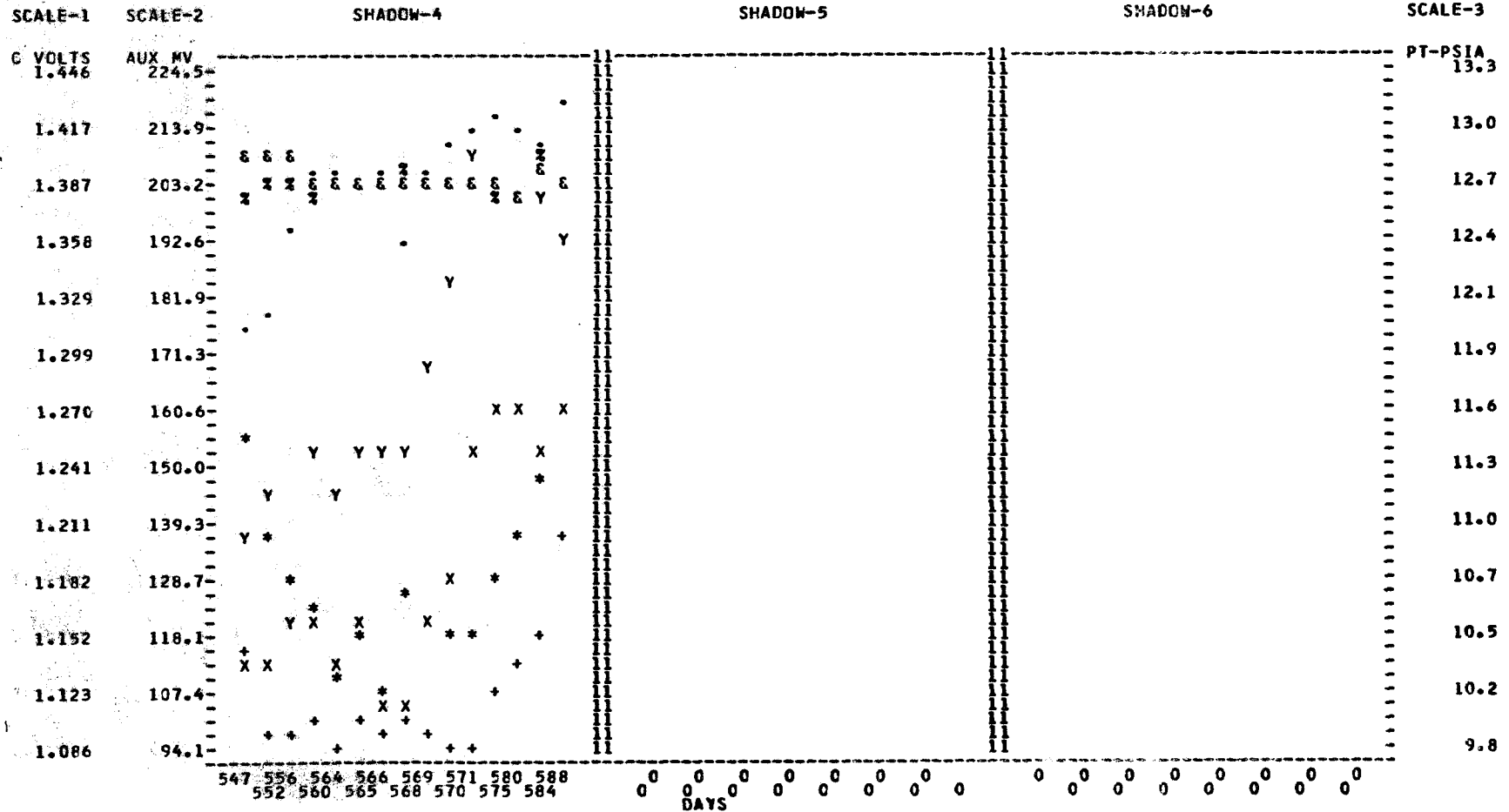


FIGURE 19 (Contd)

QE/C 71-183

KEY
* AHO
% AHI-TOTAL
& AHI AT TRIP

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 10

DEPTH DISCHARGE 80.0
TEMPERATURE 20.0 C
AMPERE RATE 12.0
CATALOG 428012AB
SERIAL 9-5,9-7,10-8,10-9,9-14
GENERAL ELECTRIC CELLS
PROJECT ATS F&G

