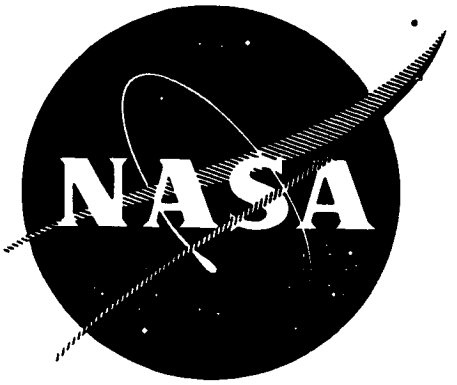
GPO PRICE $
OTS PRICE(S) $
Hard copy (HC) 6.00
Microfiche (MF) 1.25



EVALUATION PROGRAM
for
SECONDARY SPACECRAFT CELLS

FIRST ANNUAL REPORT

OF

CYCLE LIFE TEST

prepared for
GODDARD SPACE FLIGHT CENTER

CONTRACT W11,252B

N65-26408 (ACCESSION NUMBER)
205 (PAGES)
Cr 63424 (NASA CR OR TMX OR AD NUMBER)
1 (THRU)
(CODE)
03 (CATEGORY)
FACILITY FORM 602



QUALITY EVALUATION LABORATORY

NAD CRANE, INDIANA

QUALITY EVALUATION LABORATORY
UNITED STATES NAVAL AMMUNITION DEPOT
CRANE, INDIANA

EVALUATION PROGRAM FOR SECONDARY SPACECRAFT CELLS

FIRST ANNUAL REPORT OF CYCLE LIFE TEST

QE/C 65-356

14 MAY 1965

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QE/C 65-356

REPORT BRIEF

CYCLE LIFE TEST

OF

SECONDARY SPACECRAFT CELLS

Ref: (a) National Aeronautics and Space Administration Purchase Order Number W11,252B
(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) Preliminary Work Statement for Battery Evaluation Program of 25 August 1961

I. TEST ASSIGNMENT BRIEF.

A. In compliance with references (a) and (b), evaluation of secondary spacecraft cells was begun according to the program outline of reference (c). This first annual report covers all of the cycle life test, the third phase of the evaluation program of secondary spacecraft cells, through 31 December 1964. The acceptance tests and general performance tests, the first and second phases of the evaluation program were reported earlier.

B. The object of this evaluation program is to gather specific information concerning secondary spacecraft cells. Information concerning the performance characteristics and limitations, including cycle life under various electrical and environmental conditions, will be of interest to power systems designers and users. Cell weaknesses, including causes of failure of present designs, will be of interest to suppliers as a guide to product improvement.

C. The life cycling test was begun in December 1963.

II. CELLS INCLUDED IN TEST.

A. Only cells which had passed the acceptance tests were used in the evaluation program.

B. The cycle life test program began with sealed, nickel-cadmium cells of the types listed below:

Manufacturer	Rated Capacity	Number of Cells
General Electric Company	3.0 a.h.	120
	12 a.h.	60
Gould-National Batteries, Inc.	3.5 a.h.	120
	20 a.h.	60
Gulton Industries, Inc.	6.0 a.h.	120
	20 a.h.	60
Sonotone Corporation	5.0 a.h.	120

III. DESCRIPTION OF CYCLE TEST.

A. Cells were arranged into packs of 5 or 10 cells. Each pack cycled with a given set of test parameters until more than half of the cells had failed, at which time the pack was considered to have failed.

B. Cycling test parameters included ambient temperature, charge voltage limit, percent depth of discharge, percent of recharge, and orbit period, as follows:

1. 50° C, 1.41 volts per cell limit, 15 or 25 percent depth of discharge, 160 percent recharge, and 1.5 or 3-hour orbit.

a. All packs begun at 50° C were subsequently changed to 40° C, 1.45 volts per cell limit, with the remaining parameters unchanged.

2. 25° C, 1.49 volts per cell limit, 25 or 40 percent depth of discharge, 125 percent recharge, and 1.5 or 3-hour orbit.

3. 0° C, 1.55 volts per cell limit, 15 or 25 percent depth of discharge, 115 percent recharge, and 1.5 or 3-hour orbit.

C. The ampere-hour capacity of each pack was measured at approximately 88-day intervals.

D. Failed cells were removed from the pack at the time of failure and subjected to failure analysis.

IV. TEST RESULTS.

A. A total of 29 of the original 84 packs have failed. The remaining 55 packs have completed from 291.1 to 375 days (a maximum of 6000

1.5-hour cycles) of continuous cycling as of 31 December 1964. The status of each pack is given in Table III and Figures 3(a) through 3(g).

B. It was found that 50° C was in general, an unsatisfactory ambient temperature, for the specified currents and orbit periods, due to inefficient charge acceptance and accelerated separator deterioration.

C. There have been 191 cell failures as of 31 December 1964. The table below shows the distribution according to test parameters and cell type.

Temperature, °C	Depth of Discharge	Orbit Period (Hours)	G.E. 3.0 a.h.	G.E. 12 a.h.	Gould 3.5 a.h.	Gould 20 a.h.	Gulton 6.0 a.h.	Gulton 20 a.h.	Sonotone 5.0 a.h.	Total Failures	Total Original Cells
0°	15%	1.5	0	0	0	0	4	3	1	8	55
		3	0	0	0	0	0	1	0	1	55
	25%	1.5	0	0	0	1	3	3	0	7	55
		3	0	0	0	0	5	0	0	5	55
25°	25%	1.5	0	0	7	3	6	1	2	19	55
		3	0	0	0	0	5	3	0	8	55
	40%	1.5	6	3	6	3	6	5	3	32	55
		3	0	0	7	3	6	4	3	23	55
50°/40°	15%	1.5	1/2	0/0	0/6	0/2	1/3	0/0	0/0	15	55
		3	0/6	0/0	0/7	0/0	0/6	0/0	0/1	20	55
	25%	1.5	0/7	0/3	0/10	1/2	2/4	0/3	0/6	38	55
		3	0/1	0/0	0/6	0/3	1/3	0/0	0/1	15	55
Total Failures			23	6	49	18	55	23	17	191	
Total Original Cells			120	60	120	60	120	60	120		660

1. A high percentage of cell failures were premature, due to defects in manufacture or design.

2. Cell failures in each pack are illustrated in Figures 3(a) through 3(g). Results of failure analysis are given in Tables Va through Vg.

D. Ampere-hour capacities changed with time in a manner which was strongly dependent on test parameters and cell type.

1. For those packs which had completed 264 or more days of cycling, average initial capacities and average capacities after 264 days of cycling are listed below in terms of percent of rated capacity.

	0° C	25° C	40° C*
Average Initial Capacity (Percent of Rated Capacity)	104.0	117.9	63.8
Average Capacity After 264 Days (Percent of Rated Capacity)	96.2	65.5	46.7
(Percent of Initial Capacity)	92.6	55.4	79.9

*The measurement of initial capacity at 40° C was made after the cells had been cycled at 50° C.

2. Certain packs appear to have exhibited the "memory effect".

3. Results of ampere-hour capacity measurements are shown in Table VI (page 56), Table VII (page 59), Tables VIIIa through VIIIg (pages 60 through 66), and Figures 5(a) through 5(g) (pages 67 through 73).

V. TESTS ADDED TO CYCLE LIFE TEST PROGRAM.

A. Several types of cells have been added or are to be added to the original test program. These include cells cycling with a 24-hour orbit, cell types other than those in the original program, cells of more recent manufacture, and cells using different methods of charge control.

B. All added tests are covered in the appendix, page 174, and will continue to be covered in this series of annual reports.

CYCLE LIFE TEST

OF

SECONDARY SPACECRAFT CELLS

I. INTRODUCTION.

A. Considerable research is being done to find more efficient and reliable means of storing electrical energy for orbiting satellites and similar applications. Rechargeable cells offer one such means. The test program at NAD Crane has been established in order to further the evaluation of certain types of cells and to obtain performance and failure data as an aid to their continued improvement.

B. This first annual report summarized the cycle life test work through 31 December 1964, including that contained in NAD Crane report QE/C 64-274 of 15 June 1964. The cycle life test is the third phase of the evaluation program of secondary spacecraft cells. The acceptance tests and the general performance tests, the first two phases of this program, were reported earlier.

C. On 5 December 1963 this activity began the cycle life test on 660 of the 1100 sealed, nickel-cadmium cells purchased by National Aeronautics and Space Administration (NASA). The cells were from four manufacturers, and consist of seven sample classifications ranging from 3 to 20 ampere-hours.

D. The purpose of the cycle life program was to determine the cycling performance capabilities of packs of the cells under different load and temperature conditions. The load conditions include cycle lengths (orbit periods) of 1.5 hours and 3 hours and depths of discharge ranging from 15 to 40 percent. Environmental conditions include ambient temperatures of 0° C, 25° C, 40° C and 50° C, with normal atmospheric conditions. The packs are cycled until more than half of the cells of each pack have failed.

E. Paragraphs I through IV of this report refer only to the original 660 nickel-cadmium cells. Cell packs and tests added to the original program are covered in the appendix (paragraph VI) of this report.

II. CELL DESCRIPTION.

A. General: Photograph 1 is a group picture of the seven cell types.

1. General Electric Company (G.E.):

a. 3.0 Ampere-hour: The cell container and the cell cover are made of stainless steel. The positive terminal is insulated from the cell cover by a ceramic (titanium hydride) bushing and protrudes through the bushing with a solder tab welded to the terminal. The negative terminal is a solder tab welded to the cover.

b. 12.0 Ampere-hour: The cell container and the cell cover are made of stainless steel. Both terminals are insulated from the cell cover by ceramic seals and protrude as 1/4-20 threaded posts.

2. Gould-National Batteries, Inc. (Gould):

a. 3.5 Ampere-hour: The cell container and the cell cover are made of stainless steel and serve as the positive terminal. The negative terminal is a pigtail type extension of the negative plate tab through the center of the cover. The negative terminal is insulated from the "positive" cover by a glass to metal seal.

b. 20.0 Ampere-hour: The cell container and the cell cover are made of stainless steel. Each of the terminals is insulated from the can by a nylon seal and protrudes as a 1/4-28 threaded post. The cells, equipped with pressure relief valves instead of being sealed as specified, were returned to the manufacturer to be sealed after completion of the acceptance tests. The manufacturer sealed the cells by encasing each individual cell in a mold of epoxy resin.

3. Gulton Industries, Inc. (Gulton):

a. 6.0 Ampere-hour: The cell container and the cell cover are made of stainless steel. The positive terminal is insulated from the cell cover by a ceramic seal, while the negative terminal is welded to the cover. Both are solder type terminals.

b. 20.0 Ampere-hour: The cell container and the cell cover are made of stainless steel. Both terminals are insulated from the cell cover by a ceramic seal and protrude through the cover as solder type terminals.

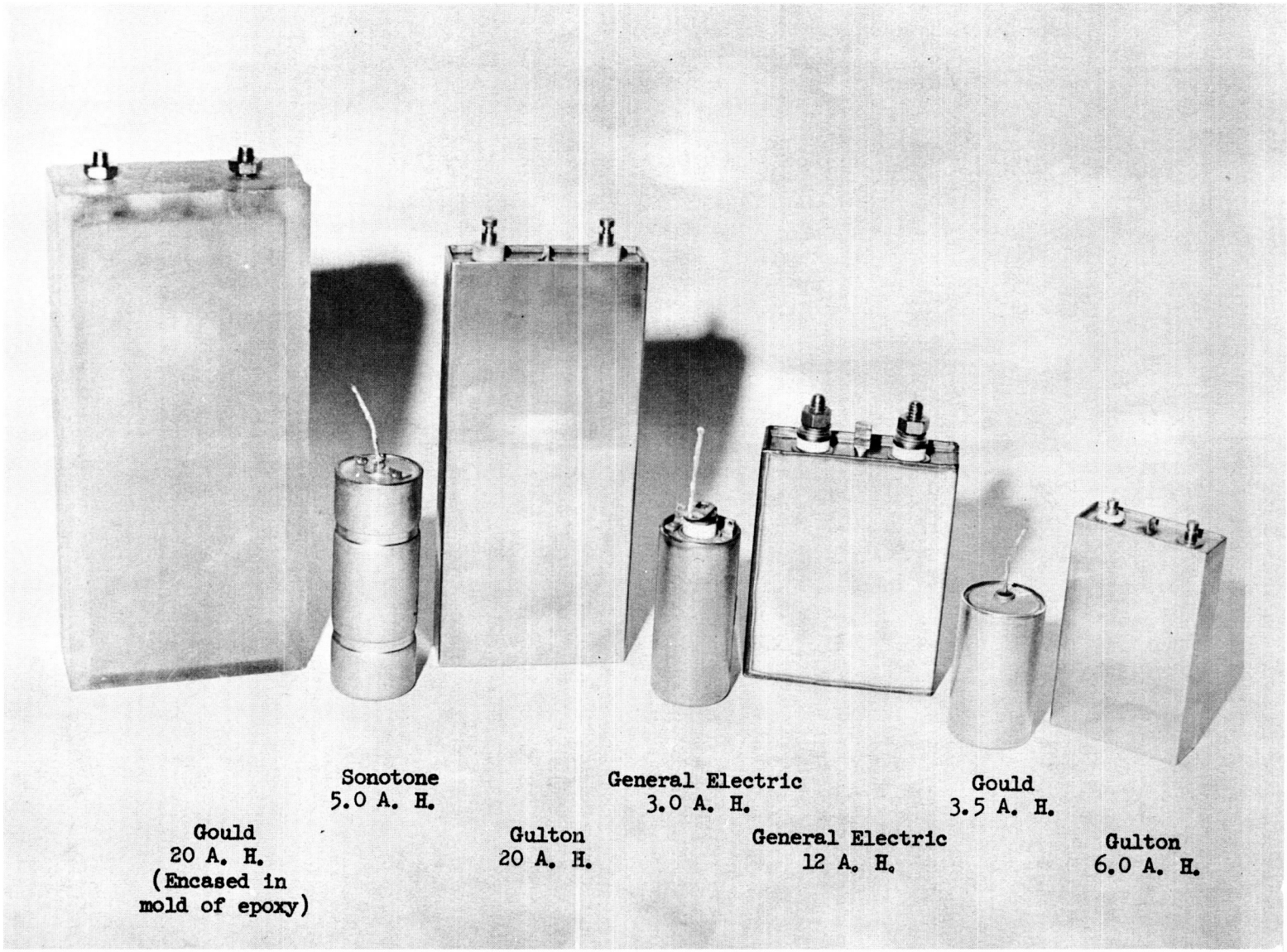
4. Sonotone Corporation (Sonotone):

a. 5.0 Ampere-hour: The cell container and the cell cover are made of stainless steel. Two stainless steel tabs, welded to the cover, serve as contacts for the negative terminal. The positive terminal is a solder type extension of the positive plate tab through the center of the cover. The positive terminal is

insulated from the "negative" cover by a glass to metal seal. Two ring indentations, about 1/32 inch deep, located approximately 7/8 inch from either end of the cell can, were crimped after cell assembly to hold the element snugly in the cylindrical can.

B. Dimensions and Weight:

1. The dimensions, weight and case polarity for each of the seven types of cells are tabulated in Table I.



Group Picture of Cell Types

PHOTOGRAPH 1

TABLE I

PHYSICAL CHARACTERISTICS OF CELLS

Manufacturer and Manufacturer's Rated Capacity	Shape	Average Dimensions (Inches) Height Base to Top of Terminal	Width or Diameter	Length or Depth	Average Weight (Grams)	Case Polarity
G.E. 3.0 a.h.	Cylindrical	3.10	1.25 D	--	155.0	Negative
Gould 3.5 a.h.	Cylindrical	2.22	1.28 D	--	135.2	Positive
Sonotone 5.0 a.h.	Cylindrical	3.67	1.31 D	--	237.4	Negative
Gulton 6.0 a.h.	Rectangular	3.68	2.09 W	0.81	267.0	Negative
G.E. 12.0 a.h.	Rectangular	4.59	3.02 W	1.11	562.0	--
Gould 20.0 a.h.	Rectangular	*7.95	3.05 W	0.97	1045.0	--
		**8.10	3.56 W	1.49	1423.0	--
Gulton 20.0 a.h.	Rectangular	7.10	2.98 W	0.90	871.6	--

* Before Epoxy Cover

** After Epoxy Cover

III. DESCRIPTION OF CYCLE TEST.

A. These tests are a study of the effects of the cycle period, environmental temperature, percent of recharge, and depth of discharge on the cycle life of the test samples.

B. Test Parameters:

1. The program includes a total of 12 combinations of test parameters. Cells, of comparable capacities, of each of the seven types were grouped into packs, with one pack of each type per combination of parameters. Each of the 84 packs thus obtained continues cycling at its particular combination of parameters until it has failed.

2. The 3.0 ampere-hour (a.h.), 3.5 a.h., 5.0 a.h. and 6.0 a.h. packs consist of 10 cells each. The 12 a.h. and 20 a.h. packs consist of five cells each.

3. The test parameters are as follows:

a. Three environmental temperatures, with corresponding percentages of recharge.

(1) 0 ± 2° C, with 115 percent recharge.

(2) 25 ± 2° C, with 125 percent recharge.

(3) 40 ± 2° C, with 160 percent recharge.

b. At each of the three temperatures, two depths of discharge.

(1) At 0° C, 15 and 25 percent depths of discharge.

(2) At 25° C, 25 and 40 percent depths of discharge.

(3) At 40° C, 15 and 25 percent depths of discharge.

c. Two orbit periods for all three temperatures.

(1) 1.5 hours (30 minutes of discharge, 60 minutes of charge).

(2) 3 hours (30 minutes of discharge, 150 minutes of charge).

d. Voltage limits on charge were specified according to temperature and were chosen to inhibit internal generation of

gas. These are average voltages, per cell, for the entire pack.

(1) At 0° C, 1.55 ± 0.03 volts per cell, average.

(2) At 25° C, 1.49 ± 0.03 volts per cell, average.

(3) At 40° C, 1.45 ± 0.03 volts per cell, average.

4. Cycling at 50° C.

a. Initially, the test temperatures were 0°, 25° and 50° C, with the 50° C voltage limit on charge set at 1.41 ± 0.03 volts per cell, average.

b. The 28 packs assigned to the high temperature environment began cycling at 50° C, but after a short period of cycling it became apparent that the majority of these packs would not continue to cycle satisfactorily at that temperature. For all but four of these 28 packs, the ambient temperature was therefore reduced from 50° C to 40° C, and shortly thereafter the charge voltage limit was raised from 1.41 ± 0.03 volts per cell to 1.45 ± 0.03 volts per cell.

c. The remaining four packs were left cycling at the original 50° C, in order to obtain more information about performance at that temperature, with the reservation that they be likewise changed to a 40° C ambient temperature whenever they ceased to function satisfactorily. All were cycling at 25 percent depth of discharge. All four were eventually changed to 40° C, and have since failed.

d. Considerations for cycling at 50° C and results are discussed more fully in paragraph IV.C.

5. Table II is a summary chart of all test conditions.

TABLE II

SUMMARY OF TEST PARAMETERS

For each orbit period, one pack of each of the seven cell types is cycling at each of the six temperature-depth of discharge combinations.

ORBIT PERIODS: 1.5 Hours and 3 Hours					
Discharge Time	Charge Time	Temperature °C	Percent Recharge	Percent Depth of Discharge	On-Charge Voltage Limit Ave./Active Cell
30 Minutes	60 Minutes and 2.5 Hours	(50*)	(160**)	(15) (25)	(1.41)
		40	160	15 25	1.41 (Changed to 1.45)
		25	125	25 40	1.49
		0	115	15 25	1.55

* All packs changed to 40° C ambient.

** One pack of Gulton 6.0 ah cells at 50° C was temporarily raised to 200 percent recharge, but this was not sufficient to maintain normal cycling.

C. Pack Identification: Each cell pack in the cycle life test program was assigned a pack number for convenient identification. This number is permanent and uniquely identifies the particular group of cells constituting that pack. For example, the 10 G.E. 3 a.h. cells cycling at 0° C with a 1.5-hour orbit and 15 percent depth of discharge constitute Pack 63. These numbers were assigned arbitrarily and therefore have no additional significance.

D. Discharge and Charge Currents:

1. All discharges are conducted at specified constant current rates. All charging is done at specified constant current rates until the maximum specified on-charge voltage limit for the respective temperature condition is reached, at which time charging continues at the specified maximum voltage limit with corresponding reduction of the current rate.

2. All currents were based on the manufacturer's rated ampere-hour capacity. The letter c, as used in this report, is a symbol for that current value, in amperes, which is numerically equal to this capacity. For example, in the case of a cell rated at 3.0 ampere-hours capacity, a discharge or charge current of c/10 would be 300 milliamperes.

a. The depth of discharge, which is the percent of a cell's rated capacity drawn from the cell, is expressed by the following formula: Discharge Current (Amperes) x Hours = Percent Depth of Discharge x Rated Capacity.

$$I_d \times \text{Hours} = \frac{D}{100} \times c$$

Since the discharges of the 1.5-hour and 3-hour orbit periods are one-half hour long, the discharge current for either orbit period may be found by the simplified formula:

$$I_d = 0.02\ Dc$$

where: I_d = discharge current in amperes
D = percent depth of discharge required
c = rated capacity of the cells.

For example, a pack composed of 3.0 ampere-hour cells, to be discharged to a depth of 15 percent, would require a discharge current I_d of 0.9 amperes ($I_d = 0.02 \times 15 \times 3 = 0.90$ amperes).

b. The percent of recharge is most easily defined operationally as follows: If Q_d is the number of ampere-hours to be removed from the pack on discharge and Q_c the number of ampere-hours to be

returned on charge, then $Q_c = Q_d$ x Percent of Recharge. Expressed in terms of currents, this becomes $I_c \times T_c = I_d \times T_d \times$ Percent Recharge,

where: I_c = charge current in amperes
T_c = length of charge, in hours
I_d = discharge current in amperes
T_d = length of discharge, in hours.

For example: In the case of a 3.0 ampere-hour pack, 1.5-hour orbit (30 minutes discharge, 60 minutes charge) 15 percent depth of discharge and 115 percent recharge, the charging current would be:

$$I_c = \frac{I_d \times T_d \times \text{Percent Recharge}}{T_c}$$

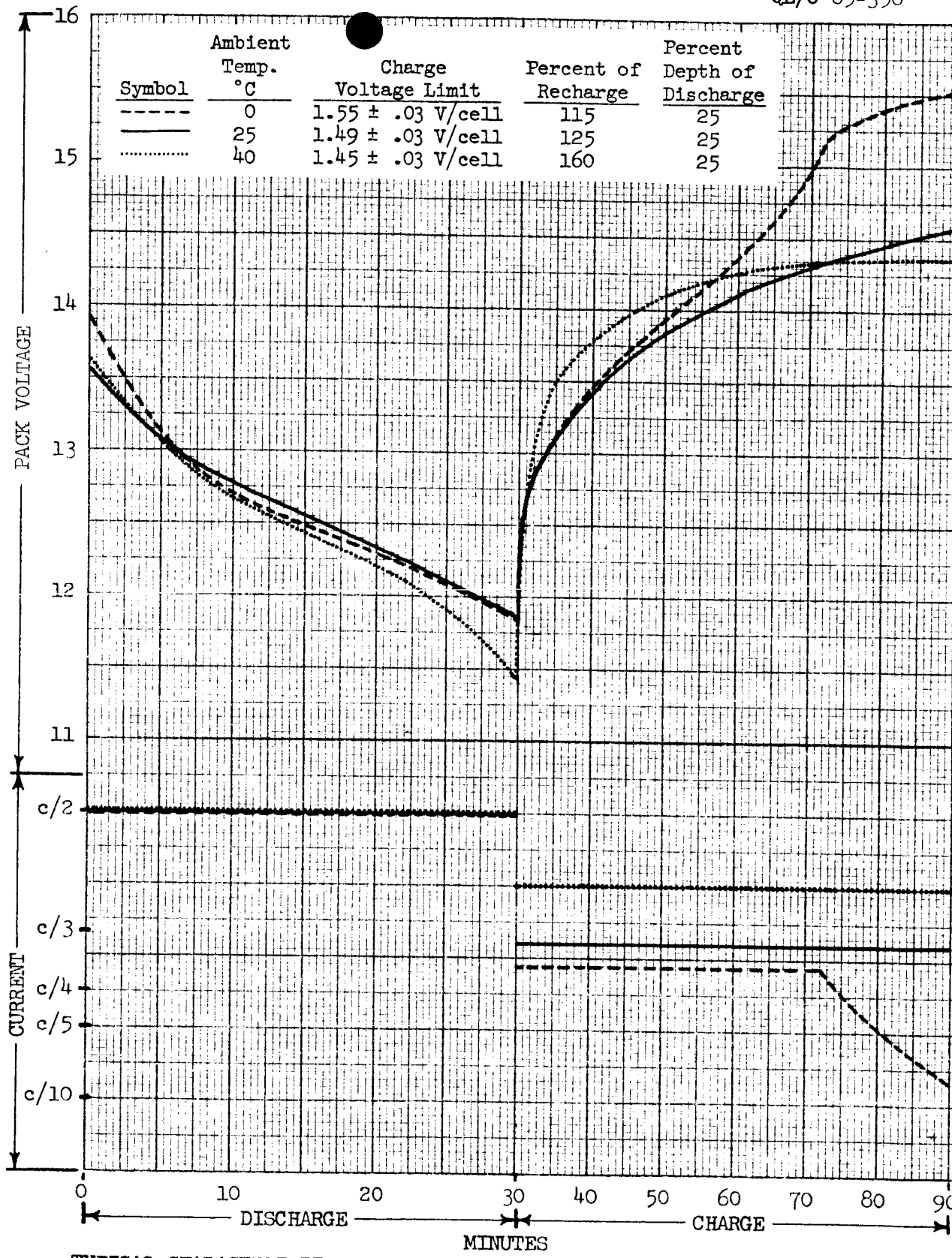
$$= \frac{(0.02 \times 15 \times 3) \times 0.5 \times 1.15}{1}$$

$$= 0.518 \text{ amperes.}$$

In the case of a 3.0 ampere-hour pack, 3-hour orbit (30 minutes discharge, 150 minutes charge), 25 percent depth of discharge and 125 percent recharge, the charging current would be:

$$I_c = \frac{(0.02 \times 25 \times 3) \times 0.5 \times 1.25}{2.5} = 0.375 \text{ amperes.}$$

3. Figure 1 is a typical set of characteristic voltage and current curves for three 10-cell packs of the same cell type, all on a 1.5-hour orbit period and at 25 percent depth of discharge, but with one pack at 0° C, one at 25° C and one at 40° C.



TYPICAL CHARACTERISTIC CURVES ON CHARGE AND DISCHARGE FOR A PARTICULAR ORBIT PERIOD, DEPTH OF DISCHARGE, AND CELL TYPE

FIGURE 1

E. Physical Preparation of Cells.

1. Pack Arrangement: The cells of each manufacturer type were connected in series into 5-cell or 10-cell packs. Within each pack, the cells were given numbers from 1 to 5 or from 1 to 10, for identification of their relative electrical and physical positions. These are shown in Figure 2.

a. G.E.:

(1) 3.0 Ampere-hour (10-cell Pack): Each cell was wrapped in a double layer of 0.003 inch polyethylene sheet and arranged into oval shaped packs held together with tape, according to diagram (a) of Figure 2. The electrical leads were soldered to the terminals on the top of the cells. The cells are cycling in the vertical position.

(2) 12.0 Ampere-hour (5-cell Pack): The cells were arranged in line between two 1/4-inch steel plates and held together with four 1/4-inch steel bolts. The cells were insulated from each other and the end plates by a layer of 0.015 inch insulating paper between two layers of 0.003 inch polyethylene sheet. The electrical connections were made at screw terminals on the tops of the cells. The cells are cycling in the vertical position.

b. Gould:

(1) 3.5 Ampere-hour (10-cell Pack): Each cell was wrapped in a double layer of 0.003 inch polyethylene sheet and arranged into triangular packs held together with tape, according to diagram (b) of Figure 2. The pigtail lead extending from the center of the top is the negative terminal. Since the case is positive, a tab was soldered to the base of each cell. The series electrical connections were made by soldering the pigtail negative terminal lead of one cell to the tab at the base of an adjoining cell. The cells are cycling in a horizontal position.

(2) 20.0 Ampere-hour (5-cell Pack): The cells were arranged in line between two 1/8-inch steel plates and held together with four 1/4-inch steel bolts. The cells were insulated from each other by a double layer of 0.003 inch polyethylene sheet. The electrical connections were made at the screw terminals on the tops of the cells. The cells are cycling in the vertical position.

c. Gulton:

(1) 6.0 Ampere-hour (10-cell Pack): The cells were arranged in line between two 1/4-inch steel plates and held together with four 1/4-inch steel bolts, as in diagram (d) of Figure 2. The

cells were insulated from each other and from the end plates by a layer of 0.015 inch insulating paper between two layers of 0.003 inch polyethylene sheet. The electrical leads were soldered to the terminals on the tops of the cells. The cells are cycling in the vertical position.

(2) 20.0 Ampere-hour (5-cell Pack): The cells were arranged in line between two 1/4-inch steel plates and held together with four 1/4-inch steel bolts. The cells were insulated from each other and from the end plates by a double layer of 0.003 inch polyethylene sheet. The electrical leads were soldered to the terminals at the tops of the cells. The cells are cycling in the vertical position.

d. Sonotone:

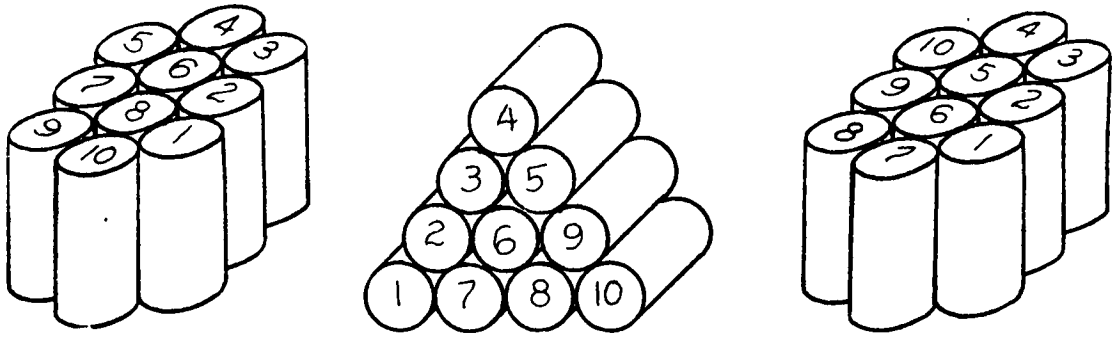
(1) 5.0 Ampere-hour (10-cell Pack): Each cell was wrapped in a double layer of 0.003 inch polyethylene sheet and arranged into oval shaped packs held together with tape, according to diagram (c) of Figure 2. The electrical leads were soldered to the terminals on the top of the cells. The cells are cycling in the vertical position.

2. Temperature Monitoring:

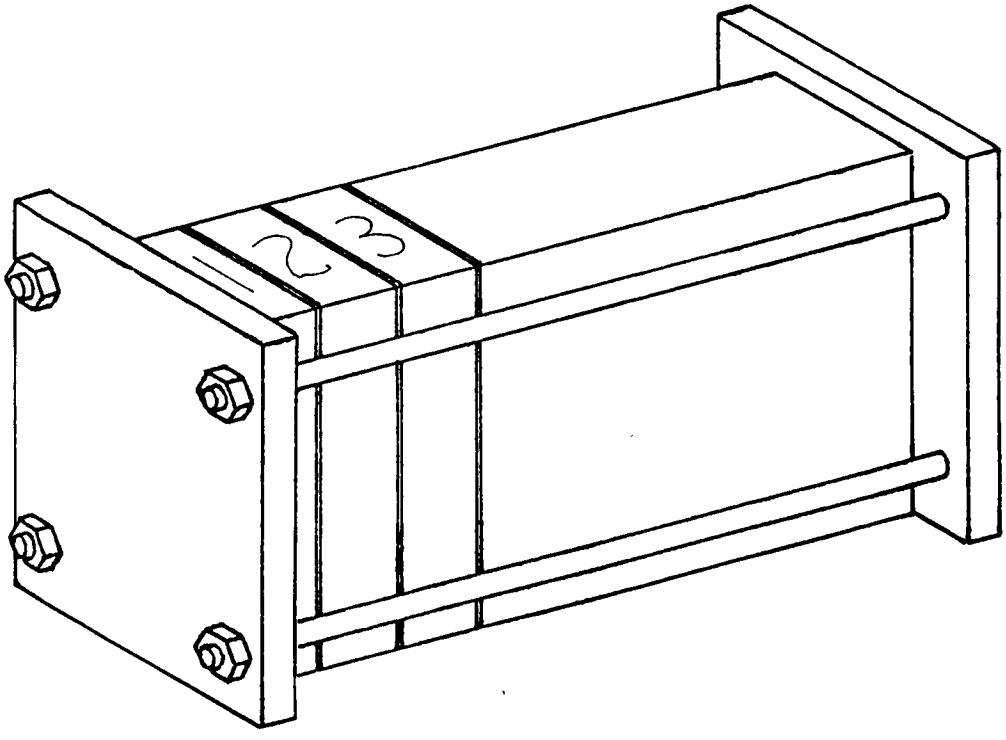
a. A thermocouple (Iron-Constantan, type J) was soldered to the positive terminal of each cell under test.

(1) In the Gould 3.5 ampere-hour cells, the case being the positive terminal, the thermocouple was soldered to the tab previously soldered to the base of the cell.

(2) Thermocouple voltages were read simultaneously with cell voltages.



a. G.E. 3.0 ah b. Gould 3.5 ah c. Sonotone 5.0 ah



d. All Rectangular Cells

DIAGRAM OF PACK ARRANGEMENTS
(Numbers identify cell position and electrical sequence)

FIGURE 2

F. Recording and Processing of Data.

1. Frequency of Data Recording: The individual cell and pack voltages, currents, and individual cell and ambient temperatures for each measured cycle are recorded at the following designated intervals:

a. During Charge: The readings during the charge period of the 1.5-hour orbit were taken at the beginning and end of charge and at 10-minute points between, whereas during the 3-hour orbit, readings were recorded at the start and end of the charge period and at 20-minute points between.

b. During Discharge: The readings during the discharge period of both the 1.5-hour and 3-hour orbit periods were taken at the beginning and end of the discharges and at 5-minute points between.

c. Measured cycles were normally the first cycle and approximately every 32 cycles thereafter. This data was also recorded whenever a possible cell failure or pack failure was indicated.

2. Data Processing: The data is typed on continuous form paper while succeeding readings are recorded on punched tape. The data is then converted to 5081 Data Processing Cards and stored according to pack and cycle number.

G. Measurements of Ampere-hour Capacity.

1. Preconditioning of Test Cells.

a. Prior to the start of the cycling program, all packs were preconditioned at their designated cycling temperatures as described below. In each case, the on-charge voltage limit was the same as set for the cycling program.

b. After all packs were discharged at the c/2 rate, the cells were equalized to zero voltage by short circuiting across their terminals. They were then recharged at the c/10 rate for 24 hours, except packs of Gulton cells which, in accordance with the manufacturer's recommendations, were recharged at the c/40 rate for 40 hours. This recharge was followed by a discharge at the c/2 rate to a cutoff of 1.0 volt per cell average or to a low of 0.5 volt on any one cell, whichever occurred first. The packs were then recharged at the c/10 rate for 16 hours and discharged at the c/2 rate to the above cutoff point. Any cell showing a significantly low capacity on this second discharge, which would limit the pack's performance on cycling, was replaced and the second charge and

discharge repeated on the entire pack. (The greatest ampere-hour capacities thus obtained for each pack are shown in Tables VIIIa through VIIIg and Figures 5(a) through 5(g).)

(1) Immediately before the start of cycling, each pack was given a 24-hour charge at the c/10 rate.

2. Preconditioning at Change from 50° C to 40° C Ambient Temperature.

a. The packs which were changed from the 50° C to the 40° C ambient temperature were preconditioned again, at the lower temperature. They were first discharged beyond the normal cutoff voltage and the cells equalized to zero voltage by short circuiting across their terminals. Each pack was then recharged for 24 hours at the c/10 rate with the pack voltage limited to an equivalent of 1.41 volts per cell. The packs were then discharged according to the original preconditioning procedure, with the exception that cells showing low capacities were not replaced. (The ampere-hour capacities on this discharge are given in Tables VIIIa through VIIIg and Figures 5(a) through 5(g).)

(1) Immediately before the start of cycling at 40° C each pack was given a 24-hour charge at the c/10 rate.

3. Periodic Capacity Checks.

a. The ampere-hour capacity of each pack, at its specified test temperature, was measured after completion of approximately each 88 days of continuous cycling. This is equivalent to about every 1400 cycles for the 1.5-hour orbit periods and every 700 cycles for the 3-hour orbit periods.

b. During the capacity checks, the on-charge voltage limit was the same as for cycling. Each pack being checked was discharged immediately after the end of the regular cycle charge period, at the c/2 rate to a cutoff of 1.0 volt per cell average or to a low of 0.5 volt on any one cell, whichever occurred first. The pack was then recharged at the c/10 rate for 16 hours and discharged again as above. (For those capacity checks which have been completed as of this report, the ampere-hours delivered on both discharges are given in Table VIIIa through VIIIg.)

c. Before being returned to regular cycling, the pack was given a 48-hour charge at the c/10 rate, with the regular cycling voltage limit on charge.

H. Cell Failures; Failure Criteria.

1. A cell is considered to have failed when the terminal voltage drops below 0.5 volt at any time during a regular discharge-charge cycle. It is removed from the pack upon completion of the cycle.

2. A pack is considered to have failed when more than one-half of its cells have failed.

IV. TEST RESULTS.

A. Current Status; Pack Failures.

1. The number of cycles completed as of 31 December 1964 by the various packs which have not failed varies because of different starting times and temporary shutdown of packs for cell removal or equipment maintenance. The number of days of continuous cycling completed, at 16 cycles or 8 cycles per day for the 1.5-hour and 3-hour orbits respectively, ranged from 291.1 days to 375 days.

2. A total of 29 of the original 84 packs have failed, the earliest being the Gulton 20 a.h. packs cycling at 25° C and 40 percent depth of discharge, after 39.2 and 44.8 days of 1.5-hour and 3-hour cycles respectively (Packs 87 and 88).

3. The number of cycles and the number of days of continuous cycling completed by each pack are given in Table III. An asterisk indicates that the pack had failed as of the given cycle.

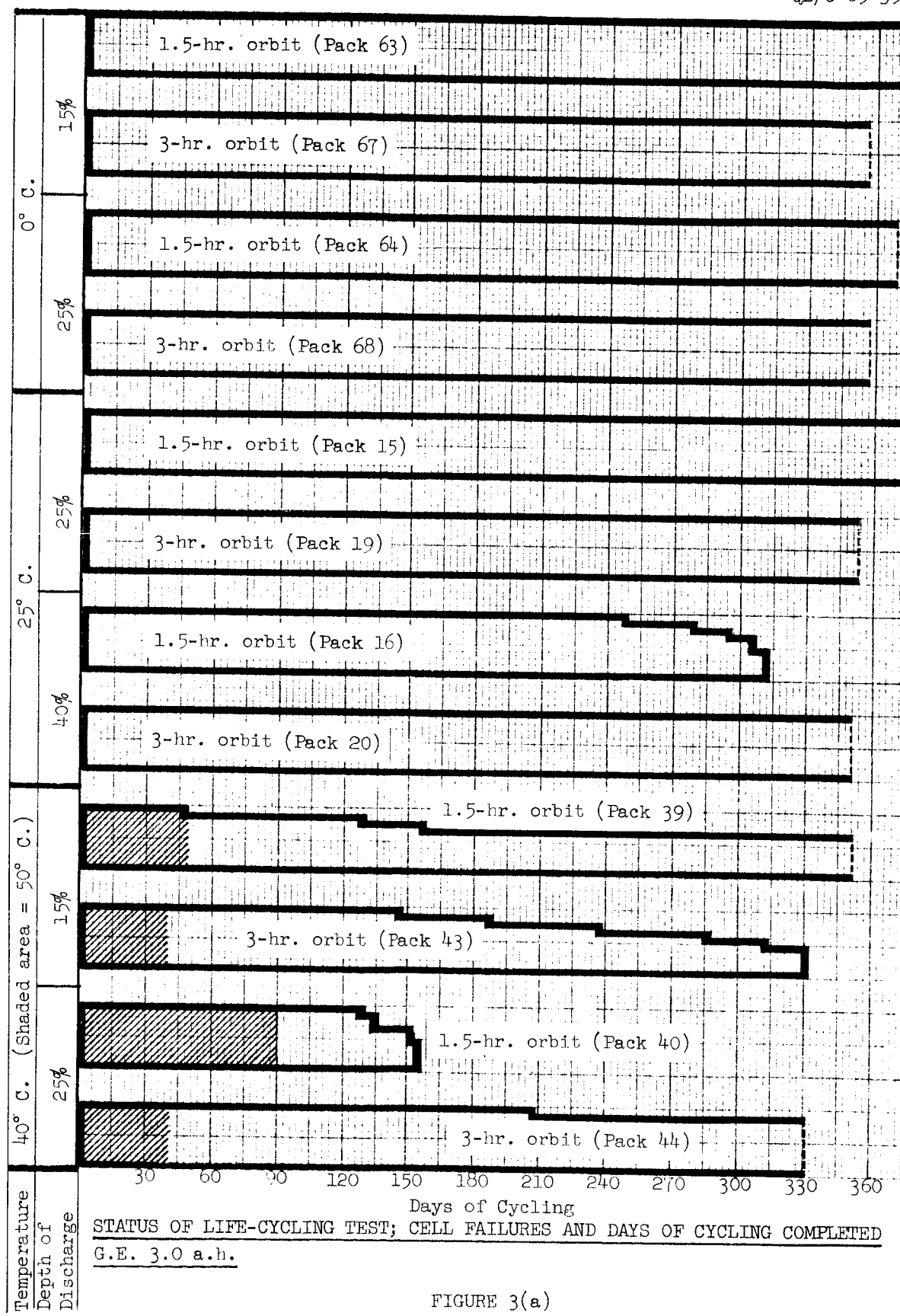
4. Figures 3(a) through 3(g) are profiles showing cell failures and status of each pack in terms of days of continuous cycling. A broken line at the end of a profile indicates that the pack is still cycling.

TABLE III

CYCLES AND DAYS OF CYCLING COMPLETED AS OF 31 DECEMBER 1964

Test Temperature	Depth of Discharge	Orbit Period (hours)	G.E. 3 a.h.			G.E. 12 a.h.			GOULD 3.5 a.h.			GOULD 20 a.h.			GULTON 6 a.h.			GULTON 20 a.h.			SONOTONE 5 a.h.		
			Pack Number	Cycles	Days of Cycling	Pack Number	Cycles	Days of Cycling	Pack Number	Cycles	Days of Cycling	Pack Number	Cycles	Days of Cycling	Pack Number	Cycles	Days of Cycling	Pack Number	Cycles	Days of Cycling	Pack Number	Cycles	Days of Cycling
0° C	15%	1.5	63	5983	373.9	110	5399	337.4	51	6000	375.0	84	5330	333.1	61	5201	325.1	101	3631*	226.9	49	5719	357.4
		3	67	2851	356.4	111	2722	340.3	55	2851	356.4	80	2670	333.8	65	2862	357.8	102	2472	309.0	53	2767	345.9
	25%	1.5	64	5909	369.3	124	5214	325.9	52	5989	374.3	98	5137	321.1	62	4829	301.8	115	2291*	143.2	50	5675	354.7
		3	68	2854	356.8	125	2721	340.1	56	2838	348.8	94	2541	317.6	66	2553	319.1	116	2329	291.1	54	2731	341.4
25° C	25%	1.5	15	5977	373.6	82	5595	349.7	3	4751*	296.9	104	2980*	186.3	13	4021*	251.3	73	5232	327.0	1	5562	347.6
		3	19	2826	353.3	83	2763	334.1	7	2863	357.9	105	2564	320.5	17	2675	334.3	74	1754*	219.3	5	2787	348.4
	40%	1.5	16	5013*	313.3	96	4020*	251.3	4	3164*	197.8	118	2837*	183.6	14	2086*	130.4	87	627*	39.2	2	5257	328.6
		3	20	2803	350.4	97	2753	344.1	8	2494*	311.8	119	1793*	224.1	18	1550*	193.8	88	358*	44.8	6	2707	338.4
40° C	15%	1.5	39	5618	351.1	85	5236	327.3	27	4485*	280.3	112	5005	312.8	37	4757	297.3	76	5040	315.0	25	5567	347.9
		3	43	2656*	332.0	86	2652	331.5	31	2524*	315.5	108	2501	312.6	41	1689*	211.1	77	2526	315.8	29	2648	331.0
50° - 40° C	25%	1.5	40	2509*	156.8	99	4853*	303.3	28	1811*	113.2	126	1569*	98.1	38	1377*	86.1	90	4045*	252.8	26	3625*	226.6
		3	44	2643	330.4	100	2519	314.9	32	974*	121.8	122	983*	122.9	42	2410	301.3	91	2438	304.8	30	2614	326.8

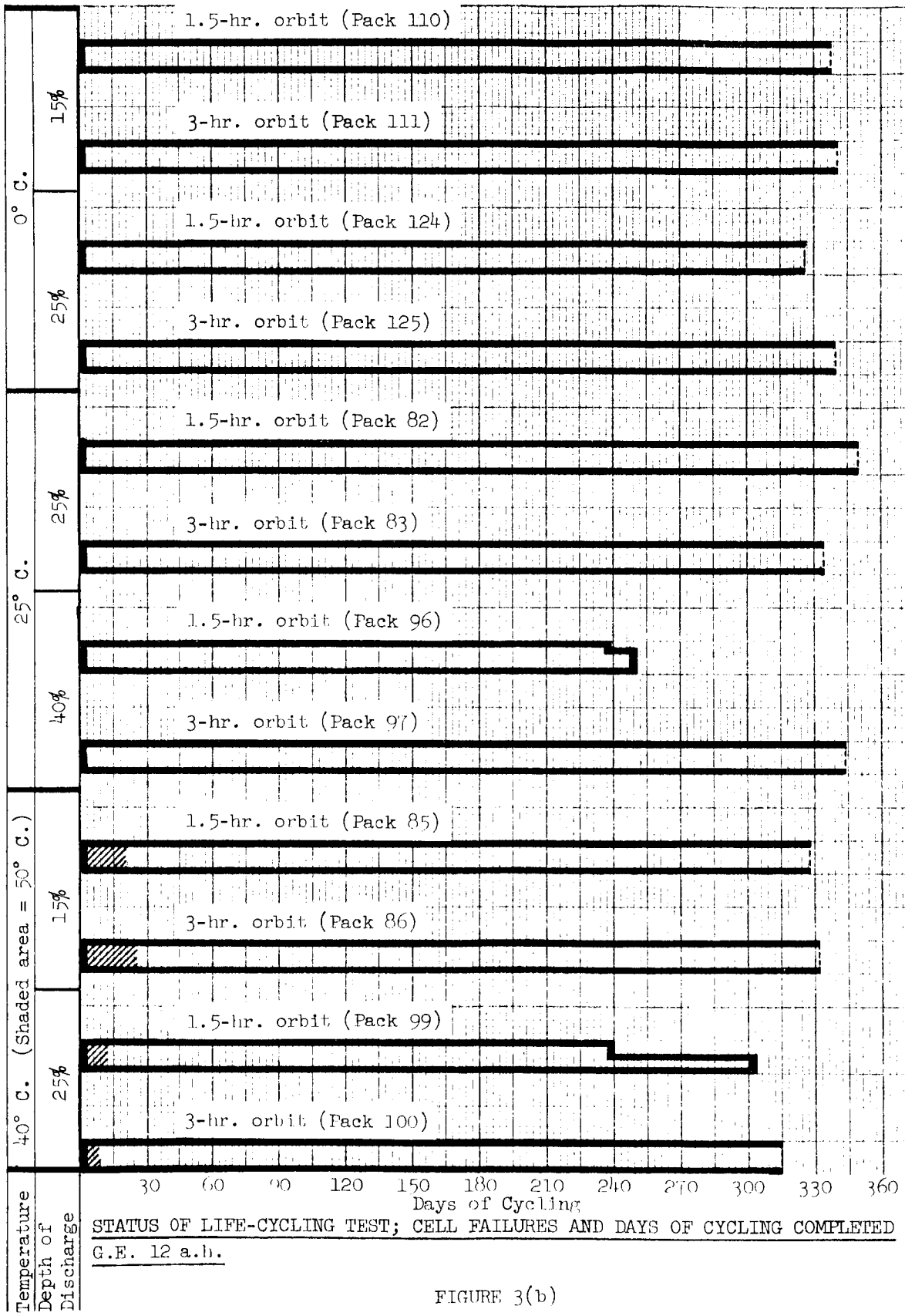
* Pack failed on this cycle.



STATUS OF LIFE-CYCLING TEST; CELL FAILURES AND DAYS OF CYCLING COMPLETED

G.E. 3.0 a.h.

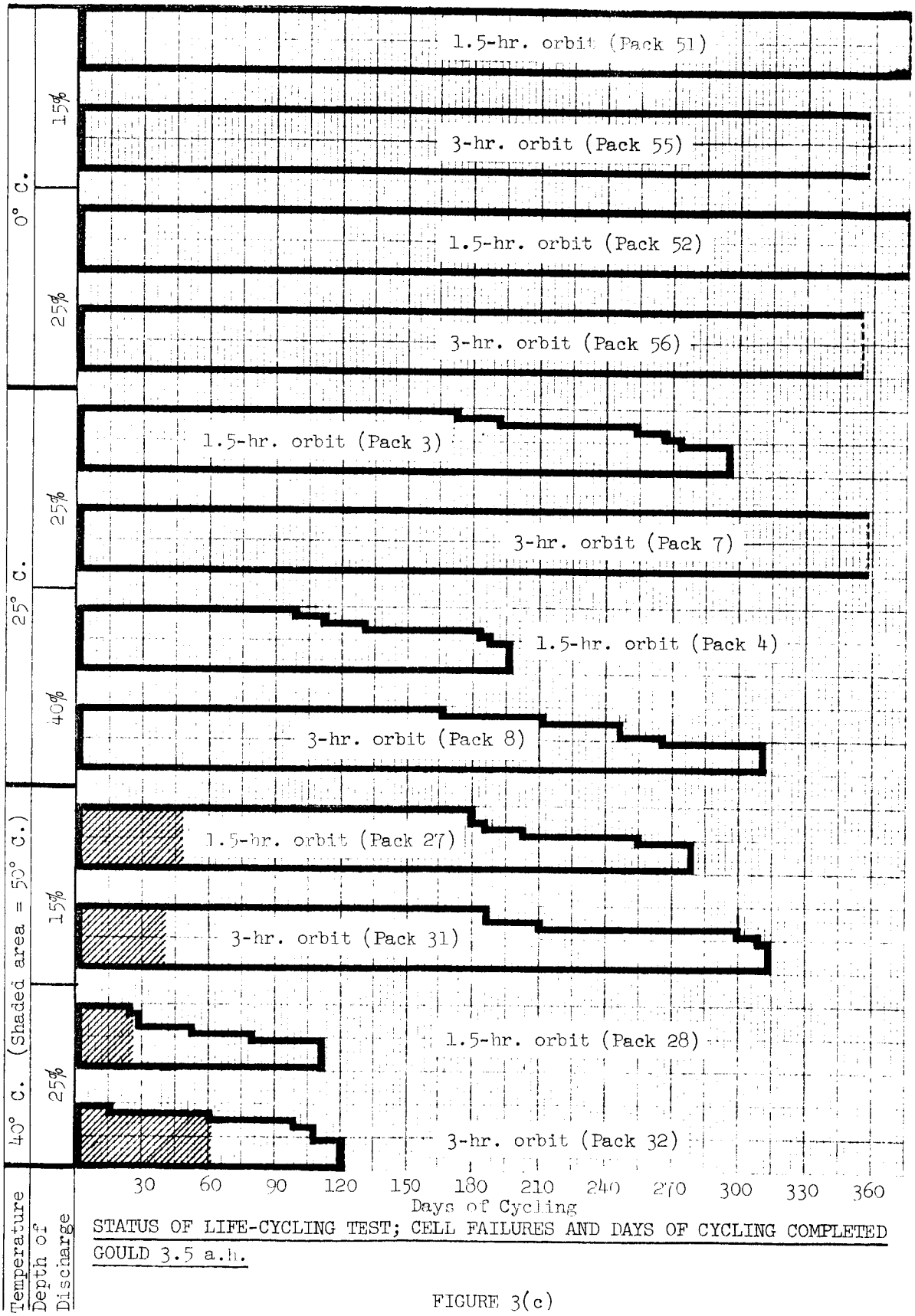
FIGURE 3(a)



STATUS OF LIFE-CYCLING TEST; CELL FAILURES AND DAYS OF CYCLING COMPLETED

G.E. 12 a.h.

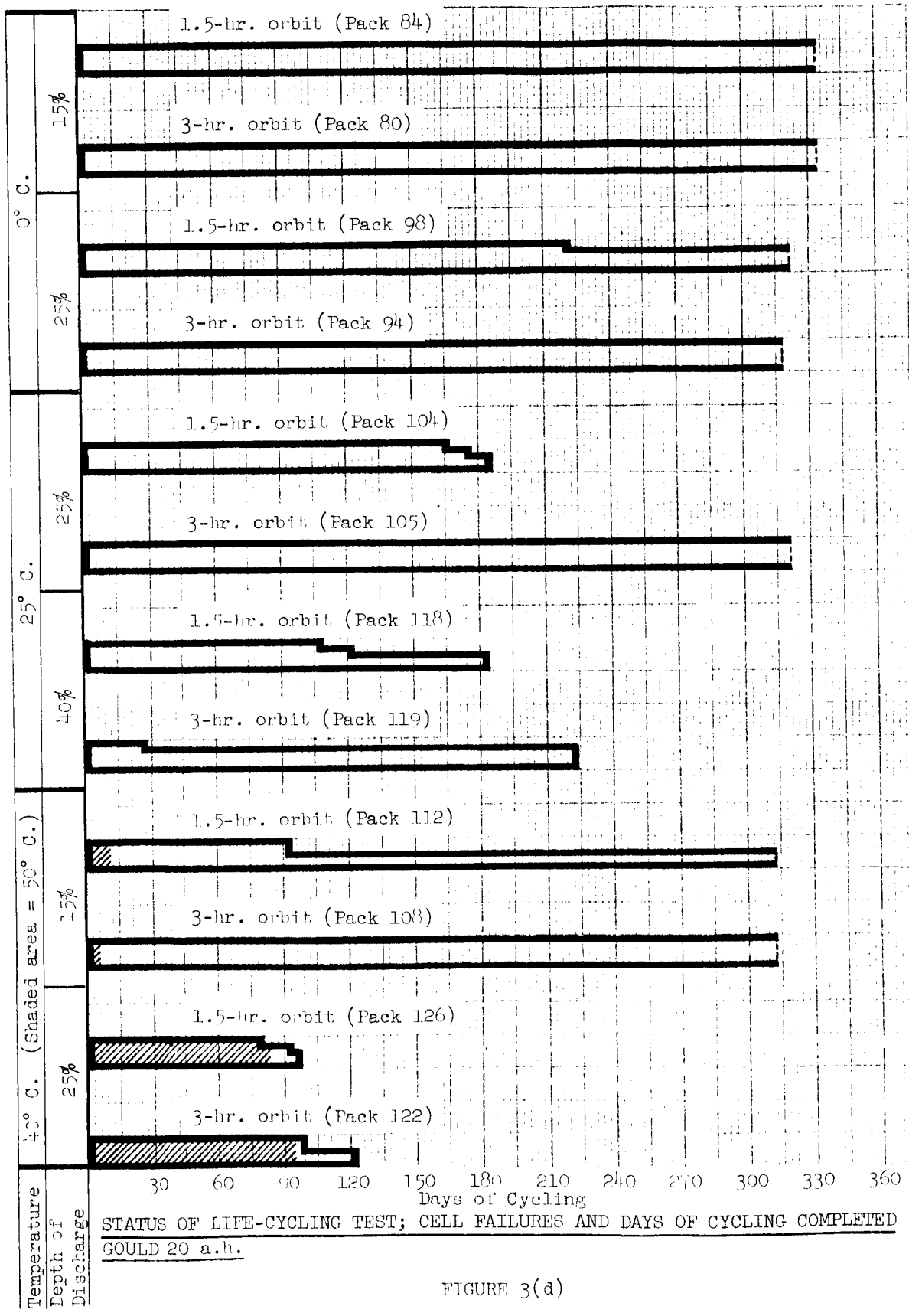
FIGURE 3(b)



STATUS OF LIFE-CYCLING TEST; CELL FAILURES AND DAYS OF CYCLING COMPLETED

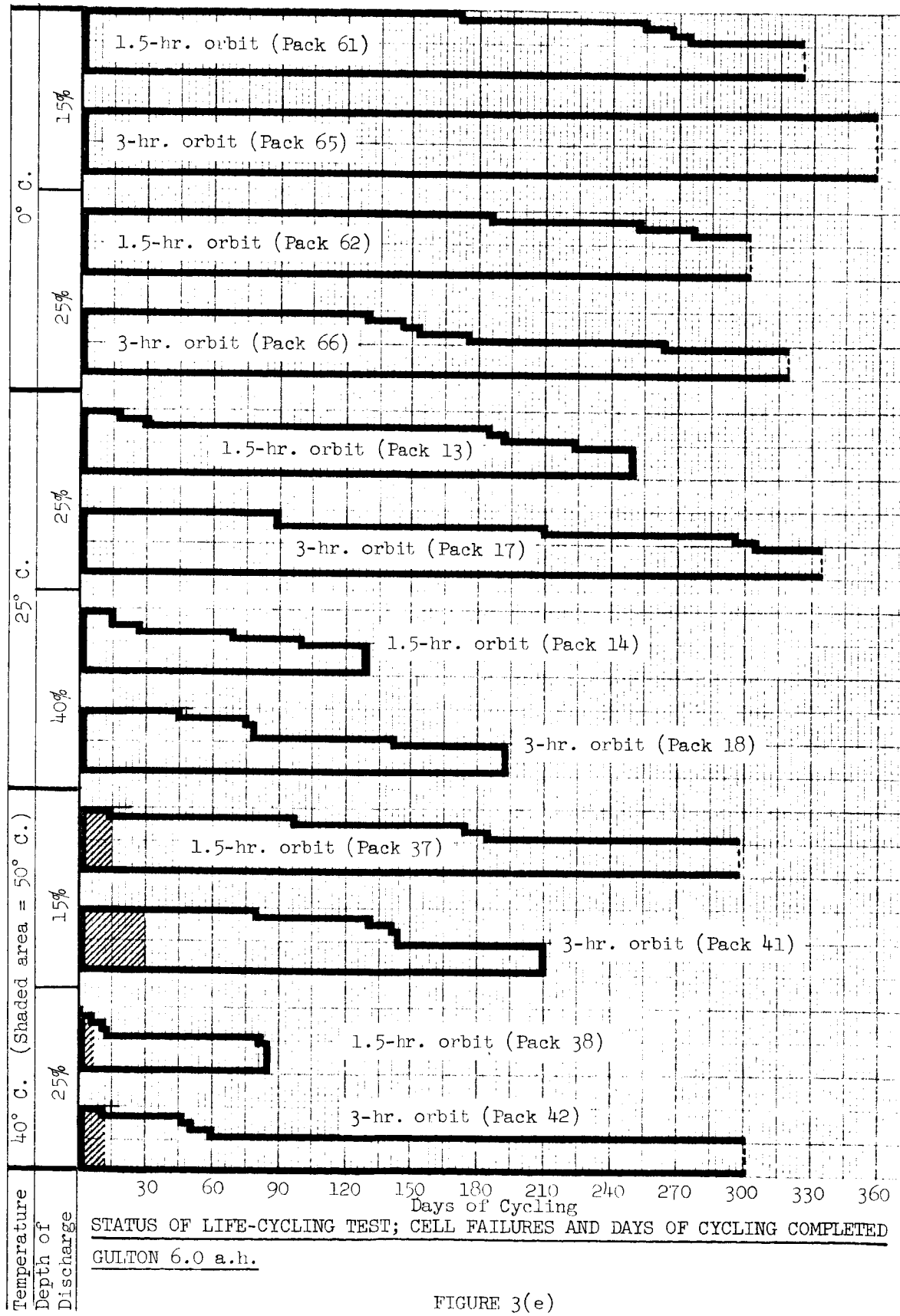
GOULD 3.5 a.h.

FIGURE 3(c)



STATUS OF LIFE-CYCLING TEST; CELL FAILURES AND DAYS OF CYCLING COMPLETED
GOULD 20 a.h.

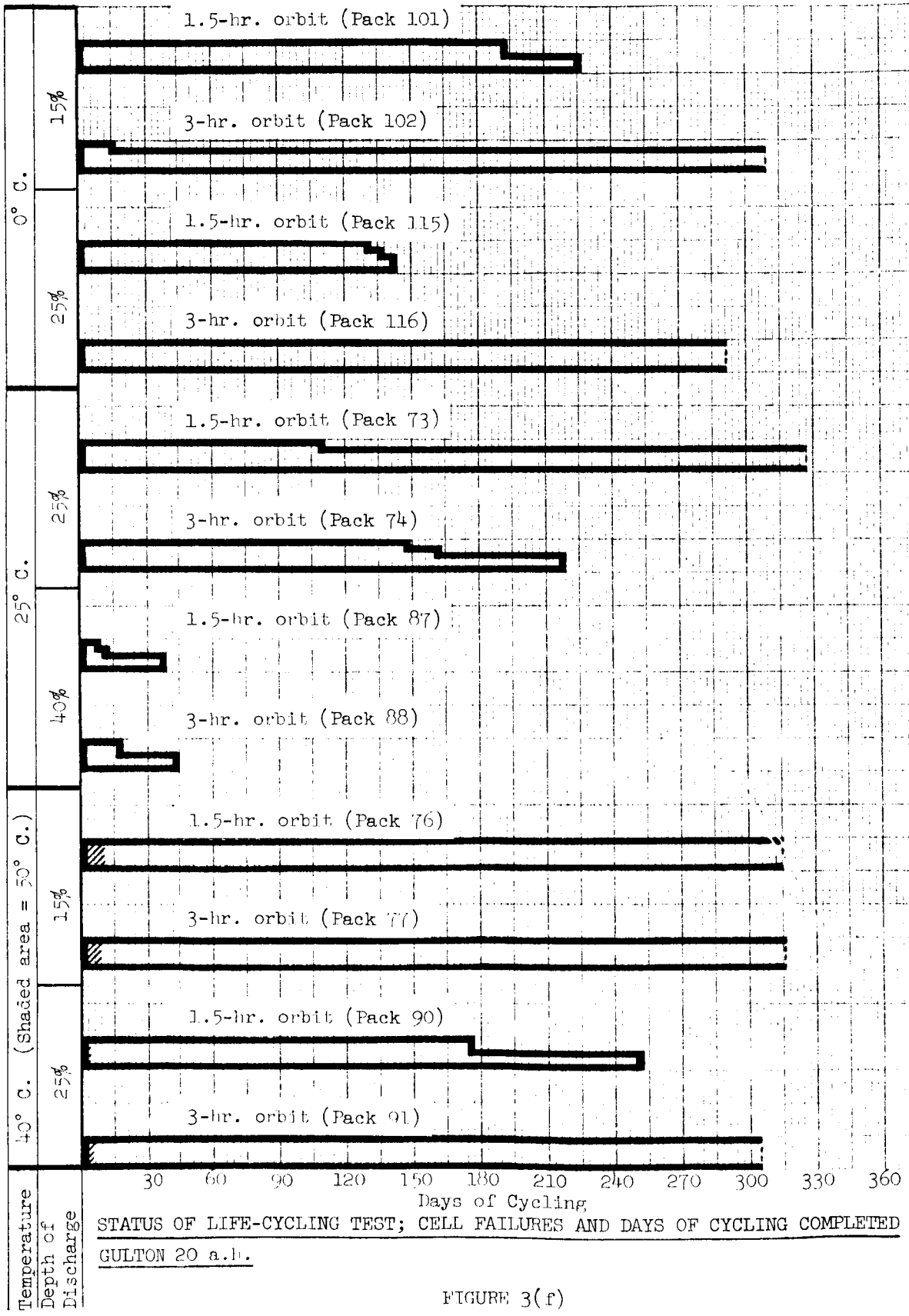
FIGURE 3(d)



STATUS OF LIFE-CYCLING TEST; CELL FAILURES AND DAYS OF CYCLING COMPLETED

GULTON 6.0 a.h.

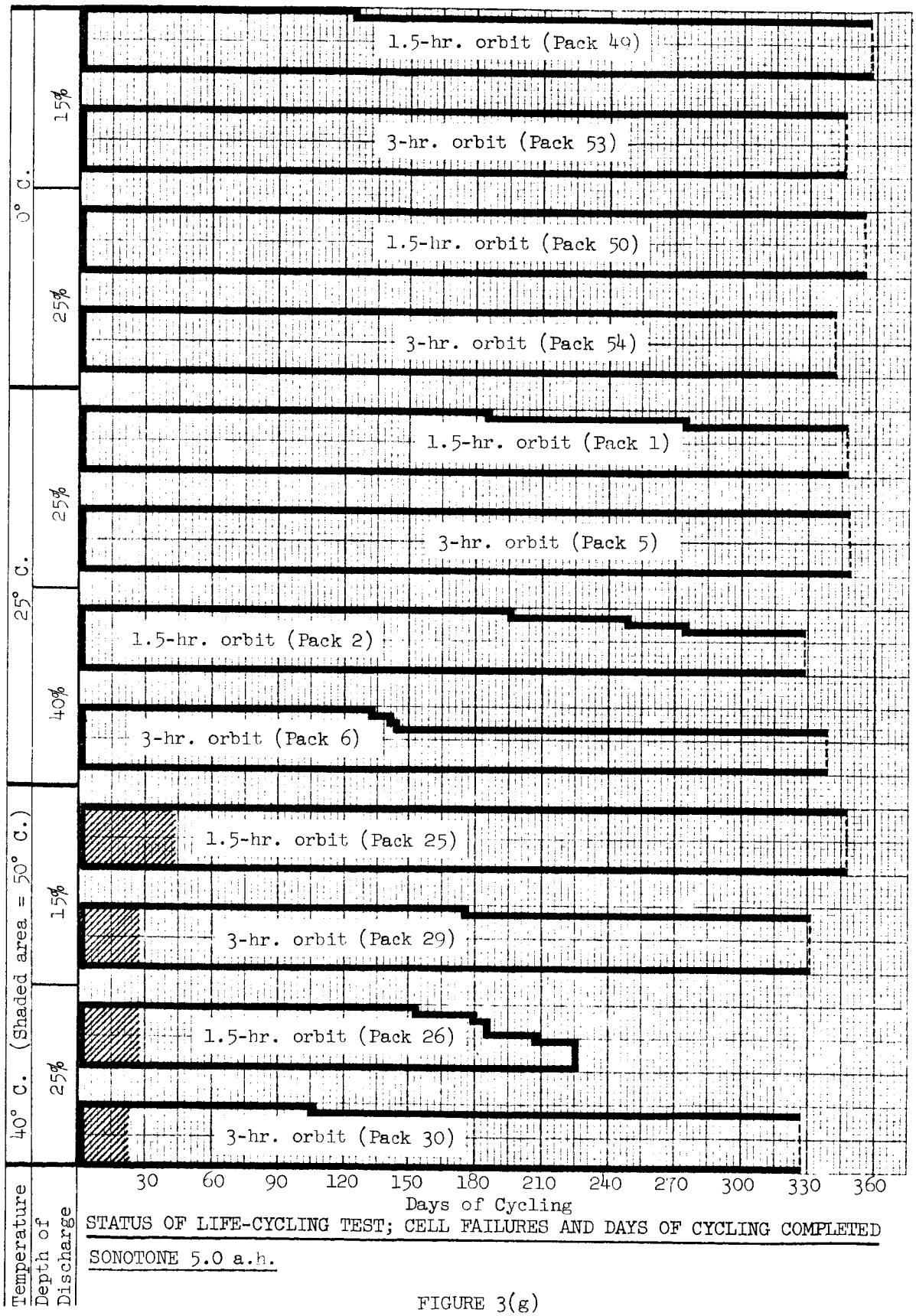
FIGURE 3(e)



STATUS OF LIFE-CYCLING TEST; CELL FAILURES AND DAYS OF CYCLING COMPLETED

GULTON 20 a.h.

FIGURE 3(f)



STATUS OF LIFE-CYCLING TEST; CELL FAILURES AND DAYS OF CYCLING COMPLETED

SONOTONE 5.0 a.h.

FIGURE 3(g)

B. Cycling Performance of Non-Failing Cells; Voltage and Current Characteristics.

1. Variations of cycling voltage and current with length of cycling time for each pack are shown in Figures 4(a) through 4(g). These graphs are actually taken from summaries of Figures 7(a) through 13(l) (pages 77 - 160), and have been included to facilitate evaluation and comparison. The points are the average voltage per active cell at the middle (15 minutes) of discharge, the end of discharge (30 minutes), and the end of charge, and the current at the end of charge. The points shown are average values, at approximately 5-month intervals, plotted against months of continuous cycling, and are chosen to indicate overall trends rather than short term variations such as cell failures. The majority of packs show greater short term variations than is indicated by Figures 4(a) through 4(g). Therefore, Figures 7(a) through 13(l) should be consulted where somewhat greater detail is desired. Pack failures are also indicated by an arrowhead and an asterisk, with the horizontal position of the asterisk giving the time of failure. The vertical position of the symbol is of no significance. At the high temperature, the first point plotted follows the change from 50° to 40° C unless otherwise noted.

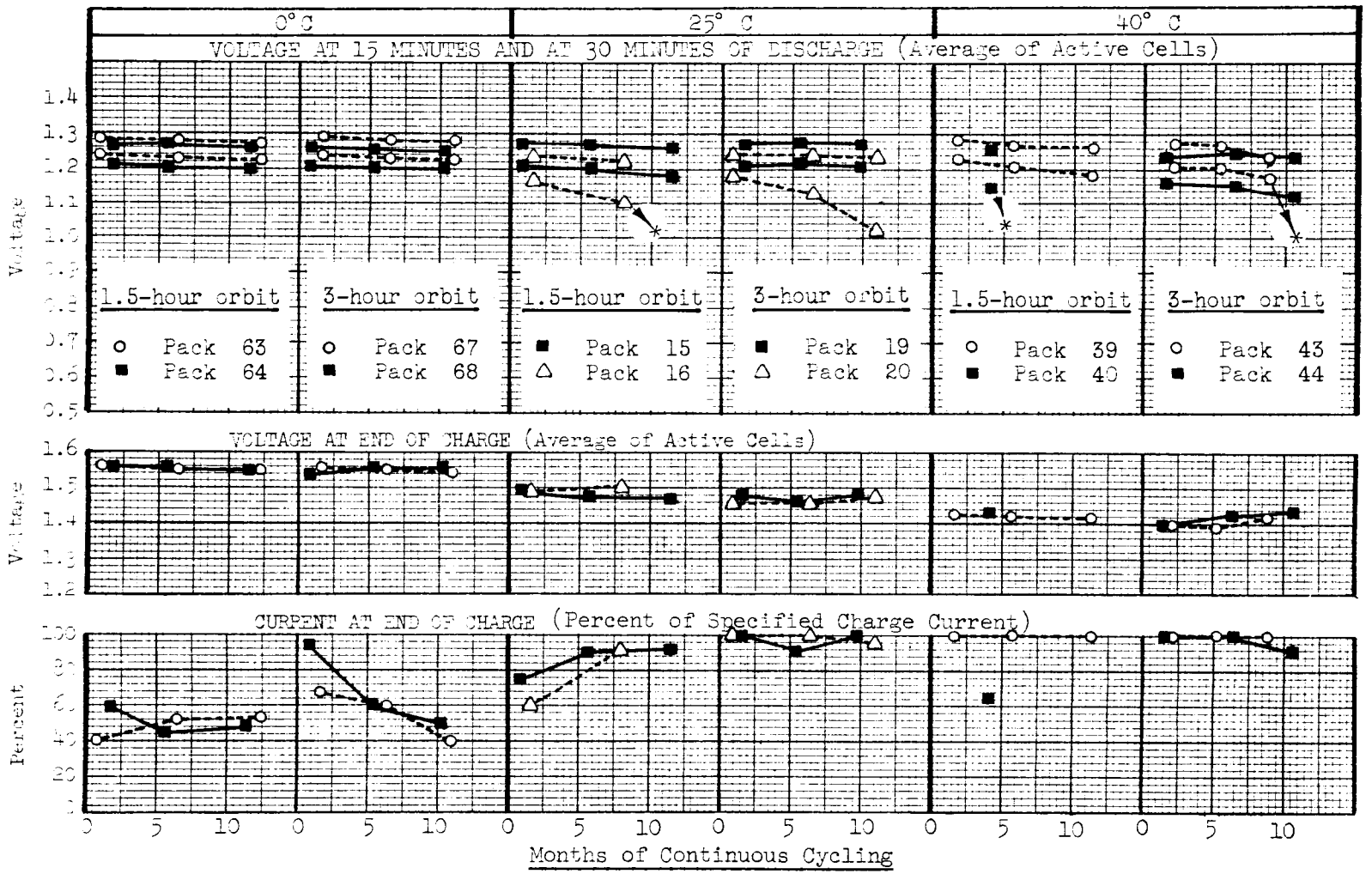
2. As is shown by Figures 4(a) through 4(g), discharge voltages tend to remain the same or to drop slightly, on the order of 0.02 volt per cell, over a period of a year. The end-of-discharge voltage may drop more than this, especially when a pack approaches failure. The least overall change is seen to occur at 0° C. One notable exception, however, was the Gulton 20 a.h. pack at 40° C, 25 percent depth and 3-hour orbit wherein all cells showed a fairly steady rise in end-of-discharge voltage from 0.9 volt per cell shortly after the change from 50° C to 40° C to 1.1 volts at the end of 10 months of cycling. For a given temperature and cell type, the discharge voltage is generally from 0.02 to 0.04 volt per cell lower at the greater depths of discharge, that is, at the higher rate, as expected. For a given cell type, the discharge voltage tends to decrease by 0.00 to 0.04 volt per cell with increase in test temperature from 0° to 40° C for each depth of discharge. The amount of decrease depends on the cell type. The orbit period seems to have little effect on the discharge characteristics of normally functioning cells (the 1.5-hour and 3-hour orbit periods both have 30-minute discharge periods).

3. End-of-charge current and voltage must be considered simultaneously since the amount by which the current is reduced during the charge portion of a given cycle is determined by the voltage. A tendency towards an increasing end-of-charge voltage will be reflected instead as a decrease in end-of-charge current if the specified voltage limit is reached. If the voltage limit is not reached, the charge current remains constant at the specified rate throughout the charge period.

a. When limiting occurs, the resulting end-of-charge current may vary considerably from one recorded cycle to the next if regular cycling has been interrupted by a capacity check, cell failure or equipment maintenance. The end of charge current then may also stabilize at a new level if the voltage limit at which the control unit automatically converts from constant current to constant voltage operation is changed slightly (the tolerance is ± 0.03 volt per cell, average). Thus, if this voltage limiting point is increased, the end-of-charge current will at least temporarily show an increase of as much as 20 percent of the specified charge current.

b. In Figures 4(a) through 4(g) the end-of-charge currents are expressed as percent of the specified charge rate. If the voltage limit was not reached, the current is shown as 100 percent. The current values plotted are averages, selected to represent overall trends.