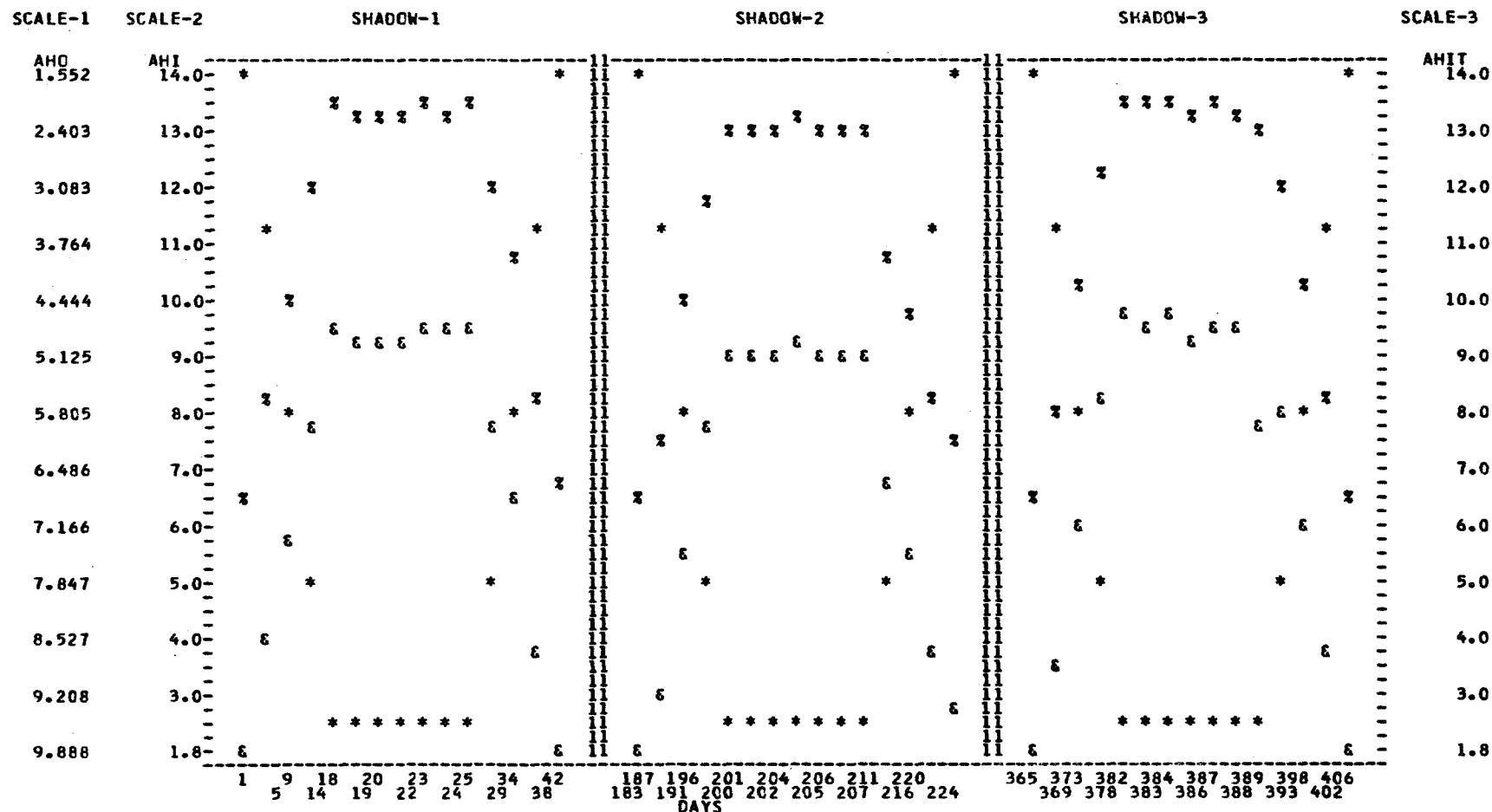


FIGURE 20

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 10

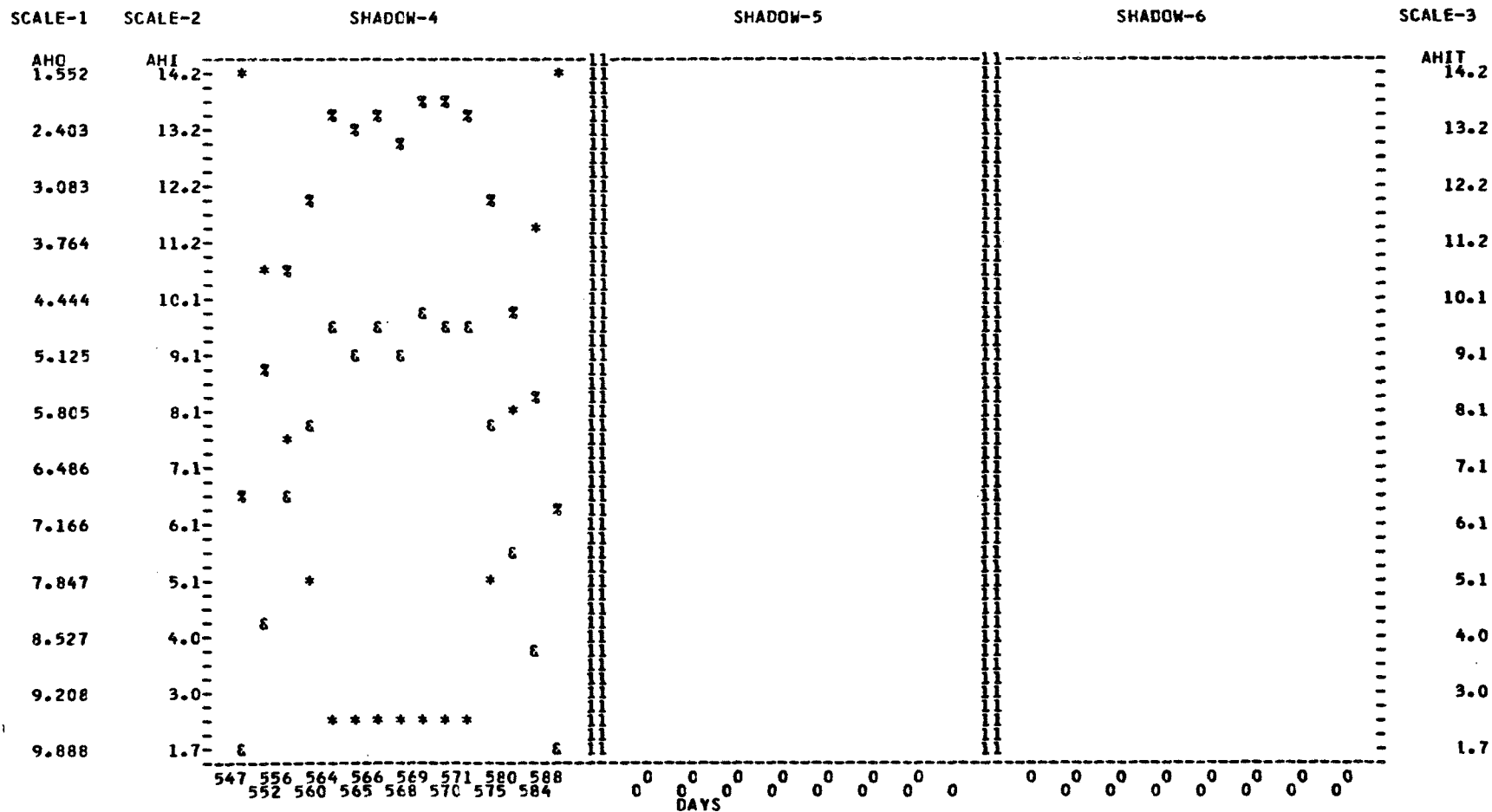


FIGURE 20 (Contd)

1. 12 80
S 20
42B012AB
0 0 0 0 0

FIGURE 21

EVALUATION OF AUX ELECTRODE CHARGE CONTROL
IN SYNCHRONOUS TYPE ORBIT
GENERAL ELECTRIC CELLS
PROJECT ATS F+G
SERIAL NO ARE 9-5,9-7,1088,10-9



3. 12 80
S 20
428012AB
0 C 0 0 0

FIGURE 23

CCODE
+ = AVERAGE CELL VOLT
• = HIGH CELL VOLT
* = LOW CELL VOLT

IN SYNCHRONOUS TYPE ORBIT

GENERAL ELECTRIC CELLS

PROJECT ATTS F+G
SERIAL NO. ABE 2

SERIAL NO ARE 9-
F F F F F

5 5 5 5 5 5 5 5 5 5 5 5 5

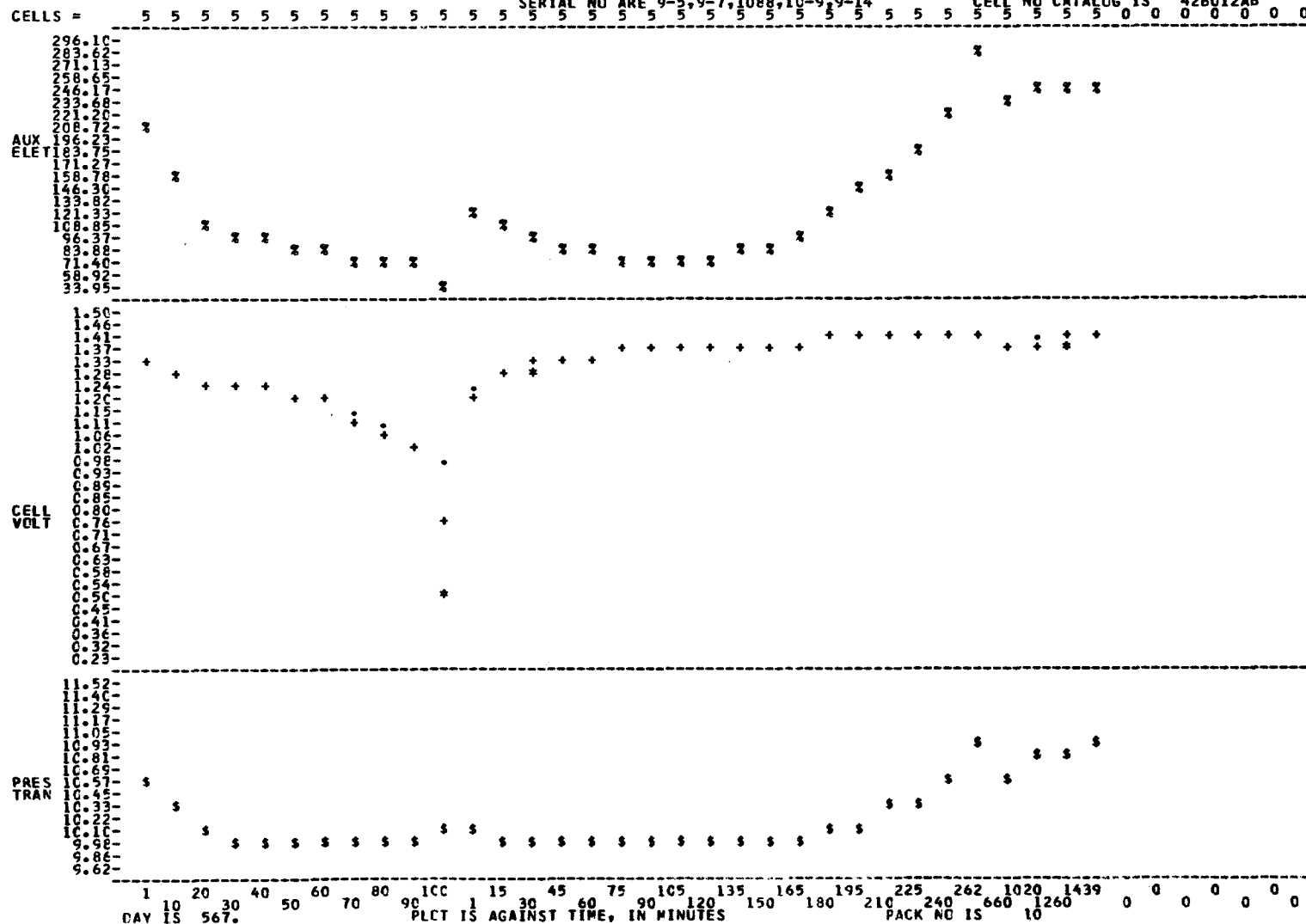


FIGURE 24

5. Sync 11 (Eclipse Seasons):

a. Average End of Discharge Voltage (***): Figure 25 shows much variation in end of discharge voltage throughout the four eclipse seasons. The basic reason for the variation is the high ambient temperature (40° C). This variation has necessitated numerous changes in charge currents and auxiliary electrode trip levels as shown in Table I. For eclipse 1, the rapid daily dropping of the end of discharge voltage prior to the capacity check signified that the original trickle charge current (0.200 ma) following the auxiliary electrode trip was not sufficient to overcome the self discharge at 40° C. An increase of trickle charge current, and three days later, an increase in trip voltage for the auxiliary electrode plus the usual reconditioning effect of the capacity checks, all combined to keep the end of discharge voltage at a higher level during the last half of eclipse 1. However near the end of the maximum discharge period the voltage again dropped off just before the time on discharge begins to decrease each day. Eclipse 2 shows a similar dip in the end of discharge voltage profile. Eclipse 3 shows extremely low end of discharge voltages throughout the maximum discharge period. The graph of eclipse 4 reveals voltages dropping below allowable limits. To improve the performance, the auxiliary electrode control was eliminated; the cells are continually charged at 1.20 amperes following discharge. The tabulation below summarizes the endpoint end of discharge voltages as shown for previous Sync packs.

	First Day	Day Prior to Capacity Check	Day After Capacity Check	Last Day of Eclipse
ECL 1	1.260	0.802	1.132	1.258
ECL 2	1.240	1.164	1.164	1.220
ECL 3	1.216	0.396	0.635	1.211
ECL 4	1.202	0.452	0.767	1.197

b. Average Cell Voltage at Trip (%%): The voltage at trip has remained relatively constant 1.35 volts except for eclipse 2. In eclipse 2 and the latter half of eclipse 4, the auxiliary electrode control was removed (see Table I) and the cells were continuously charged at the specified rates until the next discharge.

c. Average End of Charge Voltage (&&&): The end of charge voltage exceeds that of the trip voltage (where the trip voltage is in effect) by 0.02 volt on the average.

d. Average Auxiliary Electrode Voltage at End of Discharge (+++): In general the auxiliary electrode voltage profile follows that of the cell voltage during discharge for the first two eclipse seasons. For eclipses 3 and 4 there is no obvious correlation between the two profiles. This graphically substantiates that auxiliary electrode operation beyond two eclipse seasons, in a synchronous orbit regime, is not reliable at 40° C.

e. Pressure at End of Discharge (XXX) and at Trip (YYY): Pressures both at end of discharge and trip run high at this temperature. As time goes on the pressure continually increases until early in eclipses 3 and 4 the pressure jumps drastically to 100 psia or more. This is accompanied by cell voltage imbalance for the whole pack.

f. Sync 11 (Ampere-Hours During Successive Eclipse Seasons):

(1) Ampere-Hours Out (AHO, ***): Figure 26 clearly illustrates the inefficiencies of operating at 40° C. In eclipse 1, the ampere-hours out forms a profile that is not the symmetrical, inverted pyramid as noted for the previous Sync packs. Eclipse 2 is the only eclipse of the four that shows the usual symmetry. The reason for the exception is that the auxiliary electrode control was removed during most of this eclipse while the cells were continuously charged. The graph of eclipses 3 and 4 also show that the cells have failed to deliver the required capacity on discharge.

(2) Ampere-Hours In to Trip (AHI, &&&): The ampere-hours returned to trip is not sufficient to properly recharge the cell. Increasing the trip voltage level resulted in the auxiliary electrodes never reaching the level, which required a manual trip or the result would have been high voltage and pressure. Thus auxiliary electrode charge control is not recommended for a synchronous orbit regime at 40° C.

(3) Ampere-Hours In, Total (AHI-Total, %%); The graph of the total ampere-hours returned to the cell confirms the statements previously made. Insufficient charge is returned following the trip to prevent premature low voltage on the succeeding charge. When the auxiliary electrode control is removed as in eclipse 2, the discharge will go the required time during maximum discharge but the ampere-hours returned indicates the inefficiency of operation at 40° C.

g. Sync 11 (Capacity Checks): Figures 27 through 30 show the capacity checks at the middle of the successive eclipse seasons.

(1) The profiles of the auxiliary electrode voltage and the pressure follow the general trends previously discussed (paragraph IV.B.2.g.). However the values are greater and the pressure starts increasing sooner (within 1.5 hours of end of discharge during the following charge).

(2) The voltage of the cells show poor balance on charge during eclipse 4.

h. Sync 11 (Summary of Parameters During Sunlight):

(1) Cell Voltage (Sunlight): During the sunlight period following the first eclipse, the voltage averaged 1.39 volts, and the voltage balance was good for all the cells. The second sunlight period produced an increased average in cell voltage--approximately 1.44 volts. This was accompanied by voltage imbalance (as much as 0.17 volt difference between high and low cells) and high pressure--80 psia. The same cell averages and problems were encountered during the third sunlight period. During both the second and third sunlight periods, the trickle charge current had to be reduced within the first 40 days--from 600 milliamperes to 400 milliamperes, then to 200 milliamperes. In one instance, after 60 days of the second sunlight period, the charge current was removed to allow the pressure to go down.

(2) Auxiliary Electrode Voltage (Sunlight): The auxiliary electrode voltage tends to decrease with succeeding sunlight periods. The average auxiliary electrode voltage drops 100 millivolts during the second sunlight period from that of the first. The voltage drops an additional 20 millivolts, on the average, during the third sunlight period.

(3) Pressure (Sunlight): The pressure got as high as 80 psia during portions of the second and third sunlight periods due to high voltage and poor voltage balance among the cells as noted in paragraph (1) above. During the first sunlight period the pressure ranged from 13 to 16 psia, gradually increasing from the beginning to the end of the period. Throughout the second period the pressure showed a general increase from beginning to end with peaks of 80 psia during the first third of the period. Despite corrective measures at these points, the overall pressure ranged upward from 22 psia to 40 psia, beginning to end. The third sunlight period showed the overall pressure to range from 30 psia to 60 psia, beginning to end, with a peak of 63 psia.

KEY
 * AVE END DISCHARGE VOLTAGE
 % AVE CELL VOLTAGE AT TRIP
 & AVE CELL VOLTAGE AT EOC
 + AVE AUX-ELECT. VOLT. AT EOD
 . AVE AUX-ELECT. VOLT. AT TRIP
 X PRESSURE TRANS. AT EOD
 Y PRESSURE TRANS. AT TRIP

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 11

DEPTH DISCHARGE 60.0
 TEMPERATURE 40.0 C
 AMPERE RATE 12.0
 CATALOG 428012AB
 SERIAL 10-4,10-7,9-9,9-11,10-11
 GENERAL ELECTRIC CELLS
 PROJECT AT5 F&G

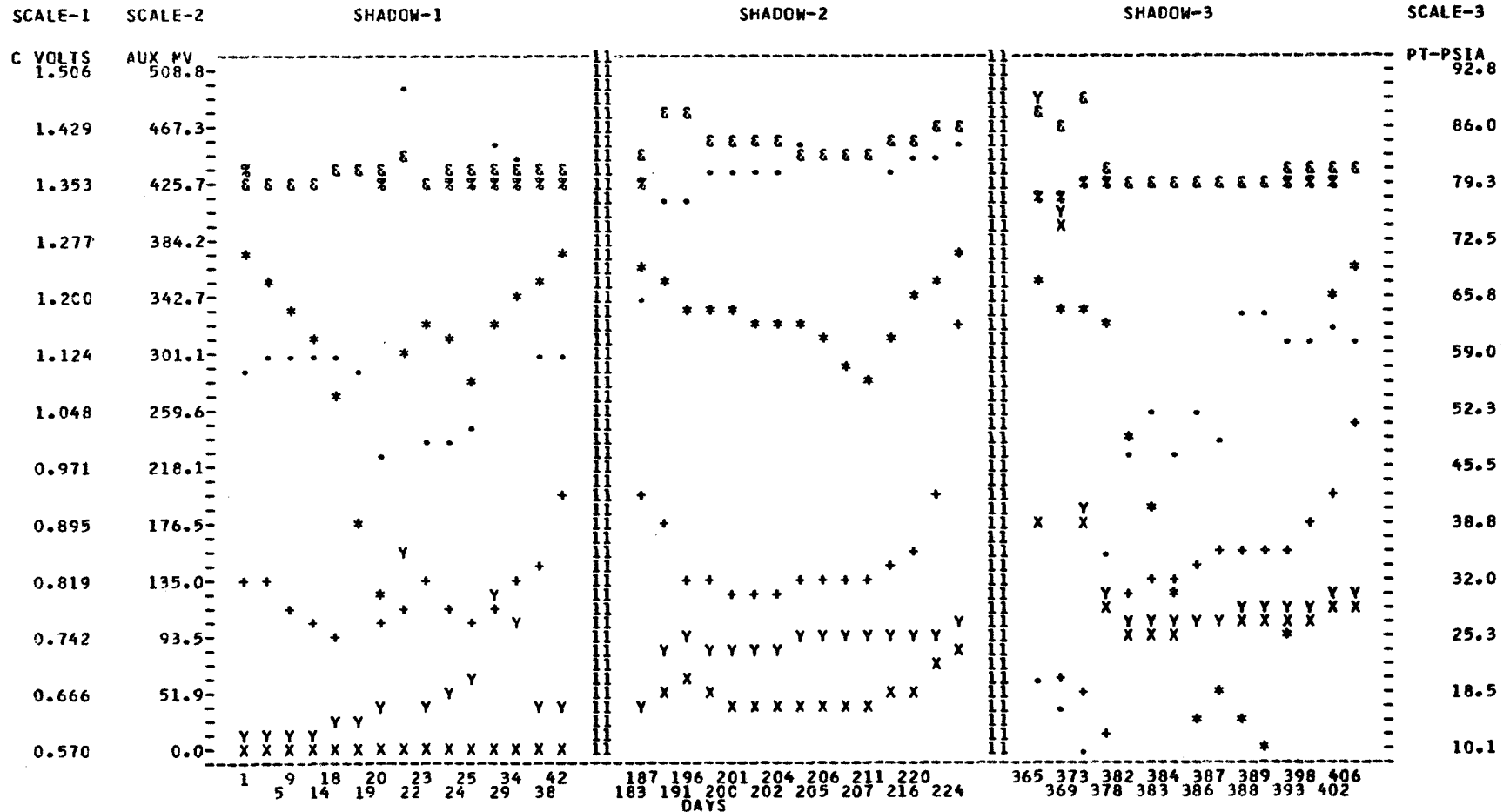


FIGURE 25

QE/C 71-183

KEY
 * AVE END DISCHARGE VOLTAGE
 % AVE CELL VOLTAGE AT TRIP
 & AVE CELL VOLTAGE AT EOC
 + AVE AUX-ELECT. VOLT. AT EOD
 . AVE AUX-ELECT. VOLT. AT TRIP
 X PRESSURE TRANS. AT EOD
 Y PRESSURE TRANS. AT TRIP

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 11

DEPTH DISCHARGE 60.0
 TEMPERATURE 40.0 C
 AMPERE RATE 12.0
 CATALOG 428012AB
 SERIAL 10-4, 10-7, 9-9, 9-11, 10-11
 GENERAL ELECTRIC CELLS
 PROJECT ATS F&G