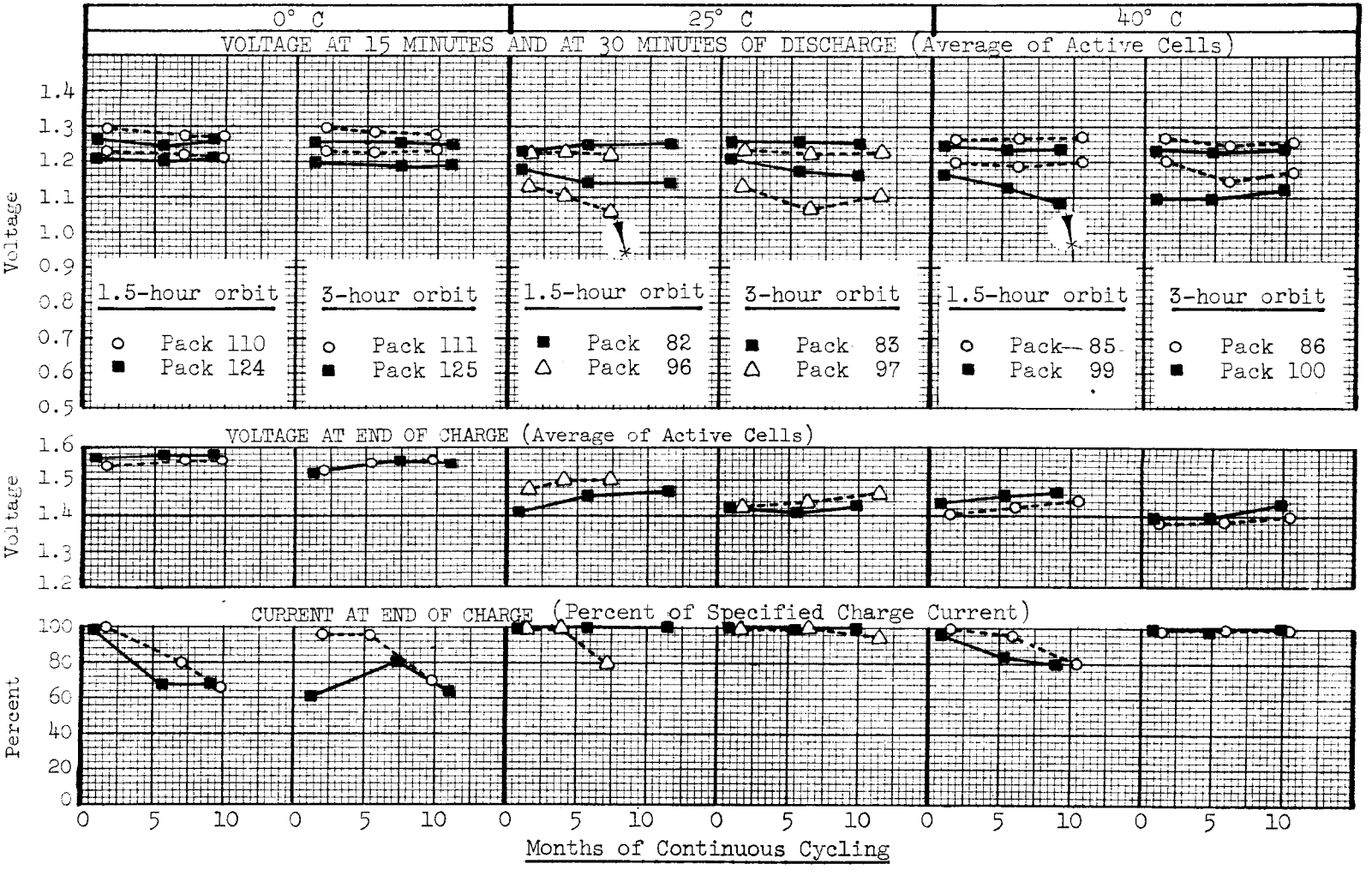
c. When pronounced, long term changes in the end-of-charge current and voltage occurred, they were almost always in the direction of lower current and higher voltage. The packs in which this effect was most pronounced were Packs 67 and 68 (G.E. 3.0 a.h.), Packs 110, 111 and 124 (G.E. 12 a.h.), Packs 4 and 27 (Gould 3.5 a.h.), Packs 118, 119 and 112 (Gould 20 a.h.), Packs 102 and 90 (Gulton 20 a.h.), and Packs 54, 2, 25 and 26 (Sonotone 5.0 a.h.). Cell failures from the packs were compared to determine possible causes for this effect. Only cells from the two Gould 3.5 a.h. packs showed weight loss as a cause. One of these and several of the Sonotone failures had weak welds in the internal electrical connections. However, among the Gould 20 a.h. and Gulton 20 a.h. packs the predominant failure conditions were related to the plate and separator materials (there were no failures from the G.E. packs). Therefore, the cause of this effect may differ for each of the packs (cell failures are discussed in paragraph IV.E.).



G.E. 3.0 a.h. CELLS. SUMMARY OF FIGURES 7(a)-7(l)

FIGURE 4(a)

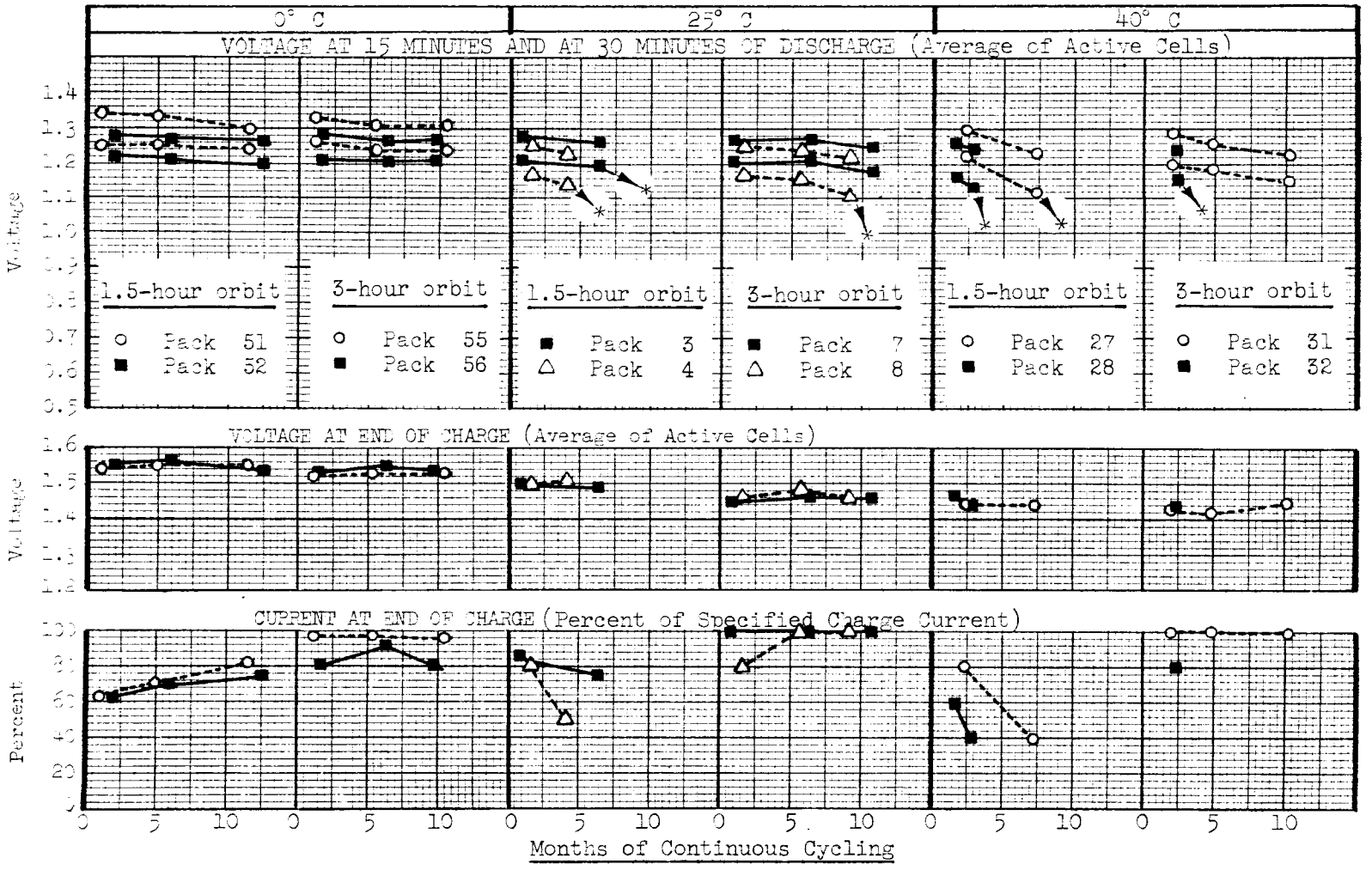
QE/C 65-356



G.E. 12 a.h. CELLS. SUMMARY OF FIGURES 8(a)-8(l)

FIGURE 4(b)

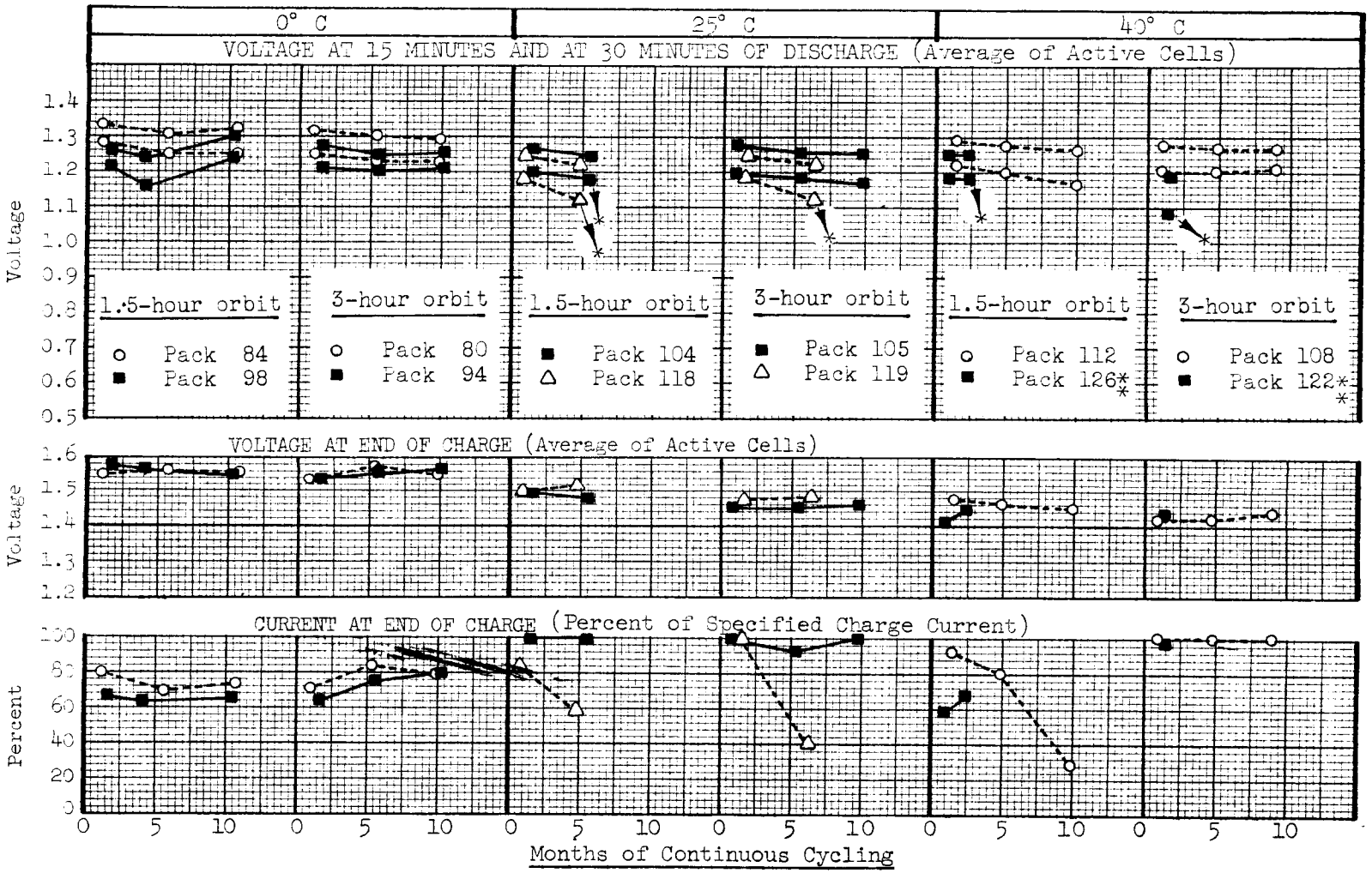
GE/C 65-356



GOULD 3.5 a.h. CELLS. SUMMARY OF FIGURES 9(a)-9(l)

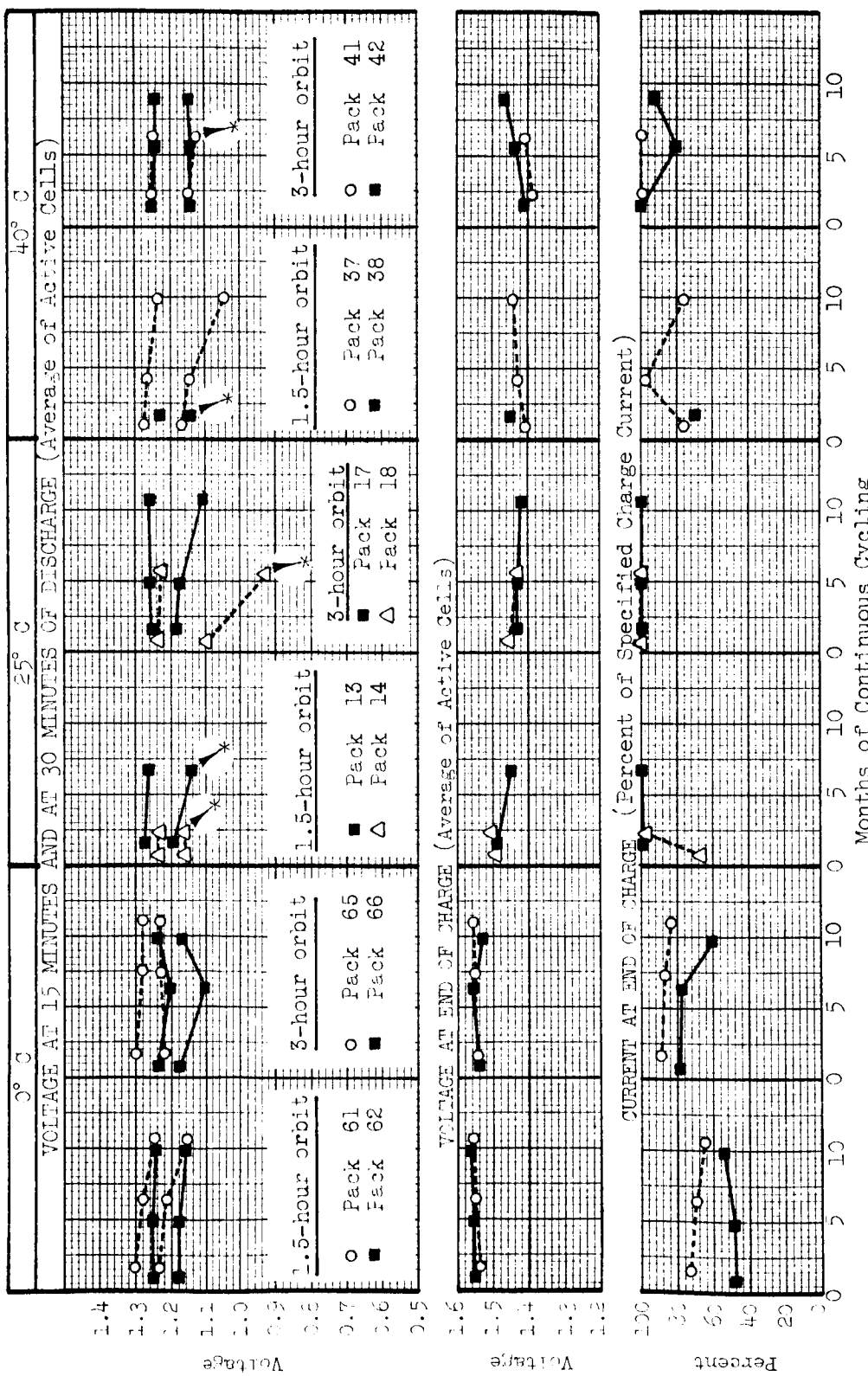
15% Depth of Discharge
25% Depth of Discharge
40% Depth of Discharge
Pack Failed

FIGURE 4(c)



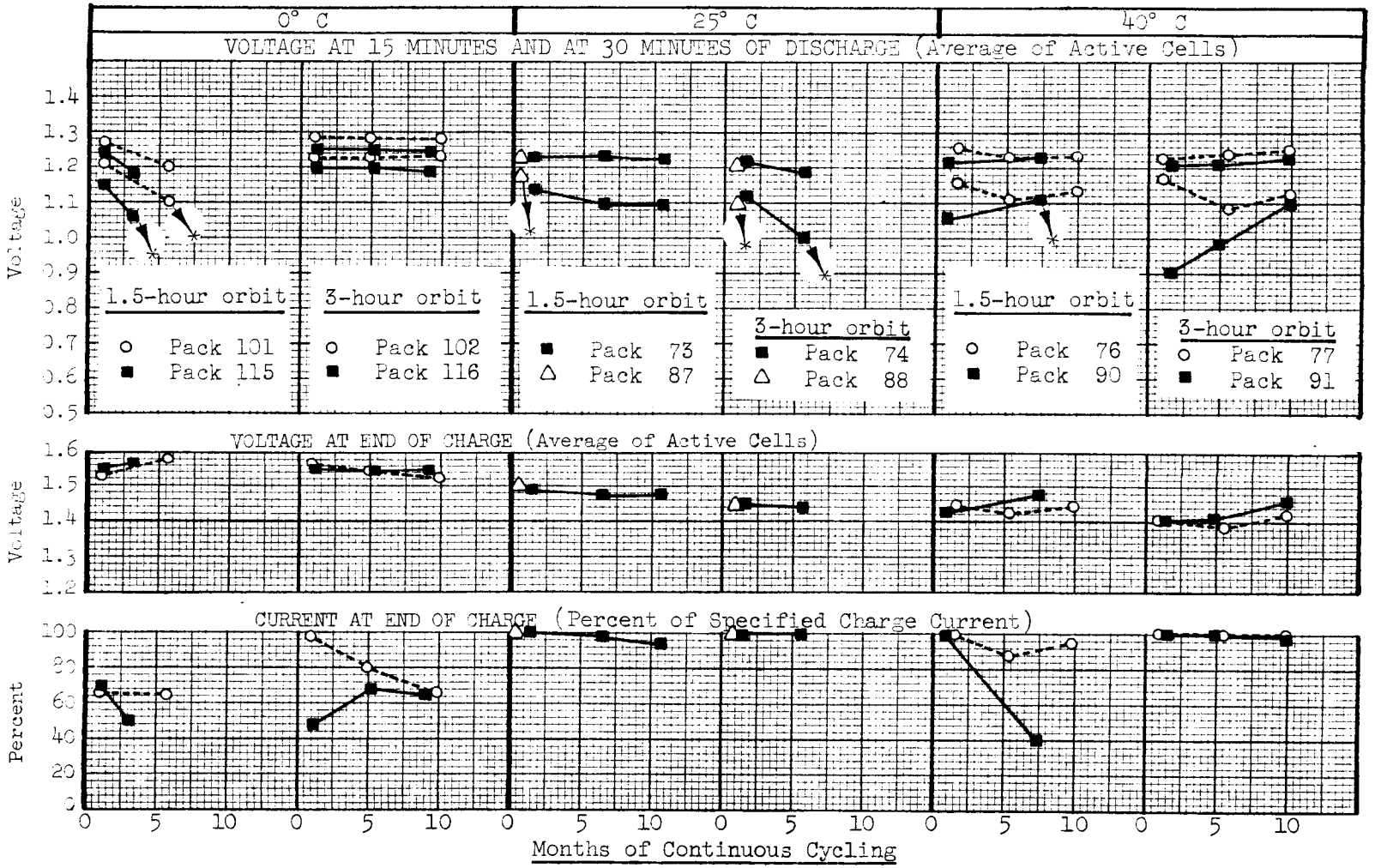
GOULD 20 a.h. CELLS. SUMMARY OF FIGURES 10(a)-10(l)

FIGURE 4(d)



GULTON 6.0 a.h. CELLS. SUMMARY OF FIGURES 11(a)-11(l)

FIGURE 4(e)

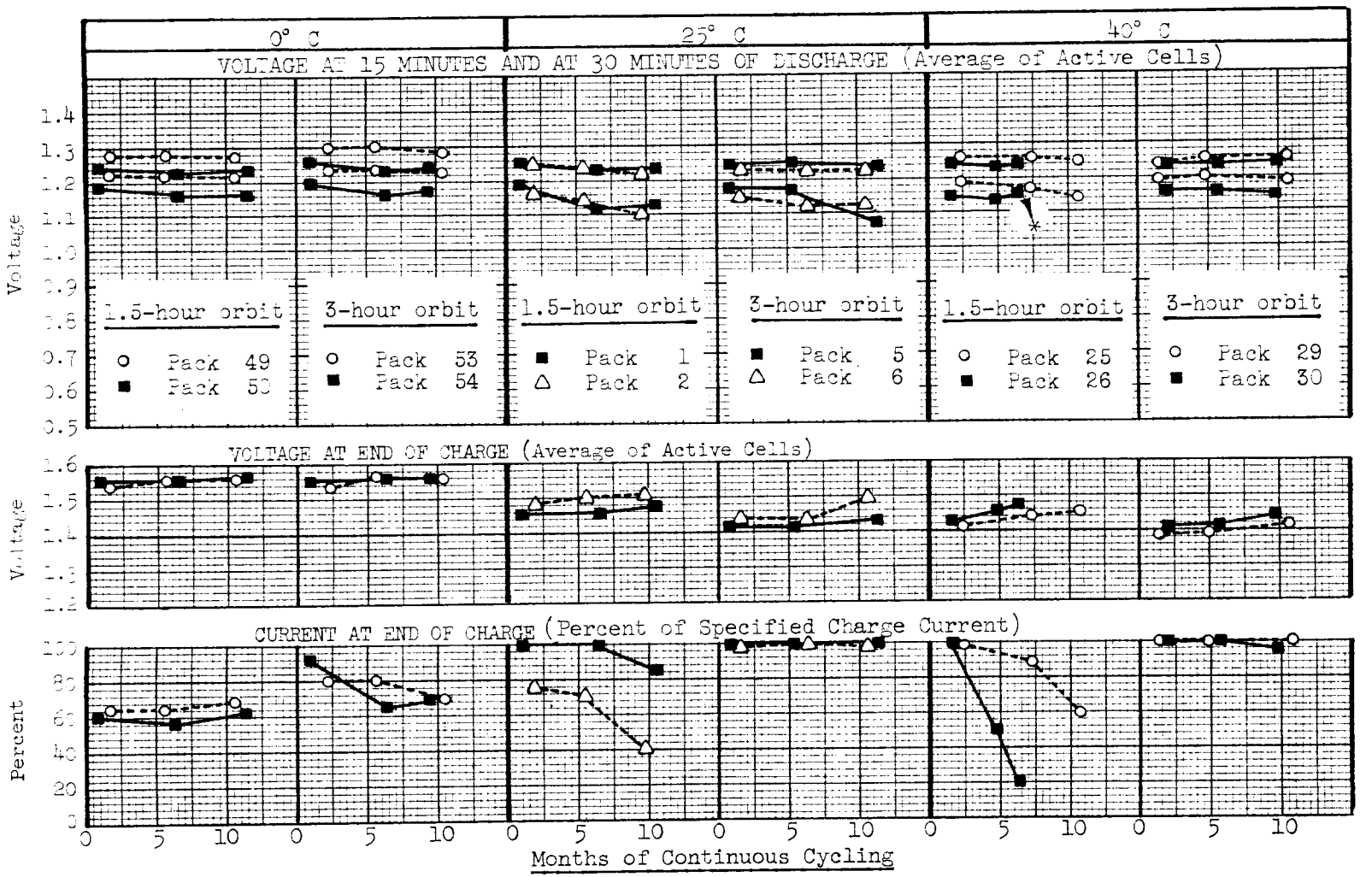


GULTON 20 a.h. CELLS. SUMMARY OF FIGURES 12(a)-12(l)

15% Depth of Discharge
25% Depth of Discharge
40% Depth of Discharge
Pack Failed

FIGURE 4(f)

QE/C 65-356



SONOTONE 5.0 a.h. CELLS. SUMMARY OF FIGURES 13(a)-13(l)

FIGURE 4(g)

QE/c 65-356

C. Performance at 50° C; Four Packs Held at 50° C:

1. Initially, the 28 packs assigned to the high temperature environment began cycling at 50° C. At the 25 percent depth of discharge, end-of-discharge voltages dropped steadily. Five cells failed within the first month of continuous cycling at that temperature. Among the Gulton 6.0 a.h. cells at 15 percent depth of discharge, end-of-discharge voltages also dropped and one cell failed. Earlier tests had indicated that, because charge acceptance is relatively inefficient at 50° C, the 25 percent depth of discharge was close to the maximum capacity that could be realized by many of the cell types under the prescribed cycling conditions. In addition, the separator materials were known to become unstable at temperatures somewhat above 40° C, so that separator deterioration was greatly accelerated. An ambient temperature of 40° C is the maximum recommended by the manufacturers.

2. In an attempt to maintain cycling at 50° C the percent of recharge for Pack 42 (Gulton 6.0 a.h., 25 percent depth, 3-hour orbit) was raised after 74 cycles to 200 percent by increasing the charge rate from c/6.25 to c/5. After 22 cycles at the new charge rate a cell failed and the attempt was discontinued.

3. Therefore, after having completed from 4.1 to 48.7 days of continuous cycling, all but four of the 28 high-temperature packs were moved to a 40° C ambient temperature. The four packs retained at 50° C ambient temperature and the cycles completed are given below:

Pack Number	Cell Type	Orbit Period	Cycles at 50° C	Additional Cycles at 40° C	Total Cycles to Pack Failure
40	G.E. 3.0 a.h.	1.5 hrs.	1440	1069	2509
32	Gould 3.5 a.h.	3 hrs.	495	479	974
126	Gould 20 a.h.	1.5 hrs.	1326	243	1569
122	Gould 20 a.h.	3 hrs.	756	227	983

Depth of Discharge: 25 percent for all four packs.

4. Cycles completed at 50° C are indicated by the shaded areas on Figures 3(a) through 3(g).

D. Cell Temperatures:

1. Table IV gives a typical temperature range during discharge and during charge for each of the 84 packs. These are readings from the thermocouples soldered to the positive terminals of the cells, and were taken during the month of March 1964. The temperatures in each case are the maximum for any cell in the pack, and the minimum for any cell in the pack.

2. At 25° C the cells are exposed directly to the moving air of the room. The midpoint of the temperature range at the positive terminals is usually from 5° to 10° C above ambient. Generally, for each type, the packs at the 40 percent depth of discharge show temperatures 3° to 5° C higher than those at the 25 percent depth, and at each depth the range for the 1.5-hour orbit is slightly higher than for the 3-hour orbit.

3. At 0° and 40° C the thermocouples are exposed to the rapidly moving air in the temperature chambers, which may account for the fact that the differences which had been observed at 25° C are less apparent. Thermocouple temperatures in the 0° C environment average 1° to 2° C above ambient, with the maximum temperature rise (8° to 9° C) being shown by the two Gould 20 a.h. packs cycling at 1.5 hours. The majority of packs in the 40° C environment showed almost no rise in average thermocouple temperature above ambient. This is also true for the three packs which were still cycling in the 50° C environment at that time. The maximum temperature rises noted at 40° C were for the Sonotone 5.0 a.h. and G.E. 12 a.h. packs operating at the 25 percent depth of discharge and 1.5-hour orbit, to 48.9° and 47.3° C respectively.

TABLE IV

TYPICAL RANGE OF PACK TEMPERATURE READINGS

Cell Type	Ambient Temp. °C	Percent Depth of Discharge	Orbit Period (Hours)	Temperatures Discharge Max.	Discharge Min.	Charge Max.	Charge Min.
G.E. 3.0 ah	0	15	1.5	4.0	0.6	4.2	0.4
	0	15	3	2.8	-2.7	4.0	-3.1
	0	25	1.5	2.2	-1.3	2.8	-1.1
	0	25	3	3.4	-1.1	2.8	-1.7
	25	25	1.5	31.4	27.8	31.5	27.5
	25	25	3	27.9	25.3	28.3	23.6
	25	40	1.5	36.5	28.3	36.8	28.8
	25	40	3	35.0	29.5	34.1	27.9
	40	15	1.5	41.9	39.5	41.9	39.8
	40	15	3	42.2	40.2	42.0	38.2
	50	25	1.5	52.3	48.3	52.3	49.5
	40	25	3	44.7	41.5	43.7	39.6
Gould 3.5 ah	0	15	1.5	4.3	0.4	4.2	1.1
	0	15	3	3.5	-0.7	3.0	-2.8
	0	25	1.5	5.2	0.6	4.4	-0.9
	0	25	3	4.8	-1.1	-4.2	-2.8
	25	25	1.5	42.1	29.8	41.9	30.2
	25	25	3	31.6	27.7	32.0	26.7
	25	40	1.5	41.6	31.5	40.0	31.2
	25	40	3	40.0	31.5	40.8	27.9
	40	15	1.5	43.5	40.6	42.9	40.0
	40	15	3	42.7	39.5	41.6	37.9
	40	25	1.5	40.0	37.6	40.0	36.2
	40	25	3	45.4	42.7	44.8	40.0
Sonotone 5.0 ah	0	15	1.5	2.0	-2.3	3.2	-1.9
	0	15	3	6.0	1.3	6.0	-0.8
	0	25	1.5	3.3	-0.7	2.8	-0.3
	0	25	3	4.0	-2.9	1.2	-3.9
	25	25	1.5	39.6	34.5	39.1	34.1
	25	25	3	34.2	29.1	34.3	28.3
	25	40	1.5	38.1	27.3	38.1	32.7
	25	40	3	36.0	29.6	37.0	29.3
	40	15	1.5	45.8	38.0	46.0	38.4
	40	15	3	43.9	41.2	44.1	40.0
	40	25	1.5	48.9	39.3	45.0	37.9
	40	25	3	44.6	41.2	44.8	41.0
Gulton 6.0 ah	0	15	1.5	3.4	-2.9	3.1	-3.3
	0	15	3	4.4	1.1	6.0	-1.5
	0	25	1.5	2.8	-0.3	4.0	-1.2
	0	25	3	4.8	-0.7	4.0	-0.7
	25	25	1.5	31.5	26.5	31.8	27.3
	25	25	3	31.9	26.8	31.4	25.0
	25	40	1.5	33.3	28.7	36.1	28.5
	25	40	3	35.6	27.3	36.0	26.8
	40	15	1.5	45.6	39.3	46.0	37.6
	40	15	3	44.6	40.8	44.6	40.0
	40	25	1.5	44.8	40.9	45.9	41.0
	40	25	3	40.8	37.9	41.7	38.0

TABLE IV (Contd)

Cell Type	Ambient Temp. °C	Percent Depth of Discharge	Orbit Period (Hours)	Temperatures Discharge Max.	Discharge Min.	Charge Max.	Charge Min.
G.E. 12 ah	0	15	1.5	2.8	-2.5	1.4	-2.5
	0	15	3	3.3	-0.9	3.2	-3.1
	0	25	1.5	3.2	-3.5	3.1	-0.9
	0	25	3	4.0	0.2	3.2	-1.1
	25	25	1.5	30.0	26.0	30.5	27.1
	25	25	3	32.0	26.0	30.4	23.8
	25	40	1.5	35.4	29.8	36.4	30.2
	25	40	3	35.0	27.5	35.8	25.8
	40	15	1.5	41.6	37.5	40.8	37.6
	40	15	3	41.9	38.1	41.0	38.1
	40	25	1.5	47.3	41.4	47.3	40.1
	40	25	3	44.8	39.6	42.9	39.2
Gould 20 ah	0	15	1.5	8.8	1.1	8.2	0.8
	0	15	3	4.0	-2.7	2.0	-1.3
	0	25	1.5	9.2	-1.3	8.0	-0.9
	0	25	3	3.0	-3.9	3.1	-1.1
	25	25	1.5	28.3	27.2	28.5	27.3
	25	25	3	30.6	25.8	30.0	23.7
	25	40	1.5	42.9	37.5	42.7	37.9
	25	40	3	39.6	31.2	37.0	27.9
	40	15	1.5	41.6	36.0	42.1	36.8
	40	15	3	41.6	38.6	42.7	38.1
	50	25	1.5	51.4	49.1	51.0	49.4
	50	25	3	55.0	49.6	51.4	49.6
Gulton 20 ah	0	15	1.5	3.2	-1.9	4.0	-0.7
	0	15	3	3.2	-4.1	1.2	-2.8
	0	25	1.5	4.8	-0.7	5.4	2.8
	0	25	3	3.3	-2.8	2.8	-3.3
	25	25	1.5	30.3	27.3	32.5	26.2
	25	25	3	31.2	26.0	31.8	27.3
	25	40	1.5	42.9	38.0	44.2	38.1
	25	40	3	36.2	25.4	38.0	26.2
	40	15	1.5	41.9	40.0	42.0	39.6
	40	15	3	41.9	38.1	42.0	37.7
	40	25	1.5	42.7	38.8	42.9	38.1
	40	25	3	43.5	39.5	45.8	41.4

E. Cell Failures.

1. Cell failures are discussed below, with detailed results of the failure analyses shown in Tables Va through Vg (pages 47 - 55).

2. Special Considerations:

a. The charge rates specified in the cycling program usually exceeded the maximum rates recommended by the manufacturers. For example, packs which are cycling in a 1.5-hour orbit at 25° C, 40 percent depth of discharge are being charged at the c/2 rate, although the maximum charge rate recommended by the manufacturers is c/10. The only charge rates below c/10 are those for the 3-hour orbit, 15 percent depth of discharge combinations, the rates for which are calculated to be c/14.5 at 0° C and c/10.4 at 40° C.

b. These cells were manufactured prior to January 1963. Because of subsequent changes in construction, newer cells of the same capacity and manufacturer may not show the characteristics discussed here. Also, the manufacturers have reported that corrective action has been taken to eliminate the sources of premature mechanical failure.

3. Definition and Description of Terms; Symbols Used in Tables Va through Vg: In order to clarify the discussion that follows, all terms are defined according to their use in this report. These are our definitions, and they may differ somewhat from usage elsewhere. Full descriptions are also included in order to simplify the remainder of the discussion.

a. The symbols used in Tables Va through Vg are explained with the column headings under which they are found. A given letter may differ in meaning, depending on the column in which it is used. A circle around a letter indicates that some form of electrical short was directly associated with the particular condition noted.

b. Definitions Used in Failure Analysis:

(1) End-of-charge Voltage: Cell voltage at the end of charge on the failure cycle, as compared to the average of the cells remaining in that pack. A cell voltage which differs by more than about 0.05 volt from the average of the remaining cells will be listed as high (H), or low (L), unless the cell was completely shorted (S) or open-circuited (O). Voltages not substantially different are indicated as normal (N). It will be seen that in a high percentage of examples the end-of-charge voltage seems to bear little relation to the results of the failure analysis and in many cases appears contradictory. Some of these may be due to the cells being stored for up to several weeks between the time of failure and the time of

analysis (while waiting for the manufacturer to assist); others may be related to the difficulty of examining the cells without affecting the internal configuration of the cell components.

(2) Weight Loss: The weight loss in grams between the weight at the time of acceptance and that at the time of failure. Gains or losses of less than one gram are not considered (slight gains may occur from traces of solder left on the cell terminals).

(3) Deposits: Carbonate deposits, at a point of leakage such as at a terminal (T) or seam (S). Deposits may or may not be accompanied by a weight loss as defined above. Deposits are not removed prior to weighing.

(4) High Pressure: Signified by a bulged cell case (B) or by a hissing of escaped gas when cell is opened (G). It may not be present at the time the cell is opened although the bulge indicates its presence at some earlier time.

(5) Concave Sides: Refers to rectangular cells only. The sides of the can are made permanently concave by the higher pressure of neighboring cells in the pack (X). This sometimes causes a short between the case and internal elements (Ⓧ).

(6) Weak Weld: An inadequate weld, as determined by the mechanical strength of the bond. The pieces separate, without tearing of the metal, when pulled apart by the fingers. This may be at a tab-to-plate connection (P), a tab-to-cell case connection (C), or a tab-to-terminal connection (T).

(7) Loosened Active Material: Positive plate active material which separates from the grid (X), when the plates are unrolled for failure analysis, and may come off in large, intact pieces. This condition is not noticed on flat plates, which are not flexed in the analysis.

(8) Extraneous Active Material: Pieces of loose active material found pressed between the plates (X). These are thought to have crumbled off the plate edges when the cell was being assembled, since there are no holes or bare spots on the plate itself. These pieces put pressure on the separator material and often cause a short circuit between the plates at that point (Ⓧ).

(9) Pierced Separator: Refers only to short circuits between plates, when caused by either a grid wire (Ⓦ) or a tab at the tab-to-plate connection (Ⓣ) piercing the separator and contacting the adjacent plate.

(10) Excess Scoring: Refers to the Sonotone 5.0 a.h. cells only. The two indentations which encircle the cell case put increased pressure on the outside layer of the plates and separators at these points. Usually this results only in increased migration of negative active material, but in some cases the scoring is deep enough to damage the wrap, plate, or separator just beneath the scoring marks (X). It may result in a short circuit between the case and the adjacent plate (Ⓧ).

(11) Burned Positive Tab: Refers to G.E. 3.0 a.h. cells only. The positive tab, above the plates, is burned (X) and sometimes broken (b). The broken tab may fall against the case and cause a short circuit (ⓑ). In all cases the tape with which the positive tab had been wrapped was also burned. At times the corrosion is such that the tab crumbles when the cell is opened, so that its prior configuration cannot be determined. The burned positive tab has been attributed to an insufficient area of welding between the tab and the positive terminal, causing a high-resistance contact. However, with one exception, this condition was found only among cells tested at 50° C - 40° C temperature where it was the predominant mode of failure. This suggests that additional factors are involved.

(12) Short Separator: Related to the burned positive tab of the G.E. 3.0 a.h. cells. The separator material just below the burned tab has pulled back, apparently from the heat generated, so that the plates are exposed (X). Usually a short between adjacent plates results (Ⓧ).

(13) Cermanic Short: Refers to Gulton cells only. It is a dark colored, conducting deposit which causes an electrical short across the ceramic insulator at the terminal, and is a result of the silver brazing used in the cells' manufacture. It is determined by measuring the resistance between the insulated terminal and the cell case after the plates have been cut off the buses. Its presence is fairly well defined, the measured resistance being on the order of 20 ohms or less (Ⓧ).

(14) Migration: Active material deposited on the surface of the separator, appearing as a uniform dark coating on the separator material (X). In small areas the plate material may penetrate completely through the separator (p) and be visible as small, dark spots on the positive plate side, usually resulting in a high-resistance short circuit. Where this condition is more pronounced there are burned spots on the separator at the points of penetration (ⓟ). Migration is always by the negative plate material except in two very advanced cases, where there was also slight migration from the positive plate (+). Migration is accelerated at points of localized pressure on the separator, especially around the edge of the

pressure area. For example in the round cells, where a pressure area is produced by a piece of tape covering the tab-to-plate connection, there is no migration at the taped area but a very dark line of migrated material outlines the tape's location. In addition, there may be brownish spots of discoloration around the edge of the tape ((t)), and usually a small hole in the center of each spot. A similar situation, due to the scoring of the Sonotone 5.0 a.h. cell case, also occurs ((s)).

(15) Blisters: Raised areas of active material, which have pulled away from the grid (+). Typically, they ranged from pinhead size to 3/8 inches in diameter, and were invariably found on the positive plates. While blistering has not been shown to have a direct bearing on cell failures, it is included here because it was common in some cell types, but rare or absent in others, and because in at least two cases the separator was burned slightly where blisters had compressed the separator material ((+)).

(16) Separator Deterioration: Decomposition of the separator material, exclusive of visible burned spots. Deteriorated separator material, as defined here, is decidedly thinner than normal, adheres to the negative plate, and has lost virtually all tensile strength (X). Shorts between the plates may result ((X)). In some of the round cells this condition may be absent at the outermost portion of the separator, but become progressively worse toward the center of the core (c).

4. Discussion of Failures:

a. General Observations:

(1) Cell failures were more frequent at higher ambient temperatures. Of the total of 191 cell failures, 21 were at 0° C, 82 at 25° C and 88 at 50°-40° C. The relatively small number of failures at 0° C is more striking when the individual cell types are examined. For example, the Gould 3.5 a.h. cells contributed nearly 39 percent of the total failures; yet none of these occurred at 0° C.

(2) In general, for a given cell type and temperature, failures occurred earliest at the greater depth of discharge, although there were exceptions. The 1.5-hour orbit was likewise more severe than the 3-hour orbit. These comparisons are shown in Figures 3(a) through 3(g).

(3) Many of the cell failures may be considered premature. That is, the failure appeared to result from a defect in manufacture or design. This is in contrast to an end-of-life failure, in which a basic component such as a separator has reached the end of its normal life span at the particular cycling conditions.

Some examples of premature failures are those due to leakage, pierced separator, burned tab, ceramic short, or extraneous active material.

(4) It is frequently difficult to isolate the exact cause of failure for a particular cell. In some cases several factors may have been responsible. In others it is not obvious why the conditions found should have resulted in failure. For this reason, unless otherwise stated, this report will not attempt to isolate the direct cause of failure; the conditions noted in Tables Va through Vg and in the discussions are included because they are abnormalities and because they may have contributed to the cell failure.

b. Discussion of Failures by Cell Type:

(1) G.E.: All failures of G.E. cells were analyzed by a representative of the manufacturer.

(a) 3.0 a.h. cells: There were 23 cell failures of which 17 were at the 50°-40° C ambient condition (one at 50° C before dropping temperature to 40° C) and six were at 25° C.

1. At 25° C, all failures were from Pack 16 (1.5-hour, 40 percent), with migration being the only failure condition in all but one of the six cells.

2. At the high temperatures, all but two of the failures were almost certainly related to burned tabs. Five of the cells, which failed on the 3-hour orbit, showed open circuit on cycling. Three of the cells, which failed on the 3-hour orbit, showed separator deterioration after 287 days. Although it is not indicated on Table Va, several cells had plates exposed at the edge of the roll, apparently due to improper placement of the separators.

(b) 12.0 a.h. cells: There were six cell failures, of which three were at 25° C and three were at 40° C. All were from the 1.5-hour orbit.

1. At 25° C, all failures showed shorting penetration (ⓟ) only.

2. At 40° C, two of the failed cells showed separator deterioration and all three showed migration.

(2) Gould: Initial failures were analyzed by a representative of the manufacturer. Later failures were analyzed by NAD Crane personnel, by direction of the manufacturer.

(a) 3.5 a.h. cells: There were 49 cell failures of which 29 were at the 50°-40° C ambient condition (three at 50° C before dropping temperature to 40° C) and 20 were at 25° C.

1. Migration was common after 100 days at 50°-40° C, and after 168 days at 25° C.

2. Separator deterioration became common after about 180 days at either temperature.

3. Twenty-two of the cells showed weight losses of 1.1 to 7.1 grams.

4. Twenty of the cells had one or more weak welds.

5. At each temperature, the distribution of of conditions found was quite similar for both orbit periods.

6. All 10 cells of Pack 28 (40° C, 25 percent, 1.5 hours) are shown as failures because the five cells remaining in the pack after 1811 cycles failed to cycle properly after a power failure had shut the pack off.

(b) 20 a.h. cells: There were 18 cell failures of which eight were at the 50°-40° C ambient condition (one at 50° C before dropping temperature to 40° C), nine were at 25° C, and one was at 0° C.

1. Nearly all of the cells developed high pressure, as evidenced by the release of gas when analyzing cells for cause of failure. The epoxy casing of some cells was cracked.

2. Most of the cells had a number of grid wire ends which protruded through the separators at the plate edges. This resulted in a short circuit in seven cells, all of which were in the 1.5-hour orbit.

3. Blisters were present on the positive plates of six cells.

4. The majority of the 18 cells failed rather suddenly, with little or no indication on previous cycles.

(3) Gulton: Initial failures were analyzed by a representative of the manufacturer. Later failures were analyzed by NAD Crane personnel, by direction of the manufacturer.

(a) 6.0 a.h. cells: There were 55 cell failures of which 20 were at the 50°-40° C ambient condition (four at 50° C before dropping temperature to 40° C), 23 were at 25° C, and 12 were at 0° C.

1. At each temperature, approximately 30 percent of the failed cells showed weight losses of 2.3 to 12.0 grams.

2. A ceramic short was exhibited by 58 percent of the failures at 0° C, by 70 percent of the failures at 25° C, and by 85 percent of the failures at 50°-40° C ambient condition.

3. Separator deterioration was rare, probably because 43 of the 55 cell failures occurred before completion of 200 days of cycling.

4. High pressure bulge was common among cells in the 0° C and 25° C environments.

(b) 20 a.h. cells: There were 23 cell failures of which three were at 40° C, 13 were at 25° C, and seven at 0° C.

1. Sixteen of the cells showed weight losses of 8.0 to 26.9 grams.

2. Five cells had ceramic shorts.

3. Thirteen cells showed evidence of high pressure.

4. Six cells were shorted as a result of concaved sides due to higher pressures of adjacent bulging cells. Three of these shorted cells indicated no leak and showed evidence of high internal pressure. The remaining three cells eventually became leakers, probably because of the inability of the terminal seals to withstand the internal pressures.

(4) Sonotone: All failures of Sonotone cells were analyzed by a representative of the manufacturer.

(a) 5.0 a.h. cells: There were 17 cell failures of which eight were at 40° C, eight were at 25° C, and one was at 0° C.

1. Many of these cells had exposed grid wires protruding through the separator at the center of the core, which resulted in the shorting of four cells.

2. Although excessive scoring of the cases produced an abnormal amount of wear on the plates of many cells, this resulted in only a few shorted cells. The plate material in one cell was broken beneath the scoring mark, resulting in a shorted cell.

3. Ten of the 17 cells showed weak welds, due primarily to insufficient cleaning of the weld area prior to welding.

4. Six of the eight failures at 40° C showed deteriorated separators.

TABLE Va

G.E. 3.0 a.h. CELLS. DATA ON CELL FAILURES THROUGH 31 DECEMBER 1964

Depth of Discharge	Pack Number	Cell Position in Pack	Cell Serial Number	Cycles Completed	Days of Cycling Completed	End-of-charge Voltage	Deposits	Loosened Active Material	Extraneous Active Material	Burned Positive Tab	Short Separator	Migration	Separator Deterioration	Additional Notes*
0° C; 1.5-hour and 3-hour orbits (No Failures)														
25° C; 1.5-hour orbit														
40%	16	7	427	3985	249	N				(b)				
40%	16	6	58	4473	280	N						p		1
40%	16	1	361	4741	296	N						p		
40%	16	5	522	4917	307	L						p		
40%	16	10	456	4917	307	L						p		
40%	16	4	719	5013	313	L						(p)		
25° C; 3-hour orbit (No Failures)														
50°-40° C; 1.5-hour orbit														
15%	39	2	541	779	49	H	T			X	(X)			2
25%	40	3	464	2073	130	H				X	(X)			
15%	39	6	540	2083	130	H	T			X	(X)			
25%	40	7	47	2182	136	H				b	(X)			
25%	40	8	3131	2182	136	N	T	X						
25%	40	5	49	2446	153	H				X				
25%	40	10	45	2461	154	H			X					
25%	40	2	466	2509	157	H	T			X				3
25%	40	6	441	2509	157	L				X	(X)			
15%	39	7	549	2532	158	H				X				
50°-40° C; 3-hour orbit														
15%	43	4	416	1182	148	L				X	(X)			
15%	43	3	499	1515	189	H				b	(X)			
25%	44	6	222	1672	209	O				X				
15%	43	6	412	1911	239	O				b				
15%	43	9	426	2298	287	O				b	X	p	X	
15%	43	7	436	2515	314	O				b			X	4
15%	43	10	435	2656	332	O				b		p	X	

*Additional Notes:

1. Short circuit between plates, no obvious cause.
2. Failed while pack was cycling at 50° C.
3. Tabs were found shorted together when cell was opened.
4. Short circuit between plates due to improper separator placement.

TABLE Vb

G.E. 12 a.h. CELLS. DATA ON CELL FAILURES THROUGH 31 DECEMBER 1964

Depth of Discharge	Pack Number	Cell Position in Pack	Cell Serial Number	Cycles Completed	Days of Cycling Completed	End-of-charge Voltage	Deposits	Migration	Separator Deterioration
0° C; 1.5-hour and 3-hour orbits (No Failures)									
25° C; 1.5-hour orbit									
40%	96	3	445	3822	239	L		(D)	
40%	96	2	446	4020	251	L		(D)	
40%	96	4	442	4020	251	L		(D)	
25° C; 3-hour orbit (No Failures)									
50°-40° C; 1.5-hour orbit									
25%	99	3	429	3841	240	L	T	D	
25%	99	2	432	3841	240	L		X	X
25%	99	1	440	4853	303	L		X	X
50°-40° C: 3-hour orbit (No Failures)									

TABLE Vc

GOULD 3.5 a.h. CELLS. DATA ON CELL FAILURES THROUGH 31 DECEMBER 1964

Depth of Discharge	Pack Number	Cell Position in Pack	Cell Serial Number	Cycles Completed	Days of Cycling Completed	End-of-charge Voltage	Weight Loss (grams)	Deposits	High Pressure	Weak Weld	Extraneous Active Material	Pierced Separator	Migration	Blisters	Separator Deterioration
0° C; 1.5-hour and 3-hour orbits (No Failures)															
25° C; 1.5-hour orbit															
40%	4	7	81	1609	101	L	3.2	T	B						
40%	4	8	90	1827	114	L	2.7	T	B						
40%	4	1	2	2110	132	L			G						c
25%	3	5	73	2785	174	H					(X)				
40%	4	6	43	2954	185	L	1.3	T					X		
40%	4	3	27	3029	189	N		T							X
25%	3	2	54	3090	193	L	1.7	T		P					
40%	4	10	198	3164	198	L	1.6	T			X				X
25%	3	9	165	4081	255	N	1.7	T		P		(t)			
25%	3	6	93	4289	268	N	2.6	T					X		X
25%	3	7	97	4401	275	N	2.5	T					X		X
25%	3	4	77	4751	297	N							X	+	X
25%	3	10	188	4751	297	N	2.1	T					X		
25° C; 3-hour orbit															
40%	8	6	68	1346	168	L	1.5	T					X		
40%	8	8	112	1704	213	N	2.0	T		P,C					
40%	8	1	39	1985	248	N		T					X		X
40%	8	10	170	1985	248	N	1.8	T		P					c
40%	8	7	78	2138	267	L	1.4	T		C			X		X
40%	8	2	41	2494	312	L	1.7	T		P			X		X
40%	8	9	130	2494	312	L	2.1	T					+		X

TABLE Vc (continued)

GOULD 3.5 a.h. CELLS. DATA ON CELL FAILURES THROUGH 31 DECEMBER 1964

Depth of Discharge	Pack Number	Cell Position in Pack	Cell Serial Number	Cycles Completed	Days of Cycling Completed	End-of-charge Voltage	Weight Loss (grams)	Deposits	High Pressure	Weak Weld	Loosened Active Material	Extraneous Active Material	Pierced Separator	Migration	Blisters	Separator Deterioration	Additional Notes*
				50°-40° C; 1.5-hour orbit													
25%	29	2	122	408	26	N	1.8	T		C							1
25%	28	7	157	484	30	N	2.0	T	B								
25%	28	8	158	484	30	N	1.9	T	B								
25%	28	5	141	860	54	H	3.5	T									
25%	28	10	168	1293	81	H				C							
25%	28	1	121	1811	113	L							(W)				
25%	28	3	133	1811	113	H				C							
25%	28	4	140	1811	113	L								(t)	+		
25%	28	6	155	1811	113	L				C				(p)			
25%	28	9	163	1811	113	L		T		C				(p)			
15%	27	3	13	2901	181	L	1.5	T			X					X	
15%	27	8	195	2901	181	N	3.6	T			X					(c)	
15%	27	7	103	2998	187	N			B			(X)					
15%	27	10	200	3270	204	N	2.5	T		C				(p)		c	
15%	27	9	197	4102	256	H	1.4	T						(t)		X	
15%	27	2	11	4485	280	N		T						X		X	
				50°-40° C; 3-hour orbit													
25%	32	6	125	138	17	N				C							1,2
25%	32	3	65	495	62	N	1.5	T									1,3
25%	32	1	1	800	100	L	3.2	T						(p)		(c)	
25%	32	4	67	875	109	L	2.2	T		C				(t)			
25%	32	7	132	875	109		4.4	T	(B)								4
25%	32	9	149	974	122	H	1.1	T		P,C		(X)					
15%	31	9	R166	1500	188	L	7.1	T								X	
15%	31	10	R179	1500	188	L	1.5	T		P				(p)		X	
15%	31	2	R92	1696	212	H						(X)				X	
15%	31	3	126	2411	301	L	2.1	T		P		(X)		X		X	
15%	31	8	R162	2477	310	H	2.4	T		C				p		X	
15%	31	1	72	2517	315	L	1.8	T		P		(X)				X	
15%	31	6	143	2517	315	L			G	P,T		(X)		X		X	

*Additional Notes:

1. Failed while pack was cycling at 50° C.
2. Corrosion noted on negative tab.
3. Glass at seal was broken.
4. Cell ruptured from high internal pressure while pack was shut

TABLE Vd

GOULD 20 a.h. CELLS. DATA ON CELL FAILURES THROUGH 31 DECEMBER 1964

Depth of Discharge	Pack Number	Cell Position in Pack	Cell Serial Number	Cycles Completed	Days of Cycling Completed	End-of-charge Voltage	High Pressure	Extraneous Active Material	Pierced Separator	Migration	Blistering	Separator Deterioration	Additional Notes*
			0° C; 1.5-hour orbit										
25%	98	5	77	3556	222	L				X		X	
			0° C; 3-hour orbit (No Failures)										
			25° C; 1.5-hour orbit										
40%	118	2	61	1747	109	L	G		(W)				
40%	118	4	R91	1963	123	L	G		(W)				
25%	104	1	69	2672	167	L	G		(W)				
25%	104	5	R36	2826	177	L	G	X	(W)				
40%	118	5	92	2937	184	L	G	(X)					
25%	104	3	5	2980	186	L	G					(X)	
			25° C; 3-hour orbit										
40%	119	5	73	222	28	L							1
40%	119	2	80	1793	224		G			X	+		
40%	119	3	86	1793	224		G			X	+		
			50°-40° C; 1.5-hour orbit										
25%	126	3	9	1273	80	L	G		(W)				2
25%	126	4	R29	1509	94	L	G		(W)		+	X	
25%	126	5	11	1569	98	L	G		(W)				
15%	112	1	17	5005	313	L	G					(X)	
15%	112	2	25	5005	313	L	G					(X)	
			50°-40° C; 3-hour orbit										
25%	122	2	16	801	100	L	G			X	+	X	
25%	122	3	58	801	100	L	G			X	+	X	
25%	122	5	18	983	123	L	G			X	+		

*Additional Notes:

1. Short circuit between plates, near edge; no obvious cause.
2. Failed while pack was cycling at 50° C.

TABLE Ve

GULTON 6.0 a.h. CELLS. DATA ON CELL FAILURES THROUGH 31 DECEMBER 1964

Depth of Discharge	Pack Number	Cell Position in Pack	Cell Serial Number	Cycles Completed	Days of Cycling Completed	End-of-charge Voltage	Weight Loss (grams)	Deposits	High Pressure	Concave Sides	Pierced Separator	Ceramic Short	Migration	Blisters	Separator Deterioration	Additional Notes*
				0° C; 1.5-hour orbit												
15%	61	5	2397	2762	173	L						(X)				
25%	62	10	1630	2995	187	H	6.8	T	B					+		1
25%	62	4	1792	4066	254	L					(t)			+	X	
15%	61	4	1825	4094	256	L			B			(X)	X	+		
15%	61	10	2311	4285	268	L			B			(X)	X	+		
15%	61	6	2400	4413	276	L			B			(X)		+		
25%	62	5	1806	4441	278	L			B			(X)		+		
				0° C; 3-hour orbit												
25%	66	6	1794	1045	131	H	5.1		B	(X)						1
25%	66	8	1843	1173	147	L				X		(X)				
25%	66	5	1781	1237	155	H		T	B					(+)		1
25%	66	3	1634	1417	177	N	2.3		B	X		(X)		+		
25%	66	7	1823	2122	265	L	7.8	T	B	X			X	+		
				25° C: 1.5-hour orbit												
40%	14	4	1623	262	16	H	12.0		B							
40%	14	5	1635	262	16	L	6.0	T	B	X						1
25%	13	1	2305	308	19	H	12.0	T	B							
40%	14	1	2356	450	28	H	12.0		B							
25%	13	10	2355	502	31	H	10.0		B							
40%	14	2	2387	1113	70	H						(X)				
40%	14	3	2391	1618	101	L						(X)				
40%	14	7	3208	2086	130	N						(X)				
25%	13	5	3134	2969	186	L						(X)		+		
25%	13	7	3211	3084	193	L						(X)		+		
25%	13	4	2613	3598	225	L						(X)		+	X	
25%	13	2	2324	4021	251	L			B			(X)	X	+	X	
				25° C; 3-hour orbit												
40%	18	6	1826	365	46	N	3.0			X		(X)				
40%	18	3	1615	608	76	N	5.1	T	B							
40%	18	7	1827	643	80	H			B			(X)				
40%	18	9	2228	643	80	H						(X)				
25%	17	3	1823	721	90	H			B			(X)			(X)	
25%	17	5	1862	721	90	H						(X)				
40%	18	5	1562	1145	143	L						(X)		+		
40%	18	1	1233	1550	194	L						(X)	X	+		
25%	17	10	2348	1688	211	L						(X)				
25%	17	1	1757	2375	297	L		T	B			(X)				
25%	17	2	1598	2449	306	L			B				p	+		

*Additional Notes:

1. Broken ceramic at seal.

TABLE Ve (continued)

GULTON 6.0 a.h. CELLS. DATA ON CELL FAILURES THROUGH 31 DECEMBER 1964

Depth of Discharge	Pack Number	Cell Position in Pack	Cell Serial Number	Cycles Completed	Days of Cycling Completed	End-of-charge Voltage	Weight Loss (grams)	Deposits	High Pressure	Concave Sides	Ceramic Short	Blisters	Additional Notes*
50°-40° C; 1.5-hour orbit													
25%	38	8	1454	37	2	S					X		1
25%	38	6	1815	114	7	L	3.5				X		1
25%	38	9	1853	187	12	N	4.0	T			X		
25%	38	3	1627	225	14	H	3.5						2
15%	37	3	1764	238	15	L	4.0				X		1
25%	38	5	2405	1333	83	N				X			
25%	38	2	1626	1377	86	L			B		X		
15%	37	8	1784	1566	98	L	10.5				X		
15%	37	4	1802	2819	176	L					X	+	
15%	37	10	2333	2981	186	N					X	+	
50°-40° C; 3-hour orbit													
25%	42	8	2309	96	12	N					X		1
25%	42	7	2346	382	48	L		S					
25%	42	9	2306	416	52	H					X		
25%	42	1	918	484	61	L	3.1	S	B		X		
15%	41	9	1771	649	81	H					X		
15%	41	6	1801	1062	133	N					X		
15%	41	2	3135	1132	142	N					X		
15%	41	7	1852	1157	145	N					X	+	
15%	41	8	2221	1157	145	N					X		
15%	41	3	1632	1689	211	N					X	+	

*Additional Notes:

1. Failed while pack was cycling at 50° C.
2. High end-of-charge voltage on cycle 219: cell was internally shorted by cycle 225.

TABLE Vf

GULTON 20 a.h. CELLS. DATA ON CELL FAILURES THROUGH 31 DECEMBER 1964

Depth of Discharge	Pack Number	Cell Position in Pack	Cell Serial Number	Cycles Completed	Days of Cycling Completed	End-of-charge Voltage	Weight Loss (grams)	Deposits	High Pressure	Concave Sides	Ceramic Short	Migration	Blisters	Separator Deterioration	Additional Notes*
0° C; 1.5-hour orbit															
25%	115	3	490	2107	132	N	26.9			(X)					
25%	115	2	508	2203	138	H			B	(X)			+		
25%	115	4	467	2291	143	H			B	(X)			(+)		
15%	101	2	435	3111	194	H	24.6	T	B						
15%	101	5	407	3111	194	H	20.4	T							
15%	101	4	438	3629	227	H	13.2	T	B	X			+		
0° C; 3-hour orbit															
15%	102	2	449	135	17	S			(B)	(X)					
25° C; 1.5-hour orbit															
40%	87	1	468	136	9	H	8.0		B						
40%	87	2	388	208	13	H	26.7				(X)				
40%	87	5	386	627	39	L	18.1		B		(X)				1
40%	87	3	394	627	39	H	16.4	T	B		(X)				
40%	87	4	454	627	39	L	21.6	T		(X)					
25%	73	3	396	1776	111	N	23.7			X					2
25° C; 3-hour orbit															
40%	88	1	404	151	19	H	25.0	T	B						
40%	88	2	422	151	19	H	25.0	T	B						
40%	88	3	466	358	45	H	16.4		B						
40%	88	5	429	358	45	L					(X)				
25%	74	4	458	1184	148	L	14.2	T					+		
25%	74	3	419	1302	163	N	21.9	T							
25%	74	2	440	1754	219	N	18.0	T		(X)		X			
50°-40° C; 1.5-hour orbit															
25%	90	4	452	2824	177	L			B,G					(X)	
25%	90	5	457	2824	177	N			B,G				+		3
25%	90	3	378	4045	253	S					(X)			X	
50°-40° C; 3-hour orbit (No Failures)															

*Additional Notes:

1. Burned spots on separator near top of plates.
2. Broken ceramic at negative seal.
3. Small short circuit between plates: no obvious cause.

TABLE Vg

SONOTONE 5.0 a.h. CELLS. DATA ON CELL FAILURES THROUGH 31 DECEMBER 1964

Depth of Discharge	Pack Number	Cell Position in Pack	Cell Serial Number	Cycles Completed	Days of Cycling Completed	End-of-charge Voltage	Deposits	High Pressure	Weak Weld	Extraneous Active Material	Pierced Separator	Excess Scoring	Migration	Separator Deterioration	Additional Notes*
				0° C; 1.5-hour orbit											
15%	49	9	6887	2010	126	L		B	P				(t)		
				0° C: 3-hour orbit (No Failures)											
				25° C; 1.5-hour orbit											
25%	1	4	4361	2995	187	H	T						X		1
40%	2	10	811	3155	197	S	T	B	P		(W)				
40%	2	5	3628	3992	250	N	T	B					X		2
40%	2	2	3613	4411	276	L			P			(X)		X	
25%	1	1	4335	4423	276	H			P			(X)		c	
				25° C; 3-hour orbit											
40%	6	8	4324	1069	134	N							X		
40%	6	10	6904	1136	142	L					(W)		+		
40%	6	4	3637	1161	145	S			P	(X)	(W)				
				50°-40° C; 1.5-hour orbit											
25%	26	1	4323	2487	155	S					(W)			X	
25%	26	9	6773	2902	181	S		G	P				(t)	X	
25%	26	6	7224	2993	187	N	T	B	P				X	X	
25%	26	7	7232	2993	187	N	T	B	P			X		X	
25%	26	3	4881	3344	209	S						(X)			
25%	26	4	4240	3625	227	L		B					P	X	
				50°-40° C; 3-hour orbit											
25%	30	7	3657	855	107	S			P					(X)	3
15%	29	1	3626	1418	177	S			P				(s)		

*Additional Notes:

1. Foreign particle shorted adjacent plates through separator.
2. Defect (hole) in separator.
3. Projection on positive plate wore through insulator and shorted to case.

F. Capacity Checks.

1. Results of ampere-hour measurements on preconditioning and capacity check cycles are listed in Tables VIIIa through VIIIg, and are plotted in Figures 5(a) through 5(g) in terms of percent of rated capacity.

2. Initial Capacity Versus Temperature:

a. For each cell type, the average preconditioning capacity of each group of four packs at 0°, at 25°, and at 50° C may be obtained from Figures 5(a) through 5(g) and are listed and compared in Table VI below. For example, the average preconditioning capacity of the four packs of G.E. 3.0 a.h. cells at 0° C was about 118 percent of the rated 3.0 a.h. capacity. In comparing the average capacities at 0° and at 50° C with those at 25° C, for each cell type, it was found that the capacities at 0° C were from 83 to 95 percent of those at 25° C, with an average of 88 percent. At 50° C the range was from 38 to 57 percent of the 25° C capacities, with an average of 45 percent. For the 40° C preconditioning capacities this comparison is somewhat less meaningful because the packs had already cycled for varying amounts of time at 50° C and had probably been affected differently. As compared with the 25° C preconditioning capacities, those at 40° C ranged from 39 to 65 percent, averaging 55 percent.

b. Comparing preconditioning capacities at 40° C and 50° C in a similar manner, capacities at 40° C were from 101 to 140 percent of those at 50° C, the average for the seven cell types being 123 percent.

TABLE VI

AVERAGE PRECONDITIONING CAPACITIES AS PERCENT OF:

	RATED CAPACITY				PRECONDITIONING CAPACITIES AT OTHER TEMPERATURES			
TYPE	0°	25°	50°	40°	0°/25°	50°/25°	40°/25°	40°/50°
G.E. 3.0	118	131	57	80	89	43	61	140
G.E. 12	119	125	58	67	95	46	54	116
Gould 3.5	98	118	45	55	83	38	46	123
Gould 20	114	122	47	47	93	38	39	101
Gulton 6.0	78	95	45	62	83	47	65	138
Gulton 20	92	108	47	60	85	44	55	127
Sonotone 5.0	105	117	67	76	90	57	65	114
				Minimum	83	38	39	101
				Average	88	45	55	123
				Maximum	95	57	65	140

3. Differences Between First and Second Discharges:

a. The first capacity discharge is begun 15 minutes after completion of the regular cycling charge period. The second capacity discharge is begun 15 minutes after completion of a 16-hour charge at the c/10 rate. At least three factors will affect differences in the ampere-hours delivered on the two discharges. First, the pack may not have been fully charged due to poor charge acceptance on cycling. Second, the so-called "Memory Effect" may limit the depth to which the cells can be discharged with the prescribed discharge rate and cutoff point (this is discussed further in paragraph IV.F.5.). The third factor is the charge rate. A lower charge rate will frequently result in a lower discharge capacity, especially at temperatures of 25° C or higher. Since the majority of packs receive a higher charge rate on cycling than on capacity check, this could partially offset the effects of the first two factors.

b. As is shown in Figures 5(a) through 5(g), the first discharge capacity is usually somewhat less than the second, especially at 25° C. The greatest increases on the second discharge were shown by the Gould and Gulton cells at 0° and at 25° C. Among these the greatest consistent difference, in terms of rated capacity, was about 40 percent, as shown by Pack 3 (Gould 3.5 a.h., 25 percent depth, 25° C, 1.5 hours).

4. Capacity Versus Days of Cycling:

a. In order to compare changes in capacity with time, a procedure similar to that used for comparing temperature effects was used. All comparisons are between the second discharge after 264 days of cycling and the preconditioning capacity. Only those packs which had not failed before this third capacity check are considered. For example, among the G.E. 3.0 a.h. cells at 40° C, one of the original four packs failed before its third capacity check. Only the remaining three, then, were included in the comparisons at 40° C, so that for these particular packs the average capacity on preconditioning at 40° C was 78.4 percent of rated capacity, and that on the third capacity check was 45 percent of the rated capacity. The 264-day capacity was therefore 45/78.4 or 57.4 percent of the preconditioning capacity. Similar computations for all of the cell types at each temperature showed that at 0° C the 264-day capacities ranged from 85.6 to 103.1 percent of the 0° C preconditioning capacities, the average being 92.6 percent. Likewise at 25° C the 264-day capacities ranged from 33.6 to 91.4 percent of the 25° C preconditioning capacities, the average being 55.4 percent. The percentages of the 40° C, 264-day capacities ranged from 48.9 to 177.5 percent of the 40° C preconditioning capacities, the average being 79.9 percent. Results at 40° C are

again complicated by the prior cycling at 50° C. The unusual rise to 177.5 percent was by the two Gould 20 a.h. packs at 15 percent depth of discharge, of which one had an unusually low preconditioning capacity and the other showed an increase in capacity with each capacity check.

b. Except for the Gould cells at 25° C and 40° C, which retained a much higher percentage of their preconditioning capacities after 264 days of cycling, the capacity losses at each temperature for all cell types after 264 days of cycling were within a fairly narrow range, as shown in Table VII. At 40° C, the apparently high percentage of the preconditioning capacity retained by the Gould cells after 264 days of cycling is due partly to the comparatively low preconditioning capacity.

TABLE VII

COMPARISON OF CAPACITIES AFTER 264 DAYS CYCLING AS PERCENT OF RATED AND INITIAL (PRECONDITIONING) CAPACITIES

Manufacturer and Type (a.h.)	AT 0° C			AT 25° C			AT 40° C		
	Number of Packs	Preconditioning Percent of Rated	After 264 Days of Cycling Percent of Rated	After 264 Days of Cycling Percent of Preconditioning	Number of Packs	Preconditioning Percent of Rated	After 264 Days of Cycling Percent of Rated	After 264 Days of Cycling Percent of Preconditioning	Number of Packs	Preconditioning Percent of Rated	After 264 Days of Cycling Percent of Rated	After 264 Days of Cycling Percent of Preconditioning
G.E. 3.0	4	117.6	111.3	94.6	4	131.6	74.2	56.4	3	78.4	45.0	57.4
G.E. 12	4	118.6	101.5	85.6	3	125.8	54.3	43.2	4	67.1	39.8	59.3
Gould 3.5	4	98.0	97.3	99.3	3	120.1	83.9	69.9	2	56.3	58.0	103.0
Gould 20	4	114.4	101.3	89.0	1	116.5	106.5	91.4	2	41.3	73.3	177.5
Gulton 6.0	4	78.1	68.6	87.8	2	96.7	43.3	44.8	2	61.7	35.0	56.7
Gulton 20	2	96.0	99.0	103.1	1	116.5	39.2	33.6	3	61.4	30.0	48.9
Sonotone 5.0	4	105.4	93.8	89.0	4	116.9	57.1	48.8	3	80.3	45.6	56.8
Minimum		78.1	68.6	85.6		96.7	39.2	33.6		41.3	30.0	48.9
Average		104.0	96.2	92.6		117.9	65.5	55.4		63.8	46.7	79.9
Maximum		118.6	111.3	103.1		131.6	106.5	91.4		80.3	58.0	177.5

TABLE VIIIa

G.E. 3.0 a.h. AMPERE-HOUR CAPACITIES ON PRECONDITIONING CYCLES AND CAPACITY CHECKS

Test Temperature	Depth of Discharge	Orbit Period (hours)	Pack Number	Preconditioning	Preconditioning at 40° C	88 Days		176 Days		264 Days		352 Days	
						Discharge #1	Discharge #2	Discharge #1	Discharge #2	Discharge #1	Discharge #2	Discharge #1	Discharge #2
0° C	15%	1.5	63	3.48		3.15	3.18	3.10	3.12	2.90	3.05	2.88	3.03
		3	67	3.63		3.25	3.12	3.40	3.25	3.53	3.27	2.90	2.97
	25%	1.5	64	3.50		3.30	3.33	3.70	3.53	3.30	3.38	3.28	3.35
		3	68	3.50		3.25	3.35	3.53	3.35	3.30	3.40	3.20	3.27
25° C	25%	1.5	15	4.00		3.38	3.28	2.82	2.93	2.18	2.33	1.70	1.95
		3	19	3.93		3.78	3.70	3.48	3.48	3.05	3.15	2.70	3.00
	40%	1.5	16	4.08		2.37	2.75	1.83	2.10	1.35	1.33		
		3	20	3.78		2.98	3.00	2.03	2.35	1.68	2.07	1.20	1.83
50° - 40° C	15%	1.5	39	1.65	2.43	2.10	1.92	1.40	1.53	0.95	1.25	0.85	1.17
		3	43	1.77	2.63	2.20	1.98	1.58	1.61	1.53	1.65		
	25%	1.5	40	1.80	2.50	0.73*	0.88*	0.88	0.86				
		3	44	1.60	2.00	1.17	1.35	1.05	1.19	1.08	1.15		

* At 50° C.

TABLE VIIIb

G.E. 12 a.h. AMPERE-HOUR CAPACITIES ON PRECONDITIONING CYCLES AND CAPACITY CHECKS

Test Temperature	Depth of Discharge	Orbit Period (hours)	Pack Number	Preconditioning	Preconditioning at 40° C	88 Days		176 Days		264 Days	
						Discharge #1	Discharge #2	Discharge #1	Discharge #2	Discharge #1	Discharge #2
0° C	15%	1.5	110	13.9		10.8	12.7	9.88	10.4	12.0	13.0
		3	111	14.2		11.7	13.2	10.3	10.7	10.3	11.0
	25%	1.5	124	14.2		13.2	13.5	12.4	12.9	11.8	12.8
		3	125	14.6		11.8	13.0	10.6	12.1	11.0	11.9
25° C	25%	1.5	82	15.2		8.00	7.80	7.57	5.55	3.90	5.50
		3	83	15.2		11.7	11.5	7.70	8.20	4.90	6.13
	40%	1.5	96	14.8		5.00	6.00	6.16	7.65	5.70	7.90
		3	97	14.9		5.00	5.60	5.19	5.86		
50° - 40° C	15%	1.5	85	6.80	8.20	4.80	5.00	4.70	4.70	4.26	5.00
		3	86	7.10	8.20	6.30	5.90	2.80	3.70	2.70	4.00
	25%	1.5	99	6.90	6.00	3.40	4.90	4.50	5.20	3.90	4.40
		3	100	7.00	9.80	2.90	3.80	4.70	4.70	3.15	5.70

TABLE VIIIc

GOULD 3.5 a.h. AMPERE-HOUR CAPACITIES ON PRECONDITIONING CYCLES AND CAPACITY CHECKS

Test Temperature	Depth of Discharge	Orbit Period (hours)	Pack Number	Preconditioning	Preconditioning at 40° C	88 Days		176 Days		264 Days		352 Days	
						Discharge #1	Discharge #2	Discharge #1	Discharge #2	Discharge #1	Discharge #2	Discharge #1	Discharge #2
0° C	15%	1.5	51	3.62		3.97	4.00	3.06	3.33	2.83	3.41	2.71	3.21
		3	55	3.27		3.06	3.59	2.83	3.15	3.21	3.38	2.60	3.33
	25%	1.5	52	3.33		3.73	3.85	3.35	3.53	2.51	3.18	1.23	3.30
		3	56	3.50		3.82	3.91	3.18	3.53	3.24	3.65	3.21	3.41
25° C	25%	1.5	3	4.00		2.51	3.82	1.46	2.92	1.20	2.25		
		3	7	4.32		3.94	4.03	3.79	3.76	3.41	3.53	1.63	2.77
	40%	1.5	4	3.94		3.30	3.38	2.07	2.77				
		3	8	4.29		3.68	3.65	3.30	3.35	2.54	3.03		
50° - 40° C	15%	1.5	27	1.52	2.63	2.07	1.93	1.72	1.95	0.64	1.90		
		3	31	1.60	1.31	1.66	1.75	1.66	1.98	1.49	2.16		
	25%	1.5	28	1.55	2.07	1.90	2.86						
		3	32	1.55	1.66	0.82	1.49						

TABLE VIIId

GOULD 20 a.h. AMPERE-HOUR CAPACITIES ON PRECONDITIONING CYCLES AND CAPACITY CHECKS

Test Temperature	Depth of Discharge	Orbit Period (hours)	Pack Number	Preconditioning	Preconditioning at 40° C	88 Days		176 Days		264 Days	
						Discharge #1	Discharge #2	Discharge #1	Discharge #2	Discharge #1	Discharge #2
0° C	15%	1.5	84	22.5		25.7	27.7	24.2	26.5	23.0	24.2
		3	80	23.0		18.7	23.2	20.0	21.5	17.0	20.3
	25%	1.5	98	23.0		19.0	21.2	7.60	15.2	14.8	18.7
		3	94	23.0		15.0	17.5	13.3	25.0	16.3	18.2
25° C	25%	1.5	104	25.0		11.8	18.5	12.2	14.0		
		3	105	23.3		22.2	23.5	19.3	22.2	19.7	21.3
	40%	1.5	118	24.7		23.0	23.3				
		3	119	24.8		17.5	24.7	21.7	19.5		
50° - 40° C	15%	1.5	112	9.67	6.83	15.7	12.2	15.2	15.3	3.50	12.5
		3	108	9.50	9.67	11.8	9.83	14.2	14.8	14.2	16.8
	25%	1.5	126	9.00	13.9	15.0	15.2				
		3	122	9.33	7.50	4.67*	8.17*				

* At 50° C.