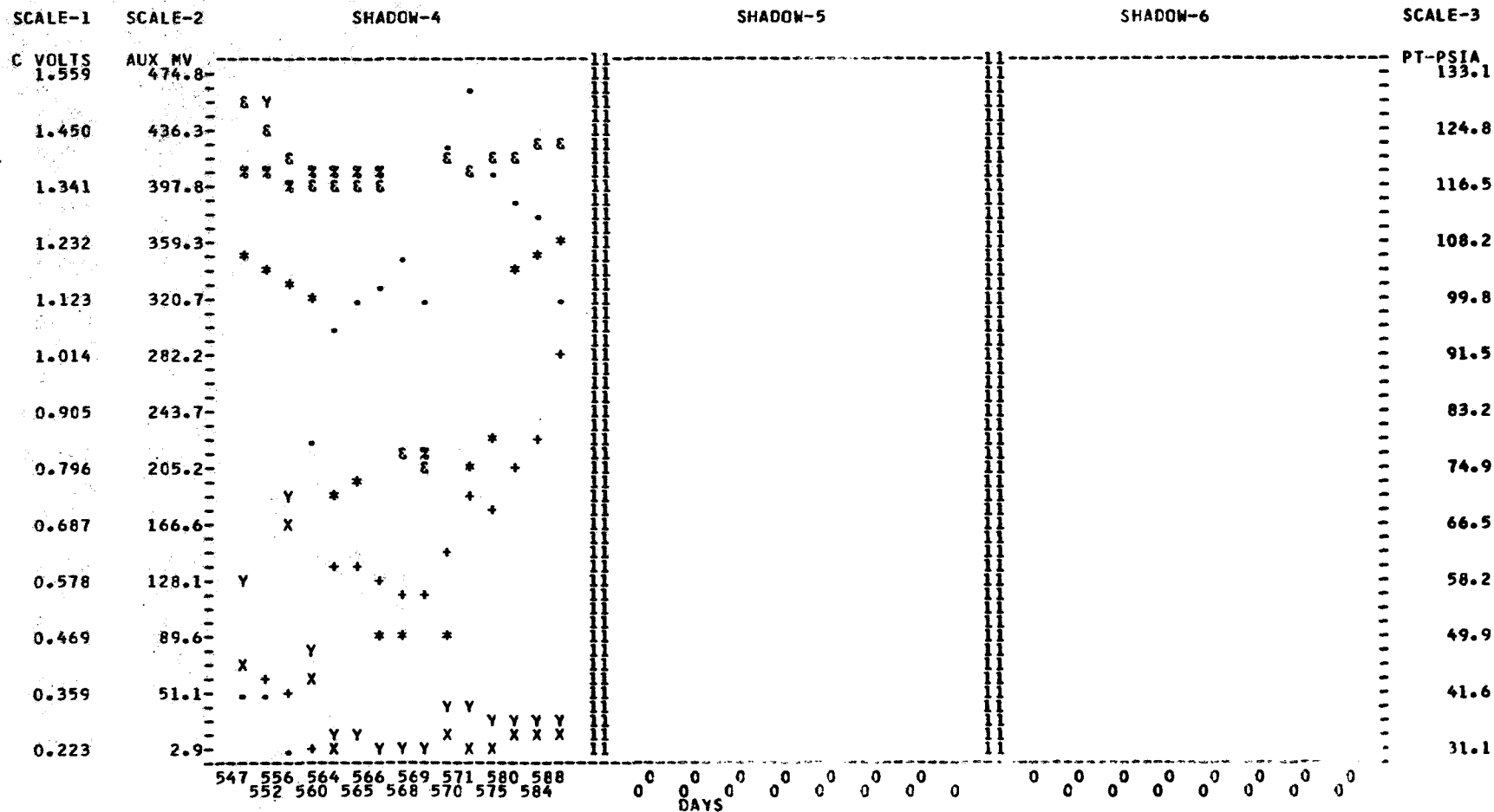


FIGURE 25 (Contd)

QE/C 71-183

KEY
* AHO
% AHI-TOTAL
& AHI AT TRIP

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 11

DEPTH DISCHARGE 60.0
TEMPERATURE 40.0 C
AMPERE RATE 12.0
CATALOG 428012AB
SERIAL 10-4,10-7,9-9,9-11,10-11
GENERAL ELECTRIC CELLS
PROJECT ATS F&G

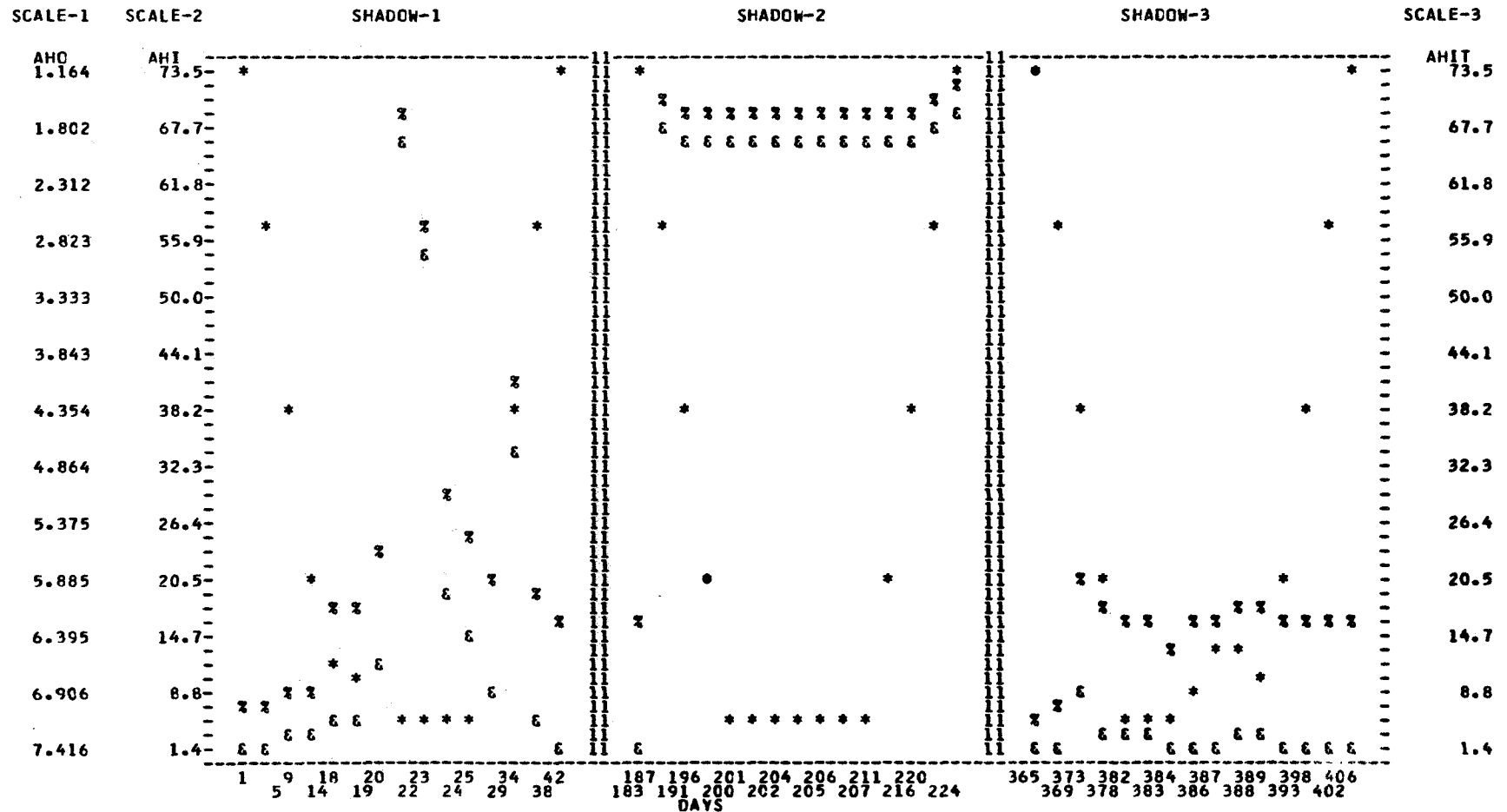


FIGURE 26

DEPTH DISCHARGE 60.0
TEMPERATURE 40.0 C
AMPERE RATE 12.0
CATALOG 42B012AB
SERIAL 10-4,10-7,9-9,9-11,10-11
GENERAL ELECTRIC CELLS
PROJECT ATS F&G

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 11

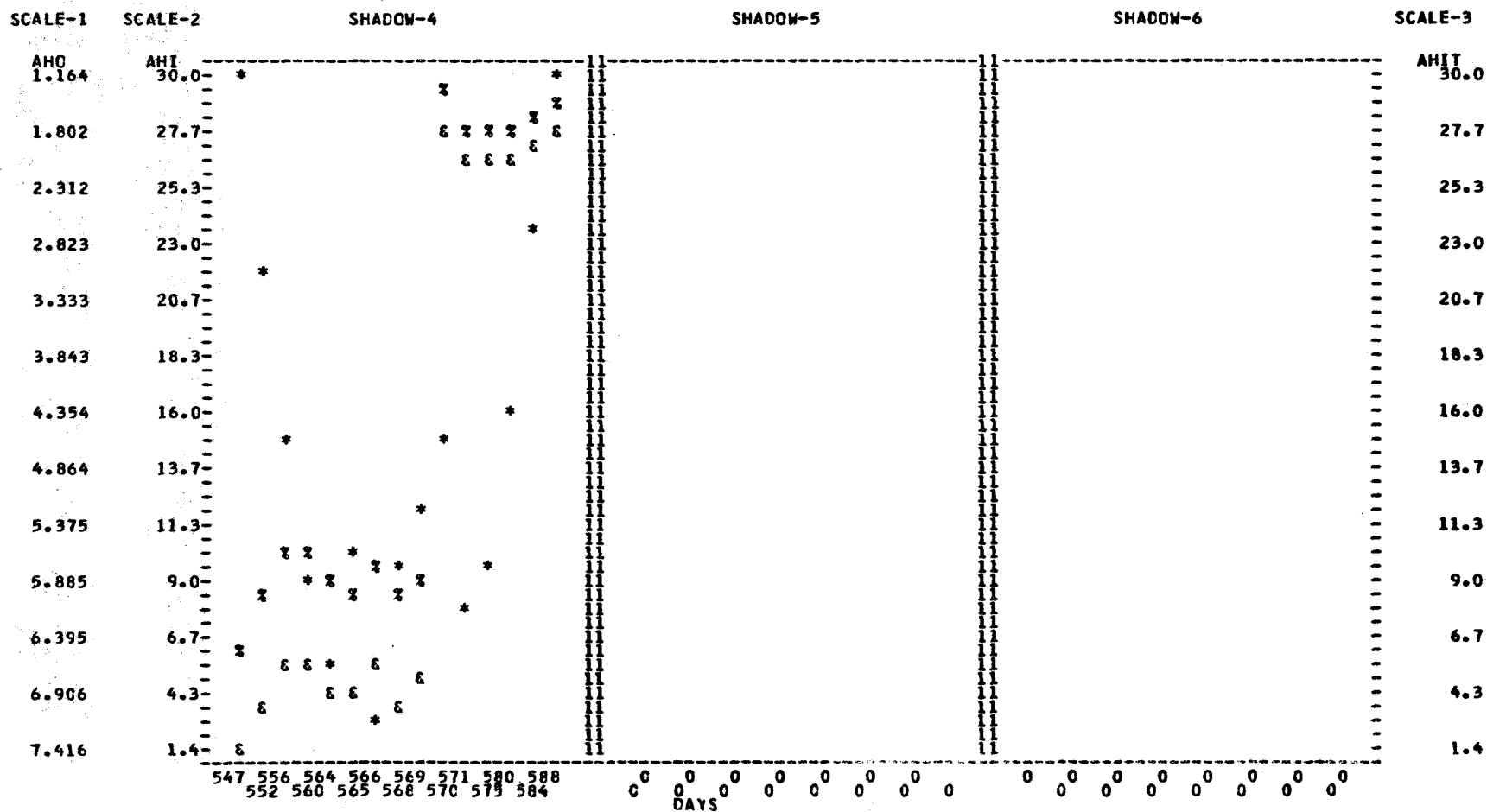


FIGURE 26 (Contd)

EVALUATION OF AUX ELECTRODE CHARGE CONTROL
IN SYNCHRONUS TYPE ORBIT
GENERAL ELECTRIC CELLS
PROJECT ATS F+G
SERIAL NO ARE 10-4,10-7,9-9,9-1



FIGURE 28

FIGURE 30

6. Sync 12 (Eclipse Seasons):

a. Average End of Discharge Voltage (***): Figure 31 indicates an erratic end of discharge voltage for eclipse 1. This is due to the low operating temperature (-20°C) which necessitated a large number of parameter changes during this eclipse (see Table I). With the exception of eclipse 1, the capacity check has caused a slight voltage increase in succeeding end of discharge voltages immediately following the capacity check; this is in accordance with similar observations of the previous Sync packs. The end of discharge voltages for eclipse 2 and 3 are more stable as shown by their respective profiles in Figure 31. However for eclipse 4, the end of discharge voltages are erratic and at a lower level overall. In general, the voltages for successive eclipses and corresponding days have dropped rapidly with time--particularly during the maximum discharge period on either side of the capacity check. The tabulation below summarizes the endpoint end of discharge voltages as shown for previous Sync packs.

	First Day	Day Prior to Capacity Check	Day After Capacity Check	Last Day of Eclipse
ECL 1	1.260	0.878	0.722	1.228
ECL 2	1.152	1.112	1.126	1.220
ECL 3	1.158	1.072	1.113	1.211
ECL 4	1.155	1.007	1.018	1.197

b. Average Cell Voltage at Trip (%%): The average voltage at trip has ranged from 1.53 to 1.54 volts during the first three eclipse seasons. Then the average drops to 1.43 volts during the fourth eclipse. The voltage plotted is an open circuit voltage. Open circuiting the cells following trip has been necessary intermittently since the fourth day of eclipse 1 due to pressure problems at this temperature (-20°C).

c. Average End of Charge Voltage (&&): The end of charge voltage is really an open circuit voltage after eclipse 1. This is due to high pressure problems encountered when a trickle charge follows the regular charge, after the trip, for the remainder of the 24-hour cycle.

d. Average Auxiliary Electrode Voltage at End of Discharge (+++): The auxiliary electrode profile of Figure 31 shows no general trends thus far. In an effort to control the high pressure

and cell voltage problems, the charge rates, trickle charge rates and auxiliary electrode trip levels, have required frequent changes. Therefore, if trends exist, they are not obvious. The following four observations may be noted from Figure 31: (1) The auxiliary electrode voltage at end of discharge follows the profile of the cell voltage during discharge for the first half of eclipse 1, but not the second half. (2) Eclipse 3 produces an auxiliary electrode voltage that is nearly constant at 15 millivolts. (3) During eclipse 3, the auxiliary electrode voltage increases as the end of discharge cell voltage decreases. (4) Figure 31, eclipse 4, shows the auxiliary electrode voltage to follow a pattern similar to that found in eclipse 3, except the voltage runs higher and peaks at 75 millivolts.

e. Pressure at End of Discharge (XXX) and at Trip (YYY): Both pressures follow the cell voltage profile, at end of discharge, during eclipse 1. The pressure at trip exceeded 100 psia both at the beginning and at the end of eclipse 1. The pressures were stable at 17 psia most of eclipse 2. This was due to removal of the trickle charge. However the pressure started a rapid increase toward the end of eclipse 2. During eclipse 3 both pressures plateaued at approximately 75 psia but rose sharply toward the end of the eclipse--peaking near 150 psia. Figure 31 shows the pressure profile of eclipse 4 to steadily increase--peaking near 190 psia for the end of discharge pressure and 170 psia for the trip pressure. The tendency for the pressure to increase near the end of successive eclipse seasons is felt due to the auxiliary electrode losing "sensitivity" over a period of time. Thus more charge is returned to the cells during the latter portions of each eclipse before the auxiliary electrode trips due to this lack of sensitivity for oxygen produced during charge. This evidence is further substantiated in Figure 32 which graphs the ampere-hours returned for Sync 12.

f. Sync 12 (Ampere-Hours During Successive Eclipse Seasons):

(1) Ampere-Hours Out (AHO, ***): Figure 32 shows that the ampere-hours removed on discharge was irregular during the first part of eclipse 1, but stabilized after numerous parameter adjustments listed in Table I. The ampere-hours removed continues to be stable for each eclipse and equal to 9.60 ampere-hours at the periods of maximum discharge.

(2) Ampere-Hours In to Trip (AHI, &&&): In general the ampere-hours returned to trip (ampere-hours, total and ampere-hours to trip are equal after eclipse 1 because of trickle charge removal) increases during the last half of a given eclipse over that of the first half. This is felt due to the auxiliary electrode losing

sensitivity to oxygen produced during charge, and returning more ampere-hours to the cell than should be, before the auxiliary electrode reaches its trip level.

(3) Ampere-Hours In, Total (AHI-Total, %%%): Except for eclipse 1, the ampere-hours in to trip and the ampere-hours in, total, are equal because the pack was put on open circuit.

g. Sync 12 (Capacity Checks): Figures 33 to 36 show the capacity checks at the middle of the successive eclipse seasons.

(1) Eclipse 1 shows an abnormal voltage profile for the auxiliary electrode near end of discharge. It increases sharply at the start of charge, tapers downward within 1 hour and plateaus at a higher level than that of the end of discharge voltage. The rest of the auxiliary electrode and the pressure profile are typical (see paragraph IV.B.2.g.) except the auxiliary electrode voltage level is much lower than for previous Syncs. Eclipse 2, figure 34, shows typical profiles except after end of discharge. Within 1 hour of the start of charge, the pressure shows an increase instead of the usual plateau. The auxiliary electrode shows no increase until the very end of charge. The increase is usually gradual over long periods of time for Syncs at other temperatures. Eclipse 3, figure 35, shows no initial downward taper for the discharge voltage of the auxiliary electrode. A small increase of auxiliary electrode voltage is noted after end of discharge similar to eclipse 1. The voltage again shows a sharp increase at the very end of charge. Eclipse 4, Figure 36, shows the increase of auxiliary electrode voltage at end of discharge as observed in eclipses 1 and 3. The corresponding pressure increase follows 30 minutes later on charge. The pressure is extremely high throughout the capacity check cycle--ranging from 126 to 142 psia.

h. Sync 12 (Summary of Parameters During Sunlight):

(1) Cell Voltage (Sunlight): It was found early in the first sunlight period (first 2 days) that the cells must remain on open circuit or they would develop excessively high voltages--1.66 to 1.70 volts. From this time on, the cells have remained on open circuit during each sunlight period following the last charge of the preceding eclipse season. Thus the open circuit voltage tapers downward from the beginning to the end of the sunlight period--ranging from 1.40 to 1.29 volts. Voltage balance presents no problem under these conditions.

(2) Auxiliary Electrode Voltage (Sunlight): The auxiliary electrode voltage remains at, or near, 0.0 millivolt

under the conditions specified in the previous paragraph. Thus the problem of the auxiliary electrode becoming "desensitized", as noted for sunlight periods of previous Sync packs, is not observable under these conditions. However this problem is considered in paragraphs IV.B.6.e. and IV.B.6.f.

(3) Pressure (Sunlight): The only pressure problems during sunlight periods occur at the beginning of the period as a result of residual pressures developed during the preceding eclipse.