TABLE VIIIe

GULTON 6.0 a.h. AMPERE-HOUR CAPACITIES ON PRECONDITIONING CYCLES AND CAPACITY CHECKS

Test Temperature	Depth of Discharge	Orbit Period (hours)	Pack Number	Preconditioning	Preconditioning at 40° C	88 Days		176 Days		264 Days		352 Days	
						Discharge #1	Discharge #2	Discharge #1	Discharge #2	Discharge #1	Discharge #2	Discharge #1	Discharge #2
0° C	15%	1.5	61	5.00		5.10	5.10	4.65	5.40	3.70	4.45		
		3	65	4.50		4.65	5.45	5.00	5.35	4.75	5.15		
	25%	1.5	62	5.00		1.40	4.75	2.60	3.80	3.15	4.35		
		3	66	4.25		2.80	5.00	1.50	3.50	1.50	2.50	2.40	3.80
25° C	25%	1.5	13	5.80		2.34	2.75	1.60	2.85	2.10	2.70		
		3	17	5.80		1.70	3.65	2.95	3.45	2.00	2.50		
	40%	1.5	14	6.40		2.65	3.45						
		3	18	4.55		4.15	4.95	2.10	3.16				
50° - 40° C	15%	1.5	37	2.75	3.60	0.80	1.70	2.95	2.20	0.80	1.85		
		3	41	2.75	4.55	1.80	2.05	1.20	1.63				
	25%	1.5	38	2.65	2.90	1.20	1.55						
		3	42	2.60	3.80	1.60	2.15	1.85	2.10	1.82	2.35		

TABLE VIIIf

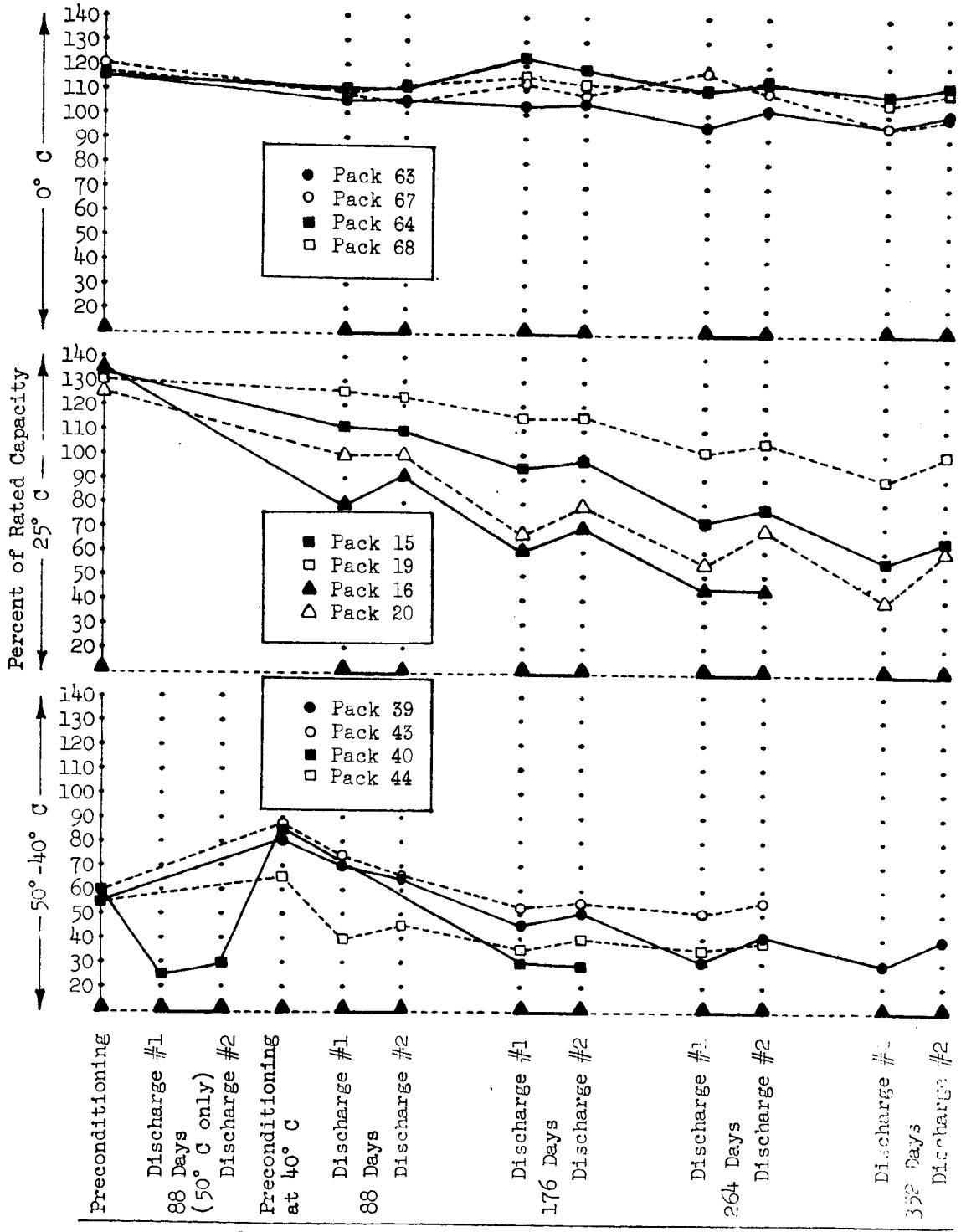
GULTON 20 a.h. AMPERE-HOUR CAPACITIES ON PRECONDITIONING CYCLES AND CAPACITY CHECKS

Test Temperature	Depth of Discharge	Orbit Period (hours)	Pack Number	Preconditioning	Preconditioning at 40° C	88 Days		176 Days		264 Days	
						Discharge #1	Discharge #2	Discharge #1	Discharge #2	Discharge #1	Discharge #2
0° C	15%	1.5	101	17.2		12.5	12.2	3.00	5.67		
		3	102	16.7		18.8	18.3	21.0	25.2	20.2	20.3
	25%	1.5	115	17.7		4.83	11.2				
		3	116	21.7		20.1	20.7	20.8	21.8	17.7	19.3
25° C	25%	1.5	73	23.3		5.67	7.17	6.60	9.50	5.33	7.83
		3	74	20.3		4.00	6.17	4.83	7.17		
	40%	1.5	87	23.3							
		3	88	19.8							
50° - 40° C	15%	1.5	76	10.3	13.8	6.00	6.50	3.67	4.83	3.93	5.50
		3	77	9.50	12.7	5.67	7.33	3.67	5.33	3.17	4.83
	25%	1.5	90	9.00	11.3	4.50	6.00	9.17	10.3		
		3	91	9.17	10.3	4.50	6.67	4.83	6.67	6.17	7.67

TABLE VIIIg

SONOTONE 5.0 a.h. AMPERE-HOUR CAPACITIES ON PRECONDITIONING CYCLES AND CAPACITY CHECKS

Test Temperature	Depth of Discharge	Orbit Period (hours)	Pack Number	Preconditioning	Preconditioning at 40° C	88 Days		176 Days		264 Days		352 Days	
						Discharge #1	Discharge #2	Discharge #1	Discharge #2	Discharge #1	Discharge #2	Discharge #1	Discharge #2
0° C	15%	1.5	49	5.45		3.67	5.54	5.08	5.50	4.79	4.96	4.46	4.79
		3	53	5.64		5.75	5.79	5.38	5.67	5.21	5.42	4.65	5.33
	25%	1.5	50	5.04		4.58	4.96	4.25	4.58	3.83	4.25	3.17	3.79
		3	54	4.92		3.63	3.96	3.50	3.96	3.42	4.13	3.33	3.96
25° C	25%	1.5	1	5.42		3.25	3.67	1.92	2.33	2.21	2.88	1.67	2.79
		3	5	5.71		4.17	4.58	2.42	3.04	1.29	2.04		
	40%	1.5	2	6.42		3.79	4.38	3.38	4.17	2.46	3.25		
		3	6	5.83		3.04	4.50	2.50	3.29	2.42	3.25		
50° - 40° C	15%	1.5	25	3.08	3.63	1.92	2.25	1.38	1.83	2.04	2.04		
		3	29	3.33	4.92	1.92	2.75	1.38	2.38	1.17	2.42		
	25%	1.5	26	3.17	3.17	1.63	2.75	2.93	2.67				
		3	30	3.75	3.50	1.63	1.88	2.17	2.88	1.54	2.38		



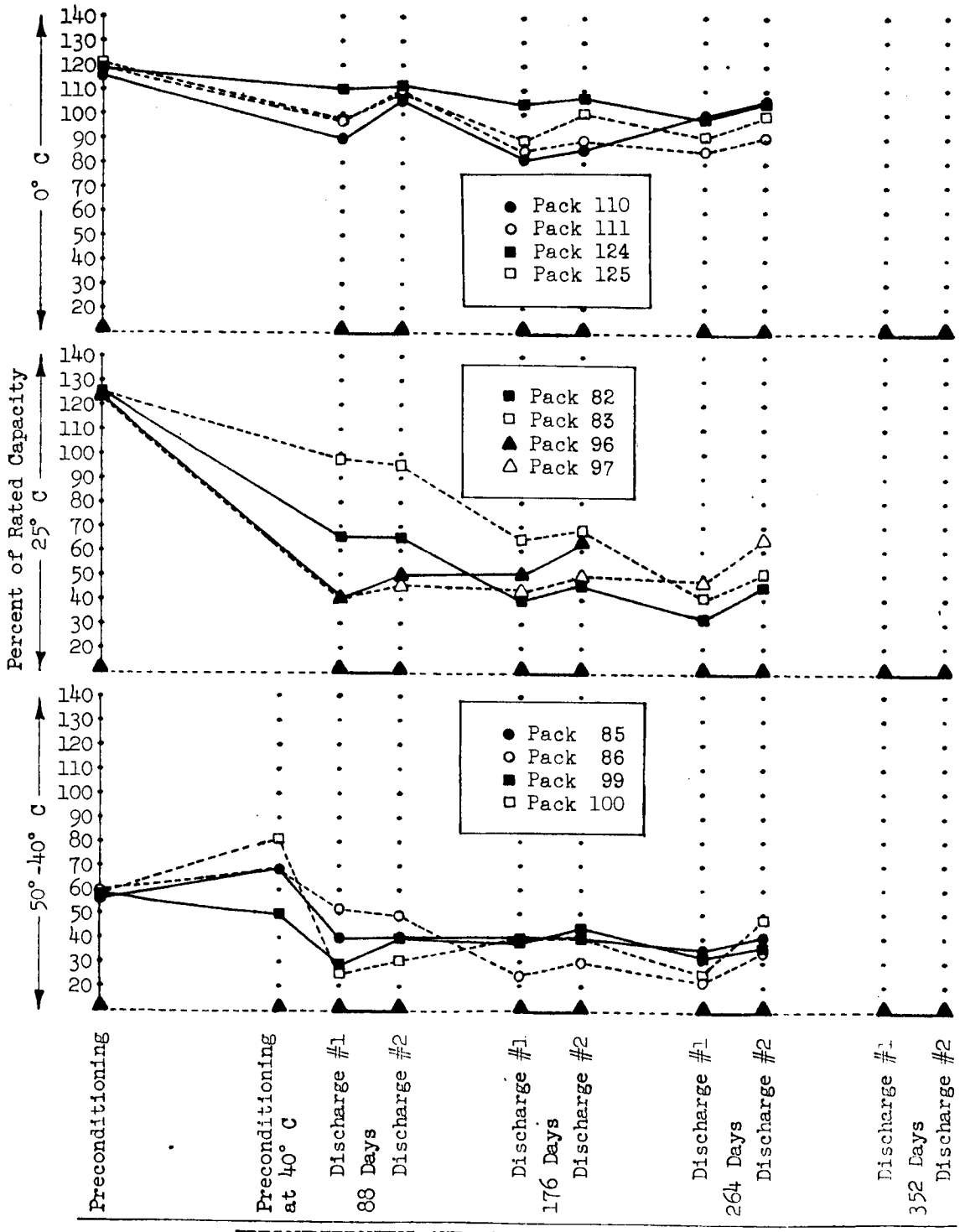
PRECONDITIONING AND CAPACITY CHECK CYCLES

(Measured ampere-hours expressed as percent of rated capacity)

G.E. 3.0 a.h.

1.5-hr. Orbit	3-hr. Orbit	Depth of Discharge
●—	--○--	15%
■—	--□--	25%
▲—	--△--	40%

FIGURE 5(a)

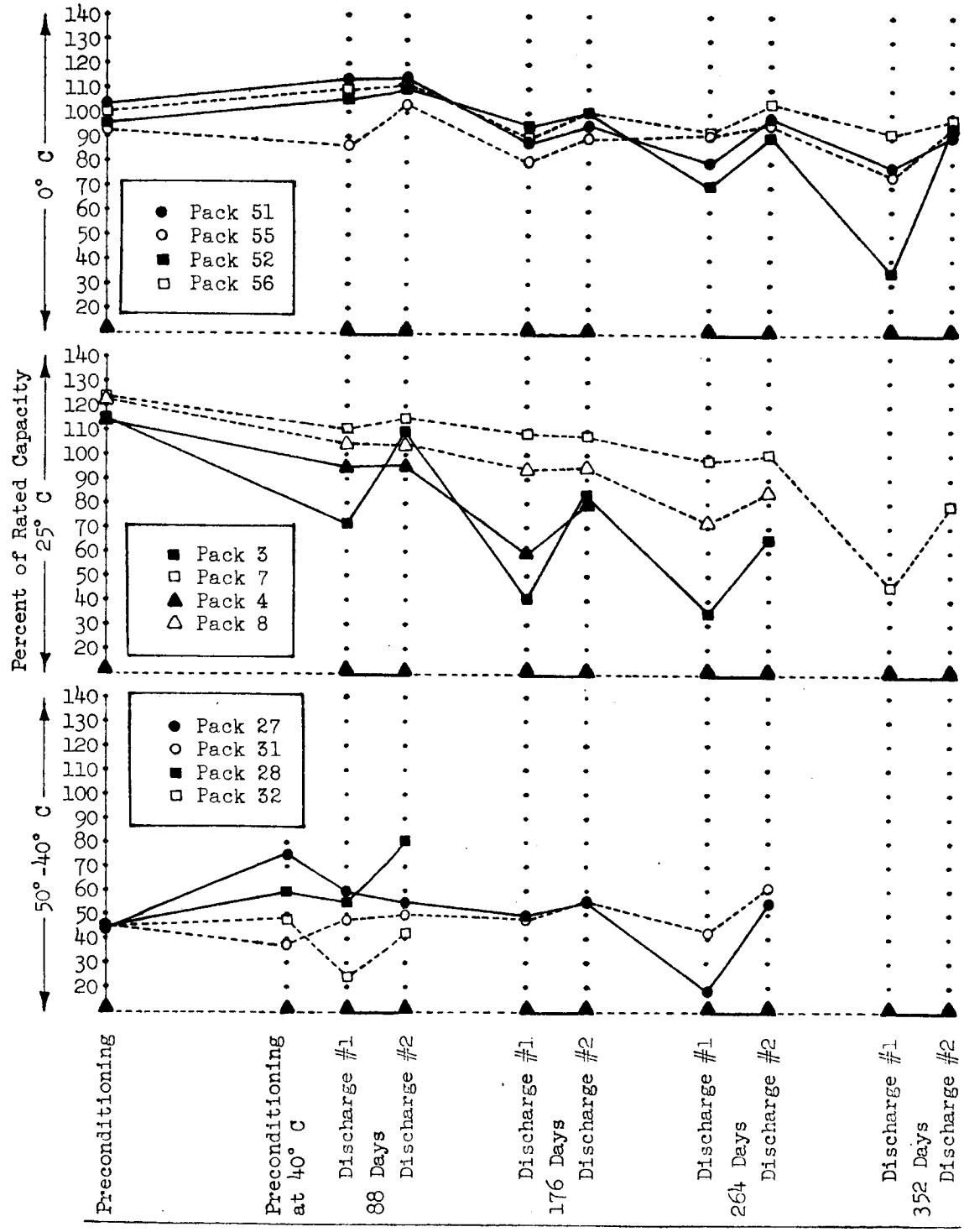


PRECONDITIONING AND CAPACITY CHECK CYCLES

(Measured ampere-hours expressed as percent of rated capacity)

G.E. 12 a.h.	1.5-hr. Orbit	3-hr. Orbit	Depth of Discharge
	●—	-○-	15%
	■—	-□-	25%
	▲—	-△-	40%

FIGURE 5(b)



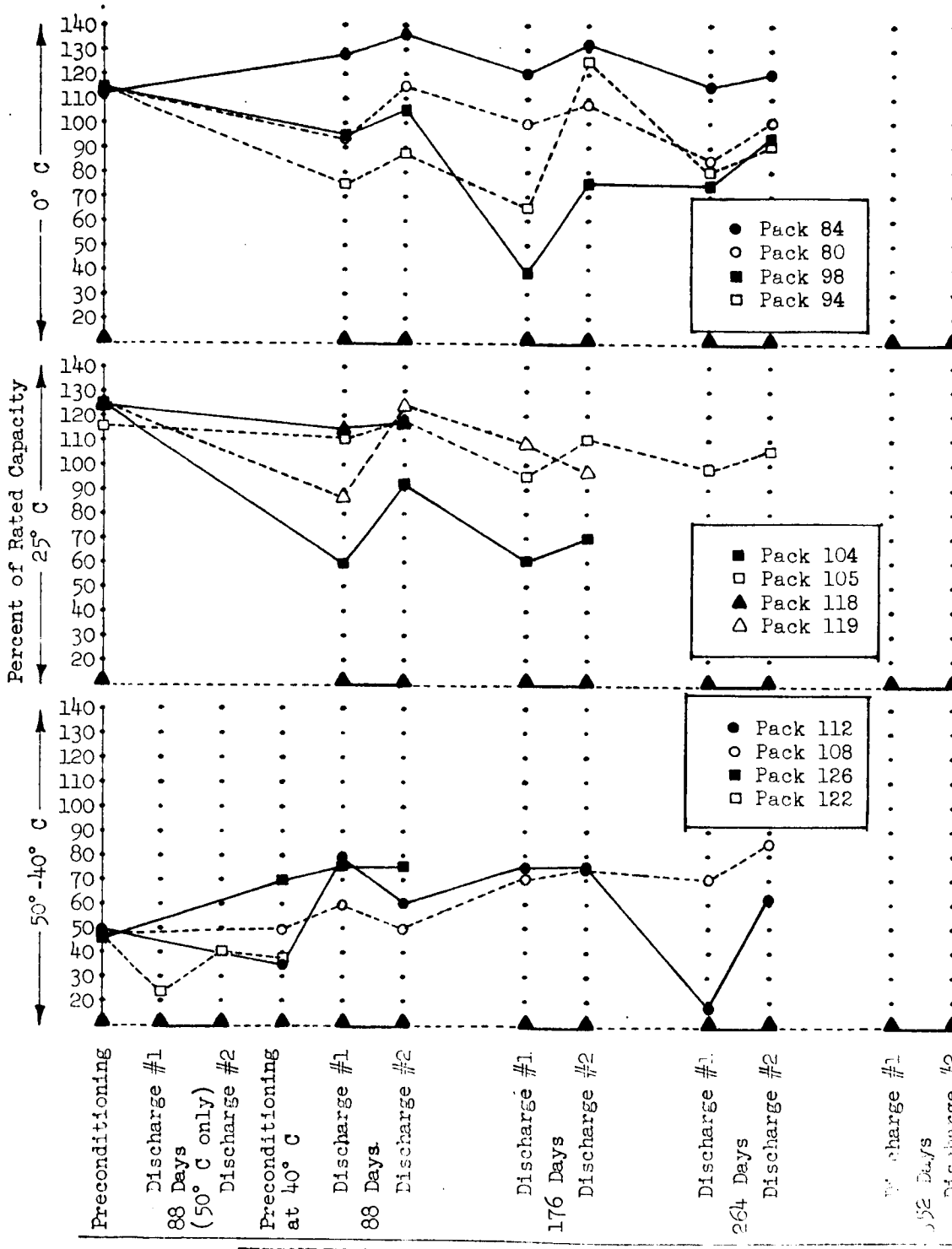
PRECONDITIONING AND CAPACITY CHECK CYCLES

(Measured ampere-hours expressed as percent of rated capacity)

Gould 3.5 a.h.

1.5-hr. Orbit	3-hr. Orbit	Depth of Discharge
●—	-○-	15%
■—	-□-	25%
▲—	-△-	40%

FIGURE 5(c)



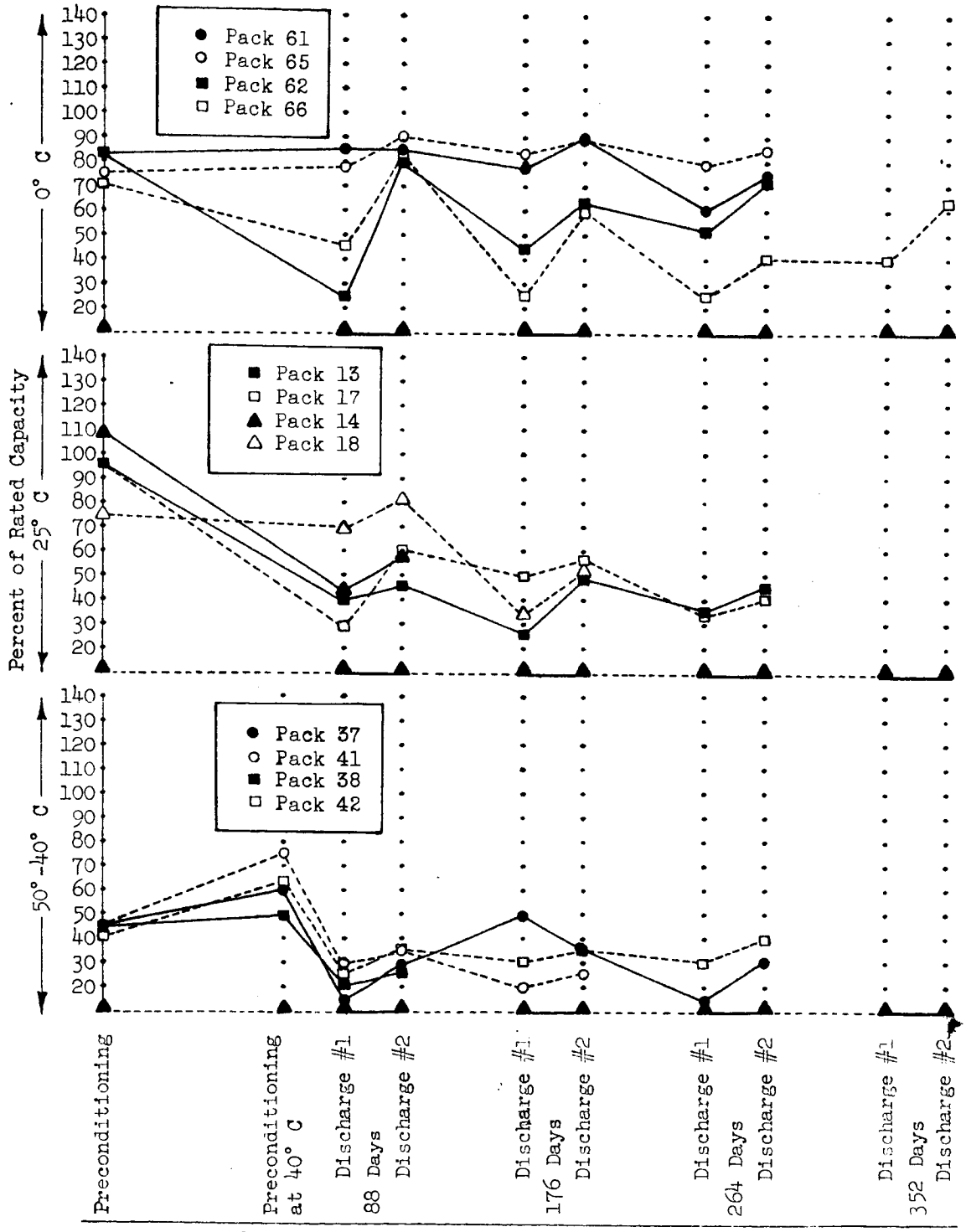
PRECONDITIONING AND CAPACITY CHECK CYCLES

(Measured ampere-hours expressed as percent of rated capacity)

Gould 20 a.h.

1.5-hr. Orbit	3-hr. Orbit	Depth of Discharge
●	○	15%
■	□	25%
▲	△	40%

FIGURE 5(d)



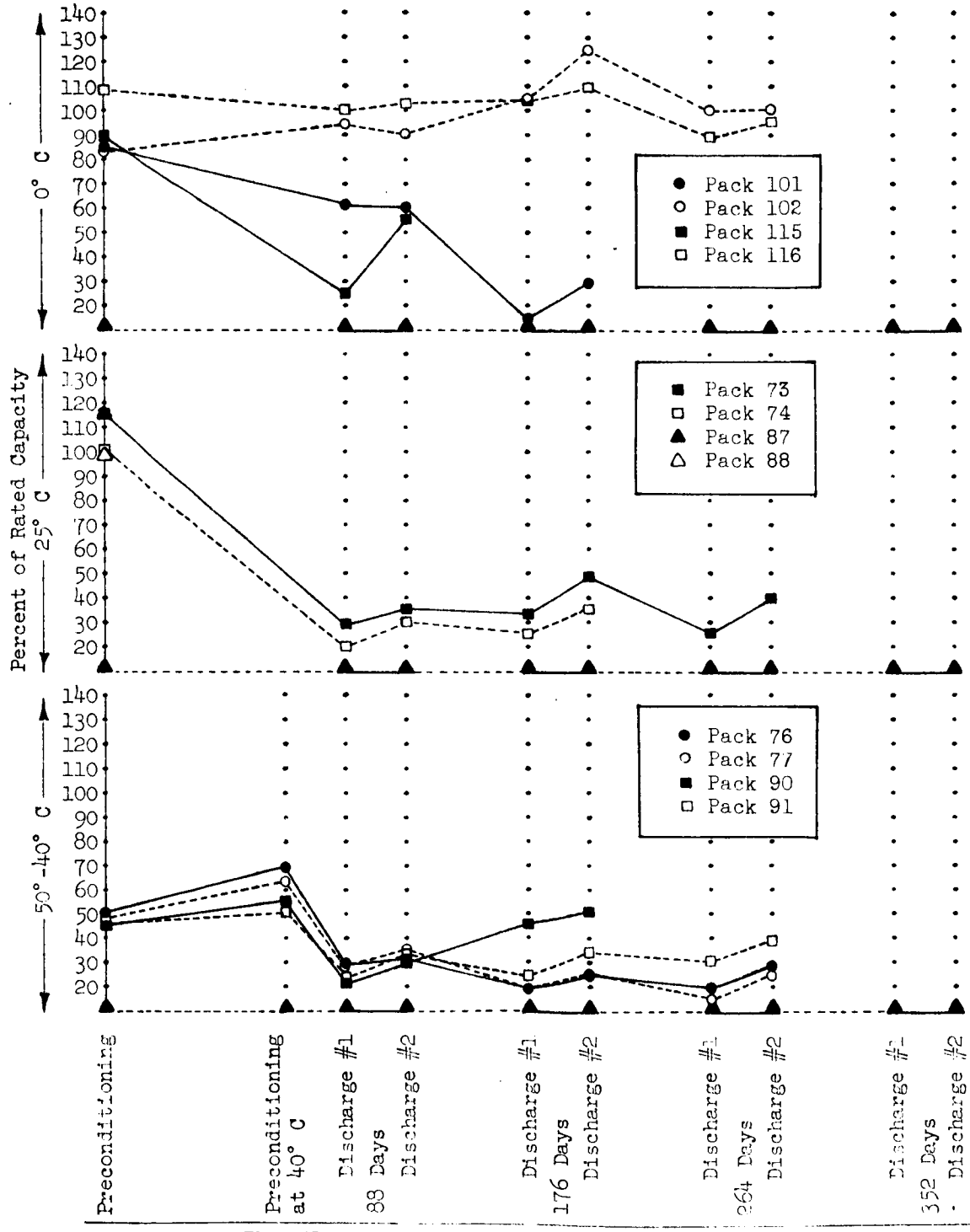
PRECONDITIONING AND CAPACITY CHECK CYCLES

(Measured ampere-hours expressed as percent of rated capacity)

Gulton 6.0 a.h.

1.5-hr. Orbit	3-hr. Orbit	Depth of Discharge
—●—	--○--	15%
—■—	--□--	25%
—▲—	--△--	40%

FIGURE 5(e)



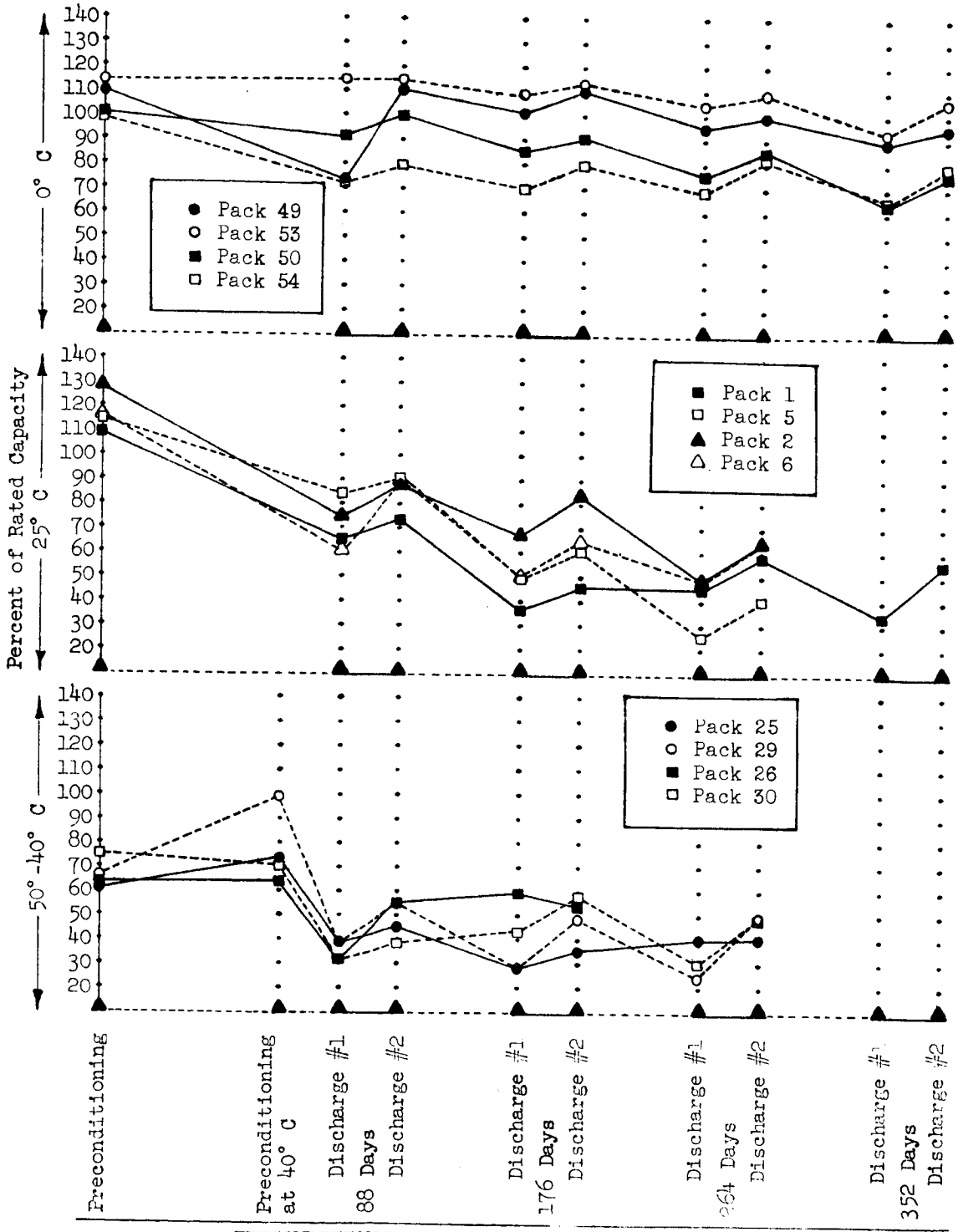
PRECONDITIONING AND CAPACITY CHECK CYCLES

(Measured ampere-hours expressed as percent of rated capacity)

Gulton 20 a.h.

1.5-hr. Orbit	3-hr. Orbit	Depth of Discharge
●—	-○-	15%
■—	-□-	25%
▲—	-△-	40%

FIGURE 5(f)



PRECONDITIONING AND CAPACITY CHECK CYCLES

(Measured ampere-hours expressed as percent of rated capacity)

Sonotone 5.0 a.h.	1.5-hr. Orbit	3-hr. Orbit	Depth of Discharge
	●—	-○-	15%
	■—	-□-	25%
	▲—	-△-	40%

FIGURE 5(g)

5. "Memory Effect":

a. Because of the conflicting opinions regarding its nature, we hesitate to attribute test results definitely to memory effect. Briefly, it may be described as a condition wherein a cell, after a number of identical cycles, will drop below one volt as soon as it is discharged beyond the depth of discharge at which it was cycled, even though it was fully charged at the start of the discharge. Where this effect is operating, one would expect the first discharge on a capacity check to yield approximately 15, 25 or 40 percent of the rated capacity, depending on the depth at which the pack was being cycled. Such a result was observed, and was strongly dependent on cell type. It was most prominent at all three temperatures among certain of the Gulton 6.0 a.h. and 20 a.h. packs although some packs of other types showed it occasionally at 25° C and 40° C.

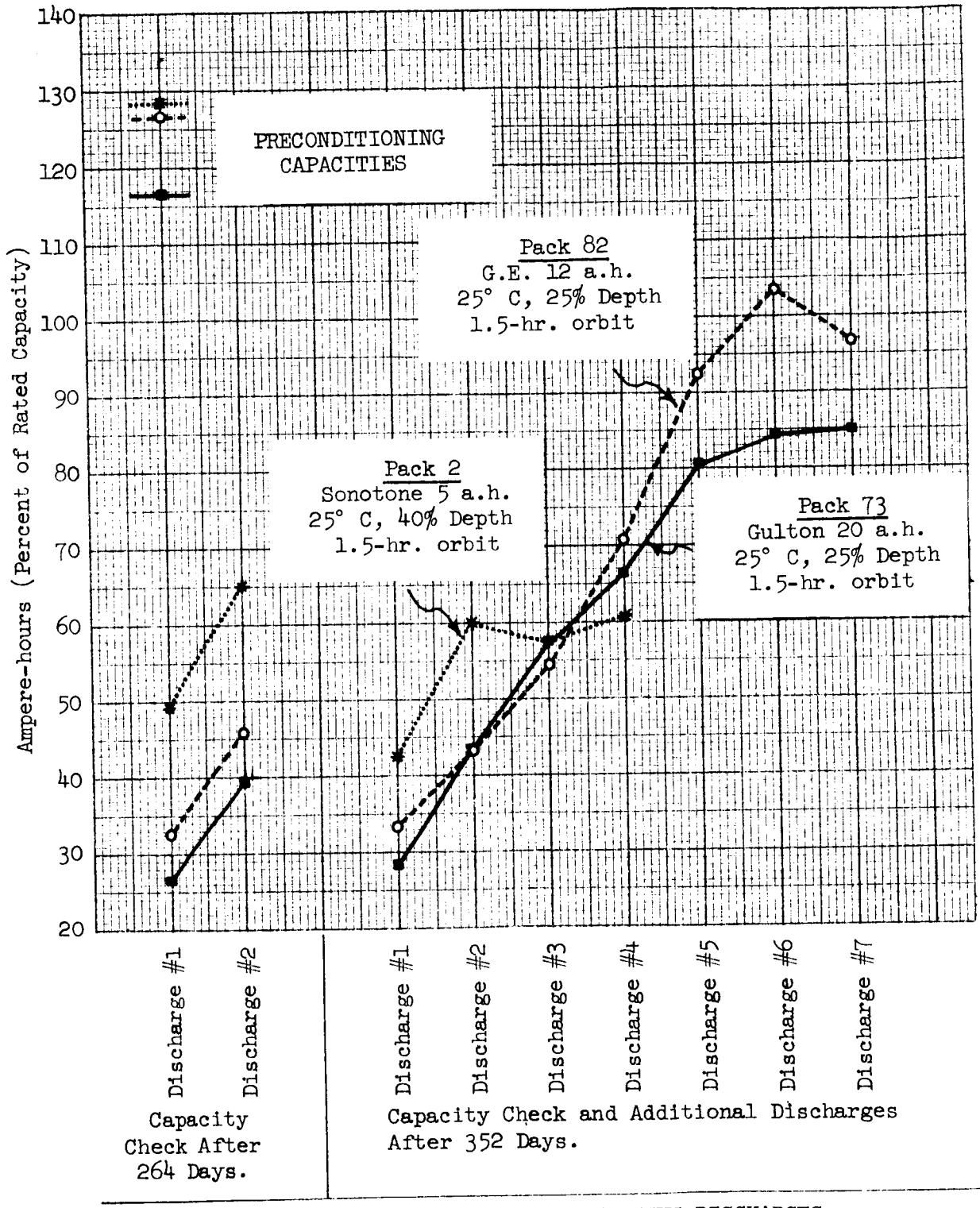
b. The first discharge of the capacity check and the subsequent 16-hour charge at c/10 are designed to break the memory effect and otherwise prepare the packs for a truer capacity measurement on the second discharge. Nonetheless, after the first 88 days some packs showed a considerable loss of capacity which was never regained, although the subsequent losses were fairly small. Good examples of this are found among the G.E. 12 a.h. and Gulton 20 a.h. packs at 25° C.

c. In order to obtain additional information, three packs which had shown considerable loss of capacity at 25° C were subjected to a series of cycles similar to those of the capacity checks. The packs first underwent their regular, scheduled capacity check procedures after 352 days of cycling, including the final 48-hour charge. Then, instead of being returned to automatic cycling, the packs were given a series of cycles consisting of the capacity check discharge to the normal cutoff voltage, which was recorded, followed by a continued discharge at a lower rate until the cells could be shorted externally for at least 12 hours, and a recharge at the c/10 rate for 24 hours. This procedure was repeated until no significant increase in capacity was obtained.

d. The three packs selected were Pack 82 (G.E. 12 a.h., 25° C, 25 percent depth, 1.5 hours), Pack 73 (Gulton 20 a.h., 25° C, 25 percent depth, 1.5 hours), and Pack 2 (Sonotone 5.0 a.h., 25° C, 40 percent depth, 1.5 hours). The results are shown in Figure 6. During the four discharges following the capacity check after 352 days of cycling, the capacities of the G.E. and Gulton cells both increased from 43 to 104 and 85 percent respectively, of their rated capacities. However, the previous capacity checks of these cells showed a maximum yield of 66 percent of the rated capacity for the G.E. 12 a.h. cell on the capacity check following 88 days of cycling, and a maximum yield of 50 percent of the rated capacity

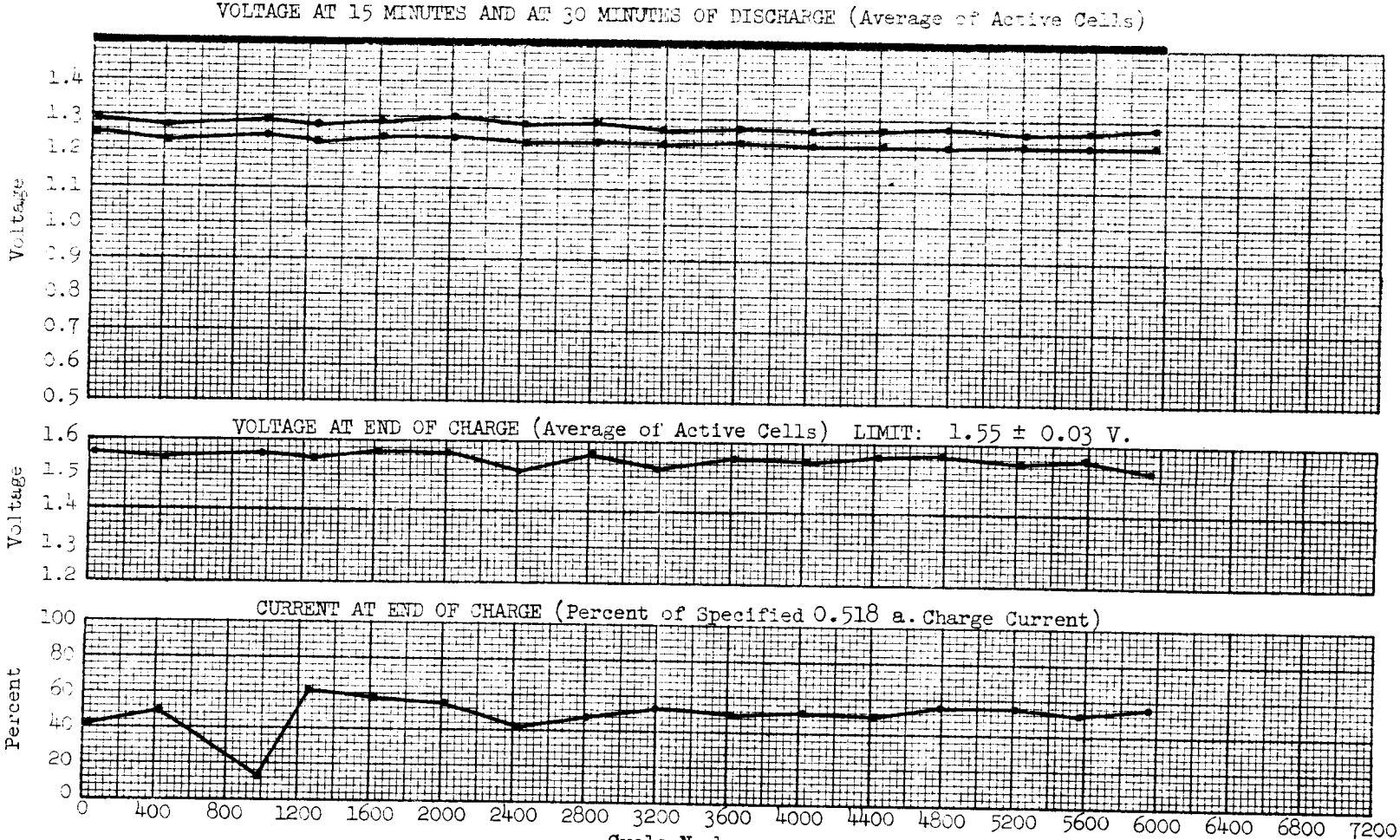
for the Gulton 20 a.h. cells on the capacity check following 176 days of cycling. The additional discharges of the Sonotone 5.0 a.h. cells showed no increase in capacity over that of the capacity check following 352 days of cycling, which was 60 percent of the rated capacity. (The results for these capacity checks are not shown elsewhere than in Figure 6 because they were obtained after 31 December 1964.)

e. These results may indicate that the memory effect can be broken more easily on the Sonotone cells than on those having SAFT plates (the G.E. and Gulton cells). In discussing these results with manufacturers and users, we have not been able to obtain any clear explanation of the phenomenon. There is conflicting opinion as to whether the data reflect a regainable loss of capacity or a very temporary "false" gain induced by the special test procedure itself. It sufficient interest in memory effect exists, it is suggested that a study program be initiated to investigate it in detail.



AMPERE-HOUR CAPACITIES ON SEVERAL SUCCESSIVE DISCHARGES AFTER 352 DAYS OF CYCLING.

FIGURE 6



Cell Number	Cycle Failed

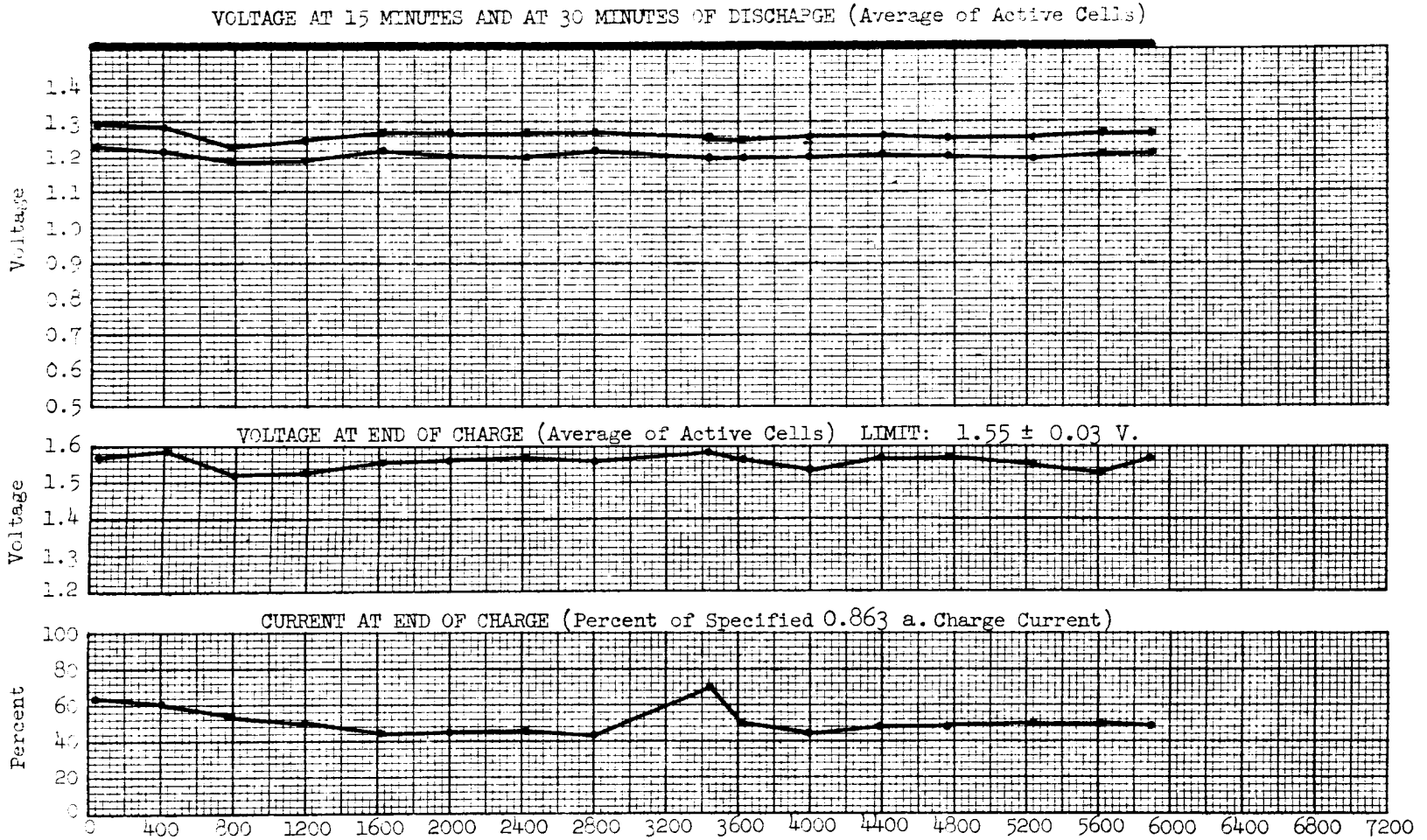
G.E. 3.0 a.h. (Pack 63)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: 10 cells cycling after 5983 cycles.

Notes

1. Cycles 1546, 2944, 4100, 5607: Capacity Check.

FIGURE 7(a)



Cell Number	Cycle Failed

G.E. 3.0 a.h. (Pack 64)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

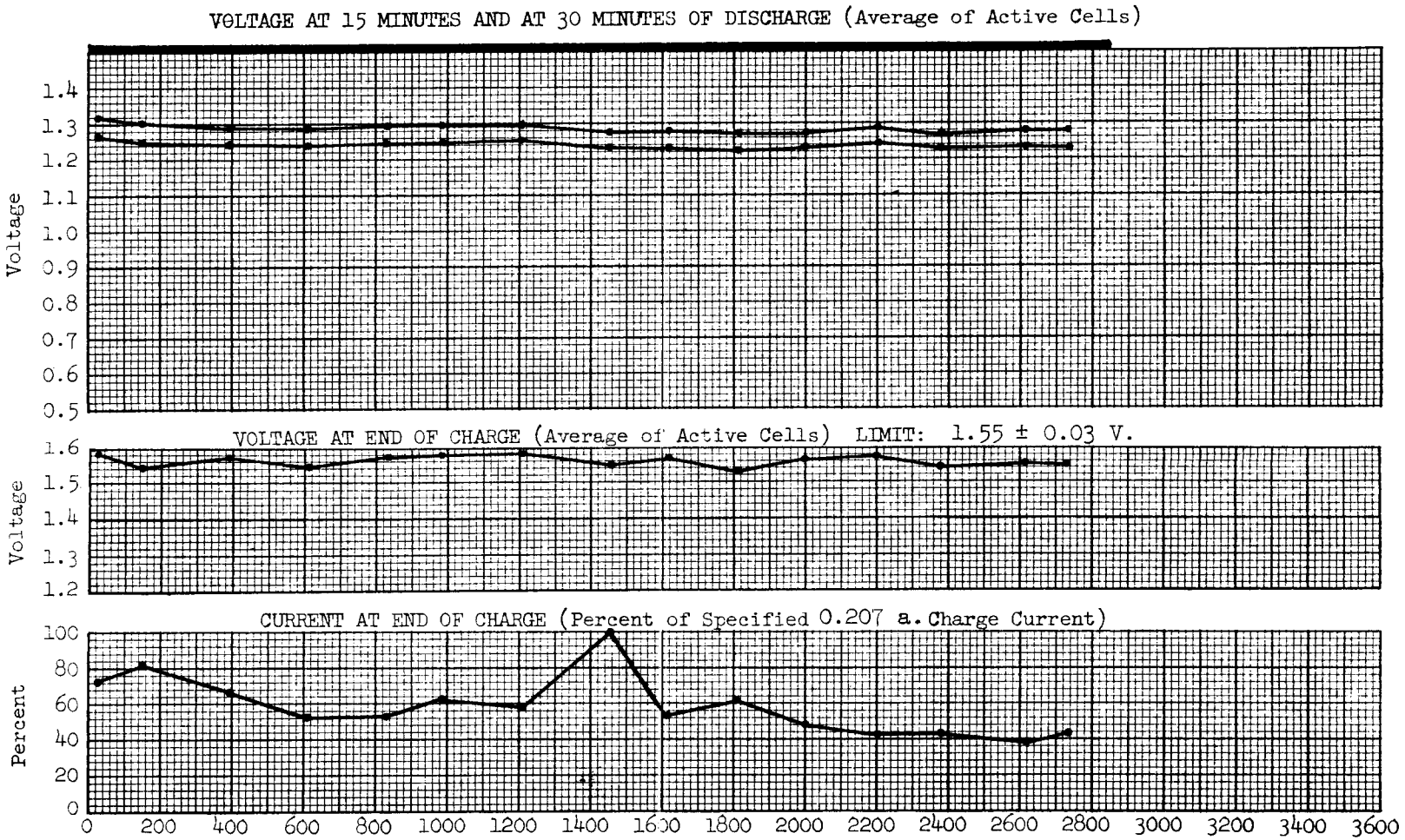
Status: 10 cells cycling after 5909 cycles.

Notes

1. Cycles 1442, 2841, 4045, 5472: Capacity Check.

FIGURE 7(b)

GE/C 65-356



Cell Number	Cycle Failed

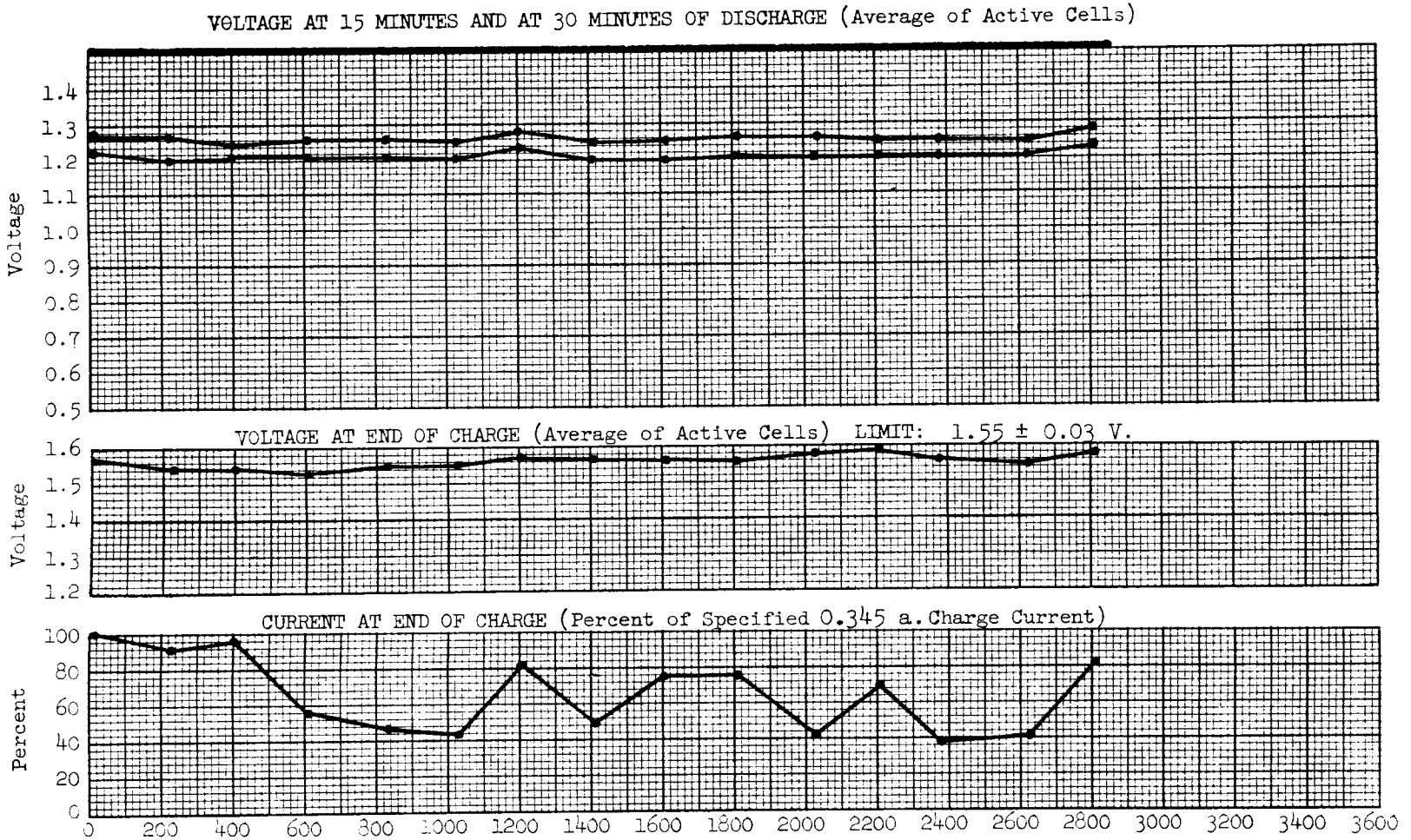
G.E. 3.0 a.h. (Pack 67)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: 10 cells cycling after 2851 cycles.

Notes

1. Cycles 719, 1374, 2015, 2762: Capacity Check.

FIGURE 7(c)



Cell Number	Cycle Failed

G.E. 3.0 a.h. (Pack 68)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 25%

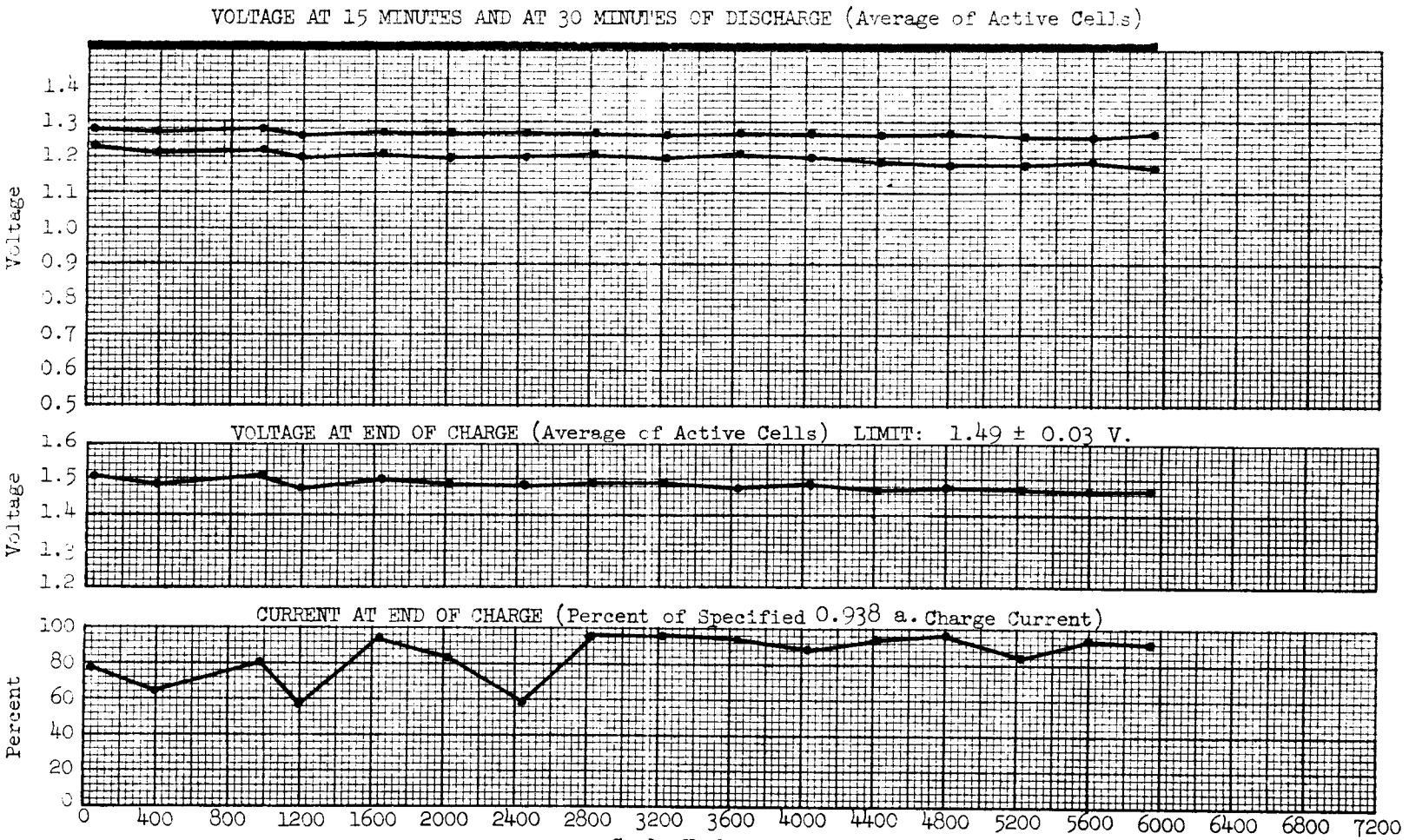
Status: 10 cells cycling after 2854 cycles.

Notes

1. Cycles 715, 1431, 2050, 2804: Capacity Check.

FIGURE 7(d)

QE/C 65-356



Cell Number	Cycle Failed

G.E. 3.0 a.h. (Pack 15)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

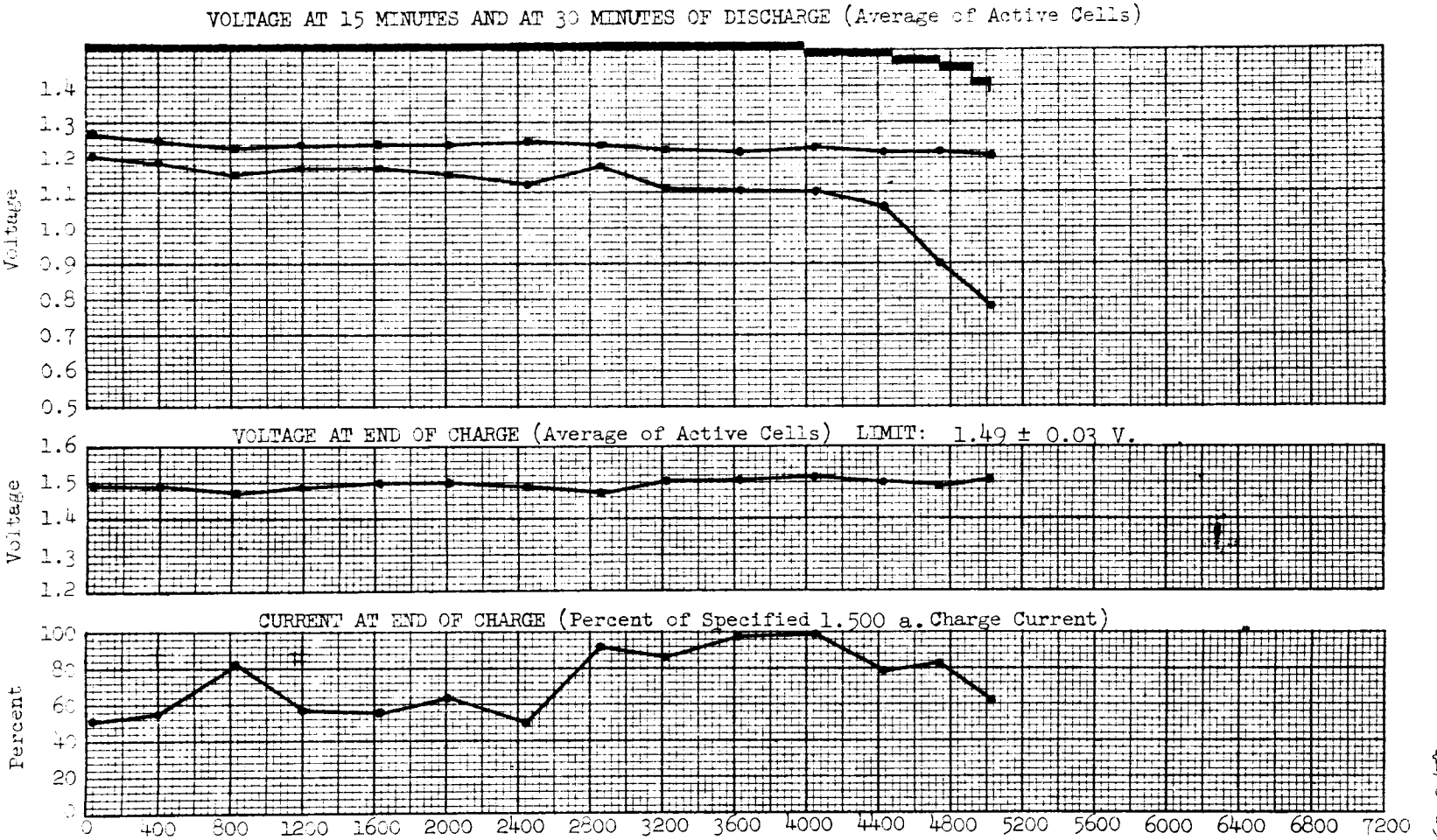
Status: 10 cells cycling after 5977 cycles.

Notes

1. Cycles 1544, 2878, 4151, 5543: Capacity Check.

FIGURE 7(e)

QE/c 65-356



Cell Number	Cycle Failed
427	3985
58	4473
361	4741
522, 456	4917
719	5013

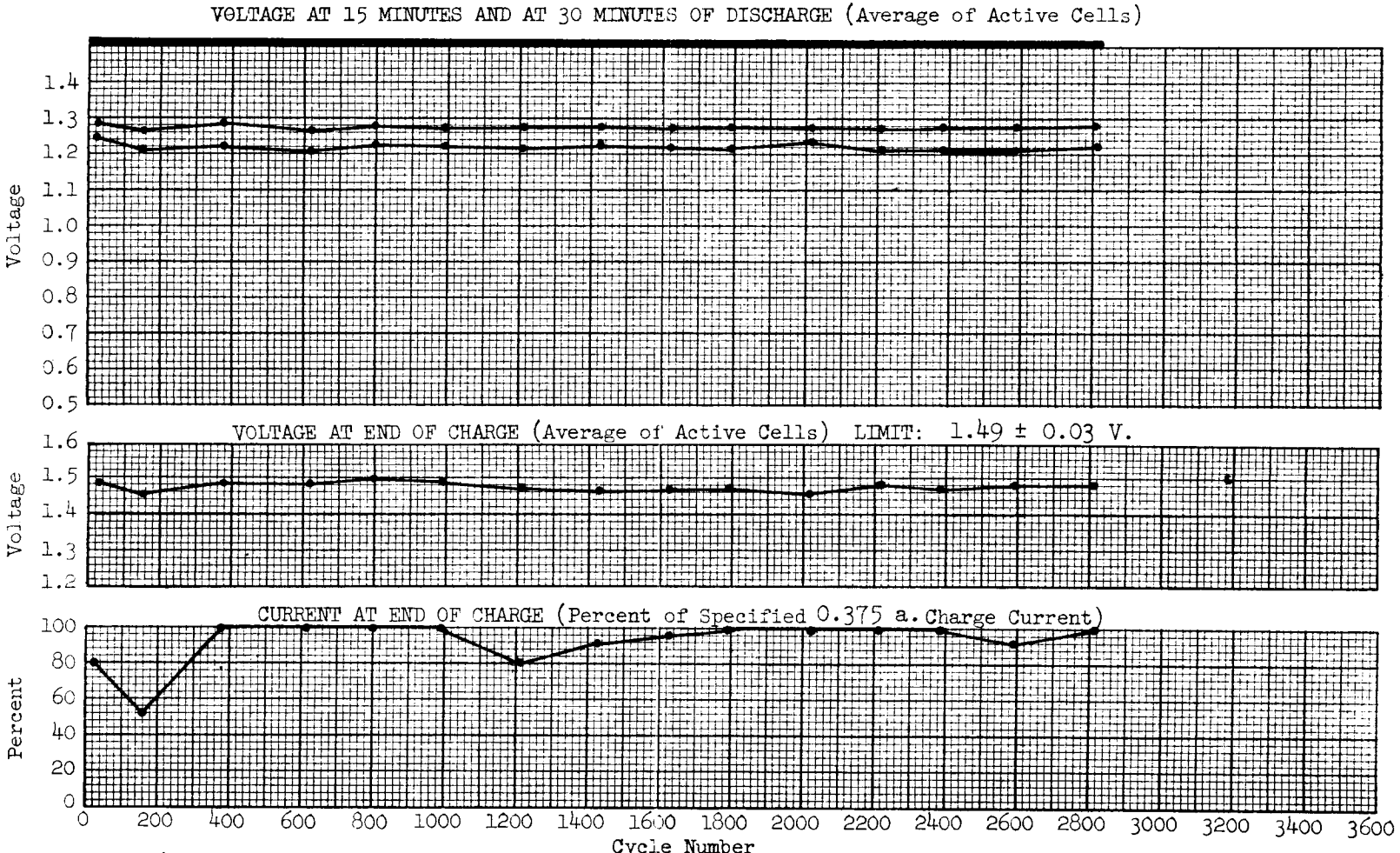
G.E. 3.0 a.h. (Pack 16)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 40%

Status: Pack Failed: Cycle 5013

Notes

1. Cycles 1427, 2811, 4092: Capacity Check.

FIGURE 7(f)



Cell Number	Cycle Failed

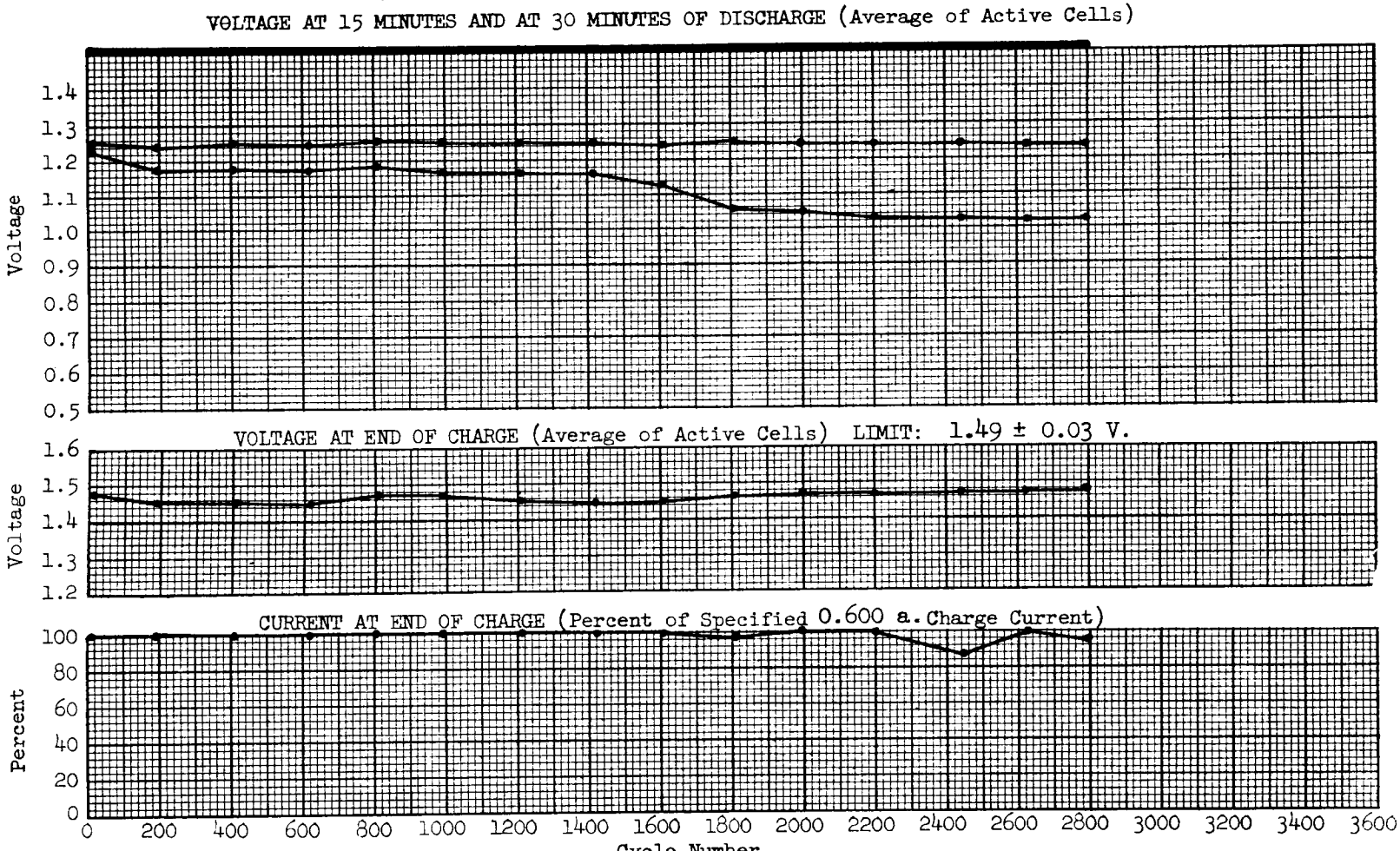
G.E. 3.0 a.h. (Pack 19)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: 10 cells cycling after 2826 cycles.

Notes

1. Cycles 674, 1381, 2008, 2722: Capacity Check.

FIGURE 7(g)



Cell Number	Cycle Failed

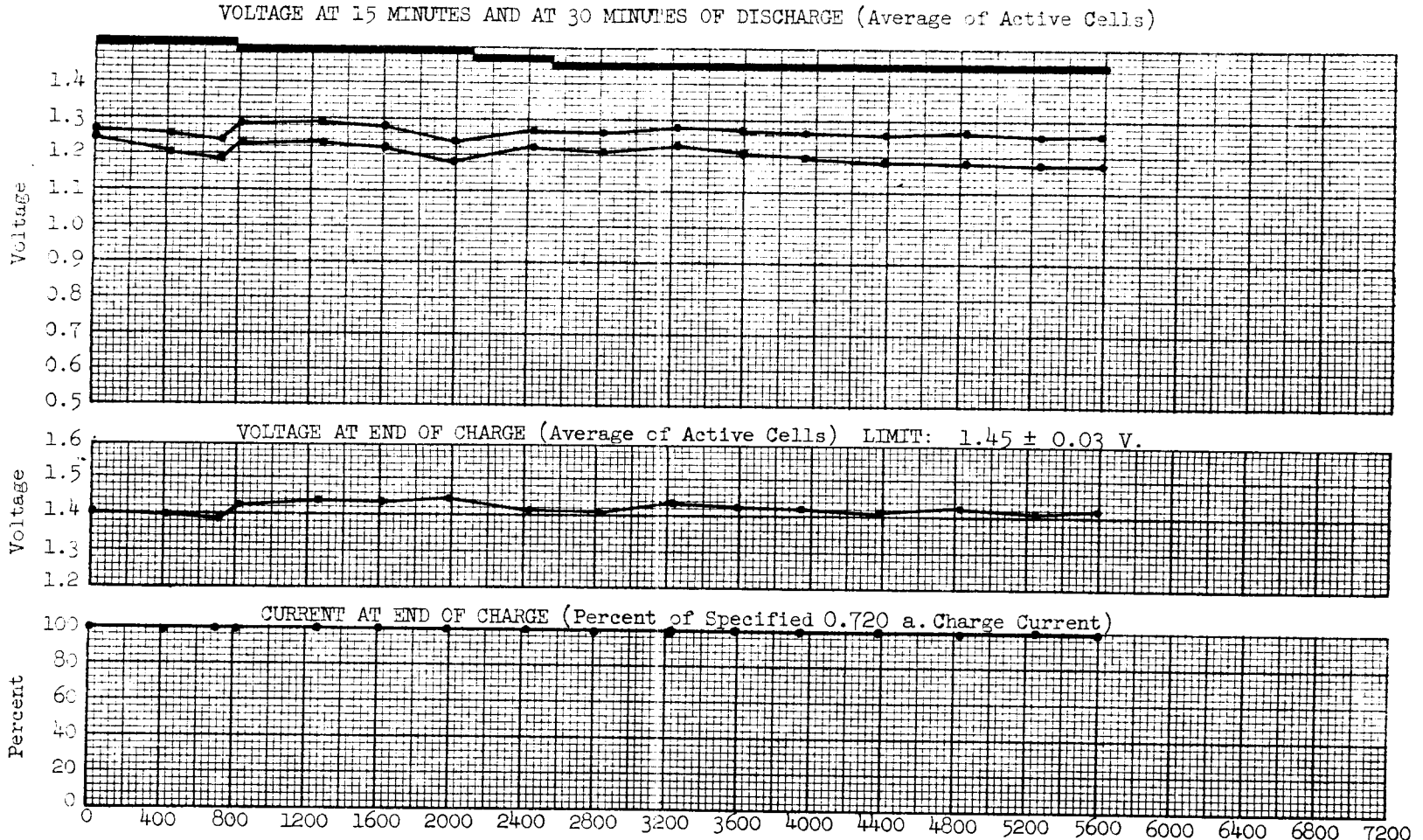
G.E. 3.0 a.h. (Pack 20)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 40%

Status: 10 cells cycling after 2803 cycles.

Notes

1. Cycles 676, 1373, 2071, 2601: Capacity Check.

FIGURE 7(h)



Cell Number	Cycle Failed
541	779
540	2083
549	2532

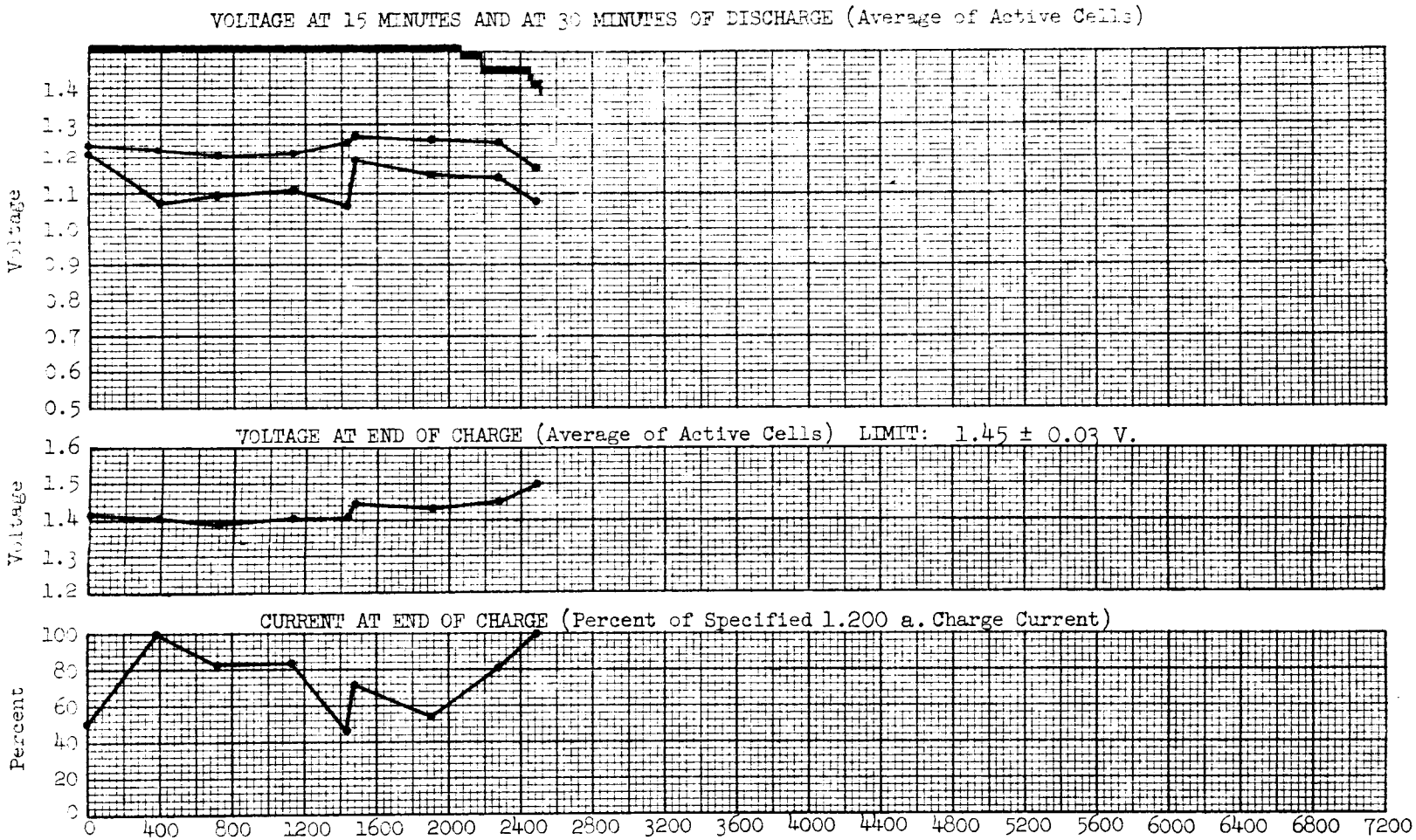
G.E. 3.0 a.h. (Pack 39)
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: 7 cells cycling after 5618 cycles.