KEY
 * AVE END DISCHARGE VOLTAGE
 % AVE CELL VOLTAGE AT TRIP
 & AVE CELL VOLTAGE AT EOC
 + AVE AUX-ELECT. VOLT. AT EOD
 . AVE AUX-ELECT. VOLT. AT TRIP
 X PRESSURE TRANS. AT EOD
 Y PRESSURE TRANS. AT TRIP

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 12

DEPTH DISCHARGE 80.0
 TEMPERATURE -20.0C
 AMPERE RATE 12.0
 CATALOG 428012AB
 SERIAL 9-3, 10-15, 9-16, 9-18, 9-20
 GENERAL ELECTRIC CELLS
 PROJECT ATS F&G

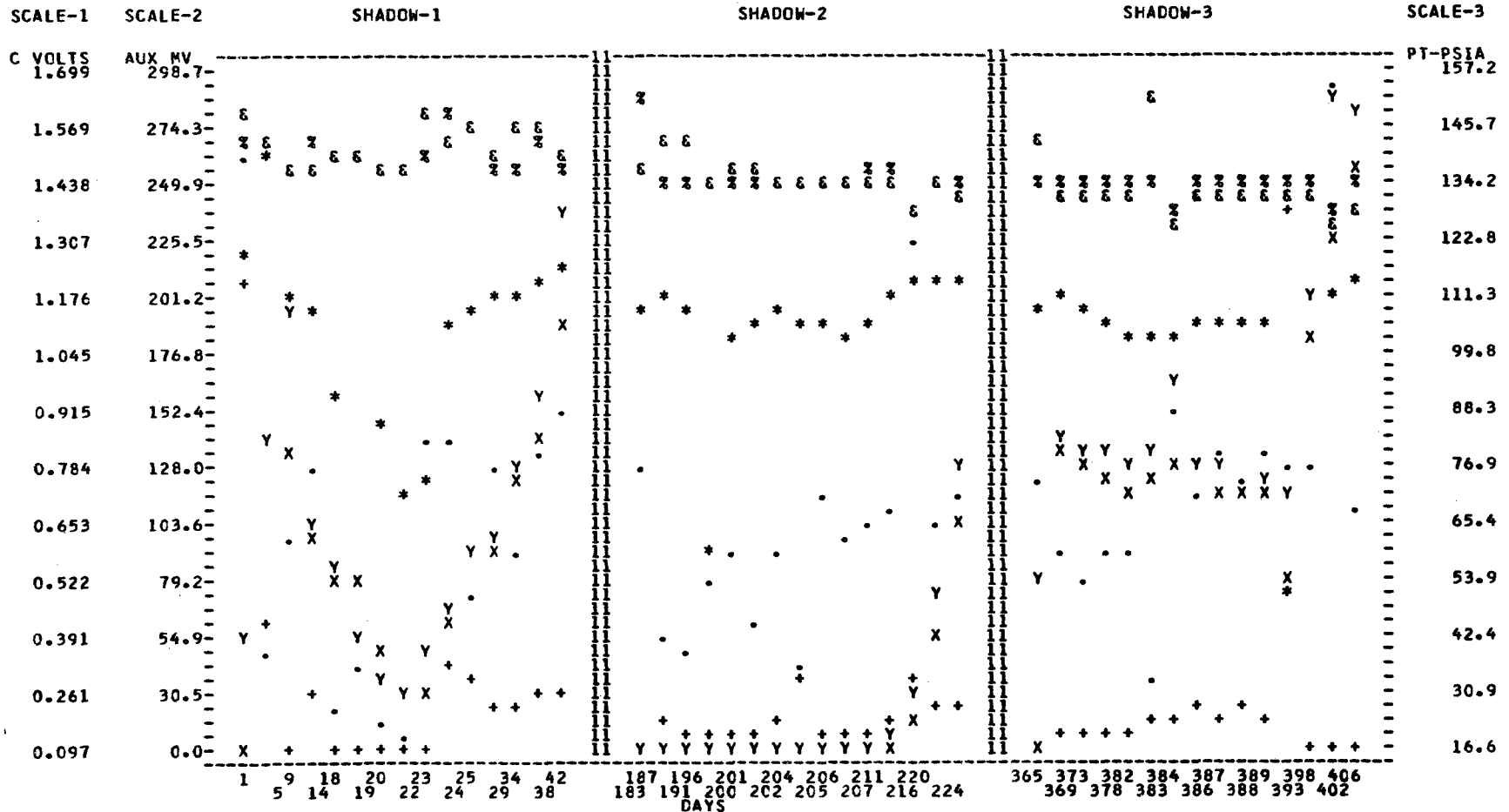


FIGURE 31

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 12

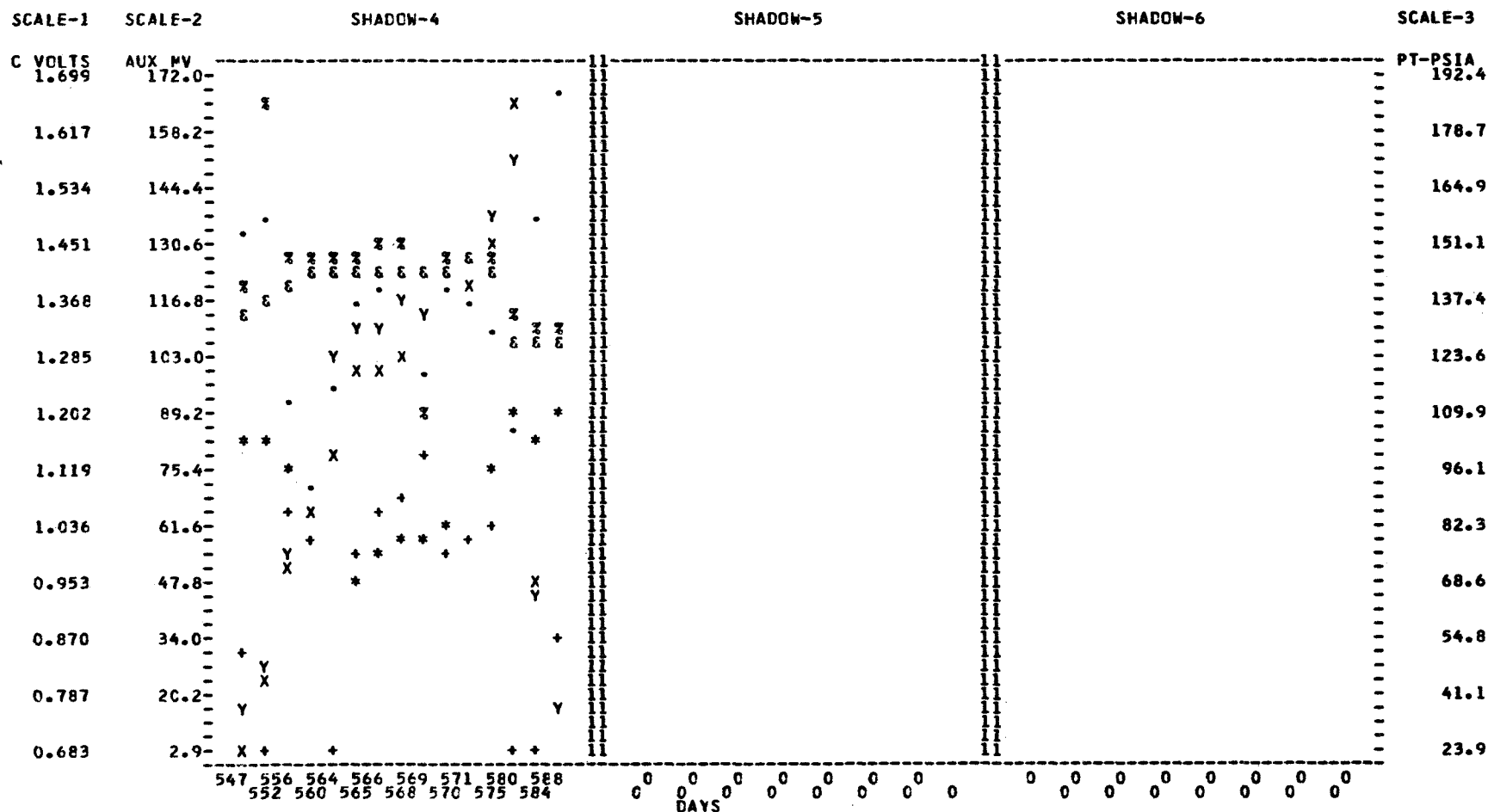


FIGURE 31 (Contd)

KEY
 * AHO
 % AHI-TOTAL
 & AHI AT TRIP

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 12

DEPTH DISCHARGE 80.0
 TEMPERATURE -20.0C
 AMPERE RATE 12.0
 CATALOG 428012AB
 SERIAL 9-3, 10-15, 9-16, 9-18, 9-20
 GENERAL ELECTRIC CELLS
 PROJECT ATS F&G