Notes

1. Cycle 779: Changed to 40° C.
2. Cycle 1065: Voltage limit raised to 1.45 V/cell.
3. Cycles 1400, 2712, 3994, 5429: Capacity Check.

FIGURE 7(i)



Cell Number	Cycle Failed
464	2073
47, 3131	2182
49	2446
45	2461
466, 441	2509

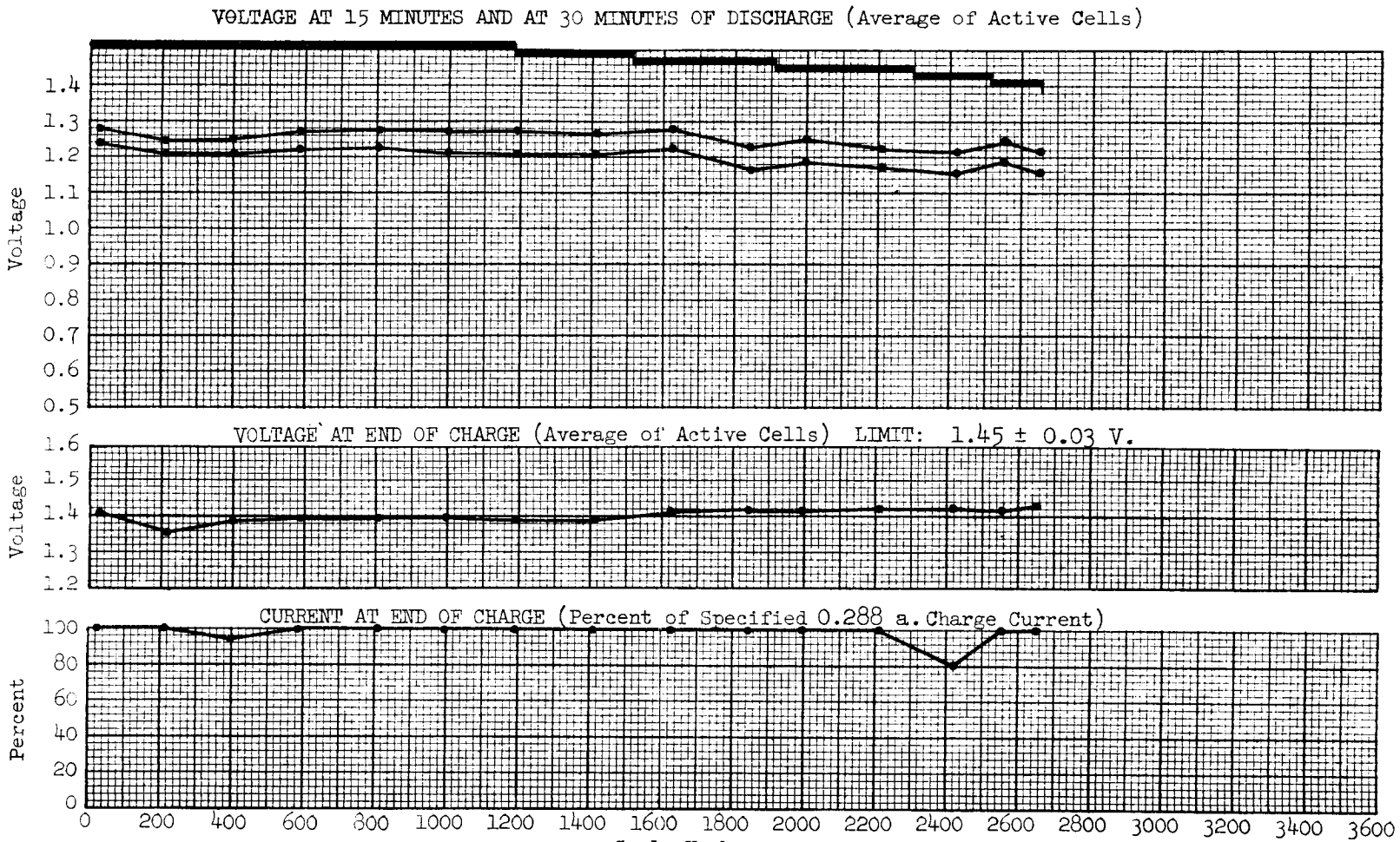
G.E. 3.0 a.h. (Pack 40)
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 2509

Notes

1. Cycles 1410, 2507: Capacity Check.
2. Cycle 1440: Changed to 40° C, with voltage limit raised to 1.45 V/cell.

FIGURE 7(4)



Cell Number	Cycle Failed
416	1182
499	1515
412	1911
426	2298
436	2515
435	2656

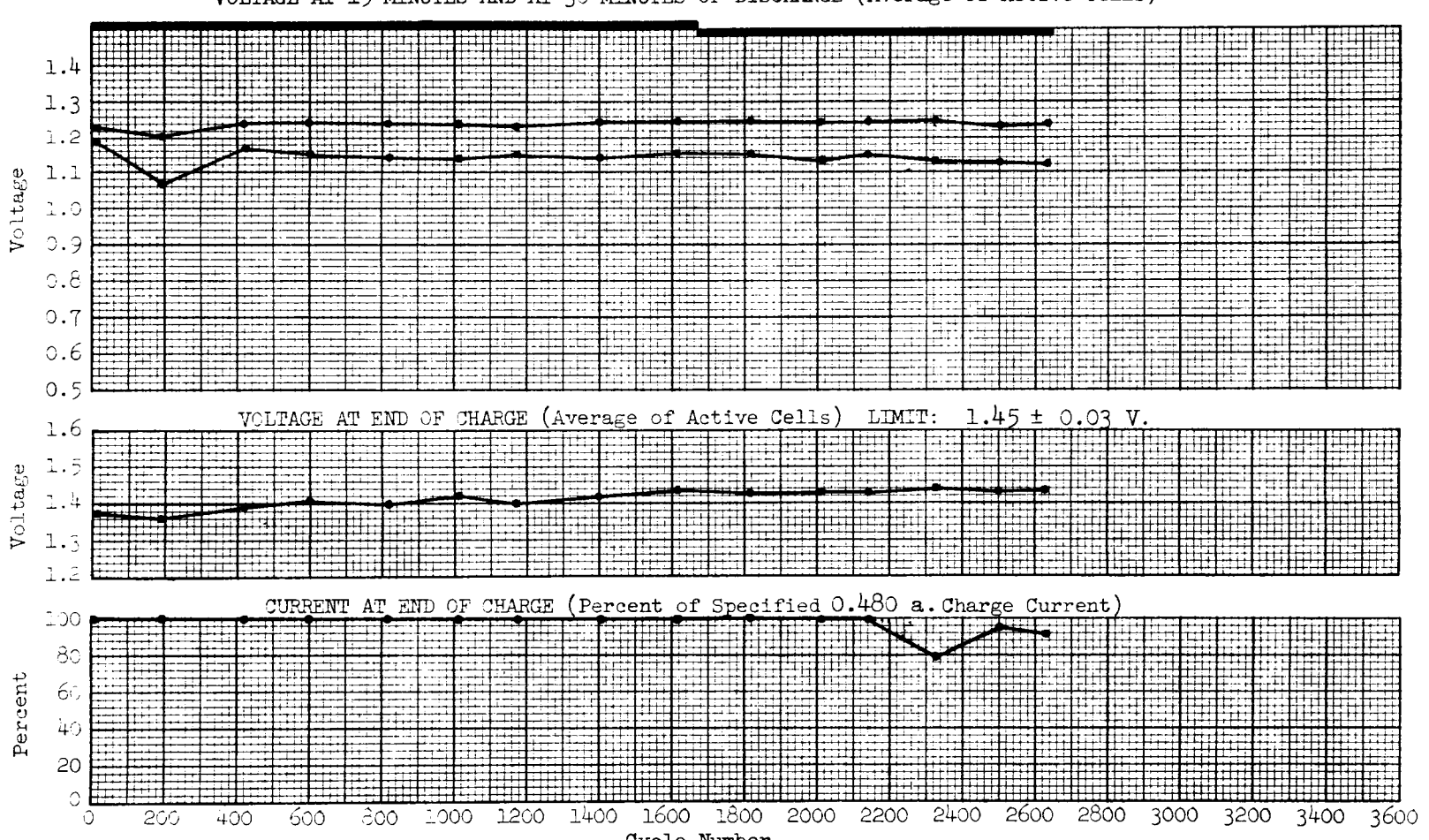
G.E. 3.0 a.h. (Pack 43)
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: Pack Failed: Cycle 2656

Notes

1. Cycle 320: Changed to 40° C.
2. Cycle 478: Voltage limit raised to 1.45 V/cell.
3. Cycles 757, 1509, 2170: Capacity Check.

FIGURE 7(k)



Cell Number	Cycle Failed

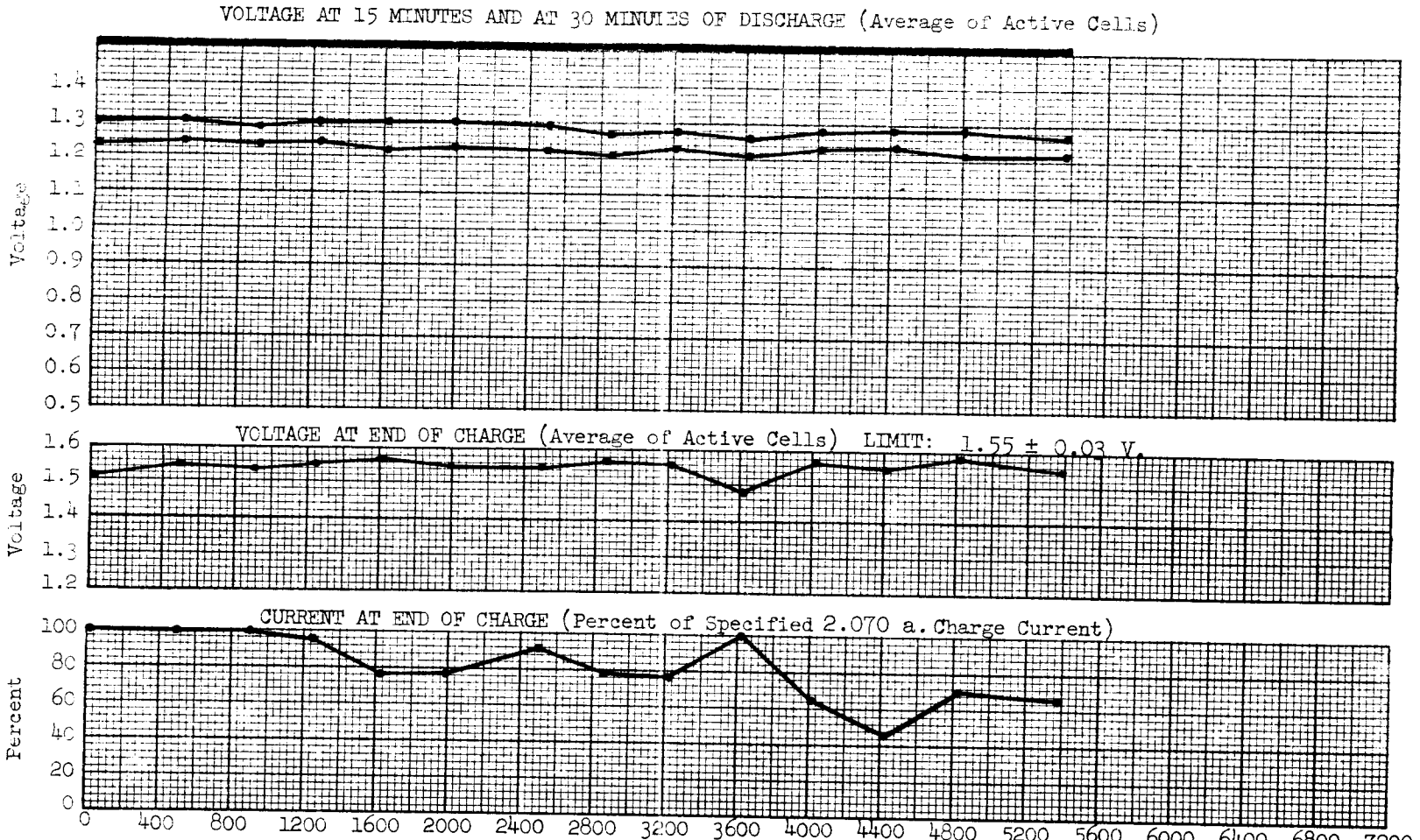
G.E. 3.0 a.h. (Pack 44)
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: 9 cells cycling after 2643 cycles.

Notes

1. Cycle 327: Changed to 40° C.
2. Cycle 487: Voltage limit raised to 1.45 V/cell.
3. Cycles 696, 1402, 2053: Capacity Check.

FIGURE 7(1)



Cell Number	Cycle Failed

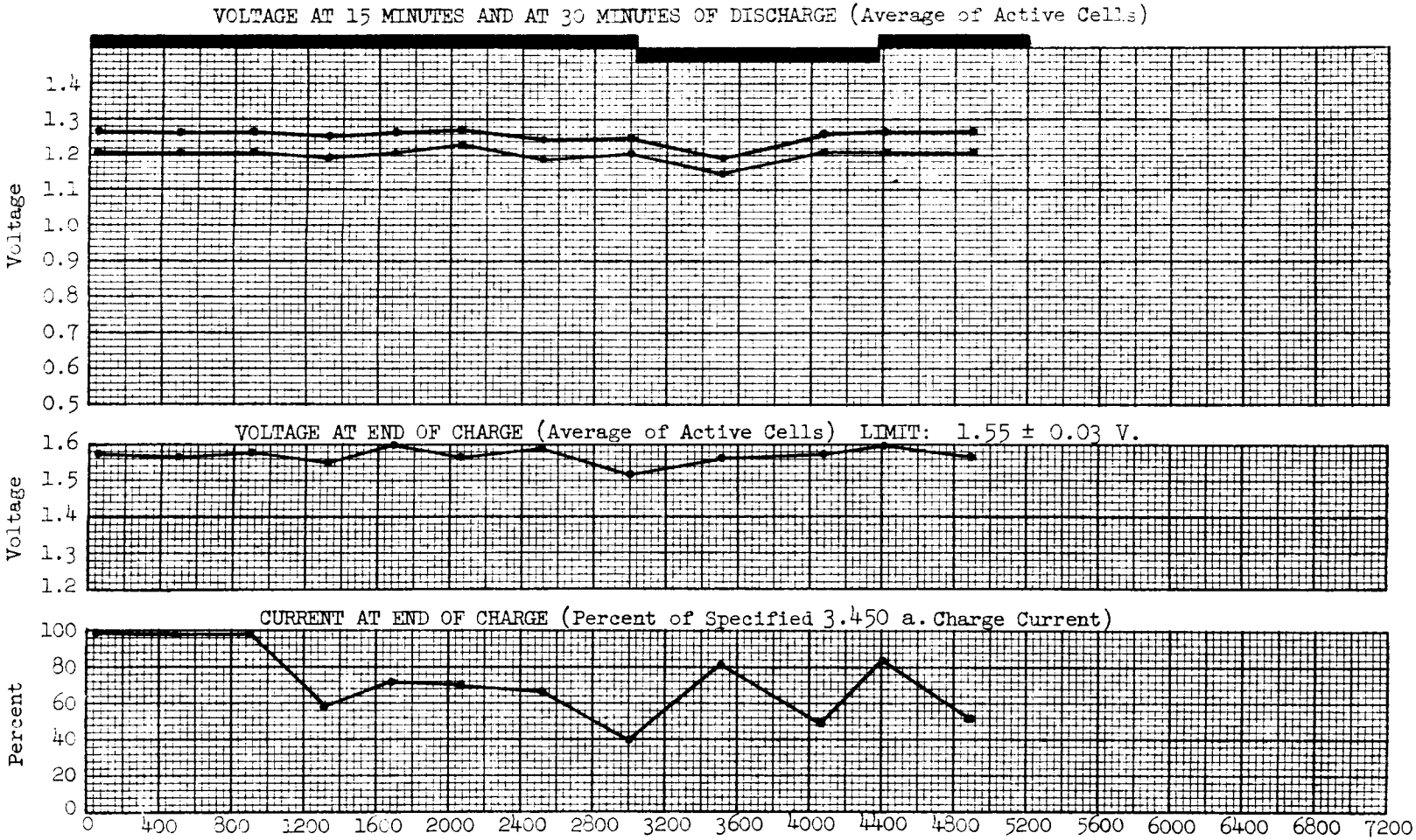
G.E. 12 a.h. (Pack 110)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: 5 cells cycling after 5399 cycles.

Notes

1. Cycles 1440, 2898, 4410: Capacity Check.

FIGURE 8(a)



Cell Number	Cycle Failed

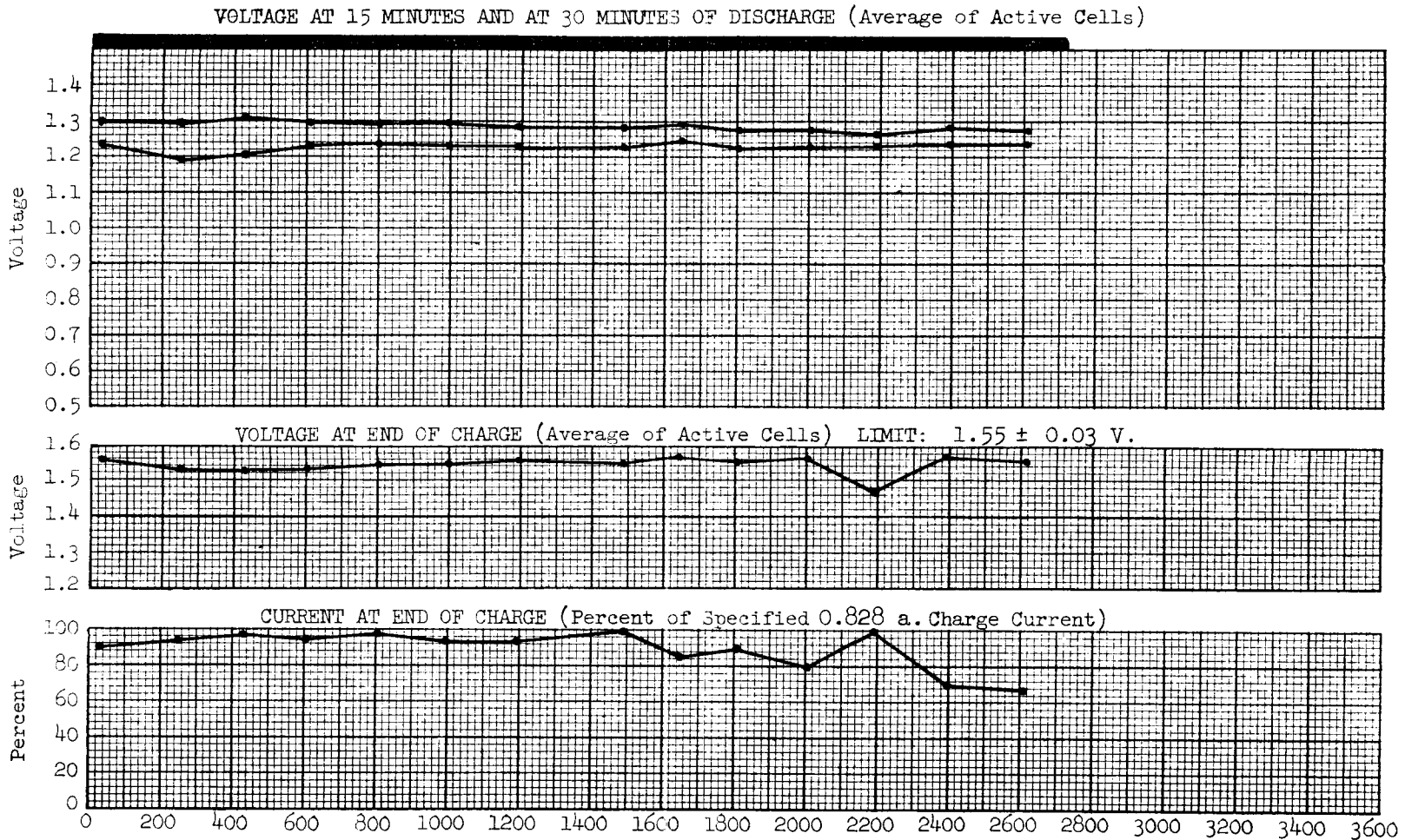
G.E. 12 a.h. (Pack 124)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 5214 cycles.

Notes

1. Cycles 1481, 2976, 4301: Capacity Check.
2. Cycles 3037-4375: Cell 410 failed; returned to pack after it regained normal capacity during failure tests.

FIGURE 8(b)



Cell Number	Cycle Failed

G.E. 12 a.h. (Pack 111)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 15%

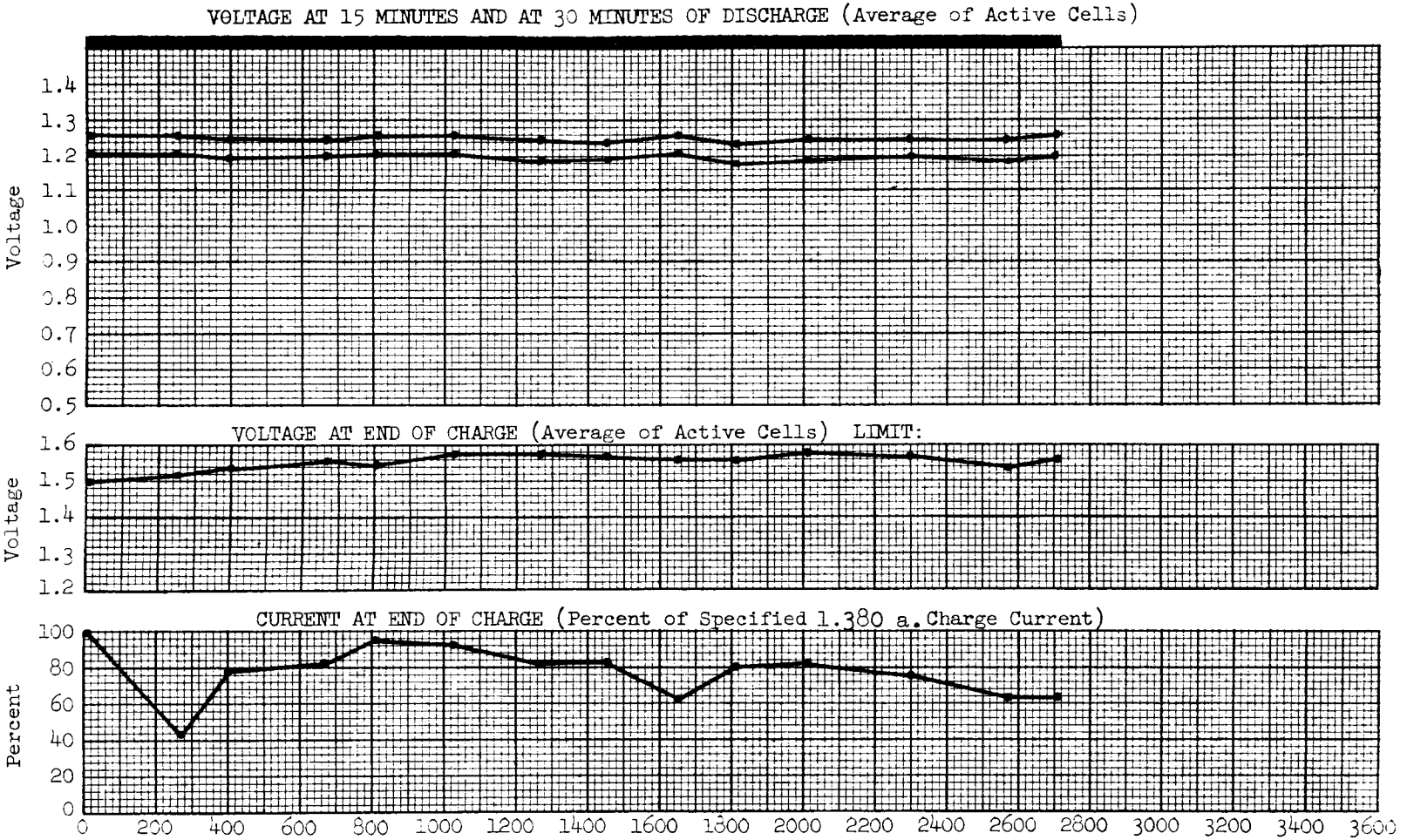
Status: 5 cells cycling after 2722 cycles.

Notes

1. Cycles 696, 1533, 2179: Capacity Check.

FIGURE 8(c)

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Cell Number	Cycle Failed

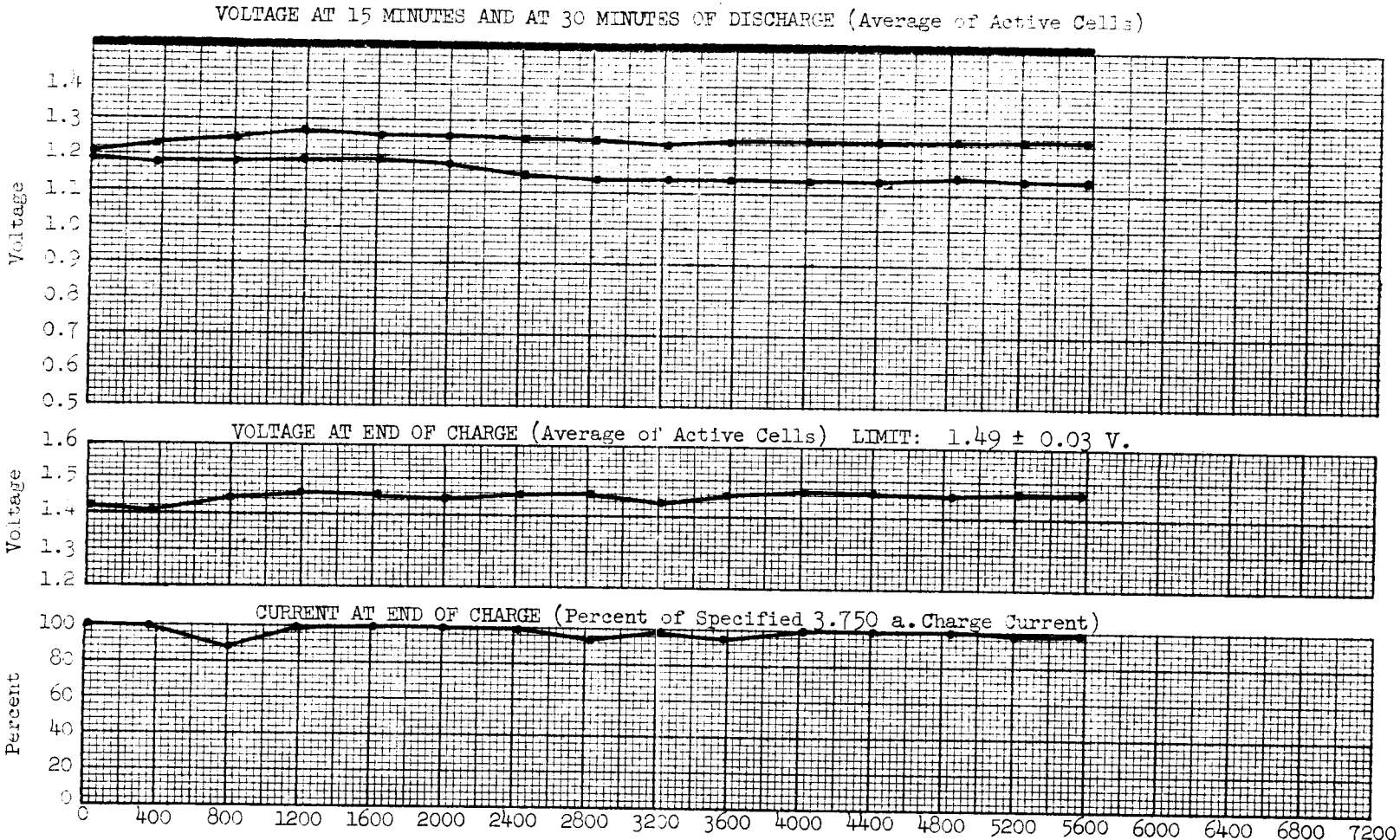
G.E. 12 a.h. (Pack 125)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 2721 cycles.

Notes

1. Cycles 695, 1533, 2178: Capacity Check.

FIGURE 8(d)



Cell Number	Cycle Failed

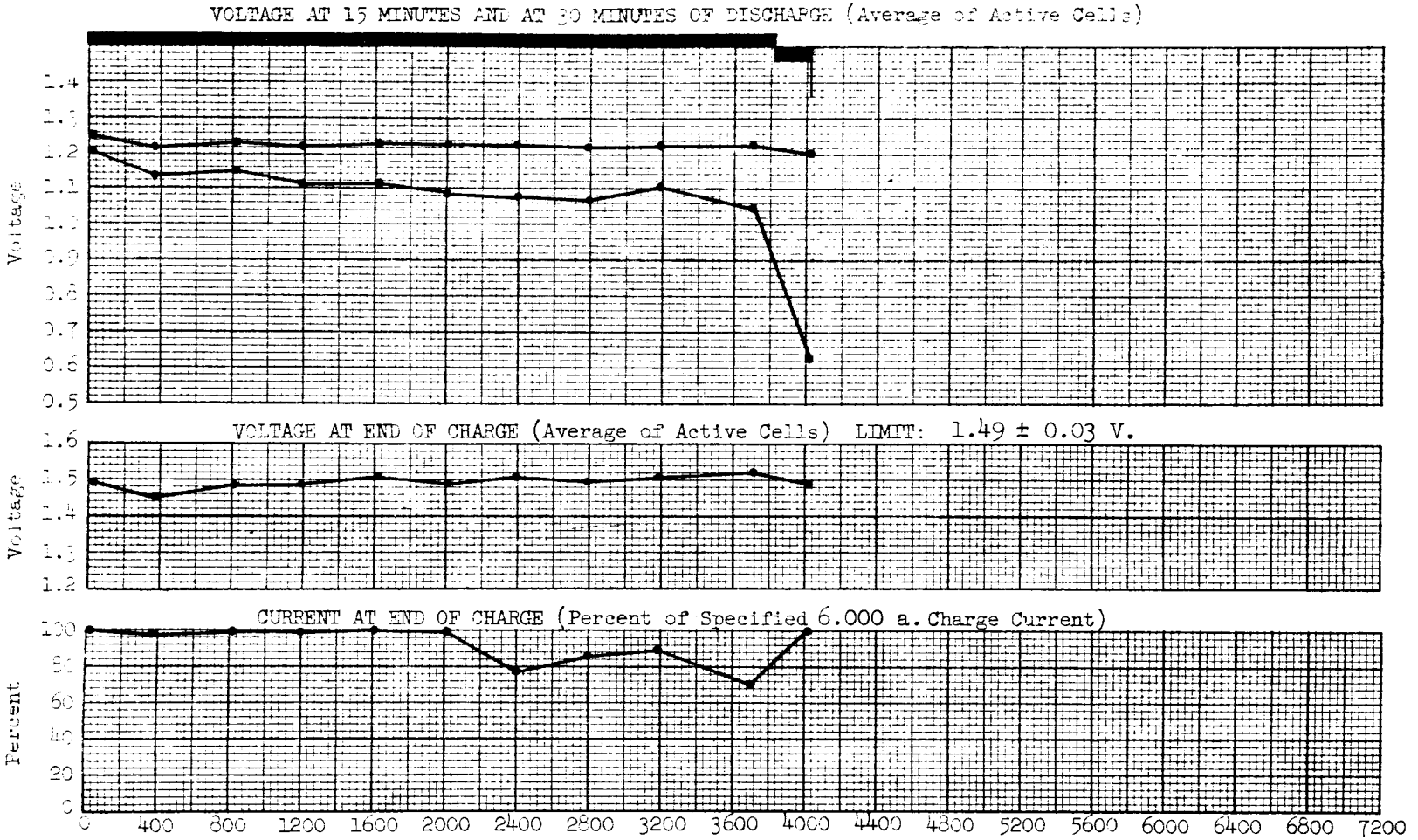
G.E. 12 a.h. (Pack 82)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 5595 cycles.

Notes

1. Cycles 1479, 2948, 4604: Capacity Check.

FIGURE 8(e)



Cell Number	Cycle Failed
445	3822
446, 442	4020

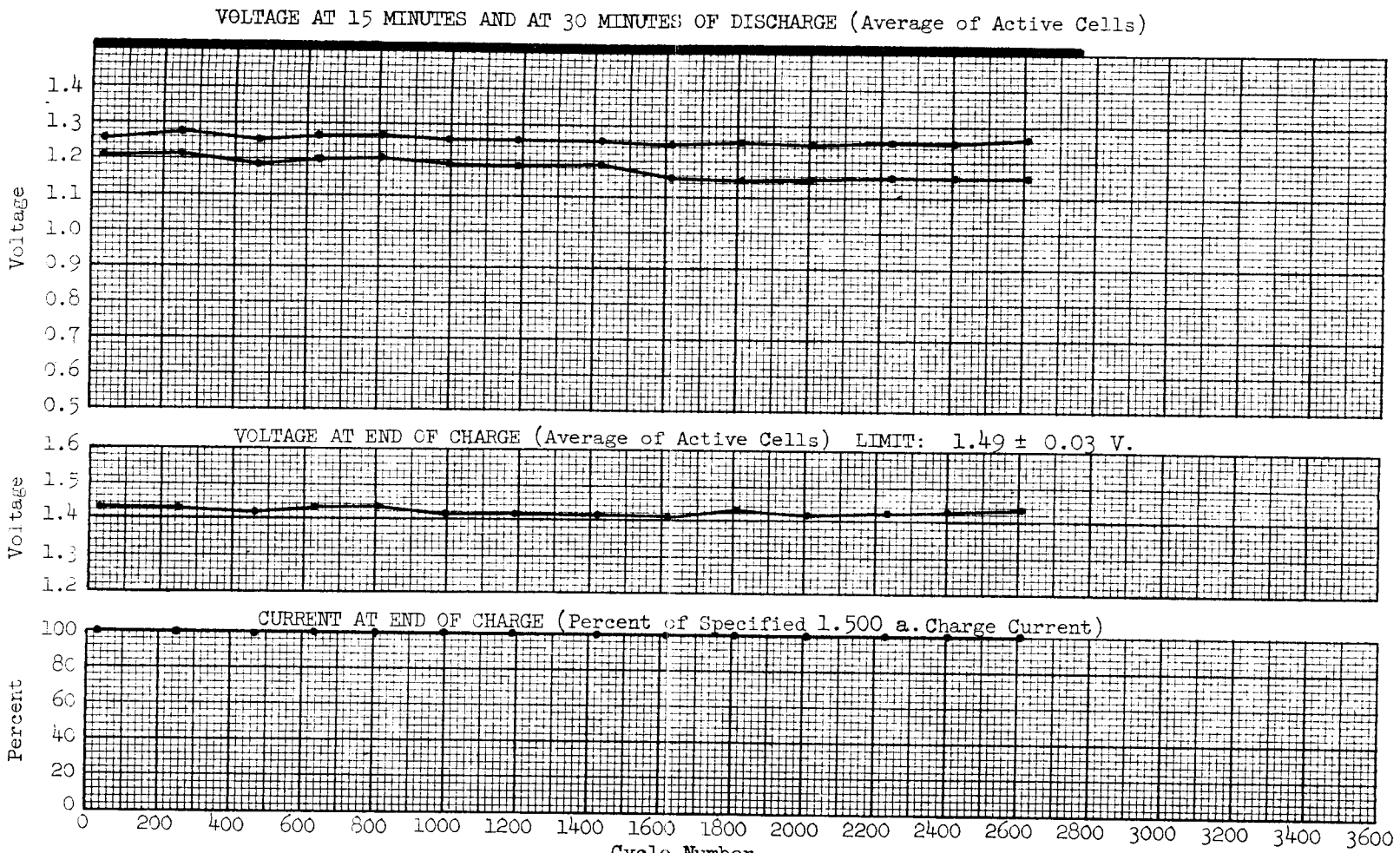
G.E. 12 a.h. (Pack 96)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 40%

Status: Pack Failed: Cycle 4020

Notes

1. Cycles 1478, 2946: Capacity Check.

FIGURE 8(f)



Cell Number	Cycle Failed

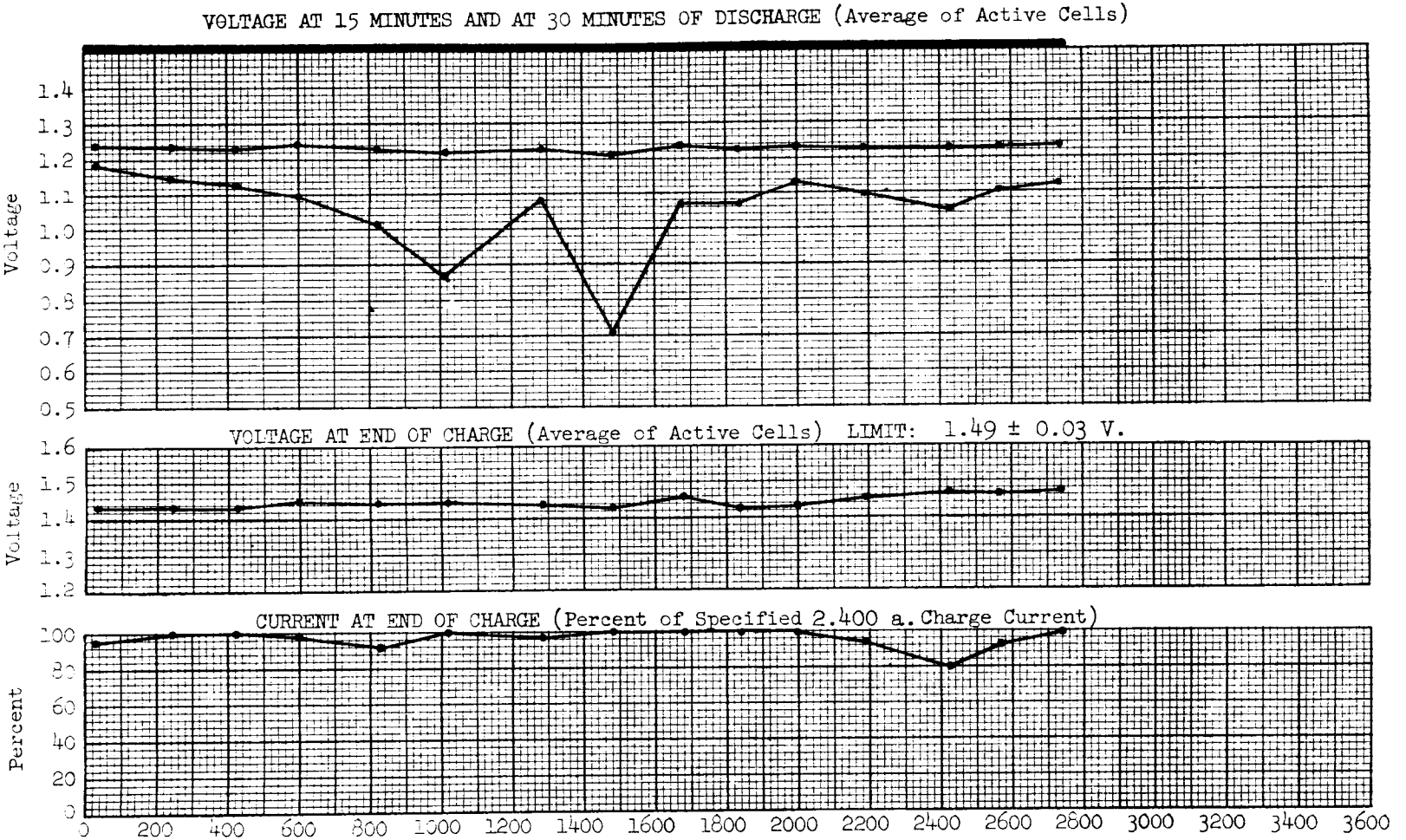
G.E. 12 a.h. (Pack 83)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 2753 cycles.

Notes

1. Cycles 693, 1362, 2155: Capacity Check.

FIGURE 8(g)



Cell Number	Cycle Failed

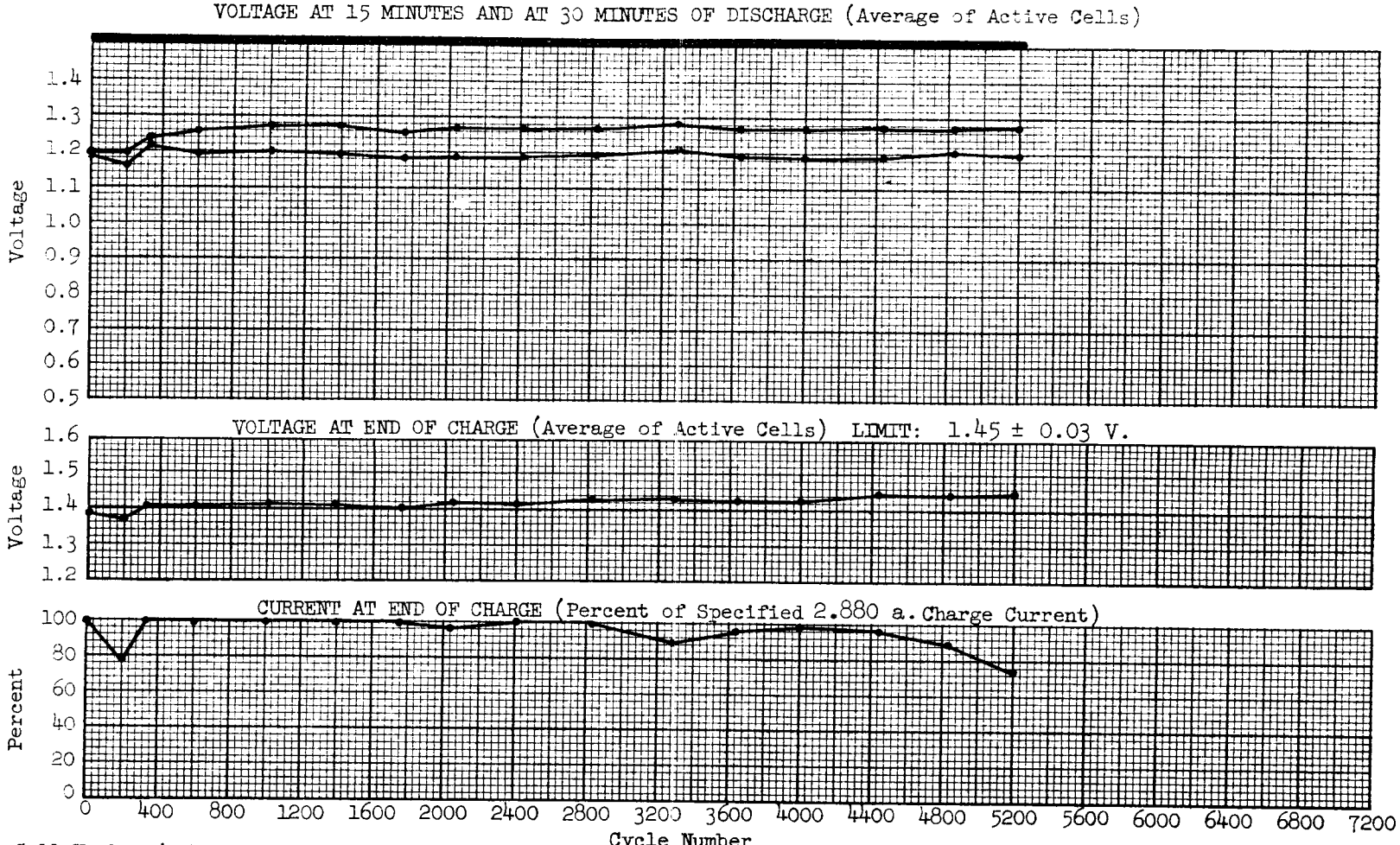
G.E. 12 a.h. (Pack 97)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 40%

Status: 5 cells cycling after 2753 cycles.

Notes

1. Cycles 749, 1447, 2209: Capacity Check.

FIGURE 8(h)



Cell Number	Cycle Failed

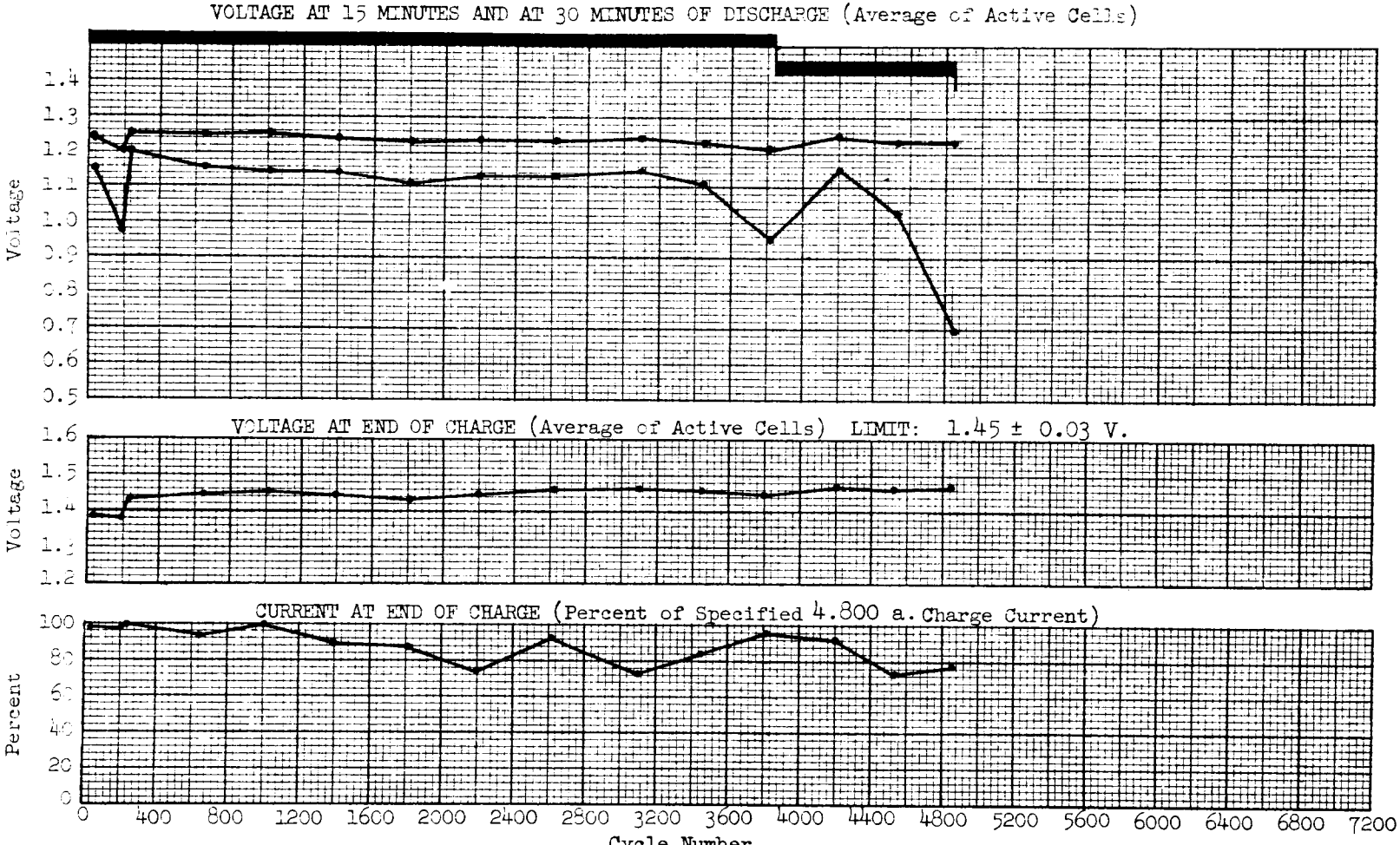
G.E. 12 a.h. (Pack 85)
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: 5 cells cycling after 5236 cycles.

Notes

1. Cycle 334: Changed to 40° C.
2. Cycle 434: Voltage limit raised to 1.45 V/cell.
3. Cycles 1494, 3037, 4483: Capacity Check.

FIGURE 8(i)



Cell Number	Cycle Failed
429, 432	3841
440	4853

G.E. 12 a.h. (Pack 99)
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

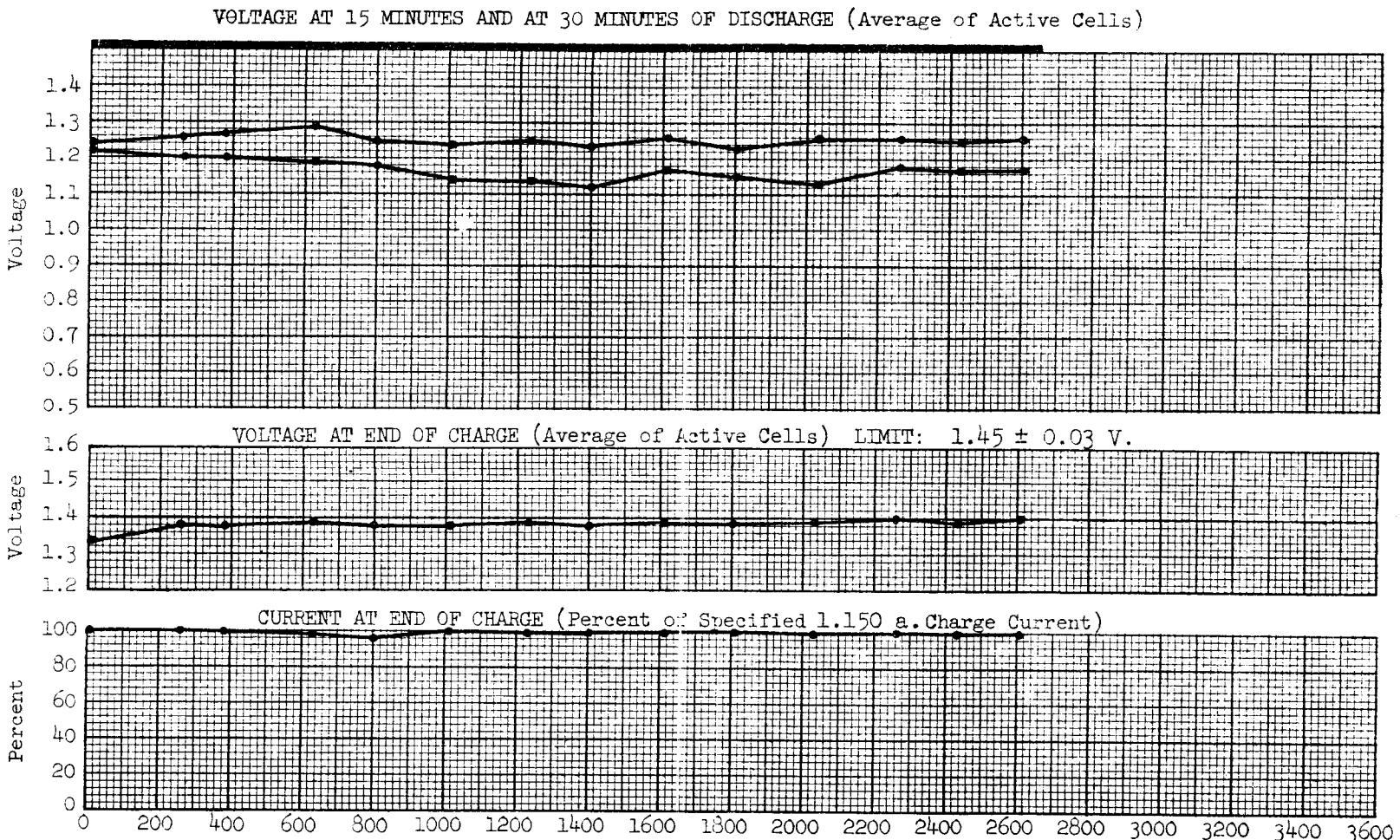
Status: Pack Failed: Cycle 4853

Notes

1. Cycle 195: Changed to 40° C.
2. Cycle 249: Voltage limit raised to 1.45 V/cell.
3. Cycles 1420, 2990, 4125: Capacity Check.

FIGURE 8(j)

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Cell Number	Cycle Failed

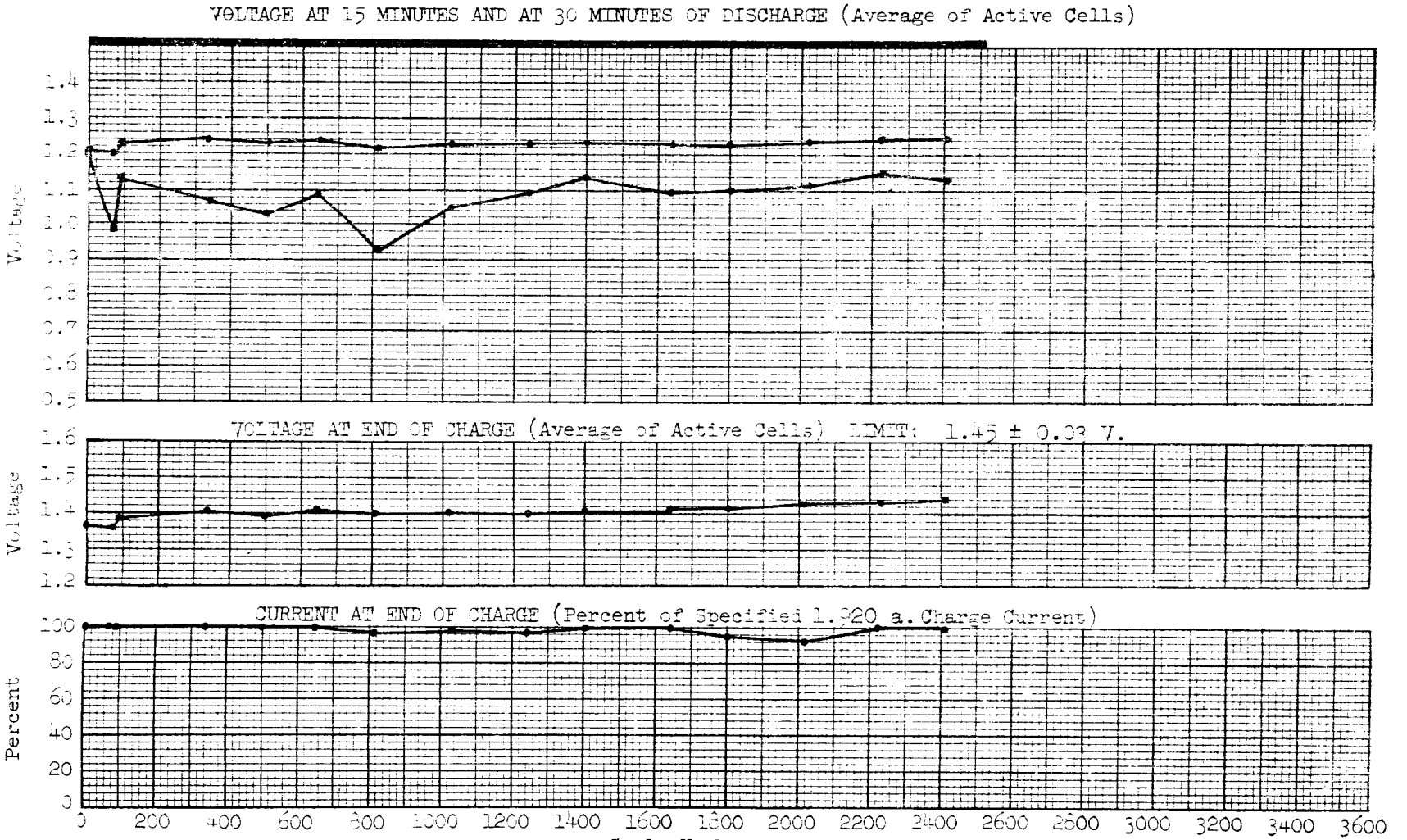
G.E. 12 a.h. (Pack 86)
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: 5 cells cycling after 2652 cycles.

Notes

1. Cycle 205: Changed to 40° C.
2. Cycle 365: Voltage limit raised to 1.45 V/cell.
3. Cycles 682, 1519, 2213: Capacity Check.

FIGURE 8(k)



Cell Number	Cycle Failed

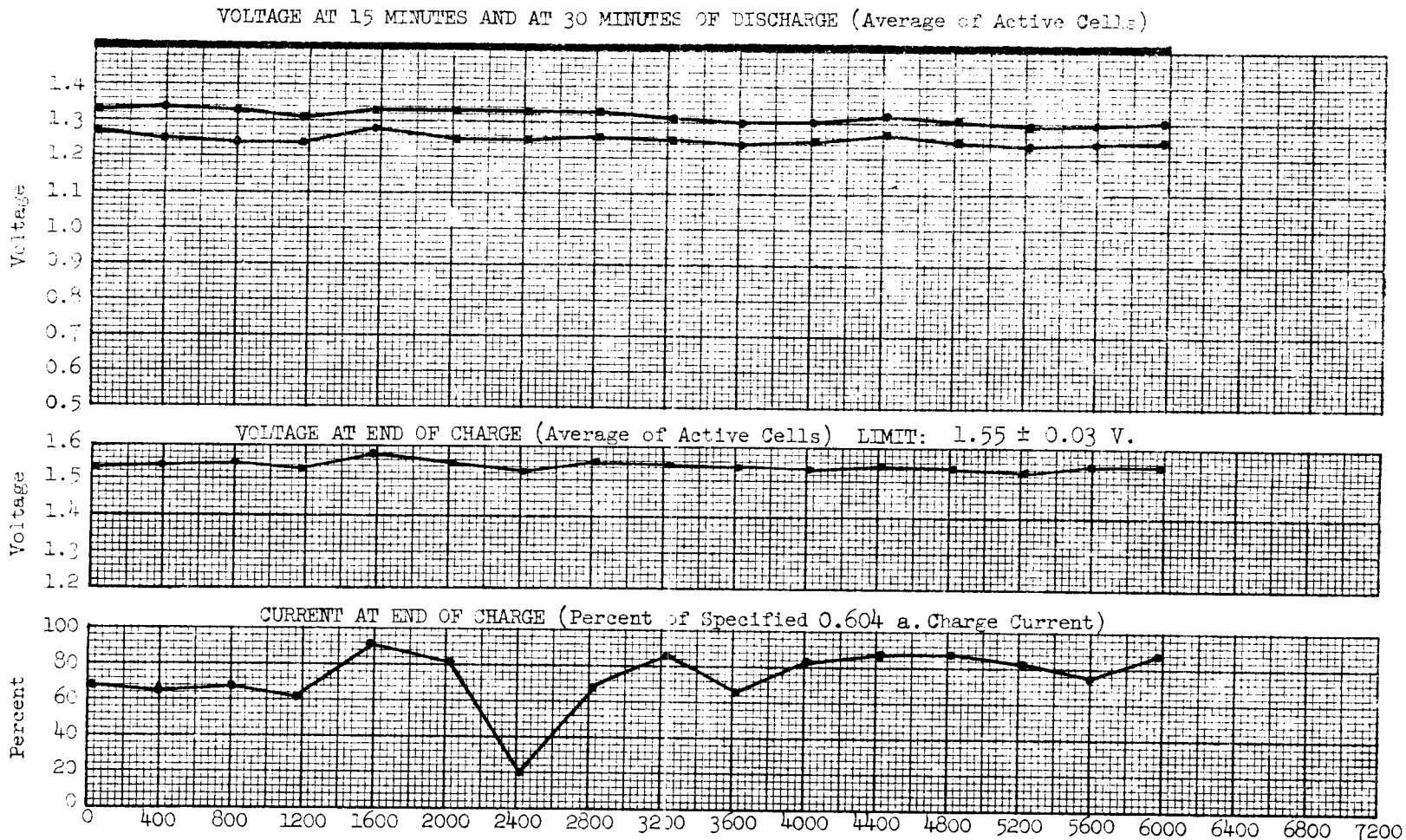
G.E. 12 a.h. (Pack 100)
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 2519 cycles.

Notes

1. Cycle 70: Changed to 40° C.
2. Cycle 230: Voltage limit raised to to 1.45 V/cell.
3. Cycles 717, 1499, 2206: Capacity Check.

FIGURE 8(1)



Cell Number	Cycle Failed

GOULD 3.5 a.h. (Pack 51)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

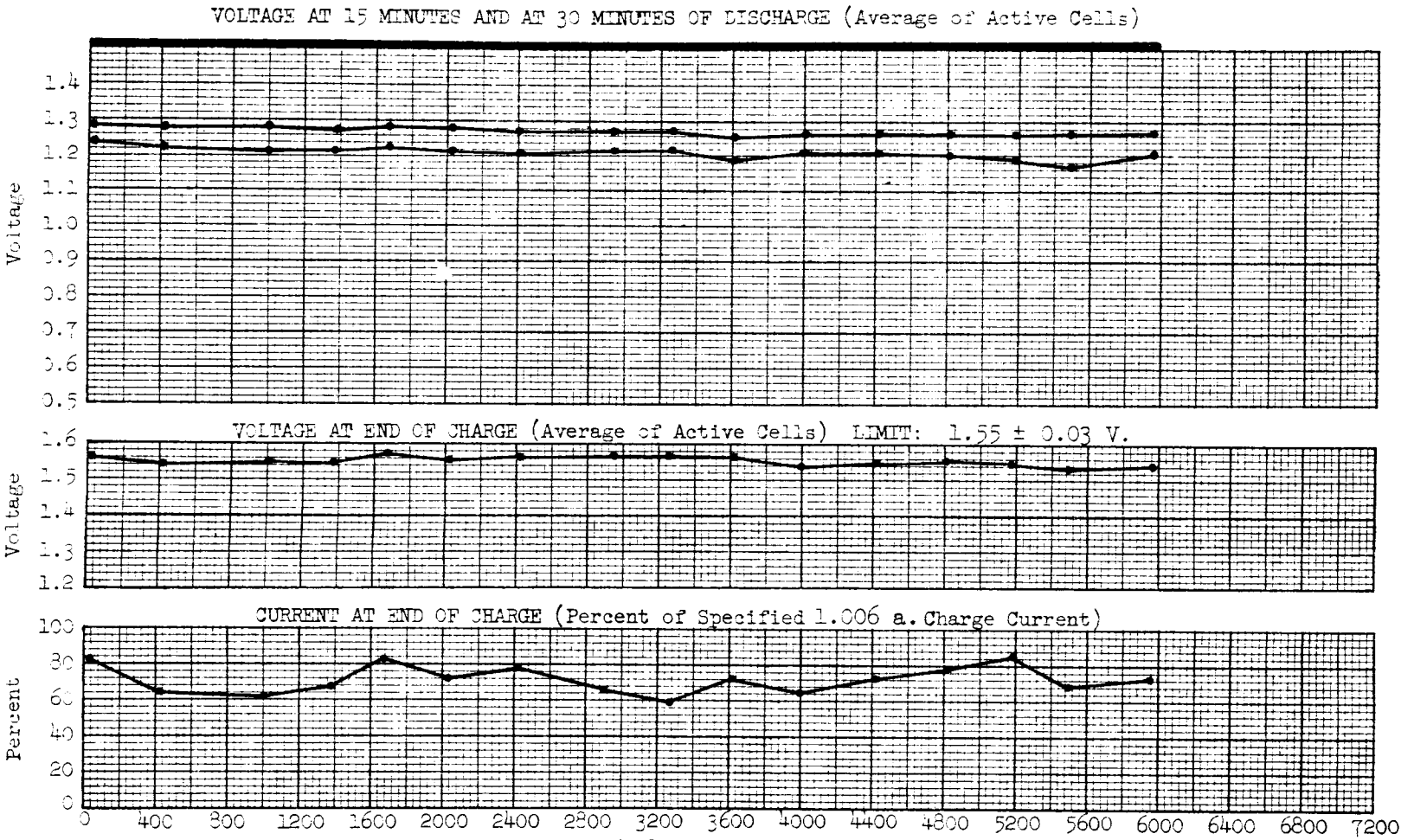
Status: 10 cells cycling after 6000 cycles.

Notes

1. Cycles 1546, 2944, 4165, 5565: Capacity Check.

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FIGURE 9(a)



Cell Number	Cycle Failed

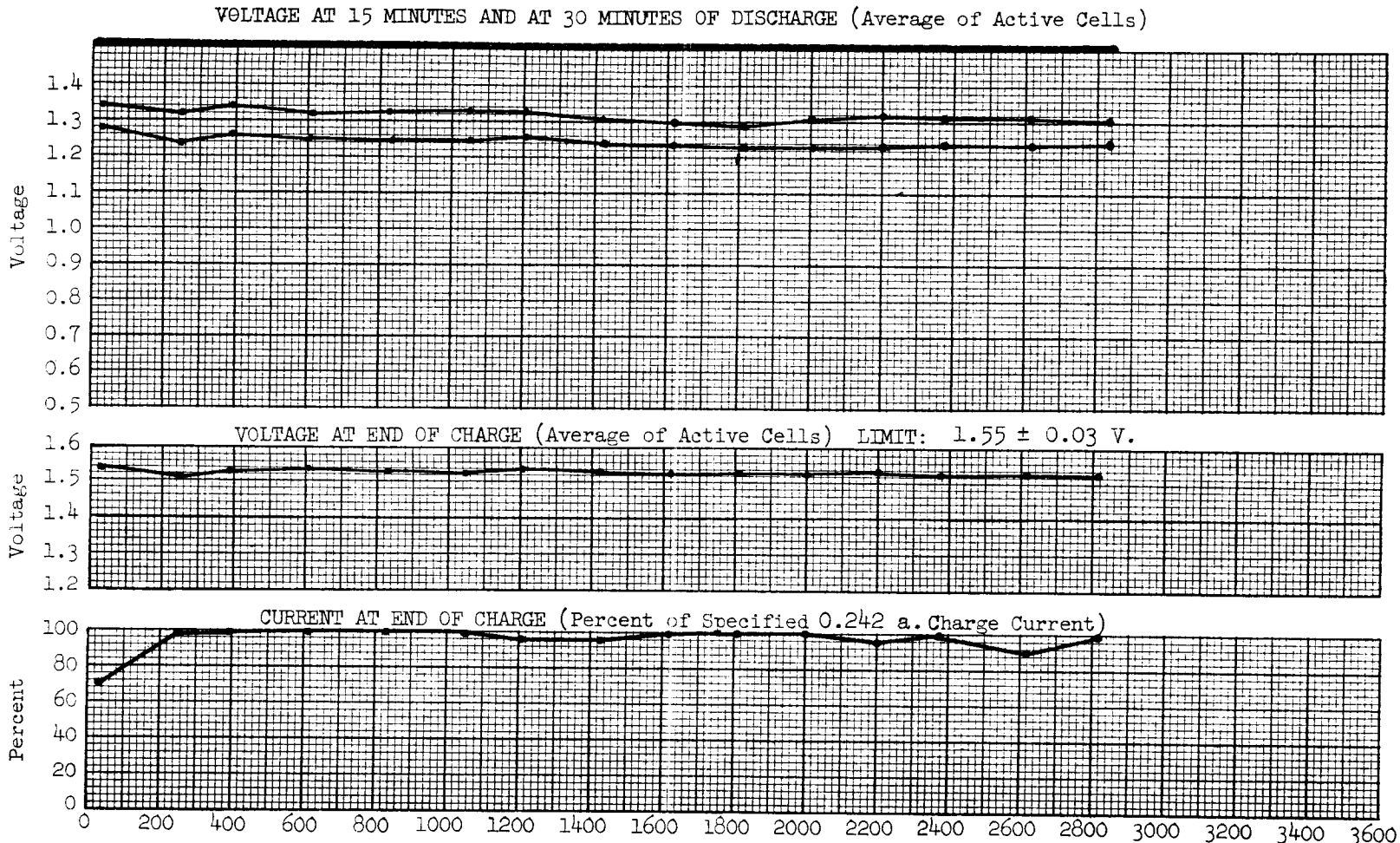
GOULD 3.5 a.h. (Pack 52)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 10 cells cycling after 5989 cycles.

Notes

1. Cycles 1428, 2827, 4125, 5552: Capacity Check.

FIGURE 9(b)



Cell Number	Cycle Failed

GOULD 3.5 a.h. (Pack 55)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 15%

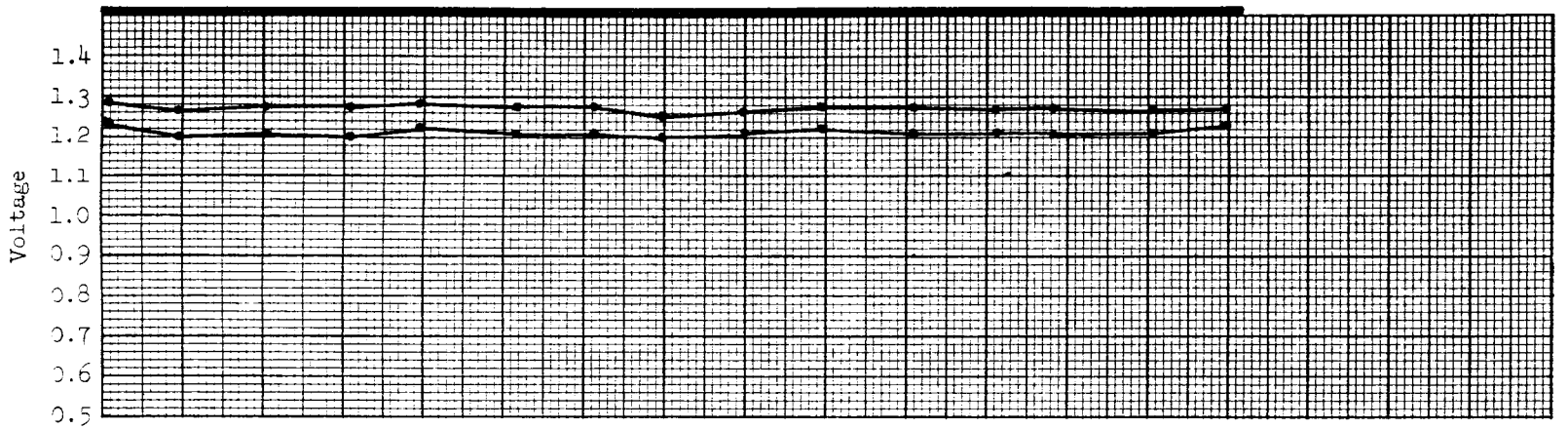
Status: 10 cells cycling after 2851 cycles.

Notes

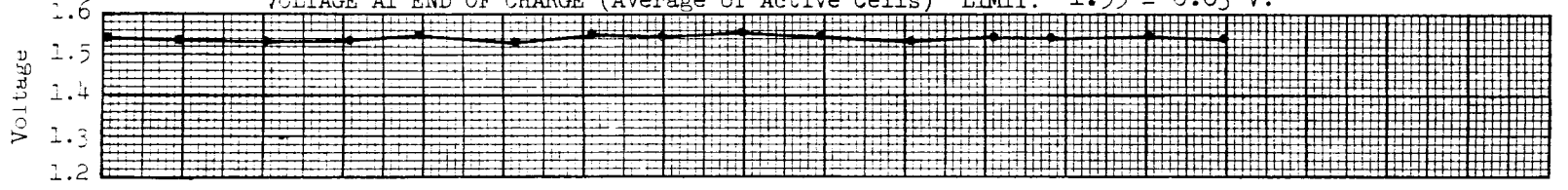
1. Cycles 719, 1374, 2015, 2762: Capacity Check.

FIGURE 9(c)

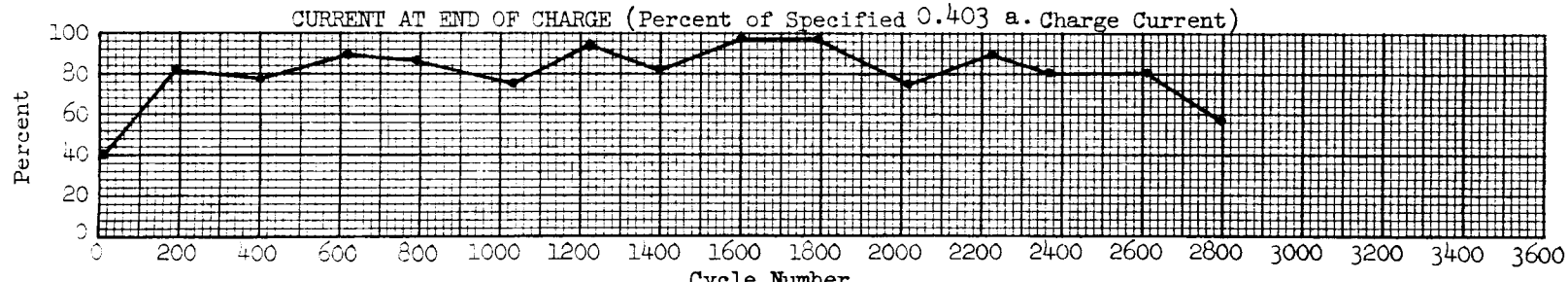
VOLTAGE AT 15 MINUTES AND AT 30 MINUTES OF DISCHARGE (Average of Active Cells)



VOLTAGE AT END OF CHARGE (Average of Active Cells) LIMIT: 1.55 ± 0.03 V.



CURRENT AT END OF CHARGE (Percent of Specified 0.403 a. Charge Current)



Cell Number	Cycle Failed

GOULD 3.5 a.h. (Pack 56)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: 10 cells cycling after 2838 cycles.

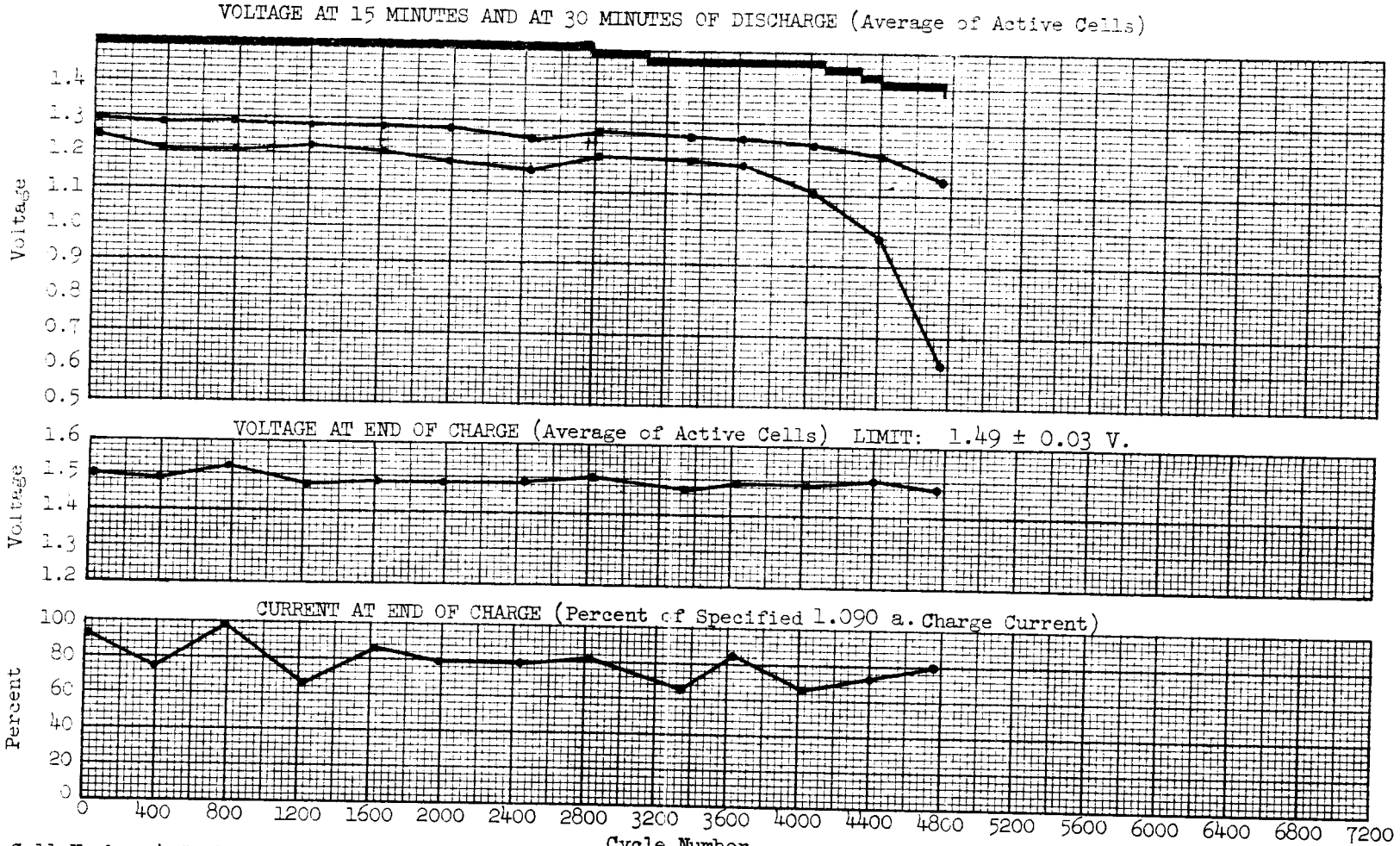
Notes

1. Cycles 715, 1415, 2034, 2788: Capacity Check.

FIGURE 9(d)

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Cell Number	Cycle Failed
73	2785
54	3090
165	4081
93	4289
97	4401
77, 188	

GOULD 3.5 a.h. (Pack 3)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

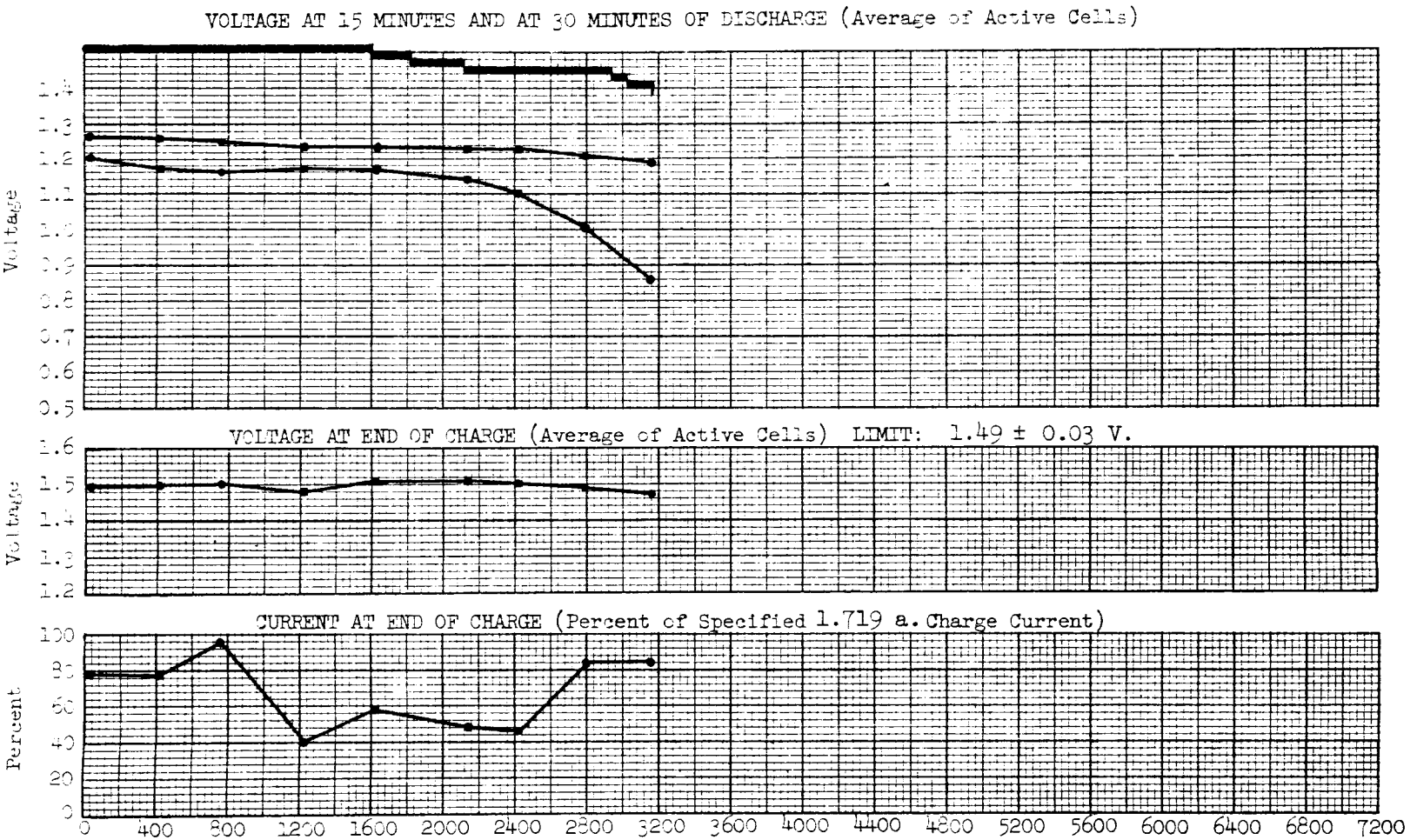
Status: Pack Failed: Cycle 4751

Notes

1. Cycles 1544, 2878, 4115: Capacity Check.

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FIGURE 9(e)



Cell Number	Cycle Failed
81	1609
90	1827
2	2110
43	2954
27	3029
198	3164

GOULD 3.5 a.h. (Pack 4)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 40%

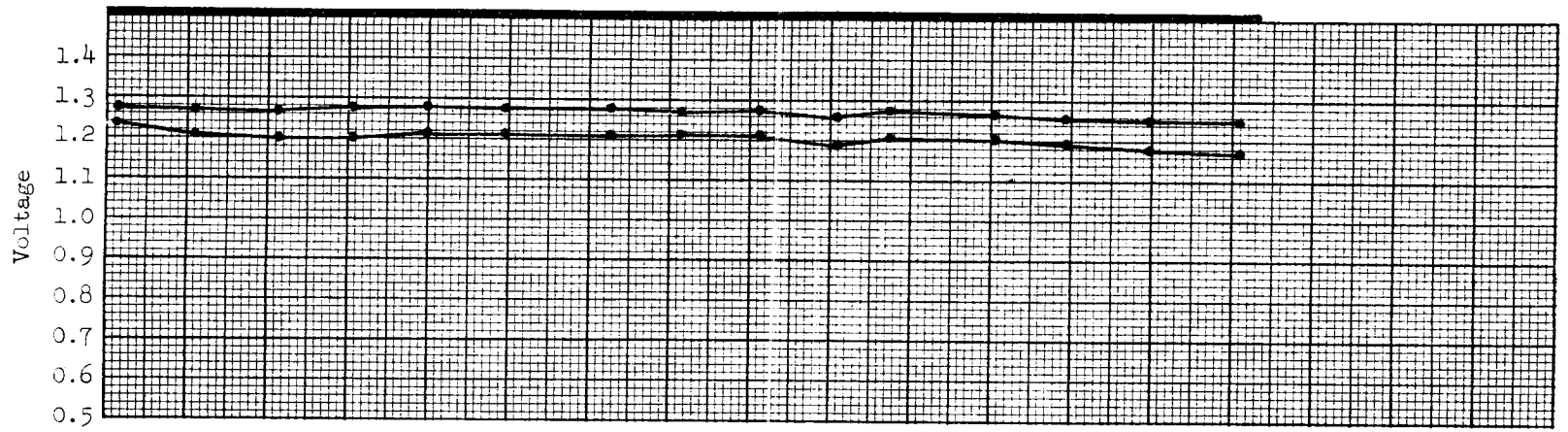
Status: Pack Failed: Cycle 3164

Notes

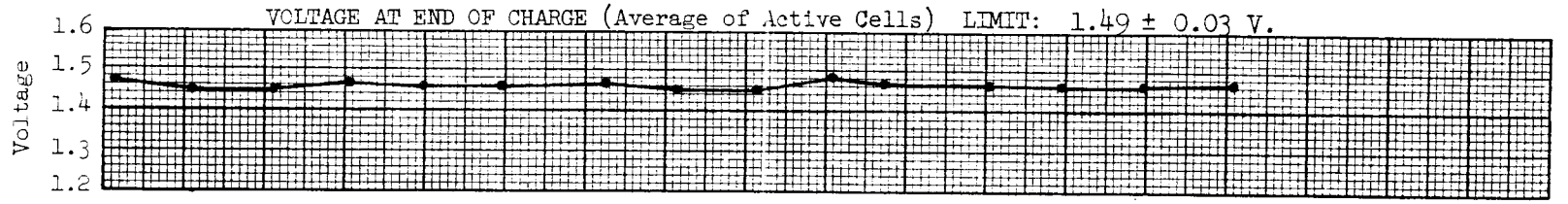
1. Cycles 1404, 2803: Capacity Check.

FIGURE 9(f)

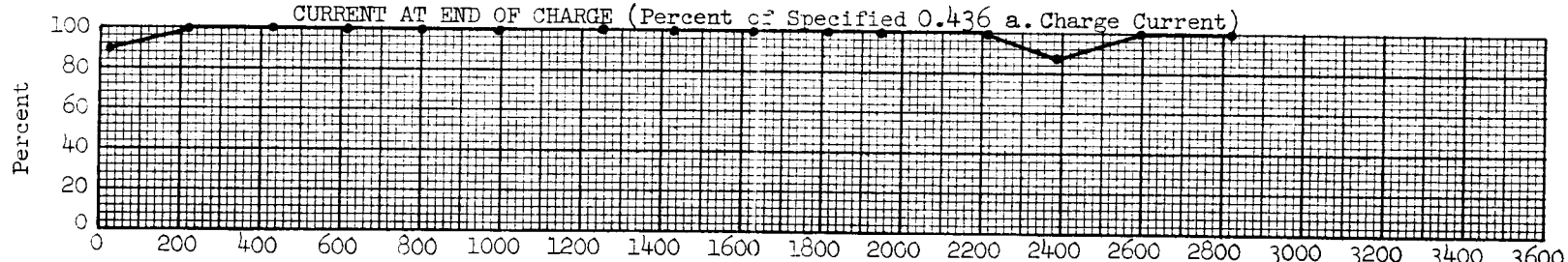
VOLTAGE AT 15 MINUTES AND AT 30 MINUTES OF DISCHARGE (Average of Active Cells)



VOLTAGE AT END OF CHARGE (Average of Active Cells) LIMIT: 1.49 ± 0.03 V.



CURRENT AT END OF CHARGE (Percent of Specified 0.436 a. Charge Current)



Cell Number	Cycle Failed

GOULD 3.5 a.h. (Pack 7)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 25%

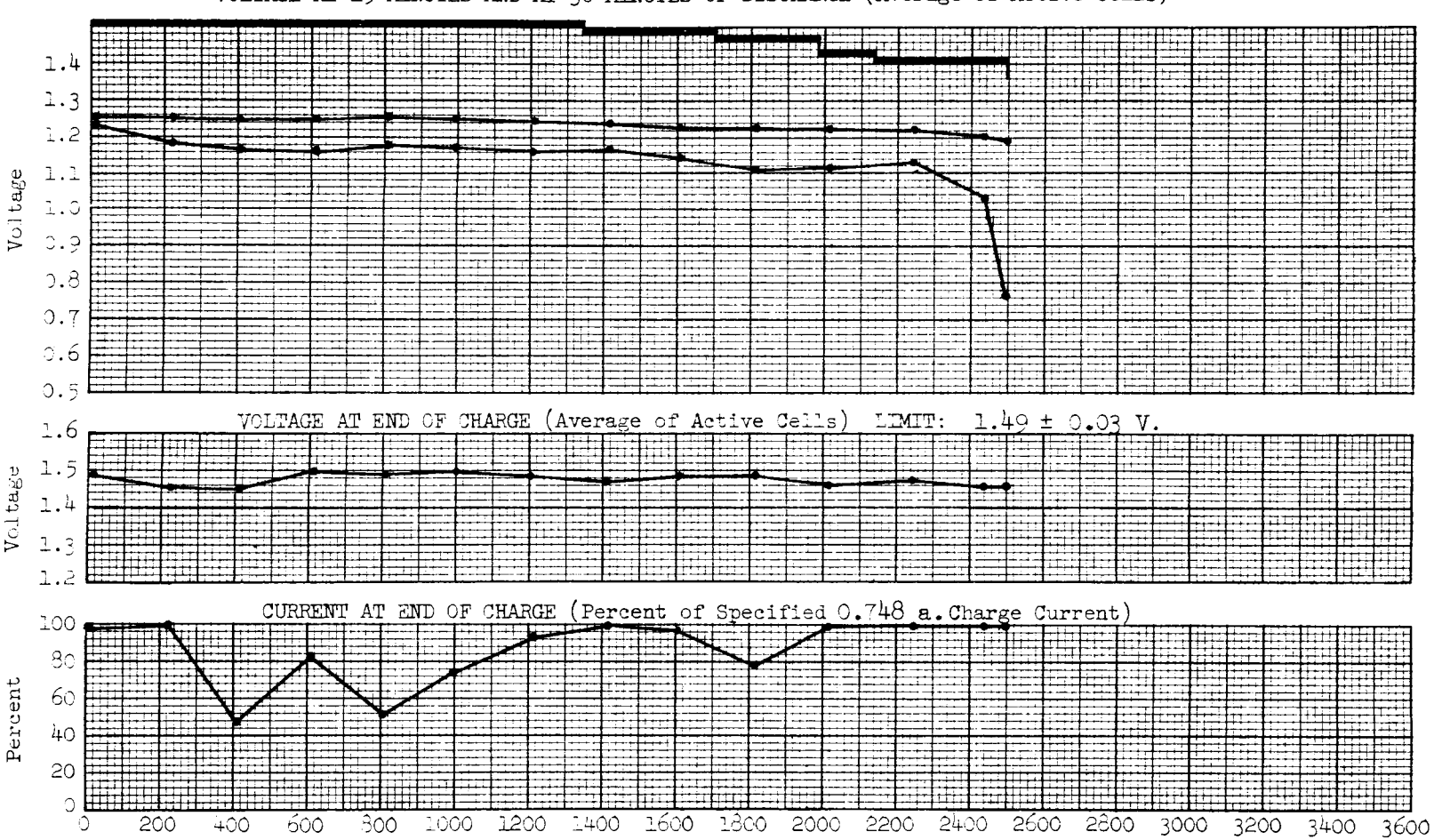
Status: 10 cells cycling after 2863 cycles.

Notes

1. Cycles 674, 1381, 2006, 2758: Capacity Checks.

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FIGURE 9(g)



Cell Number	Cycle Failed
68	1346
112	1704
39, 170	1985
78	2138
41, 130	2494

GOULD 3.5 a.h. (Pack 3)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 40%

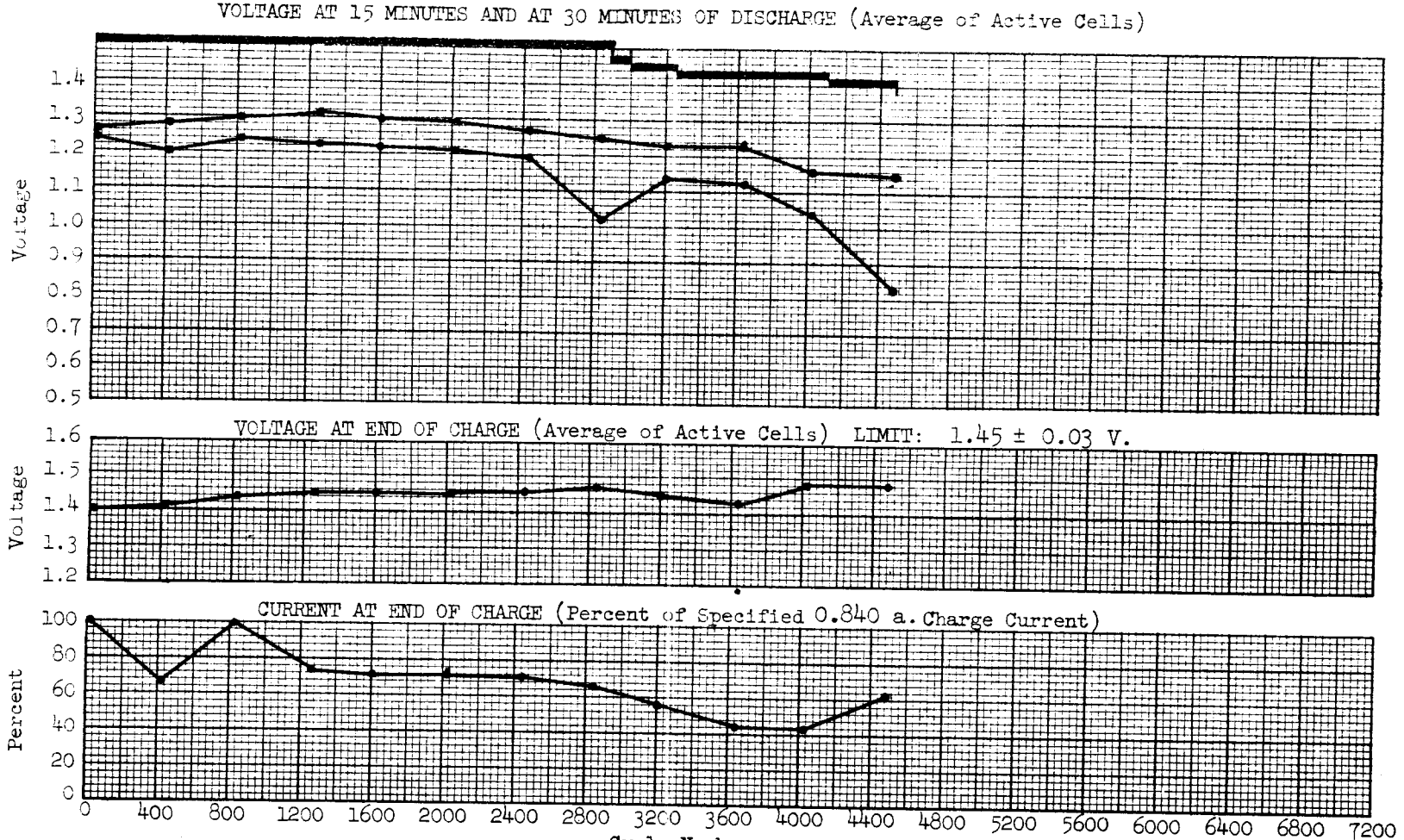
Status: Pack Failed: Cycle 2494

Notes

1. Cycles 676, 1373, 2016: Capacity Check.

FIGURE 9(h)

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Cell Number	Cycle Failed
13, 195	2901
103	2998
200	3270
197	4102
11	4885

GOULD 3.5 a.h. (Pack 27)
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

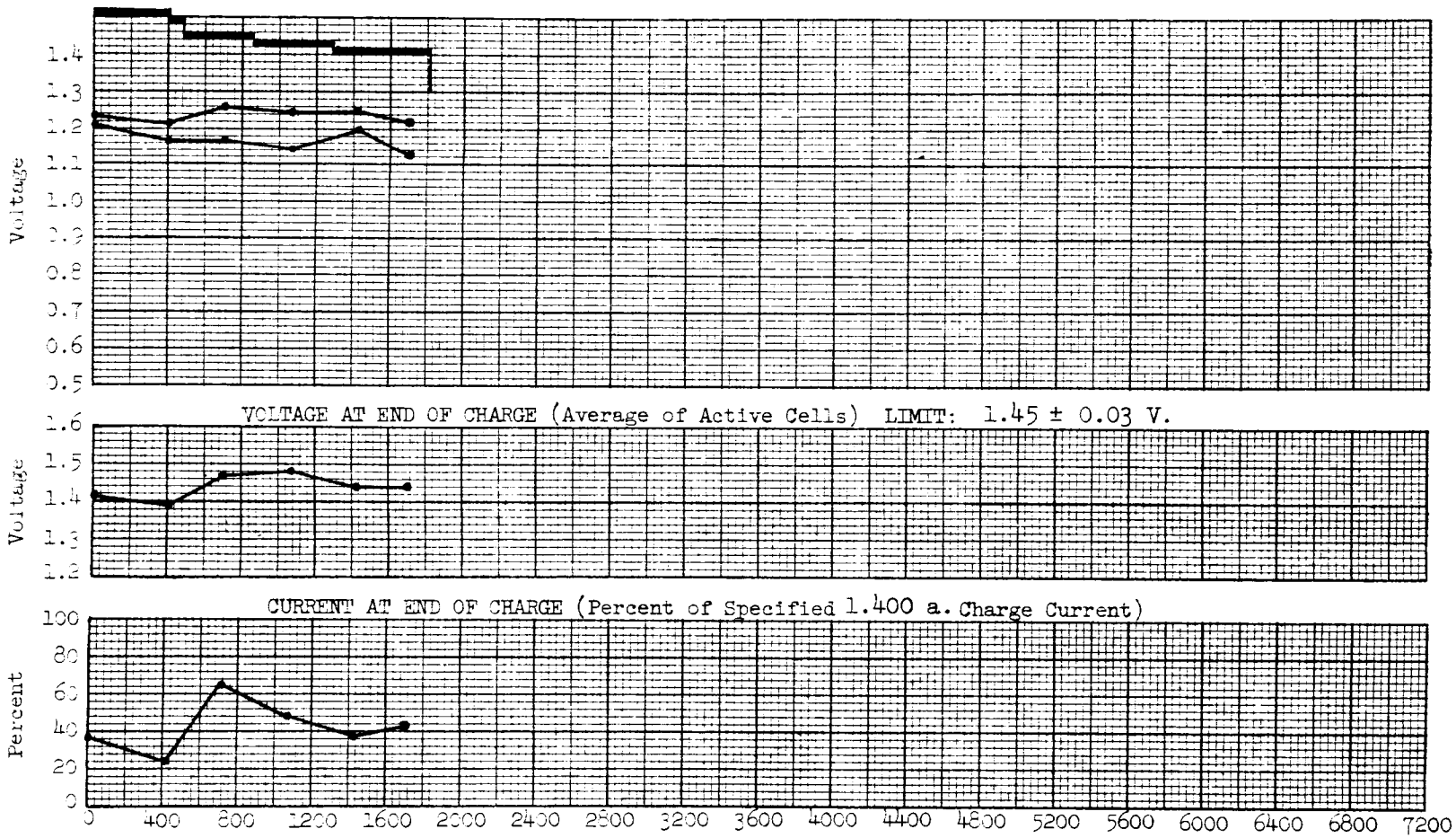
Status: Pack Failed: Cycle 4885

Notes

1. Cycle 779: Changed to 40° C.
2. Cycle 1063: Voltage limit raised to 1.45 V/cell.
3. Cycles 1395, 2708, 3877: Capacity Check.

FIGURE 9(i)

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Cell Number	Cycle Failed
122	408
157, 158	484
141	860
168	1293
All	1811

GOULD 3.5 a.h. (Pack 28)

Test Temperature: 50° - 40° C

Orbit Period: 1.5 hours

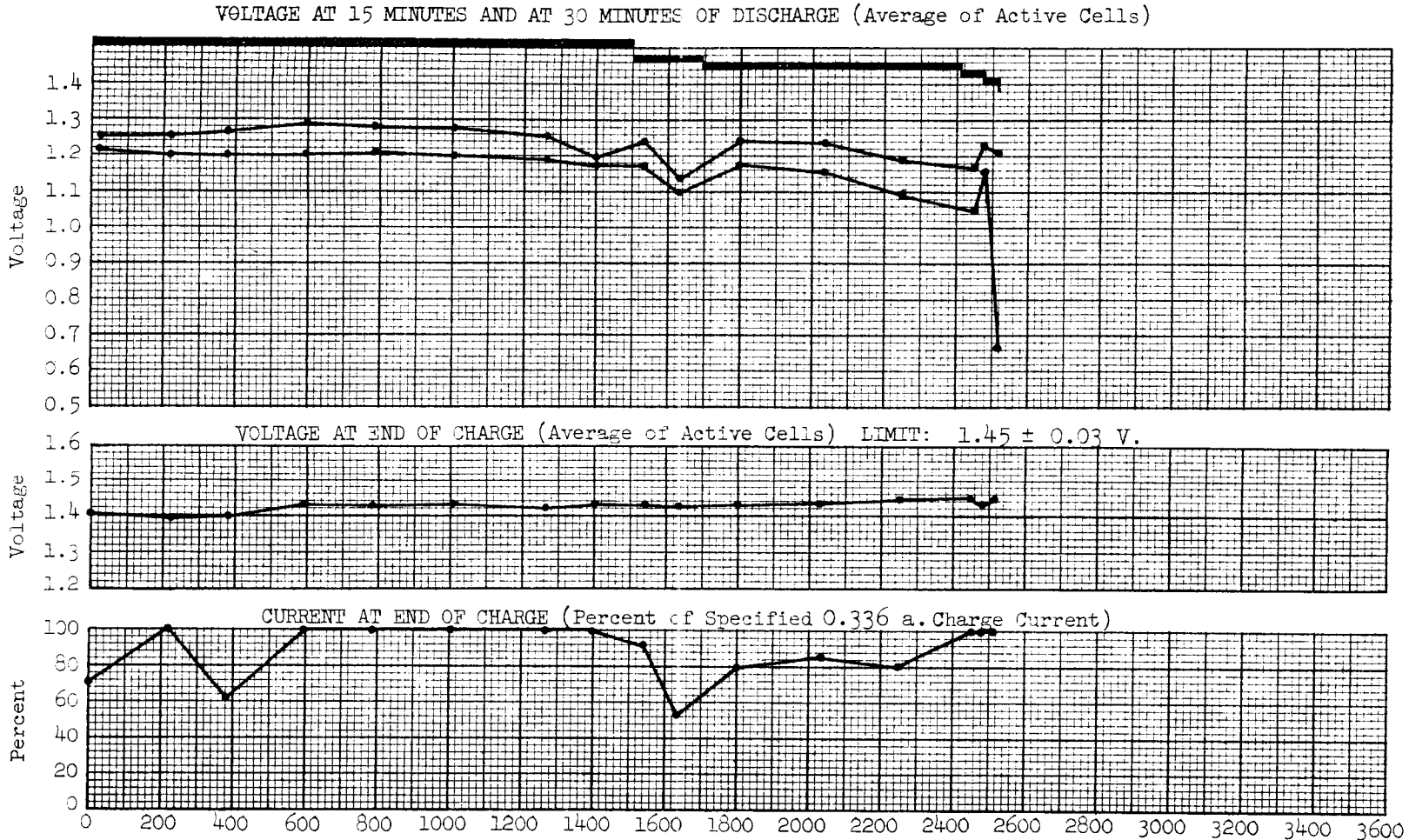
Depth of Discharge: 25%

Status: Pack Failed: Cycle 1811

Notes

1. Cycle 424: Changed to 40° C.
2. Cycle 657: Voltage limit raised to 1.45 V/cell.
3. Cycle 1367: Capacity Check.

FIGURE 9(j)



Cell Number	Cycle Failed
166, 179	1500
92	1696
126	2411
162	2477
72, 143	2517

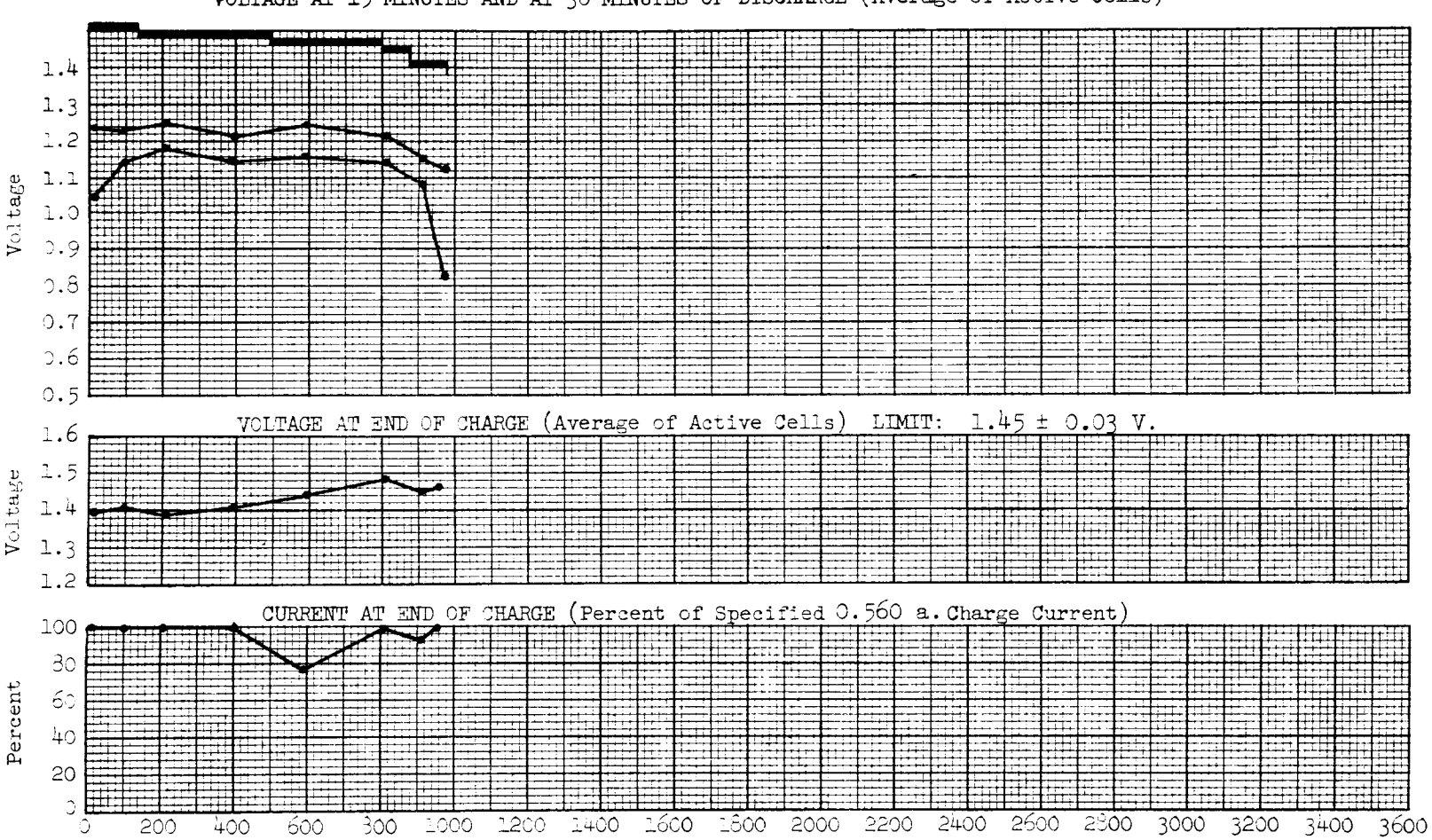
GOULD 3.5 a.h. (Pack 31)
Test Temperature: 30° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: Pack Failed: Cycle 2517

Notes

1. Cycle 328: Changed to 40° C.
2. Cycle 486: Voltage limit raised to 1.45 V/cell.
3. Cycles 701, 1400, 2077: Capacity Check.

FIGURE 9(k)



Cell Number	Cycle Failed
125	138
65	495
1	800
67, 132	875
149	974

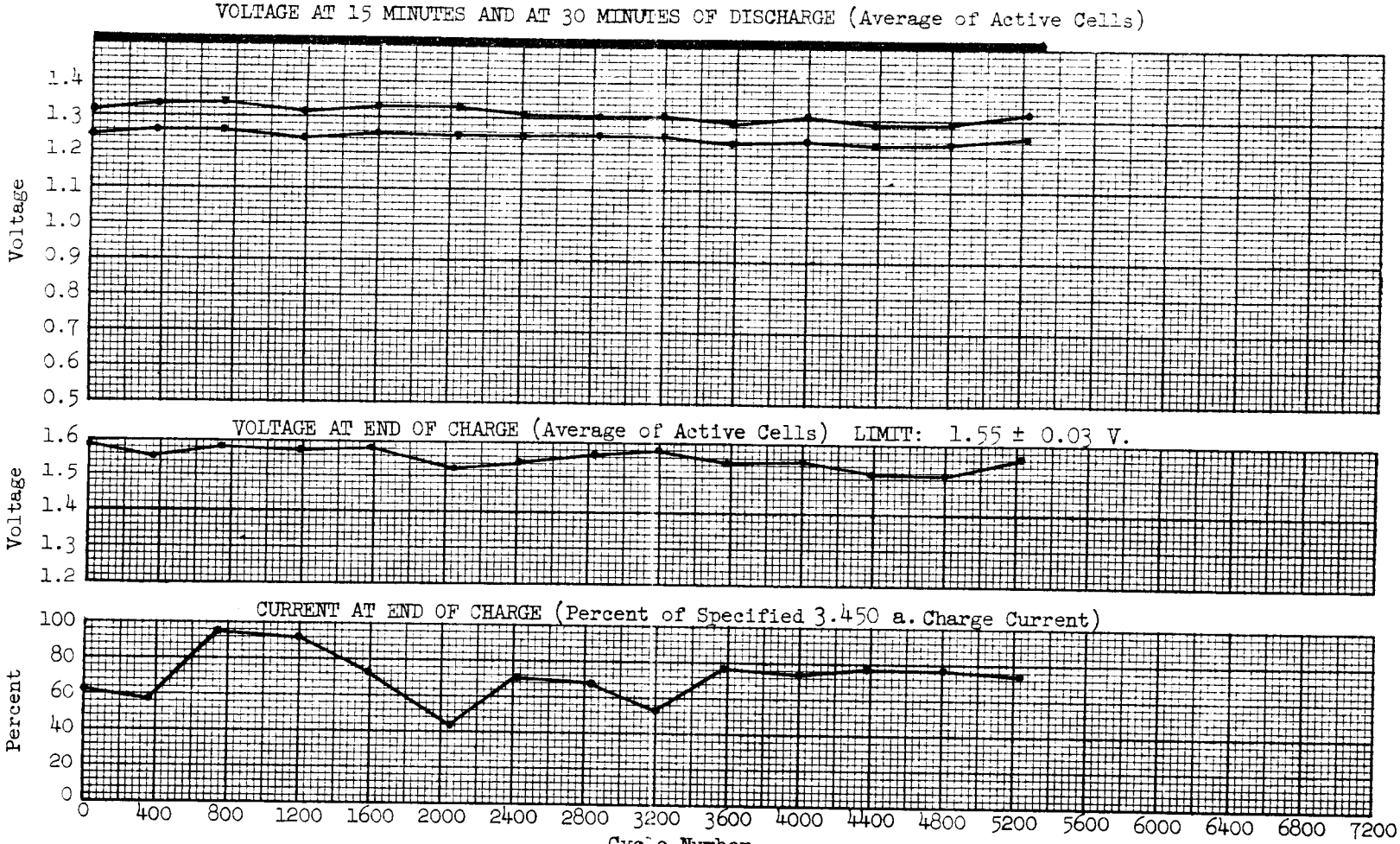
GOULD 3.5 a.h. (Pack 32)
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 974

Notes

1. Cycle 495: Changed to 40° C, with voltage limit raised to 1.45 V/cell.
2. Cycle 747: Capacity Check.

FIGURE 9(1)



Cell Number	Cycle Failed

GOULD 20 a.h. (Pack 84)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

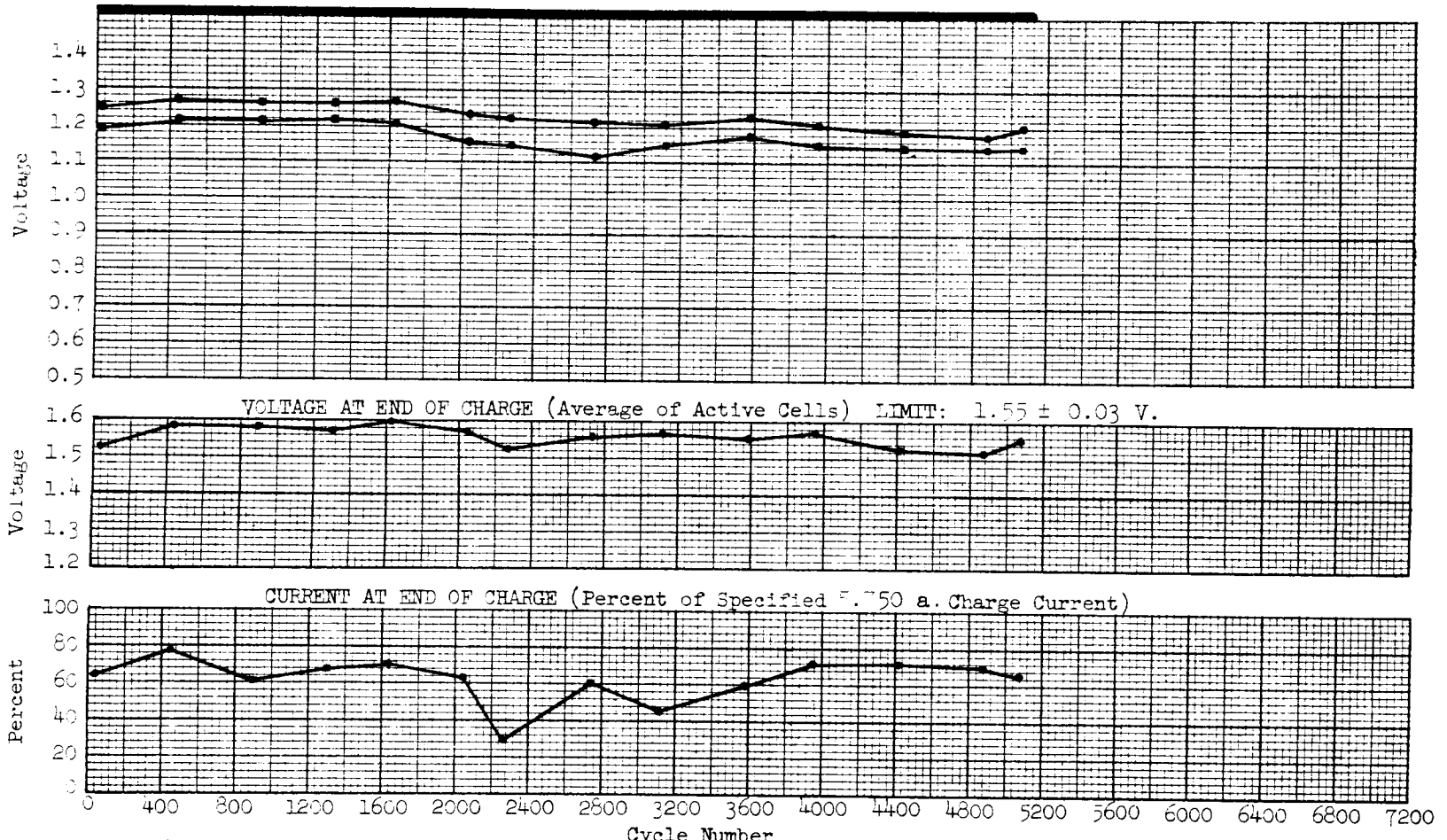
Status: 5 cells cycling after 5330 cycles.

Notes

1. Cycles 1471, 3133 4378: Capacity Check.

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FIGURE 10(a



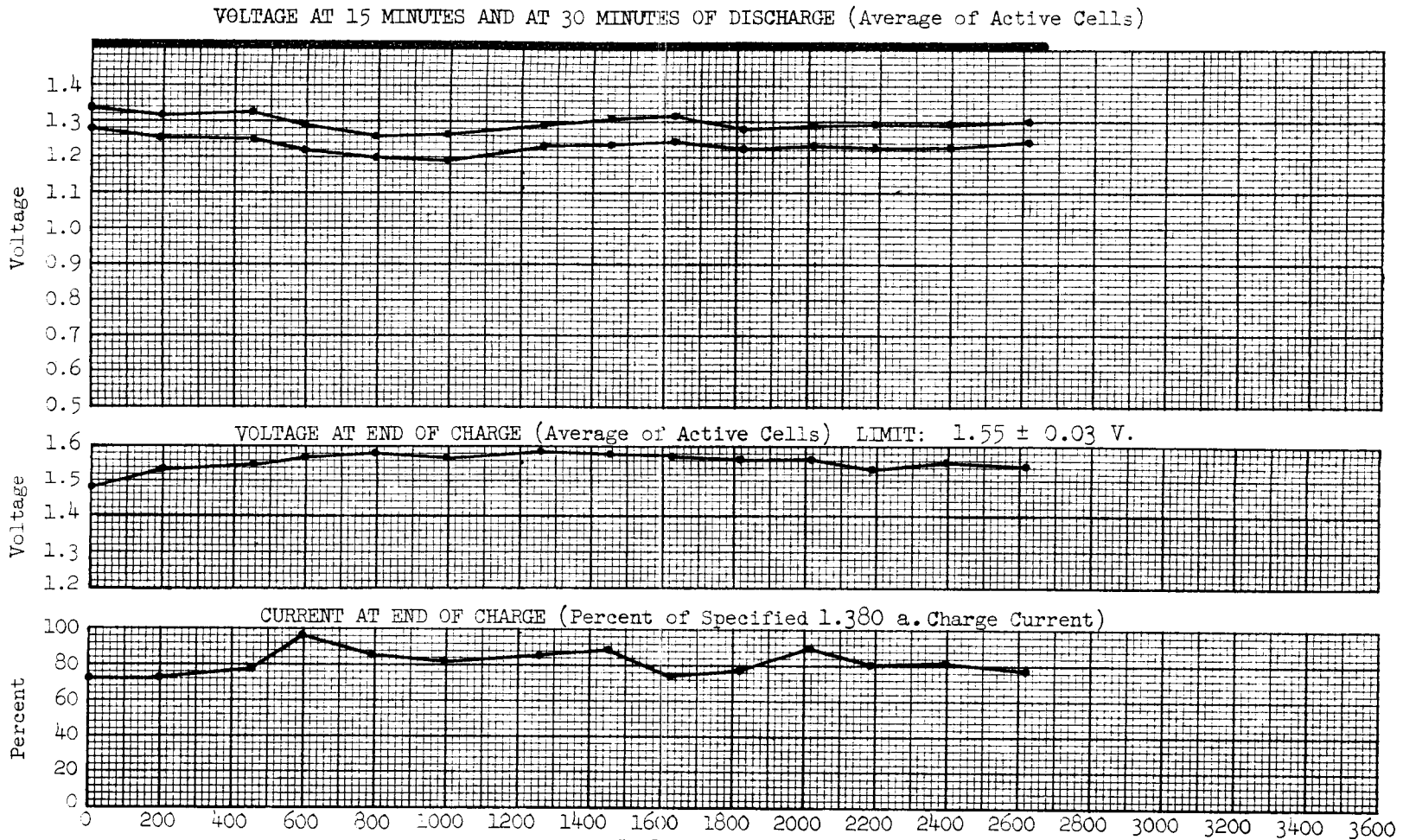
Cell Number	Cycle Failed
77	3556

GOULD 20 a.h. (Pack 98)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 4 cells cycling after 5137 cycles.

Notes
1. Cycles 1430, 3028, 4185: Capacity Check.

FIGURE 10(3)



Cell Number	Cycle Failed

GOULD 20 a.h. (Pack 80)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 15%

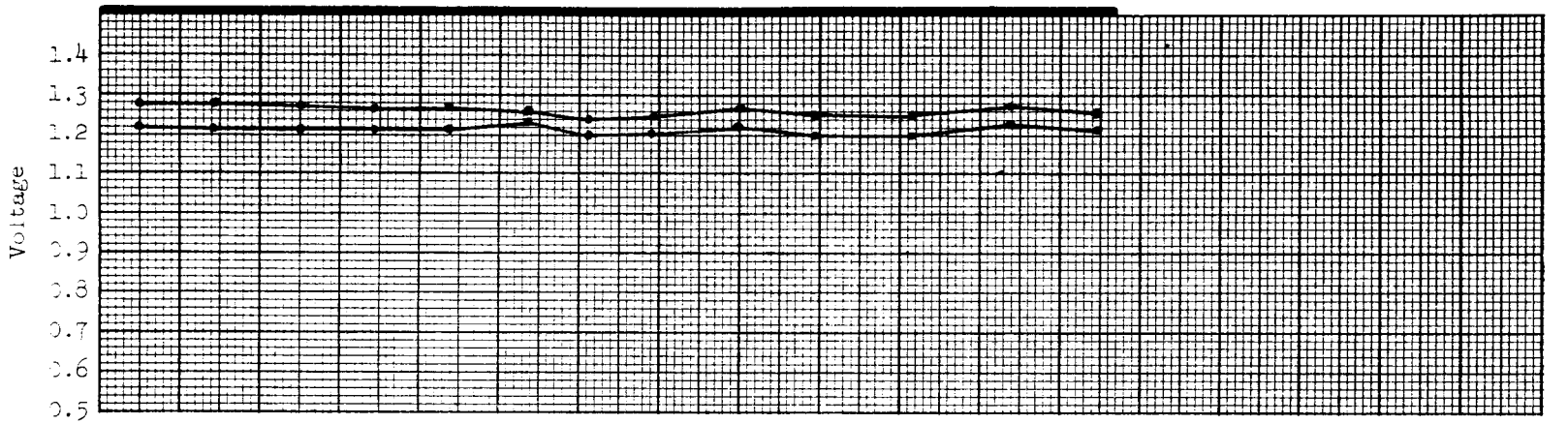
Status: 5 cells cycling after 2670 cycles.

Notes

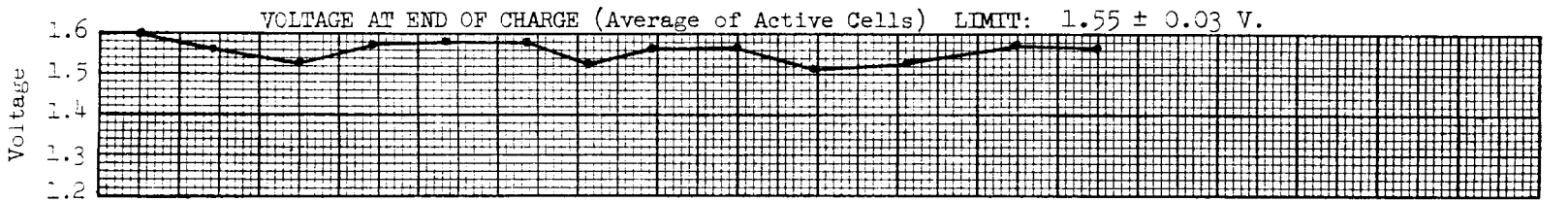
1. Cycles 740, 1611, 2468: Capacity Check.

FIGURE 10(c)

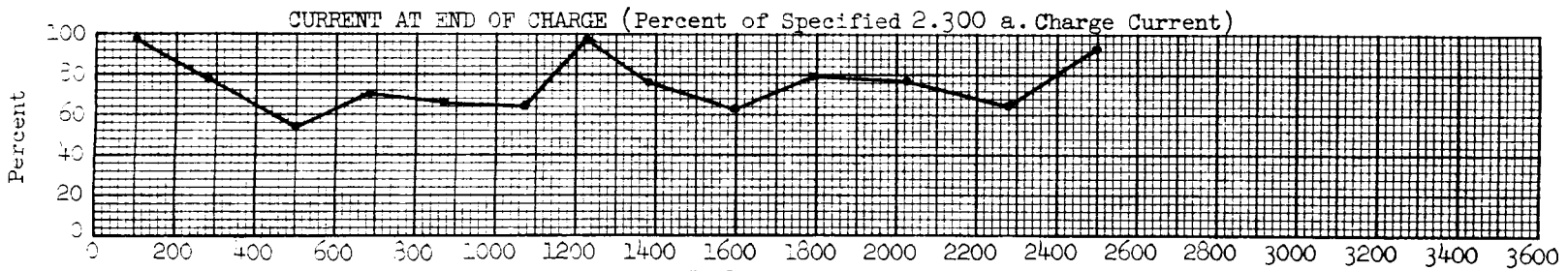
VOLTAGE AT 15 MINUTES AND AT 30 MINUTES OF DISCHARGE (Average of Active Cells)



VOLTAGE AT END OF CHARGE (Average of Active Cells) LIMIT: 1.55 ± 0.03 V.



CURRENT AT END OF CHARGE (Percent of Specified 2.300 a. Charge Current)



Cell Number	Cycle Failed

GOULD 20 a.h. (Pack 94)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 25%

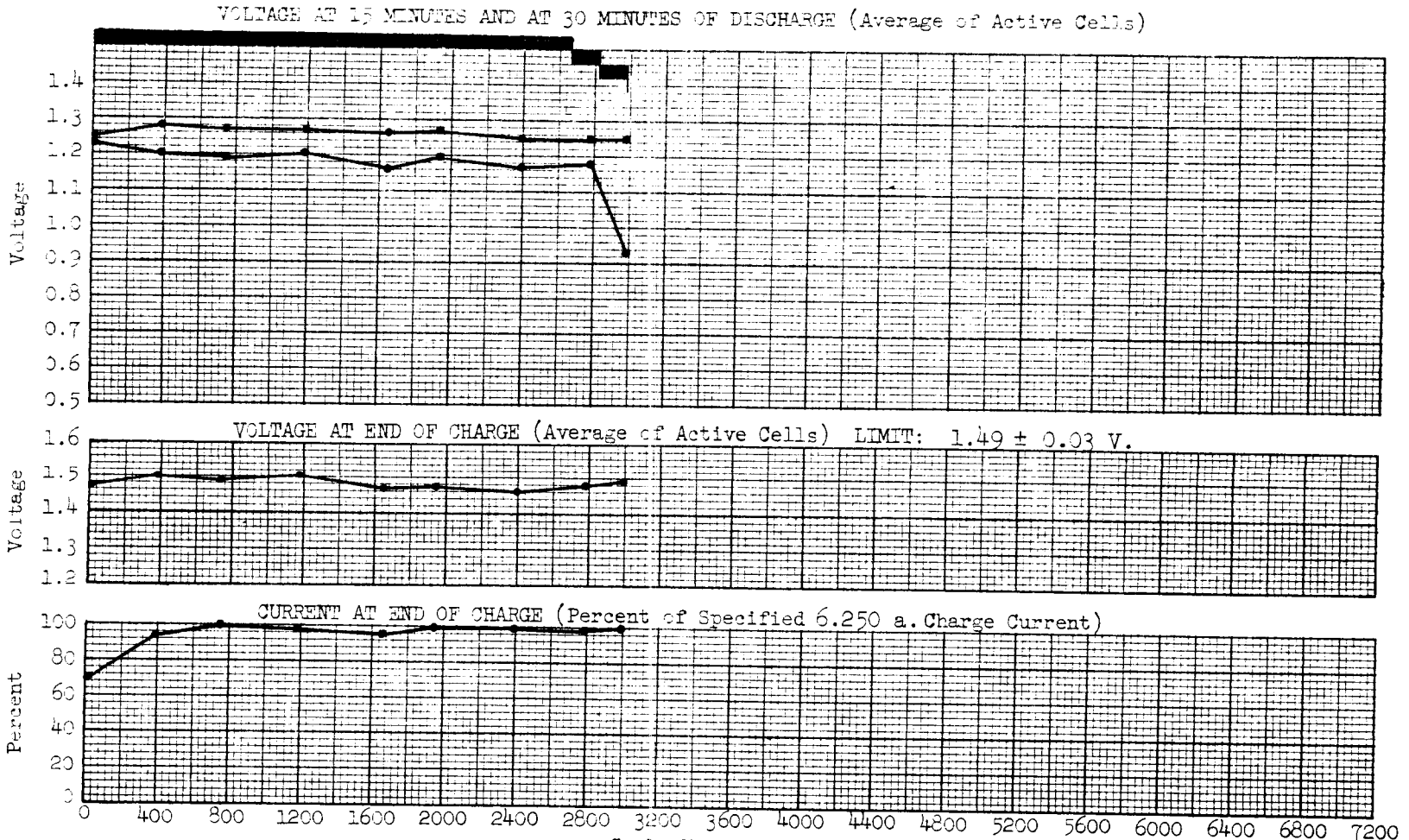
Status: 5 cells cycling after 2541 cycles.

Notes

1. Cycles 727, 1506, 2173: Capacity Check.

FIGURE 10(d)

QE/C 65-356



Cell Number	Cycle Failed
69	2672
R36	2826
5	2980

GOULD 20 a.h. (Pack 104)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

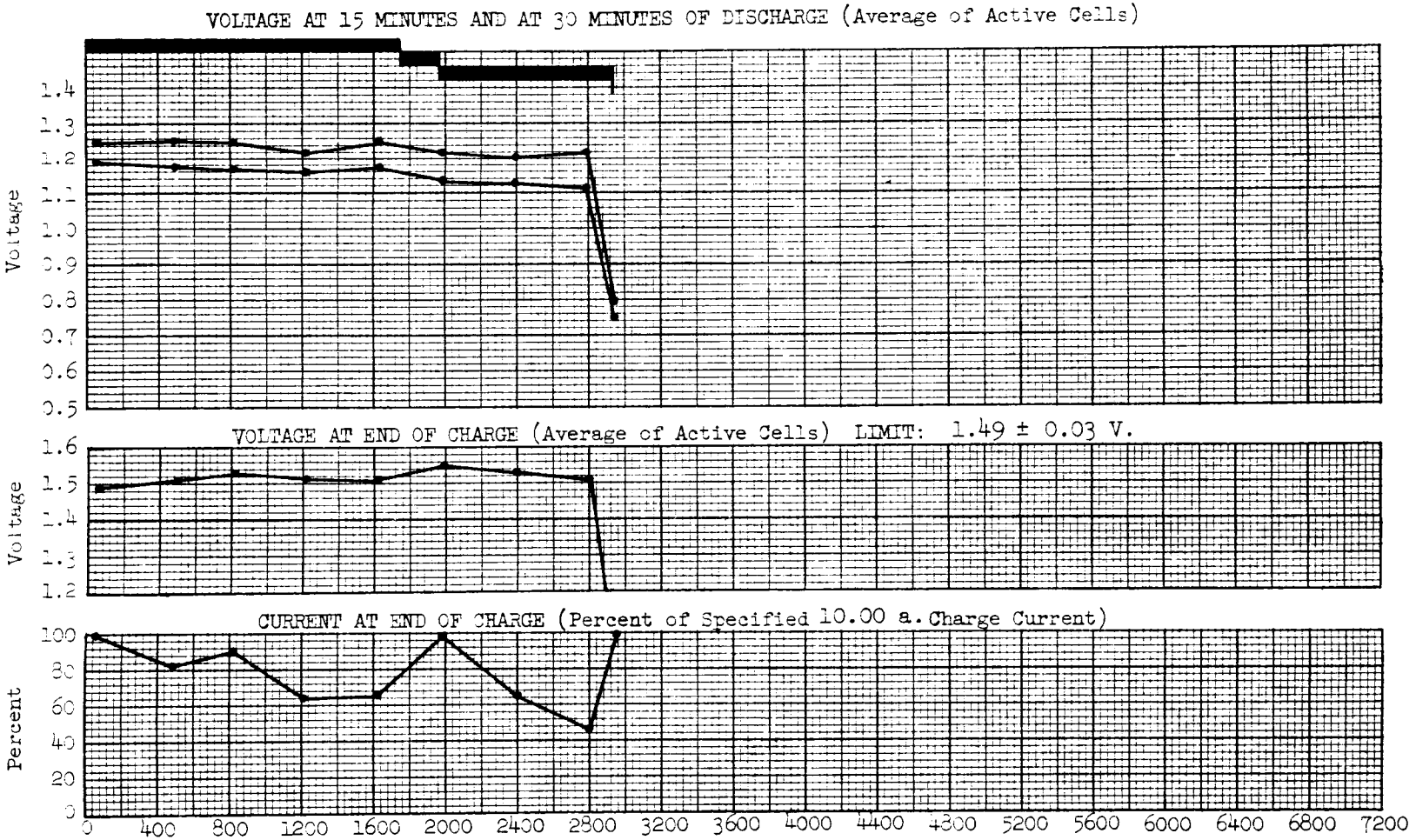
Status: Pack Failed: Cycle 2980

Notes

1. Cycles 1360, 2802: Capacity Check.

FIGURE 10(e)

QE/C 65-356



Cell Number	Cycle Failed
61	1747
R91	1963
92	2937

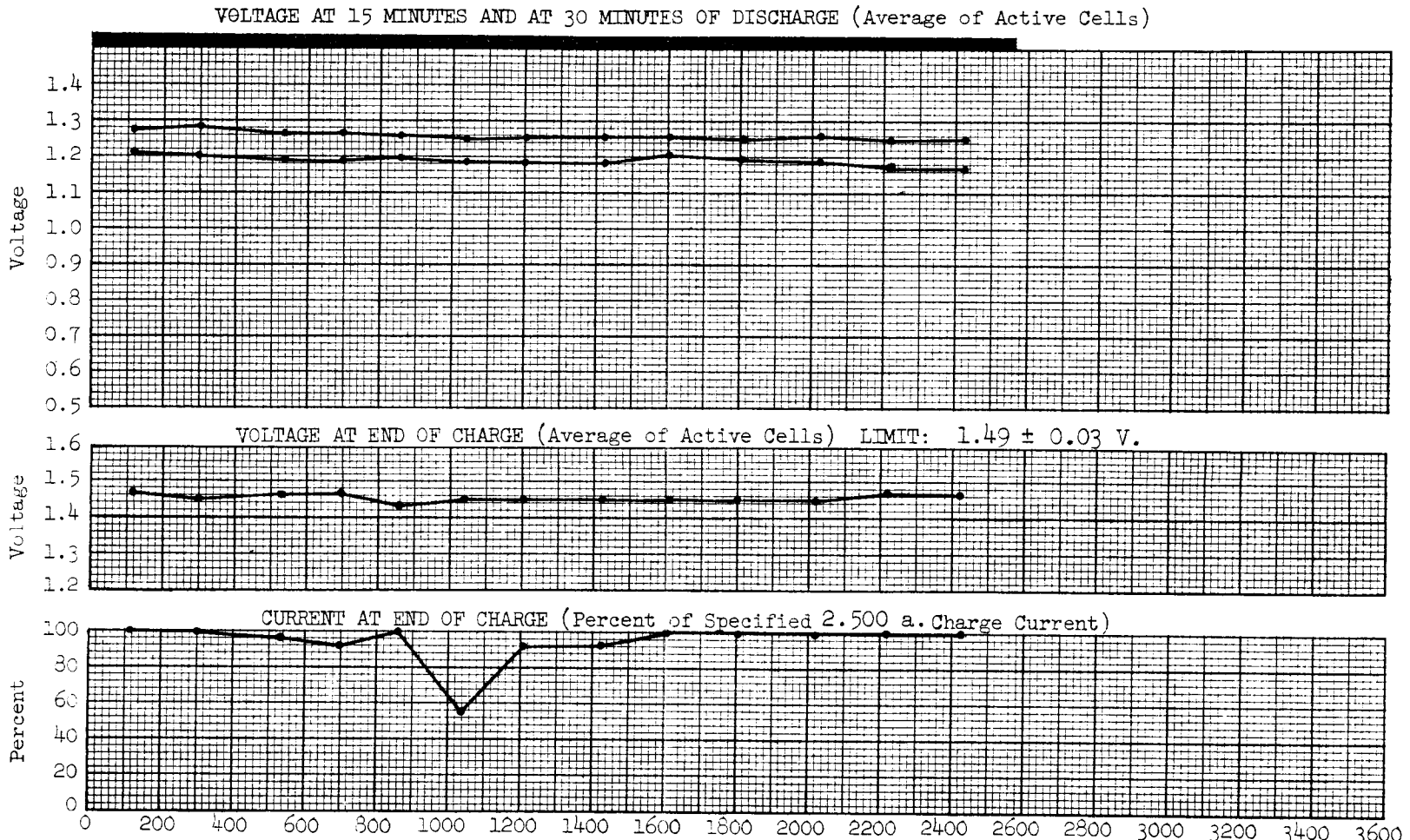
GOULD 20 a.h. (Pack 118)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 40%

Status: Pack Failed: Cycle 2937

Notes

1. Cycle 1358: Capacity Check.

FIGURE 10(f)



Cell Number	Cycle Failed

GOULD 20 a.h. (Pack 105)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 25%

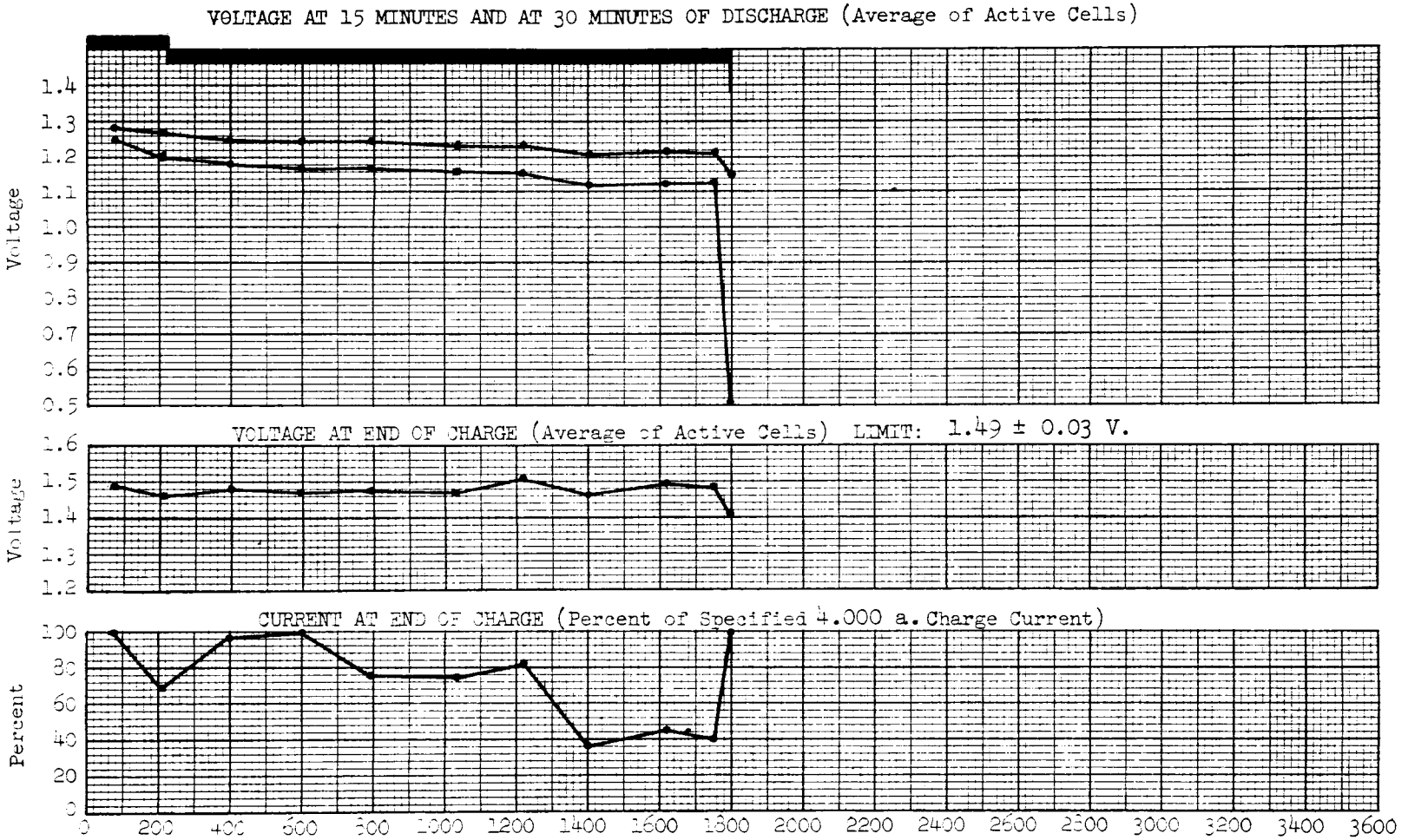
Status: 5 cells cycling after 2564 cycles.

Notes

1. Cycles 740, 1577, 2231: Capacity Check.

FIGURE 10(g)

QM/C 65-356



Cell Number	Cycle Failed
3	222
80, 86	1793

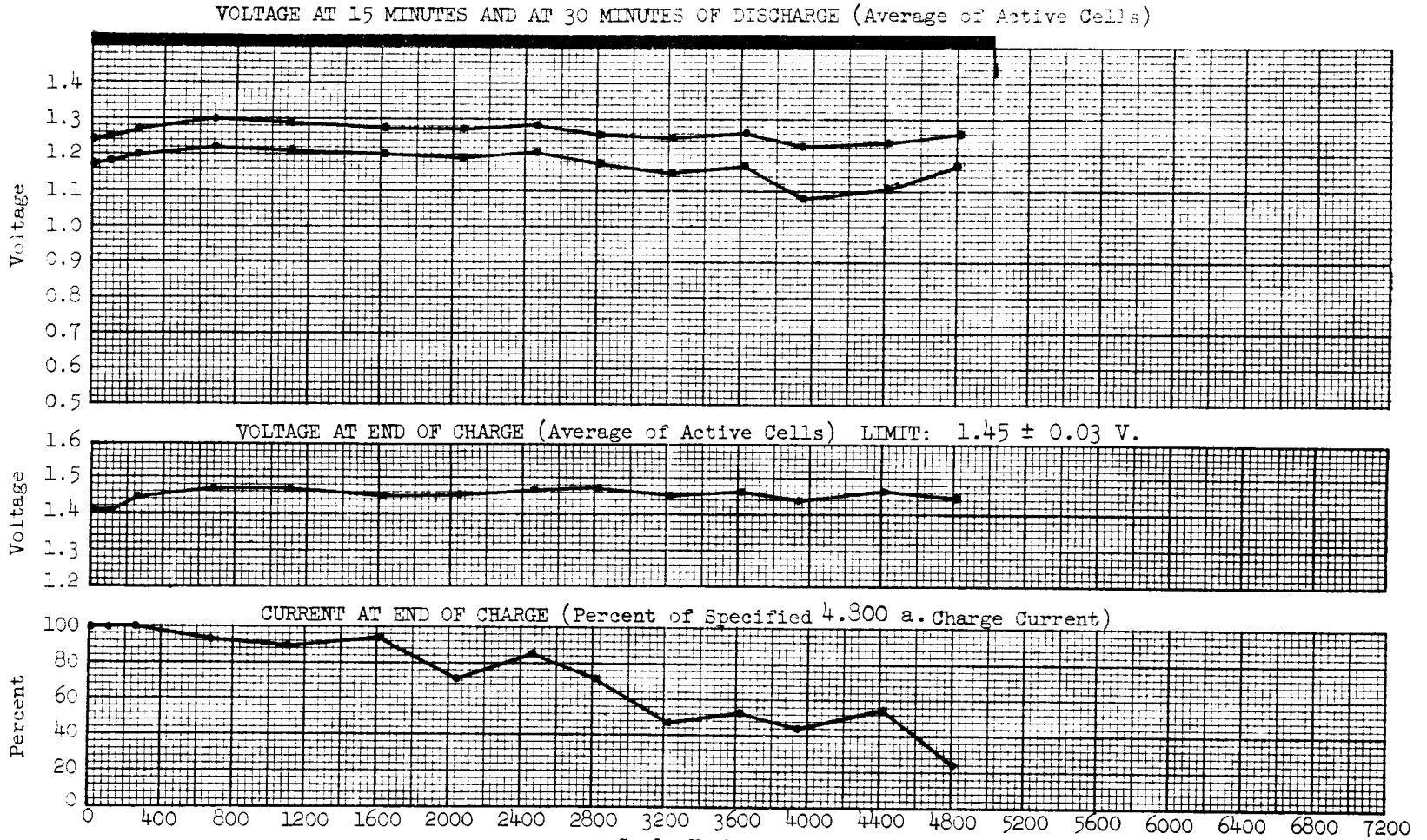
GOULD 20 a.h. (Pack 119)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 40%

Status: Pack Failed: Cycle 1793

Notes

1. Cycles 726, 1506: Capacity Check.

FIGURE 10(h)



Cell Number	Cycle Failed
17, 25	5005

GOULD 20 a.h. (Pack 112)
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

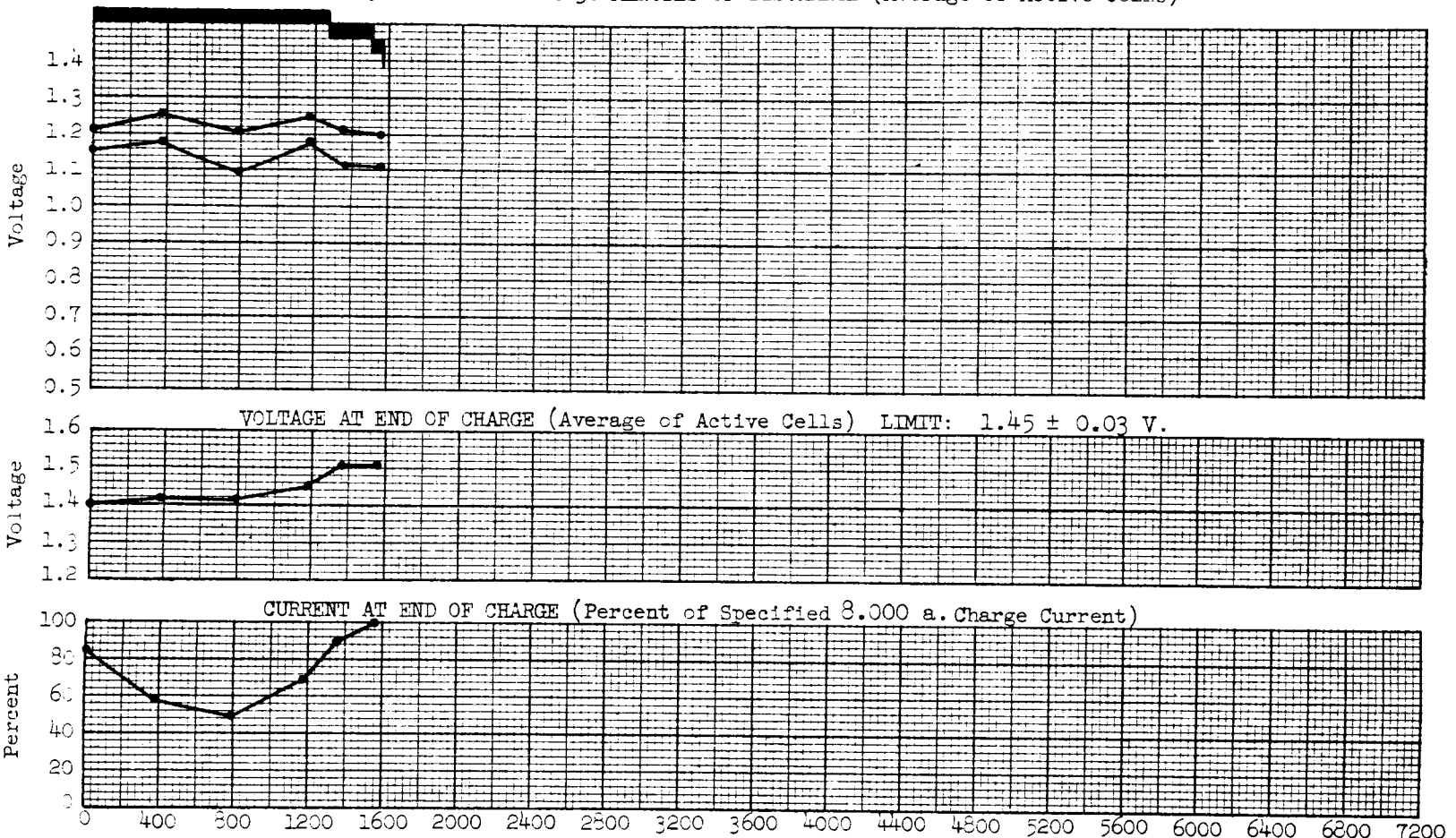
Status: 3 cells cycling after 5005 cycles.

Notes

1. Cycle 183: Changed to 40° C.
2. Cycle 485: Voltage limit raised to 1.45 V/cell.
3. Cycles 1395, 2950, 4370: Capacity Check.

FIGURE 10(i)

GE/c 65-356



Cell Number	Cycle Failed
9	1273
R29	1509
11	1569

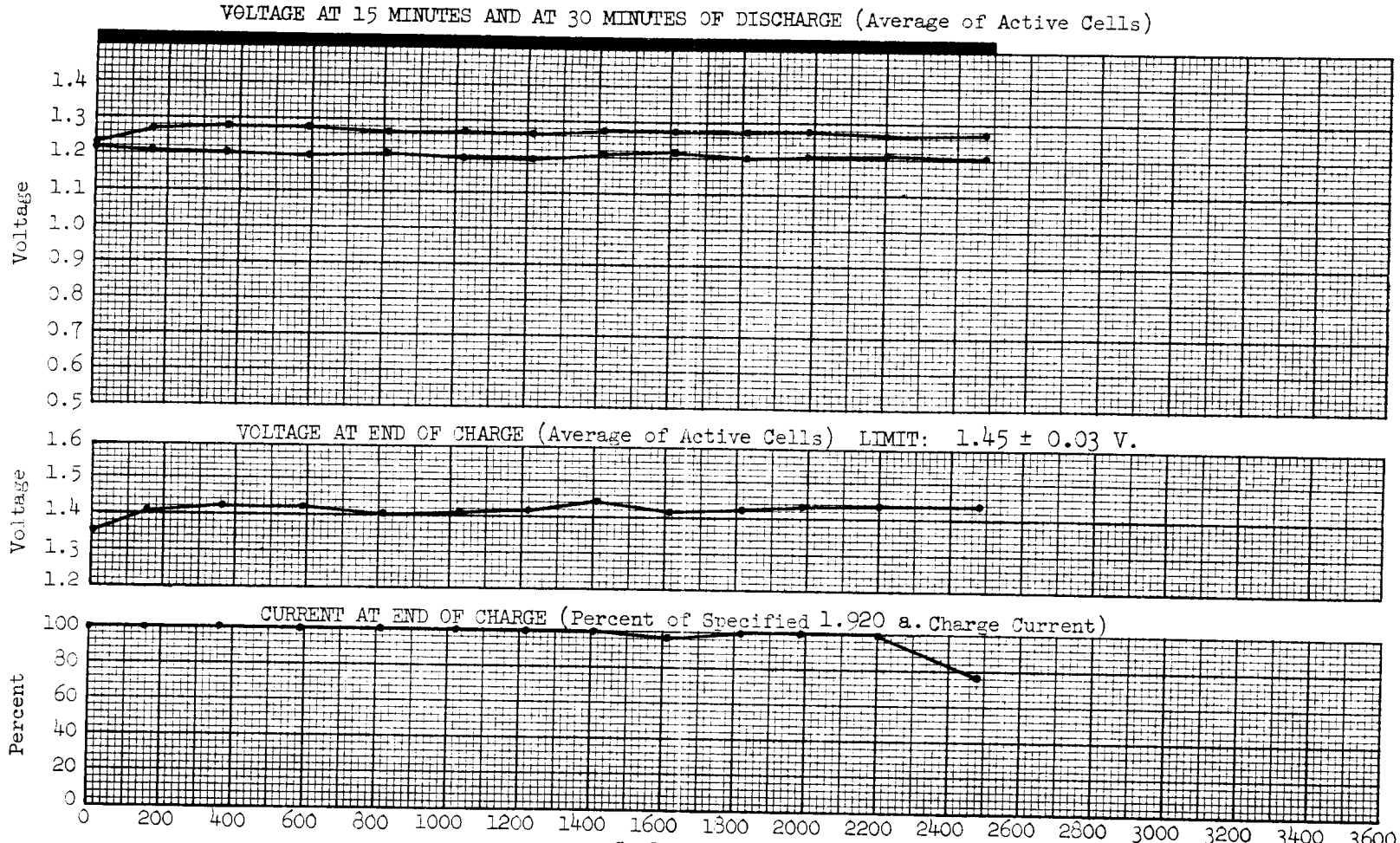
GOULD 20 a.h. (Pack 126)
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 1569

Notes

1. Cycle 1326: Changed to 40° C with voltage limit raised to 1.45 V/cell.
2. Cycle 1463: Capacity Check.

FIGURE 10(j)



Cell Number	Cycle Failed

GOULD 20 a.h. (Pack 108)
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 15%

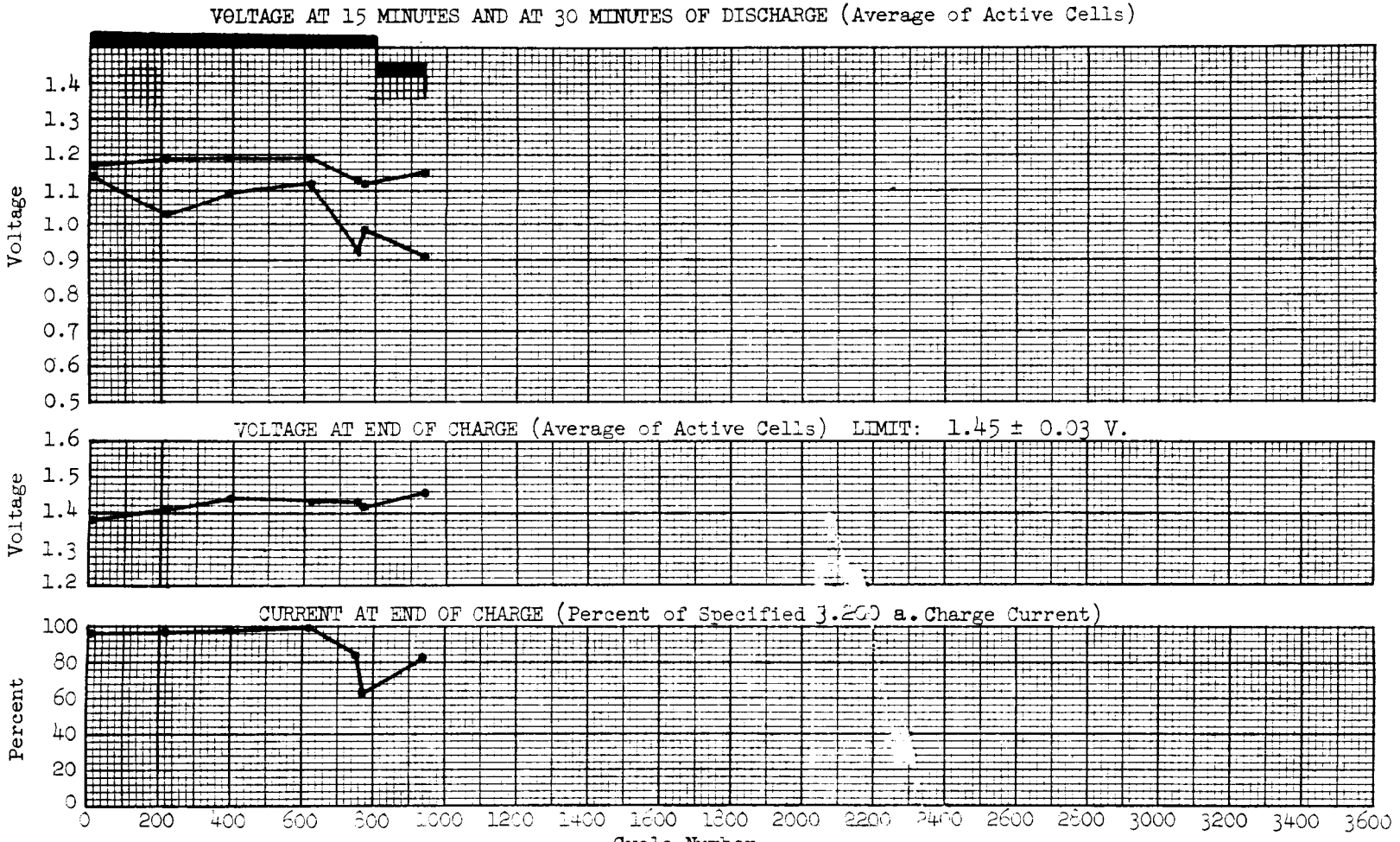
Status: 5 cells cycling after 2501 cycles.