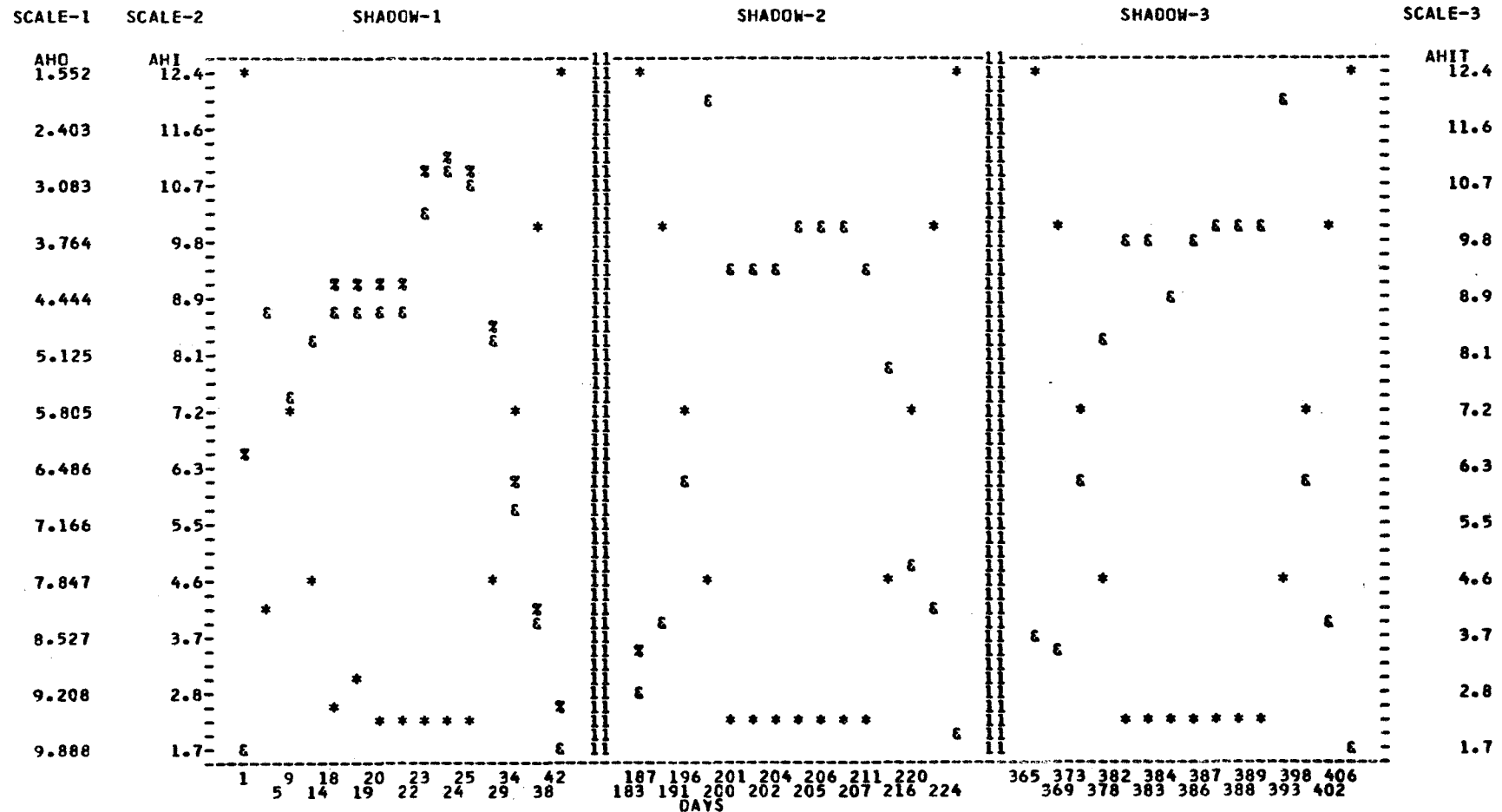


FIGURE 32

QE/C 71-183

KEY
* AHO
% AHI-TOTAL
& AHI AT TRIP

SYNCHRONOUS ORBIT SHADOW PLOT

PACK = 12

DEPTH DISCHARGE 80.0
TEMPERATURE -20.0C
AMPERE RATE 12.0
CATOLOG 428012AB
SERIAL 9-3, 10-15, 9-16, 9-18, 9-20
GENERAL ELECTRIC CELLS
PROJECT ATS F&G

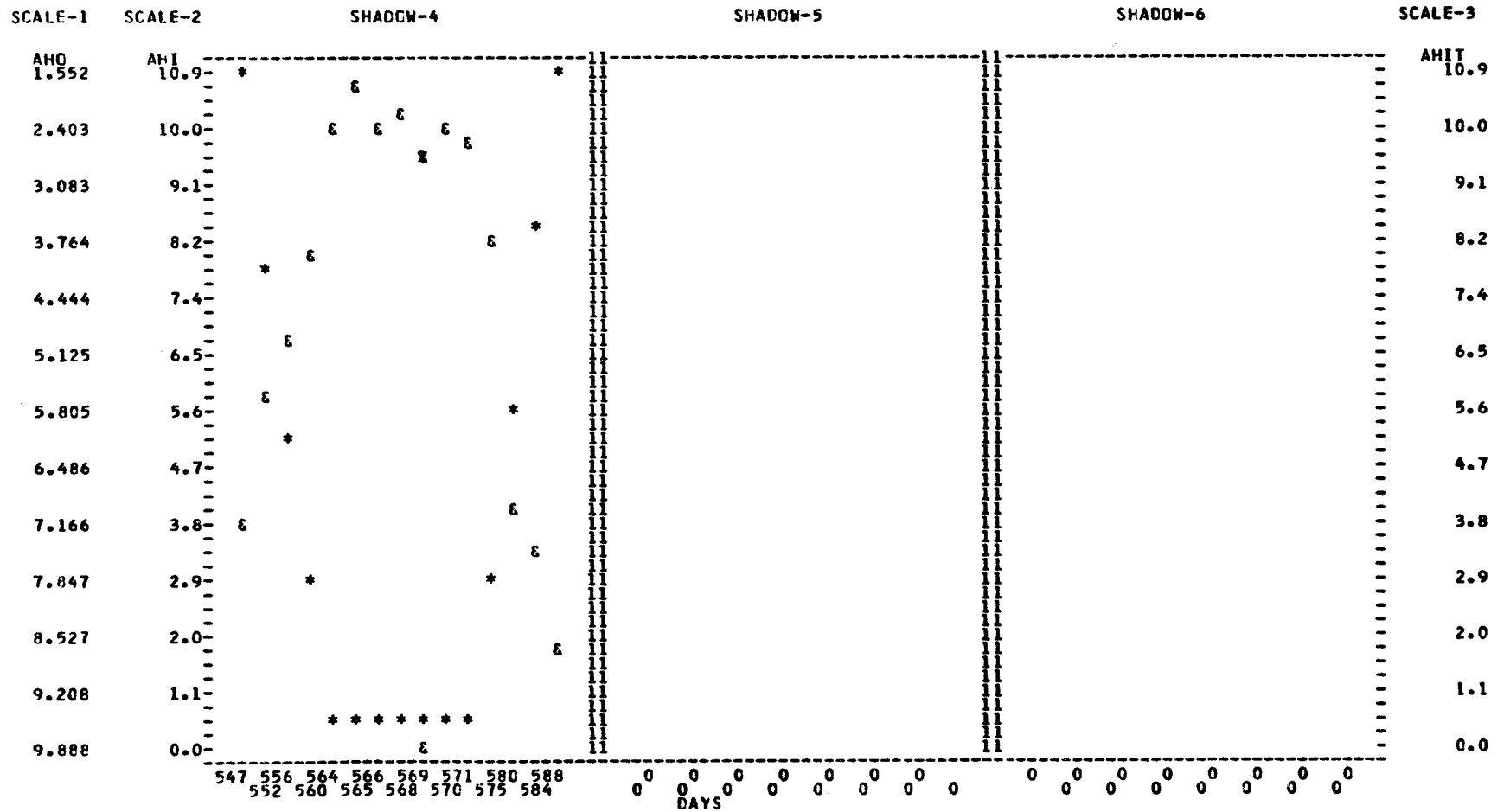


FIGURE 32 (Contd)

70

EVALUATION OF AUX ELECTRODE CHARGE CONTROL
IN SYNCHRONOUS TYPE ORBIT
GENERAL ELECTRIC CELLS
PROJECT ATTS F+G
SERIAL NO ARE 9-3,10-15,9-16,9-
5 5 5 5 5 5 5 5 5 5 5 5 5



FIGURE 35

4.
S 12 80
-20
428012AB
0 C 0 0 0

CODE
+ = AVERAGE CELL VOLT
• = HIGH CELL VOLT
* = LOW CELL VOLT

EVALUATION OF AUX ELECTRODE CHARGE CONTROL
IN SYNCHRONOUS TYPE ORBIT
GENERAL ELECTRIC CELLS
PROJECT ATS F+G
SERIAL NO ARE 9-3,10-15,9-16,9-

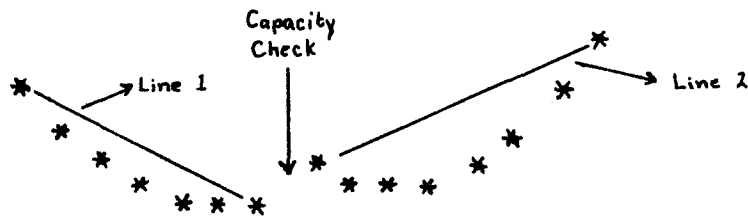
ECLIPSE SEASON 4.
AMPERE HOUR RATE IS 12
DEPTH OF DISCHARGE IS 80
TEMPERATURE IS -20
CELL NO CATALOG IS 42B012AB
E E E 0 0 0 0 0 0 0 0 0 0

[illegible]

FIGURE 36

C. Effect of the Capacity Check on Cell Voltage:

1. Shown below is a sketch typifying the end of discharge voltage as it varies from day to day during a given eclipse season. In most instances, as shown, the voltage will show an increase following the capacity check and will often show a higher voltage on the last day of the eclipse than on the first day. While there appears to be an immediate rejuvenation in cell voltage, the average, daily increase in end of discharge voltage (line 2) does not equal that of the daily decrease (line 1). Thus the net effect of the capacity tends to be slightly injurious to the cells' capability to deliver power during the last half of each eclipse season. This observation is contrary to similar observations made for 6 ampere-hour cells without auxiliary electrodes as outlined in reference (c).