Notes

1. Cycle 47: Changed to 40° C.
2. Cycle 206: Voltage limit raised to 1.45 V/cell.
3. Cycles 717, 1544, 2189: Capacity Check.

FIGURE 10(k)

QE/c 65-356



Cell Number	Cycle Failed
16	801
58, 18	983

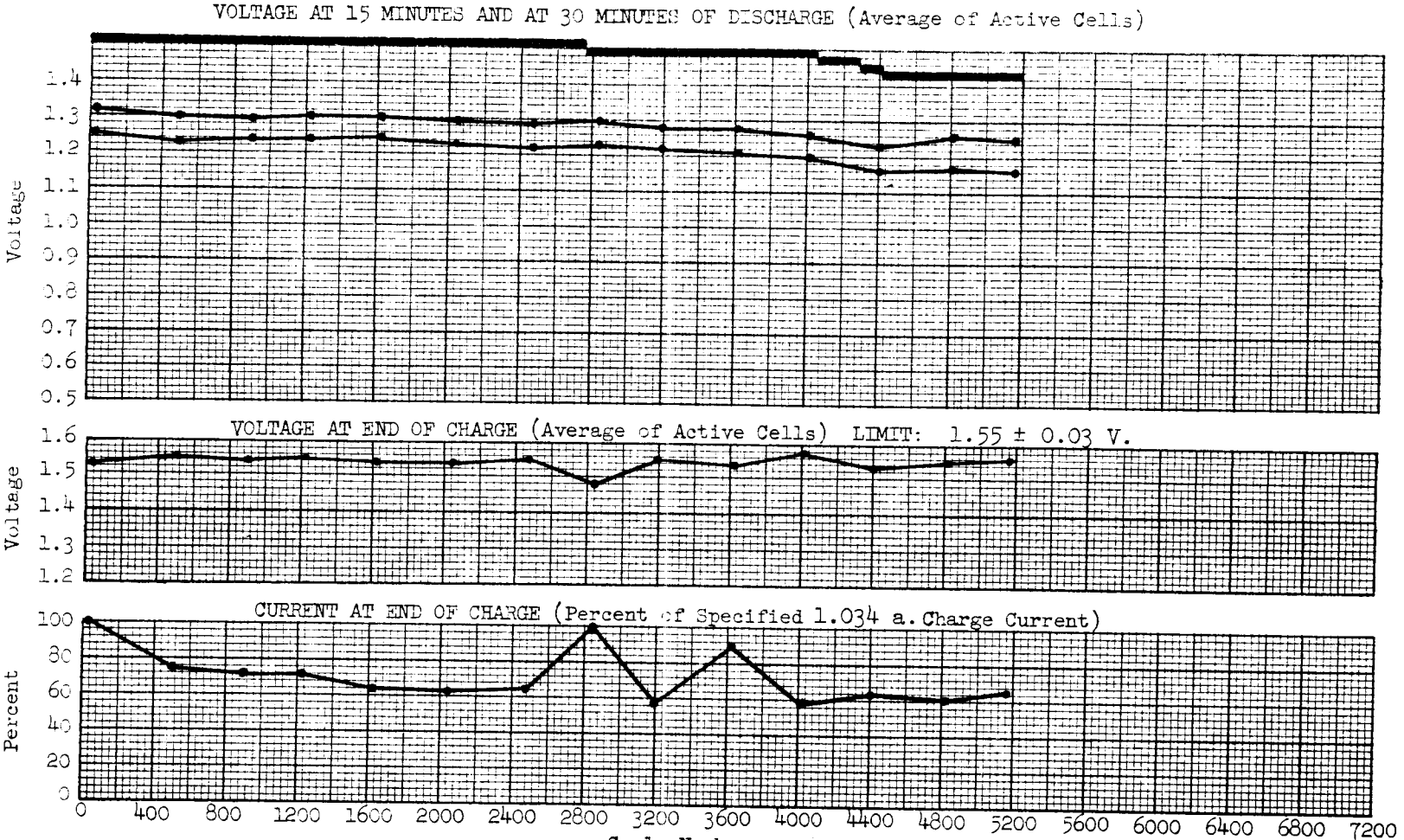
GOULD 20 a.h. (Pack 122)
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 983

Notes

1. Cycle 757: Changed to 40° C with voltage limit raised to 1.45 V/cell.
2. Cycle 713: Capacity Check.

FIGURE 10(1)



Cell Number	Cycle Failed
2397	2762
1825	4094
2311	4285
2400	4413

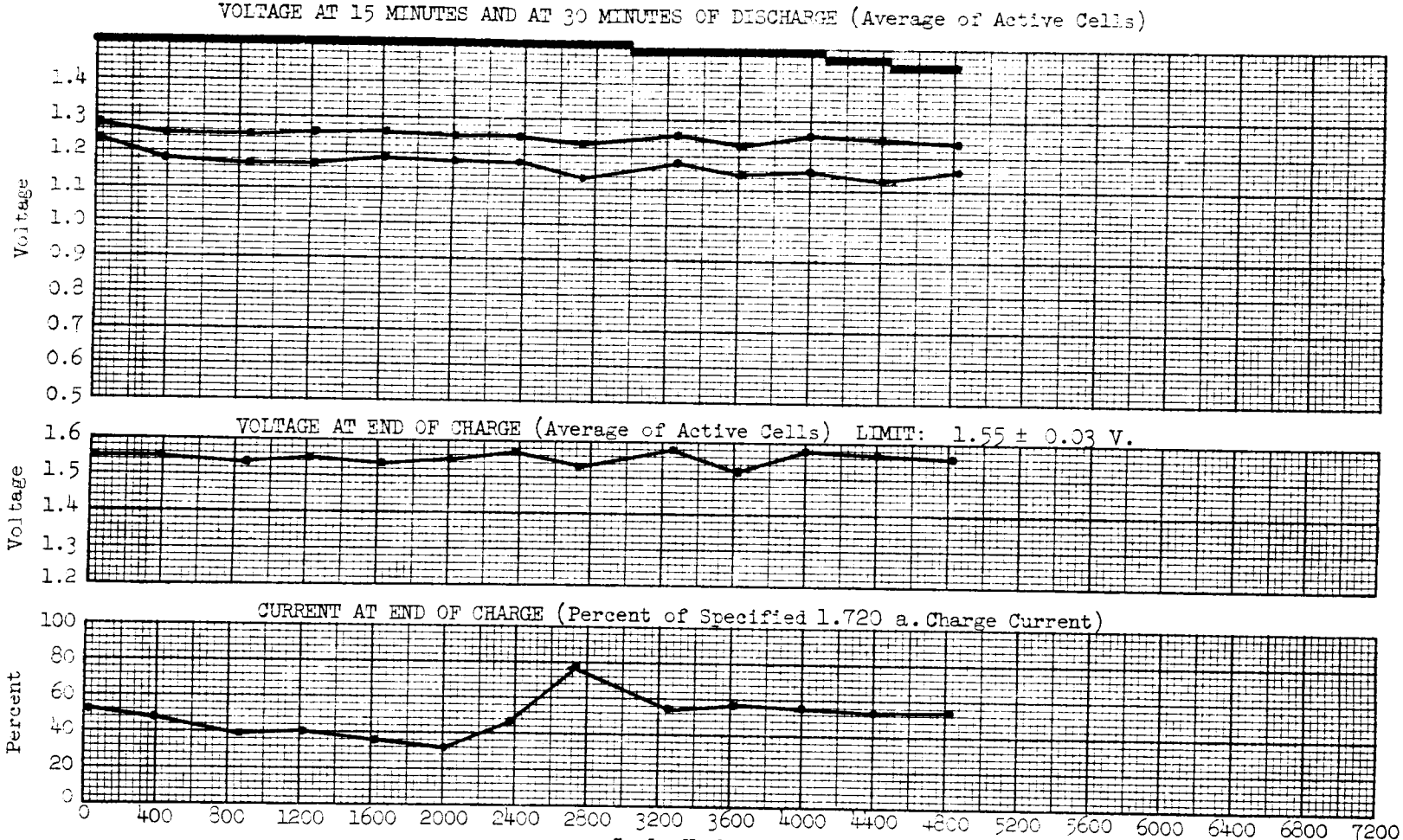
GULTON 6.0 a.h. (Pack 61)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: 6 cells cycling after 5201 cycles.

Notes

1. Cycles 1467, 2897, 4074: Capacity Check.

FIGURE 11(a)



Cell Number	Cycle Failed
1630	2995
1792	4066
1806	4441

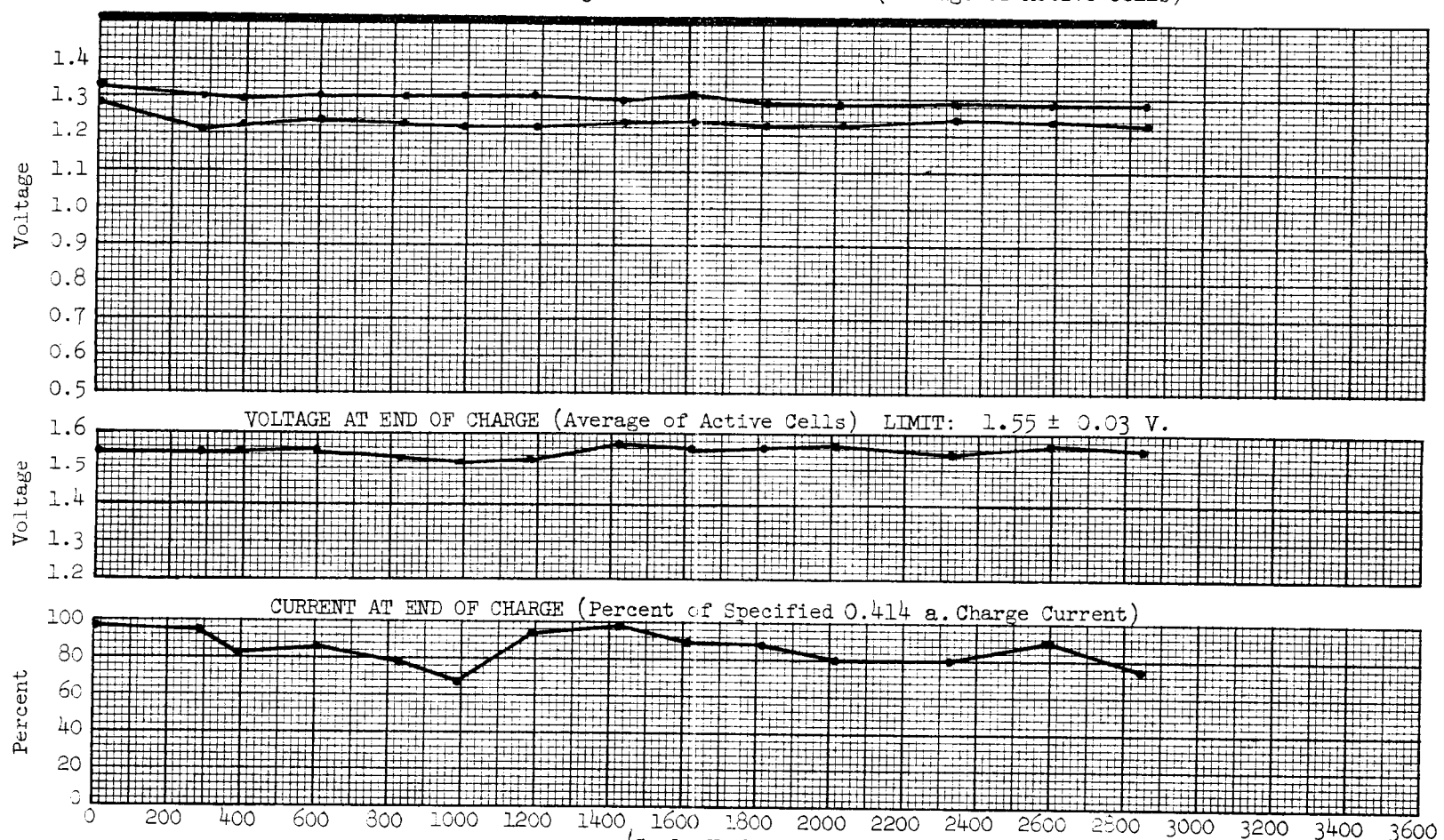
GULTON 6.0 a.h. (Pack 62)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 7 cells cycling after 4829 cycles.

Notes

1. Cycles 1386, 2741, 4090: Capacity Check.

FIGURE 11(b)



Cell Number	Cycle Failed

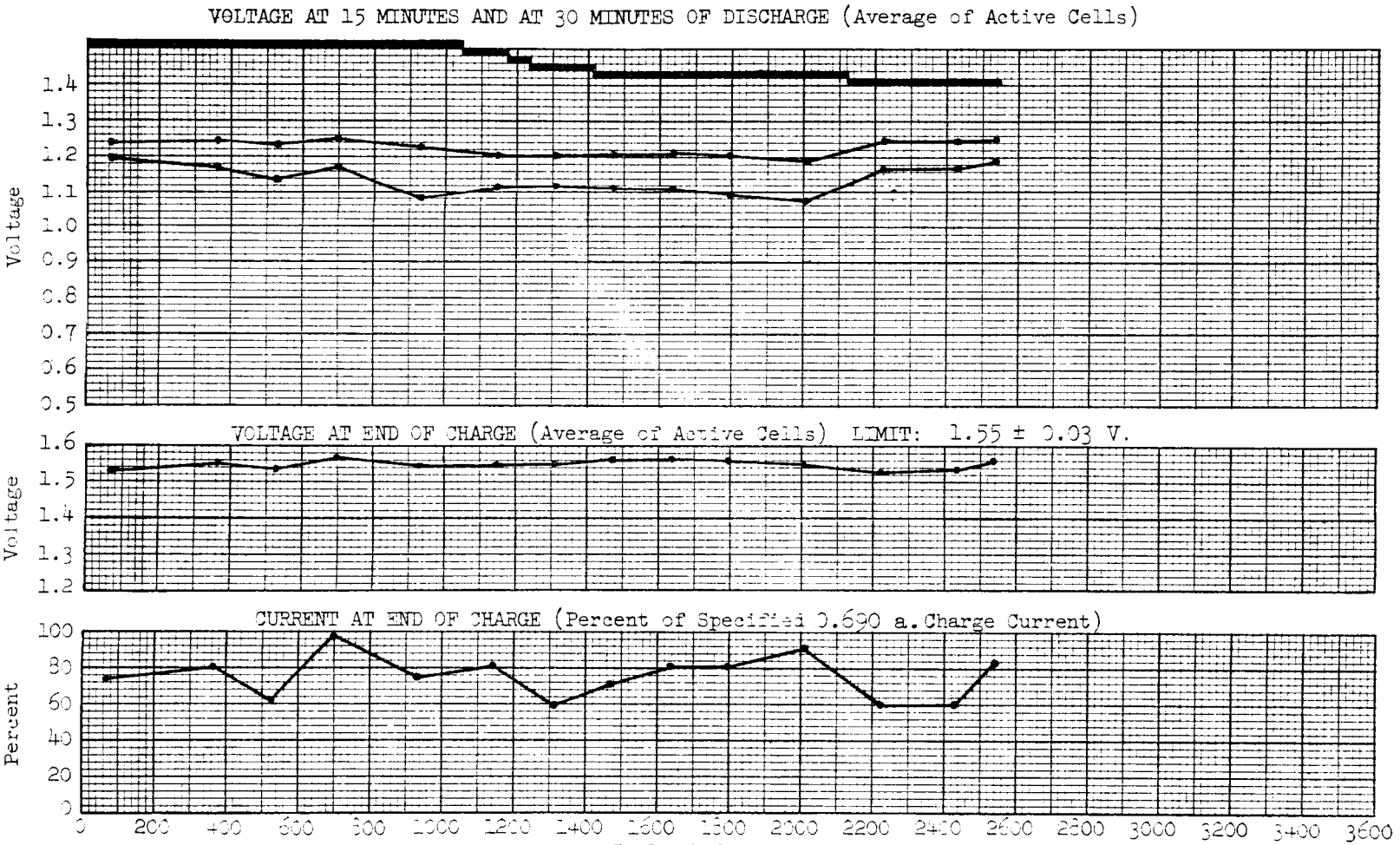
GULTON 6.0 a.h. (Pack 65)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: 10 cells cycling after 2862 cycles.

Notes

1. Cycles 694, 1440, 2200: Capacity Check.

FIGURE 11(c)



Cell Number	Cycle Failed
1794	1045
1843	1173
1781	1237
1634	1417
1823	2122

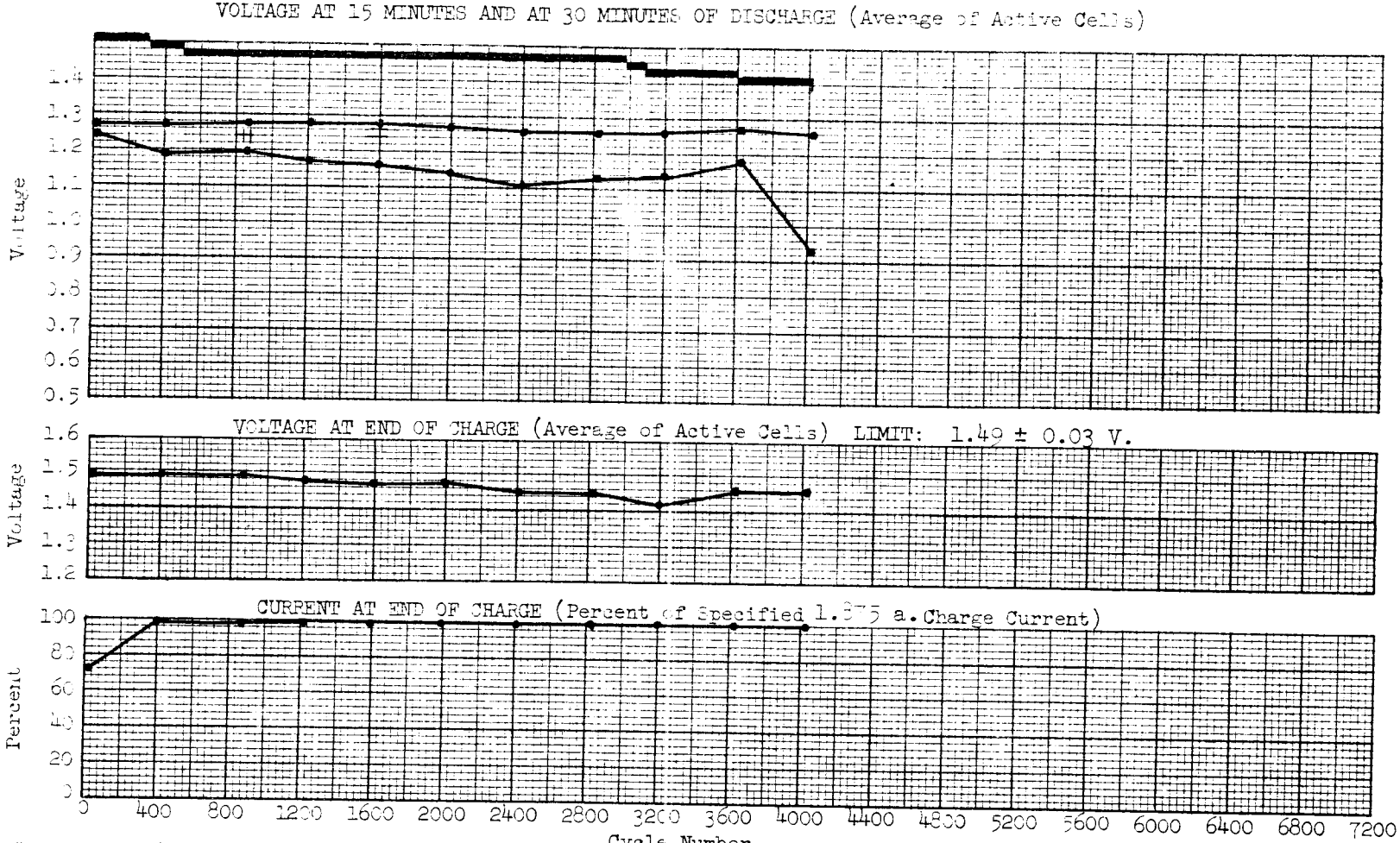
GULTON 6.0 a.h. (Pack 66)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 2553 cycles.

Notes

1. Cycles 701, 1292, 1911, 2503: Capacity Check.

FIGURE 11(d)



Cell Number	Cycle Failed
2305	308
2355	502
3134	2969
3211	3084
2613	3598
2324	4021

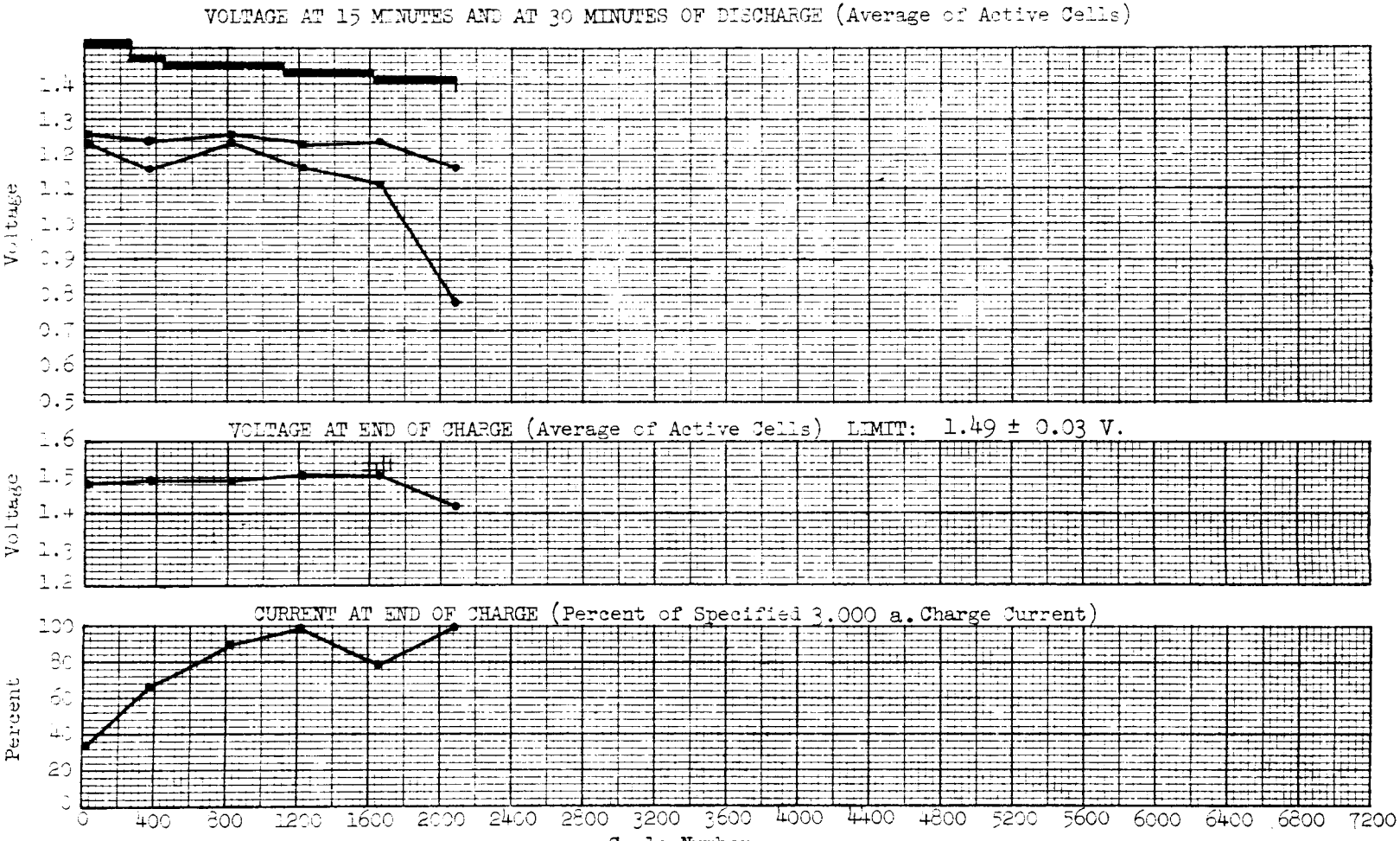
GULTON 6.0 a.h. (Pack 13)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 4021

Notes

1. Cycles 1426, 2955, 3881: Capacity Check.

FIGURE 11(e)



Cell Number	Cycle Failed
1623, 1635	262
2356	450
2387	1113
2391	1618
3208	2086

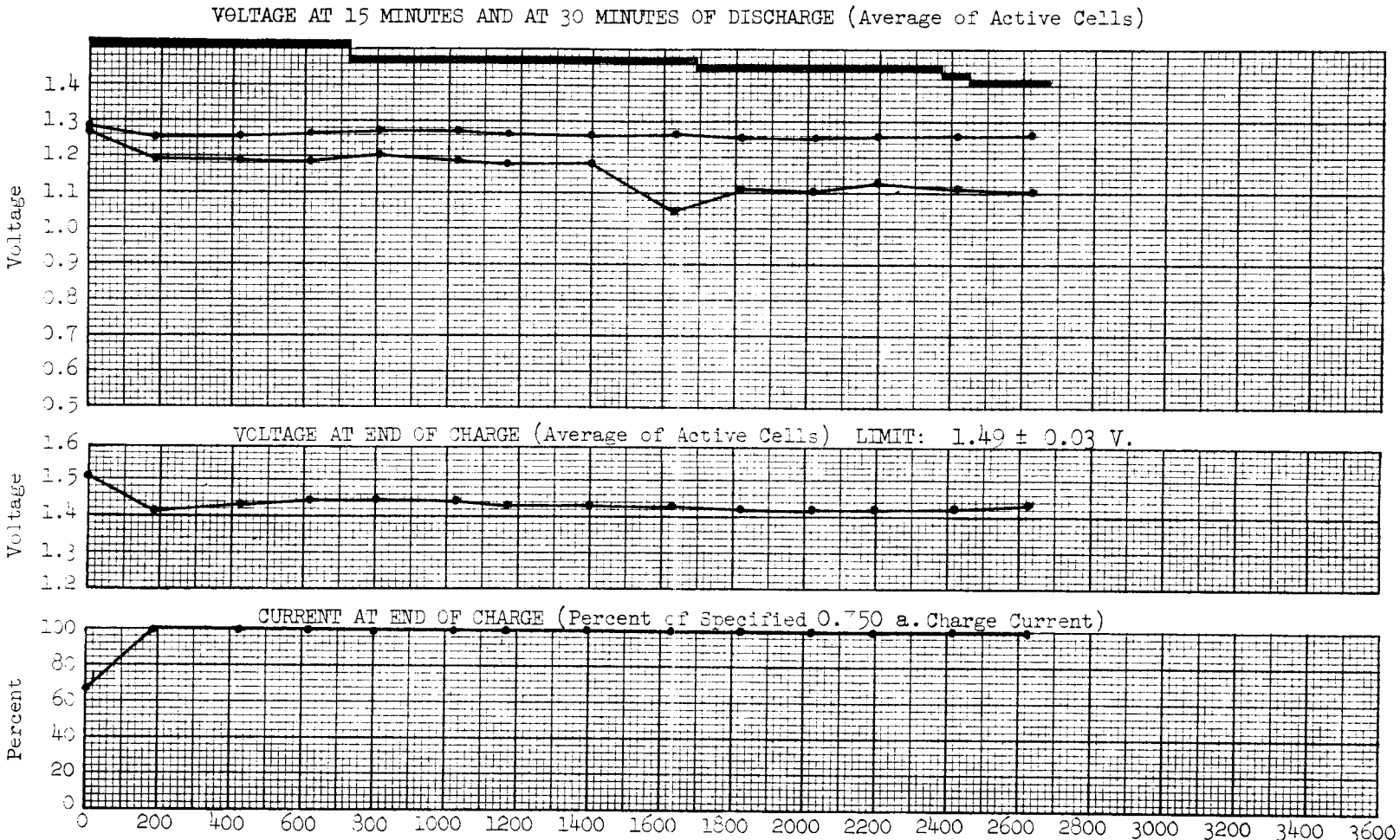
GULTON 6.0 a.h. (Pack 14)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 40%

Status: Pack Failed: Cycle 2086

Notes

1. Cycle 1368: Capacity Check.

FIGURE 11(f)



Cell Number	Cycle Failed
1823, 1862	721
2348	1688
1757	2375
1598	2449

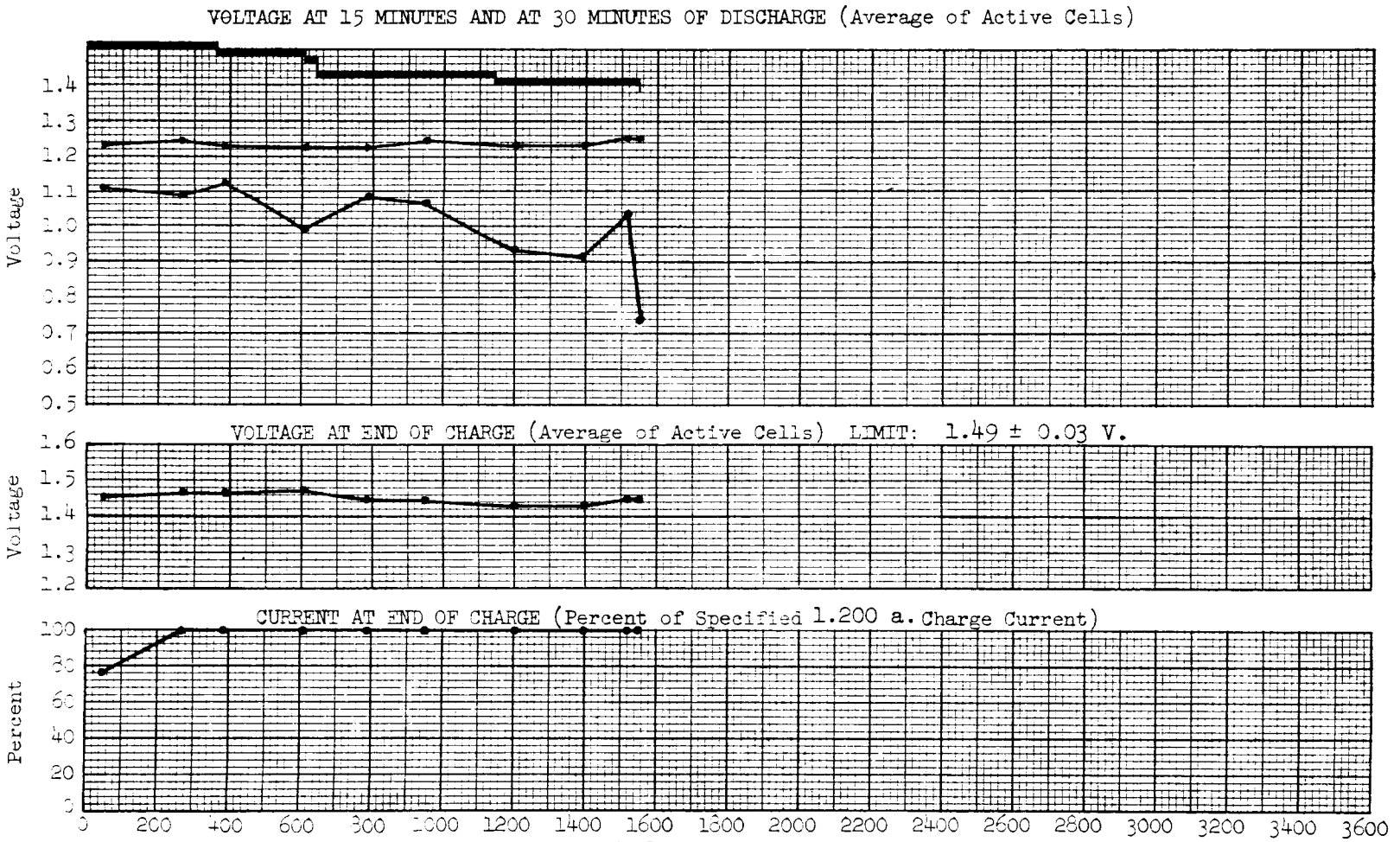
GULTON 6.0 a.h. (Pack 17)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 2675 cycles.

Notes

1. Cycles 702, 1317, 2075: Capacity Check.

FIGURE 11(g)



Cell Number	Cycle Failed
1826	365
1615	608
1827, 2228	643
1562	1145
1233	1550

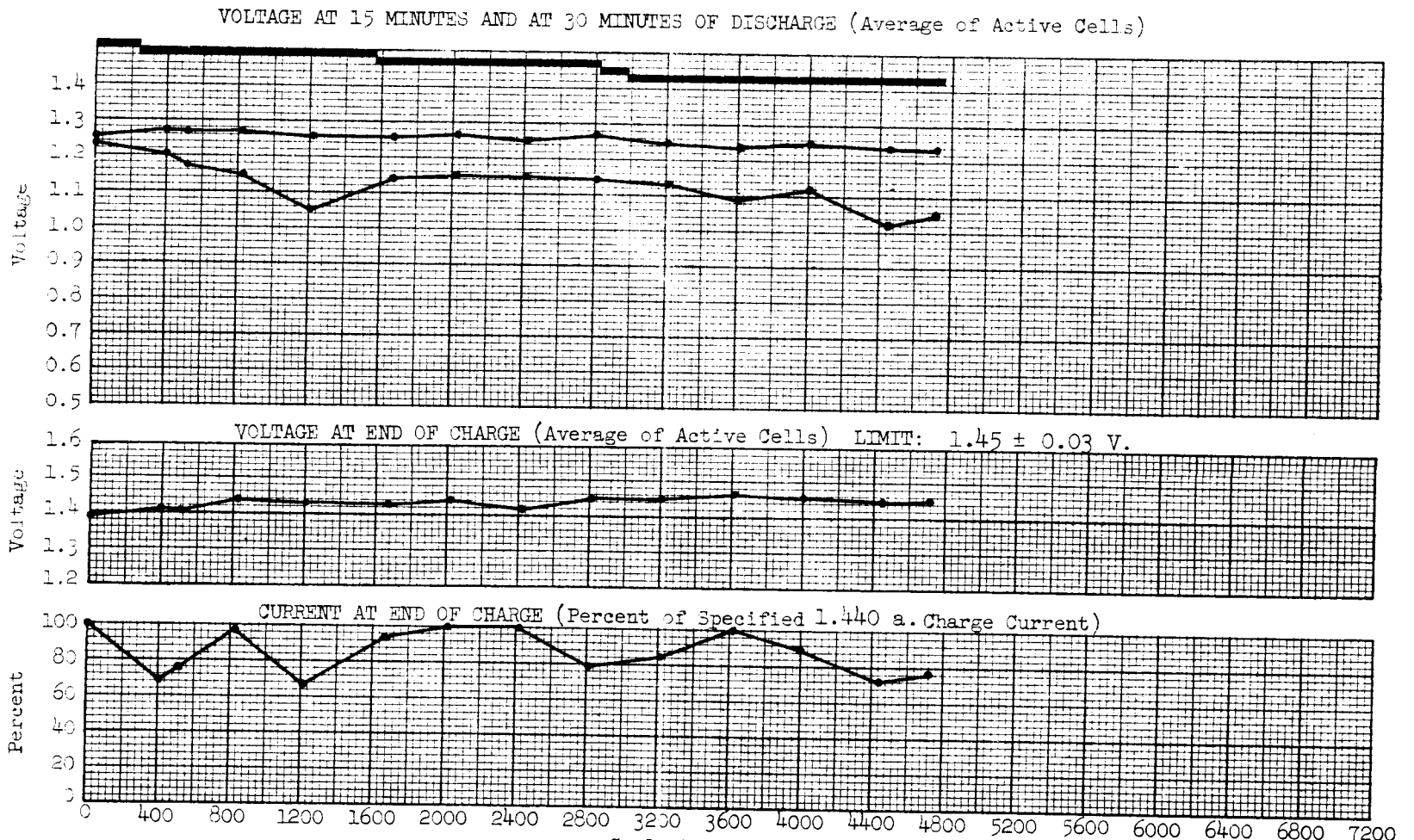
GULTON 6.0 a.h. (Pack 18)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 40%

Status: Pack Failed: Cycle 1550

Notes

1. Cycles 637, 1357: Capacity Check.

FIGURE 11(h)



Cell Number	Cycle Failed
1764	238
1784	1566
1802	2819
2333	2981

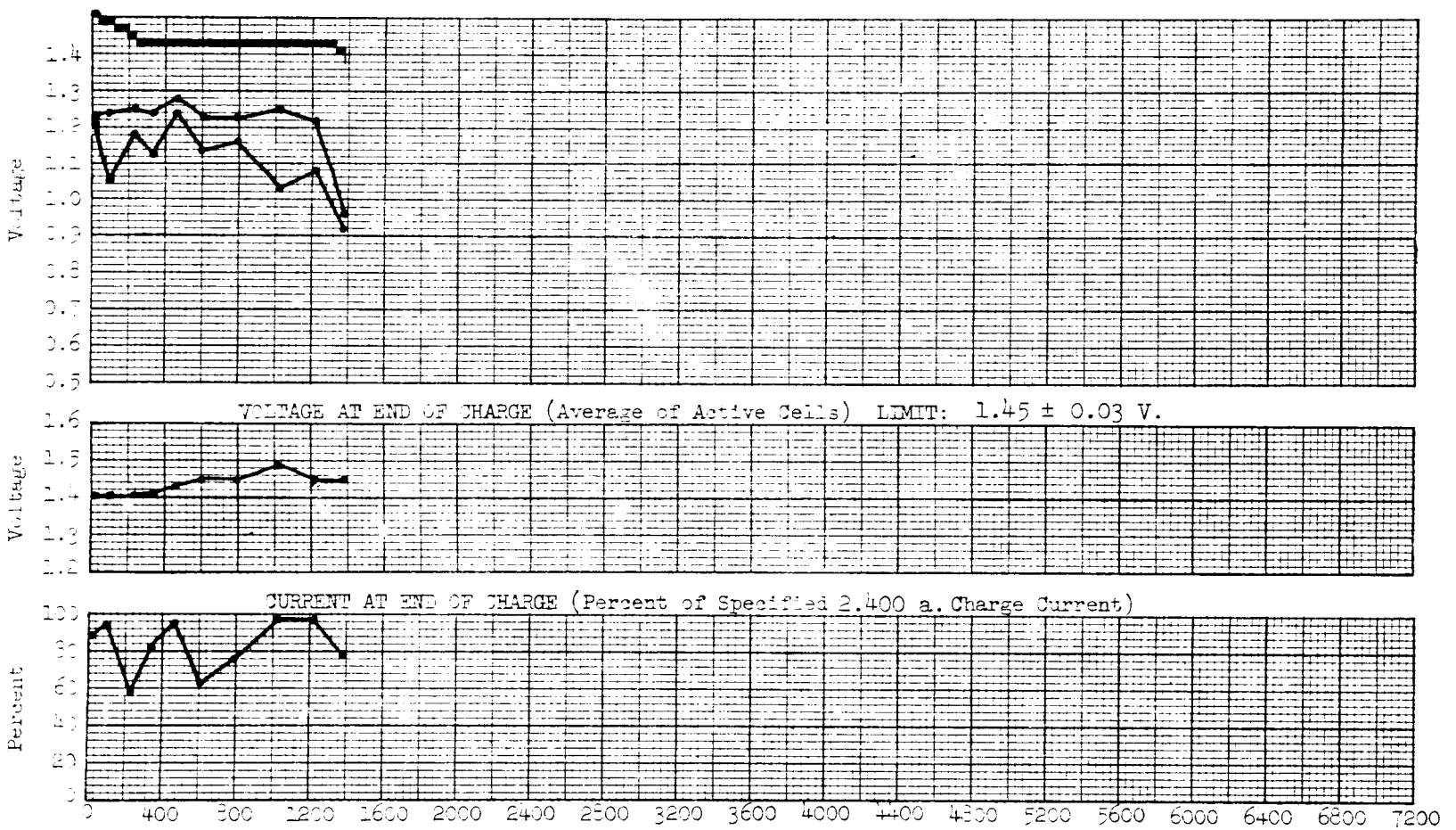
GULTON 6.0 a.h. (Pack 37)
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: 6 cells cycling after 4757 cycles.

Notes

1. Cycle 239: Changed to 40° C.
2. Cycle 527: Voltage limit raised to 1.45 V/cell.
3. Cycles 1441, 2819, 3810: Capacity Check.

FIGURE 11(i)



Cell Number	Cycle Failed
1454	37
1815	114
1353	187
1627	225
2405	1333
1625	1377

GULTON 6.0 a.h. (Pack 38)
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 1377

Notes

1. Cycle 114: Changed to 40° C.
2. Cycle 346: Voltage limit raised to 1.45 V/cell.
3. Cycle 1323: Capacity Check.

FIGURE 11(j)

QE/C 65-356



Cell Number	Cycle Failed
1771	649
1801	1062
3135	1132
1852, 2221	1157
1632	1689

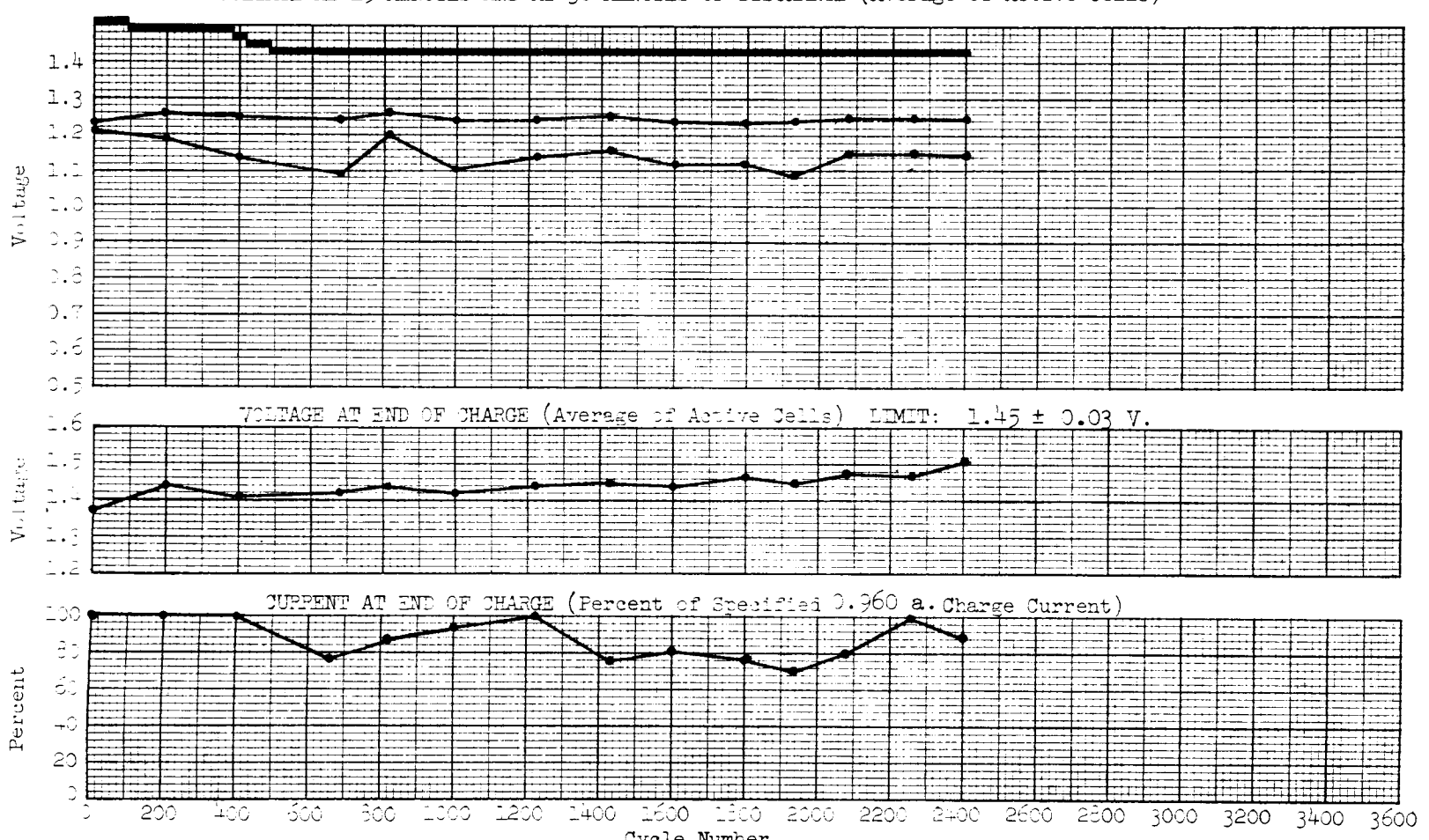
GULTON 6.0 a.h. (Pack 41)
Test Temperature: 30° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: Pack Failed: Cycle 1689

Notes

1. Cycle 239: Changed to 40° C.
2. Cycle 397: Voltage limit raised to 1.45 V/cell.
3. Cycles 702, 1294: Capacity Check.

FIGURE 11(k)



Cell Number	Cycle Failed
2309	96
2346	382
2306	416
918	484

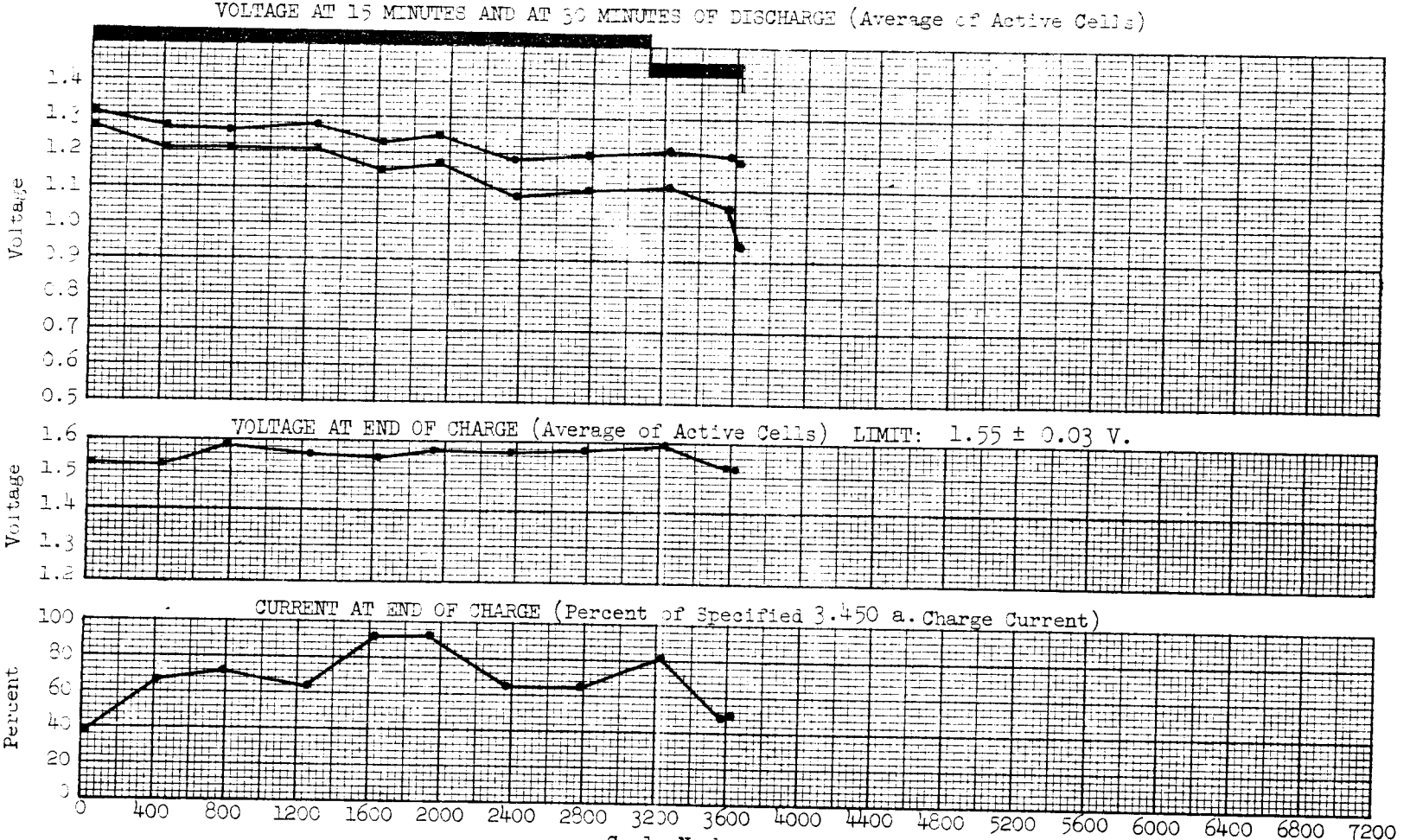
GULTON 6.0 a.h. (Pack 42)
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: 6 cells cycling after 2410 cycles.

FIGURE 11(1)

Notes

1. Cycle 74: Raised charge current to 1.20 a. (200% recharge).
2. Cycle 96: Charge current lowered back to 0.960 a. (160% recharge); changed to 40° C.
3. Cycle 243: Voltage limit raised to 1.45 V/cell.
4. Cycles 665, 1435, 2097: Capacity Check.



Cell Number	Cycle Failed
435, 407 438	3111 3629

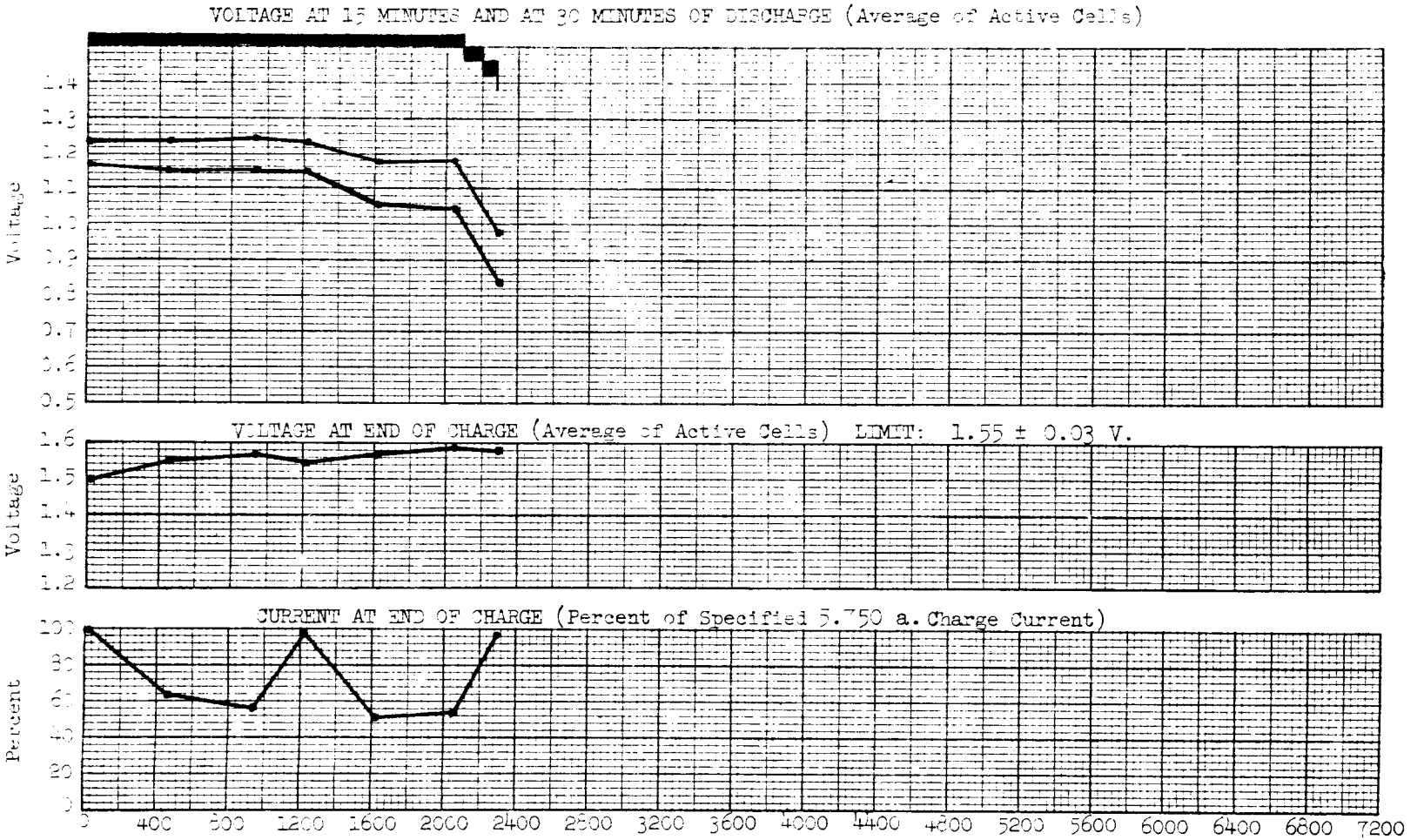
GULTON 20 a.h. (Pack 101)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: Pack Failed: Cycle 3631

Notes

1. Cycles 1406, 3024: Capacity Check.

FIGURE 12(a)



Cell Number	Cycle Failed
490	2107
508	2203
467	2291

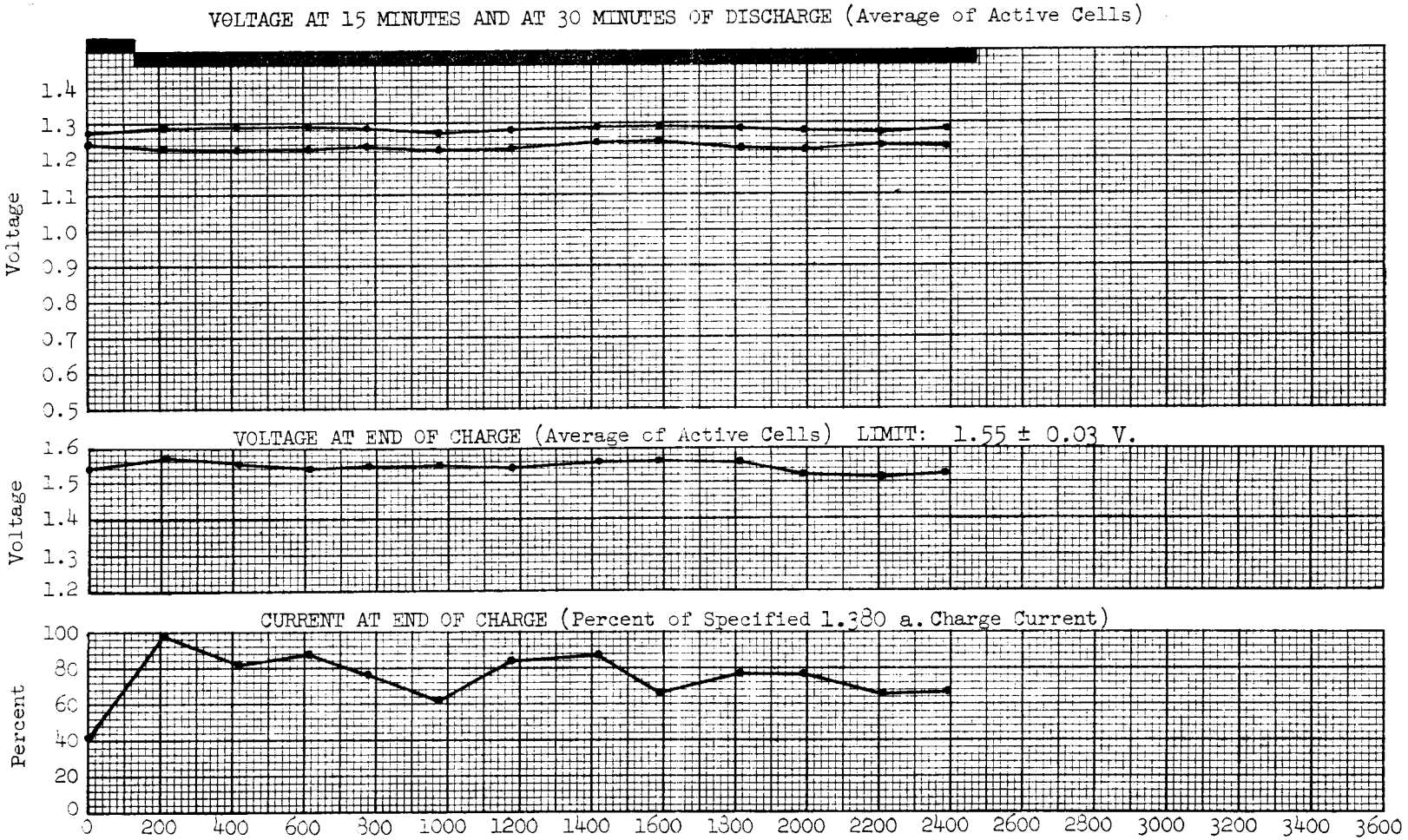
GULTON 20 a.h. (Pack 115)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 2291

Notes

1. Cycle 1408: Capacity Check.

FIGURE 12(b)



Cell Number	Cycle Failed
449	135

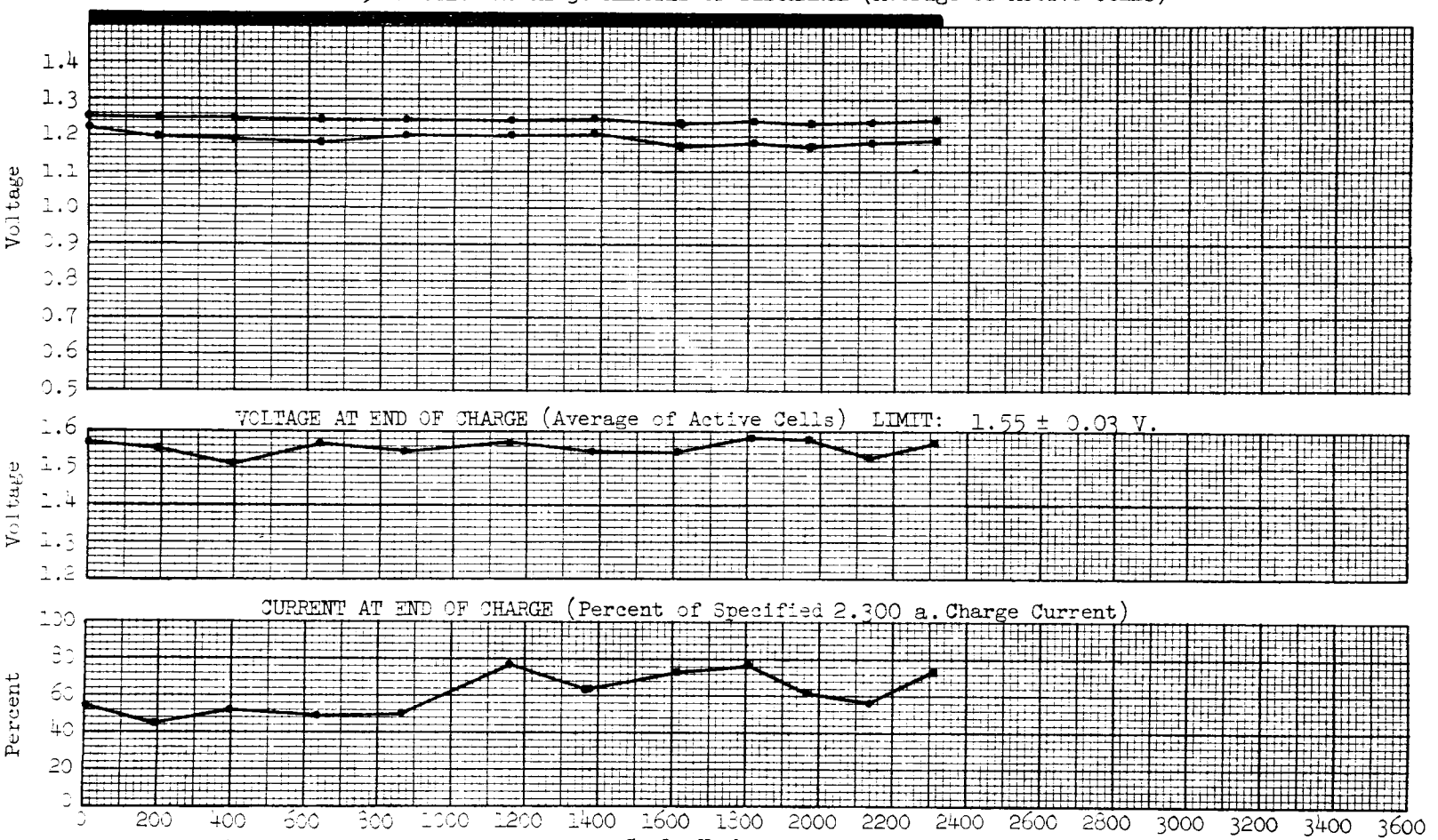
GULTON 20 a.h. (Pack 102)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: 4 cells cycling after 2472 cycles.

Notes

1. Cycles 716, 1437, 2104: Capacity Check.

FIGURE 12(c)



Cell Number	Cycle Failed

GULTON 20 a.h. (Pack 116)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 25%

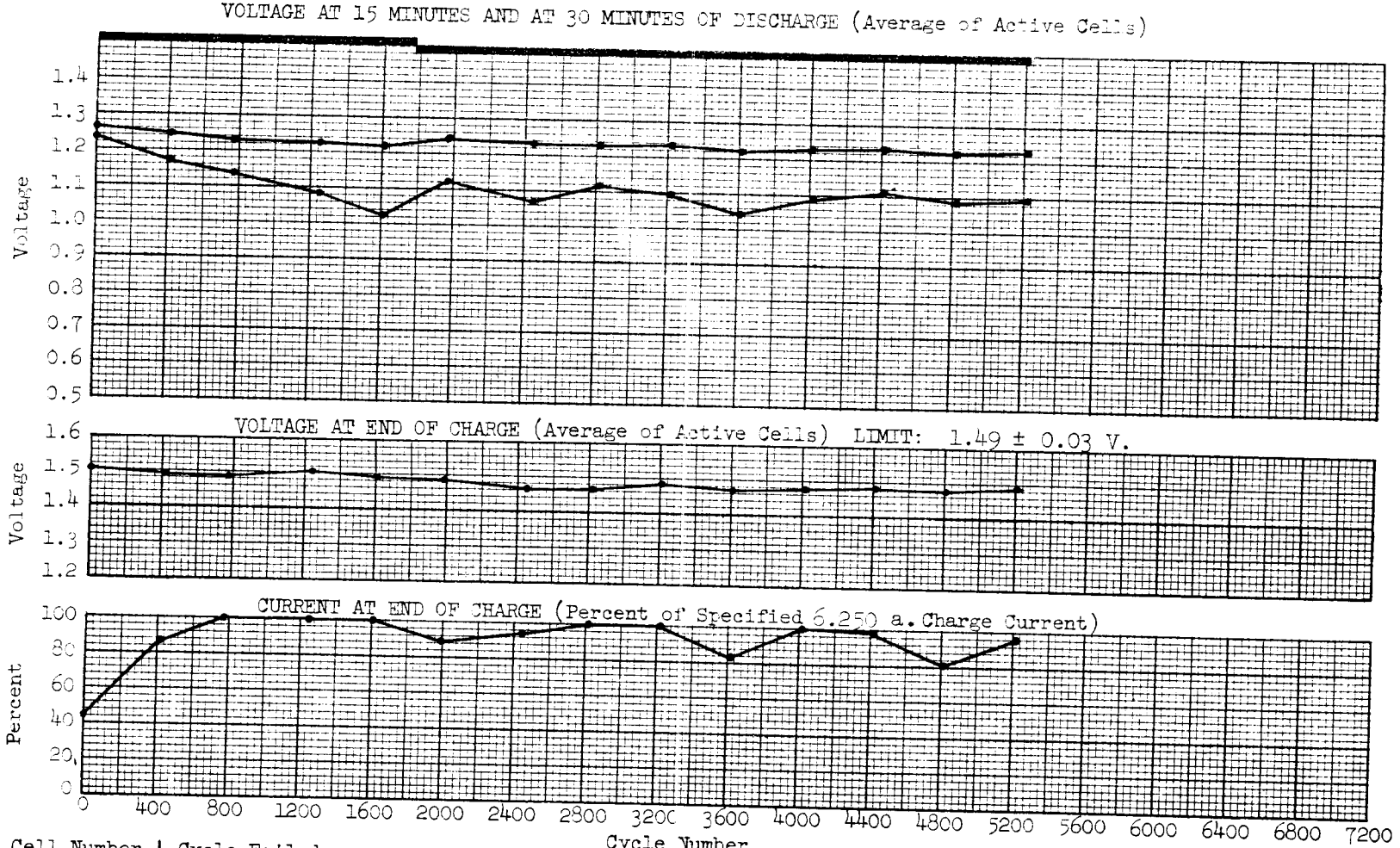
Status: 5 cells cycling after 2329 cycles.

Notes

1. Cycles 760, 1357, 2017: Capacity Check.

FIGURE 12(d)

QE/C 65-356



Cell Number	Cycle Failed
396	1776

GULTON 20 a.h. (Pack 73)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

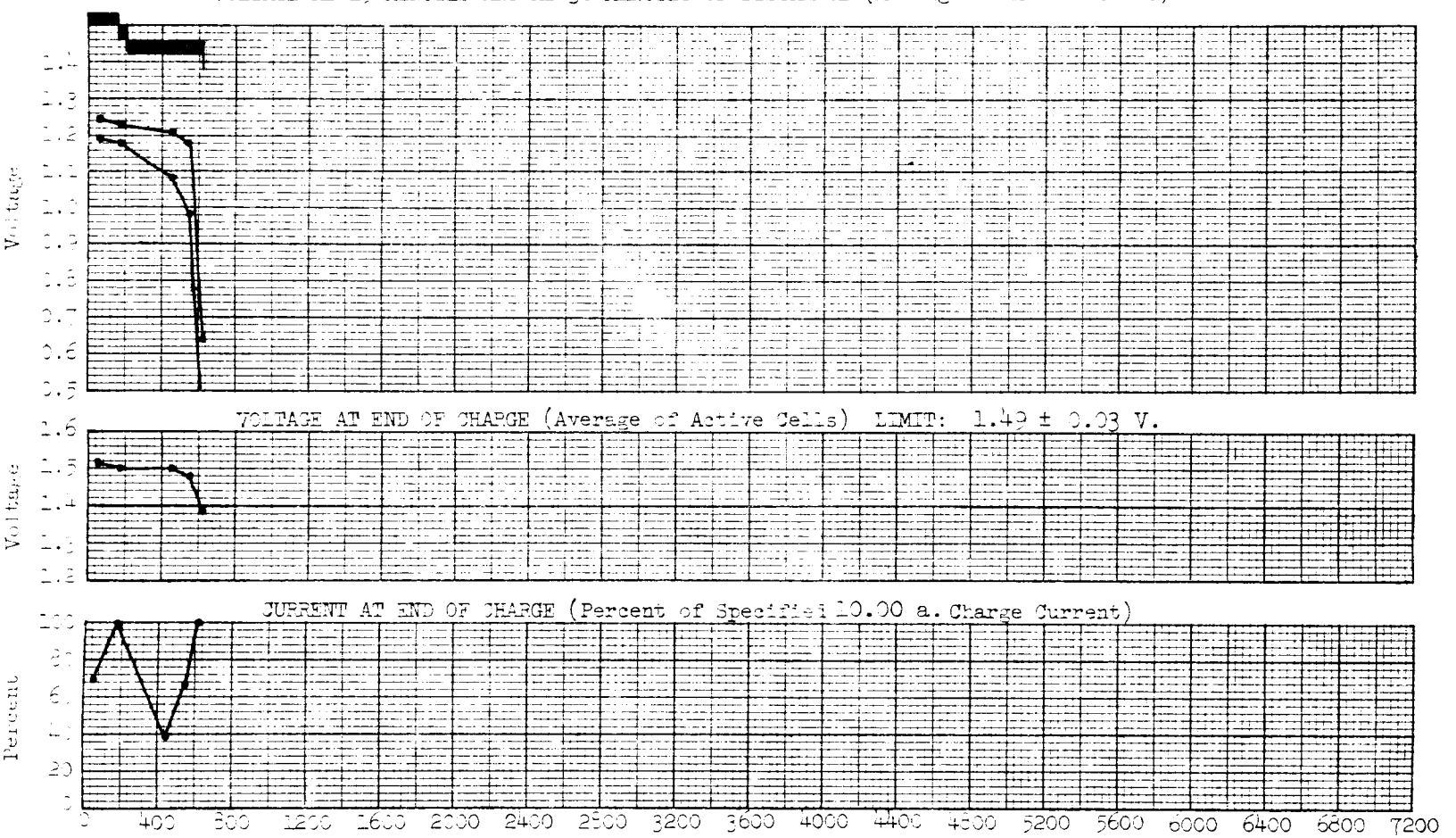
Status: 4 cells cycling after 5232 cycles.