2. Table II lends itself to the following type of calculation.

Example: Sync 7, Eclipse 1

$$a. \frac{1.218 - 1.298 \text{ (Volts)}}{20 - 1 \text{ (Day)}} = -4.21 \times 10^{-3} \frac{\text{Volts}}{\text{Day}}$$

(Negative Slope of Line 1)

$$b. \frac{1.288 - 1.234 \text{ (Volts)}}{42 - 22 \text{ (Day)}} = +2.70 \times 10^{-3} \frac{\text{Volts}}{\text{Day}}$$

(Positive Slope of Line 2)

c. Difference of Absolute Slope Values:

$$\text{Line 1} - \text{Line 2} = [(-4.21) - (-2.70)] \times 10^{-3} = 1.51 \times 10^{-3} \frac{\text{Volts}}{\text{Day}}$$

d. Percent Difference:

$$\frac{\text{Line 1} - \text{Line 2}}{\text{Line 2}} \times 100 = \frac{1.51 \times 10^{-3}}{2.70 \times 10^{-3}} \times 100 = 55.9\%$$

e. These calculations are summarized in Table III. The significant point illustrated by this table is that the majority of the values calculated for the percent difference are positive. As defined by the calculations, this means that the daily end of discharge voltage of each eclipse tends to descend more rapidly prior to the capacity check than it ascends afterward. A negative value for percent difference means simply the reverse. The most notable exception to the trend is found for Sync 12. This Sync has all negative, percent differences. The implication is that the capacity check gives more overall rejuvenation to Sync 12 than to the other packs, because the negative values show the ascent of end of discharge voltage following the capacity check is more rapid than the descent preceding the check.

TABLE II

ENDPOINT VOLTAGES AT THE END OF DISCHARGE DURING ECLIPSE SEASONS

Sync Pack	Eclipse Number	Day 1 (Volts)	Day Preceding Capacity Check (Volts)	Day Following Capacity Check (Volts)	Last Day of Eclipse (Volts)
7	1	1.298	1.218	1.234	1.288
	2	1.280	1.200	1.224	1.290
	3	1.268	1.197	1.218	1.284
	4	1.275	1.198	1.216	1.284
8	1	1.270	1.204	1.212	1.260
	2	1.250	1.176	1.192	1.268
	3	1.238	1.169	1.189	1.213
	4	1.245	1.173	1.186	1.263
9	1	1.294	1.220	1.240	1.286
	2	1.280	1.190	1.230	1.276
	3	1.279	1.188	1.222	1.287
	4	1.282	1.184	1.221	1.288
10	1	1.276	1.196	1.222	1.272
	2	1.262	1.164	1.200	1.260
	3	1.258	1.153	1.189	1.269
	4	1.260	1.127	1.183	1.271
11	1	1.260	0.802	1.132	1.258
	2	1.240	1.164	1.164	1.260
	3	1.216	0.396	0.635	1.237
	4	1.202	0.452	0.767	1.248
12	1	1.260	0.878	0.722	1.228
	2	1.152	1.112	1.126	1.220
	3	1.158	1.072	1.113	1.211
	4	1.155	1.007	1.018	1.197

TABLE III

COMPARISON OF DAILY DISCHARGE VOLTAGE PRIOR TO CAPACITY CHECK (LINE 1) COMPARED TO THAT FOLLOWING CAPACITY CHECK (LINE 2)--(SEE SKETCH OF PARAGRAPH IV.C.1.)

Sync Pack	Eclipse Number	Avg Neg Slope Line 1 (mv/day)	Avg Pos Slope Line 2	Difference of Slopes [Line 1] - [Line 2] (mv/day)	Percent Difference <u>[Line 1] - [Line 2]</u> Line 2
7	1	-4.21	+ 2.70	1.51	55.9
	2	-4.21	3.30	0.90	27.3
	3	-3.74	3.30	0.44	13.3
	4	-4.05	3.40	0.65	19.1
8	1	-3.47	2.40	1.07	44.6
	2	-3.89	3.80	0.90	23.7
	3	-3.63	1.20	2.43	202.5
	4	-3.79	3.85	-0.60	-26.0
9	1	-3.89	2.30	1.59	69.1
	2	-4.74	2.30	2.44	106.0
	3	-4.79	3.25	1.54	30.8
	4	-5.16	3.53	1.63	46.2
10	1	-4.21	2.63	1.58	60.1
	2	-4.89	3.00	1.89	63.0
	3	-5.53	4.00	1.53	38.3
	4	-7.00	4.40	2.60	59.1
11	1	-24.1	6.30	17.8	282.5
	2	-4.00	4.80	-0.80	-16.7
	3	-43.2	30.1	13.1	43.5
	4	-39.5	24.1	15.4	63.9
12	1	-20.1	25.3	-5.20	-20.6
	2	-2.11	4.70	-2.59	-55.1
	3	-4.53	4.90	-0.37	-7.6
	4	-7.79	8.95	-1.16	-13.0

D. Capacity versus Time on Test: (See Figure 37)

1. Effect of Temperature: Figure 37 shows 0° C to provide the best ambient temperature for maintaining the highest capacity (ranging from 15.2 to 17.3 ampere-hours for Syncs 7 and 8) during the time on test thus far. The capacity actually shows a slight increase with time at this temperature. At 20° C, the capacity averages a little over 1 ampere-hour less than the packs operating at 0° C. The range is 13.3 to 16.0 ampere-hours for Syncs 9 and 10. Further the tendency is to maintain capacity or slightly decline in capacity (at 80 percent depth of discharge) during the time on test. The poorest capacity is delivered by Sync 11 operating at 40° C. This pack has delivered the manufacturer's rated capacity of 12.0 ampere-hours only once. The capacities have ranged from 6.0 to 12.0 ampere-hours. Sync 12, at -20° C, has shown the measured capacity to be almost as low as Sync 11--ranging from 9.3 to 13.3. Only once has the measured capacity equalled or exceeded the manufacturer's rated capacity.

2. Effect of Depth of Discharge: Figure 37 shows no net effect of depth of discharge for Syncs 7 and 8 at 0° C. The capacities have averaged nearly equal values regardless of the depth of discharge. At 20° C, the pack operating at the highest depth of discharge (Sync 10, 80 percent) shows a decline in capacity with time on test. Only one pack operated at each of the temperatures, 40° C and -20° C. Thus little can be determined for the effects of depth of discharge at these temperatures.

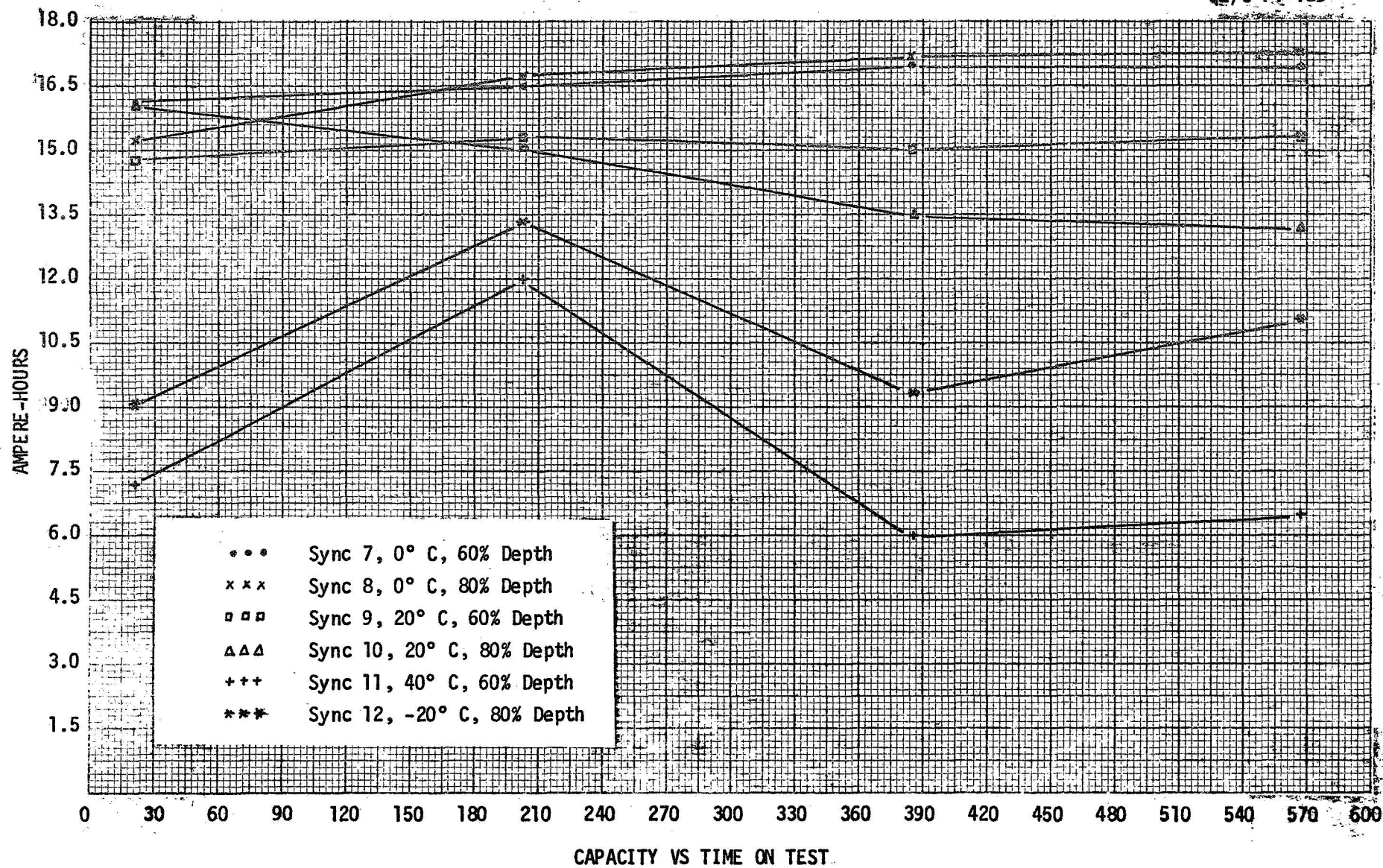


FIGURE 37

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