Notes

1. Cycles 1358, 2663, 4242: Capacity Check.

QE/c 65-356

FIGURE 12(e)



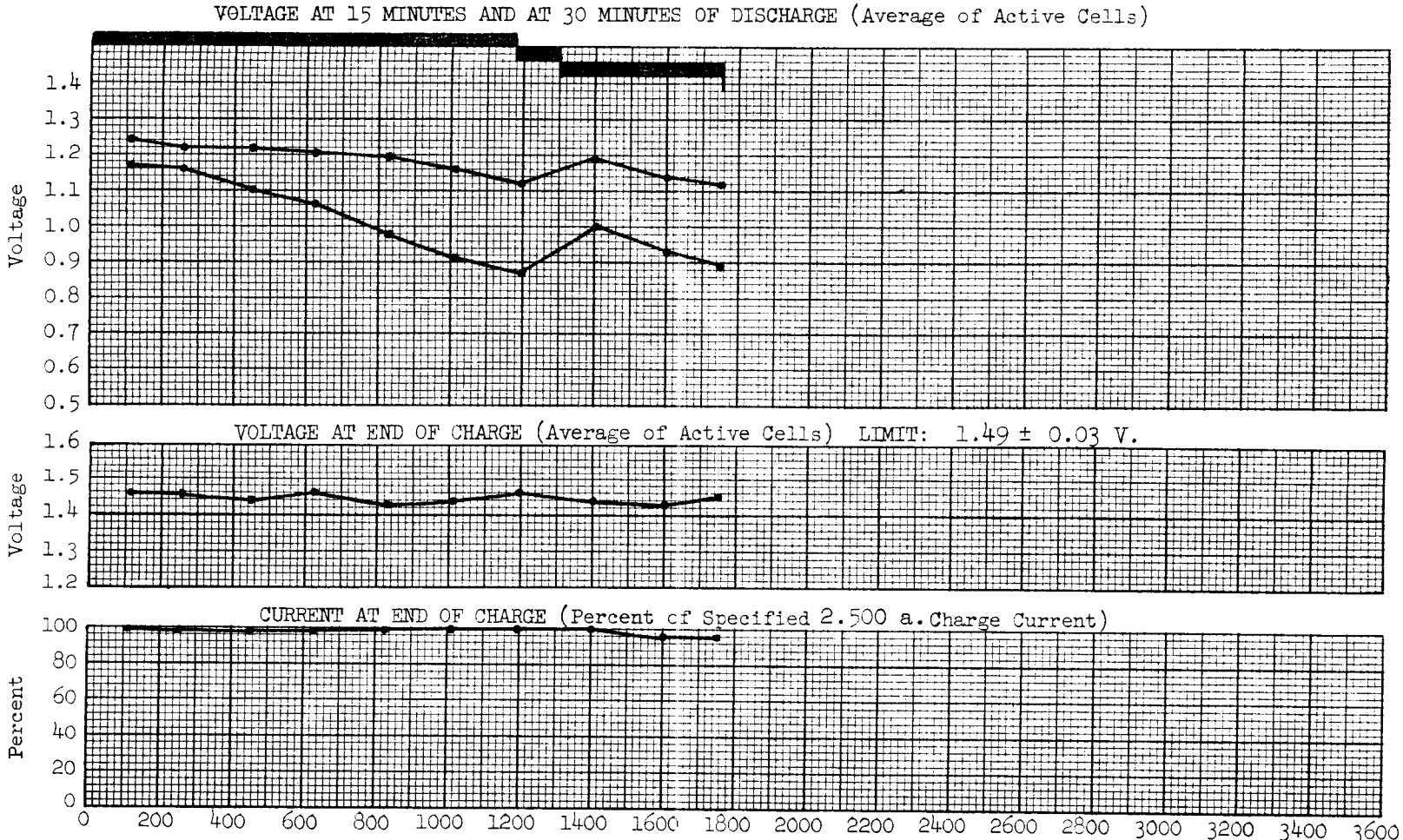
Cell Number	Cycle Failed
468	136
388	208
386, 394 & 454	627

GULTON 20 a.h. (Pack 37)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 40%

Status: Pack Failed: Cycle 627

Notes

FIGURE 12(f)



Cell Number	Cycle Failed
458	1184
419	1302
440	1754

GULTON 20 a.h. (Pack 74)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 1754

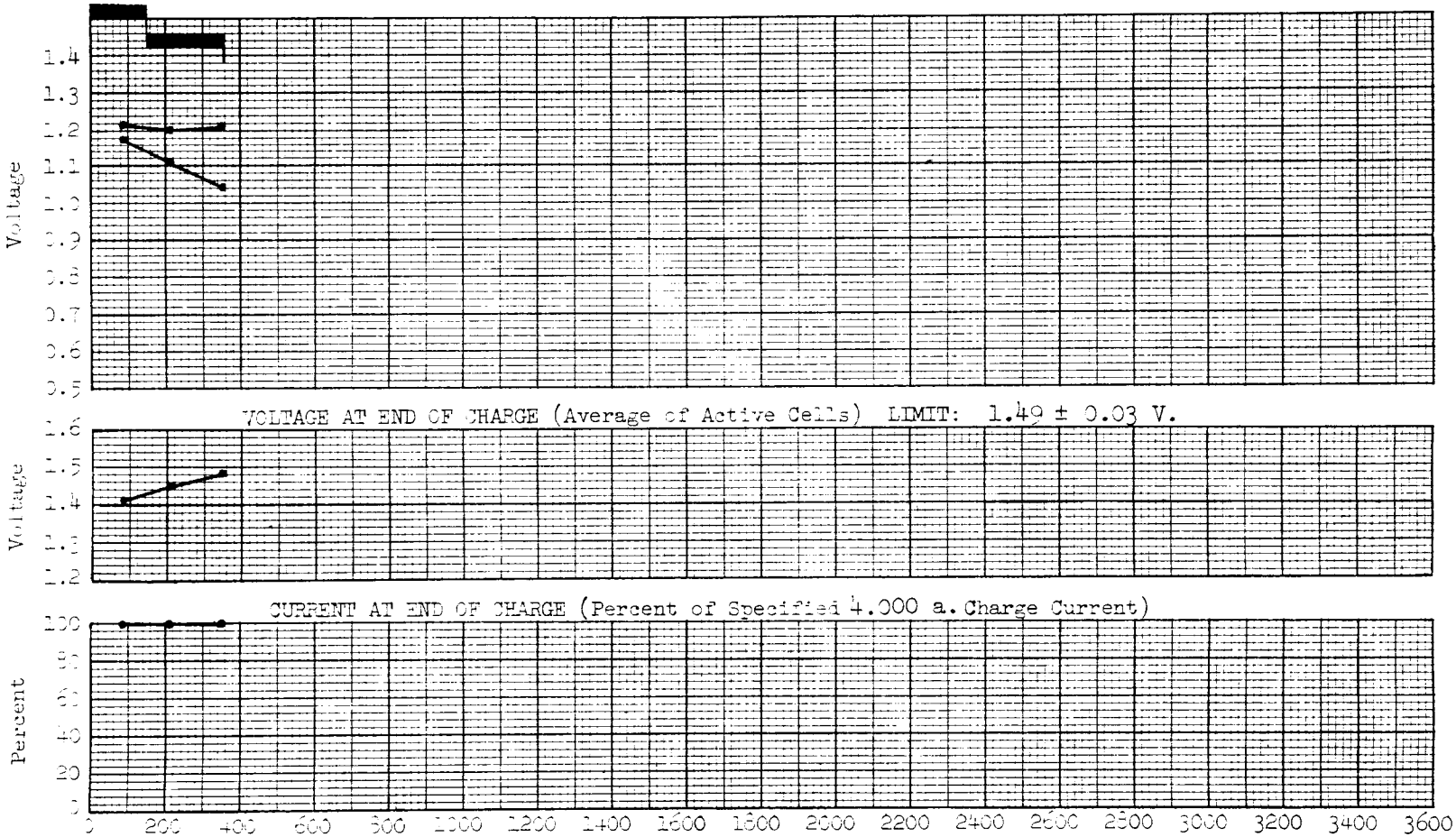
Notes

1. Cycles 739, 1427: Capacity Check.

FIGURE 12(g)

GE/c 65-356

VOLTAGE AT 15 MINUTES AND AT 30 MINUTES OF DISCHARGE (Average of Active Cells)



Cell Number	Cycle Failed
404, 422	151
466, 429	358

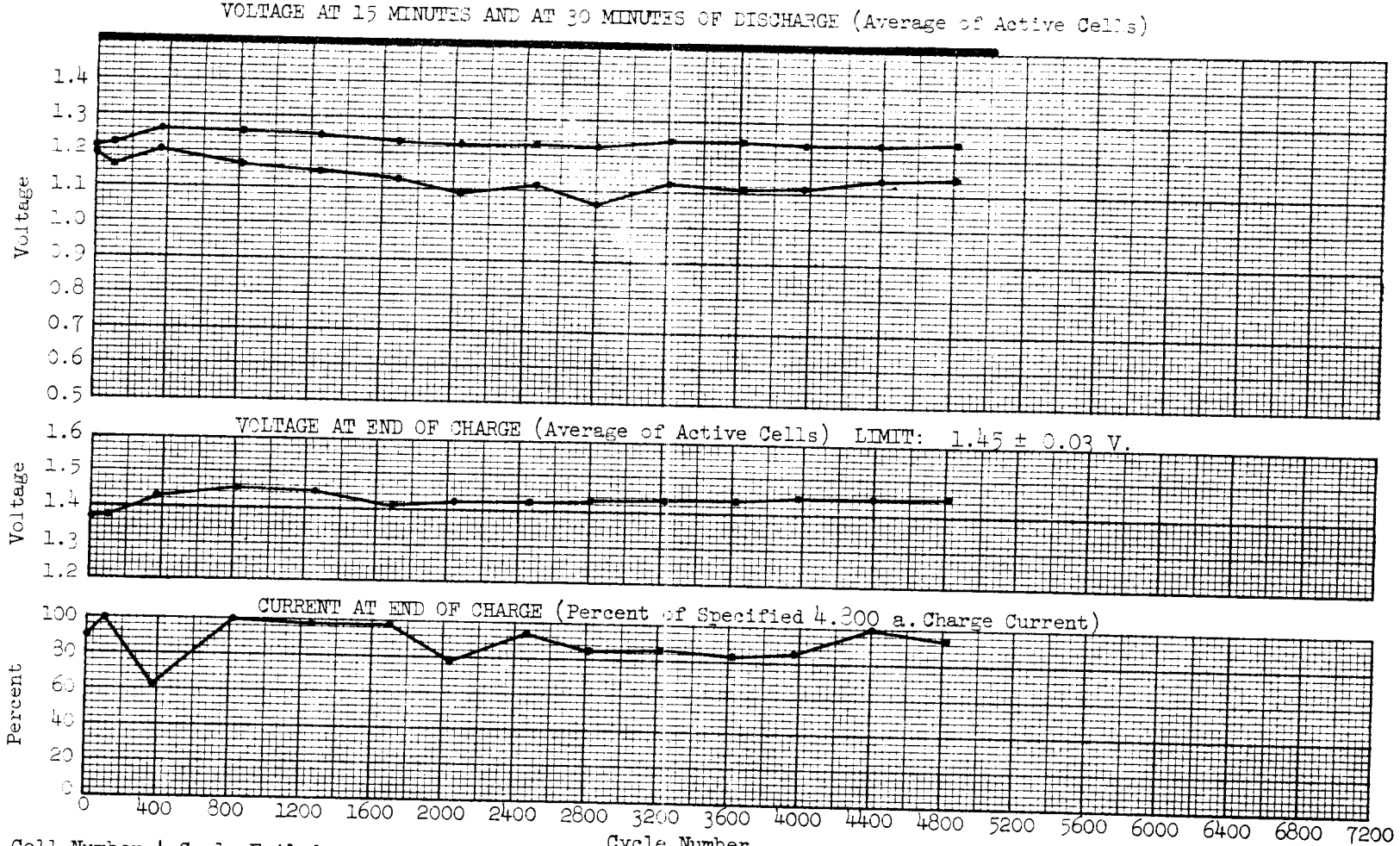
GULTON 20 a.h. (Pack 38)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 40%

Status: Pack Failed: Cycle 358

Notes

GE/c 65-356

FIGURE 12(h)



Cell Number	Cycle Failed

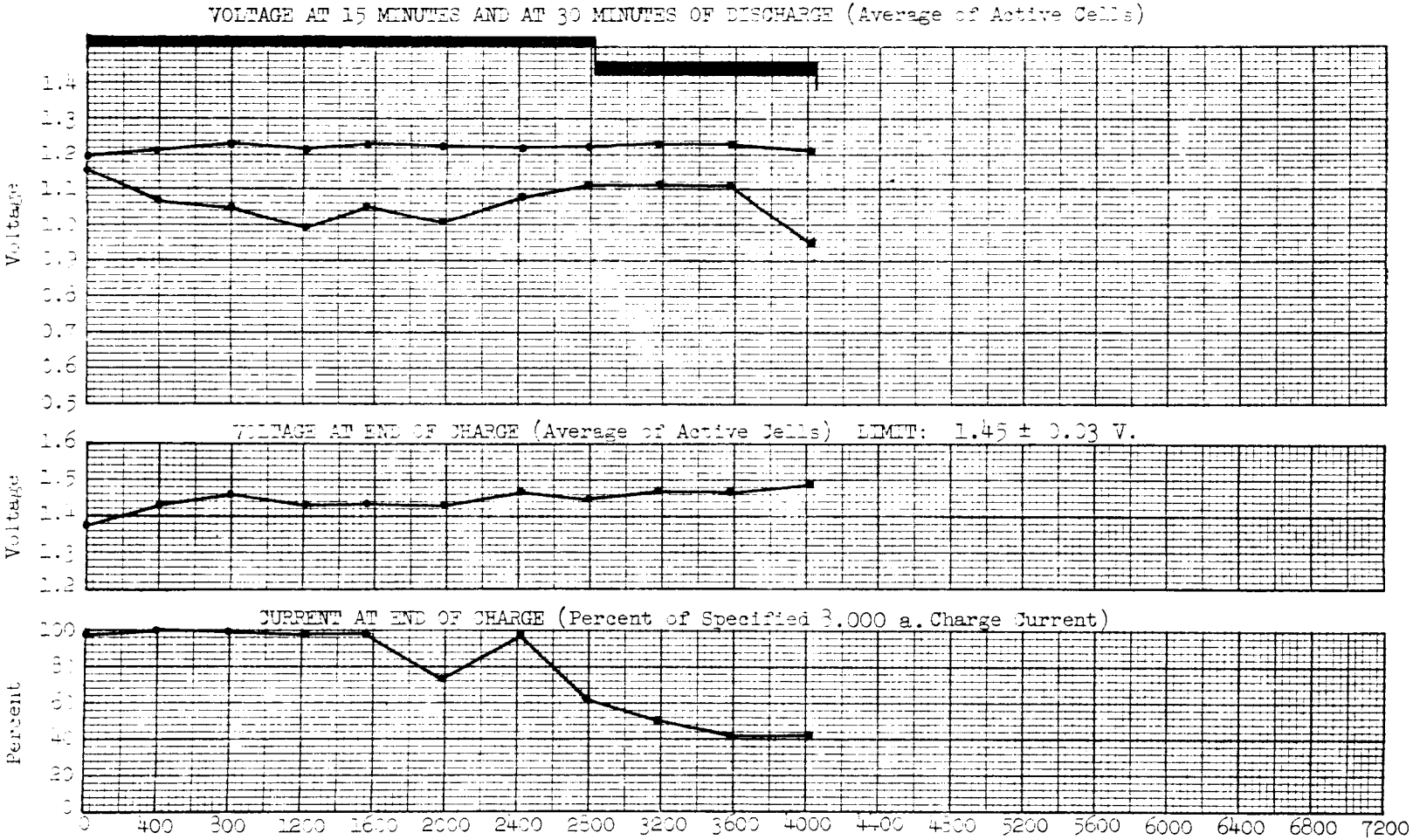
GULTON 20 a.h. (Pack 76)
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: 5 cells cycling after 5040 cycles.

Notes

1. Cycle 172: Changed to 40° C.
2. Cycle 474: Voltage limit raised to 1.45 V/cell.
3. Cycles 1338, 2911, 4326: Capacity Check.

FIGURE 12(i)



Cell Number	Cycle Failed
452, 457	2824
378	4045

GULTON 20 a.h. (Pack 90)

Cycle Number

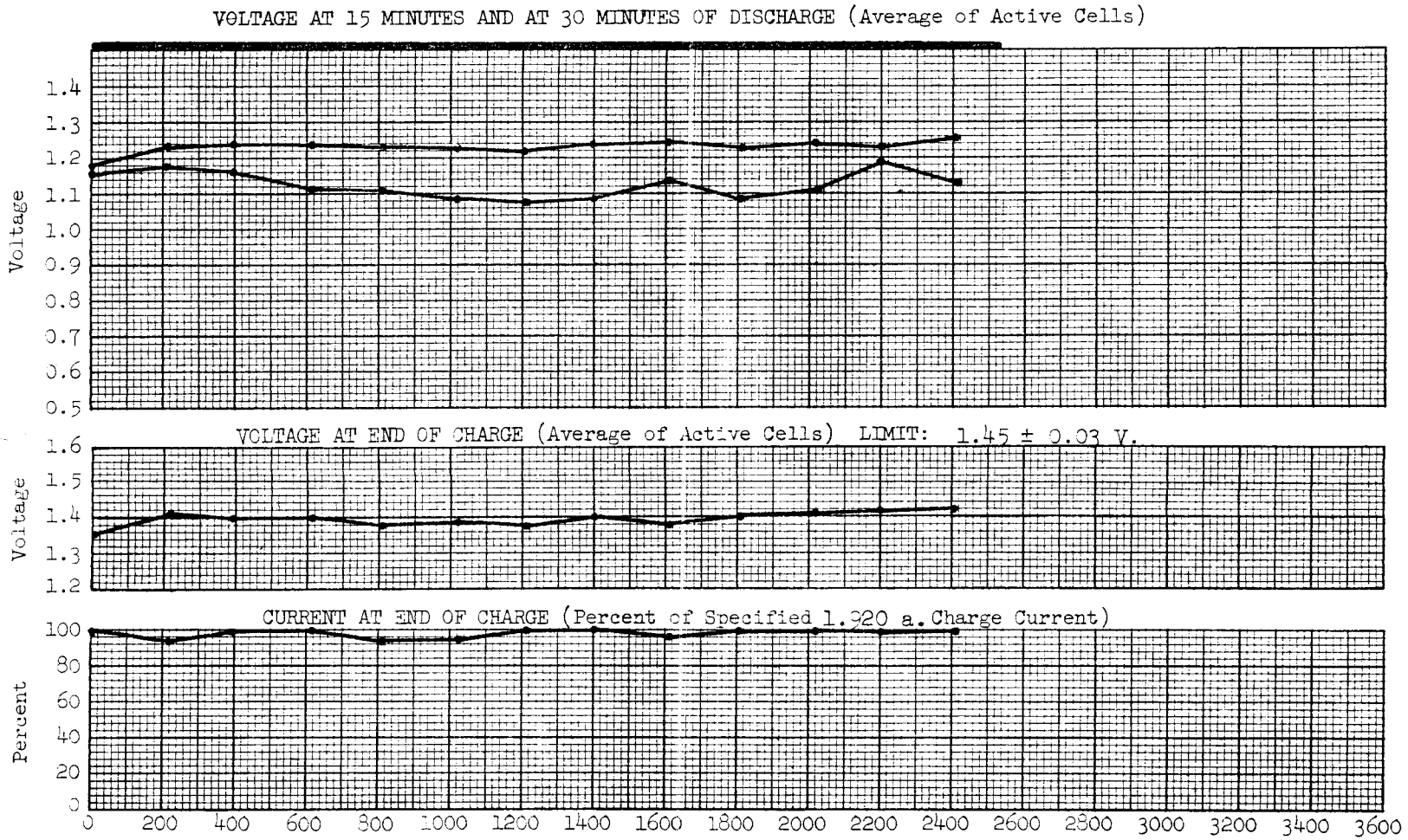
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 4045

Notes

1. Cycle 65: Changed to 40° C.
2. Cycle 367: Voltage limit raised to 1.45 V/cell.
3. Cycles 1447, 2841, 4045: Capacity Check.

FIGURE 12(j)



Cell Number	Cycle Failed

GULTON 20 a.h. (Pack 77)
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 15%

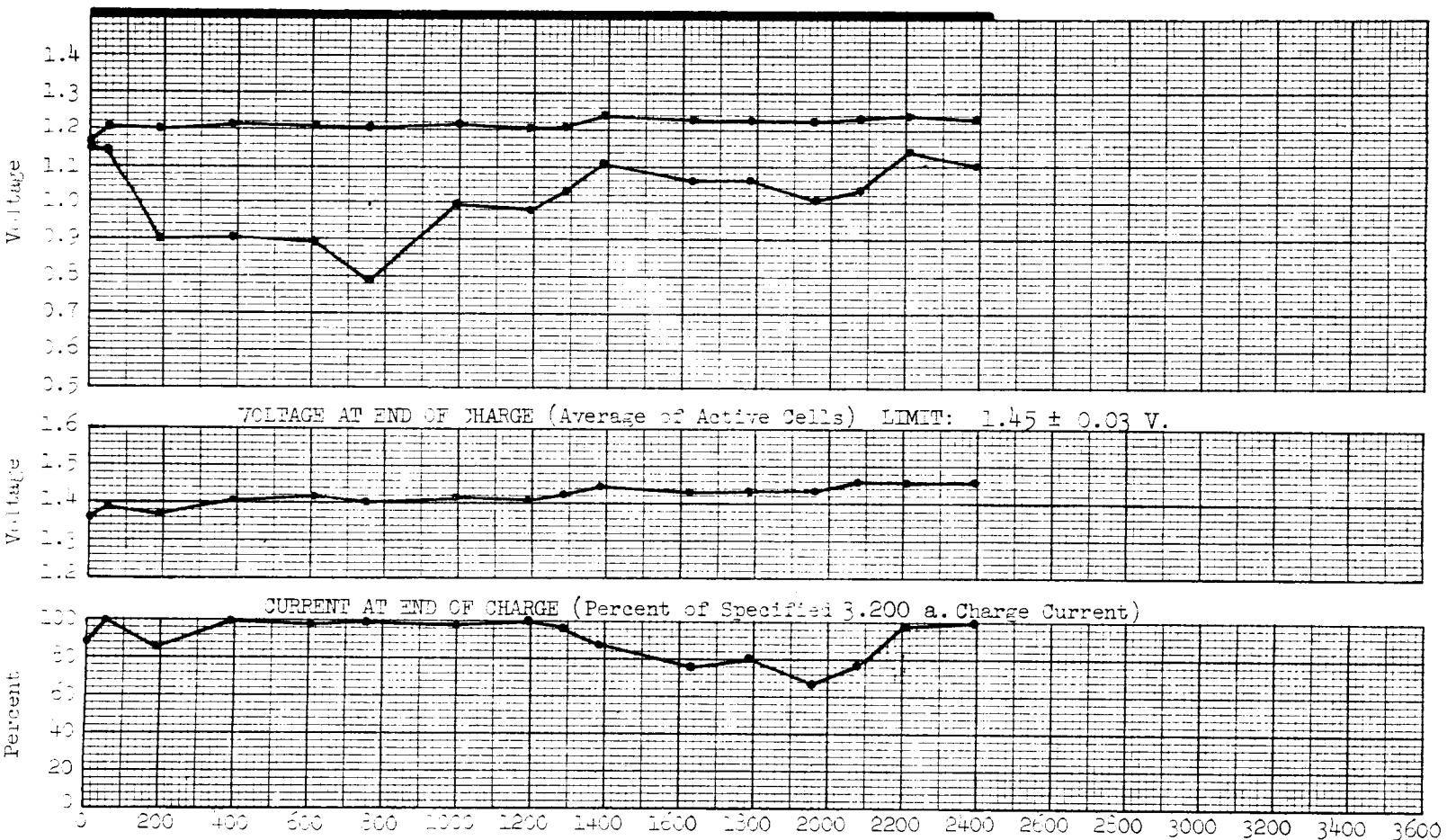
Status: 5 cells cycling after 2526 cycles.

Notes

1. Cycle 71: Changed to 40° C.
2. Cycle 231: Voltage limit raised to 1.45 V/cell.
3. Cycles 740, 1550, 2198: Capacity Check.

FIGURE 12(k)

QE/C 65-356



Cell Number	Cycle Failed

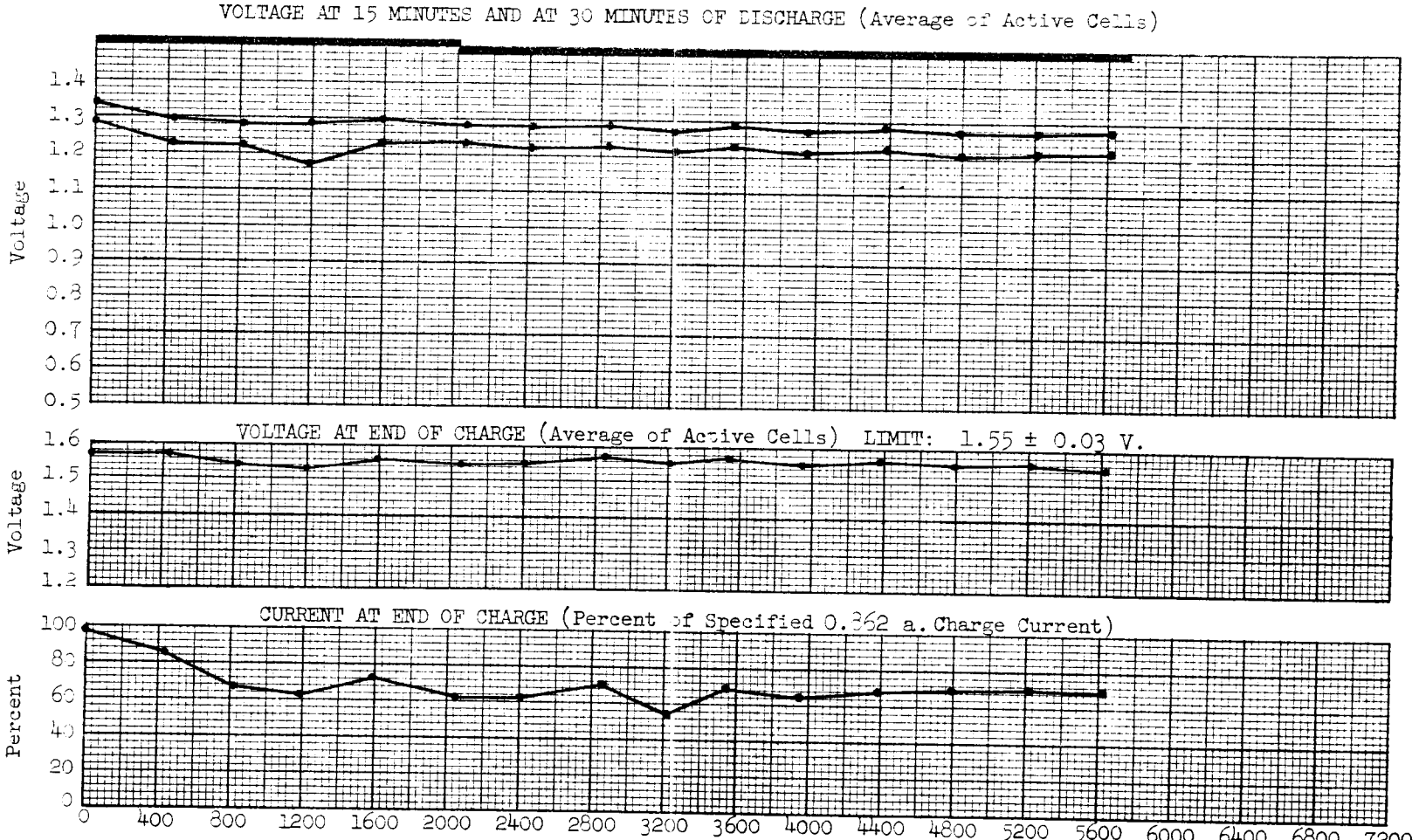
GULTON 20 a.h. (Pack 91)
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 2438 cycles.

Notes

1. Cycle 47: Changed to 40° C.
2. Cycle 207: Voltage limit raised to 1.45 V/cell.
3. Cycles 741, 1465, 2111: Capacity Check.

FIGURE 12(1)



Cell Number	Cycle Failed
6887	2010

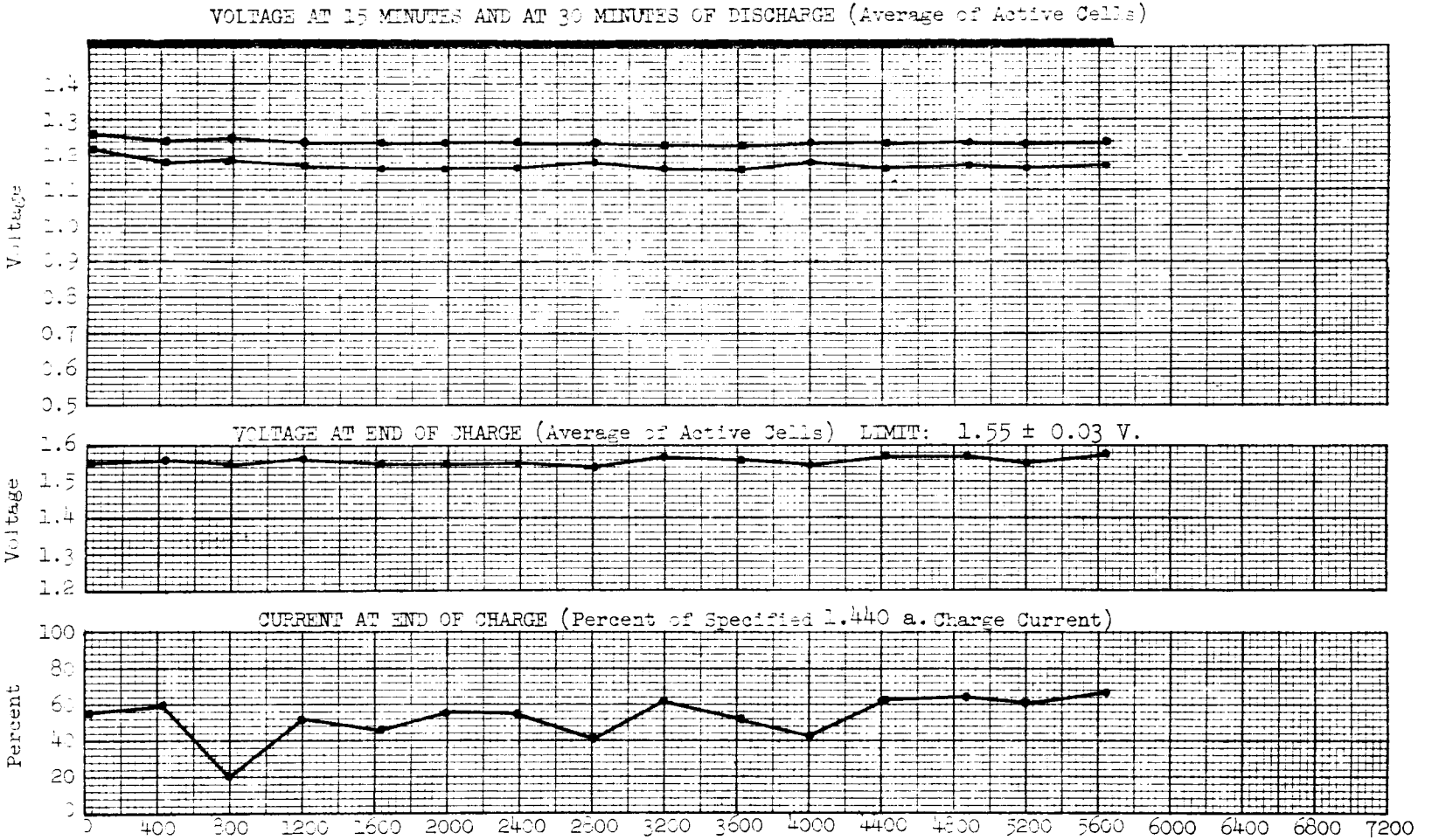
SONOTONE 5.0 a.h. (Pack 49)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 9 cells cycling after 5719 cycles.

Notes

1. Cycles 1405, 2691, 3965, 5395: Capacity Check.

FIGURE 13(a)



Cell Number	Cycle Failed

SONOTONE 5.0 a.h (Pack 50)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

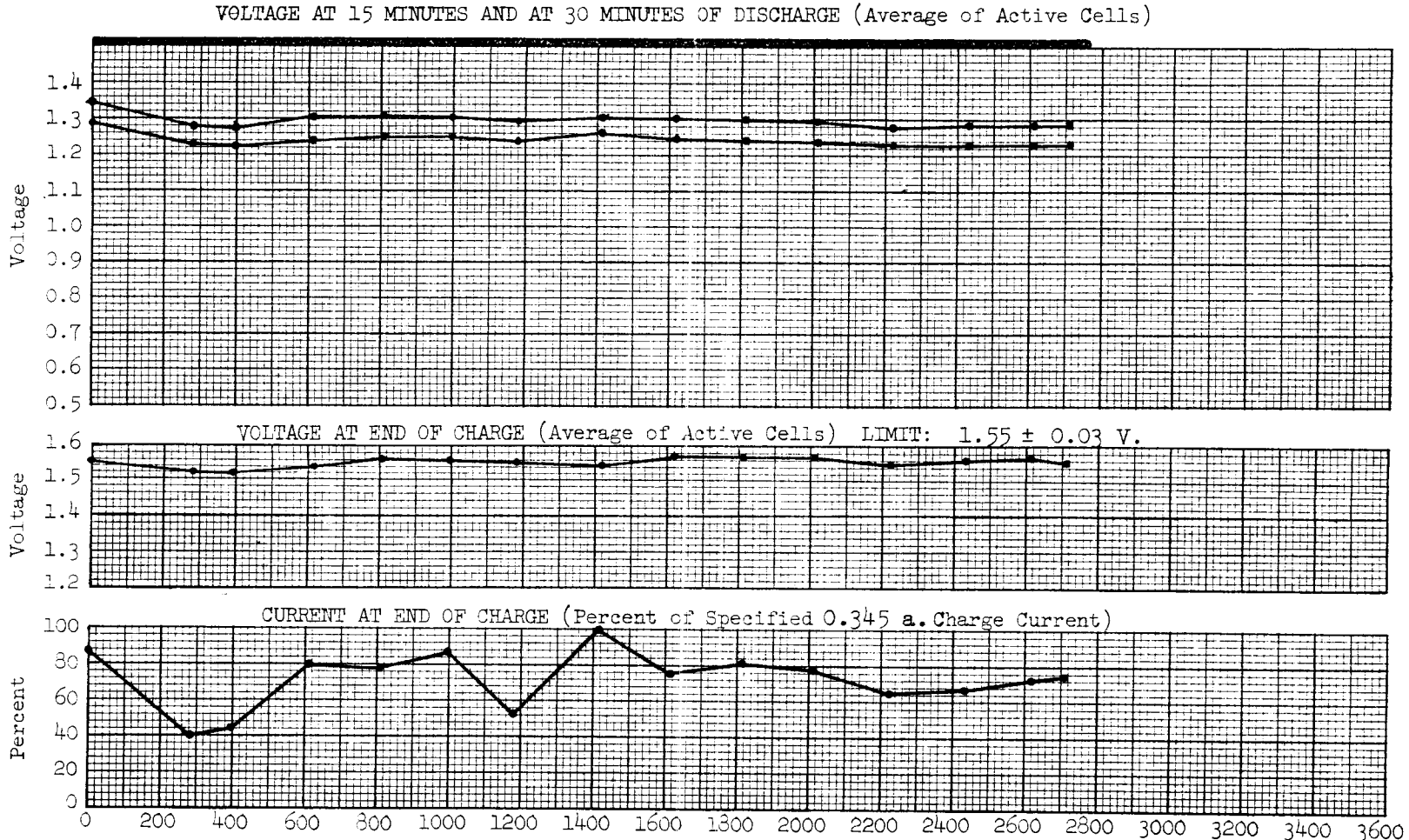
Status: 10 cells cycling after 5675 cycles.

Notes

1. Cycles 1435, 2648, 3921, 5351: Capacity Check.

FIGURE 13(a)

QE/C 65-356



Cell Number	Cycle Failed

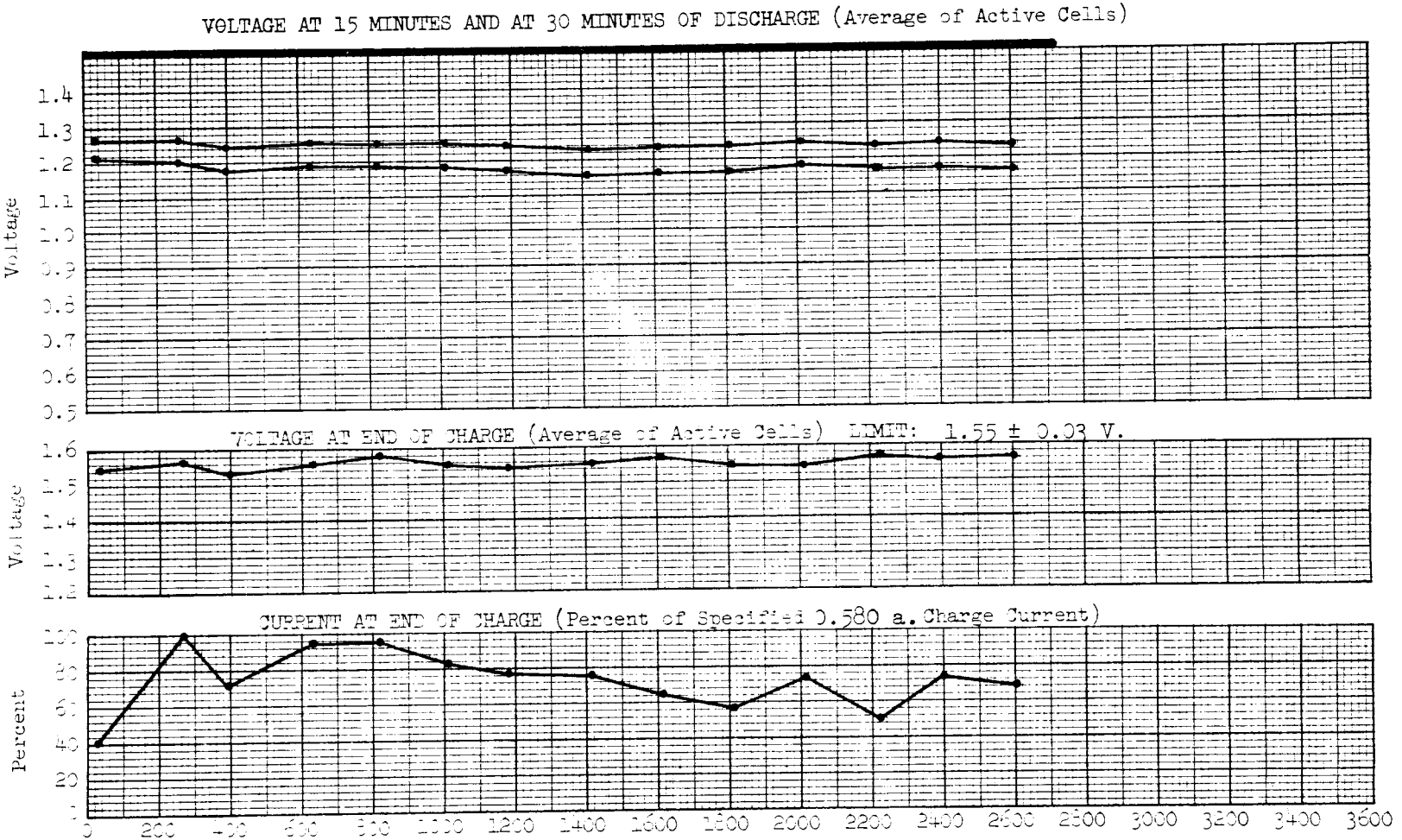
SONOTONE 5.0 a.h. (Pack 53)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: 10 cells cycling after 2767 cycles.

Notes

1. Cycles 702, 1332, 2068, 2767: Capacity Check.

FIGURE 13(c)



Cell Number	Cycle Failed

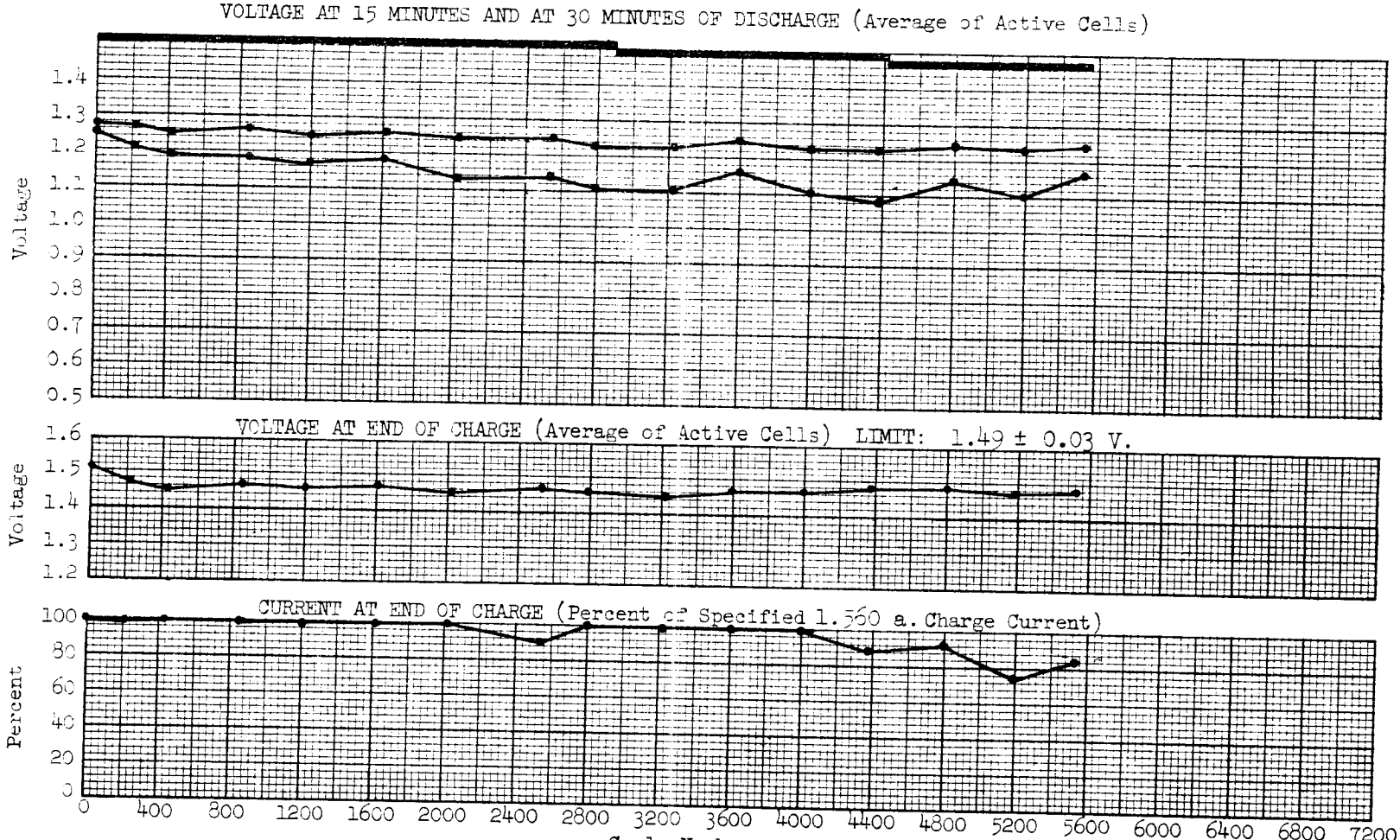
SONOTONE 5.0 a.h. (Pack 54)
Test Temperature: 0° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: 10 cells cycling after 2731 cycles.

Notes

1. Cycles 701, 1310, 1984, 2681: Capacity Check.

FIGURE 13(d)



Cell Number	Cycle Failed
4361	2995
4335	4423

SONOTONE 5.0 a.h. (Pack 1)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

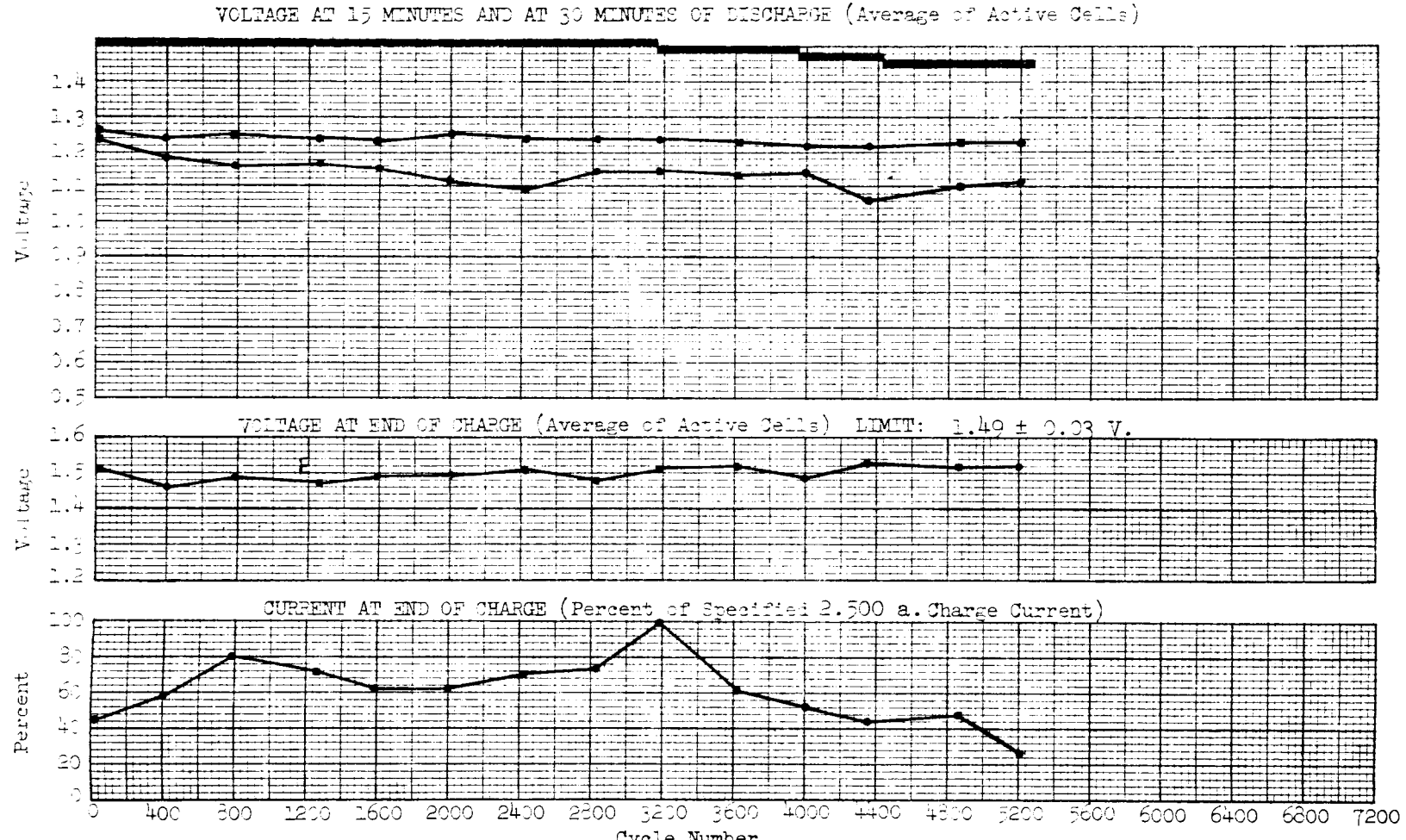
Status: 8 cells cycling after 5562 cycles.

Notes

1. Cycles 1387, 2686, 3786, 5349: Capacity Check.

FIGURE 13(e)

QF/C 65-356



Cell Number	Cycle Failed
311	3155
3628	3992
3613	4411

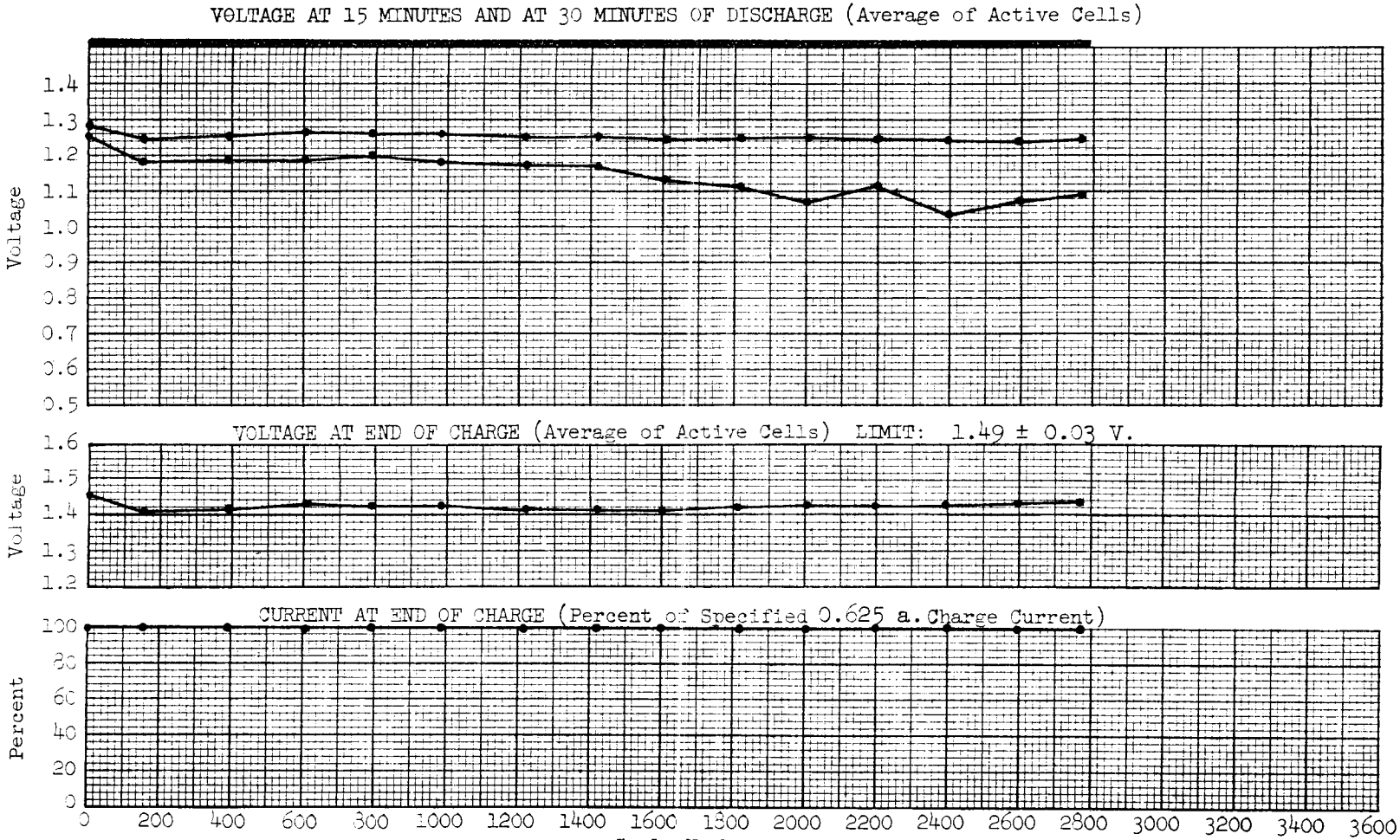
SONOTONE 5.0 a.h. (Pack 2)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 40%

Status: 7 cells cycling after 5257 cycles.

Notes

1. Cycles 1400, 2697, 4015: Capacity Check.

FIGURE 13(f)



Cell Number	Cycle Failed

SONOTONE 5.0 a.h. (Pack 5)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 25%

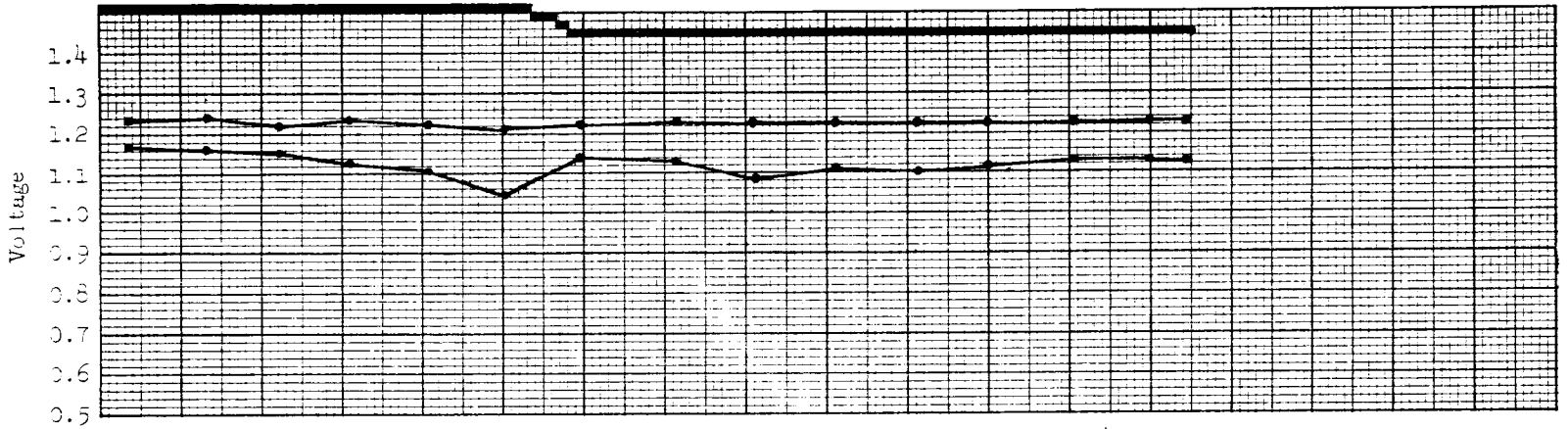
Status: 10 cells cycling after 2787 cycles.

Notes

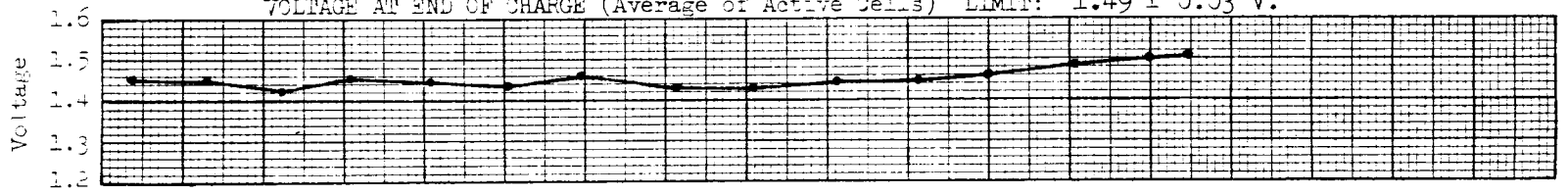
1. Cycles 702, 1368, 2125: Capacity Check.

FIGURE 13(g)

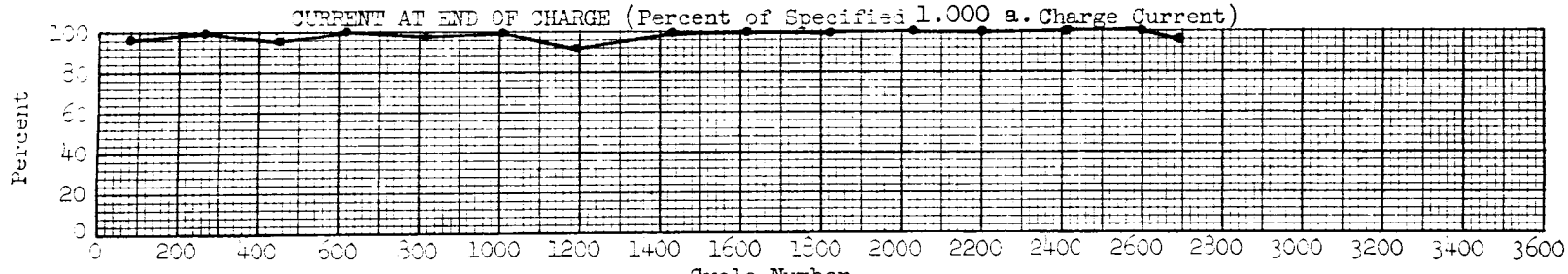
VOLTAGE AT 15 MINUTES AND AT 30 MINUTES OF DISCHARGE (Average of Active Cells)



VOLTAGE AT END OF CHARGE (Average of Active Cells) LIMIT: 1.49 ± 0.03 V.



CURRENT AT END OF CHARGE (Percent of Specified 1.000 a. Charge Current)



Cycle Number

Cell Number	Cycle Failed
4324	1069
6904	1136
3637	1161

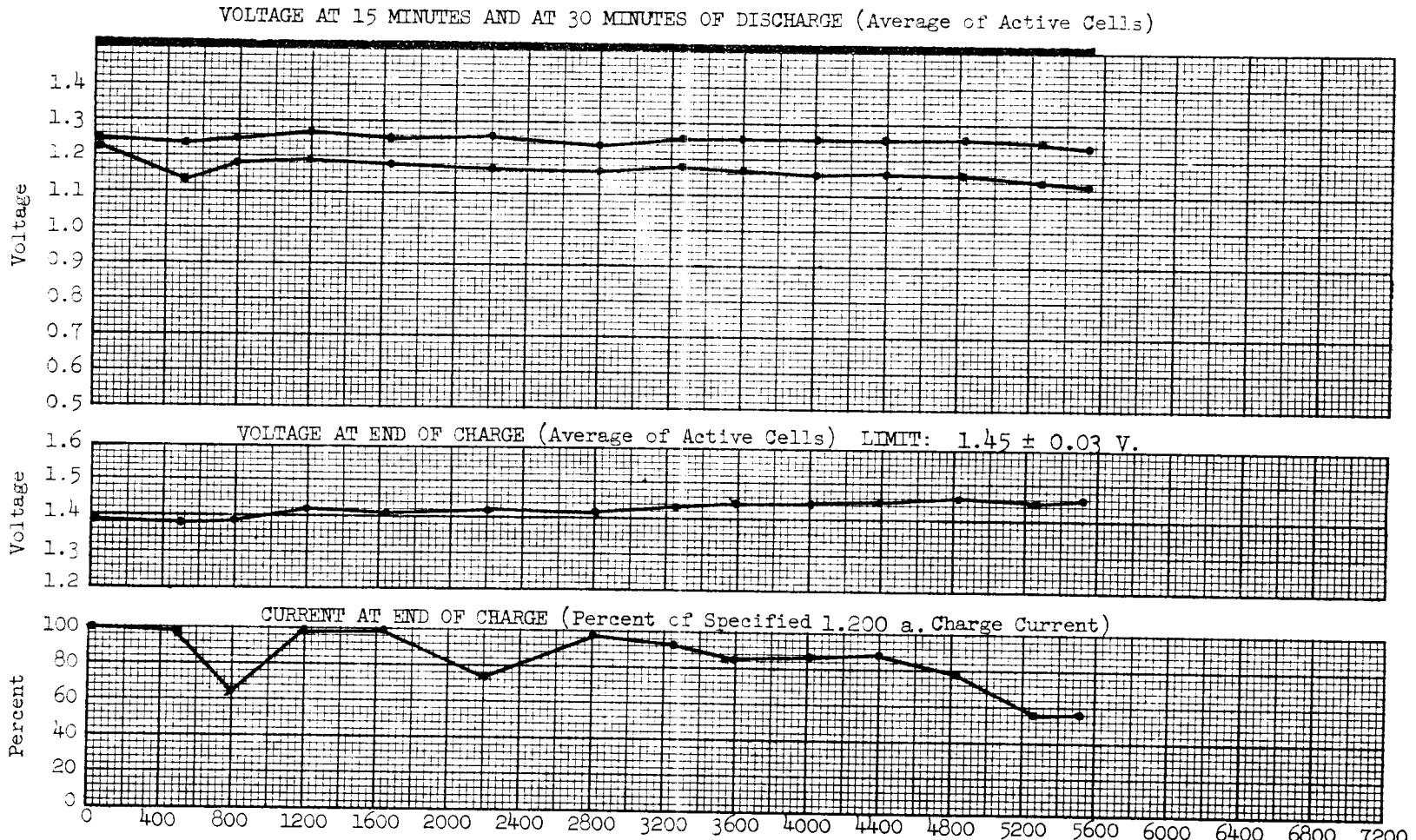
SONOTONE 5.0 a.h. (Pack 6)
Test Temperature: 25° C
Orbit Period: 3 hours
Depth of Discharge: 40%

Status: 7 cells cycling after 2707 cycles.

Notes

1. Cycles 700, 1365, 2100: Capacity Check.

QE/C 65-356



Cell Number	Cycle Failed

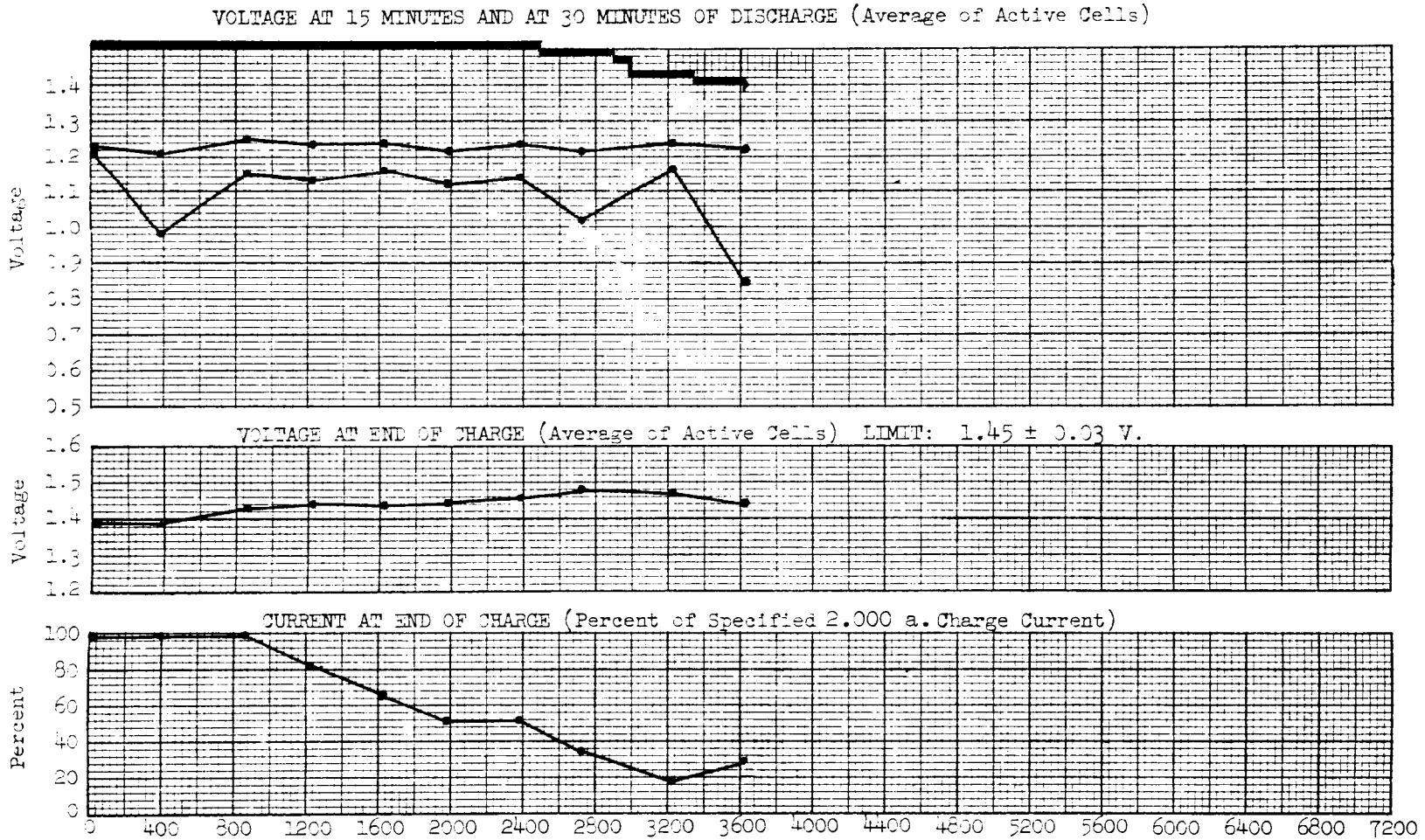
SONOTONE 5.0 a.h. (Pack 25)
Test Temperature: 30° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: 10 cells cycling after 5567 cycles.

Notes

1. Cycle 703: Changed to 40° C.
2. Cycle 1004: Voltage limit raised to 1.45 V/cell.
3. Cycles 1417, 2755, 4246: Capacity Check.

FIGURE 13(i)



Cell Number	Cycle Failed
4323	2487
6773	2902
7224, 7232	2993
4381	3344
4240	3625

SONOTONE 5.0 a.h. (Pack 26)
Test Temperature: 50° - 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

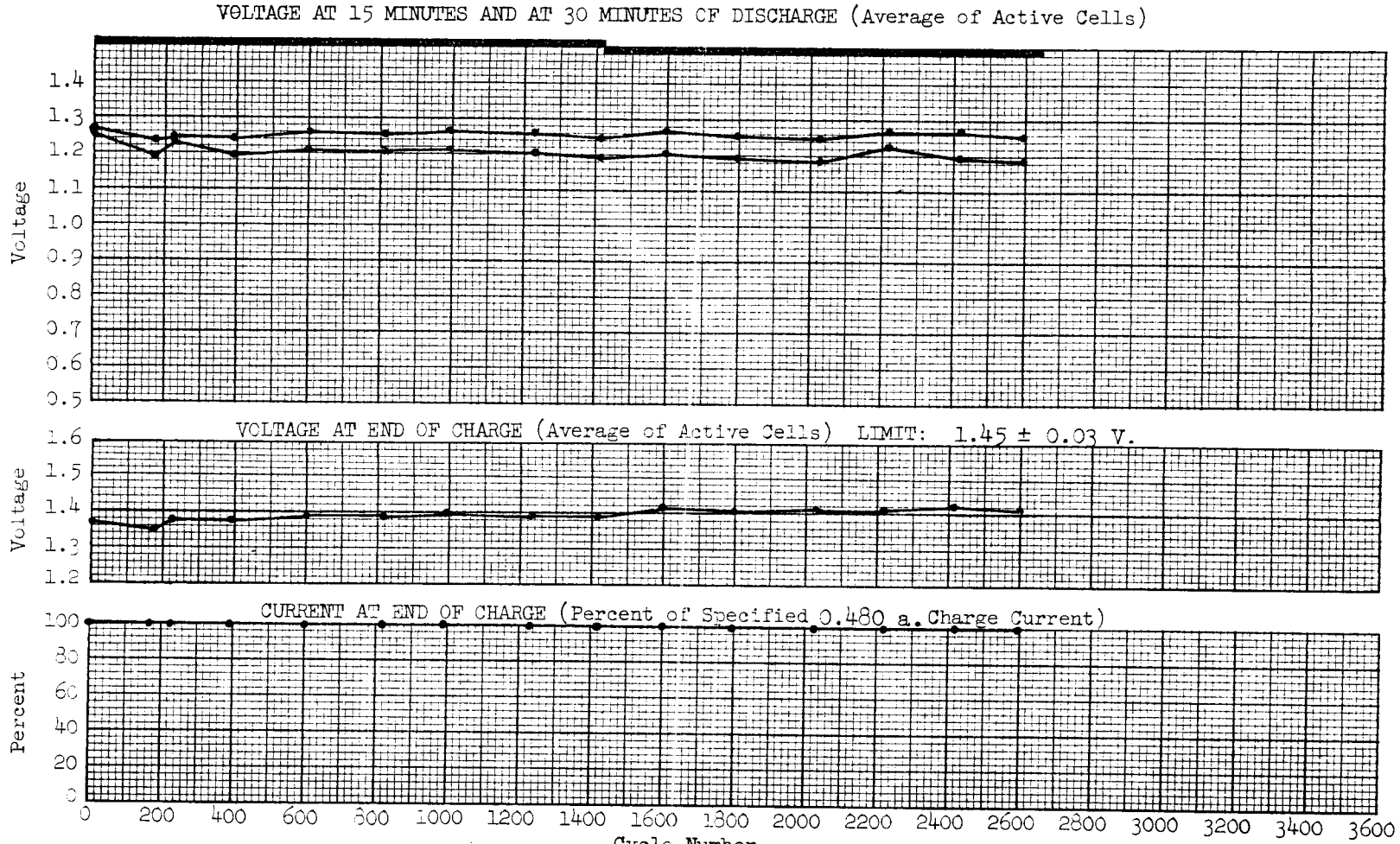
Status: Pack Failed: Cycle 3625

Notes

1. Cycle 446: Changed to 40° C.
2. Cycle 676: Voltage limit raised to 1.45 V/cell.
3. Cycles 1413, 2917: Capacity Check.

FIGURE 13(j)

QF/C 65-356



Cell Number	Cycle Failed
3626	1418

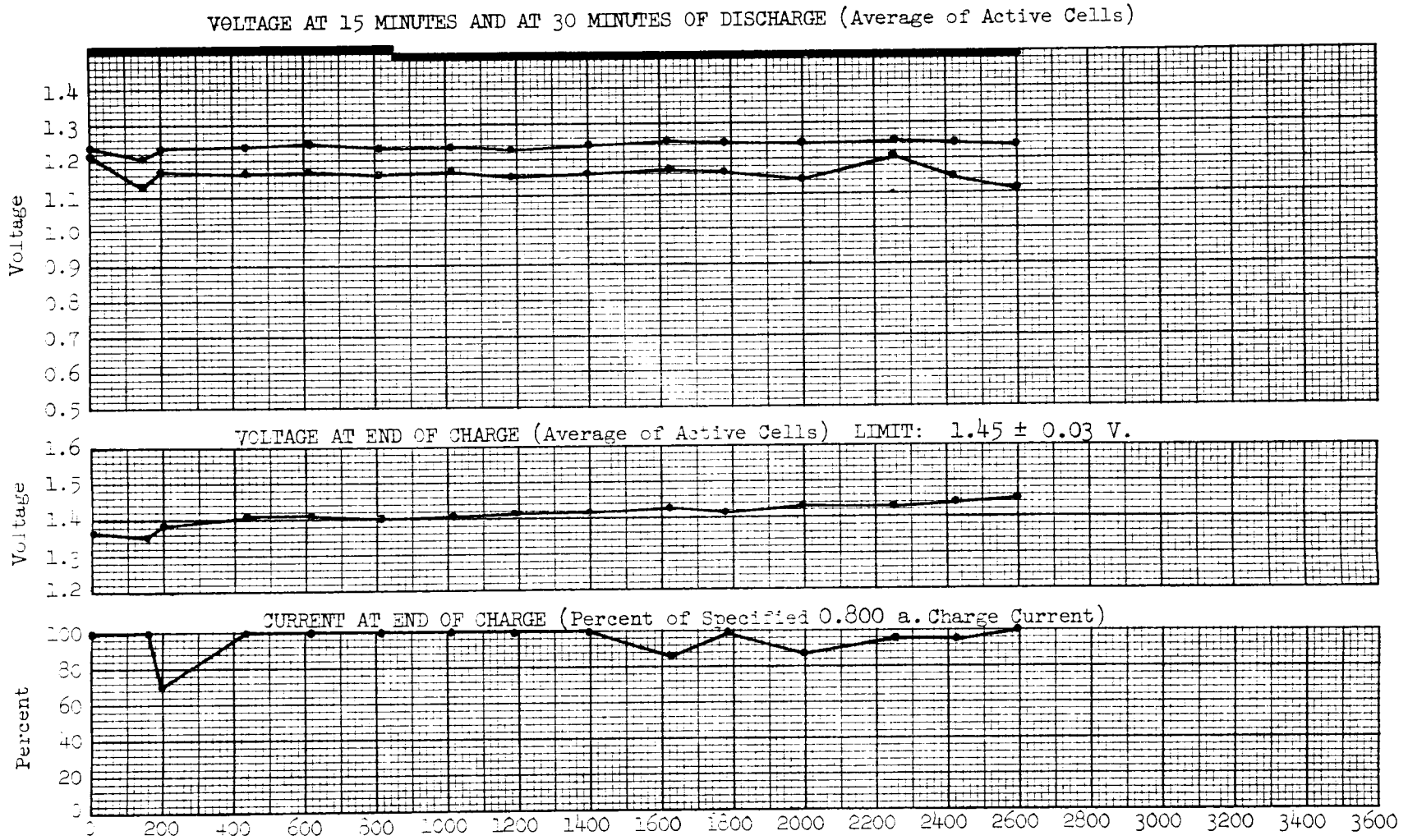
SONOTONE 5.0 a.h. (Pack 29)
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 15%

Status: 9 cells cycling after 2648 cycles.

Notes

1. Cycle 223: Changed to 40° C.
2. Cycle 381: Voltage limit raised to 1.45 V/cell.
3. Cycles 726, 1552, 2207: Capacity Check.

FIGURE 13(k)



Cell Number	Cycle Failed
3657	855

SONOTONE 5.0 a.h. (Pack 30)
Test Temperature: 50° - 40° C
Orbit Period: 3 hours
Depth of Discharge: 25%

Status: 9 cells cycling after 2614 cycles.

Notes

1. Cycle 183: Changed to 40° C.
2. Cycle 329: Voltage limit raised to 1.45 V/cell.
3. Cycles 726, 1552, 2207: Capacity Check.

FIGURE 13(1)

V. TEST FACILITIES.

A. Environmental Chambers: Ambient test temperature conditions were obtained with the following equipment:

1. 0° C.

a. A 27 cubic foot chamber manufactured by the A. Webber Engineering Corporation, Model WF-27-40, temperature controls accurate to within ± 1.5° C.

b. A 12 cubic foot chamber manufactured by General Thermodynamics Inc., Model UCH 322 C-B, temperature controls accurate to within ± 1.5° C.

2. 25° C. Packs cycling at 25° C are located in an air conditioned room with other temperature critical equipment. The temperature is maintained at 25 ± 2° C.

3. 40° C. A 27 cubic foot chamber manufactured by Tenney Engineering Inc., Model UF-40240, temperature controls accurate to within ± 1.5° C.

B. Charge and Discharge Control Units.

1. Each cell pack is connected to its own, independent, solid state current limiting charging unit. These units control the charge rates and voltage limits by regulating the current supplied by a 28 VDC generator which is common to all units. They also discharge the packs by a relay switching system which changes the current lead connections within the units. Each has two ammeters rated at ± 1 percent accuracy for visual monitoring of charge and discharge currents, and three separate controls for setting the currents and voltage limit at the desired values. A 3-position switch selects between continuous charge, continuous discharge and automatic cycling operation. Automatic cycling is controlled by 1.5-hour and 3-hour synchronous motor timers, each of which is common to all corresponding units through a relay switching system. Reference voltages for the voltage limiting circuits are supplied by small transformer DC power supplies from a regulated 117 volt AC source.

2. Photograph 2 shows a front view of several charge-discharge units.

C. Upper and Lower Voltage Limit Monitoring System.

1. Each pack is connected to its own lower limit voltmeter which sets off an alarm common to the system and turns on an identifying light for the particular pack when the terminal voltage of the

pack falls below a preset limit. Photograph 3 is a picture of the lower voltage limit monitoring system.

2. An additional system is used to scan each individual cell voltage. When the voltage of any cell is found to be outside the preset upper or lower limits, the system automatically sets off the alarm and the identifying light in the lower voltage limit monitoring system and also disconnects the current leads of that pack by de-energizing a relay. The system includes a 900-point modified crossbar scanner which scans continuously at a rate of 330 points per minute, so that each cell is scanned every 2 minutes. Voltages are measured by a DC to frequency converter and a frequency counter. The scanning system is shown in Photograph 4.

D. Data Logging System.

1. Brief Summary.

a. Recordings are made by means of a data logging system (Photograph 5) obtained from Gulf Aerospace Corporation. All monitoring leads from a given pack of cells are scanned, converted to digital form and fed to the Tally Mark 45P paper tape punch and programmed reader. The system permits the current, pack terminal voltage, all cell voltages and thermocouple voltages for a given pack to be read and punched out within less than 4 seconds. An additional switching arrangement permits recording up to six 10-cell packs and 12 5-cell packs at one time.

2. Technical Description.

a. This system is designed to record data from 30 data channels by sampling and scanning the input voltages. The data is converted to binary code by a precision amplifier and a high speed analog to digital converter and is presented serially by character to the paper tape punch for storage of the data. Figure 14 is a block diagram of the data logging system.

b. The system measurements are either timed and controlled by the system's digital clock, or manually controlled by the operator. Additional features of the system provide for a typed report of the stored data.

c. The system has 30 input channels. Of these, channels 1 to 10 have a full scale input of 10 volts and measure battery cell voltages. Channels 11 and 13 have a full scale range of 20 volts and measure the total pack voltages. Channels 12 and 14 have a full scale range of 100 millivolts and measure the voltage across 100 millivolt current shunts.

d. All of these inputs, 1 to 14, are sample and hold type inputs. They are sampled simultaneously for 400 milliseconds. The attenuated input signal voltages, all of which are normalized to 100 millivolts full scale, are stored on high quality capacitors. The scanner then sequentially scans these capacitors for data readout. This technique is used to eliminate any difference in time between the first 14 input readings. The accuracy of these channels is ± 0.25 percent of full scale reading.

e. Channel 15 is used for battery pack identification. Another instrument, which provides selection for monitoring a given pack from a group of packs, provides an output from which the particular pack selected can be identified. This output voltage is read on channel 15 as the position identifying the pack. The operator or project leader correlates these readings with specific packs being tested.

f. Channels 16 through 30 are low level input channels (± 10 millivolts full scale) designed to monitor thermocouple inputs with an accuracy of ± 1 percent of full scale. These channels have a maximum common mode voltage that can exist between the signal and the system ground of ± 10 volts. If the common mode voltage exceeds this value, accurate readings can no longer be taken. (Common mode voltages of over ± 20 volts may damage the differential amplifier.)

g. Cycle time for this system is less than 4 seconds for all 30 channels. The readout system, a Tally Mark 45P, is capable of receiving data from the analog to digital converter, from a prepunched paper tape, or from the Selectric typewriter by manual input and may be programmed to print out the data, off line, in any desired format.

3. System Operation.

a. During the scanning process each channel in turn is routed to the input of a high impedance differential amplifier, the gain of which is automatically switched between 100 (the amount used for the high level channels) and 1000 (the amount required for the low level channels). The sensing for the gain change is supplied by the relay drivers. Provisions are made to eliminate amplifier drift while sampling voltage across the storage capacitors. The output of the amplifier is applied through a low pass filter at the input of the analog to digital converter. The analog to digital converter is then given a command to read.

b. The analog to digital converter converts the analog signal to a binary coded decimal signal. A serializer sequentially sends one digit at a time from the output of the clock or from the analog to digital converter to the perforator driver. The zero generator and the parity generator maintain the proper digital format for

punching paper tape and operating the Selectric typewriter in the Tally Mark 45P system. The punched-paper-tape code is compatible with IBM binary coded decimal code (Hollerith).

4. System Controls.

a. The 30-position data scanner has several modes of operation. Mode switch may be set to continuous cycling, preset cycle, single cycle, single step, and manual select. In the continuous cycling position the scanner continues to sample the data at a rate determined by the digital clock. In the preset cycle position the scanner takes a sample of the data at a time determined by the preset time selector. In the single cycle position the scanner samples the data once each time the step/cycle push button is depressed. In the single step position the scanner is advanced one channel at a time by depressing the step/cycle push button switch. In the manual select position the scanner remains at the channel selected by the manual select switches. When in either of the two manual modes a reading is taken by pushing the print button. The scanner has two front panel displays, one for channel number and one for voltage. All system functions are timed by a unijunction oscillator and are controlled by logic circuits in the scanner assembly.

E. Central Wiring Panel.

1. All electrical connections are made through a centrally located wiring panel which houses the current shunts and a plug-in panel. Photograph 6 shows the front view of the central wiring panel.

F. Pack Selector Switch.

1. Up to six 10-cell packs and 12 5-cell packs may be plugged into a selector system from the central wiring panel. Through reed relays operated by a selector switch, any of these packs can then be connected to the input of the data logging system. This arrangement allows all currents and cell and thermocouple voltages for all 18 packs to be recorded by the data logging system within 48 seconds.

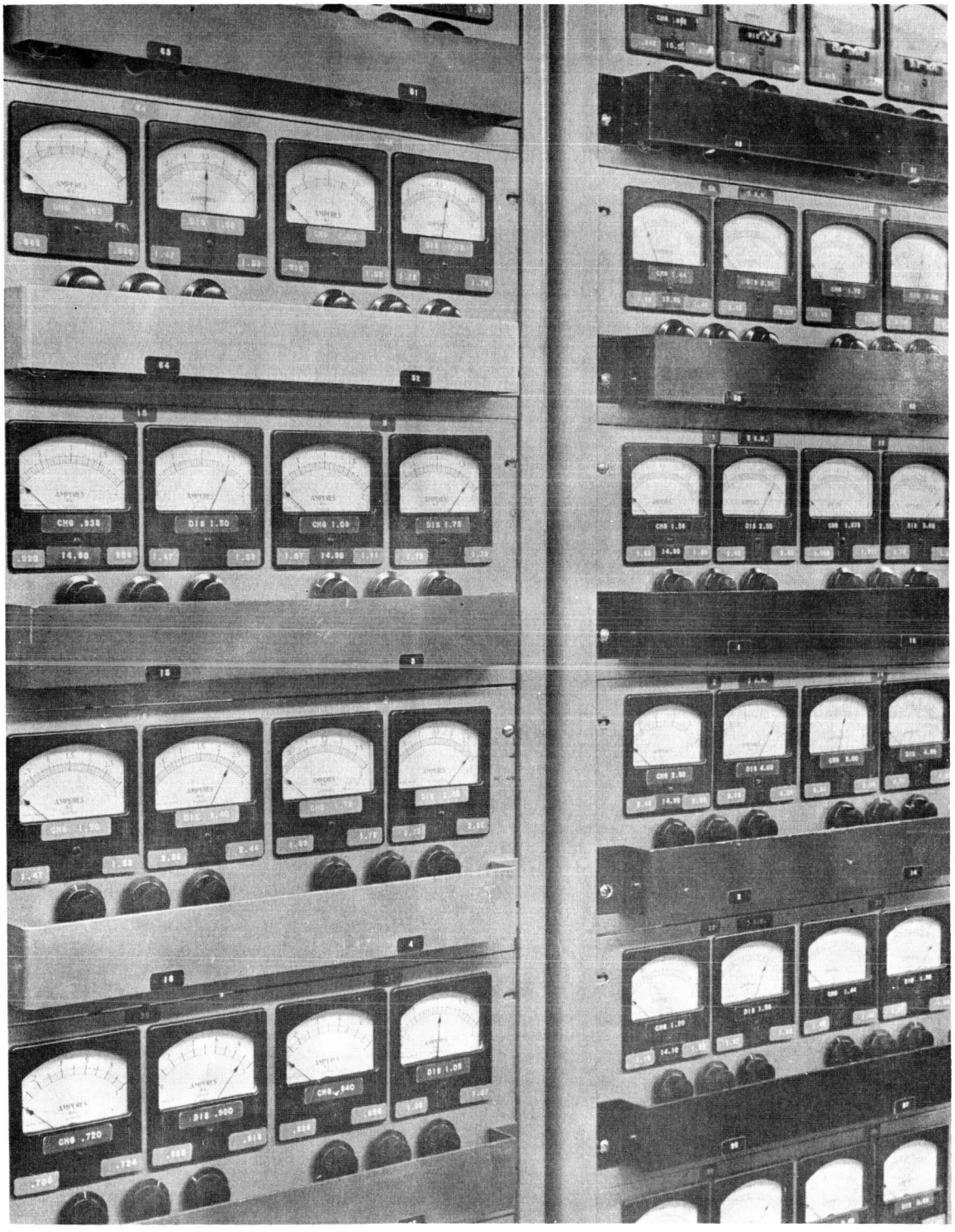
2. The switching system also provides a voltage which identifies the selected position and which is automatically recorded as part of the data for the pack selected.

3. Photograph 4 shows the pack selector switch located on top of the data logging system.

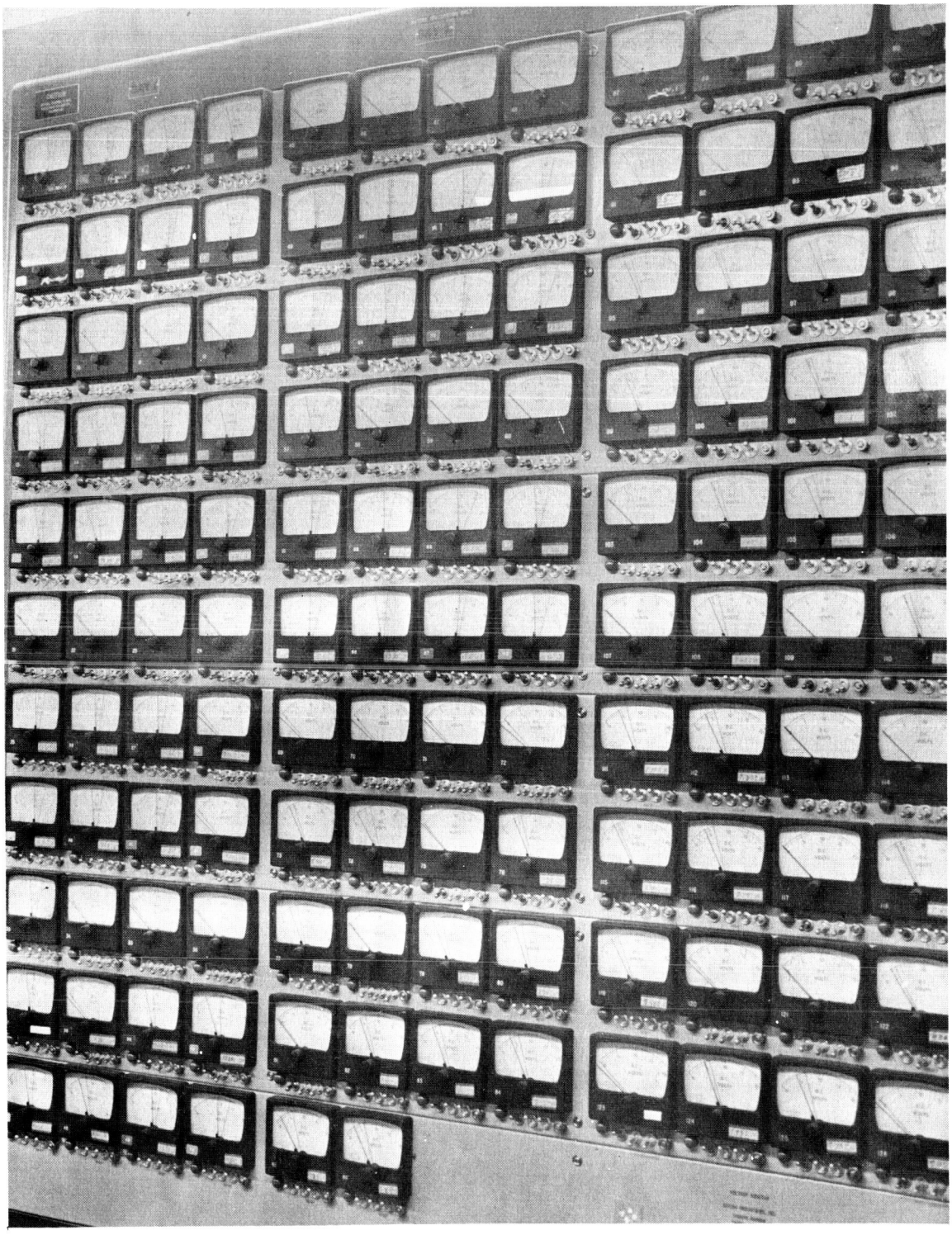
G. Block Diagram of Entire Test Setup: Figure 15 shows the arrangement from the packs at each of the three ambient temperatures to the central wiring panel. Leads from the central wiring panel connect all packs and/or cells to the charge-discharge units and

the 28 volt DC source, the circuit relay switching system, the voltage limiting monitoring system and the data logging system.

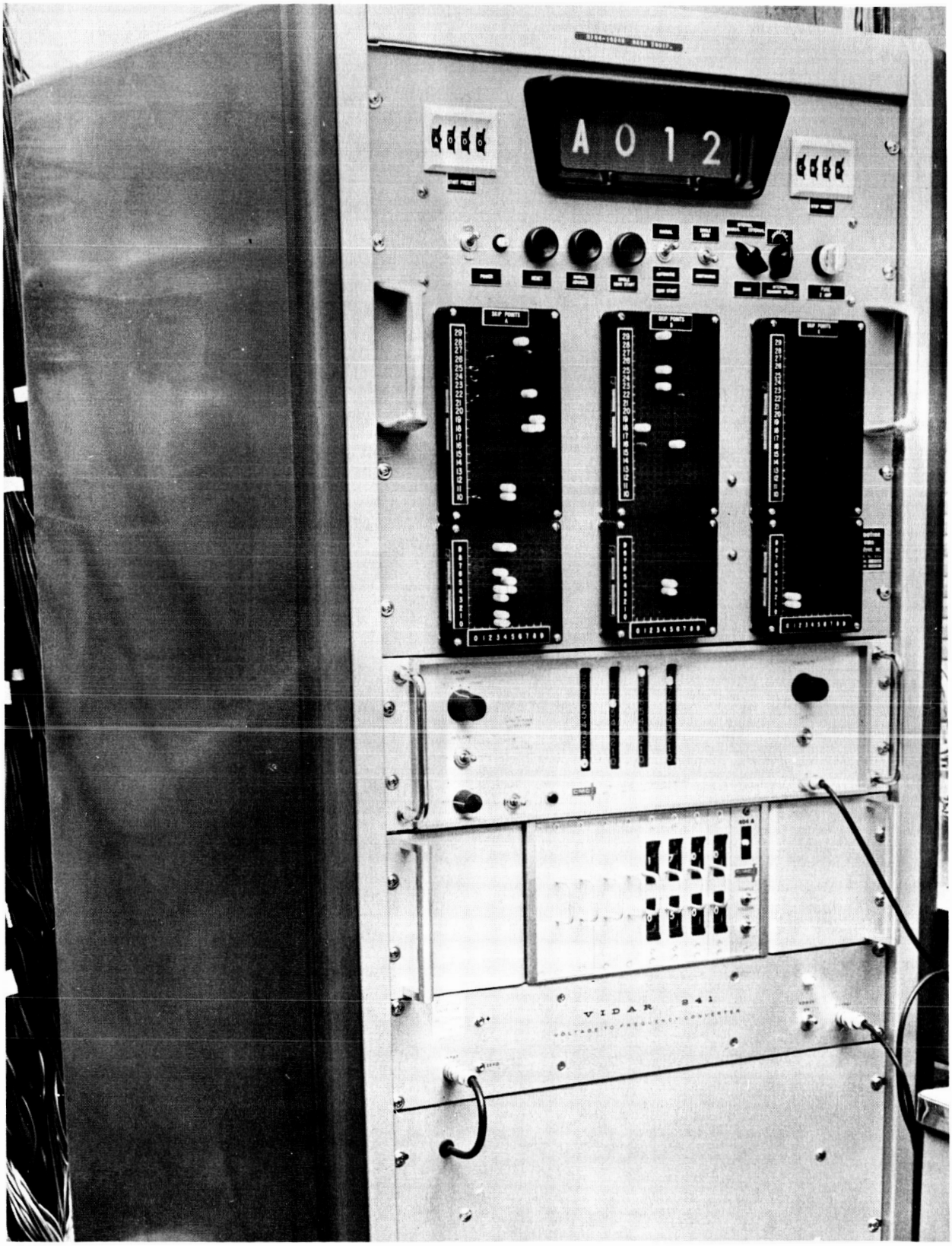
H. Photograph of Test Area: Photograph 7 shows the overall arrangement of the test equipment described in paragraphs V.B. through V.G.



Several Charge and Discharge Control Units
PHOTOGRAPH 2



Pack Voltage Monitoring Panel
PHOTOGRAPH 3



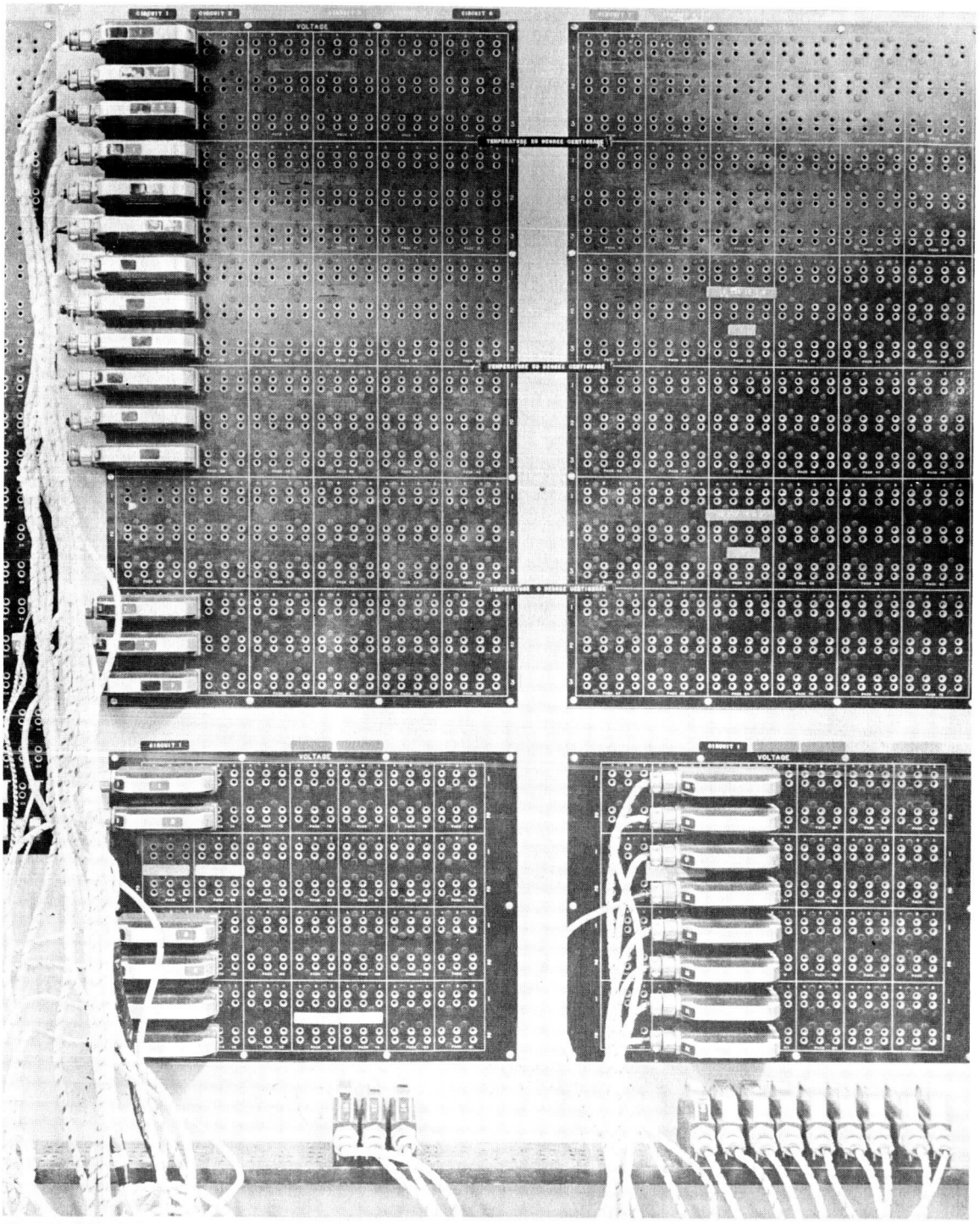
Individual Cell Voltage Scanning System

PHOTOGRAPH 4



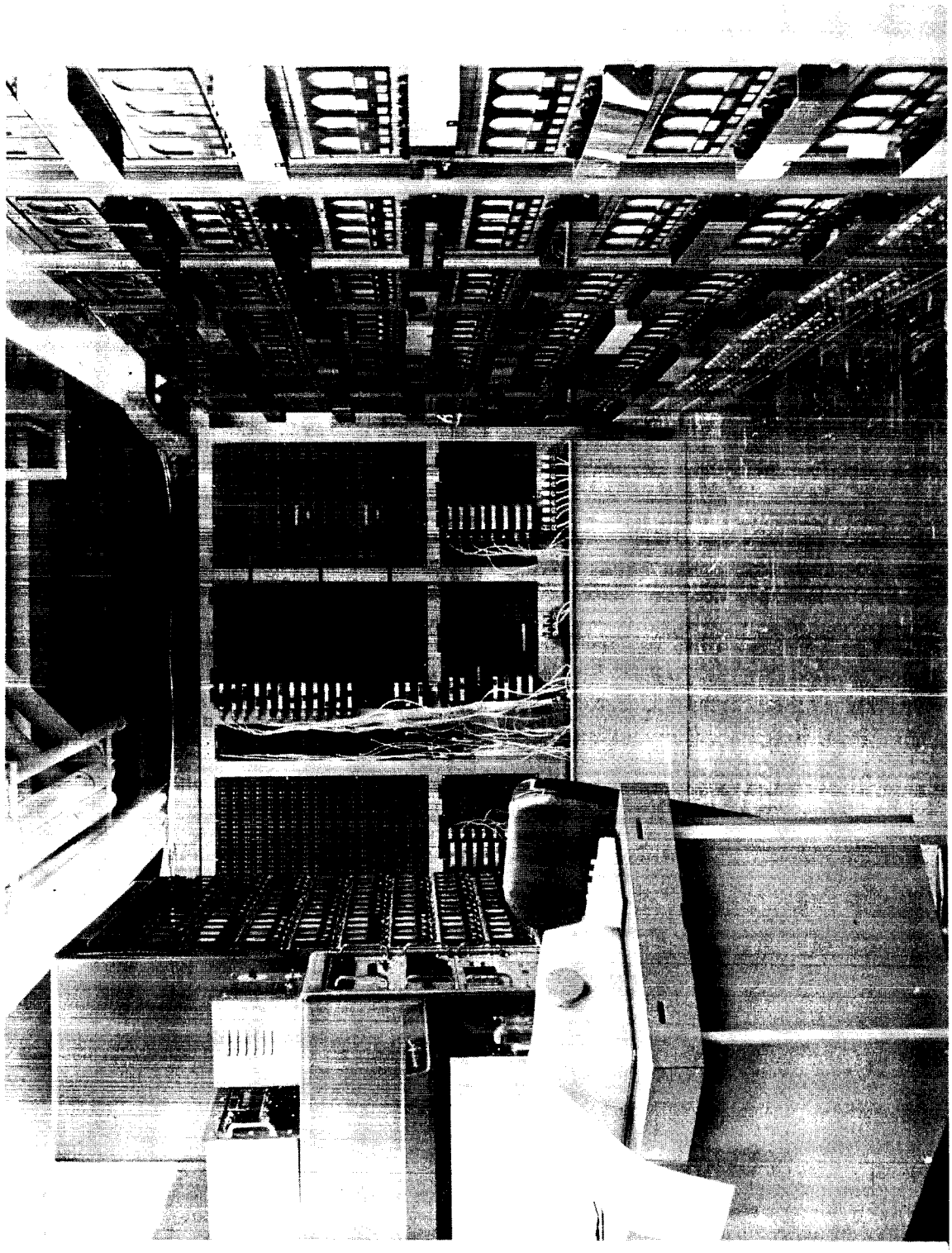
Data Logging System

PHOTOGRAPH 5

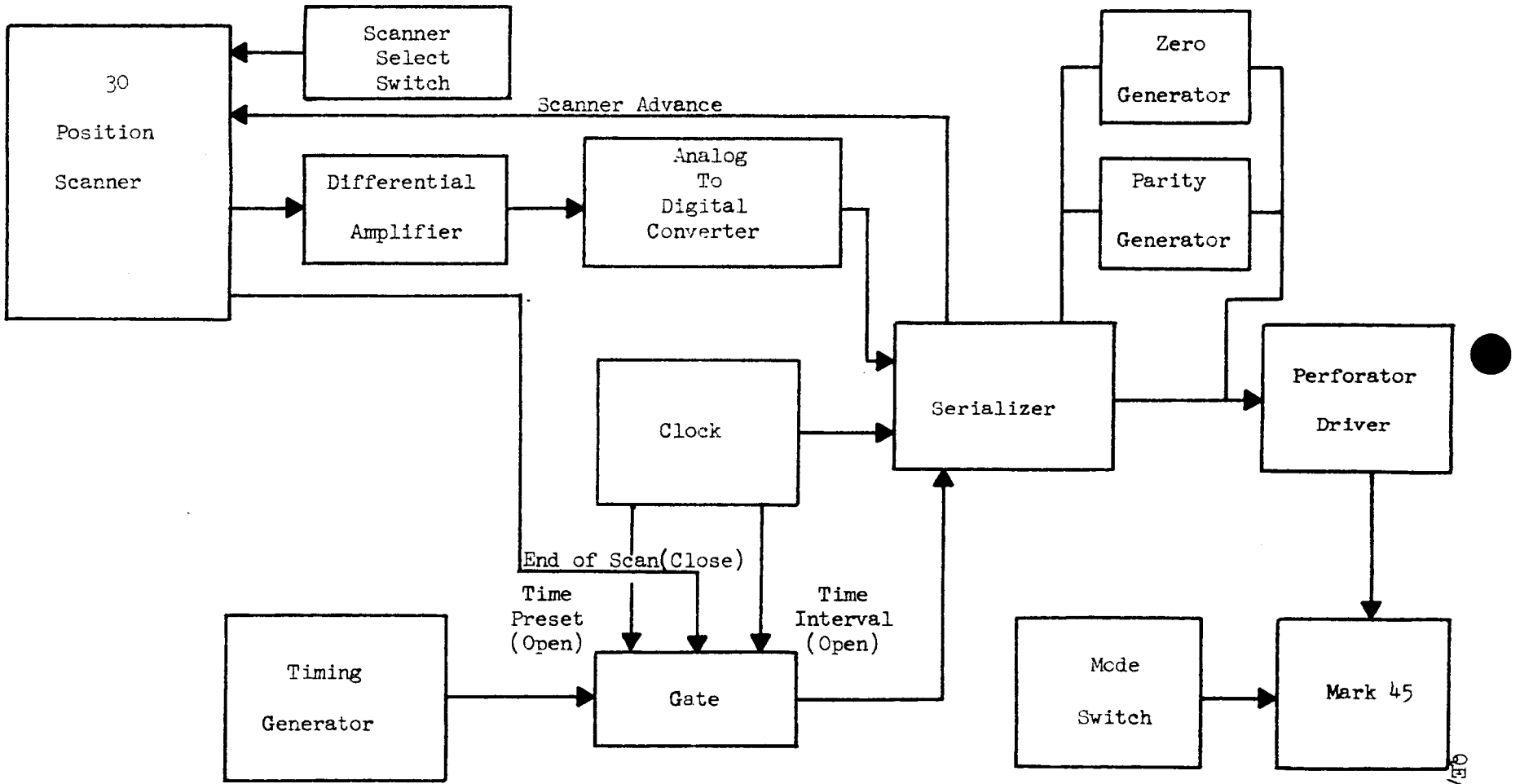


Portion of Central Wiring Panel

PHOTOGRAPH 6

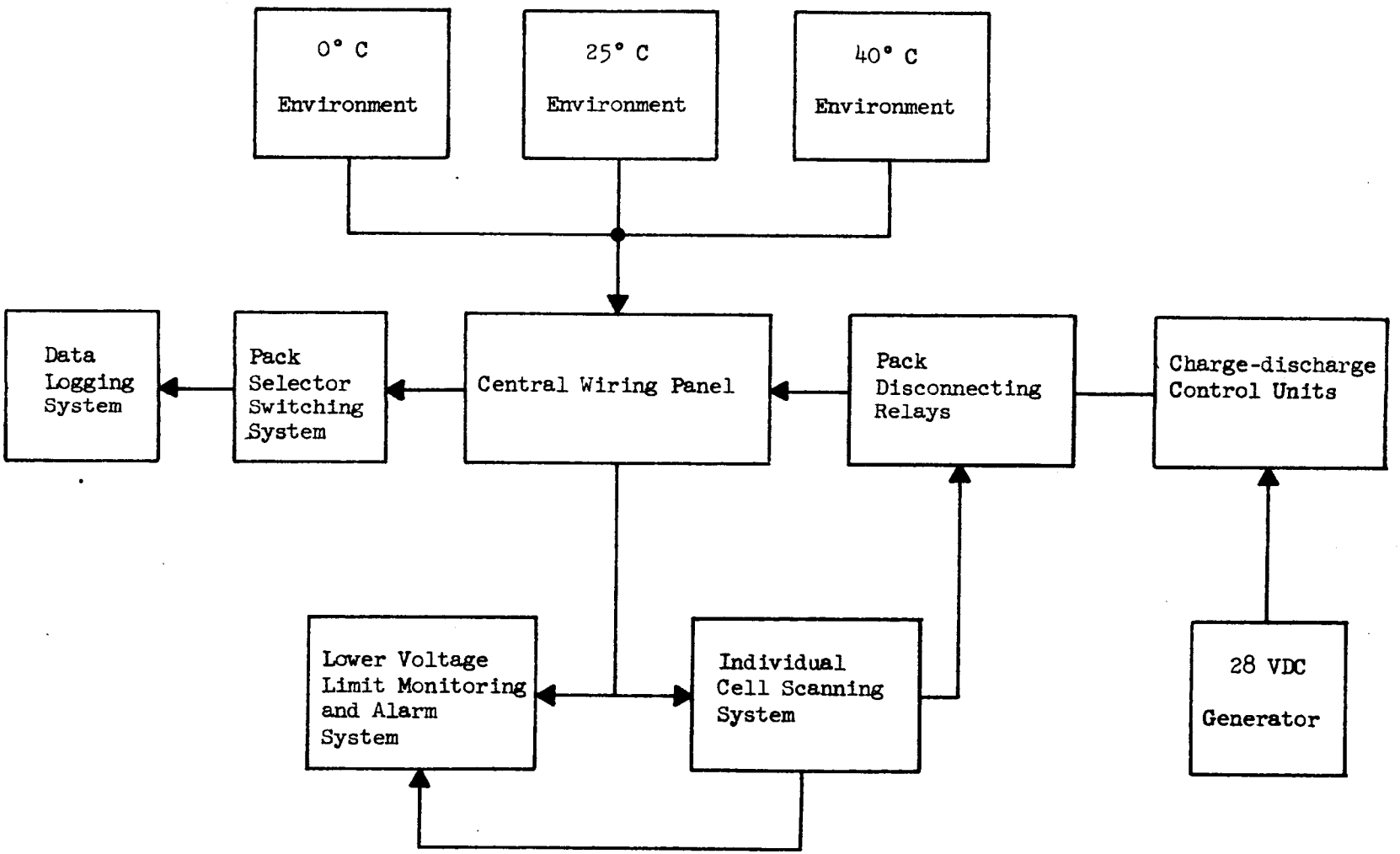


Test Area
PHOTOGRAPH 7



Block Diagram of Data Logging System

FIGURE 14



Block Diagram of Test Setup
FIGURE 14

VI. APPENDIX: TESTS ADDED TO THE CYCLE LIFE TEST PROGRAM.

A. G.E. 12 a.h. 5-cell Pack, 24-hour Orbit Period (Pack 93):

1. The cells used were of the type described in Paragraph II.A.1.b.

2. Test Parameters:

a. Initial Test Parameters:

(1) Orbit Period: 1-hour discharge, 23-hour charge.

(2) Test Temperature: 25° C.

(3) Depth of Discharge: 50%.

(4) Percent of Recharge: 150%.

(5) Charge Voltage Limit: 1.49 volts per cell, average.

b. Changes in Test Parameters:

(1) Due to low end-of-discharge voltage, the percent of recharge was raised to 200 percent after 57 cycles, after which the pack appeared to operate satisfactorily.

(2) In order to gain additional information, the environmental temperature was raised after 173 cycles from 25° C to 40° C, with the charge voltage limit lowered to 1.45 volts per cell, average.

3. Results:

a. Performance on Cycling: (Figure 16.)

(1) Average end-of-discharge voltage fell to less than 1.0 volt per cell under the original test parameters, although satisfactory operation was obtained with the 200 percent recharge.

(2) At 40° C the pack did not operate as well. End-of-discharge voltages were low and quite variable. Two cells appeared to have failed on cycle 266. The first cell showed no defects upon failure analysis. The second cell was discharged completely, shorted externally overnight, charged for 16 hours at the c/10 rate, and finally discharged again at the c/2 rate, all at 25° C. Its capacity was thus found to be 12.9 a.h. It was returned to the pack and has continued to cycle well into the next year (1965). The cycling

behavior of these two cells has been attributed to a combination of memory effect and insufficient percent of recharge.

(3) At no time was the voltage limit reached on charge. The end-of-charge voltage remained close to 1.39 volts per cell at both temperatures.

b. Capacity Checks: Results of preconditioning and capacity check cycles are as follows:

(1) Preconditioning (25° C): 13.0 a.h.

(2) First capacity check, first and second discharges (25° C, 200 percent recharge on cycling): 6.55 a.h. and 7.60 a.h.

(3) Second capacity check, first and second discharges (40° C, 200 percent recharge on cycling): 5.20 a.h. and 6.50 a.h.

B. Gulton 6 a.h. 5-cell Pack, 24-hour Orbit Period (Pack 79):

1. The cells used were of the type described in paragraph II.A.3.a.

2. Test Parameters:

a. Initial Test Parameters:

(1) Orbit Period: 1-hour discharge, 23-hour charge.

(2) Test Temperature: 25° C.

(3) Depth of Discharge: 50%.

(4) Percent of Recharge: 150%.

(5) Charge Voltage Limit: 1.49 volts per cell, average.

b. Due to low end-of-discharge voltage the percent of recharge was raised to 200 percent after 57 cycles.

3. Results:

a. Performance on Cycling: (Figure 17.)

(1) All cell voltages became quite low at the end-of-discharge with the original 150 percent of recharge. Increasing this to 200 percent caused the end-of-discharge voltages of all five cells to remain fairly constant at about 0.9 volt. Two cells failed after

149 and 168 cycles, and the end-of-discharge voltages of the remaining three climbed to an average of 1.08 volts per cell in the next 30 cycles. The reason for this is not known.

(2) The singularity in end-of-discharge voltage on cycle 66 is due to a 24-hour charge at the c/10 rate, which preceded cycle 65. This was done because a generator failure had caused the pack to be shut off for several days.

(3) The end-of-charge voltage remained fairly constant, between 1.38 and 1.40 volts per cell, average.

b. Cell Failures: Two cells failed, after 149 and 168 cycles. No failure analysis has been made to date.

c. Capacity check results are as follows:

(1) Preconditioning: 6.60 a.h.

(2) First capacity check, first and second discharges (200 percent recharge on cycling): 2.88 a.h. and 3.55 a.h.

(3) Second capacity check, first and second discharges: 3.15 a.h. and 4.40 a.h.

C. Yardney 12 a.h. Silver-cadmium, two 10-cell packs, 24-hour Orbit Period (Packs 33 and 57):

1. These are rectangular cells, double sealed. That is, the sealed nylon cell case is enclosed in a second, hermetically sealed stainless steel container.

2. Test Parameters:

a. Orbit Period: 1-hour discharge, 23-hour charge.

b. Test Temperatures: 0° C (Pack 57) and 40° C (Pack 33).

c. Depth of Discharge: 50%.

d. Charge Voltage Limit: 1.50 volts per cell, average, at both temperatures.

3. Results:

a. At 40° C, the plateau voltage among the nonfailing cells on discharge was fairly steady at about 1.06 volts per cell for the first 110 cycles, with little or no drop-off at the end of discharge. Thereafter, plateau voltage began to drop steadily and

end-of-discharge voltage became quite erratic. At 0° C, low end-of-discharge voltages occurred after as few as 31 cycles, and persisted erratically until the pack failed.

b. Pack 33 (40° C) failed after 210 cycles. Cell failures were as follows:

Cell Position in Pack	Cycles to Failure
3	58
2	126
1	152
8	197
4 and 10	210

(1) All of the above cells had dried out because of electrolyte leakage.

c. Pack 57 (0°C) failed after 166 cycles. Although cell voltages had frequently fallen below the 0.5 volt failure point, they had not been failed sooner because of their erratic behavior. After 162 cycles, however, electrolyte had leaked out and formed a pool over the tops of the cells, thus shorting them out. Seven of the cells were cleaned and returned to cycling, but after four more cycles the condition had recurred. All cells were leaking.

d. Capacity checks were made after approximately 140 cycles. Results were as follows:

Pack	Preconditioning Capacity	Capacity Check	
		First Discharge	Second Discharge
33	13.5 a.h.	11.2 a.h.	12.0 a.h.
57	13.8 a.h.	5.9 a.h.	8.6 a.h.

D. Gulton 4.0 a.h. Cells (commercial), six 5-cell packs, 1.5-hour Orbit Period:

1. These are rectangular cells of commercial grade, which are not hermetically sealed as supplied. They were epoxy-potted into 5-cell packs at the Goddard Space Flight Center in order to seal the cells and were subsequently tested at NAD Crane.

2. Test parameters are as follows:

Pack Number	Test Temperature	Percent Depth of Discharge	Percent of Recharge	Charge Voltage Limit, Per Cell
315	0° C	15	115	1.55 ± 0.03
326	0° C	25	115	1.55 ± 0.03
204	25° C	25	125	1.49 ± 0.03
214	25° C	40	125	1.49 ± 0.03
228	40° C	15	160	1.45 ± 0.03
240	40° C	25	160	1.45 ± 0.03

a. These duplicate the sets of parameters used for the cells in the original program, with the exception that the 3-hour orbit is omitted.

3. Test Results:

a. Performance on Cycling: (Figures 18(a) through 18(f).)

(1) These packs have completed from 2296 to 2517 cycles, with no cell failures to date. In all cases there appears to have been a slight tendency towards increasing end-of-charge voltage or decreasing end-of-charge current. Some leakage occurred, as follows:

(a) Pack 315: Leakage under the epoxy and carbonate deposits around the terminals which were embedded in the top of the epoxy block.

(b) Pack 326: Possible slight leakage under the epoxy.

(c) Pack 204: Some leakage under the epoxy.

(d) Pack 214: Leakage under the epoxy; a crack also developed at the bottom of the epoxy case after 1785 cycles, allowing some electrolyte to escape.

(e) Pack 228: Some leakage under the epoxy.

(f) Pack 240: Possible slight leakage under the epoxy.

b. Capacity Checks: Ampere-hours on preconditioning and capacity check cycles are as follows:

Pack Number	Preconditioning	First 88 Days Discharge #1	First 88 Days Discharge #2
315	5.04	3.28	3.57
326	4.87	3.23	4.00
204	4.63	2.30	2.47
214	5.00	1.93	2.00
228	4.20	1.77	1.70
240	3.37	1.13	1.17

E. Gulton 50 a.h., two 5-cell packs, 1.5-hour Orbit Period (Packs 95 and 123):

1. These are rectangular, hermetically sealed nickel-cadmium cells.

2. Test parameters were as follows:

Pack Number	Test Temperature	Percent Depth of Discharge	Percent of Recharge	Charge Voltage Limit, Per Cell
95	0° C	25	115	1.55 ± 0.03
123	40° C	15	160	1.45 ± 0.03

3. Test Results:

a. Pack 123 (40° C, Figure 19): The cell in position two failed after 1873 cycles, and those in positions three and four went dead while the pack was shut off in order to remove cell number two. The separators of all three cells had deteriorated; two had several burned spots on the separator where the plates had shorted together. In two of the cells the outside negative plates had stuck to the cell case. All three had bulged cases from high pressure; one had a carbonate deposit at the positive terminal and the other two were still under pressure when opened.

b. Pack 95 (0° C, Figure 20): This pack failed after 3227 cycles. The cells in positions three and five shorted out after 2643 and 2938 cycles, respectively. In both the separators were dry and short circuits had occurred between the plates. Cell 3

had blisters on the positive plates, and cell 5 showed slight migration from the negative plates. Cell 1 failed after 3227 cycles. The end-of-charge voltage was high; the cell showed migration, large blisters on the positive plates, and one negative plate stuck to the cell case.

c. Ampere-hour Capacities:

(1) The preconditioning capacity of Pack 123 at 40° C was 27.9 a.h. An equipment failure interrupted the first capacity check. The pack was then allowed to complete an additional month of cycling in order to let the cells stabilize again before receiving a capacity check, but the pack failed shortly before the capacity check was to have begun.

(2) Results for Pack 95 are as follows:

	First 88 Days		Second 88 Days	
Preconditioning	First Discharge	Second Discharge	First Discharge	Second Discharge
54.6 a.h.	57.5 a.h.	59.6 a.h.	21.7 a.h.	45.4 a.h.

F. Delco-Remy, Silver-zinc Cells, three 5-cell Packs:

1. 25 a.h. cells, standard model except for an addition of one percent palladium to the positive plates (Pack 75).

a. Test Parameters:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: 40%.

(3) Charge Voltage Limit: 1.97 volts per cell.

(4) Orbit Period: 1-hour discharge, 23-hour charge.

b. This pack failed after 32 cycles.

2. 25 a.h. cells, standard model (Pack 89).

a. Test Parameters:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: 40%.

(3) Charge Voltage Limit: 1.97 volts per cell.

(4) Orbit Period: 1-hour discharge, 23-hour charge.

b. This pack failed after 80 cycles.

3. 40 a.h. cells, standard model (Pack 275).

a. Test Parameters:

(1) Test Temperature: 25° C.

(2) Depth of Discharge: 40%.

(3) Charge Voltage Limit: 1.97 volts per cell.

(4) Orbit Period: 1-hour discharge, 23-hour charge.

b. One cell failed while the pack was being prepared for test; a second cell failed after 34 cycles. The remaining cells were still functioning after 139 cycles, at which time the pack was discontinued.

G. Tests to be Added to the Cycle Life Test Program:

1. Gulton 12 a.h. cells, six 5-cell packs, 1.5-hour orbit period:

a. These cells are similar to the 20 a.h. cells discussed in paragraph II.A.3.b. but were manufactured about 2 years later. They are of the type used in the OGO satellite.

b. The test parameters are the same as for the 4.0 a.h. cells discussed in paragraph VI.D.2.

2. G.E. 12 a.h. and Gulton 6.0 a.h. cells with auxiliary electrodes, 1.5-hour orbit period:

a. Six 5-cell packs of each type will be included. The auxiliary electrodes are to be used for gas recombination and for control of the charge current.

b. Test parameters are expected to be as follows:

Test Temperature	Depth of Discharge
0° C	25%
0° C	40%
25° C	25%
25° C	40%
40° C	15%
40° C	25%

3. Gulton 6.0 a.h. cells, three 5-cell packs, 1.5-hour orbit period:

a. These cells are similar to the 6.0 a.h. cells discussed in paragraph II.A.3.a. but are of more recent manufacture and are of an improved type.

4. Other Tests:

a. Sonotone cells utilizing a coulometer for charge control.

b. Three 5-cell packs of Sonotone cells utilizing a stabistor for charge control.

c. Sonotone 3.0 a.h. "D" cells.

d. Delco-Remy 25 a.h. silver-zinc cells.

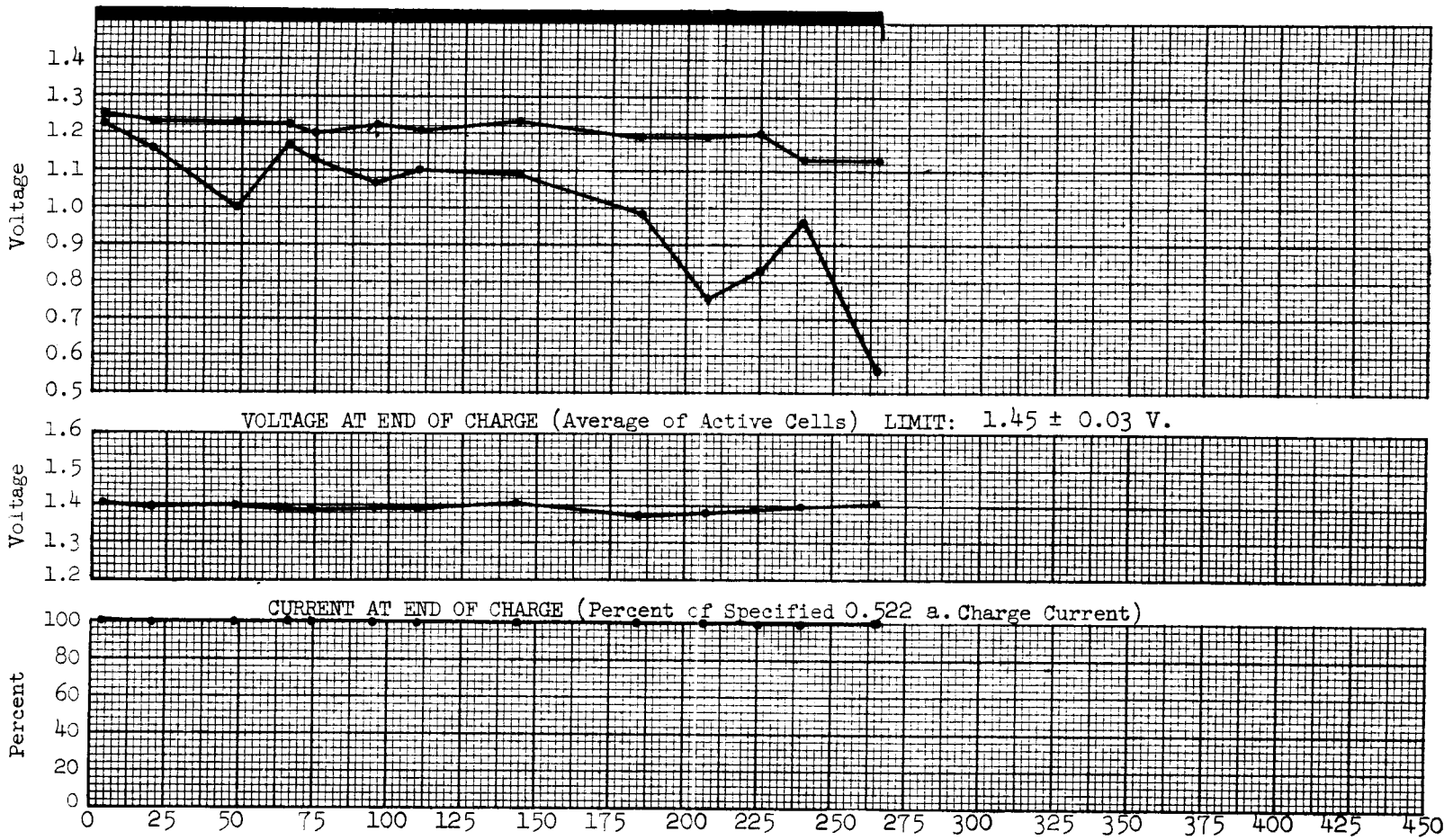
(1) Five cells containing one percent palladium in the positive plates and using 2.2xH Radiation Application Company separators.

(2) Five cells containing one percent palladium in the positive plates and using the standard separator material, but with 45 percent NaOH as electrolyte.

e. Nimbus cells manufactured by G.E. and by Gulton, six 5-cell packs from each manufacturer.

f. Yardney 12 a.h. silver-zinc cells.

g. Various types of silver-cadmium cells.



Cell Number	Cycle Failed
208 (Position 2)	266

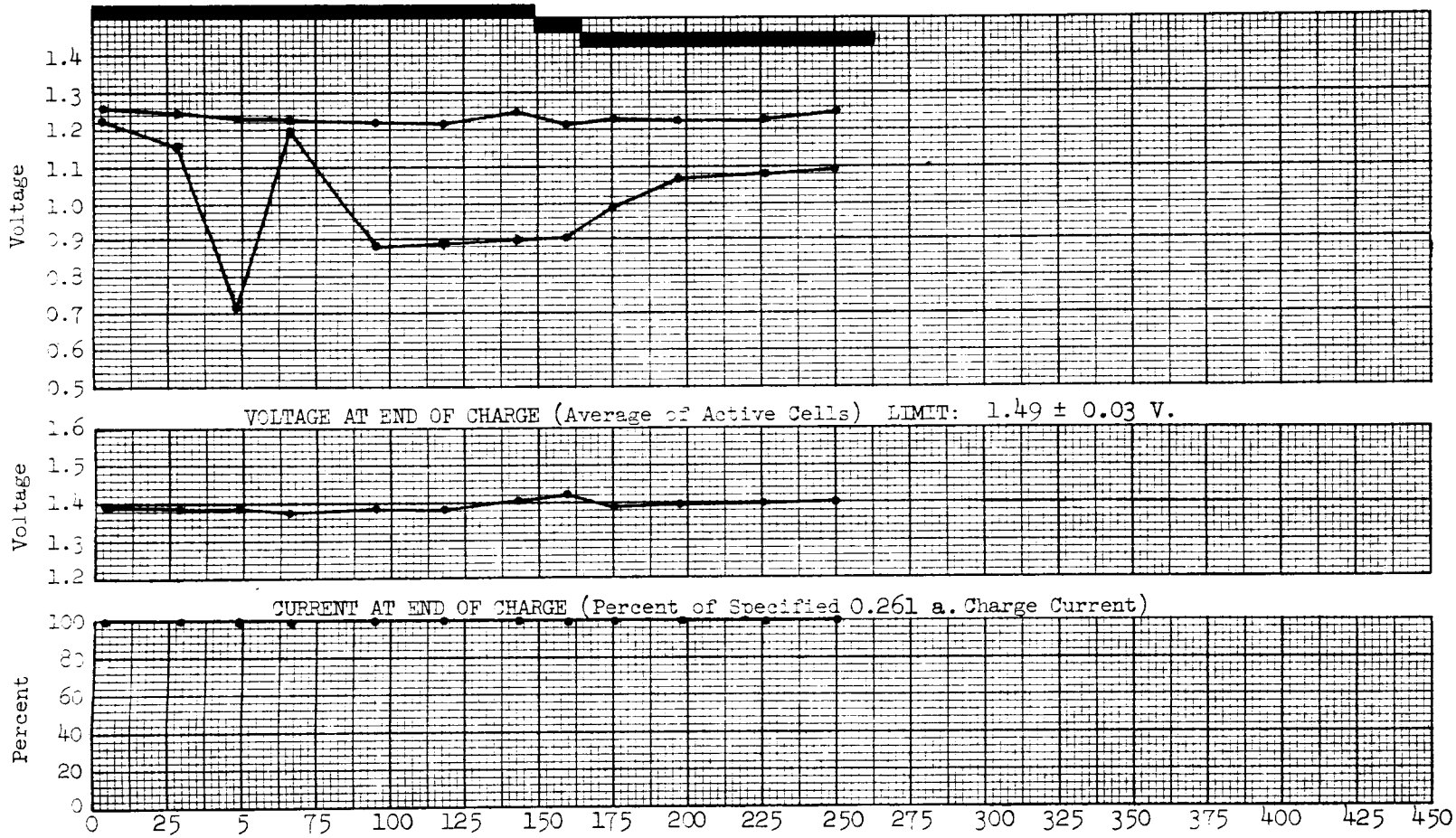
G.E. 12 a.h. (Pack 93)
Test Temperature: 25° - 40° C
Orbit Period: 24 hours
Depth of Discharge: 50%

Status: 4 cells cycling after 266 cycles.

Notes

1. Cycle 57: Raised charge current from 0.391 a. (150% recharge) to 0.522 a. (200% recharge).
2. Cycle 173: Changed from 25° (with 1.49 V. limit) to 40° C ambient (with 1.45 V. limit).
3. Cycle 231: Capacity Check.

FIGURE 16



Cell Number	Cycle Failed
2982 (Position 1)	149
2984 (Position 3)	164

GULTON 6.0 a.h. (Pack 79)
Test Temperature: 25° C
Orbit Period: 24 hours
Depth of Discharge: 50%

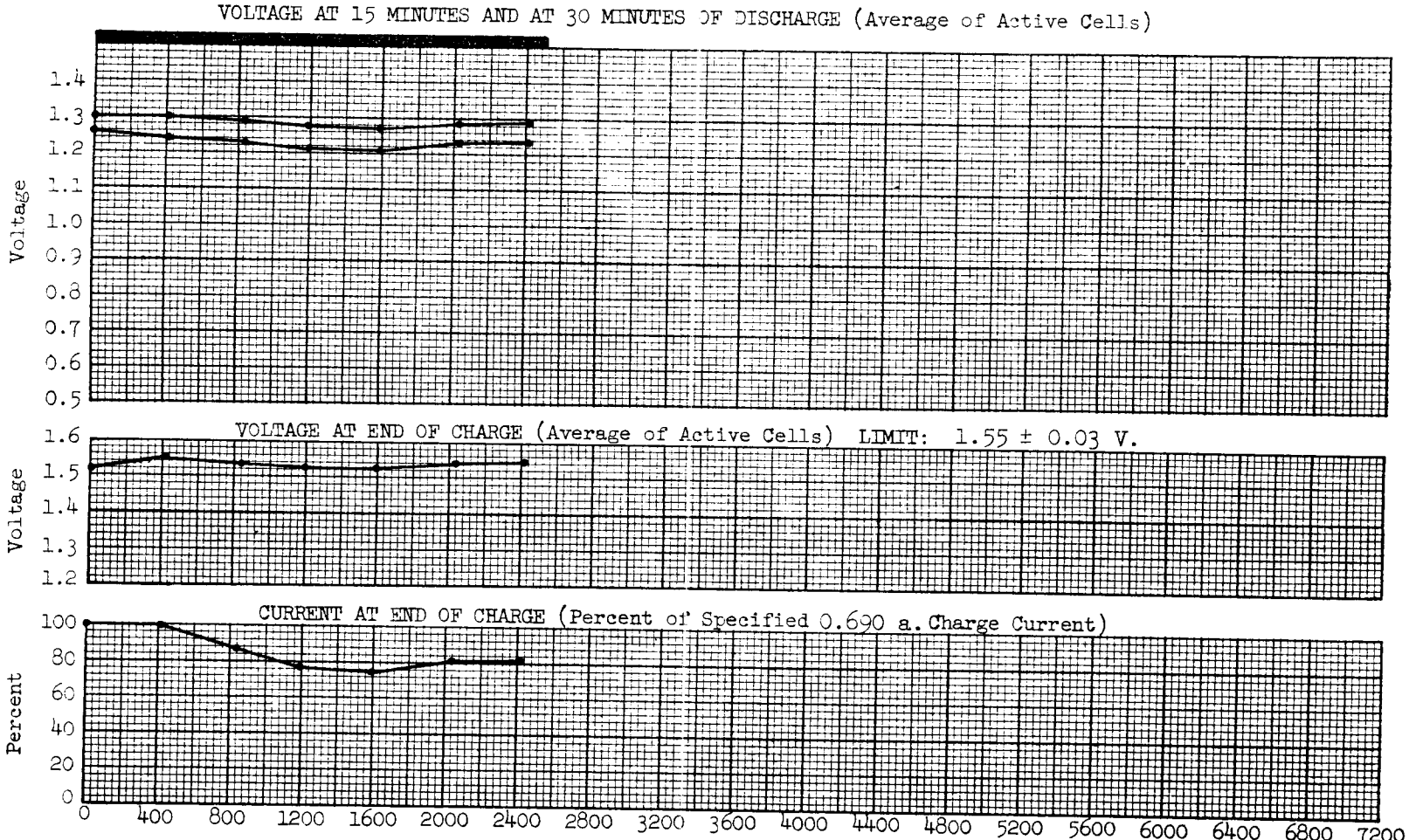
Status: 3 cells cycling after 267 cycles.

Notes

1. Cycle 57: Raised charge current from 0.196 a. (150% recharge) to 0.261 a. (200% recharge).
2. Cycle 232: Capacity Check.

FIGURE 17

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Cell Number	Cycle Failed

GULTON 4.0 a.h. (Pack 315)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

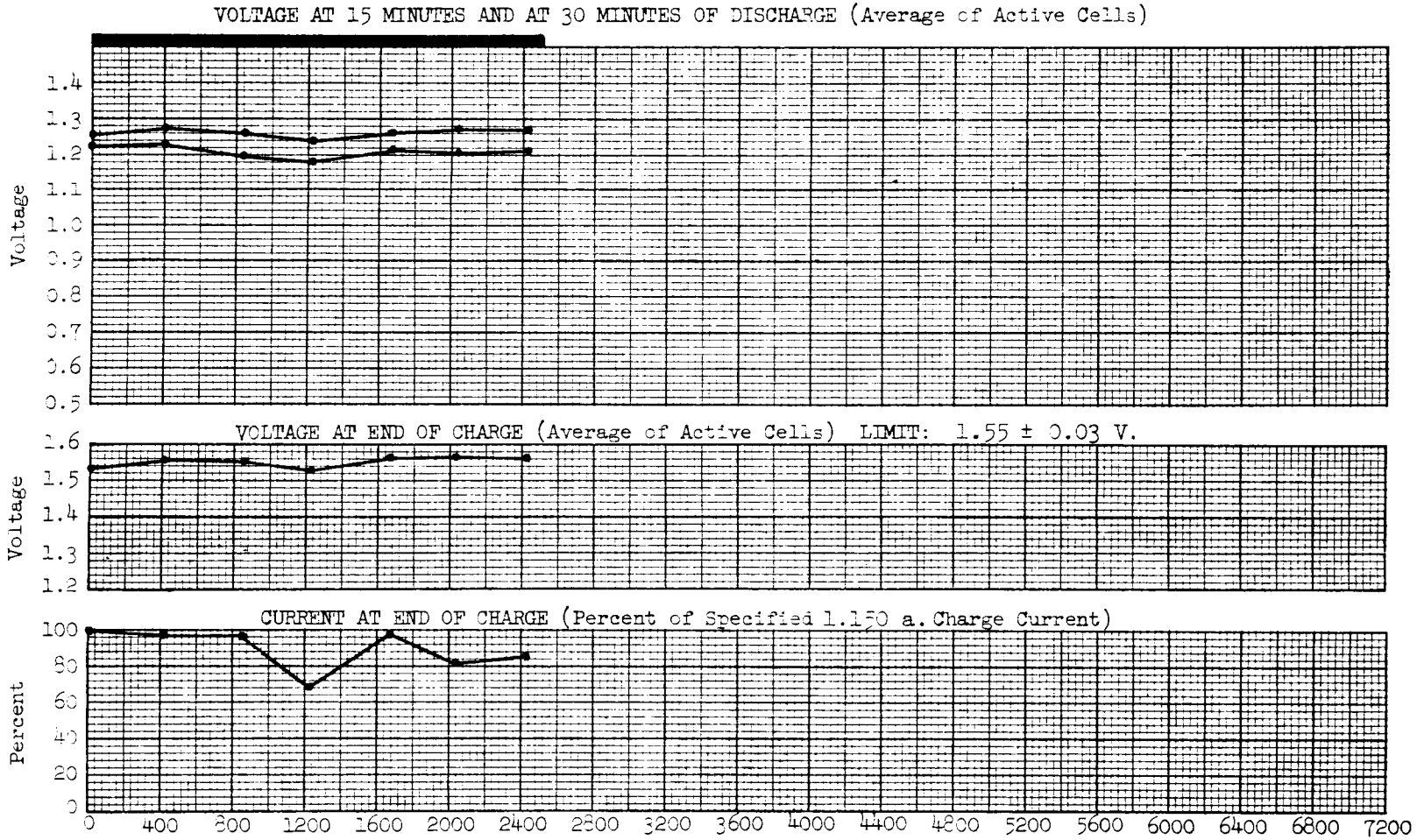
Status: 5 cells cycling after 2514 cycles.

Notes

1. Cycle 1669: Capacity Check.

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FIGURE 18(a)



Cell Number	Cycle Failed

GULTON 4.0 a.h. (Pack 326)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

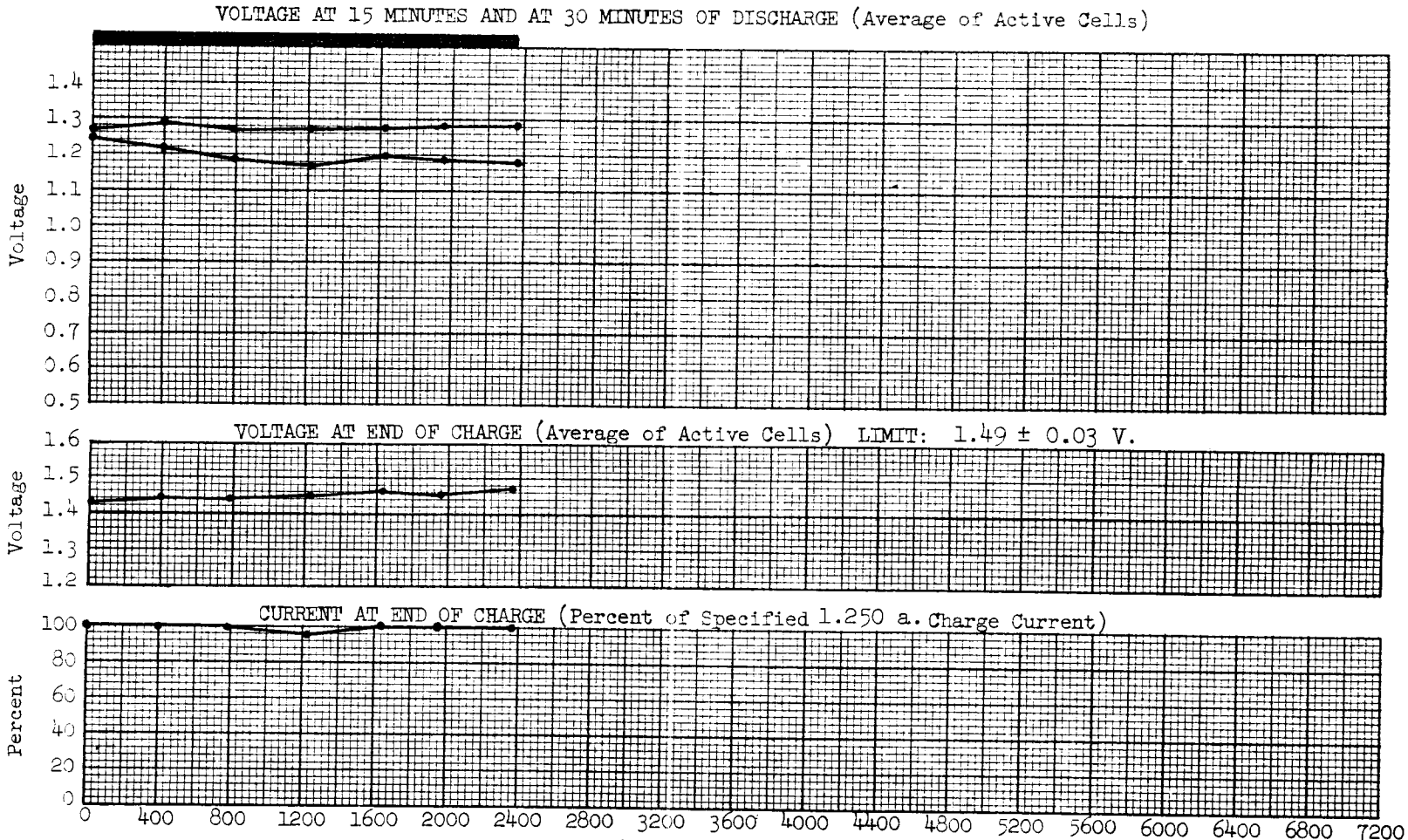
Status: 5 cells cycling after 2517 cycles.

Notes

1. Cycle 1669: Capacity Check.

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FIGURE 18(b)



Cell Number	Cycle Failed

GULTON 4.0 a.h. (Pack 204)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

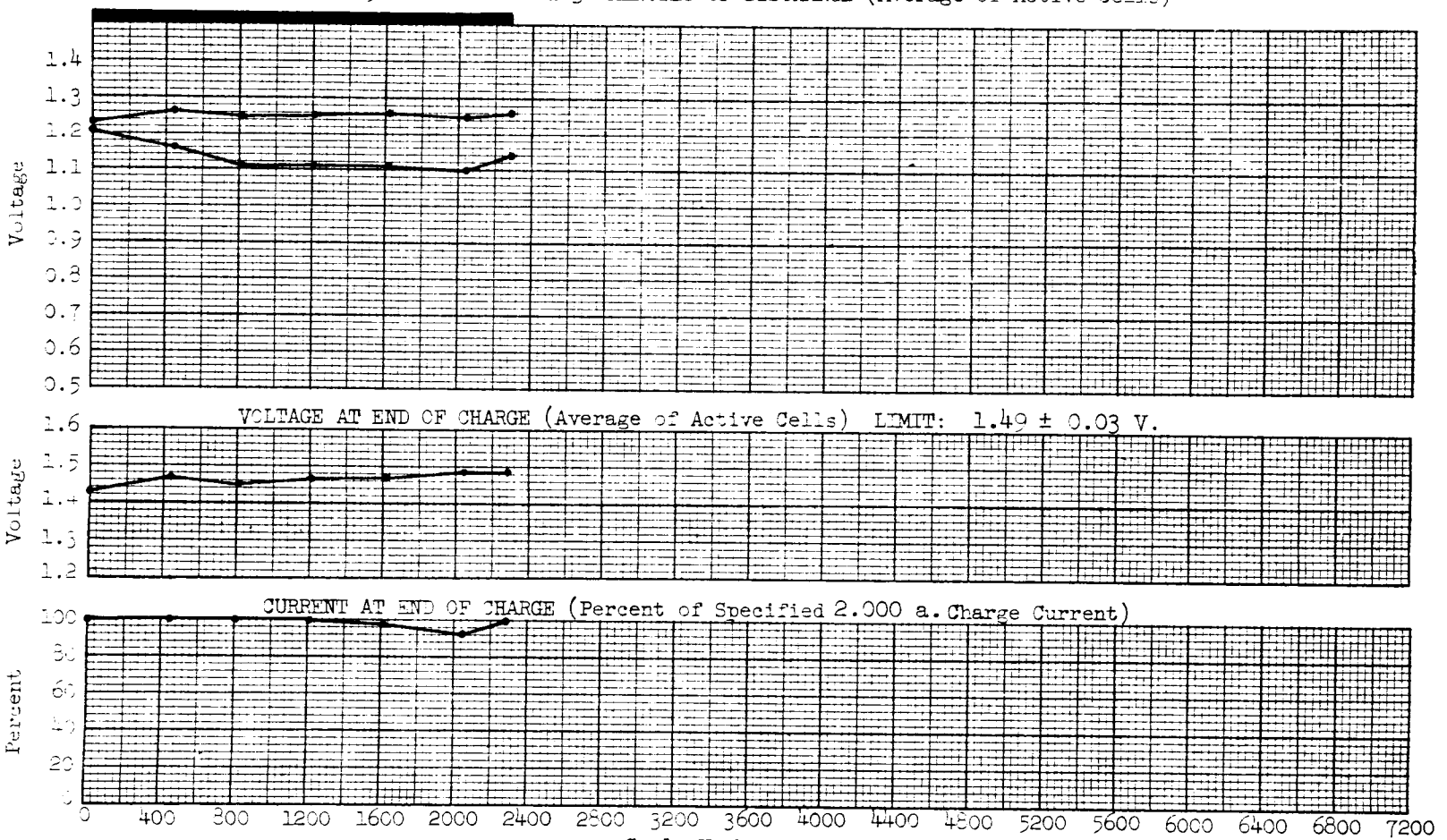
Status: 5 cells cycling after 2360 cycles.

Notes

1. Cycle 1484: Capacity Check.

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FIGURE 18(c)



Cell Number	Cycle Failed

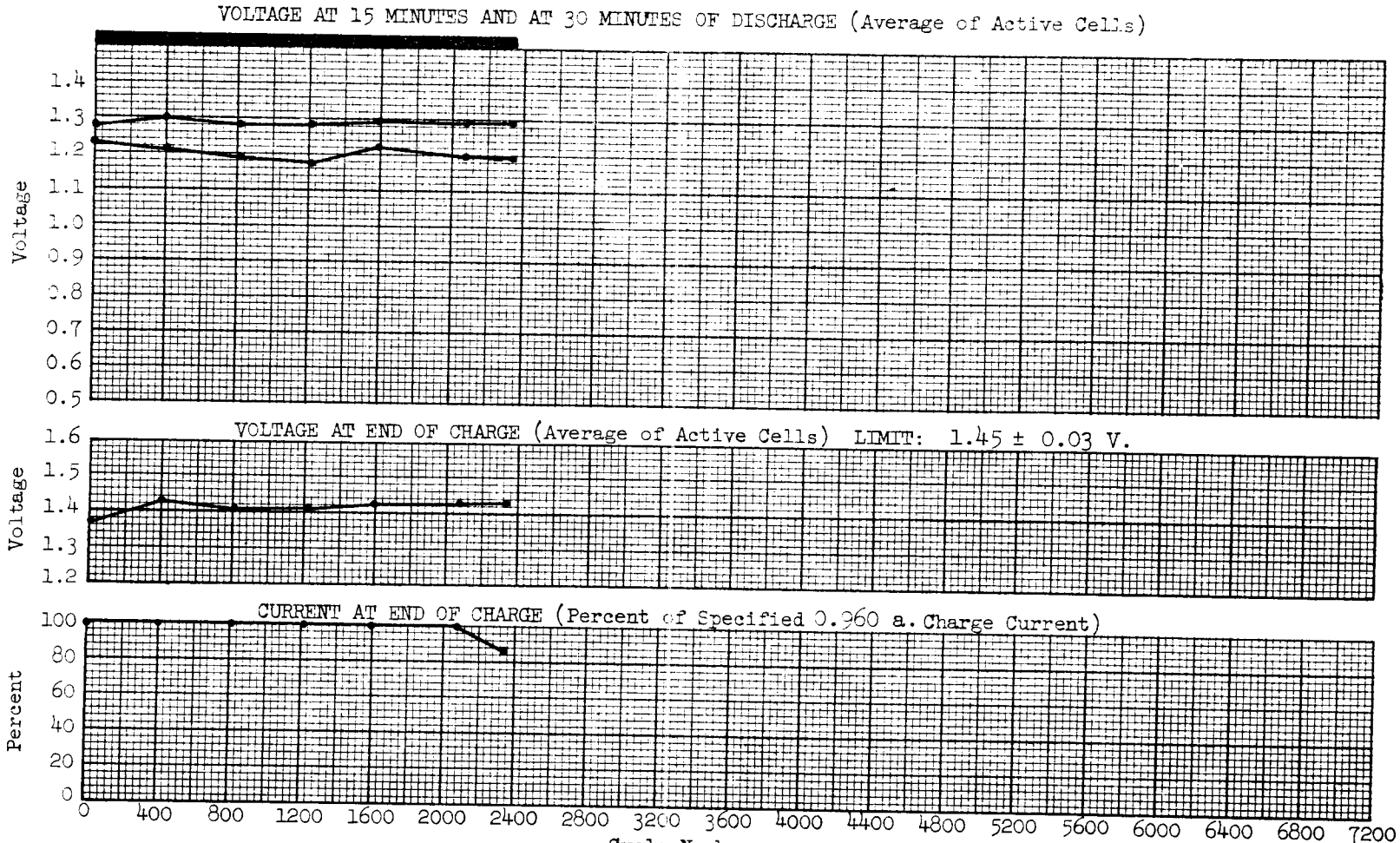
GULTON 4.0 a.h. (Pack 214)
Test Temperature: 25° C
Orbit Period: 1.5 hours
Depth of Discharge: 40%

Status: 5 cells cycling after 2296 cycles.

Notes

1. Cycle 1515: Capacity Check.

FIGURE 18(d)



Cell Number	Cycle Failed

GULTON 4.0 a.h. (Pack 228)
Test Temperature: 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

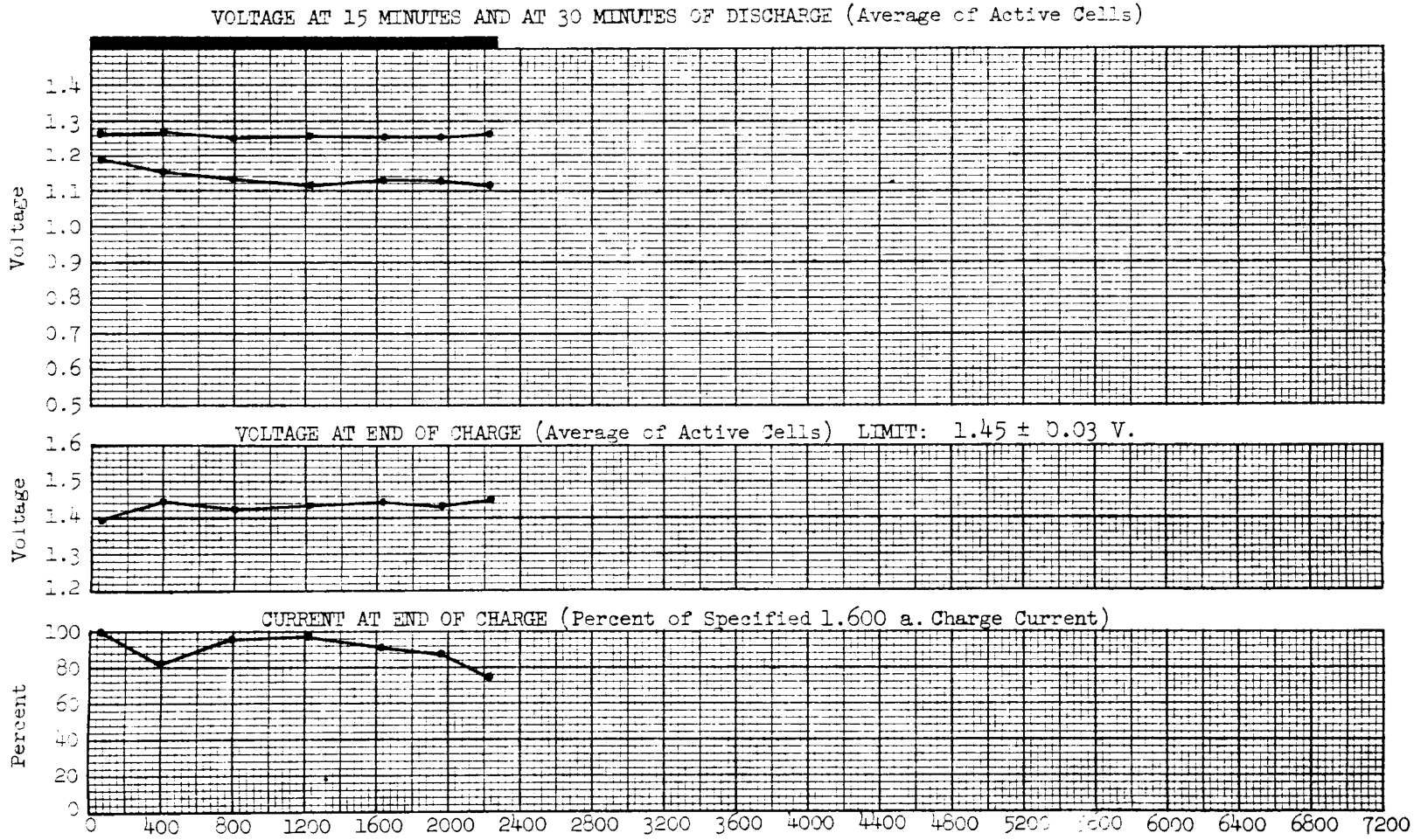
Status: 5 cells cycling after 2361 cycles.

Notes

1. Cycle 1483: Capacity Check.

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FIGURE 18(e)



061

Cell Number	Cycle Failed

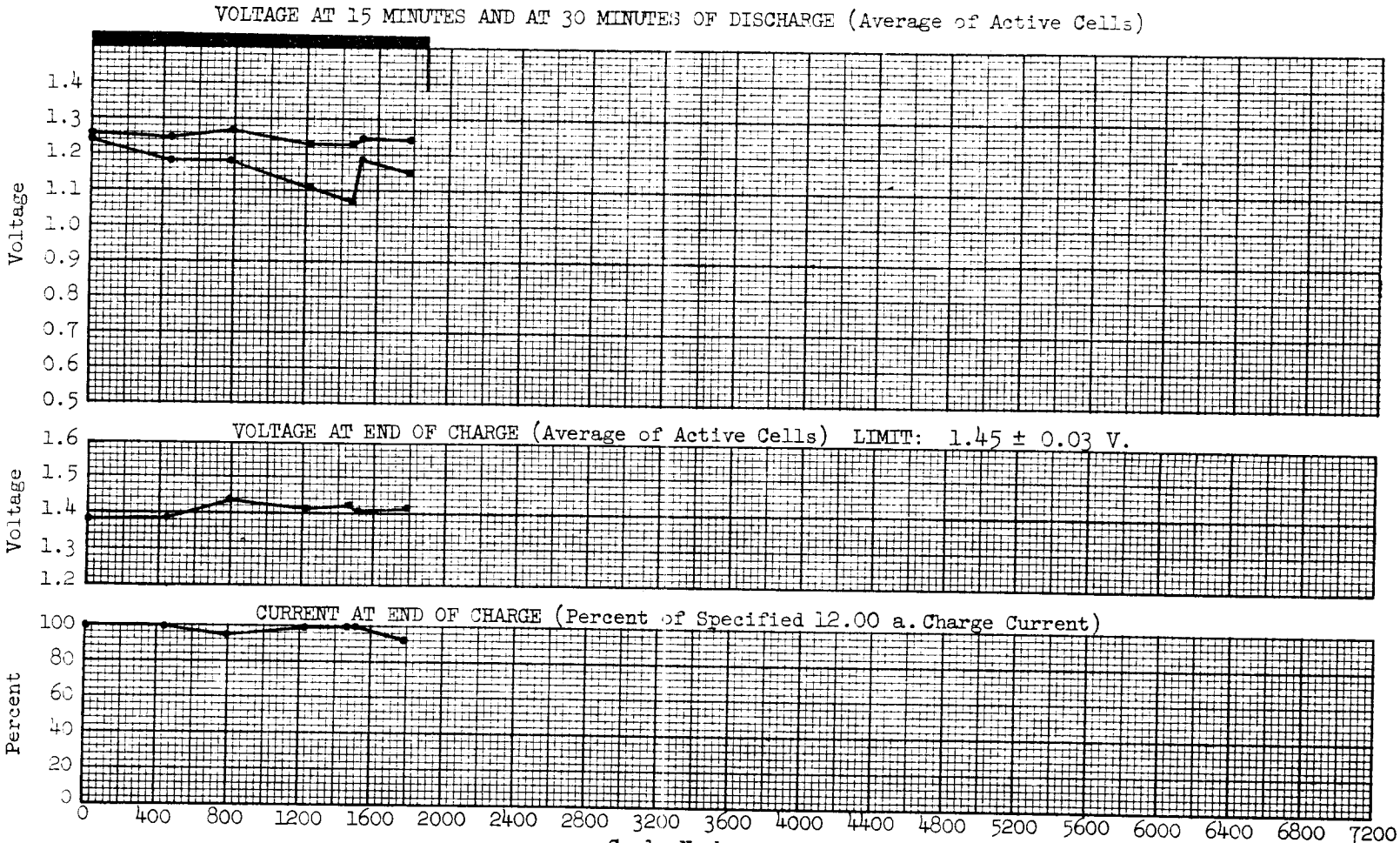
GULTON 4.0 a.h. (Pack 240)
Test Temperature: 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: 5 cells cycling after 2363 cycles.

Notes

1. Cycle 1517: Capacity Check.

FIGURE 18(f)



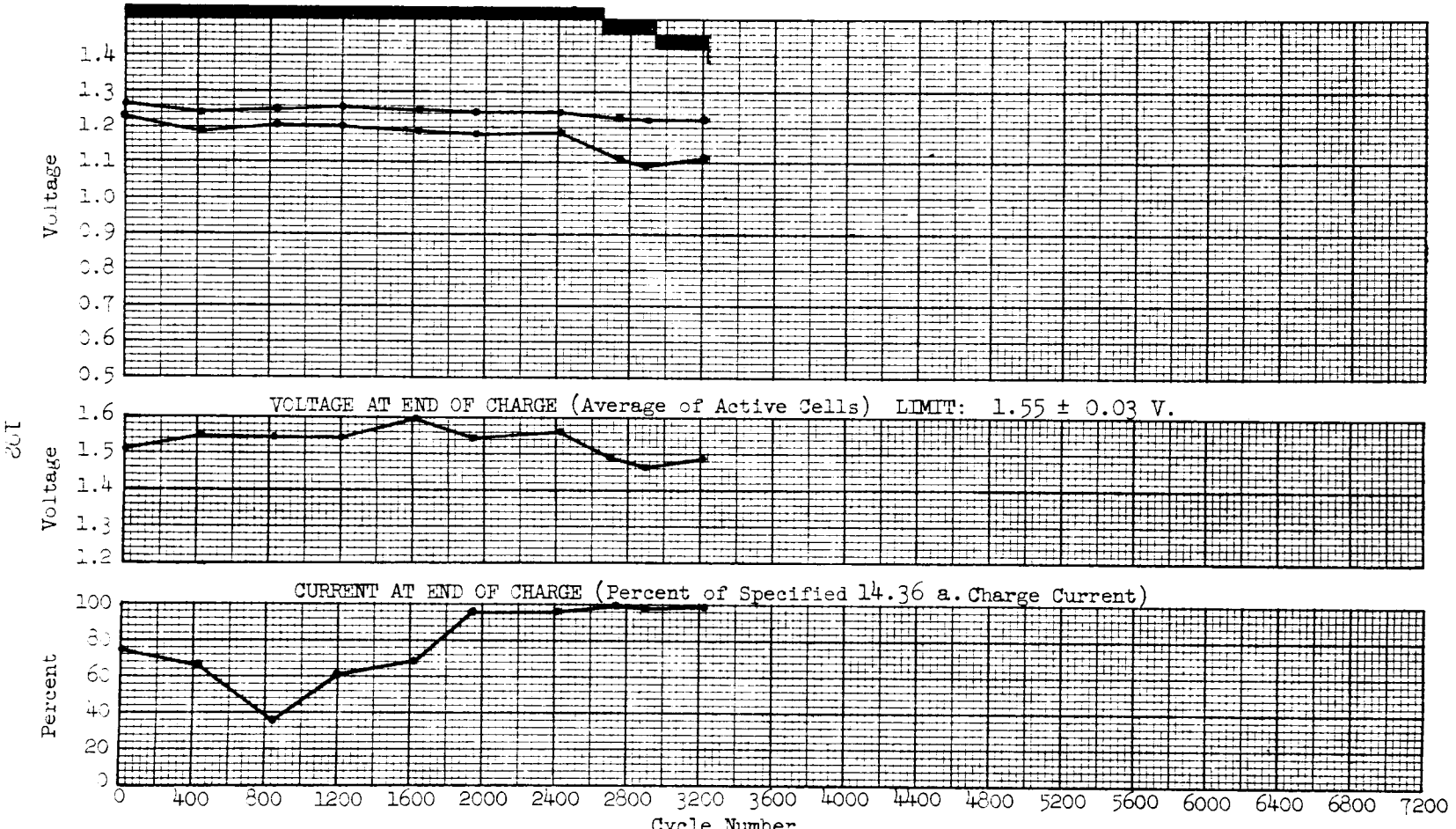
Cell Number	Cycle Failed
117 (Position 2)	1873
118 (Position 3)	1873
119 (Position 4)	1873

GULTON 50 a.h. (Pack 123)
Test Temperature: 40° C
Orbit Period: 1.5 hours
Depth of Discharge: 15%

Status: Pack Failed: Cycle 1873

Notes

FIGURE 19



Cell Number	Cycle Failed
109 (Position 3)	2643
107 (Position 5)	2938
115 (Position 1)	3227

GULTON 50 a.h. (Pack 95)
Test Temperature: 0° C
Orbit Period: 1.5 hours
Depth of Discharge: 25%

Status: Pack Failed: Cycle 3227

Notes

1. Cycles 1229, 2831: Capacity Check.

FIGURE 20

QE/c 65-356

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